

This draft of The Massachusetts Guide to Algae and Aquatic Plant Management, intended to provide an update to the 2004 Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts and the accompanying Practical Guide to Lake Management in Massachusetts, is provided for review.

Note: this document is not yet finalized nor approved for use by MEPA.

DRAFT

The Massachusetts Guide to Algae and Aquatic Plant Management



Developed by Ken Wagner and David Mitchell under contract to the Massachusetts Department of Conservation and Recreation through Water Resource Services, Inc., with oversight and review from a panel provided by the North American Lake Management Society and the staff of the environmental agencies of the Commonwealth of Massachusetts.

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FOREWORD

The original Generic Environmental Impact Report for Eutrophication and Aquatic Plant Management in Massachusetts (GEIR) was developed based on work by a UMASS team working with state agencies in the late 1990s and early 2000s. It was then edited by Dr. Ken Wagner, who also prepared a condensed version, The Practical Guide to Lake Management in Massachusetts (“Practical Guide”). The Practical Guide offered more concise guidance to project proponents and conservation commissions distilled from the GEIR. Both The Practical Guide and GEIR were submitted to the Executive Office of Environmental Affairs for review under the Massachusetts Environmental Policy Act (MEPA) and received a Certificate from the Secretary of EOE in 2004. These documents characterized the Massachusetts experience with eutrophication and algae and aquatic plant control known at that time. The 2004 EOE Certificate determined that projects conducted in accordance with the GEIR guidance do not need individual review under the MEPA but still require all applicable permits, most notably under the Wetlands Protection Act, the Massachusetts Surface Water Quality Standards Act, the Massachusetts Endangered Species Act, and Chapter 91, the Public Waterfront Act. Additional permits may also be required.

With twenty years of experience following the issuance of the Certificate, the need to update the GEIR and Practical Guide was evident and is consistent with the Certificate on the 2004 Final GEIR which stated that it should “serve as a living document, updated periodically to incorporate new and innovative techniques for lake and pond management that can further reduce the potential for environmental impacts” (Herzfelder 2004).

Over the last two decades, much experience has been gained with the management of algae and aquatic plants, including the development of new techniques and the registration of new herbicides. Most of the original guidance in the GEIR and Practical Guide remains valid, but updates to regulatory programs and the knowledge base relating to many techniques were needed. Additionally, changes in regulations have created additional needs not addressed in 2004. This document incorporates this information. Lastly, the proliferation of online resources is a complicating factor, providing considerable valuable information but also many promotions and opinion pieces that often lack proper documentation and sometimes conflict with sound guidance found elsewhere, including in scientific literature less accessible to the general public. This document provides hotlinks to appropriate information and resources.

This guide incorporates updates to both the GEIR and Practical Guide into one hybrid document titled “The Massachusetts Guide to Algae and Aquatic Plant Management” (referred to as the “2025 Guide”). The 2025 Guide provides basic information about lake and watershed ecology and key considerations in algae and aquatic plant management. Principles of lake management, especially the underlying science, provide the basis for evaluating options and restrictions for designing appropriate lake projects. The 2025 Guide provides an updated summary of available algae and aquatic plant management techniques, identifies relevant regulatory considerations, and

provides guidance for planning, implementation, and monitoring of algae and aquatic plant management projects. As provided for in the 2004 EOECA Certificate, the expectation is that if projects are conducted in accordance with the 2025 Guide, individual review under the MEPA will not be required, although all the other regulatory requirements remain in full effect.

The primary differences between this 2025 Guide and the original GEIR and Practical Guide include:

- The 2025 Guide is designed as an editable online resource for internet access.
- Hotlinks in the 2025 Guide allow readers to access factual and accurate online materials.
- Emphasis is placed on the importance of a sound and comprehensive lake management plan and how to develop one in the 2025 Guide.
- Updated science related to lake ecology is provided in the 2025 Guide. For example, the role of internal loading of phosphorus from sediment exposed to low oxygen in generating cyanobacteria blooms is now better understood and emphasized.
- The 2025 Guide acknowledges the increasingly important role of climate change.
- The 2025 Guide has a greater focus on the management of algae and aquatic vascular plants.
- The 2025 Guide acknowledges that separate guidance must be sought for other ancillary issues, such as fishery management, dam safety, or flood control.
- Regulatory requirements are consolidated into one chapter of the 2025 Guide.
- The 2025 Guide provides clarification and distinction of those lake management techniques deemed acceptable for use in Massachusetts versus alternative techniques either not accepted, rarely applied, or without a sufficient track record to allow proper evaluation. Many of those alternative techniques may be applicable and even appropriate but require additional scrutiny.
- Experience with techniques is provided within the review of each technique in the 2025 Guide, rather than as a separate chapter for overall experience in the original GEIR.
- Experience with several techniques, including phosphorus inactivation, circulation, and oxygenation, has expanded greatly, allowing more guidance for best results in the 2025 Guide.
- Forms of dredging have been covered in a single section in the 2025 Guide, rather than as separate treatments for dry, wet, and hydraulic dredging in the GEIR.
- Coverage of active ingredients in algaecides and herbicides registered for use in Massachusetts as of 2024 has been added; herbicides and algaecides are addressed in a single section.
- There are changes in the guidance for how drawdowns should be conducted without MEPA review, but an appendix is also provided in the 2025 Guide for considerations for projects where a MEPA review may be necessary.

This new guide should serve as a useful reference for those contemplating lake projects and regulators who must evaluate proposals for lake projects. Knowledge gaps for some techniques and conflicts relating to meeting regulatory standards for different agency programs remain, and this document, like the original GEIR, should be considered a living document, to be updated when necessary. Note that any graphic or photograph without attribution in all following document chapters is from Ken Wagner, one of the authors of this 2025 Guide.

77

78 **1. ESSENTIAL BACKGROUND INFORMATION**

79 This chapter is devoted to general information on lakes that will help readers understand the types
80 of lakes in MA, the features of those lakes, and key processes that affect those features and overall
81 ecological function. An understanding of lake features and processes is essential to proper lake
82 management.
83

84

85 **Lakes and Ponds in MA**

86 **Types of Lakes**

87 The Commonwealth of Massachusetts (MA) has a large and varied inventory of lakes and ponds,
88 estimated at over 3,500 waterbodies (DCR 2006). This number does not include the innumerable
89 beaver ponds established in the last two decades¹ or the many small ornamental ponds or farm
90 ponds created by property owners. These lakes and ponds represent important natural resources
91 affording valuable services such as plant and wildlife habitats, flood control, water supplies,
92 recreational opportunities, and aesthetic enjoyment. MA recognizes the special status of
93 approximately 230 [Great Ponds](#). Throughout the United States, a Great Pond is generally any
94 large waterbody held in trust for the public good. However, in MA it is specifically defined as any
95 pond or lake that contains more than 10 acres in its natural state. Any project located in, on, over,
96 or under the waters of a Great Pond is within the jurisdiction of [Chapter 91](#) of the MA General
97 Laws.

98 The vast majority of lakes and ponds in MA can be broadly divided into two categories: those
99 created by natural processes (e.g., glacial activity, riverine meanders, coastal shoreline processes)
100 and those established by human activity (e.g., mostly dammed streams or rivers for hydropower,
101 flood control, or water supply or quarries). In many cases, the current lake basin contains an
102 original natural pond that was further expanded by impoundment (i.e., installation of a dam or
103 related water elevation control device) and/or dredging.

104 Whittier et al (2002) estimated that 46% of the 10,608 lakes and ponds in the Northeast USA are
105 impoundments. Most natural drainage lakes are found in upland areas (68%) while only 26% of
106 lowlands lakes are of natural origin. Comparing the two sets of waterbodies, impoundments are
107 typically smaller, shallower, have shorter water residence times, and are in watersheds with greater
108 human activity. More than half (55%) of lowlands impoundments were eutrophic, accounting for
109 67% of eutrophic or hypereutrophic waterbodies in the Northeast. In addition, impoundments host
110 greater proportions of fish and wildlife species tolerant of human disturbance, as well as greater
111 occurrence of non-native species compared to natural drainage lakes (Whittier et al. 2002).

112 In MA, there are similar disparities in these characteristics for lakes in upland areas versus lowland
113 areas due to differences in topography, soils, population, and current and historic lake use.
114 Regionally within the state, waterbodies often share characteristics driven by common glacial
115 history, geology, and soils (e.g., depth, hydrology, fertility of surrounding soils, pH). These
116 differences are summarized conceptually in the ecoregion concept (Omernik 1987). Ecoregions
117 denote areas of general similarity in ecosystems and in the type, quality, and quantity of

¹ Beaver populations in MA significantly increased after the use of leghold traps to trap animals underwater was banned in 1997 after the passage of the Wildlife Protection Act, an initiative codified as Mass. Gen. Laws Ch. 131 § 80A.

environmental resources. They often serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and their components. The EPA divides Massachusetts into three level III ecoregions: the Northeastern Highlands (all or parts of Berkshire, Franklin, and Hampshire counties), the Northeastern Coastal Zone (all or parts of Essex, Middlesex, Suffolk, Norfolk, Bristol, Plymouth, Worcester, Hampden, and Hampshire counties) and the Atlantic Coastal Pine Barrens (some of Plymouth and all of Barnstable, Dukes, and Nantucket counties). These ecoregions can be further divided at a finer scale into 13 subregions.

Important environmental factors may vary across these ecoregions. For examples, Rohm et al, (1995) divided Massachusetts into regions based on typical phosphorus (P) levels in lakes. Accordingly, natural ecological features and habitat expectations for a drainage lake in the Berkshires (Northeastern Highlands) may differ greatly from that of a kettlehole pond on Cape Cod (Northeast Coastal Zone) and proposed lake management goals and options should reflect these inherent differences.

Coastal Plain Ponds, Kettlehole Lakes

In MA, Coastal Plain Ponds primarily occur within the Southeast Coast and Islands sub-ecoregion (Sorrie 1994). There is also an inland variety in the southern part of the Connecticut River Basin. These systems have variable depth, are highly acidic, have naturally low nutrient levels, and are fed mainly by groundwater and precipitation in sandy glacial outwash. Most lack any inlet or outlet. They were created by stranded blocks of glacial ice over 10,000 years ago, and represent the other end of the lake origin continuum from impoundments.

Although not all kettlehole lakes are deep to start with, some have enough depth in the center to thermally stratify into two layers during summer. These systems are dependent on fluctuating water levels driven by the water table that, in most years, leaves the pond's shore exposed for certain shoreline or shallow-growing plants during the summer and autumn. Without human influence these ponds change very slowly. They support fewer rooted plants and less phytoplankton in their natural state, but are sensitive to human-influenced accumulation of organic matter which gradually increases their fertility. Human influences, including wastewater disposal in nearby soils, discharge of stormwater runoff, and agricultural uses such as poultry farms and cranberry bogs are typically responsible for productivity problems in kettlehole lakes. However, the legacy inputs from those sources may continue to recycle even after the sources are eliminated, particularly where oxygen near the sediment surface is low, and can continue to cause excessive productivity.

Impoundments, or Water Bodies Created by Damming Rivers/Streams

Impoundments can range substantially in area and depth and in the size of the drainage area contributing to them and the number of streams involved. Sedimentation of these impoundments and the rate of eutrophication will depend largely on which end of the spectrum the impoundment lies, but most impoundments in MA are small relative to their drainage areas and are subject to

greater inputs of water and contaminants. Water quality issues may be mitigated to some extent by more rapid flushing, but a considerable portion of the incoming sediment will remain in the impoundment. These smaller impoundments can age quickly even in undisturbed landscapes and more rapidly in watersheds that are agricultural, developed, or have wastewater discharges.

Some impoundments are large relative to their watersheds and have very long detention times and accumulate much less sediment and nutrients from the small streams that feed them. Quabbin Reservoir is the largest impoundment in MA and it takes several years for water to pass through the system. The watershed is relatively undisturbed and conveys little sediment and nutrients to the impoundment. Otis Reservoir and Lake Garfield in western MA are also relatively large in relation to their drainage areas and receive water from only small feeder streams. Those impoundments represent expansions from original, smaller lakes. There is more development in those drainage areas than in the Quabbin watershed and occasional water quality issues arise, but sedimentation and eutrophication are far less evident than in many smaller impoundments with large, developed watersheds.

Vernal Pools or Ephemeral Ponds

Vernal pools are seasonal depressional wetlands with no permanent inlet or outlet. These are systems that have water in the spring but dry out in most summers. They may be isolated from other wetlands or internal to larger wetland systems. These tend to be highly productive and naturally nutrient rich systems that become breeding grounds for amphibians and invertebrates during spring. Vernal pools usually harbor no fish but floodplain pools and ponds can seasonally have fish. While these water bodies can be quite small and thus are not typically targets for lake management, they are worth describing as they are protected in MA and are often subjected to significant human impacts. Actions that drain vernal pools or fragment the surrounding habitat can have great adverse impacts on these systems and the associated water-dependent species. While most traditional lake management activities focused on control of algae or rooted plants will not be applicable to vernal pools, management plans should recognize the presence of any vernal pools in the watershed and avoid adverse impacts.

Lakes as Dynamic Systems

Although lakes constitute an enduring geologic feature of the MA landscape, many of the lakes in MA were created by damming flowing waters or raising dams on existing waterbodies. Whether natural, human-made, or some combination of the two, lakes are dynamic systems, subject to gradual natural change over time but also susceptible to rapid deterioration due to human influences. These changes, both natural and anthropogenic (i.e., due to human actions), represent stages in the eutrophication process sometimes referred to as the “aging” of a lake (Figure 1). Lakes may exhibit substantial resilience with respect to individual episodes of nutrient loading, drought, or other environmental stressors, but eutrophication is naturally a one-way process whereby lakes become more fertile over time and more likely to experience productivity problems that threaten designated uses of the waterbody.

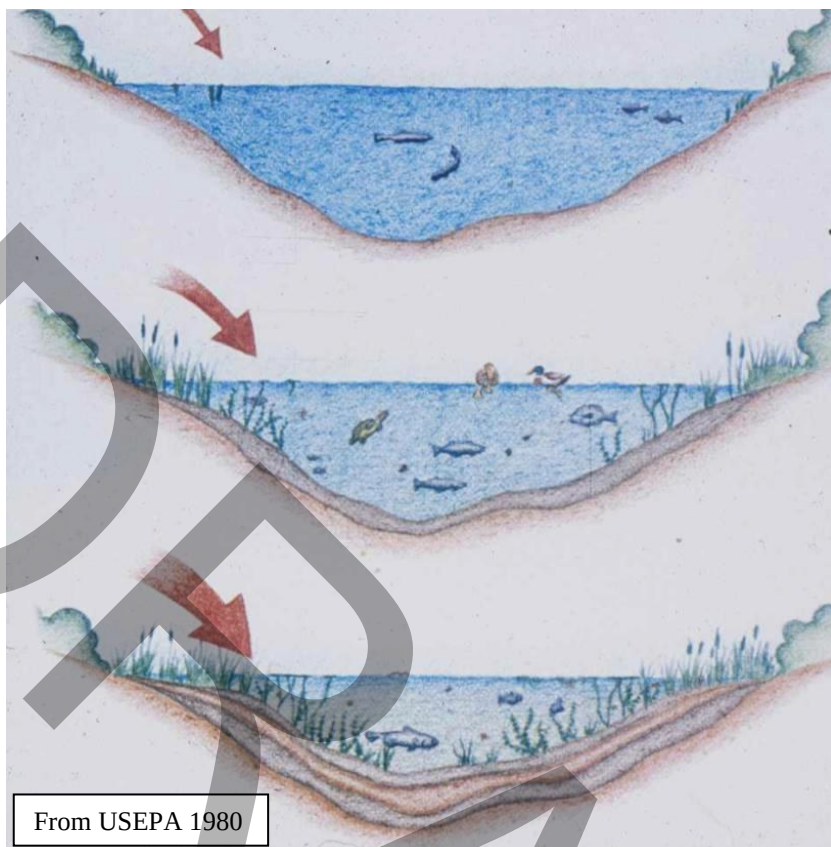


Figure 1. Progression of eutrophication, whereby lakes lose depth and increase in fertility.

Eutrophication, or lake aging, is the process through which lakes become shallower and more eutrophic (nutrient-rich) and eventually fill with sediment until they become emergent wetlands. Natural eutrophication occurs over very long time scales, usually thousands of years, but the aging process is not identical for all lakes. Some lakes age more quickly, others very slowly, and not all start out in the same condition. Some lakes that were formed by the glaciers no longer exist, aging to wetlands, while others have changed little in 10,000 years. Multiple processes are involved and many factors must be considered when evaluating where a lake stands on the aging continuum.

Lakes can be subdivided into categories depending on their position along a continuum of nutrient fertility or productivity. Nutrient-poor lakes are termed oligotrophic, nutrient-rich lakes are eutrophic, and those in between are mesotrophic. These so-called trophic state determinations are approximate since many lakes do not easily fit into a particular category and lakes change over time. Lakes can be productive in many ways including producing biomass in the water column (i.e., floating algae called phytoplankton), experiencing growth of rooted aquatic vegetation (i.e., macrophytes) on the bottom, and supporting fish and other water-dependent wildlife. Therefore, a determination of trophic state should consider the totality of the lake's productivity. It is also not appropriate to assume that eutrophication is universally undesirable. While dense expanses of rooted plants and algae blooms may impair many human uses of a lake, higher productivity supports more fish and wildlife. Natural eutrophication, being a slow process, allows for biological

adaptation and adjustment, but eutrophication brought on by human actions is more rapid and can have dire consequences.

Human-Induced or Cultural Eutrophication

The rate of aging of a lake is determined by many factors including the depth of the lake, the nutrient richness of soils in 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 can be expected to vary as well. In general, lakes created by damming of rivers tend to age more quickly. These lakes are rarely deep to begin with, have larger watershed to lake area ratios, and are often located within developed watersheds with higher nutrient inputs.

Human activity can unduly accelerate the process of lake aging or, in the case of introduced species or pollutants, force an undesirable response. Undesirable responses include the loss of native aquatic species or shifting of the relative abundance of species present as a result of acid deposition, algal blooms resulting from excessive nutrient enrichment, and the development of a dense monoculture of an introduced plant species. Human-driven cultural eutrophication can be very rapid, with ecosystem changes obvious over just a few years to a decade. While the response can be rapid, the restoration process may take much longer. Further, it would be unrealistic to assume that managing cultural impacts on lakes can easily reverse the aging process and/or convert them into infertile basins of clear water. For this reason, most of what we do to manage lakes qualifies as rehabilitation, not restoration (Cooke 2005).

Importance of the Lake Setting

One of the important early advances in the field of ecology² was the recognition of lakes as ecosystems. An ecosystem is a system of interrelated organisms and their physical-chemical environment. It forms a useful conceptual unit that can be reasonably studied and helps explain all or most of the characteristics of the lake. A lake is a web of interactions between hundreds of biological species, chemical compounds, hydrological processes, and human actions. A change in one part of the system will often result in changes in other parts of that system. They are all connected.

The most commonly used definition of the lake ecosystem is the combination of the lake and its contributing watershed. The watershed typically defines the terrestrial sources of the lake's water operating as part of the hydrologic cycle (Figure 2). However, in some lakes, particularly kettlehole lakes in sandy soils, the operative hydrologic watershed may be better defined by the limits of groundwater flow to the lake. In addition, all lakes receive atmospheric precipitation that may be affected by processes far beyond the watershed boundary.

² Ecology is the scientific study of relationships between component plant, animal and microbial communities and the physical, chemical, and biological factors that shape them. Limnology is the study of freshwater ecology.

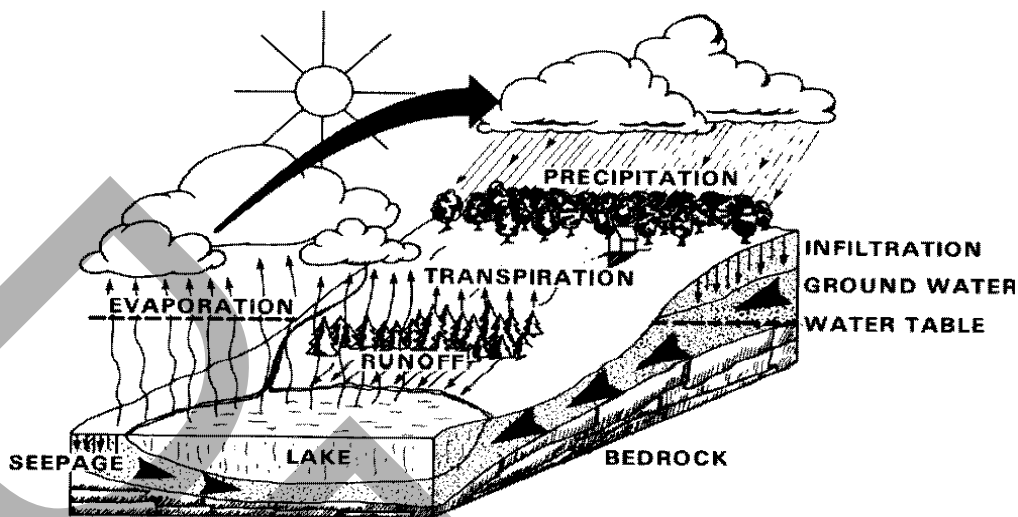


Figure 2. The hydrologic cycle (from Olem and Flock 1990)

Most impacts on lakes can be related to characteristics of the watershed. However, deposition of acidic precipitation, mercury, and other toxic air pollutants demonstrate that not everything important to lakes occurs within the immediate watershed but can be imported from other regions. However, this also means that national reductions in pollutant levels due to environmental regulation (e.g., Clean Air Act, mercury controls) can result in improvement in MA lake conditions, as has been observed in the rebounding pH levels of lakes over the last three decades.

Another influence at the regional level is climate change with its accompanying long-term shifts in precipitation trends, strong storm frequency, drought occurrence, and temperature fluctuations. These patterns transcend local watershed limits. Lake management in response to these changing patterns will be challenging and problems induced by climate change are likely for a long time to come (IPCC 2021).

In addition to the natural influences on a lake, lake management must also acknowledge the importance of the socio-economic setting of a lake. Lakes are important public resources with designated uses under state law. Lakes can be local economic assets, increasing property value and the associated tax base as well as supporting various local businesses. Lake management should therefore strive to achieve a carefully considered balance between protection of natural resource values and accommodation of reasonable expectations of public use and enjoyment.

The desire to accommodate human uses may create conflicts within the MA regulatory system. The [Wetlands Protection Act](#) (WPA) provides provisions for water-dependent uses (e.g., swimming areas, boating lanes) and [Chapter 91](#) allows for docks and other structures that support human uses, but there are constraints on related actions. Conflicts need to be worked out in the regulatory process and a well-constructed management plan will seek to minimize those conflicts.

Key Features of Lakes

Watershed and Shoreline

Watershed

A watershed is a defined area of land within which surface water and groundwater flows downgradient to a hydrologic feature, such as a river, stream, pond, lake, wetland, or estuary. Precipitation falling on a watershed may create runoff that enters permanent or intermittent streams, percolate into the groundwater where it may or may not interact with tributaries and the lake, or evaporate back into the atmosphere, either directly from surface pools or through vegetation as evapotranspiration. Precipitation falling on undisturbed land mostly percolates into the ground although some runoff may be expected. Precipitation landing on hard (impervious) surfaces such as roads and parking lots will mostly enter storm drainage systems that eventually discharge into waterbodies. The fate of precipitation landing on agricultural land will depend on the condition of that land at the time of the storm. Direct precipitation on the lake may be conditioned by influences far beyond the watershed boundary, but most of the water entering MA lakes comes from the watershed, making the watershed the functional unit of evaluation and management with regard to a lake.

Watersheds vary tremendously in size. A watershed for a seasonal spring freshet might be as small as a few acres while those for a large river can extend for hundreds of miles and drain numerous smaller streams³. In MA, 28 [major river watersheds](#) have been identified. These classifications serve both as geographic delineation useful for watershed management as well as an organizational basis for [water quality classifications](#).

Watershed limits were historically identified by examining the bounding topographic features and delineating where water flows divide between two adjacent watersheds. While this was typically done by examination of United States Geological Service (USGS) topographical maps, the current practice is by downloading watershed maps from Geographic Information System (GIS) data. In MA, watershed boundaries are among the myriad of relevant physical, environmental, and biological mapping available as [MassGIS Data Layers](#). This resource has greatly improved and expedited watershed mapping and analysis as part of informed lake management. Additionally, the USGS provides statistics for watershed area and stream flow through [StreamStats](#).

Assessment and mapping of watershed characteristics, including patterns of existing land use, hydrology, geomorphic conditions (soil and geology), and important biotic habitats provides useful and complementary information to the chemical, physical, and biological parameters commonly measured by water quality monitoring programs (USEPA 2012).

³ The Connecticut River watershed is the largest in MA, draining 11,260 square miles of land in VT, NH, MA and CT, about 2300 square miles of which are in MA.

Land use in the watershed should be mapped as it is a driving factor in determining the hydrologic and chemical characteristics of the receiving waterbody. Vegetated landscapes stabilize soil, recycle nutrients, retain sediments, and regulate surface and groundwater hydrology while bordering riparian forests regulate temperature and input of organic matter to headwater streams (National Research Council 2008). Conversely, agricultural and urban land uses almost always serve as net exporters of sediment and nutrients, increasing surface runoff and decreasing infiltration to groundwater reserves.

Watershed hydrology is driven by climatic processes, surface and subsurface characteristics, such as topography, vegetation, and geology, and human processes, such as water and land use (USEPA 2012). A watershed can consist of a surface catchment (drainage basin) plus a subsurface catchment. A drainage basin can be defined as the surface area that, on the basis of topography, contributes all the runoff that passes through a given cross section of a stream. In contrast, drainage that occurs via subsurface flow, controlled by hydrogeology, is called the subsurface catchment. Groundwater can enter and exit a watershed via inflow and outflow through aquifers that extend beyond the surface catchment.

One useful index derived from watershed delineation is the ratio of watershed area to lake area. The greater the size of the watershed relative to the lake volume, the greater the runoff generated and potential mobilization of sediment, nutrients, and other anthropogenic materials (e.g., salt, pesticides) downstream to the lake. Accordingly, lakes with greater relative watershed sizes tend to receive greater chemical loadings and generally are more productive compared to lakes with smaller ratios.

This size of the watershed relative to the size of the lake has important implications for lake management, as water quality in lakes with greater watershed ratios will be more difficult to improve solely through local actions at the lake since the sources of important inputs may be quite distant and difficult to manage. The index should be considered when assessing the effectiveness of management options such as P inactivation or dredging, which are unlikely to lead to lasting improvements if significant loading of nutrients or sediment continues unabated. On the other hand, lakes with low watershed to lake area ratios may be more amenable to lake-based restoration treatments. While there is no definitive criterion for when this shift in watershed influence occurs, and the volume of the lake may be as important as area, a ratio of 10:1 (watershed area to lake area) provides an approximate estimate. Lakes greatly exceeding this ratio will likely require significantly more effort spent in watershed source controls if an improvement in downstream water quality is to be achieved.

Watershed management is a term that describes the wise environmental use of land and water resources. Watershed management may include goals and processes such as reducing the amounts of pesticides and fertilizers that wash off farm fields and into nearby waterbodies, placing environmentally sensitive areas into conservation land, or establishing appropriate zoning to guide future development to minimize water quality impacts. If land is available in the watershed for

conservation or protection, priority areas include: 1) critical ecological habitats; 2) aquatic corridors; 3) undeveloped areas, such as forests; 4) buffers to separate water pollution hazards from aquatic resources; and 5) cultural areas that sustain both aquatic and terrestrial ecosystems (Center for Watershed Protection 2008).

Effective watershed management planning is important to many aspects of lake management. Among the various useful guidance documents for watershed management available from federal and state agencies, the [Massachusetts Watershed-Based Plan](#) (WBP) provides essential information to improve the health and beneficial uses of the Commonwealth's waters.

Shoreline

Lake management has historically focused on the protection or rehabilitation of the quality of habitat in open-water areas. However, there is growing recognition that restoration and management of shoreline upland buffer and bank areas and near-shore physical habitat (i.e., littoral zone) are also critical for supporting biota and ecological processes in lakes. Native shrubs and trees can root deep into the soil and hold the bank in place, stabilizing the water's edge against wave action and storm impacts and providing important wildlife and fish habitat. Such plants also help filter non-point runoff that flows off nearby driveways and roofs, although a substantial buffer zone width is needed to be effective.

The littoral zone in a waterbody is adjacent to the shoreline and is generally characterized by the presence of some light at the sediment level with the corresponding growth of partially-submerged to fully-submerged aquatic plants. Littoral zones vary in relative size as a function of basin bathymetry but often comprise a large proportion of the bottom area in shallow lakes and small ponds. Littoral zone environments typically have abundant dissolved oxygen, nutrients, and water motion, and may have periodic intervals of submergence and exposure (i.e., land seasonally inundated). The littoral zone rarely extends to water depths of 20 feet (6 m) and may end in water as shallow as 5 feet where light penetration is limited by algae or suspended sediment.

Ecologically, the littoral zone buffers the transfer and processing of energy and material flowing into the lake from watershed runoff, groundwater, or tributaries, and influences physical and biological processes. The littoral zone is generally the most productive area of the lake, especially in terms of aquatic plants and invertebrates. In many cases, anthropogenic uses of aquatic systems (e.g., swimming, fishing, irrigation) are also maximal in the littoral zone.

Habitat quality at the shallow edge of the lake is dependent on living and non-living features such as overhanging vegetation, aquatic plants, large woody debris, brush, boulders, and rock ledges. Lakes with greater and more varied shallow water habitat are typically able to support greater and more diverse aquatic life more effectively because they have many complex ecological niches. The near-shore areas are important for a variety of biotic activities including fish spawning and nesting areas, turtle and amphibian overwintering in the sediment, waterfowl feeding, and protecting insect diversity.

Unfortunately, dense shoreline residential development and its accompanying secondary impacts, including removal of native shoreline bordering vegetation, alteration or removal of natural habitat or woody debris in shallow areas, installation of impervious surfaces (buildings, driveways, and even some lawns) draining directly to the lake, and sealing lake borders with concrete or masonry seawalls, adversely impact these shallow habitats, with negative effects on the birds, frogs, salamanders, turtles, insects, fish and other wildlife that depend on plants or organic detritus for their survival. The impact of this alteration of overall lake ecology has been documented by many studies, including the National Lakes Assessment (USEPA 2012, USEPA 2017). This study, repeated every five years, indicated that in every ecoregion across the nation near-shore habitat condition was negatively impacted by anthropogenic pressures. As of 2017, only 36.7% of lakes in the northeast were rated as having low levels of nearshore disturbance. Gradients of increased anthropogenic disturbance were accompanied by progressive simplification of littoral and riparian physical habitat. In addition, the proportion of lakes with degraded near-shore physical habitat was equal to or greater than that impacted by excess nutrients (Kaufmann et al. 2014).

Freshwater shoreline management involves assessing and protecting lake shorelines from excessive development and other anthropogenic effects, plus rehabilitation where possible. Freshwater shoreline assessment can include tracking shoreline change over time, determining areas of concern, with follow-up education for shoreline property owners. Revitalization programs and educational stewardship programs support private landowners in planting native vegetation to enhance shoreline and riparian zones, rehabilitate and maintain healthy shoreline habitat, provide erosion protection, and improve water quality. Increased focus on protecting littoral and riparian physical habitat through better management of near-shore anthropogenic disturbance should be an integral part of any lake management planning. Maine and New Hampshire have active programs to aid shorefront property owners in proper property management to limit impacts on lakes, called [LakeSmart](#), that could serve as models for MA.

Lake Physical Attributes

Water

Water is an essential component for all living organisms. Its abundance and unique physical properties are the principal controlling factors for the general and spatial characteristics of lakes and ponds in MA. Unlike virtually all other chemical compounds, water does not become increasingly denser as it becomes colder. Instead, water increases in density as it is cooled until it reaches a maximum density at 4°C (39°F). Upon further cooling to 0°C (32°F), water becomes lighter and floats to the surface until it has cooled sufficiently to freeze. Absent this unique physical property, lakes would freeze solid in our winters and many aquatic organisms would not survive. Water also has a high specific heat and high latent heat of fusion; thus, lakes are slow to thaw in spring and slow to cool in winter, thereby providing a 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 minerals and chemical compounds dissolve in it, providing the baseline natural components of water quality.

Lake basin and bathymetry

While water is the physical medium of the lake, the spatial boundaries are defined by the lake basin and its vertical extent (depth) as shown by the lake's bathymetric map⁴. The lake basin surface size and shape determine its physical characteristics such as its width and length, longest dimension (fetch), shoreline length and development index. These surface features are easily obtainable from traditional sources (e.g., USGS topographic map) or digital mapping available from state agencies (e.g., MassGIS).

In contrast, bathymetric data provide important sub-surface information for lake management such as average and maximum depth, the volume of water, and calculation of water residence time (also called detention time and inversely related to flushing rate, the number of times the water is replaced in a year). Bathymetry may also provide clues as to the origin of the lake, with certain shapes and depth profiles common to kettlehole lakes and impoundments. MassWildlife provides [bathymetric maps](#) for many lakes with public access. Construction of a bathymetric map requires a lake-specific survey, conducted by taking systematic depth measurements over the entire waterbody and then configuring contours indicating areas of equal depth (i.e., depth isopleths). Not every lake has such a map, but it is a critical part of lake management planning.

Seasonal water level fluctuations, both natural (drought) and human-induced (e.g., drawdowns) may alter the lake surface area and depth during over time, usually in a cyclic pattern. Older bathymetric maps may be less accurate as lake basins can fill in with sediment over time due to watershed erosion or bulk transport of sediment during extreme storm events. In the last few decades, conducting a lake depth survey has become much easier due to the development of inexpensive depth finders, GPS positioning, and software to automate the drawing of lake depth isopleths. Acquiring a reliable bathymetric map is an important early step in any lake management plan.

Sediment

The bottom substrate underlying the water in the lake basin may be composed of peat, muck, clay, sand, gravel, or rock, depending on the type and age of a lake. These constituents are collectively termed sediments. Most lakes will have multiple types of sediment within them, usually with the coarser material around the periphery and finer sediments offshore, a function of sediment movement and accumulation over time. Lake sediments, particularly the upper layer of about a foot, are very important in lake processes. As the ultimate deposition site for organic and inorganic materials sinking out of the water column, the bottom sediments represent the substrate that supports bacteria, fungi, microorganisms, insects, other macroinvertebrates, fish, and bottom-

⁴ Bathymetric maps show the relative depths of lakes below adjacent shorelines. In contrast, topographic maps show elevation of landforms above sea level.

feeding wildlife (e.g., some waterfowl, muskrat and beaver). The sediments play a critical role in nutrient cycles including storage, remineralization, resuspension, and regeneration. The bottom provides the rooting substrate for aquatic rooted vegetation (macrophytes) and growing surface for algal mats.

Sediments often reflect the legacy of the type and intensity of past and current human activities in the watershed. For example, they can be repositories for a variety of anthropogenic pollutants (e.g., metals, pesticides, polychlorinated biphenyls (PCBs)) that not only can adversely affect aquatic organisms in the lake but usually provide significant technical and economic challenges with regard to their environmentally safe removal and disposal. [Regulation of sediment disturbance](#) in MA is handled by MassDEP and testing of sediment quality is usually required whenever more than 100 cubic yards of sediment or related plants and debris are expected to be removed (dredging) or disturbed as part of a lake restoration project.

Hydraulic residence time

The average time a water molecule remains in a lake is the hydraulic residence time, also known as detention time. It is equivalent to how long it would take to fill the lake if it was empty, and its inverse is the number of times the water volume of a lake can be replaced in a year, called the flushing rate. These measures are derived from lake bathymetry (i.e., water volume) and the range of inflows over time (i.e., hydrologic inputs). Many of the larger, deeper lakes in MA have hydraulic residence times ranging from months to years (e.g., the Quabbin Reservoir has a residence time of approximately three years), while smaller, shallower, river impoundments have short hydraulic residence times of days to weeks. Summer residence time in stratified lakes is somewhat complicated by separation of the bottom layer, but despite the smaller volume likely to be replaced, summer flows tend to be lower and residence time tends to increase. Residence time and flushing rate of a lake will often determine how a lake responds to nutrient or pollutant inputs, with longer detention or less flushing leading to greater impact. Residence time is important to certain lake management techniques, such as herbicide application, where very short residence time will reduce exposure of target plants and may limit effectiveness.

Thermal Stratification and Mixing

Thermal layering of lakes is an important determinant of waterbody ecology. Layering due to temperature-dependent density differences is called thermal stratification. With more than a few degrees of temperature difference, mixing is retarded or even prevented. 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. Lakes can vary in the frequency of mixing periods when the occurrence of equal temperature allows the exchange throughout the entire water column. Most of the deeper lakes in MA have a dimictic mixing pattern with water turnover in spring and fall although other patterns may be possible due to lake specific characteristics of depth, climate and salinity.

Lake thermal structure is determined by several factors. Lakes receive the vast majority of their heat at the surface from solar heating. Since warmer (less dense) water floats, the water column must have an energy input to mix that heat deeper into the water column. For most lakes, it is wind and wave action that provides mixing energy. A lake exposed to strong winds will be well mixed in spring and have a cooler but thicker upper layer overlying the colder water if it stratifies. A lake that is well protected from the wind (e.g., topographically depressed basin and/or heavily forested shoreline around a small lake) will have a warmer but shallower layer at the surface with cold water below. Deeper lakes often have a three-layered structure throughout the summer that consists of an upper warm layer (the epilimnion), a middle transition layer (the metalimnion), and a colder bottom layer (the hypolimnion). The point of greatest temperature change with increasing depth is called the thermocline.

Not all lakes and ponds are stratified. For many shallow MA lakes, the mixed layer may extend to the lake bottom. Lakes with a depth of more than about 30 feet (9 m) will stratify and have at least a thin hypolimnion. Lakes <10 feet (3 m) deep rarely have any stable stratification, although dense rooted plants can limit mixing and allow a significant top to bottom temperature gradient. Lakes with depth in between 10 and 30 feet will be subject to the influences discussed above and may or may not be stratified during summer. Some thermal gradient is likely with depths >10 feet, and that gradient can be an important determinant of water quality and habitat.

Thermal structure is seasonally dynamic throughout the year and exhibits an annual cycle. Beginning at ice out in early spring, all the water in a lake, top to bottom, is close to the same temperature; the density difference is slight, and water is easily mixed from top to bottom by spring winds. With warmer days, the temperature difference between the surface and bottom waters increases until thermal stratification occurs if applied energy is insufficient to prevent it, which is almost always the case for deeper lakes (Figure 3). In early fall, solar heating declines and heat is lost to the air at night at colder temperatures and the upper layer begins to cool and sink. Eventually, the lake reaches a stage with similar temperature from top to bottom (i.e., isothermal) allowing mixing throughout the water column. In winter, ice forms at the surface and inverse stratification (colder water perched over cool water) may be established and persist until ice-out.

Lake Chemical Attributes

Natural mineral content

Natural water is a complex chemical solution containing gases, mineral and organic substances in the form of true solutions (dissolved phase), as well as suspended and colloidal materials (particulates). The composition of chemicals in a lake determines its general properties, including salinity, alkalinity, pH, hardness, acidity, and corrosivity. Knowledge of water chemistry is necessary for determining the suitability associated with water uses including human water supply (drinking, hygiene, industrial, agricultural), recreation, and support of fish and wildlife propagation. The concentrations of minerals in a lake are generally related to two main factors: the abundance of those minerals in the watershed and the solubility of their compounds.

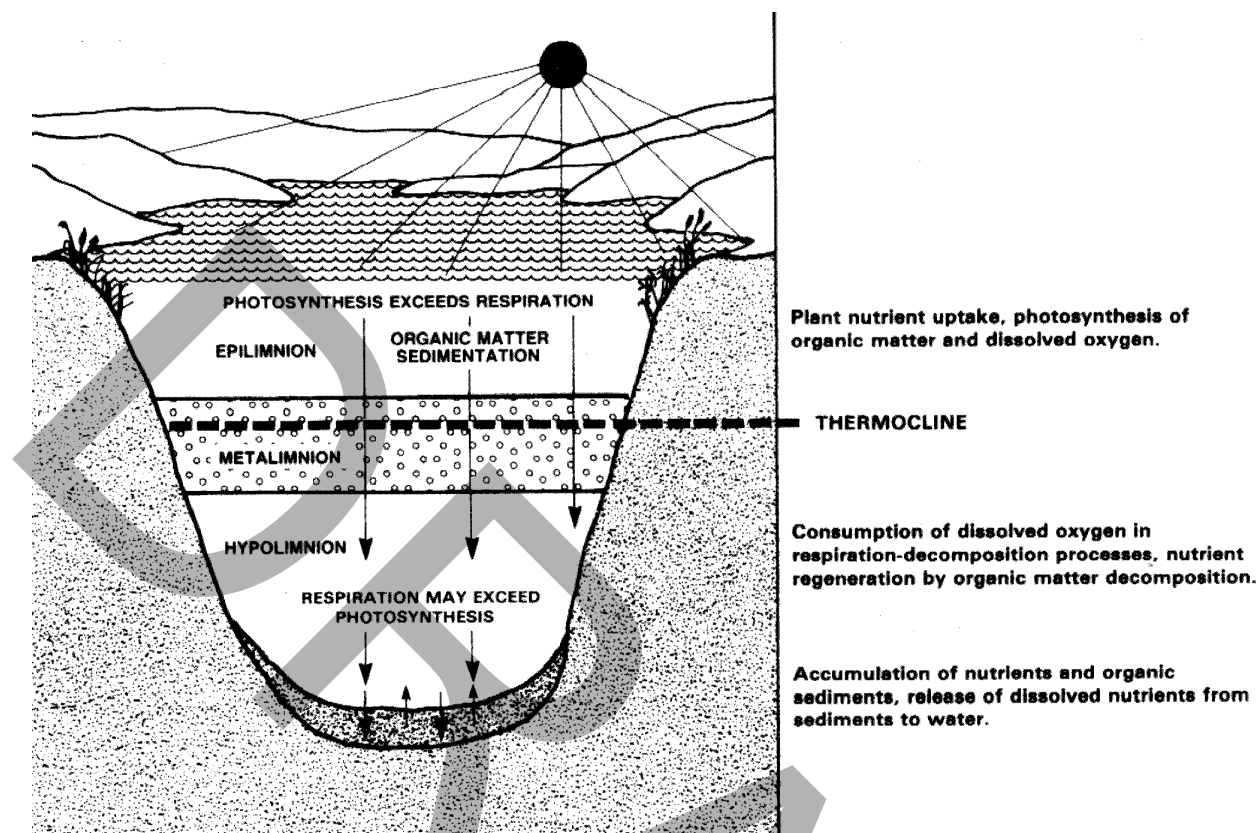


Figure 3. Influences of photosynthesis and respiration/decomposition processes on oxygen and nutrients in a stratified lake (after Olem and Flock, 1990)

Mineral substances contained in natural waters in the dissolved state include major ions that determine overall water chemistry and account for the bulk of natural water mineral content (up to 95% for fresh water). The main anions contained in natural water are chloride, sulfate, hydrogen, bicarbonate, and carbonic acid. The main cations are calcium, sodium, magnesium, and potassium.

In addition, there are minor ions occurring only under certain conditions and in very small concentrations (e.g., micronutrients such as cobalt, vanadium, and molybdenum). An intermediate position is occupied by ions of hydrogen, compounds of nitrogen, phosphorus, iron, and silicon dissolved in water. This “soup” of largely invisible components mixed with water is an important determinant of which aquatic organisms will thrive in that water and differs greatly across the Commonwealth from Cape Cod to the Berkshires.

Dissolved oxygen

Dissolved oxygen (DO) is the measure of how much oxygen is dissolved in the water and is one of the most important indicators of water quality. DO is essential for the survival of fish and other aquatic organisms. Both the level of DO in a lake and its spatial and temporal pattern of distribution constitute a critical diagnostic tool to understand the health of a particular lake.

Oxygen diffuses into the surface of the lake from the atmosphere and input is enhanced by the aerating action of wind and waves. Oxygen is also introduced into lake water as a metabolic byproduct of photosynthesis (e.g., from algae and vascular plants). The amount of oxygen that lake water can hold is directly related to temperature. The colder the water, the more dissolved oxygen can be contained (Figure 4). Conversely, as water temperatures increase, less oxygen can be dissolved in the water. Salinity can also be an important factor in determining the amount of DO a body of water can hold; fresh water can absorb more oxygen than salt water. To a lesser extent, altitude also affects DO, with higher levels found at lower elevations and decreasing with elevation.

Lake DO levels are reduced by two main processes: respiration and decomposition (Figure 3). Respiration by aquatic life uses oxygen to produce energy, releasing carbon dioxide and water as by-products. Decomposition is the process by which bacteria and fungi consume oxygen to break down dead organic material. Higher levels of decomposition can lead to decreased levels of biologically available DO, in some cases leading to fish kills and impacts to other aquatic organisms.

In seasonally stratified lakes, there is often a strong depth profile of DO in the summer with the upper layer (epilimnion) being near saturation (i.e., the maximum amount that can be dissolved in water for a specific temperature) and the bottom water (hypolimnion) having greatly reduced levels (hypoxia) or even devoid of measurable oxygen (anoxia). Anoxia occurs because respiration and decomposition at the bottom of the lake consume all the available DO. The oxygen can't be replenished because it is isolated from the top of the lake by the thermal differences (density layers) that resist mixing and there is inadequate light to support photosynthesis in the deeper water. In the spring and fall when the lake mixes again, the oxygen levels at the bottom of the lake get replenished. The oxygen demand exerted by sediment can be measured and is an important feature in lake ecology and is greater with increasing organic content.

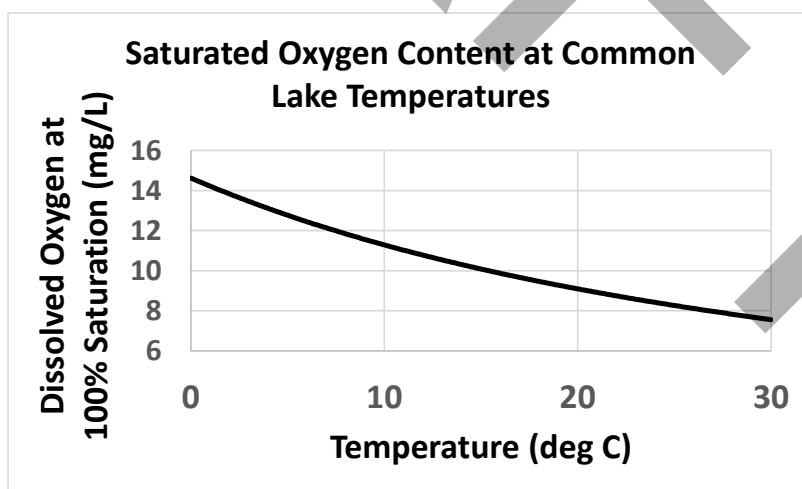


Figure 4. Relationship between oxygen saturations level and temperature in water

Loss of DO is a major impairment of lakes with multiple negative consequences. Fish and invertebrates cannot survive without oxygen. Reduced compounds that impart taste and odor build up when there is no oxygen to support oxidation processes. Another consequence of the bottom layer of a lake becoming anoxic (usually in summer and late winter) is that chemical processes at the sediment-water interface favor the release of P from the sediments. This enhancement of the lake P supply can support increased phytoplankton growth. This process is called internal loading or recycling from the sediments (see Nutrients below) and may be a major source of P to lakes and cause of algae blooms including cyanobacteria.

Nutrients

Nutrients are chemical elements critical to the development of plant and animal life. All plants need an appropriate balance of the essential major nutrients, particularly (P), nitrogen (N), and carbon (C), with additional plant-specific needs for minor nutrients or trace elements, such as silicon, iron, boron, vanadium, and others. In lakes, availability of nutrients is usually correlated to the overall productivity of the lake. The “limiting nutrient” concept states that whatever nutrient is in shortest supply relative to the needs of the plant will limit productivity. The limiting nutrient concept is one of the most important principles of lake management particularly in the control of excessive algal growth and eutrophication. However, not all plants (including algae) have identical nutrient needs, and the concentrations of nutrients can change, so the limiting nutrient may change over time and space. This has been called a state of dynamic equilibrium. Yet a severe shortage of an essential nutrient can control overall productivity, and many lake management techniques are intended to reduce nutrient inputs or availability.

The ratios of plant chemical growth requirements to the concentrations of nutrients in water suggest that P is generally the scarcest nutrient relative to plant demand in most freshwater systems, although N or trace elements can sometimes be limiting. All algae and plants need P but the need for other nutrients varies in terms of form and quantity. Therefore, P availability usually determines how much growth there will be, while the other nutrients determine what type of phytoplankton will be favored for growth. Diatoms need more silicon than other algae and drop out of the phytoplankton assemblage as silicon becomes scarce. Green algae need more N than most other algae and drop out as available N is used up. Cyanobacteria need minimal silica and some forms can utilize dissolved N gas not available to other algae, allowing them to become dominant when other algae are limited.

As noted above, P is the most common limiting nutrient and P input and availability tend to be easier to control than many other nutrients, therefore making P the logical target of management to control algae in lakes. Both C and N have gaseous phases, so the atmosphere is a major source and makes them difficult or infeasible to effectively reduce. Lake managers typically compartmentalize forms of P into three categories: dissolved, particulate, and their sum, total P. Dissolved P is readily available for uptake by algae and, consequently, is usually found only in low concentrations in lake water during the growing season. At that time, most of the P will either

be adsorbed to particles such as fine soil or clay or contained in living or dead plant or animal cells. However, the death and decay of an organism can release the P in dissolved form where it can almost instantly be taken up by other organisms. As the forms of P can rapidly change, productivity potential is generally assessed based on total P.

Development of a nutrient budget (loading analysis) provides insight into both the causes and potential means of rehabilitation of lake eutrophication. Generation of nutrient budgets is essential to the planning of effective long-term algal control efforts. Nutrient budgets estimate the amounts of a nutrient that are provided by sources such as natural surface runoff or groundwater flow, non-point source pollution, wastewater disposal systems, other human-induced discharges, atmospheric deposition, and wildlife or pets. Nutrient budgets also estimate the quantity of nutrients lost from the lake system by outflow and deposition to the sediments. Quantifying nutrient loading requires assessment of the water budget and sampling and analysis of the concentration of the nutrient in each major water input.

The quantity of any 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 since their growth is often not tightly linked to nutrient concentrations in the water column, but rather to available nutrients in the sediment, although some higher plants do utilize nutrients dissolved in lake water.

Internal loading refers to nutrients recycled from sediments. Internal loading may be a large source of P to the lake in certain circumstances when dissolved oxygen levels in bottom waters are depleted or near zero. The rate of hypolimnetic oxygen demand is lake specific and is a product of several factors, including the thermal stratification structure, organic loading, community respiration, and sediment oxygen demand. Most values for oxygen demand, expressed on an areal basis, fall between 0.5 and 4.0 g/m²/day. With oxygen demand in excess of 1 g/m²/day it is likely that a stratified lake will experience anoxia at the sediment-water interface by late summer. At an oxygen demand in excess of 2 g/m²/day, that anoxia can occur in early summer.

When lake sediments become anoxic (lacking available oxygen) as they usually do in a stratified eutrophic lake, P that is normally adsorbed to iron oxides under oxygenated conditions is released in dissolved form. This hypolimnetic P may be returned to upper water layers during turnover or even during stratification by diffusion or smaller mixing events. Where even a little light penetrates to an anoxic sediment-water interface, algae can grow at that interface then rise in the water column to form blooms. Decay of organic matter also releases P back into the overlying water. Resuspended sediment (mobilized by wind or motorized watercraft) may release P back into the water column. Additional P may be “pumped” from shallow water sediments by rooted aquatic

macrophytes, particularly when the plants die. Internal P loading is often hard to accurately estimate. The timing of this internal loading may make it more important than its magnitude suggests; internal cycling of nutrients may not be dominant in a yearly budget but may be very important during the summer stratification period, which is also the growing season.

Nutrient loads are commonly determined in two primary ways: by direct measurement or by estimation from various empirical relationships from the literature. Accurate determination of a nutrient load by direct measurement is monitoring-intensive, requiring frequent seasonal measurement of water flow and nutrient concentration in all major input/output components. Flow rates are hard to determine precisely without automated equipment, especially during storm events. Infrequent rain events may be important; one large storm may provide a large percentage of the nutrient input and, if unmeasured, the load will be underestimated. Groundwater samples may be difficult and/or expensive to collect, and groundwater flows can be difficult to measure or calculate.

In practice, it is difficult to achieve or afford this level of monitoring, although some amount of monitoring is essential to support any loading assessment. Consequently, nutrient loads are often calculated by loading estimates through modeling based on land uses. Research on many watersheds has provided a database of approximate loading factors or export coefficients associated with various types of land use, atmospheric inputs, numbers of human residents or wildlife, sediment sources, and other more easily measured factors such as discharges. The quality of the nutrient budget will depend on the similarity between the study watershed and the selected export coefficients derived from the studied watersheds in the literature.

No method is likely to produce a very accurate estimate of the nutrient load if monitoring frequency is low or if the watershed's land use pattern is only moderately comparable to selected export coefficients. However, the credibility of the estimate can be substantially increased if multiple methods are used and produce comparable results. Agreement among multiple models, especially when calibrated for the study watershed with data specific to that system, can increase confidence in loading estimates. Key sources of nutrients and other contaminants should be assessed (Figure 5).

Particulates

Particulates may be inorganic or organic in nature, typically defined as any object larger than 0.45 thousandths of a millimeter. This is functionally determined by filtering a water sample and separating the liquid (dissolved materials) from that retained by the filter (particulates). Larger particles will typically not stay suspended in water for long, while smaller particles such as fine clays may settle very slowly or not at all. Colloids are fine particles with almost the same density as water that can remain suspended almost indefinitely. 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.

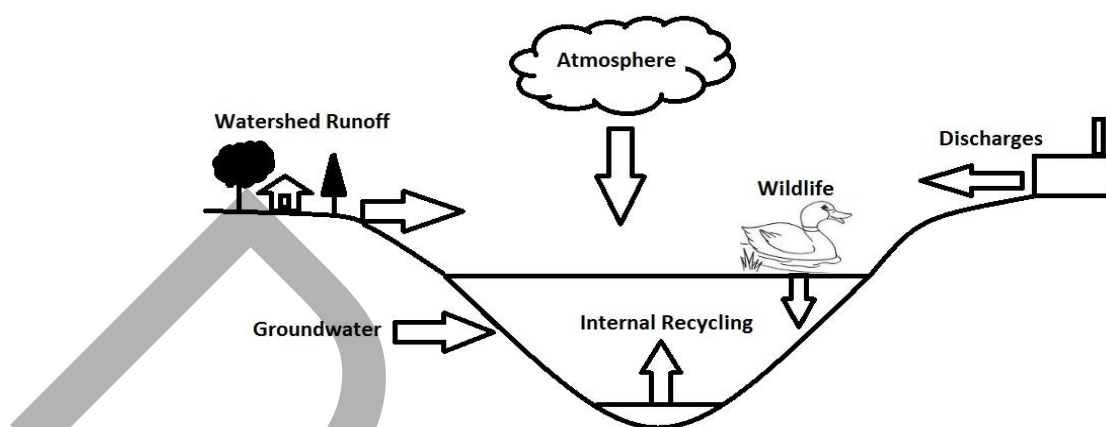


Figure 5. Sources of nutrients and other contaminants to lakes

Toxic pollutants

Lakes, particularly those with urban watersheds, may be subject to inputs of various toxic pollutants that can pose concerns for aquatic life, recreation, and drinking water potability. These inputs are usually derived from runoff or groundwater associated with current or past industrial uses or waste disposal in the watershed but may also enter lakes as a result of agricultural activities or via atmospheric deposition. Many toxic pollutants adhere, or “sorb”, to sediment rather than staying dissolved in water and, since many of “legacy” contaminants degrade poorly if at all, they can persist in the sediment for years, long after they are no longer detectable in the overlying water. Many of these toxic pollutants also bioaccumulate⁵ through the food chain resulting first in contamination of lower aquatic life and then biomagnifying up the food chain leading to problematic concentrations in birds, gamefish, and humans. Therefore, testing of sediments suspected of harboring toxic contaminants is an essential and required step in determining options for their removal and disposal in an environmentally safe manner. Examples described here include heavy metals, polychlorinated biphenyls (PCB), organochlorine pesticides, polyaromatic hydrocarbons (PAH), and per- and polyfluoroalkyl substances (PFAS).

Heavy metals are widely distributed toxic environmental pollutants found in lakes. The term heavy metal refers to any metallic chemical element (metal or metalloid) with a relatively high density. Trace amounts of certain heavy metals (e.g., cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), selenium (Se), and zinc (Zn)) are important as micronutrients for plant metabolism and a few are essential for human metabolism at low concentrations but become toxic at higher concentrations. Other heavy metals have no essential biotic function and pose potentially serious toxic concerns, including arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), and lead (Pb). Past and current sources of these elements include arsenic used in wood preservation or

⁵ Bioaccumulation is defined as the increase of contaminant concentrations in aquatic organisms following uptake from the ambient environmental medium.

pesticides, cadmium used in pigments, batteries, and plastics, chromium used in steel, chrome plating, dyes and pigments, and leather and wood preservation, mercury used in thermometers and light bulbs, and lead used in gasoline, paint, pipes, ammunition, and batteries (USEPA 2021a).

Heavy metals can enter a lake or water supply from industrial and consumer waste, agricultural or urban runoff, air pollution, or from acidic rain leaching materials from watershed soils. In some lakes, overuse of copper sulfate as an algaecide or arsenic-based herbicides has led to elevated levels in the sediments. Heavy metals are generally not very soluble in water and are more likely to bind with organic materials and settle out. Where industrial pollution or urban storm runoff is currently or historically present, heavy metal concentrations can be quite high. How much interaction these metal accumulations have with sediment-dwelling organisms or the overlying water and its inhabitants has been the subject of considerable study and debate, with highly variable results mostly as a consequence of site specific factors.

Because heavy metals are not degraded or destroyed in nature, they have the potential to bioaccumulate. Mercury concentrations increase rapidly through the food chain and have led to toxic concerns for higher trophic level predators as well as humans. MA issues [fish consumption advisories](#) for mercury and other bioaccumulative contaminants (e.g., pesticides and PCBs) to advise citizens regarding safe consumption levels.

PCB and organochlorine pesticides are occasionally found as legacy contaminants in sediments in lakes although their environmental levels are generally on the decline. PCB are synthetic, lipophilic chemical compounds that had widespread use as insulation fluids and lubricants in electrical transformers and building materials and are common contaminants at former industrial sites or in older landfills. They tend to enter the environment through improper storage or disposal.

Organochlorine pesticides with former widespread use include dichlorodiphenyl trichloroethane (DDT) and its primary metabolite, dichlorodiphenyl dicloroethene (DDE), and hexachlorobenzene (HCB). Because of toxicity and bioaccumulation concerns, use of PCB and DDT and other organochloride pesticides was banned in the USA in the 1970s. However, PCB and organochlorine pesticides can still persist in lake sediments, particularly those in urban watersheds with historic use of those substances. Screening or testing of lake sediments for these substances is a common requirement of the permit process for sediment removal and disposal activities.

PAH are a group of over 100 different chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances. PAH enter the air mostly as releases from volcanoes, forest fires, burning coal, and automobile exhaust. PAH generated from these sources can bind to or form small particles in the air. PAH enter lakes through discharges from industrial and wastewater treatment plants or by atmospheric deposition. Since most PAH are not easily soluble in water, they bind strongly with organic substances and settle to the bottom sediments. Screening or testing of lake sediments for these substances is a common requirement of the permit process for sediment removal and disposal activities.

Per- and polyfluoroalkyl substances (PFAS) are a family of chemicals used since the 1950s to manufacture stain-resistant, water resistant, and non-stick products and certain firefighting foam. These widely used, long lasting chemicals break down very slowly over time and have been coined “forever chemicals”. They are considered an emerging contaminant of national concern. Testing has shown that PFAS are widely found in lakes and reservoirs in MA (MassDEP 2024) and nationwide. Because of their widespread use (e.g., food packaging, non-stick cookware, water-resistant clothing and materials, cleaning products, personal care products and cosmetics, paints, varnishes, and sealants) and their persistence in the environment, many PFAS are present at low levels in the environment as well as in the blood of people and animals. Scientific studies have shown that exposure to some PFAS in the environment may be linked to harmful health effects in humans and animals. Investigation of the magnitude and risk implication of PFAS contamination is the subject of on-going research. Currently, the MassDEP requires testing for numerous chemicals in all public drinking water systems and has set a combined limit for the six most concerning [PFAS chemicals](#) at 20 parts per trillion.

Lake Biological Attributes

Bacteria

Bacteria are by far the most abundant and diverse group of organisms in a lake and play the central role in decomposing organic matter into its inorganic components which are then recycled. They occupy an incredibly varied set of habitats, metabolic pathways, and functional interconnections with the organic and inorganic carbon fractions. Due to this taxonomic and functional diversity, this document cannot fully describe their role, but a brief overview is provided.

Bacteria may be free-floating in the water column, attached to a substrate, or buried in the sediments. Many are aerobic, requiring oxygen for the conversion of organic material to inorganic forms and energy, while 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. Bacteria also help mediate the conversion of organic nitrogen into bioavailable forms such as ammonium or nitrate. Some bacteria are photosynthetic (e.g., cyanobacteria, also called blue-green algae) and are discussed separately below.

Some bacteria can create human health problems or have proven to be useful indicators of the likely presence of threats to human health. For example, *Escherichia coli* is usually an innocuous bacterium found in the intestinal tract, but its abundance in a lake indicates that sewage, septic inputs, or other fecal contaminants are present, signaling the potential for the transfer of bacterial and viral diseases. Other sources of bacterial contamination in lakes arise from animal sources such as pet waste or waterfowl excretion. *Giardia* and *Cryptosporidium*, pathogenic protozoans, can be transmitted from any warm-blooded animal to water and may be indicated by fecal bacteria presence. Pathogenic organisms, bacteria, and viruses are of particular concern in lakes and reservoirs used as a source of potable supply or for contact recreation. In the case of potable

supplies, modern water treatment processes, including disinfection, ensure that water supplied to the human population should have minimal contamination, but protection of water sources is still warranted.

Algae

Algae are primary producers consisting mostly of microscopic plants that may be variously free-floating (phytoplankton), attached to a substrate such as rooted macrophytes (periphyton), or form on sediments (algal mats). They vary greatly in cell size and may be single-celled or multi-cellular. Importantly, each group has particular characteristics that affect their value to the food web and may impact lake water quality. Depending on the taxonomic systems, as many as 14 classes of algae can be recognized, but three major groups recognized on the basis of pigment differences and three additional minor groups represent more than 90% of the algae we encounter in MA lakes (Figure 6). Brief descriptions of the important groups are given below.

Blue-green algae (cyanobacteria) are evolutionary intermediates between heterotrophic bacteria and algae. The term cyanobacteria is generally preferred, but algae include a wide range of organisms that represent a challenge for unified classification. Many blue-greens can use (or “fix”) atmospheric N gas that is dissolved in the water. Accordingly, a shortage of available N in the water may give nitrogen-fixing cyanobacteria a competitive edge in growth. Within the cyanobacteria, there are many species with adaptations that allow them to persist and thrive in the summer plankton, including higher thermal tolerance, flotation through cellular gas pockets, and gelatinous sheaths and large particle sizes that make them inedible to many grazers (i.e., zooplankton).

For most lakes, cyanobacteria are a year-round component of the phytoplankton community. This includes many “healthy” lake ecosystems. However, cyanobacteria can become abundant in warm, minimally mixed, nutrient-rich surface waters that receive a lot of sunlight. In high concentrations they can form nuisance blooms, causing fluctuations in pH and oxygen, taste and odor problems, or even toxicity. The most common problem types include *Microcystis*, *Aphanizomenon*, *Dolichospermum* (formerly *Anabaena*), and *Planktothrix*, but there are dozens of other cyanobacteria that can become abundant in lakes.

Most cyanobacteria can produce toxins that can cause illness in humans, pets, livestock, waterfowl, and other animals that come in contact with the algae, mainly through ingestion but possibly by skin contact or inhalation. However, toxin production does not always occur, even if possible toxin producers are present; there is no way to know for sure that toxins are present without directly testing for them. There are simple field kits to assess a few of the more common toxins, but complete testing is an expensive laboratory endeavor. The probability of toxins being present at a hazardous level even when the water is obviously discolored by a cyanobacteria bloom is not high (Lindon and Heiskary 2009, Graham and Jones 2009, Bigham et al. 2009, USEPA 2012), but blooms present risk and windblown accumulations near shore and surface scums represent the

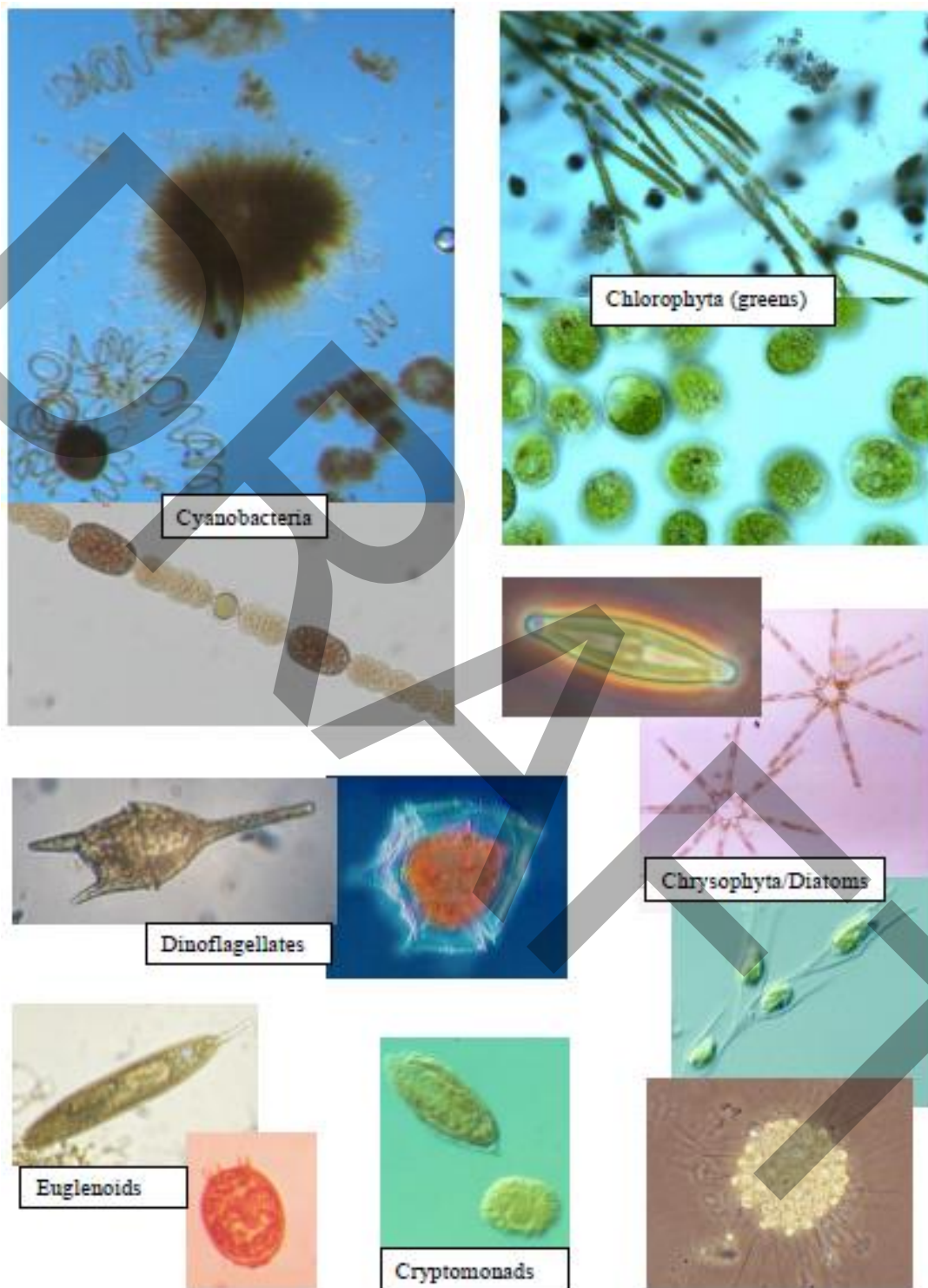


Figure 6. Major types of freshwater algae

greatest risk. There are other algae that can produce toxins but nearly all are rare in MA. As a result, when Harmful Algae Blooms (HAB) are documented in MA, they almost always involve cyanobacteria.

Toxic blooms can kill livestock and pets that drink the water. Signs of a toxic bloom may include dead fish, waterfowl, or other water-dependent animals or sudden, unexplained sickness or death of pets or livestock, especially if cyanobacteria are found on mouths, legs, or feet. Exposure by humans to high levels of cyanobacteria and their toxins can cause diarrhea, nausea or vomiting, skin, eye or throat irritation, and allergic reactions or breathing difficulties. Human death from exposure to cyanobacteria is very rare but some toxins attack the liver and others affect the nervous system, so serious reactions are possible. Local health departments are the primary point of contact for reporting blooms and/or toxins in recreational waterbodies. The MA Department of Public Health (MassDPH) advises local health departments regarding testing and posts lists of lakes with [cyanobacteria bloom advisories](#). MassDEP maintains a website for [cyanobacteria information](#) and additional information can be found on the [North American Lake Management Society online cyanobacteria resources](#).

In contrast, a group within the Chrysophyta (golden algae) known as diatoms usually forms an important part of the food chain and rarely causes problems in recreational lakes. These algae construct silica shells of many shapes with intricate markings. 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 include forms that live in shells that look like wine glasses or spiny coats with whipping flagella to move them about. Some of these chrysophytes can cause taste and odor problems in drinking water reservoirs but are rarely a significant problem in recreational lakes. Many golden algae can consume bacteria and organic compounds, acting more like animals than plants, and allowing survival under very low light conditions where photosynthesis is limited. Diatoms and golden algae can be found at any time of year but tend to be dominant in cold water.

Green algae (Chlorophyta) constitute an incredibly diverse group ranging from single-celled to complex multicellular organisms on the main evolutionary line to vascular plants. They are important constituents in the food chain, but some species are difficult to ingest or digest and can cause blooms in eutrophic lakes. They generally prefer a higher ratio of N to P than cyanobacteria. Many filamentous green algae form mats that can carpet the bottom, form clouds in the water column, or accumulate around macrophytes. Mats can trap gases and rise to the surface with windblown accumulation along shore. The Charophyta, recently split off from the Chlorophyta but with similar pigmentation and cell wall composition, include taxa like *Chara* and *Nitella* that grow attached to sediment and behave more like vascular plants than algae.

The dinoflagellates (Pyrrophyta) tend to be less abundant than the above groups but are sometimes dominant in freshwater. Some dinoflagellates cause harmful algal blooms in marine environments, but freshwater forms are not known to be toxic. Dinoflagellates are often associated with high

871 organic content waters and occasionally ingest bacteria or other organic particles for nutrition.
872 Because all are motile, they can often dramatically change their position in the water column to
873 take advantage of local nutrient or light conditions.

874 Euglenoids are another mostly flagellated group that share pigment composition similarity with
875 the green algae but make use of organic particles and dissolved compounds more like the
876 dinoflagellates, some chrysophytes, and cryptomonads. They can form surface scums that vary in
877 color from green to red, and at high abundance are normally indicators of very poor water quality.
878 Cryptomonads are small flagellates the make excellent zooplankton food; they are ubiquitous but
879 rarely abundant. Other algal groups (i.e., red and brown algae) are rare in freshwater lakes and
880 occur mainly in marine environments.

881 Knowing which species is in “bloom” can help understand the cause of the bloom. For example,
882 certain cyanobacteria often bloom when P is abundant and nitrate is scarce because they can fix N
883 from dissolved gas. Internal loading from sediments almost always has a low N:P ratio and tends
884 to foster cyanobacteria blooms. Where the cyanobacteria responsible for a bloom are buoyant
885 forms that have gas pockets in their cells, there is a high potential that growth initiated at the
886 sediment-water interface or near the thermocline. The diatoms tend to prefer times of high mixing,
887 cooler temperatures and higher silica availability, conditions found in lakes at spring and fall
888 turnover. Summer diatom blooms are likely to indicate strong mixing events. Many dinoflagellates
889 and euglenoids prefer water with above average organic content, so a shift to those algae may
890 signal increased organic inputs.

891 The bloom formation mode whereby algae initially grow at the sediment-water interface, on
892 sediments that tend to be nutrient-rich but shallow enough that some light penetrates to the bottom,
893 before rising into the water column. This means that even lakes with relatively low concentrations
894 of P and N in the upper waters can be susceptible to algae blooms. Many cyanobacteria are
895 particularly adapted to this growth mode and many filamentous green algae apply this mode.
896 Actively swimming forms of golden algae and dinoflagellates can also descend to the sediment-
897 water interface to acquire nutrients and move upward to get more light. Legacy inputs of nutrients
898 harbored by sediment are therefore of great management interest in otherwise “clean” lakes.

899 The dynamics of the thermal, light, and nutrient regimes in lakes cause shifting environmental
900 conditions that cause a fairly predictable pattern in the seasonal succession of algal groups in
901 northern temperate lakes (Figure 7), but there may be year-to-year deviations from this pattern for
902 any particular lake due to climatic variation or other factors.

903 Typically, spring conditions favor diatoms and golden algae which may become very abundant
904 but usually do not cause severe impacts on human use, although some species cause taste and odor
905 problems in drinking water reservoirs and can clog filters. During thermal stratification, green
906 algae often dominate, but they may be replaced by cyanobacteria at higher temperatures, lower
907 inorganic N concentrations, and high pH. Diatoms and goldens tend to dominate again in autumn,
908 but summer cyanobacteria may persist. Winter ice cover limits photosynthesis and overall algal

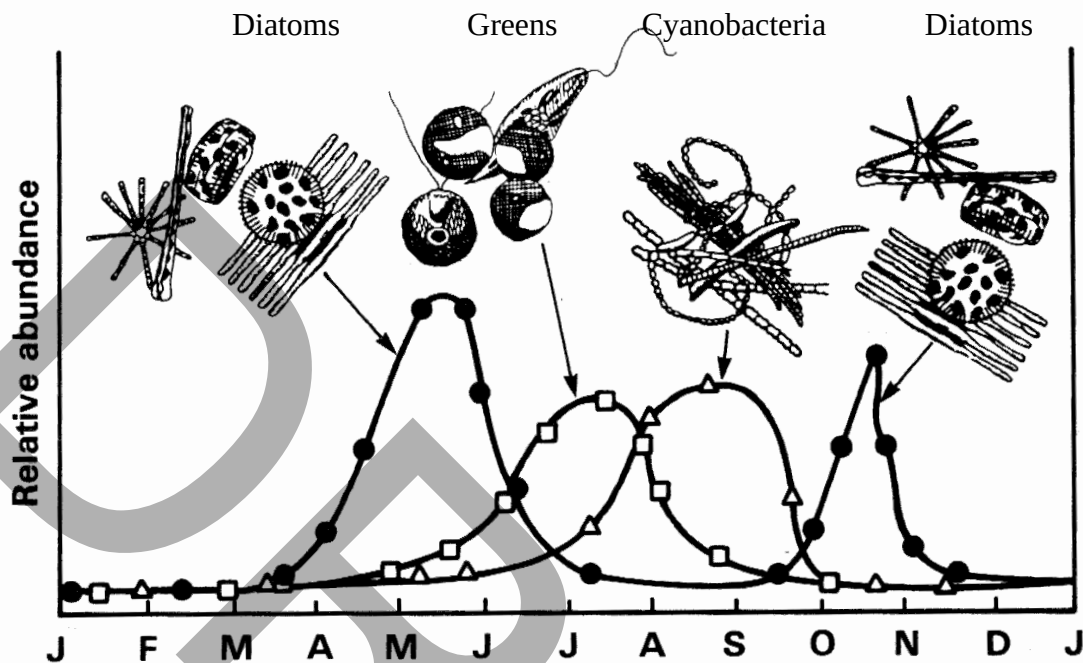


Figure 7. Seasonal succession of phytoplankton (after Olem and Flock 1990).

abundance; diatoms and greens tend to dominate but cyanobacteria can persist as well. Alternative sequences or biomass peaks are possible as a function of disturbance, including high flushing rates, erratic nutrient or organic matter inputs, drought, or aberrant temperature swings.

Because there are so many species of algae and quantification requires considerable expertise, limnologists have developed surrogate measures of algal biomass. One of these is to measure the primary photopigment that all algae share, chlorophyll-*a*. Chlorophyll-*a* can be estimated relatively easily by several techniques, including probes that utilize fluorescence. However, the correspondence between the amount of chlorophyll and the actual biomass of algae is variable. Not all algal species have equal amounts of chlorophyll per unit volume or mass and the amount of chlorophyll in each species varies with the nutritional health of the cells. Nevertheless, chlorophyll has become a useful measure for lake management.

A second, 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 8). Visibility has been reasonably well correlated to chlorophyll, at least where non-algal turbidity is low, and the measurement is easy to make. Secchi transparency readings can be made by volunteers with very little training and provide a low-cost means to track algal abundance. Use of a viewing tube that extends just below the water surface is advised to eliminate interference from waves or sun glare that could induce variation not due to algae. Yet this relatively simple tool provides a valuable surrogate for more complex algae measurements.

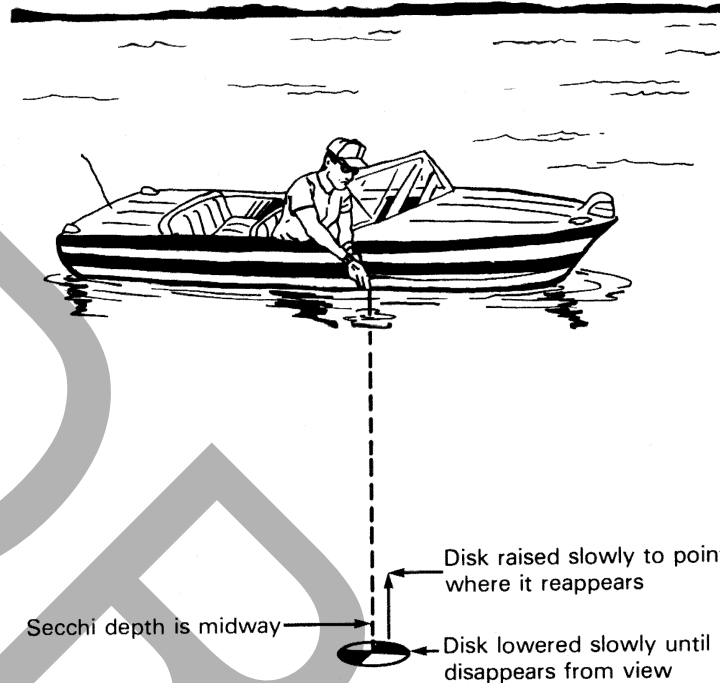


Figure 8. Measurement of Secchi disk transparency (Olem and Flock 1990)

Aquatic Macrophytes

Aquatic macrophytes are large aquatic plants, easily visible to the naked eye. In shallow lakes with soft bottoms, the vast majority of lakes in MA, plants are often abundant. Macrophytes may be rooted in sediment or free-floating, although most are rooted (Figure 9). They may also be submergent, emergent, or floating-leaved. There are many taxonomic groups, but these functional categories are often the most useful for understanding macrophyte problems and determining an appropriate management strategy. Within each category many species may look similar as their growth habit responds to common lake conditions, but there are ecological differences that warrant proper identification. There are many plant identification guides available, including the [MassDCR MA-specific plant guide](#).

Aquatic invasive species include some of the most troublesome plants (Table 1) and it is important to properly identify all plant species in a lake when considering management. For example, a drawdown may reduce densities of Eurasian watermilfoil (*Myriophyllum spicatum*) but may increase densities of spiny naiad (*Najas minor*) based on their overwintering strategies (vegetative vs. seeds). Plant species protected under the [MA Endangered Species Act](#) (MESA) will require special consideration when present.

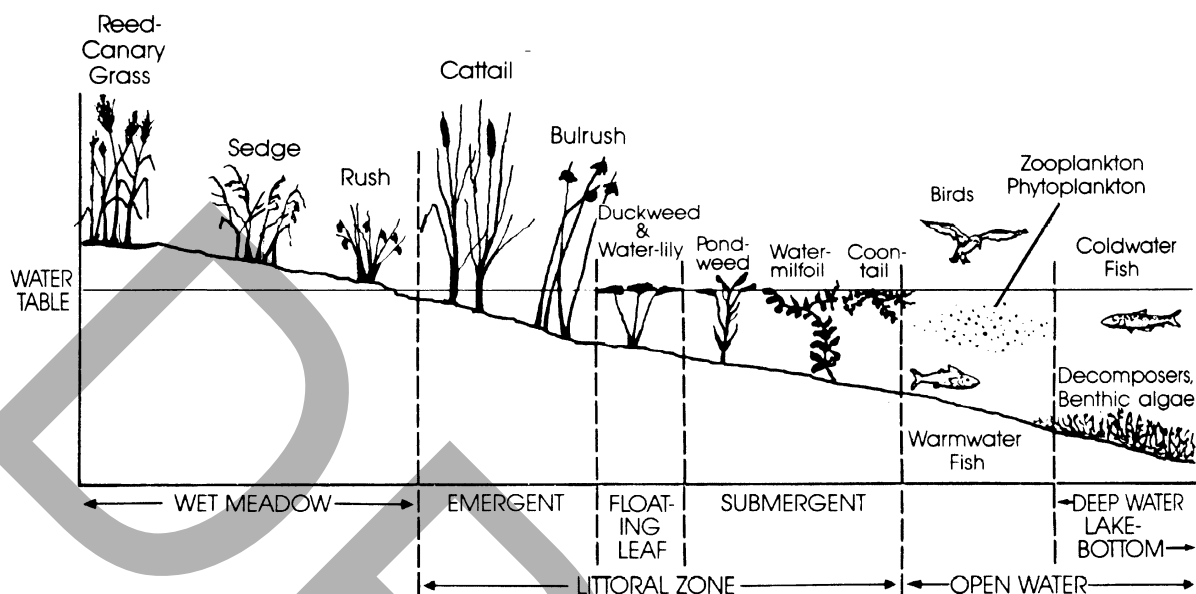


Figure 9. Typical aquatic plant zones in lakes and ponds (From Kishbaugh et al. 1990)

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, similar to 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 or littoral 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 are not limited by light, except in cases of self-shading when growths are dense, but these plants cannot use the sediments as a source of nutrients and must depend on nutrients in the water column. Finally, floating-leaf plants have attempted to achieve the best possible situation by having their roots in the sediment and leaves at the surface, but they still have depth limits and tend to grow at water depths intermediate to emergent and submergent forms.

MA is highly susceptible to introductions of non-native macrophyte species, also referred to as non-indigenous species or aquatic invasive species (AIS). A book on AIS in MA (Wong 2023) covers both plants and animals in detail, including potential control methods. Unfortunately, many (although not all) of the plants have high nuisance potential. Unlike the natural biota and even the non-native biota introduced more than a hundred years ago, non-indigenous nuisance plants have few if any local biological controls and are often invasive pests that can totally dominate and depress or even eliminate native populations. They have been introduced in a variety of unwitting ways, most notably through the aquarium and horticulture trades with subsequent transfer among

lakes by boats that are not cleaned or sanitized between uses in different lakes. Waterfowl can also act as important vectors.

Introduced non-native species can negatively impact or even replace healthy native aquatic communities and produce economically and recreationally severe impacts even though no other change has occurred in the watershed. In many situations where a non-native species has been introduced, a near monoculture of that species develops, reducing recreational utility and habitat value. MA maintains a list of [prohibited plants](#) that may not be brought into MA, only a subset of which are aquatic and known to create nuisance conditions in MA to date (Table 1).

Table 1. Introduced aquatic plant species known to create nuisance conditions in Massachusetts

Scientific Name	Common Name
<i>Cabomba caroliniana</i>	Fanwort
<i>Egeria densa</i>	Brazilian elodea
<i>Hydrilla verticillata</i>	Hydrilla
<i>Lythrum salicaria</i>	Purple loosestrife
<i>Myriophyllum aquaticum</i>	Parrotfeather
<i>Myriophyllum heterophyllum</i>	Variable leaf watermilfoil
<i>Myriophyllum spicatum</i>	Eurasian watermilfoil
<i>Najas minor</i>	Spiny naiad
<i>Nelumbo nucifera</i>	Asian or Indian Lotus
<i>Nymphoides peltatum</i>	Yellow floating heart
<i>Phragmites australis</i>	Common reed grass
<i>Potamogeton crispus</i>	Curly leaf pondweed
<i>Trapa natans</i>	Water chestnut
<i>Utricularia inflata</i>	Swollen bladderwort

Rapid expansion of introduced species in many lakes in MA and other states has severely impacted otherwise healthy lakes. Within just a few years, a small patch of an introduced species can grow to fill acres of the lake within the photic zone, often filling the water column or covering the lake surface.

While an overabundance of native species and diminution of desired uses can be managed over time, the initial detection of an introduced species should trigger immediate action if eradication is to be achieved. 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 once it becomes established, but the probability of achieving and maintaining control is maximized through early detection and rapid response. There are many guidance documents at the federal and state level outlining planning and strategies for detection and rapid responses to invasive outbreaks. Information and regulations regarding [control of nuisance invasive species](#) are

available as well as the [Aquatic Invasive Species Assessment and Management Plan](#) developed for water supply reservoirs.

MassDEP 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* (watermilfoil, actually 3 species), *Cabomba* (fanwort) and *Lythrum* (loosestrife). MassDEP and MassDCR are working on an updated database, but it is not yet publicly available. Contact the Lakes and Ponds Program within MassDCR to report a possible invasive species or check to see if your waterbody is known to harbor invasive species.

Some species not found in the 320 surveyed lakes from before 1995 are known from MA lakes now, most notably *Hydrilla* and *Myriophyllum aquaticum* found in Cape Cod lakes. All of the species listed in Table 1 have been found in MA as of 2003, when MassDCR staff updated the earlier survey (see Appendix VI of the GEIR). While a few populations of invasive species have been eradicated, the frequency of most has increased since the 1994 listing. The United States Geological Survey maintains a list of [non-indigenous aquatic species in the USA](#) with distribution maps and general abundance designations.

In general, a healthy native plant community is considered desirable within a lake ecosystem. Where the sediment is suitable and light penetrates, rooted plants will inevitably grow. Thus, 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 provides valuable habitat and will not necessarily create nuisance conditions. Invasive species 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 due to the presence of competition and native controlling agents (e.g., herbivores). However, under certain conditions, some native species can become a nuisance, expanding into areas either not previously colonized or at one time occupied by other native species. Such imbalances can lead to nuisance conditions such as dense coverage by water lilies (*Nymphaea* or *Nuphar*) or watershield (*Brasenia*). Submergent growths of some native pondweeds (*Potamogeton*) or coontail (*Ceratophyllum*) can become very dense, expand into the upper water column, and become nuisances to boaters or swimmers as well as compromising habitat value for some aquatic fauna. Native plant communities may therefore require management to remain in balance, especially where human impacts on lakes have made them more susceptible to excessive plant growth (e.g., sediment inputs).

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 or open selected areas for water-dependent uses (e.g., swimming, boating). 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 for both native and non-native aquatic plants.

Zooplankton

Zooplankton are tiny invertebrates that swim in the water column, eating algae or each other. There are four major groups, the Cladocera, Copepoda, Rotifera and Protozoa (Figure 10), in decreasing order of typical size, but there are other less common groups that could be important in any given lake. As many are filter feeders, size matters greatly, as filtering capacity is related to the cube of body length. Consequently, a dozen large cladocerans such as *Daphnia* in a quart of lake water can filter out all edible algae in a day, while over 2000 rotifers of typical size would be needed to filter that same water volume. And what is edible is largely related to particle size, with larger cladocerans able to consume much larger particles than most other zooplankton.

All four groups have ecological value, and most zooplankton assemblages contain some members of each group, but cladocerans and copepods are responsible for the vast majority of algae consumption and are the best source of food for small fish. Larger zooplankton represent more energy in a single packet for those small fish, maximizing the energetics of feeding. Therefore, an abundant zooplankton assemblage dominated by cladocerans and copepods, and especially one dominated by the cladoceran *Daphnia* (the most impactful grazer in open water), tends to provide the clearest water possible and supports more small fish.

Some algae, including many cyanobacteria, form larger filaments or colonies that are difficult for zooplankton to consume, and an overfertilized lake will often grow more algae than even the most desirable zooplankton assemblage can consume, so the control exercised by zooplankton on algae has limits. Additionally, the feeding of small fish on zooplankton, especially in early summer after most young-of-the-year fish have hatched, will tend to be size selective and will depress the abundance of larger zooplankton (Hall et al. 1976). Some fish, including alewife and shad, are very effective feeders and can greatly depress zooplankton mean size and abundance. As an intermediate link in the food chain, zooplankton are subject to many biological influences in addition to physical (e.g., flushing) and chemical (e.g., dissolved oxygen) factors that may limit abundance.

Assessment of zooplankton involves collection with a fine net and microscopic examination. One might observe larger zooplankton swimming in a jar of water pulled from the lake, but a concentrated sample is needed for a proper analysis. But just because they are not readily visible does not mean they are not important; zooplankton are a critical link in the food web and knowledge of zooplankton community composition and abundance yields information valuable in lake management.

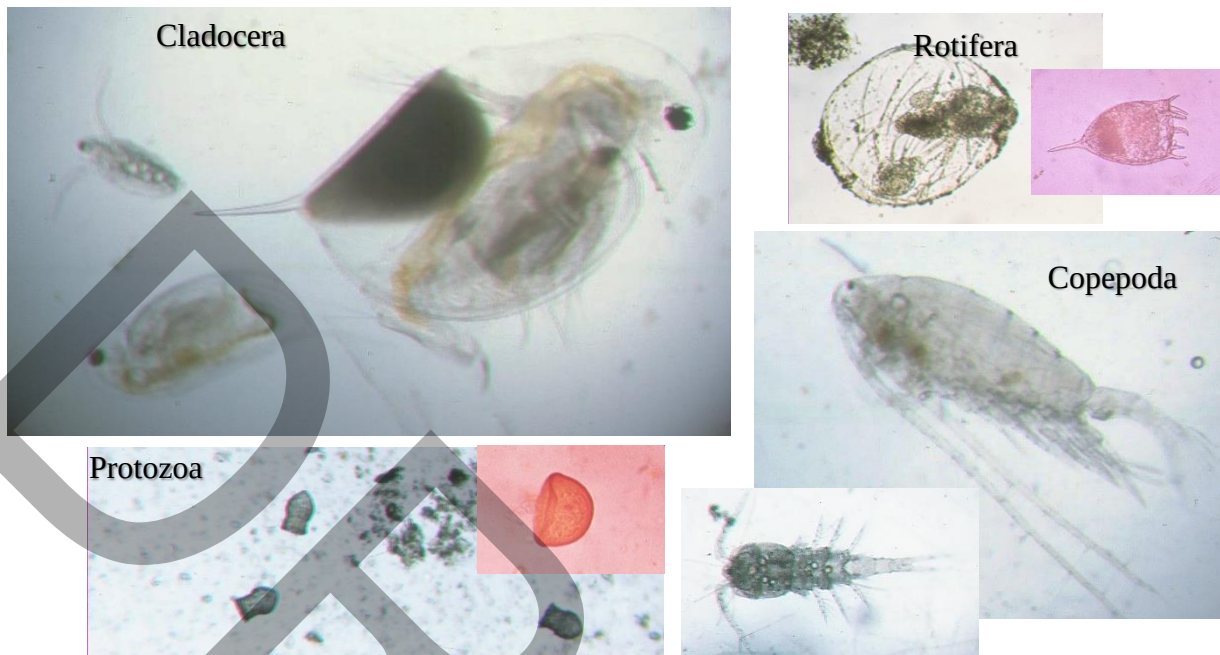


Figure 10. Examples of major zooplankton groups in lakes.

There are several invasive zooplankton that can be found in lakes and ponds in surrounding states and provinces but are not yet known from MA. For example, the spiny water flea (*Bythotrephes* spp.) is a non-native predaceous cladoceran that eats the highly desirable *Daphnia*. It has a long tail spine that often catches on fishing lines and is noticed by fishermen.

Benthic macroinvertebrates

Benthic macroinvertebrates are small invertebrates that live on or in the substrate of lakes and their tributaries. The majority of individuals are likely to be insect larvae, but there are many non-insect groups among the benthic macroinvertebrates. Insect groups that are often abundant in lake sediment include a wide variety of fly larvae (Diptera), dragonflies and damselflies (Odonata), mayflies (Ephemeroptera), caddisflies (Trichoptera) various beetles (Coleoptera), and true bugs (Hemiptera). Non-insect groups that are often abundant include snails (Gastropoda), mussels (Bivalvia), crayfish (Decapoda) and freshwater shrimp (Amphipoda). Leeches (Hirundinea) are of concern to many human lake users.

Collectively, benthic macroinvertebrates are an important source of food for fish and other aquatic life, support neighboring terrestrial ecosystems, and provide other critical ecosystem services that ultimately benefit humans. Snails consume algal slimes that form on rocks and plants. The types of macroinvertebrates present will be a complex function of water quality, sediment features, the plant community, and the abundance of organisms that feed on invertebrates (e.g., many fish, some birds, muskrats). Consequently, the value of [benthic macroinvertebrates as indicators](#) is substantial, reflecting overall waterbody condition by close and varied relationships with environmental and biological factors.

There are both invasive and state-listed (protected) benthic macroinvertebrates, most being mollusks. Asian clams and Chinese mystery snails are non-native species that continue to expand in MA. Zebra mussels are invasive but have been found only in Laurel Lake and the Housatonic River in the Berkshires to date. Many other Berkshire lakes are susceptible to invasion by zebra mussels, which can cover rocky substrate, coat mooring lines and dock pilings, and alter lake ecology by their feeding and excretion. A recent book on AIS in MA (Wong 2023) covers these species in detail, including control methods. Quagga mussels, closely related to zebra mussels, have not been found in MA as of 2023. State listed species are protected under the MESA, which is administered by the NHESP within MassWildlife. Multiple species of freshwater mussels and snails are protected in MA under MESA, as well as some dragonflies, damselflies, and other insects that spend their larval stage in lakes or surrounding shoreline vegetation. Knowledge of the benthic invertebrate community of a lake is therefore important when planning lake management activities.

Fish

There are more than 40 species of fish found in MA lakes, ranging from the small and state-listed bridled shiner to the large and introduced common carp. Fish are often classified ecologically as herbivores (eating plants), planktivores (eating zooplankton and possibly some algae), benthivores (eating benthic invertebrates), or piscivores (eating other fish), but a fish can make use of more than one food group and often does over the course of its life cycle. Most fish start out eating zooplankton and progress to larger prey as they grow.

There are very popular fisheries for many fish species in MA, from trout grown in state hatcheries and stocked as adults specifically for recreational purposes to warmwater species like largemouth and smallmouth bass, pickerel, and several species collectively referred to as panfish. There are few lakes that support self-sustaining populations of coldwater fish (i.e., Quabbin and Wachusett Reservoirs), as most stratified lakes have surface water that is too warm and bottom water that has too little oxygen during summer. Coastal lakes and ponds are important to anadromous species like alewife and blueback herring that return from the ocean to spawn in lakes. These species can be major ecological factors in accessible lakes, consuming most zooplankton and limiting grazing on algae but providing a valuable food base for predatory gamefish. When juveniles leave the lake at the end of summer, they become a major food resource in the ocean.

Almost all fish species that use the littoral zone of lakes and ponds benefit from the proper balance of aquatic vegetation and other habitat like woody material for food and shelter. The habitat needs and ecology of fish species varies substantially, so knowing which fish are present in a lake will be important to planning lake management activities. MassWildlife maintains a database of [fish species presence](#). Additional data may be available directly from MassWildlife, which maintains records of fish surveys.

Fish distribution is greatly influenced by temperature and oxygen, determining which species will be present and where in the lake they will be found. Human influence has also been important in the distribution of fish among MA lakes. Historically, fish were frequently moved among lakes

1154 and various experimental introductions were conducted, but the stocking of any vertebrate species
1155 requires a permit and is subject to review by MassWildlife. Consultation with MassWildlife is
1156 recommended if there is any question about the fish resources of a target lake.

1157 ***Reptiles***

1158 Reptiles such as snakes and turtles utilize MA lakes but are less diverse or abundant than in more
1159 southern climates. Northern water snakes, painted turtles, and snapping turtles are among the most
1160 common species observed, but there are many other less common reptile species associated with
1161 MA lakes or surrounding wetlands or that travel through lakes, some protected under MESA (e.g.,
1162 Blanding's turtle, northern red-bellied cooter). Red-eared sliders have been introduced to many
1163 water bodies. Many reptile species overwinter in or near lakes, necessitating consideration where
1164 winter drawdown is conducted. Reptiles breed in riparian and upland areas moving between a lake
1165 to the breeding area and back again, which is an important consideration in watershed and shoreline
1166 management. As MassWildlife has responsibility for all vertebrate resources of a lake, consultation
1167 is advised where there are any questions about reptile resources of a target lake.

1168 ***Amphibians***

1169 Amphibians such as frogs and newts have at least one obligate aquatic stage in their life and tend
1170 to spend most of their life in or very close to water. Green frogs, American bullfrog, and eastern
1171 newts are probably the most commonly encountered amphibians in MA lakes, with spring peepers
1172 and gray treefrogs found in surrounding wetlands. The main lake amphibians overwinter under
1173 water, making water level fluctuations, oxygen status, and sediment features important
1174 considerations. Other amphibians, such as wood frogs or tree frogs, use waterbodies mainly for
1175 breeding and prefer fishless lakes or vernal pools, so there is likely less interaction with lake
1176 management activities, but spring access is still a concern.

1177 Frog abundance has varied considerably in the northern USA in recent decades and causes have
1178 included disease, habitat degradation, and predation. As with reptiles, temperature conditions are
1179 not as favorable for amphibians in northern climates, but there are still numerous amphibians in
1180 and around MA lakes. Consultation with MassWildlife is recommended if there is any question
1181 about the amphibian resources of a target lake.

1182 ***Water dependent birds***

1183 Some birds are highly dependent on lakes for food and some for shelter. Many bird species,
1184 including ducks, geese, swans, herons, grebes, kingfishers, loons, and eagles have at least a
1185 seasonal presence on MA lakes. Some of these species are year-round residents (most ducks, geese,
1186 swans, eagles) and others are seasonal residents (loons), while others may use lakes as stopover
1187 points during migration for rest and feeding. Mute swans have expanded outside their native range
1188 and compete with our resident swans. Both herbivorous and carnivorous species of birds find food
1189 in lakes, with types of plants and abundance of small fish as key determinants of the value of a

lake as a feeding area. Relatively few birds remain at MA lakes for the winter, and those that do (e.g., eagles) often change their diet when ice restricts access to the lake.

Although some birds will dive to substantial depths in search of food, most forage in the shallowest parts of lakes, so activities in the nearshore zone will have the greatest influence on water-dependent bird populations. Too much or too little vegetation can be a factor, as well as water clarity and the species/form of aquatic plants. Shoreline stability and vegetation features, including downed trees or other perching points over the water, can greatly affect habitat value and should be considered in lake management projects. On developed waterbodies, extensive bordering lawns attract Canada geese and greatly increase human-wildlife conflict as well as adding nutrient loads to the lake.

Water dependent mammals

Some mammals are tightly associated with aquatic habitats, including beaver, muskrat, otter, and mink. Many other mammals come to the lake edge to drink or feed (e.g., deer, raccoon). Most remain in or near the lake during winter. Food includes vegetation, invertebrates, and fish. Shelter may involve burrows or lodges (e.g., muskrat, beaver) with subsurface entryways. Water levels are therefore an integral part of the ecology of many of these species. Types and density of vegetation and water clarity will affect habitat value.

The presence of most of the water dependent mammals are enjoyed by human lake users, but the habits of beavers can create conflicts and management of beavers in MA has been found necessary to avoid flooding and damage to trees near the lake. Various engineering solutions intended to prevent damming have been devised and permitted trapping is sometimes used to reduce beaver populations. Yet beaver create habitat for many plants, invertebrates, and wildlife, so some degree of tolerance is encouraged by fish and wildlife agencies. Beaver and muskrat depend on predictable water elevations in the fall and winter to survive the cold weather and can be impacted by winter drawdowns.

Key Factors Affecting Lake Condition

The many features of lakes described previously provide diversity to lakes in MA. Some features and processes tend to be especially important in determining the condition of a lake, and these are described briefly below. There is overlap with the features described above, but here we consider the actual impact of the feature or process on lake ecology and management. Not all lakes are created equal and two adjacent lakes can be very different as a result of variation in these factors.

Bathymetry

The maximum depth and depth contours of a lake will likely determine if it thermally stratifies, has multiple basins, or more readily accumulates soft sediment in the littoral zone. The length of the shoreline (more or less round vs highly sinuous with coves and peninsulas) will influence habitat, access, and nearshore activities. The relative area and volume of the upper water layer

1226 (epilimnion) and lower water layer (hypolimnion), if any, will be a function of bathymetry. Having
1227 a reliable bathymetric map and information on water volume and hydraulic residence time (HRT)
1228 is essential to evaluate different management scenarios, particularly since HRT is a parameter
1229 frequently used when modeling lake trophic state.

1230 **Watershed to Lake Area Ratio**

1231 The ratio of the area of the watershed to the area of the lake (W:L) has great influence on system
1232 hydrology and contaminant loading. Large W:L ratios indicate higher flushing rates (recall that
1233 this is the inverse of residence time), which in turn affect water quality, contaminant loading, and
1234 the time it takes to raise or lower the water level if there is outlet control. W:L ratios of <10 usually
1235 lead to detention times long enough to allow most input contaminants to have full effect and be
1236 ultimately trapped in the sediment; most kettlehole lakes have low W:L ratios. W:L ratios >50:1
1237 will usually translate into faster flushing and shorter detention, maximizing water quality variation
1238 and the influence of watershed runoff on the lake; many impoundments have high W:L ratios and
1239 even with minimal human activities in the watershed, water quality impacts can be expected. The
1240 influence of the watershed at W:L ratios in between 10 and 50 will largely depend on the volume
1241 of the lake and the level of development or agriculture in the watershed.

1242 **Watershed Geology and Soils**

1243 Geology is the mother of all ecosystems. The rocky part of the earth's mantle underlying any given
1244 area will have a large, long-term influence on soils and vegetation. The mix of elements present in
1245 rock determine many features of overlying soils as they weather and greatly influences the pH and
1246 mineral content of water. The split between sedimentary and igneous rocks creates substantive
1247 differences that influence the development of biological communities. Terrestrial vegetation will
1248 vary with soils that in turn vary with geology and will influence system hydrology and water
1249 quality.

1250 Overlaid on regional geology is the influence of glaciers. Glacial activity moved rock and soil,
1251 created many lakes, and determined the topography of much of MA. While technically separate
1252 from geology, the interaction of glaciers and geology set the stage for lake conditions in MA and
1253 creates major differences in lakes across the Commonwealth.

1254 **Watershed Development**

1255 The settlement of MA by mostly European immigrants drastically changed the landscape and is
1256 responsible for many of the lakes as we know them through dam construction. Farming and
1257 residential/commercial development, with attendant transportation corridors, greatly enhances the
1258 movement of contaminants from the land to lakes. Runoff is the main transport mechanism, but
1259 movement through groundwater and air can also be significant and is impacted by human
1260 activities. Conversion from natural cover to human uses at more than about 10% of the watershed
1261 area is likely to cause detectable changes in water quality and development or agriculture at more
1262 than about 30% of the watershed area is likely to cause distinct deterioration of lake conditions

(CWP 2003, Coles et al. 2004, Bellucci et al. 2009). Human uses of watersheds tend to increase nutrient loading by tenfold or more, while application of best management practices rarely achieves a reduction of more than 50% (Osgood 2017, Clary et al. 2020) and the cost of control can be very high (USEPA 2015). Much can be done to reduce impacts from development and agriculture, but impacts cannot be avoided or eliminated in most cases. A variety of online resources are available for understanding watershed influences and management needs, including the [MassDEP watershed planning program](#) and [MA Watershed Coalition programs](#). The North American Lake Management Society also provides guidance for [watershed planning](#).

Addition of New Species

The introduction of a new species to a lake, intentionally or not, can result in major changes in lake condition. This is most apparent with invasions by non-indigenous aquatic species, whereby native species are displaced and human uses are negatively impacted. Zebra mussels, Eurasian or variable leaf watermilfoil, and fanwort are examples of invasive species with major consequences for lakes and lake users once established. Introduced species can also carry diseases or parasites that can negatively impact native species. Even species native to a region can cause problems when introduced to a lake where they were not previously present. Most species of water lilies and bladderwort are example plants, native to MA but able to cover large portions of shallow lakes when introduced. Species of crayfish, native or not, can reshape the biological community through impacts on other invertebrates and plants. Not every introduced species has substantial negative impacts, and some may even provide some benefits, but active introduction of any species is not allowed without a thorough process of study, review, and required approvals by applicable permitting agencies. MassDEP, MassWildlife, MassDCR, and MDAR have responsibilities related to species introductions to the state, re-patriating extirpated species, and moving species between systems. Consultation and appropriate permitting should occur before any such introductions are made.

Internal Loading

The ghost of past inputs can come back to haunt a lake. Contaminants entering the lake from the watershed may pass through the lake or may be converted into some other form of lesser concern, but many contaminants wind up in the sediment of the lake. Some are relatively inert; they may or may not impact sediment dwellers or feeders and do not re-enter the water column. However, the important plant nutrient P accumulates in sediment, often in organic matter or bound to iron. Decay of organic matter will gradually release P, although where there is oxygen the P will often be bound to iron, calcium, or aluminum and precipitate back to the sediment. Iron is the dominant binder in most MA lakes, although calcium is abundant in Berkshire lakes and aluminum is naturally common in a few lakes.

Where there is not enough oxygen to support aerobic microbial activities, shifts occur that utilize alternative sources of oxygen and sediment chemistry is changed. Under anoxia, iron and P dissociate and resolubilize, with the P becoming available to algae at the sediment-water interface

or in the water column if there is upward transport through water with inadequate oxygen or binders present. Some N is also released from the sediment, but the ratio of N to P is low and favors cyanobacteria that can utilize dissolved N gas and the available P. If enough light penetrates to the sediment surface, algae will grow there and potentially rise in the water column later to form blooms. If P and N move upward in an anoxic hypolimnion to a point where light is adequate, mid-depth layers of algae can form (called metalimnetic blooms) and those may reach the surface in a subsequent mixing event.

The release of P from surficial sediments can be a major source for algae and occurs mostly during summer when temperature and other conditions are most favorable for algae blooms. Watershed loading feeds the internal P load, often over a period of decades or longer. When conditions become favorable for internal release, this P input often sets up a cycle of excess productivity, greater organic matter deposition, faster or more extensive oxygen loss, and increasing internal loading that may then become the dominant P source. Control of watershed loading will not reverse that process and addressing the internal load becomes essential to preventing algae blooms.

Climate Change

There is no denying climate change and a human role in it; one can have a healthy debate over specific causes and corrective needs, but the data clearly show that temperatures are warmer and variability is higher (IPCC 2021), creating a number of problems for lakes and lake users. Changes in precipitation pattern are problematic, causing greater impact by flood and drought conditions for many lakes. Higher inputs of solids, nutrients, bacteria, and other contaminants can be expected with more intense storms. It is not so much the small increase in average temperature that causes problems as the greater variability in temperature, precipitation, and many related environmental features.

Warmer temperatures increase growth rates for most organisms and favor cyanobacteria. Cyanobacteria can survive over the greatest range of temperature, from under the ice to hot springs, but the chemical nature of their food storage gives them a metabolic advantage in warmer water and they tend to dominate at temperatures greater than about 25°C. Even if cyanobacteria do not become dominant, warmer water will accelerate the growth rate of any algae present and may lead to increased biomass if those algae are not consumed within the food web. Response time in grazer populations tends to lag well behind that for algae subject to enhanced growth conditions, so more blooms are expected during prolonged warm periods.

Greater temperature accelerates decomposition and increases oxygen demand, potentially increasing the internal loading discussed previously. While water deeper in a lake will almost always be colder than the water at the surface, small increases in temperature at the sediment-water interface can be particularly detrimental, fostering greater oxygen demand and faster achievement of low oxygen conditions that then allow release of P from sediment. That P can migrate upward in the water column to the point where oxygen is present and allows reactions that inactivate P (usually recombination with iron also released from the sediment), possibly allowing uptake by

algae where low oxygen conditions are extensive and extend upward to where there is even a small amount of light. However, many algae are capable of growth at the sediment-water interface, utilizing released P before it ever gets into the water column. Green algal mats and many types of cyanobacteria, all threats to lake ecology and human uses, are particularly adept at this growth mode. The green algal mats trap their own photosynthetic gases and those from decomposing organic sediment to rise in the water column while the bloom-forming cyanobacteria tend to produce gas pockets within cells and rise synchronously into upper waters to rapidly form blooms. Consequently, small increases in temperature near the sediment-water interface can have much larger impacts on algae abundance throughout the lake.

A lengthening growing season translates into more rooted plants in the photic zone of the waterbody. Rooted plants may start growing earlier and remain later in the year, expanding coverage with the increased growing season and increasing maximum density. The conversion of inorganic nutrients taken up from sediment through roots into organic forms results in more organic matter settling to the bottom, increased oxygen demand, and potentially more nutrients in the water column to fuel growth of algae and higher plants not rooted in the sediment. The eutrophication process is therefore accelerated by climate change.

More intense storms will increase non-point source pollution loading, moving more material off impervious surfaces and causing greater erosion in stream or stormwater channels. The higher water load may cause increased flushing of lakes, potentially limiting immediate pollutant impacts but also causing additional issues with flood impacts. A portion of the increased inputs will settle in the lake, gradually decreasing depth and building reserves of nutrients, metals, hydrocarbons, and other contaminants that can negatively impact lake quality and uses over time. Extended dry periods or more severe droughts can lower water levels and allow greater impact by sediment-water interactions such as the internal loading noted above, as well as exposing lake bottom, reducing habitat and compromising lake access by foot or boat. Lower inflows associated with dry periods will also allow the sun to heat remaining lake water to a greater degree, leading to the temperature-induced impacts noted above.

No action we can take will reverse the climate trend quickly; implementation of all recommended measures on a global scale would not reverse climate change for a century or more (IPCC 2021). Lake management will have to address greater external and internal nutrient loading, a higher frequency of extreme events and conditions, warmer temperatures, and fluctuating water levels to maintain desired and designated lake uses. Protective watershed management, enhanced runoff storage and processing capacity, minimization of P availability, maximization of oxygen in lakes, and a variety of rooted plant control methods are all likely to be needed to offset climate change impacts on lakes. The increased variability in temperature and precipitation over time greatly complicates management and increases potential costs, as planning must address greater extremes (e.g., maximum detention needs) and incorporate flexibility (e.g., treatment on demand).

1377 **2. LAKE MANAGEMENT PLANNING**

1378 This chapter provides information on the planning process for lake management. Planning needs,
1379 programs, and the overall process are addressed. Approaches to predicting outcomes are discussed.
1380 The importance of monitoring to support planning and later plan adjustment is emphasized.
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1382 **The Lake Management Plan**

1383 A lake management plan (LMP) sets goals for the management of the lake, defines specific
1384 objectives intended to achieve those goals, and guides the selection and implementation of
1385 potentially complex and interactive management techniques. A LMP will lay out the steps to be
1386 taken, the order of application, target locations, and monitoring needs to track progress and allow
1387 adjustment of the LMP for success. While the regulatory process in MA does not require a LMP
1388 to obtain permits, development of a LMP is highly recommended for any protective or
1389 rehabilitative action taken on a lakewide or watershed scale and will make the permitting process
1390 easier. Where cooperation of agencies, towns, institutions, landowners, and other stakeholders is
1391 needed, development of a LMP facilitates input and education that fosters cooperation and possibly
1392 funding.

1393 A LMP is particularly valuable where there are multiple and potentially competing interests at a
1394 lake and where the watershed covers multiple jurisdictions, complicating any proposed action. The
1395 process of developing a LMP may not resolve all conflicts or achieve complete cooperation, but it
1396 will offer opportunity for understanding and compromise and can develop support for ongoing
1397 management programs. Small projects like controlling excessive vegetation in a public swim area,
1398 repairing an existing boat ramp, or stabilizing shoreline on a homeowner's property may not merit
1399 a complete LMP, but should fit into an overall LMP and the existence of the LMP should ease the
1400 regulatory path for such small-scale actions.

1401 **Elements of a Lake Management Plan**

1402 The LMP represents the assimilation of all the assessment and evaluation steps into one
1403 understandable written document describing long-term goals for the lake and ways to achieve those
1404 goals, along with their ecological and financial consequences. When devising a LMP, elements to
1405 consider include:

- 1406 ➤ **Problem Statement:** List issues and problems that should be addressed. Why is management
1407 action under consideration, and what previous reports, data, historic management actions and
1408 past recommendations support this need?
- 1409 ➤ **Management Goals:** Get public input from all stakeholders to provide a concise statement of
1410 goals, desired future uses and preferred characteristics. Goals should be specific, measurable,
1411 realistic, feasible, and, to the extent possible, should balance any conflicting stakeholder values
1412 and uses. This includes balancing natural conditions and processes with human interests; not
1413 all lakes are suitable to all uses and some goals may be limited by existing regulations.
1414 Gathering public input from a wide range of stakeholders is particularly important to
1415 understand the range of perception and uses. To ultimately gain maximum support for the plan,
1416 do not marginalize any stakeholder group or interest.
- 1417 ➤ **Watershed and Lake Characteristics:** Include maps of watershed boundary, watercourses,
1418 drainage systems, geology, topography, soils, land use, zoning, and pollutant sources. Provide

1419 maps of lake bathymetry and sediment types with depth if available. Obtain data for hydrology
1420 and water quality and construct nutrient budgets. Model the system to the extent practical and
1421 necessary to predict results of management actions. Collect data for bacteria, algae, vascular
1422 plants, zooplankton, invertebrates, fish, reptiles, amphibians, birds, and mammals as they relate
1423 to identified problems and check available maps and records for protected species.

1424 ➤ **Past In-Lake Management Techniques:** Review all physical, chemical, and biological
1425 controls, and any other management techniques that have been implemented. Note the level of
1426 success achieved, any unintended impacts, and the costs associated with past management
1427 actions.

1428 ➤ **Existing Watershed Management Techniques:** Review all regulatory (e.g., zoning, resource
1429 protection bylaws, health statutes) and non-regulatory (e.g., educational, procedural,
1430 structural) management techniques that are in place and being used within the watershed.
1431 Quantify achieved benefits if possible and note any associated costs.

1432 ➤ **In-Lake and Watershed Management Alternatives:** Evaluate management options for
1433 effectiveness, feasibility, impacts, and costs to attain stated goals. An alternatives analysis
1434 should ideally start with the applicable physical, chemical, and biological options identified in
1435 the GEIR and described in this document. Conducting a thorough alternatives analysis and
1436 providing credible justification for selecting a particular approach can be the key for increasing
1437 public support and successful issuance of permits.

1438 ➤ **Management Recommendations:** Include both short- and long-term management options for
1439 in-lake and watershed management, with time frames. Preventive and mitigative measures
1440 should be included. A description of the monitoring and evaluation process to be used for all
1441 proposed actions should be included, with pre- and post-management elements.

1442 ➤ **Plan Approval:** Present the plan at one or more well-publicized public meetings and offer an
1443 opportunity for comment. Revise the plan as appropriate.

1444 ➤ **Implementation:** The five phases to implementation (funding, design, regulatory review,
1445 construction or application, and follow up monitoring and evaluation) will be lake- and
1446 community-specific but may involve considerable interaction with outside agencies and
1447 consultants.

1448 If properly developed, a LMP should be useful for a long time, potentially modified as more
1449 is learned about the lake and progress is made. When devising a LMP for a waterbody, some
1450 additional practical considerations include:

1451 ➤ **Not all plans need to have each of the components fully developed, and depending on the**
1452 **management issues, plans may not need to address some of the components at all.**
1453 Carefully consider resources and uses when prioritizing plan elements. There is no compelling
1454 reason to expend time and resources on watershed features and management if the problem is

an invasive species in the lake, unless there is some clear connection between some aspect of the watershed (e.g., an upstream source) and the problem. Absence of data for nutrient loading in tributaries may preclude prioritizing actions within drainage basins of the watershed, although a monitoring program to fill that gap should be provided.

- **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. Scale matters; there is no compelling reason to create an expansive plan if the issue is maintaining safe swimming conditions at an established beach by methods that affect only the target area (e.g., benthic barriers, hand pulling). Yet consideration of the use of herbicides on a lakewide basis should involve a thorough evaluation of potentially affected resources and likely consequences of treatment.
- **The LMP should provide a menu of options and priorities but may need to be revised and refined over time.** Elements and options may be best evaluated in consultation with an experienced lake management professional. Public input for acceptability should be sought. Creation of a primary approach with back-up options is recommended, with a process for determining when to apply alternative approaches. The LMP should be regularly reviewed (e.g., 5 years) and revised as necessary.
- **Within an LMP focused on an in-lake problem, it may still be useful to identify possible watershed components to be potentially addressed in the future.** While the problem that is being addressed may not require watershed action, lakes are influenced by their watersheds and prevention of future problems may depend on watershed management before such problems develop. It is advisable to incorporate monitoring to allow identification of watershed problems as they arise. This can be as simple as tracking land use changes in the watershed but usually involves monitoring of nutrient levels in tributaries under a range of weather conditions as well as tracking in-lake concentrations over time.

As a general rule, having sufficient and scientifically sound data for the lake and its watershed will enable the production of a more valuable lake and watershed management plan and will increase the likelihood of successful protection and/or improvement of the water body. The other general rule is that the greater the potential impact or expense of a proposed management technique, the greater the need for complete information and measurement of progress.

Massachusetts Watershed-Based Plans

While technically not a LMP, the [MA Watershed-Based Plan](#) (WBP) process, based on the USEPA framework, provides a useful tool for addressing water quality problems and for developing watershed projects, whether they are designed to protect unimpaired waters or restore impaired waters identified under Clean Water Act (CWA) Section 303(d). An interactive website is available to help guide interested parties through the [MA WBP process](#).

The MA WBP process was designed principally as a tool for non-point source (NPS) pollution prevention and abatement to improve impaired waters identified under CWA Section 303(d), but a WBP can form the basis of a LMP where goals involve protecting or improving water quality in the lake. A WBP will be less applicable to lakes where excess aquatic vegetation or invasive species are the principal issue, but where algae blooms, sedimentation, or other water quality problems must be addressed to meet LMP goals, a WBP can be helpful. A WBP can address internal loading of nutrients, contrary to what the name may imply, and having a WBP in MA is a prerequisite to receiving funding under the CWA Section 319 program as administered by MassDEP.

The overall purpose of the WBP is to organize information about the watershed and present it in a format that will enhance the development and implementation of projects that will improve or protect water quality and beneficial uses. The WBP provides a framework to help identify known and likely sources of pollution in the watershed, making it easier to prioritize problems and identify appropriate best management practices (BMPs).

The MA WBP follows the recommended format from USEPA for “nine-element” watershed plans, including:

1. Identify the causes and sources (or groups of similar sources) that will need to be controlled to achieve the load reductions recommended in the WBP to achieve other watershed goals.
2. Estimate the load reductions expected for the proposed management measures while recognizing the natural variability and the difficulty in precisely predicting the performance of management measures over time.
3. Describe the NPS management measures that will need to be implemented to achieve the desired load reductions as well as to achieve other watershed goals identified in the WBP. Provide identification (using a map or description) of the critical areas in which those measures must be implemented.
4. Estimate the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan. Example sources of funding include CWA Section 319 programs, State Revolving Funds, USDA’s Environmental Quality Incentives Program and Conservation Reserve Program, and other relevant federal, state, local, and private funds that may be available to assist in the plan’s implementation. MA communities that have passed Community Preservation Act legislation can make use of a fund established from real estate taxes for open space and natural resource preservation and enhancement.
5. Create an information/education component to enhance public (stakeholder) understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the resulting NPS management measures.

6. Propose a schedule for implementing the NPS management measures identified in the WBP that is reasonably expeditious.
7. Describe interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented.
8. Establish a set of criteria or thresholds that can be used to determine whether loading reductions are being achieved over time and if substantial progress is being made towards attaining [surface water quality standards](#) (SWQS). If substantial progress is not indicated, describe goals for determining whether the WBP needs to be revised or, if a Total Maximum Daily Load (TMDL) has been established, when and how the TMDL needs to be revised.
9. Conduct monitoring to evaluate the effectiveness of the implementation efforts over time, measured against the criteria or thresholds established above. Monitoring programs tend to be site-specific but would logically include measures of all contaminants of interest at locations and frequencies appropriate to determining implementation progress. Who conducts the monitoring and interprets the results depends on the program elements, scale of operation, and any regulatory requirements.

A WBP is required if CWA Section 319 funds are to be used (or are anticipated to be sought in the future). Accordingly, MassDEP through its Watershed-Based Plan Tool has pursued development of WBPs throughout the state so that applicable projects will be potentially eligible for Section 319 implementation funds. For more information on the Section 319 Grant program see the [MA Nonpoint Source Pollution 319 Grant Guidebook](#). In addition to watershed sources of pollution, the potential for internal loading of P to be a major source is recognized and projects to reduce internal loading are eligible for Section 319 funding.

The need for water quality data to support a WBP or LMP necessitates monitoring and useful water quality data for a watershed may be available through several state and federal sources. Water quality data and biological data may be available from MassDEP, MassWildlife, or MassDCR files that include Clean Lakes Diagnostic/Feasibility reports, state monitoring data, fish survey reports, and bathymetric surveys. Contact with these agencies is suggested to see what data they have in their files for a lake or its watershed. This recommendation holds whether stakeholders are following either the WBP or LMP development route.

The focus of most of this effort is on meeting designated uses of the waterbody. The MA SWQS regulations list the designated uses for fresh Class A and Class B waters. Class A waters include public water supplies and their tributaries, and waters that are not specifically listed or otherwise classified in the regulation are Class B. Criteria, both narrative and numeric, for evaluating water quality to support those uses are also listed in the regulation, including dissolved oxygen, temperature, bacteria indicators, nutrients, and toxins, among others.

All states administer a program to monitor and assess the quality of surface and groundwater and provide periodic status reports to the USEPA and the public. CWA Section 305(b) defines the

process whereby waters are evaluated with respect to their capacity to support designated uses as defined in state surface water quality standards. CWA Section 303(d) requires states to identify those waterbodies that are not expected to meet surface water quality standards after the implementation of technology-based controls and to prioritize and schedule them for the development of a total maximum daily load (TMDL). The [MA Integrated List of Impaired Waters](#) identifies those waters not attaining their designated uses, as defined in the MA SWQS. Lake stakeholders can check this list to see if their waterbody has been identified as impaired and to see what probable causes are identified.

Total Maximum Daily Loads

For waterbodies with identified impairments, the state can develop a [Total Maximum Daily Load](#) (TMDL) that establishes the maximum amount of a pollutant that may be introduced into a waterbody and still ensure attainment of water quality standards. A TMDL must allocate that acceptable pollutant load among all potential sources, which mirrors the initial steps of the WBP, and devise a plan to reduce pollutant loads to meet applicable water quality standards. If a TMDL has been established for a lake, this can provide much information on pollutant sources to the lake from the watershed.

A TMDL can be prepared for a lake or stream not currently listed as impaired, but nearly all TMDLs in MA cover cases of existing impairment. Once the TMDL has been prepared, it can serve as a roadmap for improving water quality, meeting designated use criteria, and getting the lake removed from the impaired waters list. Often the sources of pollution are not well regulated and require voluntary pollution reduction efforts. A broad coalition of stakeholders may be needed to advance a management plan in this regard. An LMP or WBP is helpful for these coalitions.

The Lake Management Planning Process

Gathering Input

For lakes suffering from eutrophication due to excessive inputs of nutrients or sediments, the LMP should incorporate any WBP or TMDL available for the lake or its watershed, thereby representing the most complete assessment of the system and providing the framework within which actions can be mostly easily permitted and implemented. If properly developed, it should remain useful for years, modified as warranted over time. A planned review (e.g., five-year) of the LMP, incorporating new monitoring data and revisiting overall management goals and techniques can be important in keeping the plan relevant to changing lake conditions and is likely to be helpful with renewed or additional permits.

Most plans focus on mitigating perceived problems, but protection will often 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 cannot be expected to preserve key qualities of the lake system in every case, although knowing when not to take action can be as important as knowing

what techniques to apply and when. The LMP should cover these issues to the extent possible, anticipating needs and working to prevent problems before they become serious. The cost of prevention is almost always lower than the cost of remediation.

Each of the management planning steps 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 waterbodies or even emergent wetlands; all are natural states, although human influence tends to increase productivity. Public perception also varies along a continuum with every individual potentially offering a slightly different view of a lake, its uses, and problems. 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 and biological resource monitoring and watershed evaluation, differentiating 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 development of a plan with realistic expectations.

Selecting Target Nutrient Concentrations

Many nutrients figure into algal abundance and plant growth, but the elements most likely to control system productivity are nitrogen (N) and phosphorus (P). Each comes in multiple forms which influence availability, and while the total for each is indicative of potential aquatic fertility, the actual amount of algae produced in the water column can vary considerably as a function of factors that determine N and P availability. Based on data from the National Lake Assessment program, the USEPA has developed an approach to estimating the concentration of N or P that will yield some given chlorophyll-a concentration, representing the amount of algae present and related water clarity (USEPA 2021b). A companion online [target N and P calculator](#) allows selection of N and P targets that are expected to yield chlorophyll-a concentrations at some chosen level of probability. For MA lakes, target P concentrations to keep chlorophyll-a under 10 ppb with a 90% probability are mostly between 10 and 20 ppb, while for N the range is typically 400 to 800 ppb. Lake-specific calculation of tolerable N and P levels based on lake use goals and appropriate data is encouraged in management planning.

Choosing Management Techniques

With the previous steps in place, evaluation of possible management strategies becomes a focal point for the plan. This review is principally focused on defining procedures acceptable in MA for the implementation of lake management techniques. It recognizes that there are appropriate short-term strategies that may be steps along the path of a long-term strategy or may simply constitute a

legitimate maintenance program. There may be short-term strategies that merely attempt to maximize utility to human usage without significantly changing the natural state of a lake (e.g., clearing vegetation from a swimming area or cutting channels to open water for boats). Related actions may need to occur periodically, just as homeowners shovel snow, repaint houses, or replace roofs. The spatial and time scales may vary, but the tasks are repetitive and are likely to always be needed.

Long-term strategies may eventually produce the closest approximation to a sustainable and healthy lake condition and maximize resource utility to various human and non-human user groups (e.g., nutrient loading reductions, invasive species control). Actions that provide benefits for longer periods of time are often preferable, but may carry increased cost, increase risk to non-target organisms, or require a much longer implementation period before benefits are apparent. Long-term approaches tend to represent rehabilitation of the lake, rarely actual restoration of some previous condition, and may still require some protective or maintenance methods to retain the benefits bestowed by the long-term strategy.

The appropriate choice of management techniques will depend on community priorities, regulatory restrictions, specific characteristics of the lake, community resources, and the effectiveness, adverse impacts, and costs of applicable lake management techniques. This is admittedly a lot to consider all at once, but effective lake management is rarely a simple process. Choosing lake management techniques requires a blend of science, economics, and socio-politics, each acting as the leg of a stool and each needing to be solid if the stool (management effort) is to be supported.

To aid in selection of management techniques, this revised 2025 Guide describes a range of techniques that have been applied in MA or elsewhere to address specific lake and watershed problems, some with a high probability of success under appropriate conditions (“standard” techniques) and others (“alternative” or “supplemental” techniques) that have some limitation that causes them not to be completely reliable or allowable in MA. Inclusion in the standard group does not mean that the technique is applicable in all cases or that it will work exactly as expected every time. Inclusion in the “alternative” group does not mean the technique should never be applied unless it is expressly forbidden in MA, but it does suggest that more information or experience is needed to use such techniques safely and successfully than is currently available.

Regulatory agencies may recognize the need to keep up with science and the value of experimentation in lake management, but their resources are finite and the regulations governing lake management in MA create constraints on everyone involved. Therefore, the burden of proof will fall on any applicant proposing a new or insufficiently documented strategy to justify its selection.

The importance of completing the assessment, input, and evaluation steps in arriving at an acceptable and successful implementation phase cannot be overemphasized. As described, implementation appears to be the last step, but it is actually part of a cycle of assessment and action. Implementation normally requires completion of the prior steps to be successful, but it is

1677 rare to perform a management action once and solve the problem indefinitely. The planning steps
1678 promote community support, foster funding, and minimize the effort required to continue ongoing
1679 implementation. The framework described in this guide is the currently favored approach in MA.
1680 Government programs and emphasis change over time, but the development of a LMP is based on
1681 the elements established under the federal Clean Lakes Program, CWA Section 314, back in 1980.
1682 That approach has changed little despite renaming, greater emphasis on public involvement and
1683 documentation, and various regulatory add-ons. It is a proven approach to lake management.

1684 **Predicting the Outcome of Management**

1685 **Background and Use of Predictive Models**

1686 Knowing exactly how an aquatic system and all its inhabitants will respond is not usually possible;
1687 uncertainty is a fact of life, especially in lake management. The direction of anticipated change
1688 and the general magnitude of change can be predicted, however, and some prediction of resultant
1689 conditions should be part of any lake management plan and permit application. For any such
1690 prediction there are two parts: actual demonstrable change and the duration or longevity of that
1691 change. The magnitude of change will be important to both the achievement of stated goals and
1692 acceptability within the regulatory framework. The duration of change will affect how often the
1693 action must be taken, related costs, and possibly regulatory considerations, and will vary by
1694 technique applied.

1695 For management aimed at controlling nutrients to minimize algal blooms, scientific studies of
1696 watersheds over a wide variety of lakes, ponds, and reservoirs have produced a large database
1697 useful to statistically compare nutrient inputs with average lake nutrient concentration, average
1698 chlorophyll-*a* concentration and Secchi disk transparency. Knowledge of any one of these
1699 parameters provides a rough estimate of all the others for MA lakes without dominant rooted plant
1700 growth. For lakes with abundant plant growth over most of the lake area, these “empirical” models
1701 may not work as well, but where applicable it is advisable to rely on them to make general
1702 predictions of lake response to nutrient controls.

1703 Quite a few of these models were developed in the 1970s (e.g., Dillon and Rigler 1974,
1704 Vollenweider 1975, Kirchner and Dillon 1975, Larsen and Mercier 1976, Jones and Bachmann
1705 1976, Reckhow 1977) and remain valid today. All have similar input terms and provide useful
1706 indications even though the confidence one can place in a numerical prediction for a particular
1707 lake in a specified year is limited. The details of the many available models and how to use them
1708 is the subject of entire volumes (e.g., Wagner et al. 2013) and [online modeling support](#) and is
1709 beyond what this guide is intended to cover. The ultimate goal is to understand how nutrient
1710 loading relates to lake attributes that affect lake uses, and a consistent pattern emerges. The [Lake](#)
1711 [Loading and Response Model](#) (LLRM) incorporates all the above empirical models and allows
1712 users to predict in-lake conditions from loading based on land uses in the watershed and other
1713 inputs. Having a competent professional set up LLRM or another applicable model for your
1714 watershed and lake could be advantageous if algae are the primary issue.

Water clarity is often a key determinant of stakeholder satisfaction with the appearance of a lake and exhibits a strong curvilinear relationship with P (Figure 11). Clarity is more affected by nutrient inputs when the lake is relatively pristine. A change at low total P levels results in a much larger change in transparency than the same absolute change at a higher total P level. However, considerable variation of response is possible at any P level. The sources of variability can be very important to management decisions, and include the forms and availability of P, the nature of the zooplankton community, and other sources of turbidity (such as suspended sediment). While it can be difficult to predict exactly how a change in P loading will affect the clarity of an individual lake without considerable information on these other sources of variation in the relationship, the general direction and magnitude of change can be approximated.

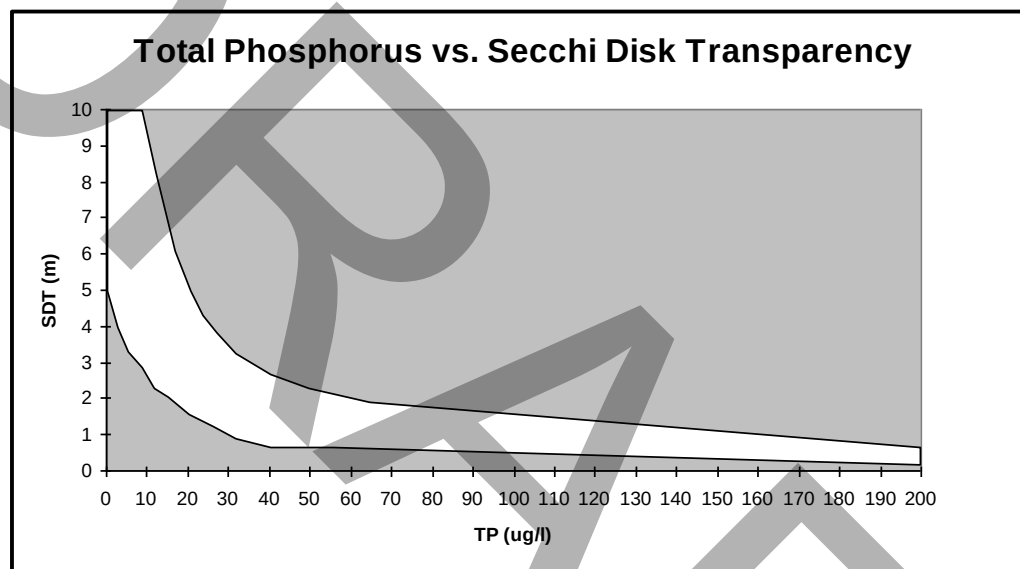


Figure 11. Expected range of water clarity with changing phosphorus concentration.

One common approach is to use 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 P, 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-*a*, the TSI has been related to problem perception of impairment (Figure 12). 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 lake rehabilitation choices based on modeling results carry high costs, either monetary or in terms of potential negative consequences. 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 very helpful to know the general order of magnitude of the loading

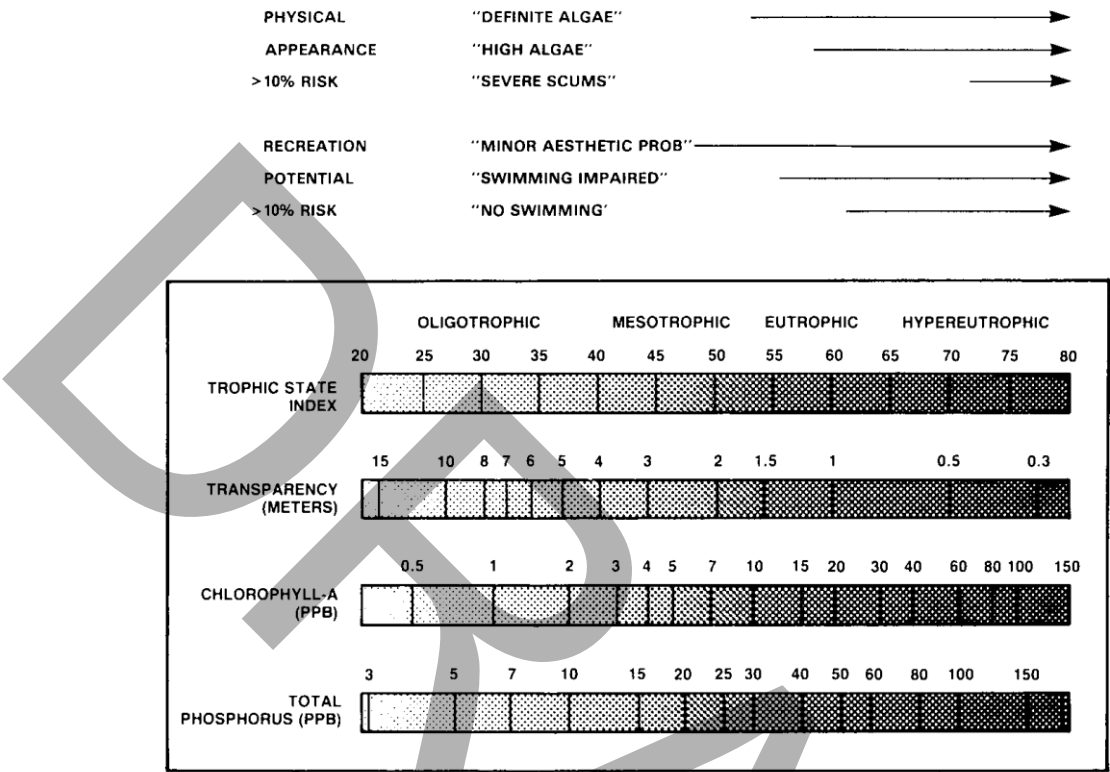


Figure 12. Carlson's Trophic State Index related to perceived nuisance conditions (Heiskary and Walker 1988). Relationships between key indicators may vary regionally and among lakes.

reduction needed to meet program objectives before embarking on a load reduction campaign. It can be extremely disappointing for stakeholders 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 righthand portion of the graph in Figure 11 with high P and low clarity. Exact numerical predictions from models should not be relied upon in most cases, but the models do reliably indicate the direction and approximate degree of change to be expected.

Predicting the outcome of direct algal control options such as algaecide application or increased lake flushing is easier and does not require models, mostly because experience with such direct control techniques has provided relatively straightforward guidelines. Copper- or peroxide-based algaecides will kill most algae if applied at a high enough (but still allowable) rate, but application is restricted to no more than half of a waterbody by the federal registration label for these products, so addressing a lakewide algae bloom may not be possible in one treatment. Flushing depends on moving enough water through the waterbody to prevent algal accumulation, with results generally proportional to the degree of flushing attained. While the theoretical success of these approaches is not really in question, practical application limitations suggest that results will not be as predictable as desired.

Predicting the outcome of vascular plant control is not really a modeling exercise and is dependent mainly on the size of the area addressed, as with indirect control by substrate alteration (e.g., dredging, benthic barriers) or light limitation (e.g., dyes, covers, dredging) or direct controls such as herbicides or harvesting. The effect of light limitation as a function of Secchi transparency can be estimated by equations (e.g., Canfield et al. 1985), and it is empirically known that lower light and coarser substrate will support less rooted plant growth. Predicting the approximate amount and general types of plant growth for a given combination of light and substrate features is possible if enough is known about the existing plant community and the ecology of the lake, but biological variability limits exact predictions.

The duration of benefits from any lake management technique are a function of the nature of the technique and magnitude of application. Models to predict longevity of biological responses have not been overly reliable, as shifts in the types of algae or plants over time can often overcome the limitations created by management. The initial results of properly conducted physical controls such as harvesting or chemical controls that include various herbicides are fairly predictable, but long-term results are less predictable as the range of plant responses is wide. Except where habitat alteration is substantial and lasting (e.g., dredging), a return to previous conditions is generally expected, often within one to four years unless follow-up actions are taken. The same is true of algae control techniques that do not involve permanent reductions in P availability. Repeated application is therefore to be expected at a frequency that tends to be specific to the technique and/or lake. The results of biological controls are less predictable, and many biological techniques are not permitted in MA as a result. Both control of target species and impacts on non-target species are less certain with biological controls, although success has been achieved in some cases.

Monitoring Management Outcomes

With a clearly stated goal for a lake attribute such as water clarity by Secchi disk or coverage and density of rooted aquatic plants, and some prediction of what a chosen management action is expected to provide, it is important to track actual progress to determine if any adjustment of management actions is needed and to document relative changes for permit compliance. There are few mandatory regulatory requirements for implementation monitoring but there may be requirements for how much impact is acceptable. Further, fiscal responsibility dictates that the results of management expenditures be documented and justified. Complete reliance on public perception of project results is not recommended. There are two categories of monitoring or assessment that should be incorporated into management plans: implementation monitoring and post-implementation monitoring.

As previously described, implementation is really part of a cycle. Assessment, planning, and permitting steps precede initial implementation but often also follow it. Monitoring during implementation is usually focused on ensuring that the action is correctly applied. Such monitoring guides implementation as it occurs and ensures compliance with permit requirements. Monitoring

1805 after implementation documents progress toward a stated goal and supports assessment of any
1806 additional management needs.

1807 ***Implementation Monitoring***

1808 Monitoring during the actual management activity, such as application of herbicides, P
1809 inactivation, mechanical harvesting, drawdown, or dredging, will be highly specific to each lake
1810 and activity. Considerable information is likely to be needed to plan the action, but during actual
1811 implementation there may be critical data needs relating to flow, water quality, sediment features,
1812 and biological resources. Those data guide decisions about timing, location, and application details
1813 that may affect project outcome or compliance with permits.

1814 Some activities require minimal oversight and monitoring once planned and permitted. For
1815 example, placing benthic barriers on a small scale is unlikely to pose any threat that needs to be
1816 assessed while placement is going on. Similarly, laying the structural components for a circulation,
1817 oxygenation, or hypolimnetic withdrawal system needs little monitoring during actual installation.
1818 Once properly planned and permitted, application of herbicides and algaecides need only some
1819 determination of where to apply the chemical (to comply with label restrictions) and sometimes
1820 tracking of the concentration where extended contact time is needed (e.g., fluridone). Some
1821 activities, however, need considerable assessment during the actual implementation phase to
1822 ensure both success and limit non-target impacts.

1823 Key aspects of lake management activities that typically need implementation monitoring include:

- 1824 ➤ Structural NPS controls – erosion controls properly installed, installation done as per plan.
- 1825 ➤ Dilution and Flushing – flows monitored, nutrient concentrations checked.
- 1826 ➤ Drawdown – track water level and rate of drawdown and refill, assess downstream flows.
- 1827 ➤ Dredging – track quantities of sediment removed, track inflows and be prepared for cessation
1828 if necessary (dry dredging), assess return water quality as needed (hydraulic dredging),
1829 evaluate containment area conditions, observe any impacts to non-target organisms, track
1830 material handling to final disposal.
- 1831 ➤ Hand Harvesting – assess thoroughness of target species removal, minimize spread of plant
1832 fragments, assess any impacts to non-target organisms, monitor quantity of vegetation
1833 removed, track any turbidity plumes generated.
- 1834 ➤ Mechanical Harvesting – assess quantity of vegetation removed, track species of plants
1835 removed, document areas harvested and when, evaluate obstructions and water level
1836 impediments to work, evaluate any impacts on non-target species and water quality.
- 1837 ➤ Hydroraking – assess quantity of material removed, track turbidity generation, observe
1838 material handling to final disposal.

- 1839 ➤ Phosphorus Inactivation – track quantity of inactivator added, when and where, monitor pH
1840 and alkalinity if there is a threat of change, assess any impacts to non-target organisms.

1841 ***Post-Implementation Monitoring***

1842 The elements of an appropriate post-implementation monitoring program will vary with lake
1843 features, goals, management technique, and extent and duration of application. A matrix of
1844 monitoring needs specific to lake management techniques (Table 2) provides guidance on what to
1845 consider in the post-implementation phase, but adjustment based on lake- and permit-specific
1846 conditions may be needed. Many of the features suggested for post-implementation monitoring
1847 may need to be assessed before implementation to provide data for comparison, but this list should
1848 not be confused with the many information needs that must be satisfied to determine the
1849 applicability of a technique or plan its implementation.

1850 Monitoring should focus on those features most relevant to assessing achievement of goals and
1851 impacts to non-target species or other valued lake features identified as part of a LMP. Monitoring
1852 should be tailored to the actual and relative area affected. There is no great need to monitor plant
1853 abundance in a swim area within a much larger lake where removal of vegetation for that water-
1854 dependent use is approved, other than to know when to conduct control actions. It may be insightful
1855 to monitor the quality of water entering a waterbody, but there is no need for such monitoring as
1856 part of a program to control an invasive plant species. It may be viewed as essential to assess water
1857 clarity as part of a program to minimize algal blooms and to evaluate any impacts of herbicide
1858 treatment on both the target species and any listed plant species known from the target lake.

1859 The range of goals, actions, and results over a large and diverse set of waterbodies such as found
1860 in MA is simply too wide to justify a standardized post-implementation monitoring program for
1861 all lake projects. While creating a standard set of monitoring protocols to be applied to all lake
1862 projects is not workable, there are monitoring needs that should be addressed for any given
1863 problem and technique. Change in algae or vascular plant types and abundance can be monitored
1864 several ways but should be monitored where algae and/or rooted plant problems are the subject of
1865 management. Use of water clarity, turbidity, chlorophyll-*a*, phycocyanin (photopigment found in
1866 cyanobacteria), and/or actual algae identification and microscopic quantification are fairly
1867 standardized options for tracking algae.

1868 Plant surveys based on visual examination (underwater video or rake tosses) at pre-selected points
1869 with recording of species and some form of coverage and density measure are less standardized
1870 but needed when assessing plant control results. Additional monitoring needs are highly specific
1871 to individual projects and may be strongly influenced by project scale.

1872 While monitoring cannot be standardized across all possible lake projects, the approach for any
1873 given project should be standardized and followed in the pre- and post-implementation stages. The
1874 same suite of lake features (e.g., temperature, oxygen, pH, nutrients, algae abundance, plant
1875 coverage) should be measured by the same method at the same locations and frequency from

Table 2. Post-implementation monitoring needs for lake management projects

TECHNIQUE	Incoming/ Outgoing Flow and Water Quality	Lake Water Clarity/Algae /Chl-a/ Turbidity	Lake Nutrients	Lake Temp/DO	Other Lake Water Quality *	Sediment Quality / Quantity	Vascular Plant Types/ Abundance	Inverte- brates	Fish	Other Wildlife
Non-Point Source Controls										
Source Management	1	1	1	2	2	4	4	4	4	4
Pollutant Trapping	1	1	1	2	2	3	3	3	3	3
Point Source Controls	1	1	1	2	2	4	4	4	4	4
Hydraulic Controls										
Dilution and Flushing	1	1	1	2	2	4	4	3	3	3
Diversion	1	1	1	2	2	4	4	4	4	4
Selective Withdrawal	1	1	1	1	2	3	4	3	3	4
Physical Controls										
Drawdown	1	2	2	2	2	4	1	2	2	2
Dredging	4	1	1	1	2	1	1	2	2	2
Reverse Layering	4	1	1	1	2	1	1	2	2	2
Hand Harvesting	4	3	3	3	3	4	1	3	3	3
Mechanical Harvesting	4	2	2	2	2	4	1	3	3	3
Hydroraking	4	2	2	2	2	1	1	3	3	3
Rotovation	2	2	2	2	2	3	1	3	3	3
Benthic Barriers	4	4	3	3	4	4	1	3	3	3
Surface Covers	3	2	2	1	3	4	1	3	3	3
Sonication	4	1	2	2	3	4	4	4	3	4
Artificial Circulation	3	1	1	1	2	4	4	4	3	4
Algae collection systems	3	1	2	2	3	4	3	2	2	2
Chemical Controls										
Phosphorus Inactivation	3	1	1	2	2	2	4	3	3	4
Hypolimnetic Oxygenation	4	1	1	1	2	3	4	3	3	4
Algaecides	4	1	2	2	2	3	3	3	3	4
Herbicides	4	2	2	2	2	3	1	3	3	3
Dyes	2	1	2	1	2	4	1	3	3	3
Biological Controls										
Zooplankton enhancement	3	1	2	2	2	4	4	4	4	4
Herbivorous Benthic Invertebrates	3	3	4	4	4	4	1	2	3	3
Herbivorous Fish	3	2	2	3	3	4	1	3	3	3
Plant Competition	4	3	3	4	4	4	1	3	3	3
Barley Straw	3	1	2	1	2	4	4	4	4	4
Bacterial Additives for algae control	3	1	1	2	2	4	4	4	4	4
Bacterial Additives for sediment red.	3	2	2	2	2	1	3	3	3	3
Removal of Bottom Feeding Fish	4	1	2	2	2	3	2	3	3	3
1 = Highest priority 2 = Secondary priority 3 = Special case interest 4 = Minimal need										
* Other water quality depends on lake and project; could include pH, conductivity, and other constituents like Fe, Al, or Ca										

1878 before the project begins to an appropriate post-implementation monitoring ending date. The
 1879 preparation of a [Quality Assurance Project Plan](#) is critical and instrumental for laying out the
 1880 details of monitoring and data interpretation, and to ensure the data are quality-controlled for their
 1881 intended purpose. Permits may not need to specify the details of monitoring but should call for an
 1882 approved monitoring plan before work begins.

General water quality features relevant to overall lake management include concentrations of nutrients (mainly forms of N and P), temperature and oxygen profiles over the maximum depth of the lake, pH, and conductivity. These may not be needed to track the results of many specific lake management projects but are appropriate to a long-term lake monitoring program that supports management. Monitoring that is specific to individual lake management techniques is considered in the discussion of those individual techniques later in this 2025 Guide, but the specific lake circumstances may require adjustment of any protocol (e.g., what to monitor, where to measure, and how often to assess). Yet some form of monitoring before and after implementation is almost always appropriate, and it makes sense to incorporate a program with criteria or targets for evaluating success and tracking non-target impacts into any LMP and permit process.

Select benchmarks for evaluation of success and compliance carefully. Reliance on numeric thresholds, including specific concentrations or dates, should be treated with caution. For example, a single water clarity measurement (Secchi disk transparency) of 3.9 m when the goal is 4.0 m hardly constitutes failure and achieving full lake level status after a drawdown a few days after the target date should also not be viewed as non-compliance. Any established thresholds should be viewed within the context of the direction of change, likely benefits of achievement, and likely impacts of non-attainment, all over the duration of the project or permit. If a project consistently fails to meet objectives, adjustment may be needed or, in extreme cases, even adoption of new management techniques or goals.

Monitoring does not need to involve research at an academic level in the vast majority of cases. Simple techniques can be applied to document goal achievement or non-target impacts in many cases, although some laboratory analysis of water chemistry (most notably P and N) is likely to be needed. Secchi disk transparency is easy and inexpensive to measure. Field instruments are available for assessment of temperature, oxygen, pH, conductivity, turbidity, chlorophyll-a, and phycocyanin, all of which may be highly relevant to lake management programs. The initial cost of instruments is not minimal but the ability to acquire real data for relevant lake features allows a much more meaningful analysis of the measurable water quality variables considered representative of management goals.

Aquatic plant management will require some identification of the plants present (at least the dominant species) and usually some quantification of coverage and density, but in many cases simple photographic documentation can clearly demonstrate lake conditions and the progress of a plant management program. Aerial images from satellites or drones, if available, facilitate reasonable overviews. The same visual approach applies to shoreline features and related actions like erosion control and buffer zone management. However, the establishment of a series of monitoring points within a lake where plant community features are annually assessed will provide quantitatively comparable data that allows statistically defensible tracking of project results. Such a monitoring program can be conducted by volunteers but may require professional assistance for at least the initial set up, training, and analysis of data.

Possible non-target impacts will vary by lake and management technique and may be more difficult to document. Where state listed species under the MA Endangered Species Act are present, some evaluation of impacts may be necessary, and the rarity of many listed species may complicate detection and assessment. In some cases, an approved professional may have to conduct the assessment at considerable cost. Even absent listed species, the relative level of concern over non-target impacts will dictate how much monitoring is required. For example, if mortality of mussels in the drawdown zone is a concern, this may justify a survey of mussels along shallow to deep transects with an accompanying analysis of possible impact to the overall population. The MA Wetlands Protection Act calls for recovery of native plant assemblages within two growing seasons of actions to control plant nuisances, so some measure of pre-control conditions should be compared to post-control conditions, probably on an annual basis. The situation at each lake will vary and the program should be crafted to meet local needs and resources within the framework of regulatory compliance.

3. THE REGULATORY FRAMEWORK

This chapter covers the regulatory process as pertains to lake management in MA. The programs and agencies that administer them are described. The process whereby permits are considered and issued or denied for proposed lake management activities is explained. The roles of applicants and conservation commissions in this process are covered. The regulatory landscape is ever changing, with new or amended laws and corresponding regulations being applied over time. The regulatory system in MA is fairly complex and many lake management activities are subject to multiple permitting processes. An understanding of the regulatory process will aid lake management planning and implementation.

The original purpose of the 2004 Generic Environmental Impact Report (GEIR) on Eutrophication and Aquatic Plant Management in Massachusetts and the companion Practical Guide to Lake Management in Massachusetts was to lay the groundwork for techniques to be applied without a lengthy project by project review under the Massachusetts Environmental Policy Act (MEPA). Techniques included in the GEIR and original Practical Guide were still subject to all the normal permitting processes under other state and federal statutes, but would not need “pre-approval” under MEPA, by virtue of having been vetted by an extensive review process conducted by agency staff and researchers at UMASS-Amherst. This did not mean that all vetted techniques were appropriate under all circumstances or were guaranteed to be approved under the Wetlands Protection Act, Massachusetts Endangered Species Act, or any other applicable law or set of regulations, but were considered to represent valid methods for lake management under the right set of conditions and restrictions. This section covers the potentially applicable regulatory processes.

Additional techniques were to be added to the GEIR as they were proposed and properly reviewed. For herbicides and algacides, there is a registration process for new products that is administered by the Department of Agricultural Resources and multiple new active ingredients have been added since 2004. However, no formal process was ever adopted for acceptance of new techniques not considered to fall under pesticide regulations and the environmental agencies are developing that process coincident with the finalization of this new 2025 Guide.

1965 **Regulatory Background**

1966 Lake management is a blend of science, economics and institutions. Among the most influential
1967 institutions are the environmental agencies at the state level, in which regulatory functions are
1968 vested. Having a scientifically valid plan that is properly funded is of no use if it cannot be
1969 permitted under the laws of MA, as administered under regulatory programs. Understanding those
1970 regulatory programs and the agencies that administer them is therefore integral to lake
1971 management in MA.

1972 Most permit programs are administered by the MA Department of Environmental Protection
1973 (MassDEP) through various divisions and offices. This includes the Wetlands Protection Act
1974 (WPA) with initial approval authority delegated to towns but ultimate responsibility for
1975 compliance resting with MassDEP. Other important lake-related programs under MassDEP
1976 include Section 401 of the federal Clean Water Act (Water Quality Certification), the Public
1977 Waterfront Act (Chapter 91 pertaining to Great Ponds), the Bureau of Water Resources (issuance
1978 of licenses to apply chemicals), and the Water Management Act (pertaining to permitted
1979 withdrawals and interbasin transfers of water). Additionally, the Watershed Planning Program
1980 engages in various activities required by the United States Environmental Protection Agency
1981 (USEPA) pursuant to the federal Clean Water Act (CWA) and associated regulations, including
1982 updates to the MA Surface Water Quality Standards (SWQS). The WPP does not issue permits,
1983 but the SWQS have substantial bearing on permit processes.

1984 The Department of Fish and Game, Division of Fisheries and Wildlife (MassWildlife), includes
1985 the Natural Heritage and Endangered Species Program (NHESP), which administers the provisions
1986 of the MA Endangered Species Act (MESA), usually the first stop in any lake management project
1987 permitting process where a listed species is involved. MassWildlife also issues stocking permits
1988 for vertebrates, usually fish, and the Division of Marine Fisheries takes an interest in fish passage
1989 and other lake management activities as relates to fish that move between lakes and the ocean
1990 (anadromous and catadromous).

1991 The Department of Conservation and Recreation (MassDCR), Office of Dam Safety, is responsible
1992 for overseeing the integrity and maintenance of dams in MA, including any changes in structure
1993 or removal. MassDCR also maintains the list of species prohibited from import or transfer among
1994 lakes, all invasive plants or animals.

1995 Various other agencies may be involved in lake management in MA where a proposed activity
1996 falls under their jurisdiction, such as the Department of Agricultural Resources (MDAR), which
1997 approves pesticides for use in MA and has regulations regarding fertilizer applications, and the
1998 State Office of Historical Preservation where cultural resources are involved. The United States
1999 Army Corps of Engineers (USACE) administers Section 404 of the federal Clean Water Act that
2000 pertains to wetlands protection at the federal level and has approval authority for dredging projects.
2001 The United States Environmental Protection Agency (USEPA) administers the National Pollutant
2002 Discharge Elimination System (NPDES) in MA, which relates to discharges of wastewater or

2003 stormwater from point sources and the application of herbicides. Although jointly administered by
2004 USEPA and MassDEP in the past, the National Pollutant Discharge Elimination System (NPDES)
2005 permit program is now administered solely by the USEPA. MassDEP administers a parallel surface
2006 water discharge (SWD) permitting program and issues its own SWD permits.

2007 **Department of Environmental Protection (MassDEP)**

2008 Programs and divisions of the MassDEP regulate most activities related to algae and aquatic plant
2009 management in lakes and ponds. Relevant information can be found in the document “*Guidance*
2010 *for Aquatic Plant Management in Lakes and Ponds as It Relates to the Wetlands Protection Act*”
2011 or simply [DEP Aquatic Plant Management Guidance](#), although this revised 2025 Guide is
2012 intended to be the primary resource when applicants and other regulators are ascertaining if a
2013 management technique or activity meets MassDEP’s regulatory requirements. An updated
2014 addendum to the DEP Plant Management Guidance document is being developed and it should
2015 complement the information in this 2025 Guide to algae and aquatic plant management in MA.

2016 **Wetlands Protection Act and Corresponding Regulations**

2017 Aquatic plant and algae management projects in lakes and ponds are subject to the jurisdiction of
2018 the Wetlands Protection Act (WPA), MGL Ch. 131, § 40 and the associated regulations in [310](#)
2019 [CMR 10.00](#). Projects must comply with the general performance standards established for each
2020 applicable resource area in the regulations (i.e., 310 CMR 10.54, 10.55, 10.56, 10.57) unless the
2021 project is accorded “limited” project status (310 CMR 10.53(4) or 310 CMR 10.53(3)(I)). If
2022 wildlife habitat thresholds described in the general performance standards are exceeded, the
2023 requirements of 310 CMR 10.60 for wildlife habitat must be met (i.e., a wildlife habitat evaluation
2024 shall be performed) unless the proposed action is an Ecological Restoration Limited Project.

2025 No project may be permitted which will have any adverse effect on specified habitat sites of rare
2026 vertebrate or invertebrate species (310 CMR 10.59) or on spawning activity of migratory fish
2027 species (i.e., anadromous or catadromous fish, 310 CMR 10.35). MassWildlife and the Division
2028 of Marine Fisheries provide input to the WPA process on such issues. The NHESP provides review
2029 of projects that may affect rare wetland wildlife habitat, called Estimated Habitat, as the associated
2030 species are listed under MESA, but this is a separate review than for Priority Habitat (covering all
2031 listed species, not just animals), of which Estimated Habitat is a subset.

2032 The regulatory process under the WPA involves the submission of a Notice of Intent (NOI) for
2033 consideration by the local conservation commission, with copies to the regional office of MassDEP
2034 and to the NHESP if the proposed project could affect state-listed species. Public notice is given
2035 for a hearing at which time the conservation commission receives input from the project applicant,
2036 interested agencies, and the general public. A decision on the project is rendered and, if accepted,
2037 a permit under the WPA, called an Order of Conditions (OOC), is issued. Other permits may apply
2038 and the OOC may not be the last step in complete project approval, but it tends to be the main step
2039 for most lake management projects. Note that other permits are likely to have bearing on the

conditions issued by the conservation commission, so the hearing process cannot be closed and an OOC cannot be issued until all relevant input from other permit programs has been received.

Ecological Restoration Limited Projects

In 2014 MassDEP revised the wetlands protection regulations under 310 CMR 10.53(4) for inland wetlands and 10.24(8) for coastal wetlands to include an ecological general permit process for six categories of Ecological Restoration Projects that are generally not applicable to aquatic vegetation or algae management unless such management results in habitat enhancement for rare species or restores shellfish habitat. However, the 2014 WPA regulation revision also included establishment of Ecological Restoration Limited Projects (ERLP) where WPA interests have been degraded or destroyed by human activities (see 310 CMR 10.04 and 10.12). This limited project status often applies to lake projects and allows some temporary or even permanent impacts to otherwise protected resources in order to achieve ecological restoration. Projects that reverse human-induced eutrophication, including excessive plant growth and algae blooms, may be eligible as ERLP.

Applicants proposing an ERLP under 310 CMR 10.53(4) must demonstrate that the project will improve the natural capacity of a resource area(s) to protect some or all the interests of the WPA. To meet this test, a project must improve the natural ability of a resource area to protect public or private surface water supply, groundwater supply, fisheries, shellfisheries, wildlife habitat, or to provide flood control, storm damage prevention, and/or to prevent pollution. Although a project does not need to improve the natural capacity of the resource area to protect all the interests of the act, it must improve at least one interest and it should minimize the adverse effect on the interests that are not targeted for improvement.

Projects that would usually qualify as limited projects under 10.53(4) include projects proposed primarily for the enhancement of fisheries habitat, projects to address cultural eutrophication, or those that would increase dissolved oxygen, reduce nutrient levels, or improve overall water quality in a water body. Proposed projects involving removal of aquatic nuisance vegetation must demonstrate that the vegetation is a “nuisance” to the interests of the act. Non-indigenous invasive plant species constitute nuisance vegetation. However, significant increases in indigenous plant species, if strongly linked to human activities, may also be considered. Also, projects proposing aquatic plant management to improve the natural ability of a resource area to provide recreation, aesthetics, odor reduction, or other benefits not specifically tied to a statutory interest of the WPA do not qualify under 310 CMR 10.53(4) because those interests are not protected by the WPA regulations. These projects would need to meet other applicable, relevant, general performance standards.

The ERLP provision that applies to inland wetland projects is outlined in 10.53(4)(e) (1-5). The section of the wetlands regulations that addresses aquatic plant management can be found in “Other Restoration Projects” (CMR 10.53(4)(e) (5)), including the removal of aquatic nuisance vegetation to retard pond and lake eutrophication, thinning or planting of vegetation to improve habitat value, as well as other specified activities that are not typical lake management actions.

There are specific ERLP eligibility requirements and procedures required to file a NOI for an ERLP and to obtain an ERLP OOC. These procedures ensure that the issuing authority (e.g., conservation commission or MassDEP) has the necessary information up front to reduce the need for additional information requests during the permit review process. A detailed [ERLP check list](#) that includes associated regulatory citations must be completed and attached to an ERLP NOI application as Appendix A, accompanying NOI Form 3.

Projects that are not eligible for ERLP include mitigation for alteration of a resource area already authorized by a final OOC or a 401 Water Quality Certificate, resource area impacts associated with natural disasters, or activities associated with enforcement actions. A 401 Water Quality Certificate may be required if the project involves dredging of 100 cubic yards or more or dredging in Outstanding Resource Waters (ORW). Questions regarding whether a project can be permitted as an ERLP can be forwarded to [MassDEP Wetlands Circuit Riders](#). An [Ecological Restoration Limited Projects video](#) is also available to explain this permitting option.

Water Dependent Uses

Water dependent uses are defined in 310 CMR 10.04 and include those uses and facilities that “require direct access to or location in marine, tidal, or inland waters and which therefore cannot be located away from said waters.” Examples of water dependent uses and facilities are provided in 10.04 and include marinas, swimming areas, fishing piers, and other public recreational use areas. Water dependent uses include other uses and facilities as further defined as water dependent in [310 CMR 9.12](#) (i.e., Chapter 91 Waterways Regulations). Lake management projects may be considered accessory (310 CMR 9.12(3)) to a water dependent use if they are necessary to accommodate a principal water dependent use. Normally, projects qualifying as water dependent uses would be confined to areas associated with facilities at specific points around the lake, but control of algae such as cyanobacteria on a lakewide basis could support water-dependent uses. All water dependent uses (e.g., marinas, public recreational areas, navigational and commercial fishing and boating facilities) that qualify for this limited project must meet all the requirements of 310 CMR 10.53(3)(l).

Outstanding Resource Waters

[Outstanding Resource Waters](#) (ORW) are designated within the MA [state surface water quality standards](#) and include Class A public water supplies and their tributaries, certain listed water resources within Areas of Critical Environmental Concern (ACEC), the Cape Cod National Seashore, designated Scenic Rivers and Wildlife Refuges, vernal pools, and certain other geographically specific wetland resource areas. ORW are afforded additional protection under the WPA, and applicants should be aware of the presence of any ORW when crafting lake management plans. ORWs can be viewed using the Watershed Planning Program’s [Water Quality Data Viewer](#). However, as of the date of this manual, the viewer displays the 2013 MA SWQS and it is therefore important to confirm the ORW against the classification tables (see 314 CMR 4.06, Tables 1 through 27) of the 2021 SWQS.

2116 **401 Water Quality Certification**

2117 A [401 Water Quality Certificate](#) (WQC) from MassDEP is required under the federal Clean
2118 Water Act for certain activities in wetlands and waters. These activities include the discharge of
2119 dredged or fill material, dredging, and dredged material disposal activities in waters of the United
2120 States within the Commonwealth that require federal licenses or permits. Statutory authority for
2121 this certification is stated in the federal Clean Water Act, 33 USC 1341, and the MA Clean Water
2122 Act, MGL Chapter 21, sections 26-53. Regulatory authority for this certification is found in 314
2123 CMR 9.00. The federal agency issuing a permit initially determines the scope of geographic and
2124 activity jurisdiction (e.g., Corps of Engineers for Section 404 permits for the discharge of dredged
2125 or fill material). The purpose of state 401 review is to ensure that a project will comply with [state](#)
2126 [water quality standards](#) and other appropriate requirements of state law. .

2127 MassDEP administers the 401 Water Quality Certification Program that reviews applications for
2128 fill and excavation in wetlands and/or dredging. WQC applications for fill and excavation in
2129 wetlands (BRP WW 10, 11) are reviewed by the appropriate MassDEP regional office in
2130 accordance with 314 CMR 9.00. Applications for WQC dredging projects (BRP WW 07, 08, 09)
2131 are reviewed by the MassDEP Wetlands - 401 WQC unit in the Boston office.

2132 Projects with less than 100 cubic yards (cy) of dredging or less than 5000 square feet of wetland
2133 impact are deemed approved upon the receipt of a valid final Order of Conditions and further 401
2134 WQC filings are not required. However, discharge of dredged or fill material to an ORW
2135 specifically identified in 314 CMR 4.06(1)(d) (e.g., vernal pools, within 400 feet of a water supply
2136 reservoir, and any other area so designated) is prohibited unless a variance is obtained under 314
2137 CMR 9.08.

2138 For projects involving hand pulling, mechanical harvesting, and hydrosucking of aquatic plants
2139 with removed volumes of 100 cubic yards or greater, or any volume in an ORW, a dredging
2140 permit could be required from the 401 WQC unit within MassDEP to ensure that the proposed
2141 project is in compliance with existing SWQS, specifically when the project involves dewatering
2142 and/or sediment repositioning. This is an area of inconsistent interpretation between state and
2143 federal regulations and MassDEP maintains that vegetation removal may require a 401 permit
2144 even where the USACOE does not require a Section 404 permit. Applicants for vegetation
2145 removal projects should consult with MassDEP to determine if a 401 WQC is needed.

2146 There are three categories for dredging permits: major project (BRP WW 07), minor project (BRP
2147 WW 08) and Amendment for Dredging (BRP WW 09). Major projects include the dredging of
2148 5,000 cubic yards (cy) or greater, minor projects (BRP WW 08) include projects not listed in the
2149 major project category and those projects involving dredging less than 5,000 cy but more than 100
2150 cy. An amended permit may be requested for project modifications, such as changes in the target
2151 area, volume of material removed, or methods of disposal. In addition, a change in one or more of
2152 the permit conditions may be allowed through an amended certification (BRP WW09).

2153 Applications for 401 Water Quality Certification must be submitted through [ePLACE](#). However,
2154 the online application system is not set up to handle vegetation management projects that might be
2155 considered subject to 401 WQC, so further guidance from MassDEP should be sought.

2156 **WM 04 Chemical Application License**

2157 The MassDEP WM04 Chemical Application License grants approval to apply chemicals for the
2158 control of nuisance aquatic vegetation or algae in accordance with authority granted to the
2159 MassDEP by MA General Laws c. 111, s. 5E. Anyone wishing to apply chemicals to bodies of
2160 water needs to acquire a WM 04 license except under the following conditions:

- 2161 ➤ When treatment is undertaken by employees and agents of the Departments of Environmental
2162 Protection, Conservation and Recreation, and Fisheries, Wildlife and Environmental Law
2163 Enforcement, or of the Reclamation Board, or of related Federal agencies, while in the conduct
2164 of their official duties
- 2165 ➤ When treatment is undertaken with algaecide containing copper by a public water system.
2166 However, the public water system shall notify the Department in writing prior to the
2167 application of such algaecides (see 310 CMR 22.20B(8), the Drinking Water Regulations).
- 2168 ➤ When treatment is undertaken in a private, single owner pond from which there is no flowing
2169 outlet during the period of chemical activity.

2170 Several prerequisites should be considered before applying for this permit:

- 2171 ➤ Chemical treatments to water, Bordering Vegetated Wetlands (310 CMR 10.55(2)(a)), and Salt
2172 Marsh (310 CMR 10.32(2)) using general or restricted use pesticides can only be performed
2173 by an applicator currently licensed by the MA Department of Agricultural Resources Pesticide
2174 Program in the aquatics category.
- 2175 ➤ Chemicals used for treatments must be currently approved for use in the state by the
2176 Department of Agricultural Resources Pesticide Bureau, which maintains the list of [herbicides](#)
2177 [approved for use in MA](#).
- 2178 ➤ A valid Order of Conditions, Negative Determination of Applicability, Administrative Consent
2179 Order or similar authorization must be obtained prior to the treatment.

2180 Since chemical treatments constitute the alteration of wetland resources, a NOI must be filed in
2181 accordance with the WPA (MGL c. 131, s. 40) and Wetlands Protection Regulations (310 CMR
2182 10.00). A valid OOC is needed to acquire the [WM 04 Chemical Application License](#).
2183 Applications for WM 04 licenses must be submitted through [ePLACE](#).

2184 **MGL Chapter 91 (Public Waterfront Act)**

2185 Where a dam on a [Great Pond](#) is licensed under [Chapter 91](#), the license conditions often allow
2186 for annual drawdowns to occur to specific levels. However, if drawdowns are sought to lower
2187 levels, new authorization must be obtained. Additionally, Section 310 CMR 9.05(2)(e) of the
2188 Waterways regulations requires that an application for a permit or permit amendment be submitted

to MassDEP for any lowering of the water level of a Great Pond, except a body of water used for agriculture, manufacturing, mercantile, irrigation, insect control purposes, or for flowing cranberry bogs, or for public water supply, unless such lowering is specified in the Chapter 91 license.

Note that this jurisdiction also applies to enhanced Great Ponds which have been enlarged by impoundment through dam construction. Since Chapter 91 jurisdiction is associated with the water column, structures and activities are regulated in enhanced Great Ponds by the same process as for Great Ponds that have not been enlarged. The additional impounded water is not exempt from regulation under Chapter 91.

Dredging projects in Great Ponds also require approval under Chapter 91. In addition to dredging projects involving sediment removal, Chapter 91 regulations define dredging as the removal of materials including plant or animal matter in any excavating, cleaning, deepening, widening or lengthening, either permanently or temporarily. Therefore, a dredging permit might be needed for mechanical harvesting of plant material if the cutting and harvesting of the plant material disturbs the bottom sediment. If harvesting operations do not move sediment to any significant degree, generally defined as in excess of 100 cy, such operations would not be considered “excavating” or “cleaning”. However, the 401 Water Quality Certification regulations may apply where >100 cy of vegetation is removed if there could be a significant impact on water quality.

Massachusetts Water Management Act

Drawdown projects may fall under the jurisdiction of the [Water Management Act](#) if water is removed or diverted from a lake beyond the established threshold in a consumptive manner (i.e., not simply passed downstream). Any project that includes the withdrawal of >100,000 gallons per day (or total withdrawal of nine million gallons over a three-month period) through pumping or other artificial means other than the removal of boards or other manipulation of a dam structure will require a Water Management Act permit and other requirements as stipulated in regulations under 310 CMR 36.00. If the Water Management Act applies, the project proponent should obtain a withdrawal permit from the MassDEP Drinking Water Program prior to initiating any work. Typical drawdowns that remove stoplogs or open an existing subsurface valve to lower lake water level with the water passing downstream from the lake are not subject to the Water Management Act.

Municipal Separate Storm Sewer System General Permit under NPDES

As of 2016, there were 260 municipalities in MA that are authorized to discharge stormwater into surface water bodies by the state and federal 2016 Small [Municipal Separate Storm Sewer System \(MS4\) General Permit](#). The permit consists of six categories of stormwater management which are referred to as minimum control measures. These minimum control measures include public education and outreach, public participation, construction-period stormwater controls, post-construction stormwater controls, illicit discharge detection and elimination, and good housekeeping. Municipalities that are authorized to discharge stormwater into surface water bodies

2226 implement the six minimum control measures that are part of the MS4 General Permit through
2227 local bylaws, ordinances, or other regulatory mechanisms, or other programs and standard
2228 operating procedures. Any tools related to lake management that are relevant to MS4, such as
2229 pollutant trapping by maintained inlet devices, buffers and swales, detention and infiltration basins,
2230 constructed wetlands, or pollution prevention through point source control are administered by the
2231 MS4 municipality and do not require any additional MassDEP program review. If those actions
2232 occur in regulated wetland resources (under the WPA) or mapped Priority Habitat for state-listed
2233 species (under the MA Endangered Species Act), permit processes still apply under those separate
2234 programs.

2235 **NPDES Pesticide General Permit**

2236 The Pesticide General Permit (PGP) issued under the National Pollutant Discharge Elimination
2237 System administered by the USEPA regulates point source discharges of biological and chemical
2238 pesticides that leave a residue. The permit covers mosquito and other flying insect pest control,
2239 vascular plant and algae pest control, animal pest control, and forest canopy pest control. Permit
2240 coverage is issued to an operator, who is either an entity who performs the application of a pesticide
2241 or who has day-to-day control of the application, or an entity with control over the decision to
2242 perform pesticide applications including the ability to modify those decisions.

2243 Entities conducting vascular plant and algae control in MA are typically covered by the WM 04
2244 Chemical Application License, issued by MassDEP in cooperation with the USEPA, but project
2245 applicants should review the PGP to determine if further submission is required and apply for any
2246 applicable coverage. The USEPA maintains an online [permit coverage decision tool](#). The
2247 criterion of greatest relevance is usually the size of the area treated, with 80 acres used as a
2248 threshold below which the PGP automatically applies. If the area is greater, additional submission
2249 may be required to get PGP coverage. In cases with larger application areas, potential impacts to
2250 federally protected resources, or where impairment relating to the chemical proposed for
2251 application is already known, an individual permit may be required.

2252 **Watershed Planning Program**

2253 The Watershed Planning Program (WPP) has a mission to protect, enhance and restore the quality
2254 and value of the waters of the Commonwealth. The program engages in various activities pursuant
2255 to the CWA and associated regulations. The CWA directs states to monitor and report on the
2256 condition of their water resources, including lakes and ponds, and whether they are healthy or
2257 impaired relative to their designated uses. The WPP is responsible for developing surface water
2258 quality standards, monitoring and evaluating water quality, and creating plans to restore and
2259 protect surface waters (see M.G.L. c. 21, §§ 26 through 53).

2260 [State water quality standards](#) (SWQS) designate the most sensitive uses of MA waters and
2261 provide criteria for evaluating water quality to support those uses. In the SWQS, lakes and ponds
2262 are defined as “[w]aterbodies having open water, situated in a topographical depression, generally

with a maximum depth of greater than two meters. Lakes and ponds do not include constructed stormwater retention basins, constructed impervious basins or impervious impoundments, permitted wastewater lagoons, constructed farm ponds into which and from which no stream or river flows, and generally do not include dammed river or stream impoundments.” (314 CMR 4.02). The WPP evaluates impounded streams and rivers as lakes that exhibit unidirectional flow and have average detention times of more than 14 days.

The WPP performs a biennial evaluation of the waters of MA according to the [Massachusetts Consolidated Assessment and Listing Methodology Guidance Manual](#). This biennial review will contain information relevant to the management of lakes and ponds in MA.

Department of Fish and Game, Division of Fisheries and Wildlife

Regulatory Authority and Role in Lake and Pond Management

The conservation (including protection, restoration, and management) of the fauna and flora of MA is the statutory responsibility of the Division of Fisheries and Wildlife (MassWildlife) as outlined in Chapters 131 and 131A of MA General Law. Specifically, it is the charge of MassWildlife to oversee the stewardship of all wild amphibians, reptiles, birds, mammals, and freshwater fishes in the state. While MassDMF has most of the responsibility for diadromous fish, MassWildlife does have responsibility for species other than striped bass and river herring beyond the point of tidal influence. MassWildlife is also responsible for the stewardship and protection of all state-listed endangered, threatened, and special concern species under the MA Endangered Species Act (MESA) through the Natural Heritage and Endangered Species Program (NHESP), including invertebrate and vertebrate animals and plants. This responsibility is established and articulated in the Constitution and General Laws of MA and is undertaken for the benefit and enjoyment of the public today and for future generations. MassWildlife applies a stewardship philosophy that focuses on science-based management that balances human and wildlife needs.

Designated [Great Ponds](#) in MA are public resources, meant to be managed in the best interest of the public. The fish and wildlife resources in all lakes and ponds, regardless of designation or land ownership, are also protected under the regulations outlined below as applicable. The public enjoyment of lakes and ponds in MA is a priority for MassWildlife as is the protection of game and non-game species and their habitats.

MassWildlife activities to protect lakes and ponds include a combination of regulations governing fishing that include protecting recreational species like warmwater and coldwater game species from overexploitation ([321 CMR 4.00](#)). MassWildlife also regulates importation and liberation of vertebrate species ([321 CMR 2.15](#)) and freshwater aquaculture activities ([321 CMR 4.09](#)). Further, MassWildlife conducts research directed toward a better understanding of lake and pond resources and the stresses they face ([MGL Ch 131 Sec 4 \(13A\)](#)) and offers technical assistance to other regulatory agencies or members of the general public, particularly as pertains to proposed lake management activities under review for permit issuance or compliance.

2300 **Massachusetts Endangered Species Act**

2301 The MESA was enacted in December 1990 (MGL Ch 131A). Implementing regulations were
2302 promulgated in 1992 and most recently revised and implemented as of January 2010 ([321 CMR](#)
2303 [10.00](#)).

2304 The MESA is a state law that is administered by the Natural Heritage and Endangered Species
2305 Program (NHESP) within MassWildlife. Those names are used interchangeably in this section but
2306 MassWildlife includes many more programs than NHESP. The MESA establishes procedures for
2307 the listing and protection of state-listed plants and animals. MESA regulations outline project
2308 review and filing requirements for projects or activities that are located within a Priority Habitat
2309 of Rare Species (Priority Habitat), provide clear review timelines, and establish an appeal process
2310 for agency actions. The MESA prohibits impact on or loss of state-listed species, interference with
2311 key behaviors (e.g., nesting, feeding, breeding, overwintering, migrating) and habitats, which is
2312 called a “Take”. The MESA regulations apply to any project or activity within Priority Habitat.
2313 Priority Habitat is the geographical extent of habitat for all state-listed species as delineated by
2314 MassWildlife. Priority Habitats are mapped for state-listed species and are subject to review by
2315 MassWildlife. Current Priority Habitat maps are available through the [MESA interactive web](#)
2316 [viewer](#).

2317 The online mapping resource will allow an applicant to determine if the project area overlaps with
2318 Priority Habitat but does not provide information on what species are potentially present. As
2319 project planning may be aided by that knowledge, an [Information Request](#) may be filed by the
2320 property owner or applicant with an ownership interest to obtain a list of state-listed species
2321 associated with the site. A request for a pre-filing consultation can also be made.

2322 All projects or activities within Priority Habitat that are not [exempted from the MESA review](#)
2323 must submit a filing with the associated fee to MassWildlife to determine whether a probable [Take](#)
2324 [under the MESA](#) would occur. The filing must include all proposed and anticipated activities
2325 related to the project.

2326 For lake and pond management projects, filing typically includes disclosure of all management
2327 activities occurring in the water body (e.g., drawdown, herbicide application, hand-pulling) even
2328 if those activities are under separate WPA filings. A chart of the activities with timeline, frequency,
2329 targets and descriptions is important as the MESA does not allow project segmentation; the
2330 combined impact of all actions is evaluated cumulatively. For shoreline activities (e.g.,
2331 stabilization, shoreline walls, beaches seasonal shoreline cleanup), disclosure of other activities in
2332 the same general area (e.g., upland clearing, drainage alterations) is important. The NHESP
2333 provides online guidance for [MESA submission](#).

2334 The requirement to file under the MESA is independent of the requirement to submit a copy of an
2335 NOI as may be required under the WPA. The trigger for submitting a copy of the NOI to the
2336 NHESP is a function of the presence of Estimated Habitat, which is a subset of Priority Habitat

that involves state-listed wetland wildlife habitats (310 CMR 10.37, 10.58(4)(b), 10.59). For most lake and pond projects, the MESA filing should include a comprehensive lake management plan that describes the goals (see Lake Management Planning section), includes a monitoring and reporting framework, and describes how each proposed activity will address the goals. This may very well be part of the NOI submission, making the NOI useful in both permitting processes.

Within 30 days of receiving a filing, MassWildlife will provide a response indicating completeness of the filing. If the submission is complete, MassWildlife has an additional 60 days to provide a determination. However, most project reviews are completed within the first 30 days if complete information is provided.

Under the MESA, a determination letter is issued stating whether or not a project or activity, as currently proposed, will result in an impact (Take) of state-listed species and can proceed (1) without conditions, (2) with conditions, or (3) must either be revised to avoid the Take or must meet the performance standards for the issuance of a [Conservation and Management Permit \(CMP\)](#).

Wetlands Protection Act – Rare Species

The WPA is a state law implemented by the local conservation commission and requires that the conservation commission consider the impact of a project on wetland resource areas. MassWildlife delineates Estimated Habitats as a sub-set of the Priority Habitats based on the geographical extent of habitat of state-listed state-listed (aka “rare”) wetlands wildlife, codified under the WPA (310 CMR 10.37, 10.58(4)(b), 10.59). State-listed animal species are identified in the WPA as a special type of wildlife and MassWildlife is assigned the responsibility for providing analysis of impacts from any proposed project that could affect them. All Estimated Habitat lies within a Priority Habitat. The WPA wildlife standard of “no short or long-term adverse effect” applies to state-listed wetland wildlife habitats, but not to state-listed plants or strictly upland species.

For projects subject to the WPA and located in Estimated Habitat, a copy of the wetland filing must be sent to MassWildlife. The conservation commission must receive proof that the filing was submitted to MassWildlife and ensure that subsequent materials sent to the conservation commission are likewise submitted to MassWildlife. For all lake projects to which MESA applies, MassWildlife must receive a complete NOI and issue a determination prior to the local conservation commission closing any hearing or issuing an Order of Conditions. Where there is Estimated Habitat and an ERP or ERLP is proposed, a determination letter from NHESP should accompany the NOI submission to the conservation commission, necessitating advance submission to NHESP. MassWildlife will provide a response to the WPA filing within 30 days of receipt in most cases but can take 30 days to determine that the application is complete and an additional 60 days to evaluate the application.

Under the WPA, the determination letter is issued stating whether or not the project or activity will result in a short or long-term adverse impact to the actual wetland resource area habitat of state-

listed wetland wildlife (“adverse effect”) and determines if the project (1) can proceed without conditions (“no adverse effect”), (2) can proceed with conditions (“adverse effect avoided through adherence to conditions”), or (3) will result in an adverse effect. If MassWildlife issues a determination of #3, adverse effect for state-listed wetland wildlife, the conservation commission may not issue any Order of Conditions until such time as the applicant obtains a CMP from MassWildlife as required by the MassDEP [Wetland Program Policy on Rare Species](#) or alters the project to avoid adverse impact and refiles for a new determination by the NHESP.

MassWildlife will send a copy of the MESA CMP to the conservation commission relevant to a WPA filing. The conservation commission should read and review the CMP for consistency with the conservation commission’s proposed conditions, ensure that plans are consistent with those submitted, and respond to any permitting requests by the project applicant for work within wetland resource areas that may be required by the plan for habitat management or restoration. The conservation commission may issue an OOC incorporating compliance with the CMP conditions at this point.

Wetlands Protection Act – Fisheries and General Wildlife

The MA WPA calls for consideration of impacts to fisheries and wildlife within the general interests of the WPA and as detailed in the performance standards. The conservation commission has an obligation to consider such impacts in reviewing applications. When a required submission is made to the NHESP relating to Priority or Estimated Habitat, NHESP staff will coordinate comments within MassWildlife. However, if no filing with NHESP is required, the conservation commission or applicant has the option to request comments on any lake and pond management filings directly from MassWildlife staff through the headquarters office in Westborough, MA. Comments from MassWildlife can aid the conservation commission in evaluating the impacts of a project.

MassWildlife also maintains the [Coldwater Fish Resources mapping tool](#). Identification of a Coldwater Fish Resource (CFR) is based on fish samples collected by MassWildlife staff or designated surrogates. A CFR is a stream, river, or tributary in which reproducing coldwater fish are found and comments from MassWildlife may refer to this status. A CFR is a particularly sensitive habitat and consideration is due where a lake project could impact a CFR. Changes in land and water use can reduce the ability of these waters to support trout and other kinds of coldwater fish.

Department of Fish and Game, MA Division of Marine Fisheries

Marine and freshwater organisms in coastal watersheds are managed by the MA Division of Marine Fisheries (MassDMF) and the MA Division of Fisheries and Wildlife (MassDFW or MassWildlife) according to jurisdictional boundaries defined in MGL Chapter 130 Sec 5. A 2003 Memorandum of Understanding (MOU) between the agencies further establishes jurisdictional boundaries in most systems as either at the “head of tide” or at the first obstruction on a coastal

stream. The provisions of the MOU also establish MassDMF as having jurisdictional management of anadromous striped bass (*Morone saxatilis*) and river herring, which include alewife (*Alosa pseudoharengus*) and blueback herring (*Alosa aestivalis*), for all waters of the Commonwealth. Jurisdiction for all other diadromous species, such as American eel (*Anguilla rostrata*) or sea-run trout species, is split between MassWildlife and MassDMF at the defined coastal boundaries.

The marine resources of the Commonwealth are afforded protections under the Wetlands Protection Act, Clean Water Act, and the Federal Fish and Wildlife Coordination Act. The [Fisheries Habitat Program](#) tracks coastal alteration projects and coordinates input from MassDMF staff to provide recommendations to local conservation commissions and state and federal permitting agencies for avoiding, minimizing, and mitigating adverse impacts to resources and habitats. MassDMF should be provided with a copy of the NOI for any project in a coastal resource area. MassDMF will provide comments to the conservation commission for consideration during the hearing process.

Coastal alteration projects such as dredging, pipeline construction, projects utilizing fill, bridges, roads, and culverts can impact specific habitats or vulnerable life history stages of species that spend part of their life cycle in freshwater and part in saltwater. Treatments to control vascular plants or algae can also impact diadromous species. MassDMF staff have generated several technical reports and best practice guidance documents in support of recommendations. MassDMF Technical Report 47 (Evans et al. 2011) provides recommended Time of Year (TOY) restrictions for coastal alteration projects to protect marine fisheries resources in MA, which are recommendations for spring and fall seasonal TOY restrictions on in-water construction work or chemical treatments that may impact diadromous fish species or habitats.

TOY restrictions will affect projects in tidal rivers and connected lakes where aquatic organism passage is possible. Species are considered vulnerable to coastal alterations if their habitat is spatially limited, if a vulnerable life stage (e.g., spawning or aggregated passage) occurs in an area proposed to be impacted, and/or if their population abundance is particularly low. Adverse impacts to diadromous fish and habitats include activities that can impede or obstruct fish passage, change the volume or flow rate of water within a fish run, or impair habitats (including water quality) necessary for various life history stages of diadromous fish.

The MassDMF [Diadromous Fisheries Project](#) seeks to provide suitable passage for saltwater fish into freshwater to spawn, including jurisdiction over diadromous fish passage in coastal rivers. This work includes collaborative, large-scale fish passage and small-scale fish ladders, habitat improvements, and eel ramp construction projects. Several guidance documents and tools are available to assist the management of diadromous fish passage, fishway operation and fishway and stream maintenance. MassDMF and MassDEP have developed a formal [Stream Maintenance Policy](#) that establishes performance standards to prevent impediments to fish migration, maintain stream flows within fish runs, and preserve spawning or nursery habitats. [Stream Channel Maintenance Protocols](#) provide guidance to landowners and municipalities to address stream

channel maintenance as a necessary natural resource management practice and assist municipalities in providing safe and efficient passage for sea-run fish.

MassDMF also maintains a publicly available [MA GIS Diadromous Fish Data Layer](#) (updated in 2023) and an accompanying [Diadromous Fish Restoration Priority List](#). The data layer identifies diadromous fish passageways, impediments, habitat, species presence and sampling stations along coastal rivers and in lakes and ponds. The GIS data layer references recommended Time of Year (TOY) restrictions established through a collaborative effort between the Diadromous Fisheries Project and the MassDMF Fisheries Habitat and Shellfish Programs to minimize impacts from aquatic management activities on sensitive life stages of diadromous species. Information on the presence of diadromous species in specific waterbodies is further described in Reback et al. (2004a,b; 2005a,b), and Appendix Table 6.1 in [Herbicides and Diadromous Fish](#). To assist the management of river herring, MassDMF has produced a Quality Assurance Program Plan for conducting river herring spawning and nursery habitat assessments (Chase et al. 2020).

Department of Conservation and Recreation

The Department of Conservation and Recreation (MassDCR) is mostly a natural resource management agency within the Commonwealth of MA, but MassDCR has responsibility for several important programs that relate to lake management.

Prohibited Plant List

MassDCR maintains a list of plant species that are prohibited from import to MA or transfer among lakes. These are invasive species known to cause ecological and economic harm when introduced. [Prohibited plants](#) may not be introduced as part of any lake management program and the removal of such plants is likely to qualify as an ERLP under the WPA.

Areas of Critical Environmental Concern

Designated Areas of Critical Environmental Concern ([301 CMR 12.00](#)) (ACEC) are designated for special recognition because of the quality, uniqueness, and significance of its natural and cultural resources. Nominated at the local level but approved by the Secretary of Energy and Environmental Affairs, ACEC are afforded additional protection under environmental laws such as the WPA and applicants should be aware of the presence of an ACEC when crafting lake management plans.

Department of Agricultural Resources

The Department of Agricultural Resources (MDAR) is responsible for reviewing and registering pesticides for use in MA. Algaecides are a subset of herbicides which are a subset of pesticides, and once the federal government (through the USEPA) has registered the pesticide product for use in the USA, a state can then determine if that pesticide will be registered for use in that state. MDAR handles that process in MA through its authority set forth in M.G.L. c. 132B.

MDAR also administers a 2012 law, Chapter 262 of the Acts of 2012 with an associated regulation [330 CMR 31.00](#) that establishes standards for the applications of plant nutrients to agricultural land and non-agricultural land, including turf and lawns. The regulation requires any person who applies plant nutrients to adhere to plant nutrient application restrictions and follow University of MA Amherst Extension [guidelines for plant nutrient management](#). On agricultural land, plant nutrient applications are to be made at agronomic rates based on assessments of soil fertility levels (determined from soil testing), crop need, and availability of nutrients from plant nutrient materials as specified in a farm-specific nutrient management plan. On lawns and turf, P-containing fertilizer may only be applied when a soil test indicates that it is needed or when turf or a lawn is being established, patched, or renovated. The regulation specifies situations and conditions when no applications of plant nutrients shall be made. MDAR has statutory enforcement authority through the act but has so far focused on providing outreach and education to assist farmers and turf management professionals with understanding and complying with the regulation. The existence of this act and regulation is a major step toward reducing nutrient pollution of waters of MA.

United States Army Corps of Engineers

Section 404 of the Clean Water Act

[Section 404 of the Clean Water Act](#) establishes a program to regulate the discharge of dredged or fill material into waters of the United States, including wetlands. Targeted activities include fill for development, dams and levee construction, infrastructure development such as highways and airports, and mining projects. Dredging activities are included as a function of likely redistribution of sediment within a water resource even where removal is intended. A federal permit is required for any dredged or fill material to be discharged into waters of the United States unless the activity is exempt from Section 404 regulation (e.g., certain farming and forestry activities). No discharge of dredged or fill material may be permitted if a practicable alternative exists or if the nation's waters would be significantly degraded. The USEPA has some responsibility for this program, but actual permitting authority is either through the United States Army Corps of Engineers (USACE) or state agencies to which authority has been delegated. MA is not a Section 404 delegated state.

Just what constitutes “waters of the United States” has been hotly contested within agencies and the courts over the last two decades, but for the purpose of many lake management activities in MA, it should be assumed that Section 404 could apply to any activity that disturbs sediment within a designated Wetland Resource Area under the WPA. There are general permits that apply to many common activities, such as shoreline stabilization, beach nourishment, and maintenance dredging, and are applied on a nationwide, regional, or state level. Programmatic General Permits (404 PGP) are often issued within states where existing state regulations already cover the proposed activity. The USACE offers 404 PGP in MA to provide consistency between state and federal programs.

The intent of general permits is to cover activities with limited scope or potential for adverse impacts, especially if all local and state regulations are followed. General permits involve minimal review or time delay at the federal level. Where significant impact is possible, an individual permit

2523 may be required, with considerably greater submission requirements and a potentially long review
2524 period. Dredging projects that exceed 5000 cy are often subject to individual permits under Section
2525 404. The USACE does not regard the removal of vegetation as a dredging operation; Section 404
2526 as administered by the USACE is not applied to vascular plant harvesting operations.

2527 **The Role of a Conservation Commission**

2528 In MA, a conservation commission is the municipal body specifically charged with protection of
2529 its community's wetland resources as defined by the WPA and any applicable town bylaws. With
2530 regard to lake management, conservation commissions have an important and unique role as they
2531 represent the intersection of regulatory requirements and local decision-making and have the
2532 critical responsibility of ensuring that lake management projects uphold the public interests that
2533 wetland resources provide under the WPA and its implementing regulations ([310 CMR 10.00](#)).

2534 The purpose of the WPA is to protect wetland resource areas and the public interests they serve,
2535 including flood control, prevention of pollution and storm damage, protection of public and private
2536 water supplies, groundwater supply, fisheries, land containing shellfish, and wildlife habitat. The
2537 law and supporting regulations include protection of a wide variety of wetland resource areas.
2538 Inland or freshwater wetland resources include, but are not limited to, areas where water is above,
2539 at, or just below the surface of the ground such as marshes, wet meadows, bogs, swamps, lakes
2540 and ponds. In addition, the WPA protects associated wetland resource areas that are not inundated
2541 year-round, such as land subject to flooding (isolated and bordering, such as the 100-year
2542 floodplain), land under waterbodies and waterways (LUWW), buffer zones, biologically
2543 significant areas like fish runs, and riverfront areas. Note that riverfront areas were added to the
2544 WPA through adoption of the MA [Rivers Protection Act](#).

2545 MassDEP is the state authority that oversees the WPA and its regulations and, as outlined in the
2546 law, delegates local/municipal authority, review, administration, and compliance to conservation
2547 commissions. MassDEP is also the appellant agency for conservation commission decisions and
2548 can provide general technical, regulatory, administrative and compliance assistance to
2549 conservation commissions so long as it is not specific to an individual project.

2550 Conservation commissions are the primary local/municipal regulatory authority for lake
2551 management projects under the WPA and project oversight needs to include actions within all
2552 relevant jurisdictional resource areas. A conservation commission may be called on to render a
2553 Determination of Applicability, which determines whether or not a more detailed filing and
2554 hearing process is necessary. A Notice of Intent (NOI) is submitted by an applicant where the
2555 WPA is deemed applicable and required by the WPA or conservation commission. The NOI
2556 review is performed to ensure that the proposed activities will not adversely alter WPA resource
2557 areas and the public interests that they support.

2558 There are many other potentially applicable permit processes for lake and watershed projects, and
2559 it is appropriate for conservation commissions to be aware of the range of possible permits needed

2560 under other regulations, but the job of the conservation commission relates specifically to the WPA
2561 and that is the focus of this section.

2562 **The Project Review Process**

2563 Conservation commission review should include a full evaluation of the work including the
2564 potential resource area(s), public interest impacts, and how the project will mitigate and address
2565 these impacts. The conservation commission must also consider the interactions of proposed
2566 activities that could impair wetland resources due to the nature and timing of the proposed activity.
2567 The conservation commission may require ongoing or post-work monitoring to assess and evaluate
2568 whether the project goals were met and maintained. Many municipalities may also have local
2569 bylaws implemented by the conservation commission that they must also address and incorporate
2570 into the review process.

2571 It is through a public hearing process that a conservation commission conducts its NOI review in
2572 a transparent manner that allows for public input. The project applicant describes the proposed
2573 work and the extent of potential alterations or impacts to wetland resource areas and to the public
2574 interests that they provide. The conservation commission reviews these potential alterations within
2575 the context of the WPA and any applicable town bylaws. This review may require additional
2576 information from the project applicant. The conservation commission may also choose to have the
2577 NOI reviewed by an outside consultant of its choosing. Project modifications may be required to
2578 bring the project into compliance with WPA regulations. Additionally, there are multiple
2579 additional permit programs applicable under other laws of the Commonwealth (Figures 13 and 14)
2580 and acceptability and conditions for projects considered under those programs may need to be
2581 considered during the hearing process.

2582 After the project is reviewed thoroughly, the conservation commission members will conduct a
2583 public vote to either (a) approve the project as proposed with standard conditions, (b) approve it
2584 with standard conditions and additional special conditions, or (c) disapprove or deny the permit
2585 application if impacts to the wetlands are significant and cannot be avoided or mitigated through
2586 conditions as required under the WPA. The conservation commission may also reject the NOI if
2587 the information needed to properly review the project has not been provided, but normally there is
2588 an interactive process whereby additional information is requested from and provided by the
2589 applicant as warranted.

2590 The conservation commission-issued decision or wetlands permit is called an Order of Conditions
2591 (OOC). An approved OOC may include additional special conditions that delineate the scope and
2592 spatial and temporal limits of the work, necessary mitigation activities to reduce potential impacts,
2593 and pre- and post-implementation inspection, mapping, plans, or other assessment to support
2594 compliance review. The conservation commission has the authority and discretion to include
2595 conditions that will enhance resource protection and/or mitigate or reduce harm to the resource(s)
2596 associated with the project. While the standard WPA conditions may be sufficient for many

Permitting Flow Chart for Lake Projects in Massachusetts

This flow chart is intended to provide the general steps involved in permitting a lake project. Given the wide range of possible projects and the many potentially applicable regulatory requirements, every option cannot be covered. Applicants are urged to consult with appropriate agencies before attempting to permit a project. Note also that for projects involving techniques or applications not fully compliant with the GEIR/Practical Guide, a MEPA review and approval process is needed. No OOC or state permits can be issued until the close of the MEPA process.

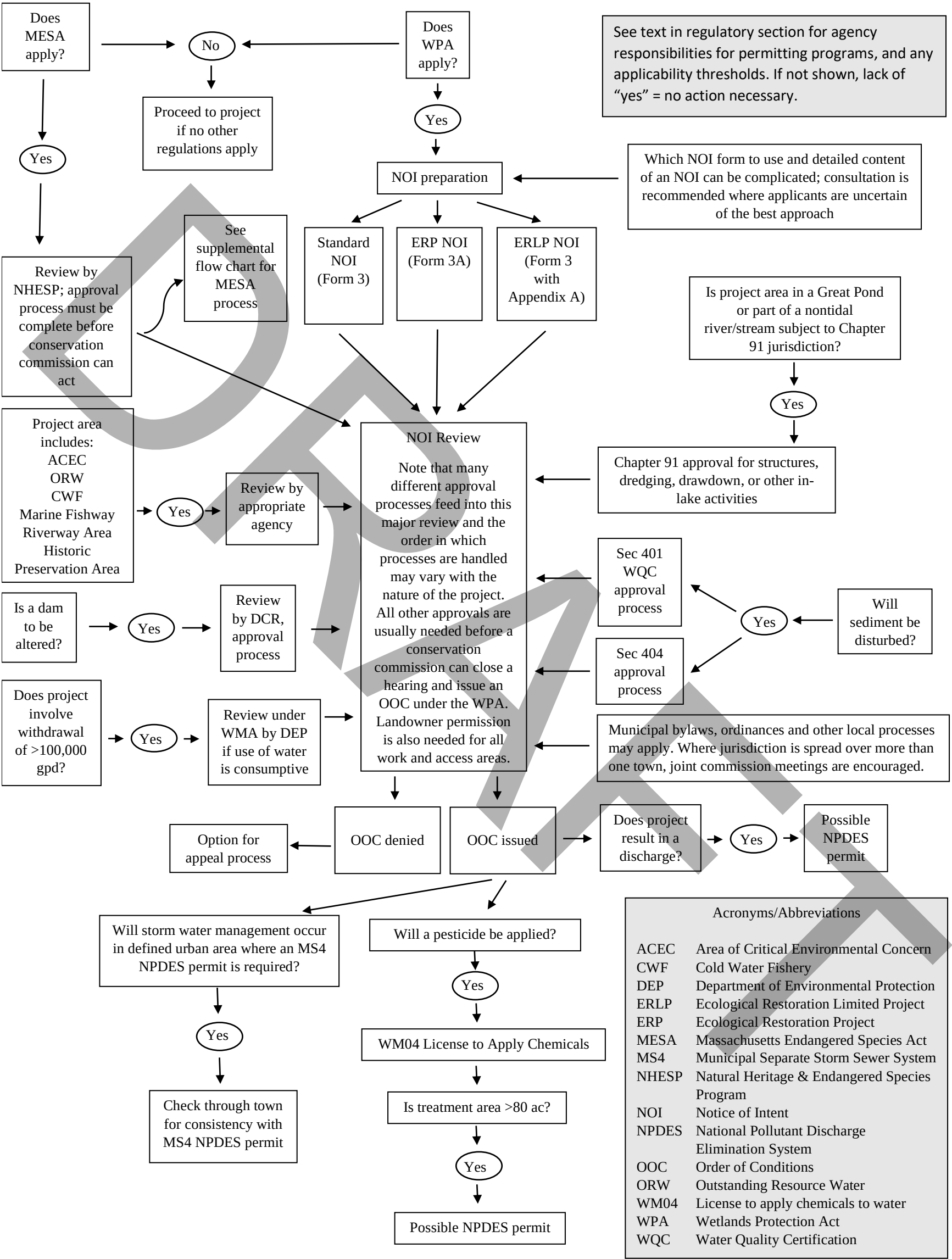


Figure 13. Permit flow chart for Massachusetts lake projects

Flow Chart for Permitting under the MESA for Lake Projects in Massachusetts

This flow chart is provided as a guide where MESA considerations may apply. Not every possible situation can be anticipated and consultation with NHESP is advised when planning a project.

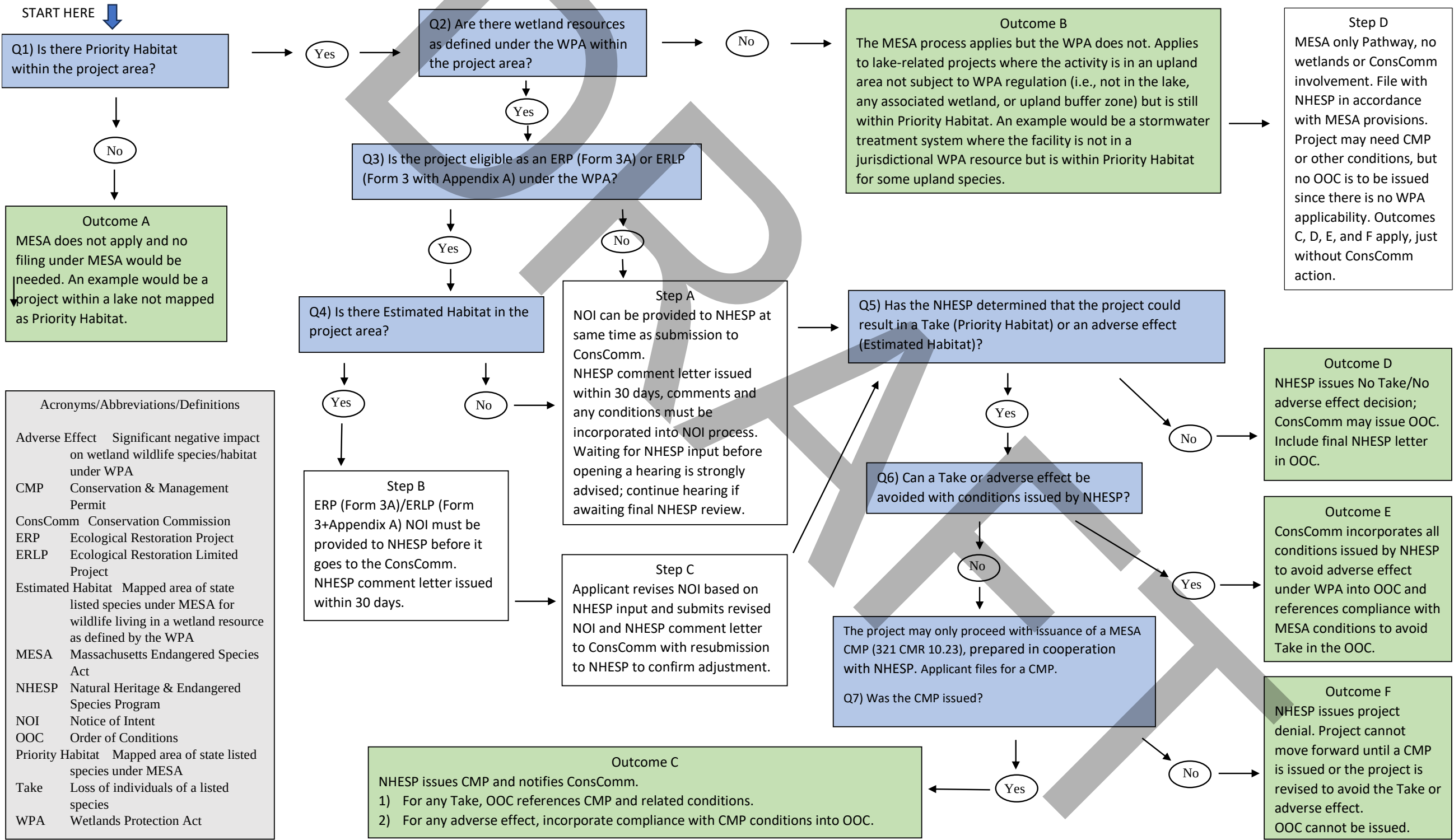


Figure 14. MESA permit flow chart for Massachusetts lake projects

projects, this 2025 Guide provides recommended technique-specific sample conditions (see Appendix). If the project work fails to comply with the OOC, the conservation commission can issue a Notice of Non-Compliance (i.e., Enforcement Order). Normally a conservation commission communicates directly with the project applicant to seek corrective action and may call for a hearing to discuss the non-compliant work and methods to rectify and mitigate the problem. Where appropriate corrective action is not taken, project work can be forced to cease.

There is an NOI option that applies to many lake management projects called the Ecological Restoration Limited Project (ERLP, 310 CMR 10.12). ERLP applications must meet certain eligibility requirements as outlined in the [ERLP checklist](#), and the associated Appendix A must be included with the NOI Form 3 for an ERLP. ERLP projects “...may result in the temporary or permanent loss of Resource Area(s) and/or the conversion of one Resource Area to another when such loss is necessary to the achievement of the project’s ecological restoration goals.” However, the eligibility requirements and conditions are very specific, and they are not meant to be used to circumvent protection by other state regulations (e.g., MESA, ACEC) or to advance projects to correct environmental degradation due to human activity subject to existing permits.

The ERLP option is most often applied to invasive species control and reversal of eutrophication caused by human activities not subject to existing permits. An ERLP may involve state-listed species under the MESA, in which case NHESP input must be incorporated into the OOC via the MESA and rare wetland wildlife provisions of the WPA.

Project Review Considerations for Conservation Commissions

Proposed lake projects may be complex with multiple approaches applied over multiple years and may have direct and indirect consequences for the wetland resources that are not always obvious, clear, or easily measurable. A complete lake management plan is merited to guide implementation and should aid conservation commissions in understanding the context and scope of the project, but smaller projects (e.g., addressing plants in a swimming area, repairing a small erosion area along shore) may not necessitate such a comprehensive plan. Conservation commissions should strive to fully understand a proposed project and may require additional information from the project applicant or seek outside expertise to address all considerations. The conservation commission should consider reasonable public use and enjoyment of lake resources while protecting the statutory interests of the WPA.

In some cases, the area affected may extend across the boundaries of multiple towns, requiring coordination with other conservation commissions or town boards. There may be special consideration of protected species or areas (e.g., MESA or ACEC). Many lake projects require additional permits that involve coordination with other agencies to obtain, including possible involvement of MassDEP programs under Section 401 of the Clean Water Act or Chapter 91 for Great Ponds, or the US Army Corps of Engineers under Section 404 of the Clean Water Act. It is not the job of a conservation commission to guide applicants through the regulatory process, but a

well-educated commission can be a great resource for applicants and an agent for appropriate and efficient lake management.

A monitoring program is likely to be needed to assess project progress and/or results. Monitoring during actual management actions may be needed to inform sequential actions, re-treatment, or other immediate implementation decisions for certain techniques. Monitoring before and after management actions, within an appropriate timeframe, is usually needed to document goal achievement and may be needed to demonstrate protection of WPA interests. Provisions should be added for a reasonable and effective monitoring plan to protect resource areas during implementation, evaluate post-implementation project effectiveness, and enforce the OOC if performance standards are not being met. This 2025 Guide attempts to supply guidance for appropriate monitoring for each management technique, but details may be project-specific.

Techniques reviewed in chapters 5-8 in this 2025 Guide have gone through rigorous professional and regulatory review and have been used successfully in MA over many years. They may not be appropriate in all circumstances, may present some risk to the interests of the WPA, and should not be accepted by conservation commissions without review of the proposed application. Yet those techniques are accepted as valid options in MA under the MEPA. New or unproven lake management techniques (some but not all techniques in the section on Alternative Techniques, chapter 9) may be proposed by project applicants and may be permitted if allowable in MA but will require additional scrutiny under the MEPA. At a minimum, an Environmental Notification Form (ENF) must be filed to allow interested parties to comment and a review to be conducted before such techniques can be permitted by a conservation commission. Where a technique is not explicitly disallowed in MA (e.g., stocking of grass carp) but has an inadequate track record to be considered reliable, additional justification is likely to be needed and a monitoring plan that clearly documents results should be required. Gathering appropriate data is expected to advance our knowledge and allow more informed evaluation of the technique.

Use of peer-reviewed publications to review lake management effects and their relationship with the WPA is preferable to other sources, although much of that information may be highly technical or otherwise specialized. This 2025 Guide and similar publications from other states or non-profit professional organizations (e.g., [NALMS](#), [APMS](#), [AFS](#), [AWWA](#)) will often summarize substantial peer-reviewed technical papers in a coherent and practical matter. While reviewing a lake management option as proposed by an applicant, conservation commissions should be particularly careful to avoid overreliance on internet or social media articles as the primary source of information. Such information may be outdated or taken out of context, aimed at primarily selling a particular management technique or misleading readers about impacts.

The WPA does not recognize recreation or economic interests as public interests, and conservation commissions must evaluate projects based on their impact on the identified WPA interests and meeting the wetlands resource area performance standards. Non-WPA benefits cannot be used to justify known negative impacts to resource areas outside of what the WPA allows. At the same

time, commissions need to recognize that in some circumstances taking no action is not the same thing as doing no harm. Most of the lake acreage and volume in MA was created by human action, mostly dam construction, so while lakes are subject to natural processes, many were not “naturally” created and may be predisposed to a variety of problems. Given the pervasive influences of watershed development, stormwater runoff, atmospheric deposition, and an increasing array of invasive species, taking no action may allow the resource to degrade and cause them to not meet their designated uses under MA statutes.

Resources for Conservation Commissions

There are many resources available to conservation commissions to help them review lake management projects, including a variety of state and national sources that can aid them in understanding lake projects, their regulatory responsibilities, and how to provide effective oversight of the permit process. This updated 2025 Guide is intended to be the primary state guidance document for lake management. Other MA information sources include [Eutrophication and Aquatic Plant Management in MA: Final Generic Environmental Impact Report](#) and [Guidance for Aquatic Plant Management in Lakes and Ponds as It Relates to the Wetlands Protection Act](#), but this 2025 Guide is intended to supply updates as anticipated in the acceptance letter for the Final GEIR and should be used as the primary reference relating to lake management in MA.

Other relevant state publications include [The Massachusetts Lake and Pond Guide, A Guide to Selected Invasive Non-native Aquatic Species in Massachusetts](#), and the [MassWildlife series of bathymetric maps](#) with pond descriptions. There are numerous lake management guidance documents from professional technical or lake stakeholder organizations and other sources that can be found via online search, such as [Diet for a Small Lake](#) from the New York State Federation of Lake Associations. There is also information regarding watershed management which may be relevant to lake project submissions; see especially publications from the [Center for Watershed Protection](#) and the USEPA’s [Watershed Academy](#) and [database for stormwater management](#).

MassDEP’s [Wetlands Circuit Riders](#) can also provide help to conservation commissions. Although they cannot provide project-specific guidance, they can provide useful technical and regulatory assistance when conservation commissions have questions related to how the WPA regulations are interpreted and how they may apply to lake projects. In addition, the [MA Association of Conservation Commissions](#) (MACC) proactively promotes training of commissioners on the fundamentals of the WPA and wetland science and offers workshops, conferences, and other resources to conservation commissions. However, training sessions on lake-based projects are currently not common.

In summary, there is no “one size fits all” solution to any lake problem and consideration of the specific lake and related circumstances is needed. As local regulatory agents and the stewards of their community’s wetland resources, informed conservation commissions are in an ideal position to make decisions in this regard. The key to successful lake management lies in properly

implementing the appropriate actions, at a rate or scale that maximizes success and minimizes adverse impacts, with a monitoring program that allows for adaptive management. Conservation commissions have the noteworthy responsibility and ability to use a combination of scientific rationale, regulatory understanding, and common sense to help MA lakes retain their important qualities as natural resources and societal amenities.

The Role of the Project Applicant

The project applicant is the party that initiates the lake management project and applies for applicable permits for the proposed actions. Project applicants may include individuals, lake or beach associations, landowner compacts, legal firms, institutions, town governments, or state agencies. Project applicants are responsible for filing permit applications, paying applicable fees, notifying abutters and/or stakeholders of the proposed action, providing other required notifications, and providing the project information that justifies its approval. The project applicant has the option to hire a qualified lake management professional or firm to aid in the wetlands permit application, called a Notice of Intent (NOI), that is submitted to the local conservation commission. Professionals (Project Representatives) may also assist in filing for other state or federal permits as applicable to the project. If the project applicant is not familiar with lake management techniques and/or the regulatory approval process, hiring help may be advantageous.

Project Applicant Responsibilities

There are several things a project applicant should know before moving a proposed project into the regulatory realm. As the primary advocate for the proposed action, the project applicant should be prepared to provide current relevant data to support an assertion of impairment or impact that requires mitigation, justify the proposed action in terms of the potential effectiveness and compatibility with the range of lake uses, understand and comply with applicable laws and regulations, and link the proposed activity to existing lake management goals. Note that lake uses may include designated uses (<https://www.mass.gov/files/documents/2016/08/vi/72wqa07a.pdf>) under the MA Surface Water Quality Standards, which include uses such as public water supply, primary and secondary contact recreation, and propagation of fish and wildlife, even if those uses are not currently exercised.

An appropriate starting point is confirmation that the project applicant has or can obtain the legal right to conduct the project in all areas of work and within the relevant lake or pond. There are differences in the right to file for actions within Great Ponds, non-Great Ponds, and privately owned water bodies. The project applicant must determine ownership of the lake and shoreline and consider the legal interests of potential stakeholders (e.g., publicly or privately held land along shore or under the water, public beaches or accesses, status as a Great Pond under MA law, and any multiple town involvement). The project applicant must also have or obtain permission for the use of all proposed points of access, laydown or dewatering areas, and adjacent support areas. The project applicant should establish which entity owns or controls any impoundment structure (i.e., dam) that controls the lake water level elevation.

The project applicant will need to identify any Priority Habitats under the MESA in all areas of proposed work, most easily accomplished by reviewing the [MESA interactive web viewer](#). Project applicants will also need to identify any local conservation areas and whether the lake is designated as an ORW ([314 CMR 4.00](#)) or lies within an ACEC ([301 CMR 12.00](#)). The project applicant should determine if any areas of work are subject to existing easements, deed restrictions, or conservation restrictions, as these may affect the ability to conduct the proposed work.

The project applicant needs to provide an up-to-date description of the current lake conditions and what technique(s) is proposed to correct any undesirable condition or protect desirable features consistent with all applicable regulations, including the WPA. If multiple approaches are proposed, indicate whether there is a sequence or priority of actions and consider including a multi-year plan of implementation. Selection of lake management methods should include an alternatives analysis to determine if other methods that accomplish a similar level of protection and/or rehabilitation should be considered and why the selected method is a better fit for the lake or problem. A well-written alternatives analysis should state the criteria used to select alternatives, consider direct and indirect impacts, effectiveness, non-target impacts, and include measures that could be applied to make the alternative acceptable. In this regard, project applicants are urged to consult and use the information provided in this 2025 Guide, applying the appropriate professional usage and performance standards it contains.

Accurate delineation of the spatial extent (area) of the proposed activity is required and is very important to both project planning and regulatory actions. Is the activity spatially limited (e.g., harvesting or herbicide spot-treatment) or lake-wide (e.g., whole lake herbicide treatment, drawdown)? Similarly, the temporal limits of the activity – frequency and seasonality – need to be described. Selection of proposed techniques should be appropriate to the defined management goal, which should be explicitly stated (e.g., reduce nutrient loading by 20%, lay down 1500 sq. ft. of bottom barrier, harvest aquatic weeds from 30% of lake bottom area). Finally, the project applicant should propose a monitoring plan that will be used to guide implementation for best results and judge whether target goals were successfully met after implementation (see section on Lake Management Planning). The project applicant assumes much responsibility when proposing a project.

Resources for Project Applicants

The written and online resources for project applicants are the same as for conservation commissions as described previously. Professional assistance carries a cost but comes with many resources for project planning, permitting, and implementation. Natural resource agencies, especially those with regulatory power, may be able to offer guidance in the project planning stage but the burden falls to the project applicant to provide the information and data necessary to meet the regulatory requirements. Initial contacts with the local conservation commission, MassDEP, and MassWildlife may be helpful in formulating the management program, but these groups do

not typically get involved in specific project planning and may have a regulatory or jurisdictional obligation that can conflict with the project applicant's goals.

The project applicant should ensure that all interests are being considered and balanced before submitting a filing, and stakeholder groups related to a target lake should be viewed as resources and collaborators in the planning stage. Lakes often have "friends of" groups, there may be camps or events that have to be considered, and recreational anglers and boaters have an interest. Not all groups will have the same goals for the lake, but the best plans tend to arise out of consideration of all interests. Additionally, MassDCR has a role in designating invasive or nuisance species and managing state-owned lakes and related facilities and may have guidance to offer during the planning process. While MassDCR is focused on public lakes, it is not a regulatory agency and has fewer conflicts when offering advice on how to address lake and watershed problems.

Regulatory jurisdiction in lake management may include multiple agencies and regulatory programs (see previous descriptions of key programs and Figures 13 and 14). Understanding the agencies, their jurisdictions, and advisory roles early in the project planning stage and communicating with all interested parties will minimize later conflicts. This 2025 Guide is intended to establish a framework for lake management in MA, but there are enough details at the local level to make each project unique. Project applicants need to be cognizant of local issues within the context of the regulatory framework for best success.

28114. OVERVIEW OF MANAGEMENT TECHNIQUES

2812 This chapter presents an overview of available techniques, dividing them into those that are
2813 considered “standard” in MA and those that are categorized as “alternative” techniques. Standard
2814 techniques are widely applicable to problems with algae and aquatic plants, have reasonable
2815 implementation potential, and have a known level of reliability. Applicability of standard
2816 techniques is not universal, however, and reliability, while known, is not necessarily high. Perhaps
2817 the most important feature of a standard technique is its implementation potential, especially as
2818 regards gaining approval through the regulatory process. Standard techniques have been used in
2819 MA and the permitting process, while not always simple, is established.

2820 Alternative techniques may be applicable to MA lake problems, but their reliability may be less
2821 well documented, creating uncertainty in the planning process. Perhaps more critically, alternative
2822 techniques often lack a clear permitting pathway for use in MA. Some, such as the introduction of
2823 grass carp or any non-native vertebrate species, are specifically prohibited. Others, such as
2824 bacterial products, some phosphorus (P) inactivation compounds, and new herbicidal active
2825 ingredients, have not undergone the necessary process of regulatory acceptance for use in MA. For
2826 any pesticide, which includes algaecides and herbicides, there is a product registration process
2827 administered by the Department of Agricultural Resources. In addition, a special joint review by
2828 MassDEP and MDAR is conducted to approve algaecides and herbicides for use in lakes and ponds
2829 in MA. It can take considerable time for new products to be reviewed and accepted or rejected.
2830 For non-pesticidal lake management products and techniques, the 2004 Generic Environmental
2831 Impact Report for Eutrophication and Aquatic Plant Management (GEIR) called for a review
2832 process to be developed under the MEPA, but no such process has been applied over the last two
2833 decades.

2834 Techniques included in the 2004 GEIR were considered accepted upon approval of that document
2835 under the MEPA, but those developed since have not been officially added to the approved list.
2836 Such techniques could be approved on a project by project basis through the MEPA, but it is
2837 desirable to provide an overall review and to develop guidance for use in MA that is lacking for
2838 most alternative techniques. This guide provides relevant information for many alternative
2839 techniques, but inclusion here does not signify acceptance under the MEPA. A few of the
2840 alternative techniques were reviewed in the GEIR and accepted under the MEPA, including
2841 dilution, flushing, selective withdrawal, and dyes, and guidance for accepted use was offered.
2842 However, these techniques have limited implementation potential in MA under current regulations
2843 and are rarely used.

2844

Lake Problems and Management Techniques Covered

Lake management techniques covered in this guide focus on preventing, managing, or reversing eutrophication, which is the process by which lakes age through nutrient and sediment inputs and become more fertile. Controlling eutrophication usually translates into watershed controls on nutrients and managing aquatic plants, which include algae and vascular plants. Techniques for controlling eutrophication in general and aquatic plants more specifically are the focus of this 2025 Guide and may be broadly classified as physical, chemical, or biological in nature. There is a wide range of techniques, some much more commonly applied than others.

Reliability is a key factor in the selection of any lake management technique. While all techniques have constraints relating to applicability and implementation, the focus in this 2025 Guide is on those techniques currently allowed under MA regulations that have a track record of success with an understanding of what makes that success possible. Technique reviews focus on those approaches for which the knowledge base and track record in MA is sufficient to consider the techniques to be reliable in the sense that one can reasonably expect a certain result from proper application and use of the technique is consistent with current laws and regulations.

This manual does include additional alternative techniques, applied in MA or elsewhere, that lack the proven track record to be considered reliable, have limited applicability to MA lakes, are difficult to properly apply, or are simply not legal under current laws and regulations. These are included because stakeholders interested in solutions to lake problems may find enticing case studies, advertisements, and other presentations online or in print touting these methods, and an objective source of information is needed. These techniques are addressed, just not to the extent of the better documented or more frequently applied standard techniques. It is acknowledged that the necessary knowledge to claim reliability may eventually be gained or the rules that currently prevent application in MA may change at some point in the future so that these methods may yet prove viable.

The use of some of the alternative techniques may be allowable in MA now with proper justification. Permitting is likely to be more involved and incorporate more monitoring to ensure that the technique is properly used, does not result in adverse impacts to non-target resources, and provides demonstrable results. Examples include bacterial products intended to compete with algae or consume organic sediment, sonication to kill susceptible algae, and dyes that restrict light and therefore the depth at which plants can grow. Many of these techniques have demonstrated success under specific circumstances but do not have as much applicability, implementation potential, and/or reliability as the “standard” techniques over the range of lake conditions encountered in MA.

All of the techniques reviewed in this guide are intended to mitigate the effects of eutrophication. As lakes age, they naturally become shallower and more fertile. Human activities can greatly accelerate that process. In MA many lakes were created or shaped by human action, usually construction of a dam in a stream corridor but sometimes by excavation or quarrying with

subsequent filling by ground water or surface water diversion. Shallow waterbodies are highly susceptible to excessive plant growth. Deeper lakes provide depth-related light limitation on rooted plant growth in the central areas but may have a peripheral fringe of plants that provides valuable ecosystem services but can also impair uses. Accumulation of sediment and loss of oxygen near the bottom foster excessive algae independent of depth, although deeper lakes are more susceptible to oxygen depletion at the bottom with associated internal P loading that increases the probability of cyanobacterial blooms.

No distinction between natural waterbodies and those formed by human action is made within the WPA and its associated regulations, but there are provisions to counter the effects of eutrophication, which include elevated nutrient concentrations, algae blooms, and excessive aquatic plant growth, especially where caused by human actions. Application of the techniques covered here may allow impacted waterbodies to meet their designated uses.

Public safety is not a primary concern under the WPA either, and the application of lake management techniques as addressed in this guide does not get into the details of possible public safety issues beyond the benefits of controlling algae (e.g., reducing toxins) and aquatic plants (e.g., avoiding entanglement in swim areas). Some techniques could have implications for public safety, such as the use of any chemical product in a drinking water supply or the influence of drawdown or artificial circulation on ice conditions. Public safety issues are usually given priority over environmental factors and need to be considered during project planning.

Overview of Options

Management options can be divided into two functional categories: control of nutrients and control of aquatic plants. Aquatic plants can be construed to include algae, although most of the time reference to aquatic plants means higher plants, those with vascular tissue and roots. Control of nutrients is usually intended to reduce algae growth, but there can be overlap with the control of vascular plants. Control of water column concentrations may prevent growth of vascular plants not rooted in sediment, primarily duckweed, watermeal, coontail, or bladderwort in MA. Aquatic vegetation with roots that extend into the sediment are much less dependent on water column nutrients and will not be reduced by improved water clarity. Increased water clarity may cause an expansion of aquatic plant coverage into deeper water and greater density of growths in shallower areas. Nutrient controls may occur in the watershed, preventing entry to the lake, or in the lake, making nutrients less available. Many nutrient controls in the watershed also limit erosion and sediment input to lakes, which can affect rooted vascular plants as well as algae.

If watershed controls are inadequate, in-lake controls may provide relief. Where internal recycling becomes the dominant source of P, in-lake controls may be necessary to prevent algae blooms. Likewise, where sediment inputs support dense growths of rooted plants, watershed management cannot reverse that situation. Control of algae and aquatic plants in the lake may involve growth inhibition, such as altering substrate features, light levels, or nutrient availability to be less hospitable to growth, or direct removal, as with harvesting or herbicide application. Direct removal

is often performed on a maintenance basis, but in some cases the plant community can be altered in more permanent ways.

An overview of techniques applicable to control of algae will be offered first and then techniques applicable to the control of vascular plants, simply called aquatic plants here, will be covered. The overall listing of applicable techniques is meant to be all inclusive; inclusion of techniques is not based on approval for use in MA or how reliable the technique is, as these aspects can change over time. We will then divide techniques into functional groupings for further assessment. The standard techniques are allowable in MA, a clear path for permitting, and a reasonably reliable track record that sets expectations. Alternative techniques may apply to MA lake problems but are either currently prohibited from use in MA or require additional approval to be used. Alternative techniques often lack enough application to have established an adequate reliability record.

Control of Algae

It is preferable to control algal populations by limiting the nutrient supply, as this prevents blooms from forming. P is the preferred nutrient for control, as it is more amenable to control than N and is more effective with regard to cyanobacteria, many species of which can utilize dissolved N gas. Even in cases where a lake is currently limited by N or some non-nutrient factor such as light, P control is usually the preferred method to limit algae growth, as P can be made to limit algae more effectively and economically. Consequently, the nutrient control options described here deal primarily with P control, although many apply to N and other nutrients as well.

Yet it is important to acknowledge the importance of N and many other nutrients in lake ecology. There are synergies among nutrients, most notably between N and P, that tend to increase the probability of algae blooms when both are increased (Bracken et al. 2015, Paerl et al. 2016). Most watershed management efforts do not focus just on P, addressing overall contaminant sources such as erosion, lawn fertilizers, or wastewater discharges, and that is appropriate. Failing to control P will usually lead to problems in lakes but controlling only P is not a guarantee of success in lake management.

The needed or expected reduction in P loading can be modeled to predict the change in trophic status and likelihood of nuisance algal blooms. Yet algal abundance in response to nutrient loading is a probability distribution, not a threshold function. Algae blooms may be expected at some reduced frequency even at fairly low P levels, and lakes will not respond identically to changes in loading. The magnitude and timing of spring runoff events in the watershed change from year to year, often with dramatic effects on algal bloom production. Managers should be prepared to adjust strategies in response to resultant lake conditions. Algal control through nutrient limitation is often an iterative process and use of the models described in the LMP development section will be helpful when determining a target P concentration.

Since the original GEIR and Practical Guide were published in 2004, the importance of internal P loading in the generation of algae blooms, especially cyanobacteria, has become widely recognized

(Steinman and Spears 2020). Recycling of nutrients from sediment exposed to low oxygen can result in large amounts of P released at a relatively low N to P ratio, favoring growth of cyanobacteria. Further, some of the well-known bloom-forming cyanobacteria start their growth cycle on sediment where there is just enough light and adequate available P in the sediment, so the P doesn't have to move far into the water column before uptake. These cyanobacteria species eventually form gas pockets in cells and become buoyant, rising to form surface blooms, explaining their often sudden appearance. While the P in that sediment very likely came from the watershed, reducing watershed inputs will not prevent this recycling process and sediment reserves may be large enough to last decades. Consequently, reducing availability of P in lake sediment may be essential before algae can be controlled.

Direct control of algae can be accomplished by several means, killing them with algaecides, flushing them out of the system, disrupting cells with sound waves, or sometimes disrupting growth by vertical mixing of the water column. However, where the goal is to prevent blooms, the control action must either occur frequently or adequate monitoring must be conducted to know when to act. Waiting until a bloom occurs to take action can have far more adverse impacts than preventing the bloom. It may still be beneficial to take direct control actions after a bloom has formed, but there may be regulatory restrictions on those control actions (e.g., no algaecide application at potentially toxic cyanobacteria concentrations >70,000 cells/mL or label limit of no more than half the waterbody treated). Prevention is therefore much preferred over direct reduction in algae abundance.

Understanding Options for Control of Algae in Lakes

All techniques have associated benefits and drawbacks, and those contemplating algae management should familiarize themselves with the following general rules for algae and key aspects of each management option (Table 3).

1. Where light and nutrients are sufficient and toxic influences are minimal, algae will grow
 - P >0.01 mg/L and nitrogen >0.3 mg/L can support blooms
 - P >0.025 mg/L and nitrogen >0.6 mg/L will usually support blooms
 - Very little light is necessary for some species of algae to bloom; accessory pigments allow many algae to grow in very dim light
 - Some algae grow at the sediment-water interface then float upward to form blooms; high nutrients in the water column are not necessary for bloom formation, only bloom maintenance
 - Metals and some organic compounds are the primary toxicants for algae; these may be in urban or agricultural runoff as well as approved algaecides
 - Algae (even cyanobacteria) are part of a healthy aquatic ecosystem; eliminating algae should not be a goal, but rather restoring balance by aiding ecological processes

- 2994 2. One factor may control the abundance of any given alga, but that factor can vary over time and
2995 among algae
2996 ➤ Natural succession of algae over the growing season is normal and is triggered by changing
2997 control factors
2998 ➤ Some cyanobacteria can turn nitrogen gas into amino acids and do not require nitrate or
2999 ammonium in the water like other algae, but require elements not needed by other algae
3000 ➤ Temperature is very influential, with cyanobacteria favored by warmer water
3001 ➤ Control of the whole algal community by one factor is not common but can occur (e.g., very
3002 low P or treatment with copper at high doses)
- 3003 3. Nutrient forms and ratios are major determinants of the type of algae present
3004 ➤ The ratio of N to P is most influential, but other nutrients like Si or Fe can be influential
3005 ➤ Cyanobacteria thrive at low N:P ratios (<10:1 by mass), while most green algae prefer high
3006 N:P ratios (>25:1 by mass)
3007 ➤ Diatoms require high silica
3008 ➤ Carbon sources can be important at very high N and P concentrations and are linked to pH
3009 ➤ Light and temperature can also be important determinants of algal assemblage composition
- 3010 4. Diversity of algal adaptations may defeat controls other than maintaining low P
3011 ➤ N fixation by cyanobacteria minimizes N limitation
3012 ➤ Buoyancy regulation allows vertical movement
3013 ➤ Auxiliary photopigments assist in low or high light habitats
3014 ➤ Heterotrophy (i.e., ingestion of organic material) can sustain some algae
3015 ➤ Anti-grazing mechanisms, especially large particle size (filaments or colonies), can minimize
3016 consumption of algae by zooplankton
3017 ➤ Resistance by some algae limits control with algaecides
- 3018 5. Productivity and biomass are related but separate concepts
3019 ➤ Productivity is a growth process
3020 ➤ Biomass is the net result of growth and loss processes
3021 ➤ High productivity leads to high biomass if loss processes are not adequate to maintain balance
3022 ➤ Control methods seek to either decrease growth or increase loss; high productivity may be
3023 desirable but high biomass is not.
- 3024 6. The most effective algae control is achieved through reduction of external and internal P loading
3025 ➤ P can be made to limit productivity most reliably
3026 ➤ It is essential to determine the relative magnitude of sources of P
3027 ➤ P control may require multiple techniques and an extended timeframe
3028 ➤ Other nutrients cannot be ignored by management, but blooms are unlikely to be eliminated
3029 without control of P
3030 ➤ It is reasonable to apply interim measures for algae control until P limitation is achieved
3031

- 3032 7. High grazing pressure yields the lowest algae biomass per unit of fertility
3033 ➤ Large-bodied, herbivorous, zooplankton (especially *Daphnia*) at high biomass (>100 ug/L) can
3034 limit the biomass of edible algae
3035 ➤ Algal adaptation can often overcome grazing pressure if nutrients are sufficient; large particle
3036 sizes (e.g., filaments, gelatinous aggregations) make algae less edible and are common with
3037 cyanobacteria
3038 ➤ Having a zooplankton community dominated by large-bodied grazers will yield the lowest
3039 algal biomass possible at the existing level of lake fertility, but will not override the influence
3040 of excessive nutrients
- 3041 8. Algaecides should only be used until growth processes can be controlled
3042 ➤ Algaecides can provide short-term control and can prevent blooms if applied at the proper time
3043 ➤ Algaecides rarely provide long-term control and can have adverse side effects
3044 ➤ Label restrictions on use of algaecides may limit lake-wide effectiveness
3045 ➤ Algaecides may provide inexpensive control but do not address the root cause (excess
3046 nutrients)
- 3047

3048
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3050

Table 3. Management Options for Control of Algae

(Adapted from Wagner 2001 with additional experience over the last 20 years).

Option	Mode of Action	Advantages	Disadvantages
Watershed controls			
1) Management for nutrient input reduction	- Includes wide range of watershed and lake edge activities intended to eliminate nutrient sources or reduce delivery to lake - Essential component of algae control strategy where internal recycling is not the dominant nutrient source, desirable even where internal recycling is important	- Acts against the original source of algal nutrition - Creates sustainable limitation on algae growth - Controls delivery of other unwanted pollutants to lake - Facilitates ecosystem management approach which considers more than just algae control	- May involve considerable lag time before improvement observed - May not be sufficient to achieve goals without some form of in-lake management - Reduction of overall system fertility may impact fisheries - May cause shift in nutrient ratios which favor less desirable algae
1a) Point source controls	- More stringent discharge requirements - May involve diversion - May involve technological improvements or operational adjustments - May involve pollution prevention plans	- Often provides major input reduction - Efficient approach in most cases - Success easily monitored as change in discharge quality	- May be very expensive in terms of capital and operational costs - May transfer problems to another watershed - Variability in results may be high in some cases
1b) Non-point source controls	- Reduction of sources of nutrients - May involve reduction or elimination of land uses or activities that release nutrients - May involve alternative product use, as with no phosphate fertilizer	- Removes source - Limited or no ongoing costs - Can be implemented and monitored at the local level	- May require purchase of land or activity - May be viewed as limitation of property owner rights - Usually requires education and gradual implementation - May require municipal bylaw or state law

3051

Option	Mode of Action	Advantages	Disadvantages
1c) Non-point source pollutant trapping	◆ Capture of pollutants between source and lake ◆ May involve drainage system alteration ◆ Involves wide range of possible treatments (detention, infiltration, filtration, active treatment) ◆ May involve stormwater collection and treatment as with point sources	◆ Sub-surface systems minimize interference with land uses and activities ◆ Allows diffuse and phased implementation throughout watershed ◆ Highly flexible approach ◆ Tends to address wide range of pollutants	◆ Does not address actual sources ◆ May be expensive on necessary scale ◆ May require substantial maintenance ◆ Usually a slow process on watershed scale ◆ Limits to level of trapping usually <50%
1d) Onsite wastewater disposal	◆ Range of conventional to advanced systems ◆ Enhancements to increase contaminant removal	◆ Avoids large point source discharge ◆ Distributes costs among homeowners ◆ Can reduce inputs to groundwater and eventually to lake	◆ Allows many diffuse discharges ◆ Site limitations may reduce effectiveness ◆ Does not address legacy inputs and ongoing transport
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 cyanobacteria ◆ May reduce internal loading of phosphorus ◆ Counteraction of anoxia improves habitat for fish/invertebrates	◆ May spread localized impacts ◆ Makes whatever nutrients remain present more available ◆ 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 algae build-up ◆ May have continuous or periodic additions	◆ Dilution reduces nutrient concentrations without lowering load ◆ Flushing minimizes detention; response to pollutants may be reduced	◆ Diverts water from other uses ◆ Flushing may wash desirable zooplankton from lake ◆ Use of poorer quality water increases loads ◆ Possible downstream impacts

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
4) Drawdown	◆ Water level lowered by outlet controls, siphon, or pumping ◆ Lowering of water allows oxidation, desiccation and compaction of sediments ◆ Duration of exposure and degree of dewatering of exposed areas are important ◆ Exposure tends to result in coarser, less nutrient-rich sediment in exposed zone ◆ Drawdown supports selective withdrawal ◆ Algae are affected mainly by reduction in available nutrients	◆ May reduce available nutrients or nutrient ratios, affecting algae biomass and composition ◆ Alters exposed sediment in ways that tend to support less algae growth ◆ Provides opportunity for shoreline clean-up/structure repair ◆ Flood control utility ◆ May provide rooted plant control as well	◆ Possible impacts on non-target resources ◆ May result in greater nutrient availability if flushing inadequate ◆ Possible impairment of water supply ◆ Alteration of downstream flows ◆ Alteration of water level and accessibility ◆ Refill dependent on weather; may be slow
5) Dredging	◆ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering/disposal ◆ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ◆ Nutrient reserves are removed, and algae growth can be limited by nutrient availability	◆ Can reduce algae if internal recycling is main nutrient source ◆ Removes algae resting stages ◆ Increases water depth ◆ Can reduce pollutant reserves ◆ Can reduce sediment oxygen demand ◆ Can improve spawning habitat for many fish species ◆ Allows major 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 ◆ Very expensive
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	◆ Facilitates more complete removal ◆ May allow drying of sediments prior to removal ◆ Allows use of less specialized equipment ◆ Greater ability to remove target sediment reliably	◆ Rarely a truly dry operation; tends to be messy ◆ Eliminates most aquatic biota unless a portion left undrained ◆ Eliminates lake use during dredging

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
5b) "Wet" excavation	◆ Lake level may be lowered, but sediments not substantially dewatered ◆ 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 turbidity concerns ◆ Normally requires intermediate containment area to dry sediments prior to disposal ◆ May disrupt ecological function ◆ Disrupts many uses
5c) Hydraulic removal	◆ Lake level not reduced ◆ Suction or cutterhead dredges create low solids slurry which is hydraulically pumped to containment area ◆ Slurry is dewatered; sediment is retained, water is discharged	◆ Creates minimal turbidity and limited 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 material ◆ Requires sophisticated and more expensive containment area ◆ Water discharge needed
6) Light-limiting dyes and surface covers	◆ Creates light limitation	◆ Creates light limitation on algae growth without high turbidity or great depth ◆ May achieve some control of rooted plants as well	◆ May cause thermal stratification in shallow ponds ◆ May facilitate anoxia at sediment interface with water ◆ Possible downstream impacts
6.a) Dyes	◆ Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting algae growth ◆ Dyes remain in solution until washed out of system.	◆ May produce appealing color ◆ Creates illusion of greater depth	◆ May not control surface bloom-forming species ◆ May not control growth of shallow water algal mats ◆ Alters thermal regime
6.b) Surface covers	◆ Opaque sheet material applied to water surface	◆ Minimizes atmospheric and wildlife pollutant inputs	◆ Minimizes atmospheric gas exchange ◆ Limits recreational use

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
7) Mechanical removal	♦ Filtering of water or settling of algae in dedicated device or facility ♦ Collection of floating scums or mats with booms, nets, or other devices ♦ Continuous or multiple applications per year usually needed	♦ Algae and associated nutrients can be removed from system ♦ Surface collection can be applied as needed ♦ May remove floating debris ♦ Collected algae dry to minimal volume	♦ Filtration requires high backwash and sludge handling capability for use with high algae densities ♦ Labor and/or capital intensive ♦ Variable collection efficiency ♦ Possible impacts on non-target aquatic life
8) Selective withdrawal	♦ Discharge of water which contains higher nutrient levels ♦ May be pumped or utilize passive head differential if not normal overflow ♦ Water may be pumped from target area or outflow increased in well mixed system	♦ Removes targeted water from lake efficiently ♦ Complements other techniques such as drawdown or aeration ♦ May prevent anoxia and phosphorus build up in bottom water ♦ May remove initial phase of algae blooms which start in deeper water ♦ May remove surface blooms ♦ May enhance downstream thermal regime	♦ Possible downstream impacts of poor water quality ♦ May eliminate colder thermal layer that supports certain fish ♦ May promote mixing of remaining poor quality bottom water with surface waters ♦ May cause unintended drawdown if inflows do not match withdrawal ♦ Lasting improvement typically requires many years of application
9) Sonication	♦ Sound waves generated by device in water disrupt algae cells ♦ Different frequencies can be applied ♦ Used on continuous basis when algae nuisances expected	♦ Affects susceptible algae, including most cyanobacteria ♦ Applicable in localized areas ♦ Decreases algae build-up ♦ Can keep substrates clean	♦ Effects on non-target organisms not completely understood ♦ May release cellular toxins or other undesirable contents into water column ♦ Rooted plant growths or other obstructions impede effectiveness

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
IN-LAKE CHEMICAL CONTROLS			
10) Hypolimnetic aeration or oxygenation	◆ Addition of air or oxygen at varying depth provides oxic conditions ◆ May maintain or break stratification ◆ Can release bubbles with absorption during rise in water column or inside a chamber ◆ Can withdraw water, oxygenate, then replace ◆ In-lake or shore-based mixing chambers possible	◆ Oxic conditions promote P binding and sedimentation ◆ Counteraction of anoxia improves habitat for fish/invertebrates ◆ Build-up of dissolved iron, manganese, sulfide, ammonia and phosphorus reduced	◆ May accidentally disrupt thermal layers important to fish community ◆ Theoretically promotes supersaturation with gases harmful to fish ◆ Biota may become dependent on continued oxygen supply
11) Algaecides	◆ Liquid or pelletized algaecides applied to target area ◆ Algae killed by direct toxicity or metabolic interference ◆ Typically requires application at least once per year or often more	◆ Rapid elimination of algae from water column ◆ May result in net loss of nutrients to lake bottom ◆ Can prevent blooms with timely application	◆ Possible toxicity to non-target species ◆ Possible restrictions on water use for short time after treatment ◆ Increased oxygen demand ◆ Possible recycling of nutrients
11a) Forms of copper	◆ Cellular toxicant, disruption of photosynthesis, nitrogen metabolism, and membrane transport ◆ Applied as wide variety of liquid or granular formulations, often in conjunction with chelators, polymers, surfactants or herbicides	◆ Effective and rapid control of many algae species ◆ Approved for use in most water supplies ◆ Can treat water column or sediment surface	◆ Possible toxicity to aquatic fauna ◆ Less effective at colder temperatures ◆ Accumulated copper may affect sediments ◆ Resistance by certain nuisance species ◆ Possible rupturing of cells can release nutrients and toxins
11b) Peroxides	◆ Attacks cell walls, disrupts cellular functions ◆ Causes structural deterioration ◆ Can be applied to water or sediment as pellets	◆ More effective on cyanobacteria than most other algae ◆ Minimal toxicity to aquatic animals at recommended doses ◆ Rapid action ◆ No problem residual compounds	◆ Will not impact all possible target algae ◆ More expensive than copper ◆ May require sequential treatments for best results

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
11c) Synthetic organic herbicides	◆ Absorbed or membrane-active chemicals which disrupt metabolism ◆ Causes structural deterioration	◆ More effective on algae mats than other algaecides ◆ 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 after treatment
12) Phosphorus inactivation	◆ Typically salts of aluminum, iron or calcium are added to the lake, as liquid or powder; lanthanum awaiting MA approval ◆ 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 ◆ Removes particulates from water as well as phosphorus ◆ Flexible application, can treat storm water, tributaries, water column, and/or sediment	◆ Possible toxicity to fish and invertebrates, mainly by aluminum at low or high pH ◆ Floc may smother some invertebrates in sediment under target area ◆ Possible release of phosphorus under anoxia (with Fe) or low pH (with Ca) ◆ May cause fluctuations in water chemistry, especially pH, during treatment ◆ Possible resuspension of floc in shallow areas
13) Sediment oxidation	◆ Addition of oxidants and possible supplements to oxidize sediment ◆ Binding of phosphorus is enhanced	◆ Can reduce P 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 cyanobacteria
14) Settling agents	◆ Direct reduction of algae through enhanced settling ◆ Lime, alum or polymers applied, usually as a liquid or slurry ◆ Creates a floc with algae and other suspended particles ◆ Floc settles to bottom	◆ Removes algae and increases clarity without lysing cells ◆ May reduce nutrient recycling ◆ Removes non-algal particles as well as algae ◆ May reduce dissolved phosphorus levels	◆ Possible impacts on aquatic fauna ◆ Possible fluctuations in water chemistry during treatment ◆ Resuspension of floc possible in shallow, well-mixed waters ◆ Increased sediment

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
15) Selective nutrient addition	- Ratio of nutrients changed by additions - 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 - Can shift algae to more edible forms	- May result in greater algae 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 increase grazing on algae - Typically alters fish community to promote growth of large herbivorous zooplankton or add algae-eating fish	- May increase water clarity by changes in algae biomass without reduction of nutrients - Can convert unwanted biomass into desirable form (fish) - Harnesses natural processes to produce desired conditions	- May involve introduction of non-native species (prohibited in MA) - Effects may not be controllable or lasting - May foster shifts in algal composition to even less desirable forms
16.a) Herbivorous fish (not permitted in MA)	Stocking of fish that eat algae	- Converts algae directly into potentially harvestable fish - Grazing pressure can be adjusted through stocking rate	- Typically requires introduction of non-native species - Difficult to control over long term - Smaller algal forms may benefit and bloom
16.b) Herbivorous zooplankton	- Reduction in planktivorous fish to promote grazing pressure by zooplankton - May involve stocking piscivores or removing planktivores - May also involve stocking zooplankton or establishing refugia	- Converts algae indirectly into harvestable fish - Rapid response to increasing algae - May be accomplished without introduction of non-native species - Generally compatible with most fishery management goals	- Highly variable response; temporal and spatial variability may be high - Requires careful monitoring and management action on 1-5 year basis - Larger or toxic algal forms may benefit and bloom

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
17) Bottom-feeding fish removal	◆ Removes fish that browse among bottom deposits, releasing nutrients to the water column by physical agitation and excretion	◆ Reduces turbidity and nutrient additions from this source ◆ May restructure fish community in more desirable manner	◆ Targeted fish species are difficult to eradicate or control ◆ Reduction in fish populations valued by some lake users (human/non-human)
18) Pathogens	◆ Addition of inoculum to initiate attack on algae cells ◆ May involve fungi, bacteria or viruses	◆ May create lakewide response with reduction of algae biomass ◆ May provide sustained control through cycles ◆ Can be highly specific to algal group or genera	◆ Largely experimental, no commercial products available ◆ May promote resistant nuisance forms ◆ May cause high oxygen demand or release of toxins ◆ Effects on non-target organisms uncertain
19) Competition and allelopathy	◆ Plants may tie up sufficient nutrients to limit algal growth ◆ Plants may create a light limitation on algal growth ◆ Chemical inhibition of algae may occur through substances released by plants	◆ Harnesses power of natural biological interactions ◆ May provide prolonged control	◆ Some algal forms appear resistant ◆ Vascular plant nuisances potentially created ◆ Decaying plants may cause depression of oxygen levels ◆ Depth or substrate limitation on plant survival
19a) Plantings for nutrient control	◆ Plant growths of sufficient density may limit algal access to nutrients ◆ Plants can exude allelopathic substances which inhibit algae growth ◆ Portable plant “pods”, floating islands, or other structures can be installed	◆ Productivity and associated habitat value can remain high without algae 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 algae blooms ◆ The switch from algae to vascular plant domination of a lake may cause unexpected or undesirable changes

Table 3 - continued

Option	Mode of Action	Advantages	Disadvantages
19b) Plantings for light control	Plant species with floating leaves can shade out many algae 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 barley 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 - Cyanobacteria are mostly more sensitive than other algae - May prevent bloom formation	- Success appears linked to uncertain and potentially uncontrollable water chemistry factors - Depression of oxygen levels may result - Not overly reliable for control of algae - Considered to be an unregistered algacide

3053

3054 There are many factors to consider when choosing an algae management approach and making

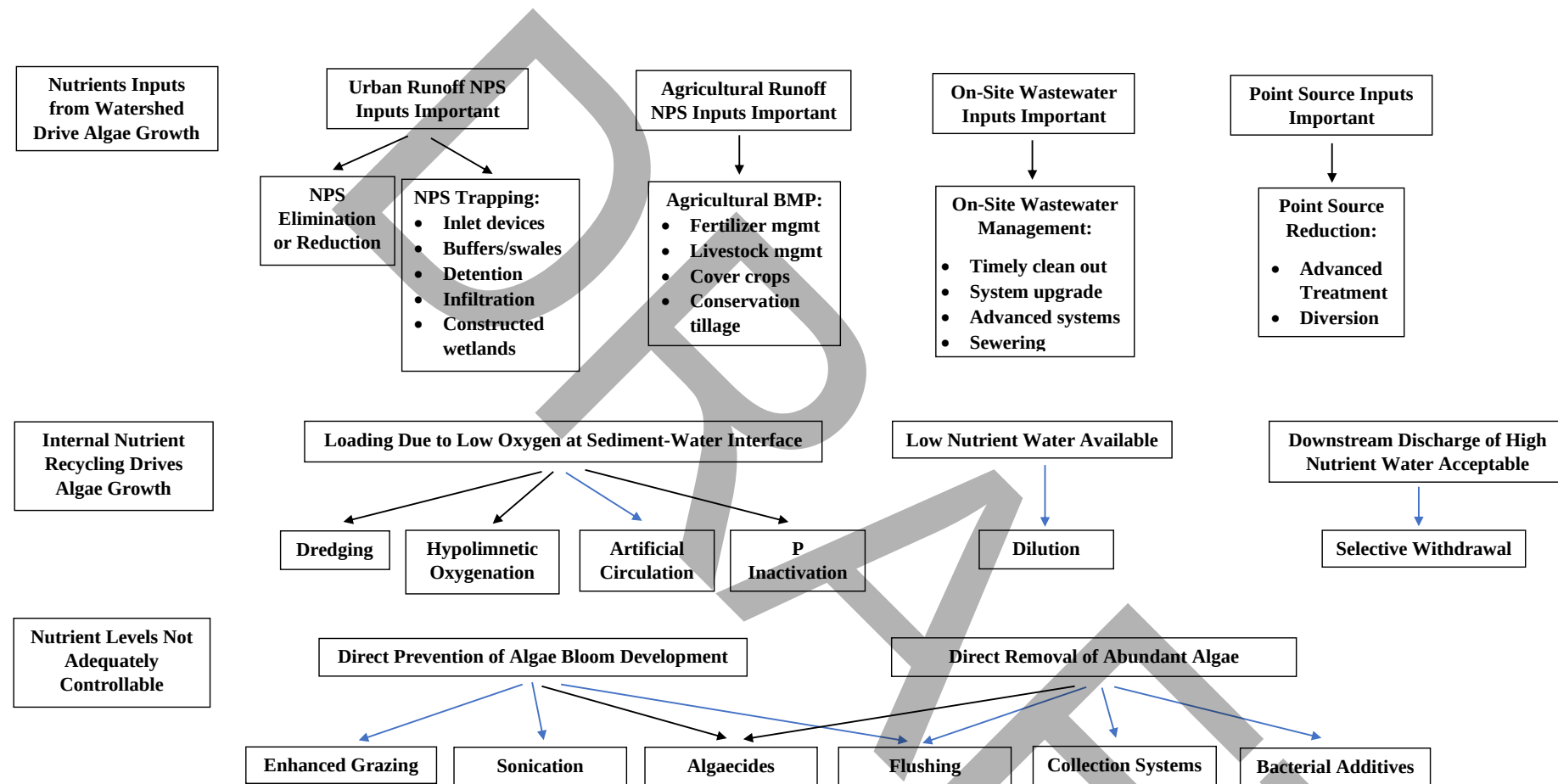
3055 definitive recommendations without consideration of site-specific features, including socio-

3056 political factors, is very speculative. Additionally, many algae control techniques are not mutually

3057 exclusive, so more than one approach could be applied. Yet in the interest of demonstrating how

3058 techniques might be chosen based on just a few general factors, a flow chart (Figure 15) is offered.

3059



Black arrows indicate higher reliability while blue arrows denote lesser reliability; however, no technique is guaranteed to work and many have inherent limits (e.g., watershed controls rarely provide >50% reduction).

Algae control techniques are mostly not mutually exclusive; it is common to address both watershed nutrient sources and internal loading and not unusual to add additional direct controls at least on an interim basis. Multiple techniques from the same grouping (e.g., urban runoff controls or reduction of internal loading) may also be applied to maximize control.

Choice of techniques within a grouping (e.g., direct bloom prevention techniques) to apply are largely driven by cost and ability to acquire permits but may also involve additional benefits derived from one technique over another (e.g., hypolimnetic oxygenation improves habitat more than P inactivation).

Figure 15. Choosing an algae control strategy

3062 **Control of Aquatic Vascular Plants**

3063 Aquatic vascular plants are an important ecological component of most lakes. Control of plants
3064 should not be a goal of lake management without an adequate understanding of the services
3065 provided by the plant community and consideration of the many aquatic and water-dependent
3066 organisms that depend on those plants for food and shelter. Lakes are not swimming pools, but
3067 they are subject to the process of eutrophication, whereby rooted plants can become dense enough
3068 to impair some uses. Additionally, lakes are subject to colonization by invasive plants that should
3069 be controlled to minimize ecological damage to the lake.

3070 The management of vegetation in shallow lakes merits special attention. Unlike deep lakes that
3071 have a fringing vascular plant growth (littoral) zone with a substantial open water area, shallow
3072 lakes can be almost entirely littoral zone, and aquatic plants may be the dominant component of
3073 lake ecology. The concept of alternative stable states (Scheffer et al. 1993) applies to these lakes
3074 and dictates that rooted plants or algae may dominate in a stable way, with disturbance potentially
3075 shifting the lake between those alternative states. When rooted plants dominate, they tend to reduce
3076 algae abundance by a combination of mechanisms and the water will be relatively clear, although
3077 the density of rooted plants may impair some lake uses.

3078 When rooted plants are lost, algae tend to become abundant, even without a major increase in
3079 nutrient inputs to the lake. The algae can keep the rooted plants from regaining dominance, mostly
3080 by light inhibition, and the ecology of the lake can be greatly changed, often causing use
3081 impairment. An extensive review of 40 years of research (Phillips et al. 2016) suggests that loss
3082 of rooted plants tends to be a progression involving decreased diversity, disturbances of natural or
3083 human origin, climatic influences, and excessive N loading. Increasing algae may be a
3084 consequence of the loss of vascular plants, but those algae can become a factor in continuing rooted
3085 plant suppression. Management efforts targeting rooted plants in shallow lakes must be especially
3086 cognizant of the balance between rooted plants and algae.

3087 Where vascular plants have no true roots extending into the sediment of the lake, the same controls
3088 used for algae will apply to those plants. Most vascular plants, however, have roots that anchor
3089 them to a substrate and provide the majority of nutrients for growth. Consequently, control requires
3090 addressing features of the sediment, limiting the amount of light available, or directly removing
3091 target rooted plants.

3092 Other than dredging, techniques that address surficial sediment nutrients are unlikely to provide
3093 rooted plant control, as roots typically extend deeper than the effect of treatment (e.g., oxygenation,
3094 P inactivation); rooted plant control by other means is needed. The depth of light that reaches the
3095 substrate can be limited by dyes or surface covers, but these create other issues in lakes and are
3096 not commonly used in MA. Changing the sediment composition by addition of coarser material
3097 can be effective but is contrary to regulations governing fill in wetland resources, which include

3098 lakes in MA. Covering the bottom with some sort of thin, synthetic barrier can be effective and is
3099 practiced on a small scale in many lakes.

3100 Direct removal of vegetation can be by physical means as simple as hand pulling or as complicated
3101 as mechanized harvesters that cut and collect plants for disposal outside the lake. Direct removal
3102 through herbicide application is also commonly practiced, with multiple active ingredients and
3103 several formulations of most available. Choice of herbicide and formulation is highly dependent
3104 on the target species and lake-specific conditions. Biological controls focus on adding animal
3105 species that consume plants; adding vertebrates such as plant-eating fish is prohibited in MA and
3106 while some invertebrate herbivore additions have been tried, most have not been deemed reliable
3107 enough to move to larger scale applications.

3108 Where aquatic vegetation management is focused on invasive species, defined as non-native
3109 species that have the potential to cause ecological and economic harm, prevention and rapid
3110 response are critical components of a plant management program. Prevention is challenging, as
3111 coverage at all boat access points all of the time is not feasible and the movement of birds among
3112 lakes is largely uncontrollable, but education of lake users can reduce the inadvertent transport of
3113 invasive species. Rapid response, whereby an infestation is detected at an early stage when
3114 eradication by available techniques is easiest and least expensive, is limited mainly by adequate
3115 monitoring to support early detection.

3116 ***Understanding Options for the Control of Aquatic Plants in Lakes***

3117 All techniques have associated benefits and drawbacks, and those contemplating aquatic vascular
3118 plant management should familiarize themselves with the following general rules for aquatic
3119 plants and key aspects of possible techniques for plant control (Table 4).

- 3120 1. In lighted areas with suitable sediments, plants will grow
- 3121 ➤ Light and substrate quality are the critical factors in plant growth
 - 3122 ➤ All lakes and ponds will normally have some amount of aquatic vegetation and it is important
3123 for lake ecology in many ways
 - 3124 ➤ Management for a diverse native plant community that does not minimize open water is an
3125 appropriate goal for a healthy lake ecosystem
 - 3126 ➤ Complete elimination of plants to facilitate water dependent uses is only practicable on a
3127 localized basis (e.g., in a swim area or at a boat launch)
 - 3128 ➤ Maintenance will always be required to keep even small areas relatively free of aquatic
3129 vegetation

- 3130 2. Understanding plant biology and ecology is essential to control
- 3131 ➤ The ecology of plant species varies and not all approaches work on all species
 - 3132 ➤ Light needs and nutrient uptake vary substantially among species and may affect control
 - 3133 ➤ Reproduction by seeds vs. vegetative propagation is important to duration of control
 - 3134 ➤ Monocotyledon vs. dicotyledon biology can affect results of herbicide use

- 3135 3. There is no “One Size Fits All” solution to plant problems
3136 ➤ Each situation is to some extent unique
3137 ➤ Adaptive strategies of plants require adaptive management for control and maintenance of a
3138 balance of native plants and open water
3139 ➤ Techniques can be applied in a wide range of levels and combinations
3140 ➤ Management plans and related permitting should incorporate multiple control options that
3141 support defined goals with thresholds for when each method would be applied
- 3142 4. It is unusual to successfully manage all plants in a lake with one technique
3143 ➤ Variation in lake and plant features usually calls for multiple techniques
3144 ➤ Initial control and follow-up maintenance often require different approaches
- 3145 5. Watershed management is unlikely to solve problems of excessive rooted plant density
3146 ➤ Very few rooted aquatic plants can be controlled by improved water quality
3147 ➤ Increased water clarity may extend the depth of plant growth and expand existing growths
3148 ➤ Watershed management complements in-lake management and should be part of a long-term
3149 lake management plan, but watershed management cannot address most rooted plant problems
- 3150 6. Prevention is far less expensive than rehabilitation but is not easy
3151 ➤ [Prevention of the importation or spread of nuisance species](#) is actively regulated in MA
3152 ➤ Prevention costs are mainly associated with monitoring, regulation, and small-scale action
3153 ➤ Vigilance is essential and requires coordination among participating stakeholders
3154 ➤ Rapid response to a new infestation is essential, has limited cost, and is best supported by [pre-](#)
3155 [existing rapid response plans](#)
3156 ➤ Delays in permitting can be detrimental to rapid response; it is important to work with all
3157 permitting authorities where an invasion is underway to expedite approval processes to take
3158 prompt action
3159 ➤ Rehabilitation costs typically involve expansive and repeated control efforts; it is very difficult
3160 to eliminate an established infestation
3161 ➤ If rehabilitation is achieved, additional prevention costs then apply to maintain the desired
3162 native plant community
- 3163 7. A regional focus is needed to protect the investment made in control
3164 ➤ Re-infestation from nearby lakes can reduce control effort longevity or allow introduction of
3165 new species
3166 ➤ Control of invasive plant species on a larger scale can be more efficient and economical
3167 ➤ Prevention measures are more effective on a regional scale

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3169
3170

Table 4. Management Options for Control of Aquatic Vascular Plants
(Adapted from Wagner 2001 with additional experience over the last 20 years).

Option	Mode of Action	Advantages	Disadvantages
PHYSICAL CONTROLS			
1) Benthic barriers	♦ Mat of variable composition laid on bottom of target area, suppressing growth ♦ Can cover area for as little as a month or permanently ♦ Maintenance improves results ♦ Usually applied around docks, in swim areas or boating lanes	♦ Highly flexible control ♦ Reduces turbidity from soft bottom sediments ♦ Can cover undesirable substrate ♦ Can improve fish habitat by creating edge effects	♦ May cause anoxia at sediment-water interface ♦ May limit benthic invertebrates ♦ Non-selective interference with plants in target area ♦ May inhibit spawning/feeding by some fish species ♦ Non-maintained barriers can fail
1a) Porous or loose-weave synthetic materials	♦ Laid on bottom and usually anchored by weights or stakes ♦ Removed and cleaned or flipped and repositioned at least once per year	♦ Allows some escape of gases which may be generated underneath ♦ Panels may be flipped in place or removed for relatively easy cleaning or repositioning	♦ Allows some plant growth through pores ♦ Gas may still build up underneath in some cases, lifting barrier from bottom
1b) Non-porous or sheet synthetic materials	♦ Laid on bottom and anchored by stakes, anchors or weights, or by layer of sand ♦ Removed or cleaned in place periodically	♦ Prevents all plant growth until sediment accumulates ♦ Minimizes interaction of sediment and water column	♦ Gas build-up may cause barrier to float if not vented ♦ Strong anchoring may make removal difficult
1c) Altering sediment composition	♦ Sediments added on top of existing sediments and plants ♦ Can limit plant growths and alter sediment-water interactions. ♦ Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique)	♦ Plant biomass can be buried ♦ Seed banks can be buried deeper ♦ Sediment can be made less hospitable to plant growths ♦ Nutrient release from sediments may be reduced ♦ Increased surface sediment appeal to human users	♦ Lake depth may decline ♦ Sediments may sink into or mix with underlying muck ♦ Permitting for added sediment difficult ♦ New sediment may contain nutrients or other contaminants ♦ Usually too expensive for large scale application

3171

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
2) Dredging	◆ Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering/disposal ◆ Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system ◆ Plants and seed beds are removed, and re-growth can be limited by light and/or substrate limitation	◆ Plant removal with some flexibility ◆ Increases water depth ◆ Can reduce pollutants including nutrients ◆ Can reduce sediment oxygen demand ◆ Can improve spawning habitat for many fish species ◆ Allows major renovation of aquatic ecosystem ◆ May allow for growth of desirable species.	◆ 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 ◆ Usually very expensive
2a) "Dry" excavation	◆ Lake drained or lowered to maximum extent practical ◆ Target material dried to maximum extent possible ◆ Conventional excavation equipment used to remove sediments	◆ Facilitates more complete removal ◆ May allow drying of sediments prior to removal ◆ Allows use of less specialized equipment ◆ Greater ability to remove target sediment reliably	◆ Eliminates most aquatic biota unless a portion of lake is left undrained ◆ Eliminates lake use during dredging
2b) "Wet" excavation	◆ Lake level may be lowered, but sediments not substantially dewatered ◆ 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 most aquatic biota	◆ Usually creates turbidity concerns ◆ May not remove all target sediment ◆ Containment area often needed to dry sediments prior to hauling ◆ May cause severe ecological disruption ◆ Impairs most lake uses during dredging

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
2c) Hydraulic (or pneumatic) removal	◆ No lake lowering ◆ Suction/cutterhead dredges create slurry which is hydraulically pumped to containment area ◆ Slurry dewatered, sediment retained, water discharged	◆ Creates minimal turbidity and limits 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 extremely coarse or debris-laden materials ◆ Requires advanced and more expensive containment area ◆ Water discharge needed
3) Dyes and surface covers	◆ Water-soluble dye is mixed with lake water, limiting light penetration and inhibiting plant growth ◆ Dyes remain in solution until washed out of system. ◆ Opaque sheet material applied to water surface	◆ Light limit on plant growth without high turbidity or great depth ◆ May achieve some control of algae as well ◆ May achieve some selectivity for species tolerant of low light	◆ May not control peripheral or shallow water rooted plants ◆ May cause thermal stratification in shallow ponds ◆ May facilitate anoxia at shallower depth ◆ Covers inhibit gas exchange with atmosphere and restrict recreation ◆ Dyes not used in water bodies with an active outlet
4) Mechanical removal (“harvesting”)	◆ Plants reduced by mechanical means, possibly with disturbance of soils ◆ Collected plants may be placed on shore for composting or hauled for disposal ◆ Wide range of techniques employed, from manual to highly mechanized	◆ Highly flexible control ◆ May remove other debris ◆ Can balance habitat and recreational needs	◆ Possible impacts on aquatic fauna ◆ Possible non-selective removal of plants ◆ Possible spread of undesirable species by fragmentation ◆ Possible generation of turbidity
4a) Hand pulling	◆ Plants uprooted by hand (“weeding”) and removed	◆ Highly selective technique ◆ No specialized equipment requirement	◆ Labor intensive ◆ Difficult to perform in dense stands ◆ Usually requires divers

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
4b) 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
4c) Harvesting (with collection)	- Plants cut up to depth of 10 ft and collected for removal from lake - May involve one machine or two, one for cutting and one for collection	- Allows plant removal on greater scale - Can create lanes and ecological edge habitat	- Limited depth of operation - Often leaves fragments which may re-root and spread infestation - May impact lake fauna - Limited selectivity within applied area
4d) 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 - May impact lake fauna - Not selective within applied area - Creates substantial turbidity
4e) Hydroraking	- Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, material collected by rake removed from lake - Usually performed near lake edge where mechanical harvesters cannot easily operate	- Can thoroughly disrupt entire plant - Also allows removal of stumps or other obstructions - Some sediment likely to be removed with plants and debris - Can grade bottom in swim areas or boat launches	- Usually leaves fragments which may re-root and spread - May impact lake fauna - Not selective within applied area - Creates substantial localized turbidity - May be treated as dredging under MA regulations

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
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 desiccation, 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
5a) Drawdown	◆ Lowering of water allows desiccation, freezing in winter, physical disruption of plants and habitat ◆ Timing and duration of exposure and degree of dewatering are critical aspects ◆ Variable species tolerance to drawdown; emergent species and seed-bearers less affected ◆ Most effective on annual basis	◆ Control with some flexibility ◆ Opportunity for shoreline clean-up/structure repair ◆ Flood control utility ◆ Protects shoreline from ice damage ◆ Impacts vegetative propagation species with limited impact to seed producing populations ◆ Develops coarser sediment in drawdown area	◆ Possible impairment of well production ◆ Reduction in water supply availability ◆ Alteration of downstream flows ◆ Possible impacts on emergent wetlands and water dependent wildlife ◆ Possible fish impacts ◆ Possible shoreline erosion and slumping ◆ May result in greater nutrient availability for algae
5b) 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 and dam control exists, 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	◆ Potential peripheral property flooding ◆ Possible downstream impacts ◆ Many species may not be affected, and some may benefit ◆ May increase nutrient and organic loading, increasing algae growth

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
CHEMICAL CONTROLS			
6) Herbicides	◆ Liquid or pelletized herbicides applied to target area or to plants directly ◆ Contact or systemic chemicals kill plants or limit growth ◆ Typically requires application every 1-5 years	◆ Wide range of control is possible ◆ May be able to selectively eliminate species ◆ May achieve temporary algae control ◆ May allow for more desirable plant growth	◆ Possible toxicity to non-target species ◆ Possible downstream impacts ◆ Restrictions of water use after treatment ◆ Increased oxygen demand from decaying vegetation ◆ Possible recycling of nutrients to allow other growths
6a) Forms of copper or peroxide	◆ Contact herbicides ◆ Cellular toxicants, membrane disruption ◆ Applied as wide variety of liquid or granular forms, usually for control of algae on plants to improve results of other herbicide applications	◆ Control of some submersed plant species but applied mostly as an aid to control by other herbicides ◆ 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 in system sediment
6b) 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 emerged 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

3172

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
6c) Forms of diquat (6,7-dihydropyrido [1,2-2',1'-c] pyrazinediium dibromide)	◆ Contact herbicide with limited translocation potential ◆ 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 emerged 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
6d) Forms of flumioxazin (N-(7-fluoro-3,4-dihydro-3-oxo-4-prop-2-ynyl-2H-1,4benzoxazin-6-yl)-cyclohex-1-ene-1,2-dicarboxamide)	◆ Contact herbicide with limited translocation potential ◆ Blocks biosynthesis in several metabolic pathways, toxic porphyrins build up ◆ Damages cell membranes, physical plant structure	◆ Moderately to highly effective control of a variety of submersed and floating leaved species ◆ More effective on algae mats than many herbicides ◆ Fairly fast action	◆ Potential toxicity to aquatic fauna, depending upon formulation and ambient water chemistry ◆ Limited selectivity ◆ Time delays for use of treated water for agriculture and turf management
6e) Forms of glyphosate (N-[phosphonomethyl glycine])	◆ Systemic 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 leaved plant species ◆ Can be used selectively, based on application to individual plants ◆ Rapid action ◆ Low toxicity to aquatic fauna at usual 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 ◆ Terrestrial formulations have caused public concern over human health impacts

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
6f) Forms of imazapyr (2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-nicotinic acid)	◆ Systemic herbicide ◆ Inhibits acetolactate synthase (ALS), an enzyme involved in the synthesis of essential amino acids ◆ Applied as liquid spray to emergent or floating leaved vegetation ◆ Causes slow death by structural deficiency	◆ Moderately to highly effective control of emergent and floating leaved plant species ◆ Can be used selectively, based on application to individual plants ◆ Low toxicity to animals, which do not have ALS	◆ Non-selective in treated area ◆ Not for use within 0.5 miles of potable surface water intakes ◆ Long time delay for agricultural use after treatment unless residue testing reveals values below set threshold
6g) Forms of imazamox ((±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid)	◆ Systemic herbicide ◆ Inhibits acetolactate synthase (ALS), an enzyme involved in the synthesis of essential amino acids ◆ Applied as liquid to emergent, floating leaved, or submerged plants, especially monocotyledons ◆ Causes slow death by structural deficiency	◆ Moderately effective control of aquatic vegetation ◆ Extends control to submergent plants unlike the similar imazapyr ◆ Limited exposure time needed ◆ Low toxicity to animals, which do not have ALS	◆ Low selectivity in treated area ◆ Not for use within 0.5 miles of potable surface water intakes ◆ Long time delay for agricultural use after treatment unless residue testing reveals values below set threshold
6h) Forms of 2,4-D (2,4-dichlorophenoxy acetic acid)	◆ Systemic herbicide ◆ 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 formulas, preferably during early growth phase of plants	◆ Moderately to highly effective control of a variety of emergent, floating, and submersed plant species ◆ Can achieve some selectivity through application timing and concentration ◆ Limited exposure time needed	◆ Potential toxicity to aquatic fauna, depending upon formulation and water chemistry ◆ Time delays for use of treated water for agriculture and recreation ◆ Not for use in potable water supplies; including lakes with nearby wells in sandy soils

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
6i) Forms of fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4[1H]-pyridinone)	◆ Systemic herbicide ◆ Inhibits carotenoid pigment synthesis and impacts photosynthesis ◆ Best applied as liquid or granules during early growth phase of plants	◆ Can be used selectively, based on concentration ◆ Gradual deterioration of affected plants limits impact on oxygen level ◆ Effective against several difficult-to-control species ◆ Low toxicity to aquatic fauna	◆ Impacts on non-target plant species possible at higher doses ◆ Extremely soluble and mixable; difficult to perform partial lake treatments ◆ Requires extended contact time
6j) Forms of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid)	◆ Systemic herbicide ◆ Disrupts enzyme systems specific to plants ◆ Applied as liquid spray or subsurface injected liquid	◆ Effectively controls many floating and submersed plant species ◆ Can be used selectively, more effective against dicotyledon plant species ◆ Effective against several difficult-to-control species ◆ Low toxicity to aquatic fauna ◆ Limited exposure time needed	◆ Impacts on non-target plant species possible at higher doses ◆ Restrictions on use of treated water for supply or recreation ◆ Not as effective on certain invasive species as other applicable herbicides
6k) Forms of florasulfuron (2-pyridinecarboxylic acid, 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxy-phenyl)-5-fluoro-, phenyl methyl ester)	◆ Systemic herbicide ◆ Synthetic auxin, alters cell wall elasticity and gene expression, disrupts tissue formation, causes slow death ◆ Liquid sprayed on emergent/floating plants or injected into water column	◆ Effectively controls several invasive species ◆ Can be used selectively, more effective against dicotyledon plant species ◆ Low toxicity to aquatic fauna ◆ Limited exposure time needed	◆ Limited target species, higher doses limited by solubility ◆ Time delays on use of treated water for irrigation ◆ Limited track record (new in MA as of 2019)

Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
BIOLOGICAL CONTROLS			
7) Biological introductions	◆ Fish, invertebrates or pathogens which feed on or parasitize plants are added to system to affect control ◆ The most commonly used organism outside MA is the grass carp, but the larvae of several insects have been used, and viruses have been tested	◆ Provides potentially continuing control with one treatment ◆ Harnesses biological interactions to produce desired conditions ◆ May produce potentially useful fish biomass as an end product	◆ Typically involves introduction of non-native species ◆ Effects may not be controllable ◆ Plant selectivity may not match desired target species ◆ May adversely affect indigenous species
7a) Herbivorous fish (not permitted in MA)	◆ Sterile juveniles stocked at density which allows control over multiple years ◆ Growth of individuals offsets losses, increases herbivorous pressure ◆ Grass carp are illegal in MA.	◆ May greatly reduce plant biomass in <2 years ◆ May provide multiple years of control from single stocking ◆ Sterility intended to prevent population perpetuation and allow later adjustments	◆ May eliminate all plant biomass ◆ Likely to impact non-target species ◆ Funnel energy and nutrients into algae ◆ Alters habitat ◆ May escape upstream or downstream ◆ Difficult to manage population
7b) Herbivorous invertebrates	◆ Larvae or adults stocked at density intended to foster control ◆ Usually intended to selectively control target species ◆ May yield broader plant control in some cases	◆ May involve species native to region, or even targeted lake ◆ Some species have no negative effect on non-target species ◆ May facilitate longer term control with limited management	◆ Some utilized species are non-native ◆ Population ecology suggests incomplete control likely ◆ Oscillating cycle of control and re-growth expected ◆ Predation by fish may complicate control ◆ Possible interference from other lake management actions that impact some life stages

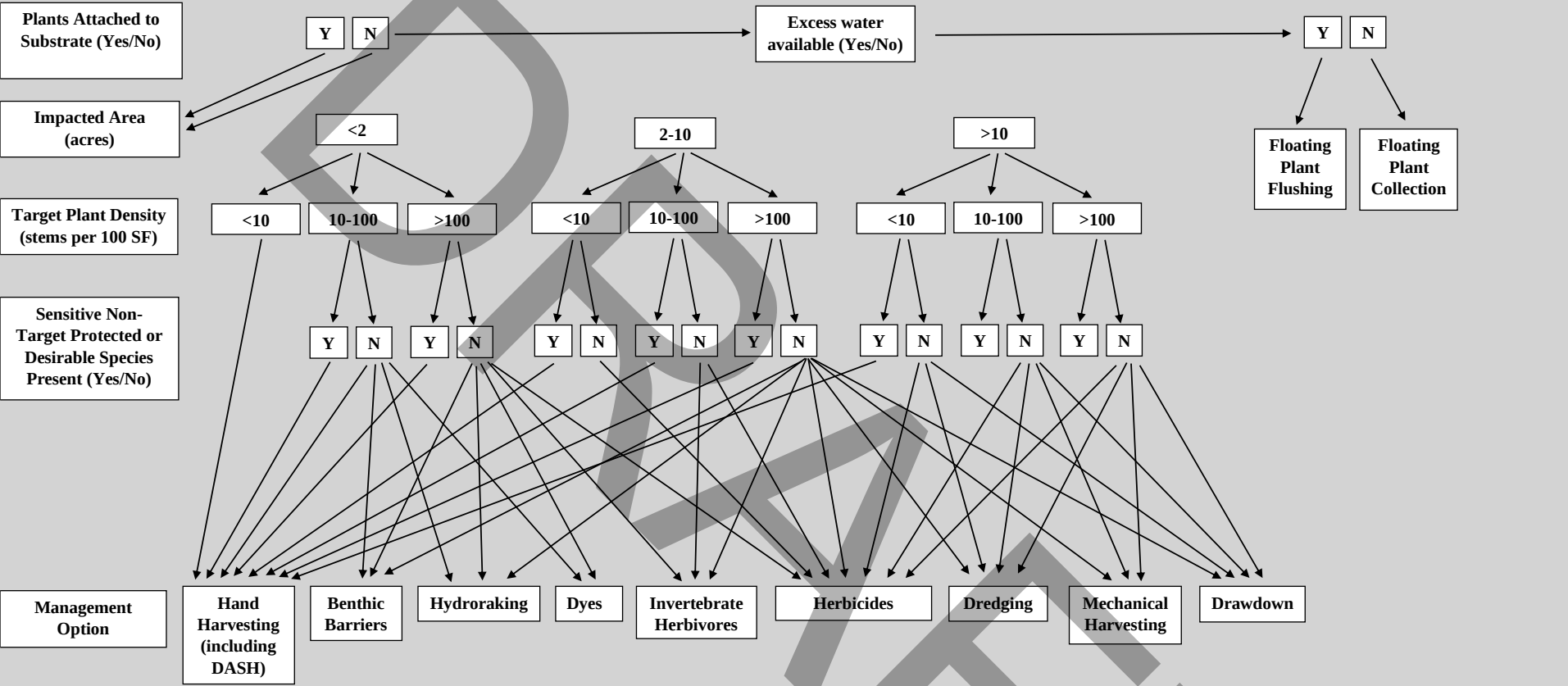
Table 4 - continued

Option	Mode of Action	Advantages	Disadvantages
7c) Fungal/bacterial/viral pathogens	◆ Inoculum used to seed lake or target plant patch ◆ Growth of pathogen population expected to achieve control over target species ◆ Very few products available, largely experimental	◆ May be highly species specific ◆ May provide substantial control after minimal inoculation effort	◆ Effectiveness and longevity of control not well known ◆ Infection ecology suggests incomplete control likely
7d) Selective plantings	◆ Establishment of plant assemblage resistant to undesirable species ◆ Plants introduced as seeds, cuttings or whole plants	◆ Can restore native assemblage ◆ Can encourage assemblage most suitable to lake uses ◆ Supplements targeted species removal effort	◆ Largely experimental ◆ Nuisance species may eventually return to dominate assemblage ◆ Introduced species may become nuisances ◆ Very limited track record in MA, but a logical follow up to invasive species control where large areas are without plants

3173

3174 There are many factors to consider when choosing a plant management approach and making
 3175 definitive recommendations without consideration of site-specific features, including socio-
 3176 political factors, is very speculative. Some plant control techniques are not mutually exclusive and
 3177 more than one technique may be needed to address the suite of species present. Yet in the interest
 3178 of demonstrating how techniques might be chosen based on just a few general factors, a flow chart
 3179 (Figure 16) is offered.

3180



Numeric thresholds are approximate; project-specific decisions on cut-off points for various techniques may vary, especially as relates to preventive vs rehabilitative actions.

Many techniques are not mutually exclusive; it is common to apply more than one technique where more than one plant species presents management issues.

Management options are more restricted when plant or animal species sensitive to any given technique are present, either by law under the MESA or WPA or just by desirability to maintain a healthy aquatic system.

However, in some cases sensitivity is partly a function of the technique, as with a choice of herbicides that may involve active ingredients, formulations, or doses that have less impact on non-target species.

Sensitivity may vary for invertebrate herbivores as well, with some impacting a wide range of plants (e.g., crayfish) while others are genus-specific (e.g., milfoil weevil).

Further, the timing of application may affect sensitivity, allowing use of many techniques at times when sensitive species or life stages are absent.

Figure 16. Choosing an aquatic plant control strategy

3184 **Functional Technique Groups for Further Review**

3185 The extensive lists of techniques for algae control (Table 3) and aquatic vascular plant control
3186 (Table 4) include some techniques that have received little application in MA, some because their
3187 use is prohibited, some because they have limited applicability or implementation potential, and
3188 some because they have not been found reliable enough for use on a wide or frequent basis.
3189 However, some appear reliable enough when applicable and properly implemented, but were not
3190 included in the 2004 GEIR and have not undergone any kind of approval process through the
3191 MEPA. Such techniques may be permissible in MA, but the process may not be clear, and a MEPA
3192 review may be necessary.

3193 While all the listed techniques have potential merit in lake and watershed management, the greatest
3194 amount of further effort in this manual is expended on the review of techniques that are applicable
3195 to algae and aquatic plant control in MA, have high implementation potential in MA, and have
3196 documented reliability (i.e., standard techniques). Implementation potential includes both the
3197 technical ability to apply a technique properly and the potential to get the necessary permits to
3198 apply it in MA. Techniques are divided into functional groups that include those that reduce
3199 nutrient inputs to the lake, those that limit nutrient availability once in the lake, methods for directly
3200 removing algae, and approaches to controlling aquatic vascular plant growth, directly or indirectly.

3201 Groupings of techniques considered applicable with high implementation potential in MA and
3202 known reliability include:

3203 ➤ Techniques to reduce nutrient (and other contaminant) inputs to lakes

- 3204 ○ Point source controls
 - 3205 ▪ Point source quality management
- 3206 ○ Non-point source controls
 - 3207 ▪ Source limitation
 - 3208 ▪ Agricultural best management practices
 - 3209 ▪ Trapping by inlet devices
 - 3210 ▪ Buffers and swales
 - 3211 ▪ Detention
 - 3212 ▪ Infiltration
 - 3213 ▪ Constructed wetlands

3214 ○ On-site wastewater management

3215 ➤ Techniques to reduce nutrient availability in lakes

- 3216 ○ Phosphorus inactivation
- 3217 ○ Artificial circulation
- 3218 ○ Hypolimnetic oxygenation
- 3219 ○ Dredging

3220 ➤ Techniques to directly remove algae

- 3221 ○ Algaecides

3222 ➤ Techniques to control aquatic plant growth

- 3223 ○ Dredging
- 3224 ○ Benthic barriers
- 3225 ○ Drawdown
- 3226 ○ Algae control options above for free-floating plants
- 3227 ○ Hand harvesting (with Diver-Assisted Suction Harvesting option)
- 3228 ○ Mechanical harvesting
- 3229 ○ Hydroraking
- 3230 ○ Herbicides

3231 Techniques that are currently recognized in MA as “alternative” techniques fall into that category
3232 as a result of either being prohibited, having fewer situations in which they are applicable, not
3233 having high implementation potential, either as a function of permitting issues or technical
3234 constraints on application, or not having enough of a track record to quantify reliability at this
3235 time. These are considered in lesser detail than the “standard” techniques, but some have definite
3236 applicability in MA and have been used. These alternative techniques are listed here with the
3237 rationale for why they are considered to represent less favorable alternatives in MA at this time.

3238 ➤ Nutrient control

- 3239 ○ Point source diversion – Diverting point source discharges from lakes is not preferable to
3240 improving the quality of such discharges and requires substantial permitting and impact
3241 consideration, but has been done in rare cases, more recently as relates to stormwater
3242 discharges regulated under NPDES, as there are very few wastewater discharges to lakes,
- 3243 ○ Selective withdrawal – Discharging poor quality water downstream is difficult to permit,
3244 while pulling enough water from a waterbody to prevent low oxygen from developing in
3245 deeper areas during summer without substantially draining the lake is challenging. While
3246 this technique has lowered nutrient concentrations in some cases, goals for nutrient control
3247 have not usually been achieved.
- 3248 ○ Dilution – While potentially allowable under existing laws, acquiring enough clean water
3249 within a given watershed to make a difference in any but the smallest ponds is a major
3250 challenge.
- 3251 ○ Phoslock and other products for P inactivation – While some concerns have been expressed
3252 regarding possible impacts to benthic biota and bioaccumulation, Phoslock and several
3253 other P inactivation products (e.g., EutroSorb) have applicability in MA and a successful
3254 track record exists for other states and countries. Approval under MEPA appears needed
3255 before these products can be used in MA and is in progress as of this time.
- 3256 ○ Removal of bottom feeding fish – Some methods (e.g., fish poisons) may not be permissible
3257 in MA while others (e.g., netting) may be. It is difficult to maintain control, but there have
3258 been successes outside MA, although this may lead to rooted plant problems in shallow
3259 lakes.

- 3260 ○ Floating islands/hydroponics – Growth of plants and related microbes can take up nutrients,
3261 but scale of application to make a difference is an issue and concerns have been expressed
3262 regarding construction materials, anchoring, and choice of plants. This is not yet a reliable
3263 approach.
- 3264 ○ Sediment oxidation – Addition of compounds to oxidize sediment and minimize P release
3265 may impact benthic biota and may release some nutrients; product approval under MEPA
3266 appears necessary for use in MA.
- 3267 ○ Selective nutrient addition – Altering nutrient ratios can shift algae composition to more
3268 desirable species but may not prevent high density of algae; addition of more nutrients
3269 raises permitting issues in MA.
- 3270 ➤ Direct control of algae
- 3271 ○ Flushing – Keeping water moving through a lake at a replacement rate of about every two
3272 weeks can prevent bloom development, although acquiring enough water to sustain this
3273 approach is challenging. Moving algal blooms downstream may not receive regulatory
3274 approval in MA.
- 3275 ○ Collection systems – Curtains with collection chambers or barges that extract algae from
3276 the water column have been developed and tested, some in MA. Such systems are
3277 applicable and permittable but have not yet enjoyed widespread use in MA or elsewhere.
3278 It is also possible but not efficient to harvest algal mats with mechanical harvesters.
- 3279 ○ Sonication – Use of sound waves to disrupt algal cell functions can kill susceptible algae
3280 and be permitted in MA but does not work on all algae and requires a network of devices
3281 within the waterbody.
- 3282 ○ Ecological management for more and larger zooplankton – Enhancing zooplankton
3283 community structure can reduce algae biomass and be permitted but produces highly
3284 variable results and control is hard to maintain. This approach tends to enhance results of
3285 P control but is not reliable as a substitute where nutrients are abundant.
- 3286 ○ Barley straw – Decaying barley straw produces compounds that do tend to reduce
3287 cyanobacteria and some other algae but has not produced consistent results and may
3288 adversely impact water quality. Barley straw has not been registered by MDAR and is
3289 therefore considered to be an unregistered algaecide, preventing permitting for use in MA.
- 3290 ○ Bacterial additives – Many products are available with very limited literature support, the
3291 mode of action is unclear in most cases and many formulations are proprietary, creating
3292 permitting issues. Some successes have been documented but product approval under
3293 MEPA and registration by MDAR appears necessary for use in MA.
- 3294 ○ Settling agents – Polymers or other compounds added to water to bind with and settle out
3295 particulates including algae are part of many water treatment systems used outside of lakes
3296 and ponds. Settling agents could be useful in lakes and are a possible component of
3297 bacterial additive approaches. Settling by coagulation fostered by aluminum added for P
3298 inactivation (e.g., alum) is presently approved for use in MA, but other settling agents are
3299 not approved at this time and would require MEPA review for use in MA.

- 3300 ➤ Direct control of algae and vascular plants
- 3301 ○ Dyes – Coloring the water a deep blue, dyes have been permitted as pesticides in MA.
- 3302 While there is some applicability to isolated ponds, dyes tend to cause shallower
- 3303 stratification and oxygen loss while not limiting growth in water <3 feet deep.
- 3304 ○ Surface covers – Floating sheet material or buoyant balls have been used to restrict light
- 3305 and limit growth, with historic use in drinking water storage reservoirs but not in public
- 3306 lakes. Surface covers interfere with most recreational and wildlife uses but may be
- 3307 applicable on a small scale on a temporary basis to support water dependent uses.
- 3308 ○ Algae or vascular plant-eating fish – Prohibited in MA at this time, this approach involves
- 3309 non-native species, tends to generate high levels of available nutrients, and is not easily
- 3310 controllable.
- 3311 ○ Algae or vascular plant pathogens – No commercial products are currently available but
- 3312 past products have not been reliable in testing programs. Any pathogenic product would
- 3313 need approval under MEPA and registration by MDAR for use in MA.
- 3314 ➤ Direct control of vascular plants
- 3315 ○ Plant competition – Rarely used in MA with some concerns over moving plants among
- 3316 lakes, techniques for replanting lake areas with desired species are not well developed but
- 3317 do represent a missing step in plant management.
- 3318 ○ Reverse layering – Moving sand from underneath organic sediment and creating a new
- 3319 layer on top was developed in MA but rarely used. Results have not been reliable for plant
- 3320 control.
- 3321 ○ Herbivorous invertebrates – While multiple species of invertebrates have been used to
- 3322 control target plant species, such as the loosestrife beetle and milfoil weevil in MA in the
- 3323 1980s and 1990s, they have not been reliable in many cases and introduced species pose
- 3324 potential ecological threats and permitting challenges.
- 3325 ○ Rotovation – Working like an underwater rototiller, rotovation equipment will destroy
- 3326 vegetation in target areas but creates plant fragments and turbidity, may not be permissible
- 3327 in MA, and has not been widely used elsewhere. Other methods are as effective with less
- 3328 adverse impact.
- 3329 ○ Physical plant disruption devices – Mechanical devices can disturb sediment by jetting
- 3330 water or dragging plastic or metal strips across the sediment surface to minimize plant
- 3331 growth, usually attached to docks or shoreline structures and operating on a small scale.
- 3332 These have not been reviewed under MEPA and may require additional permitting under
- 3333 Sec 401 depending on the level of sediment disturbance.

3334 **Additional Lake Problems**

3335 There are lake problems that may peripherally relate to eutrophication or aquatic plants that are

3336 not directly covered in this manual. These are worth mentioning, with some suggestions on what

3337 techniques that are being covered might apply and useful sources of information where this manual

3338 does not directly address the problem.

- Sedimentation – Loss of depth, independent of rooted plant or algae issues, can impair a lake. Removing the sediment is covered by dredging. Digestion of organic sediment has been claimed by some bacterial products, but evidence of success is very limited and since it is unusual for more than half the sediment in a waterbody to be organic, only partial results are possible. Most watershed management techniques address erosion and can reduce or prevent future sedimentation but will not address sediment once it is in the lake.
- Organic inputs and pathogens - Bacterial contamination, waterfowl and other wildlife inputs, and human waste are addressed to some degree by non-point source management in the watershed, but direct inputs to the waterbody are not addressed here. Bacterial testing is mandated in MA for beach facilities with closure when standards are exceeded. MassDCR has produced [guidance for controlling bacterial issues near swimming areas](#). Aside from managing the sources, which could include provision of bathroom facilities for people, collection of pet wastes, and discouraging geese and other wildlife from using the area, artificial circulation and oxygenation can help minimize pathogen problems and enhance organic decay.
- Low oxygen – Oxygen depression or depletion has multiple negative consequences for waterbodies, including loss of habitat for aerobic aquatic life, internal recycling of nutrients, enhancing methyl-mercury bioaccumulation, and odors. Dredging to remove oxygen-demanding sediment is a sound approach but the cost is too high to make most applications worthwhile unless reclaiming depth is also a priority. Oxygenation and artificial circulation directly counter oxygen loss and are covered in this 2025 Guide. Watershed management that minimizes organic inputs, most notably fall leaf collection and detention systems to trap organic sediment, can also reduce oxygen demand but will rarely reverse oxygen problems once they become chronic. P inactivation will often reduce the addition of oxygen-demanding substances to the sediment surface but will not satisfy accumulated demand or restore oxygen at all depths.
- Fish issues – Fishkills, poor survival of year classes of fish, stunted growth, diseased fish, unfavorable size distribution, undesirable species, and lack of desired species are all lake problems of general interest and particular concern to anglers and wildlife observers. This 2025 Guide is not a fish management manual, although many of the reviewed techniques offer potential benefits and possible adverse consequences for fish. Techniques that increase oxygen, reduce algae blooms, and counter extreme densities of aquatic plants may be generally beneficial, but the range of ecological strategies of fish is wide and higher fertility generally translates into greater fish production, so the impact of lake management on fish communities requires lake-specific assessment. MassWildlife is the recognized agency in MA for fish issues and contact with the regional offices of MassWildlife is encouraged where fish issues are a concern.
- Shoreline conditions – Issues with damaged shorelines and shallow areas relating to human actions may result from clearing, access amenities like beaches and docks, shoreline treatments like walls or rip-rap, and boating wakes. The WPA establishes thresholds for disturbance

within Land Under Water and Banks but does not provide explicit guidance for how to best manage those areas. Conservation commissions can condition shoreline projects to encourage retention of shoreline vegetation and minimal alteration of shoreline and related offshore conditions (e.g., retention of woody debris in water). Chapter 91 sets limits for structural alteration in Great Ponds, including dock placement, and requires permits for such alteration, but <10% of the lakes in MA are covered by Chapter 91. Coverage of these issues through non-point source controls in this 2025 Guide is limited, but many of the NPS controls apply to shoreline management and the [NH Homeowner's Guide](#) provides considerable guidance. Additional resources include the UMN Extension Service [Shoreland Management Fact Sheets](#), an informative website for [Shoreland Management in VT](#), and the [Maine LakeSmart Program](#) website.

- Import of invasive species - Preventing the introduction of non-native species is more desirable than trying to eradicate an invasive species once it has arrived. Active routes of introduction by humans include the aquarium and landscaping trades (Les, 2002) and boating (Rothlisberger et al. 2010). Movement among lakes is usually a function of downstream flow, boat traffic, or waterfowl. The need for enforcement of existing laws relating to introductions remains great, as there are no laws requiring management once the infestation has occurred. This manual focuses on remediation for excessive macrophyte growths and does not explicitly address approaches for prevention, which include but are not limited to oversight of local plant and animal sales, educational signage at boat ramps, and inspection of boats entering and leaving lakes, preferably with [boat cleaning](#) facilities available. MA has a law prohibiting the import of [invasive plant species](#) but enforcement is challenging.
- Nuisance fauna – Geese, gulls, leeches, schistosomes, and other animal life can sometimes become a problem, especially in shoreline parks and swim areas. People can minimize problems with some management actions, but some conflict may be hard to avoid. The NYS DEC [Goose Control Guide](#) and [WI Nuisance Wildlife](#) website provide useful insights. Most controls focus on making the habitat less attractive to nuisance fauna.
- Dams, docks and other in-lake structures – Structures constructed in or around lakes are regulated by various MA laws and associated regulations. Dam safety is paramount and is the focus of the [MassDCR Office of Dam Safety](#), which can provide guidance on proper inspection and maintenance practices. Construction of any kind in wetland resource areas is governed by the WPA, including docks. Chapter 91 addresses [structures in Great Ponds](#). In general, keeping shorelines as natural as possible will minimize adverse impacts to the lake and lower maintenance needs. Floating, seasonal docks are easier to permit and usually have fewer impacts than permanent structures with pilings.
- Human use conflicts – There are many possible conflicts between human users, and this 2025 Guide is not a tutorial on conflict resolution. Almost any use of a lake by humans has the potential to affect other uses. Use for potable supply often precludes contact recreation in all or part of a reservoir. Noise and waves from motorized boating affect enjoyment by swimmers, wildlife observers, and more passive users. Management of plants to facilitate swimming and

3419 boating may conflict with the desires of anglers. Understanding the range of human uses of a
3420 waterbody and how existing features and management options affect each use is an important
3421 part of lake management plan development. This is why inclusion of a wide spectrum of lake
3422 stakeholders into the lake management planning process at the earliest stages is critical. See
3423 the discussion in the Lake Management Planning section of this 2025 Guide and the guidance
3424 supplied in the ALMS [Workbook for Developing Watershed Management Plans](#). Spatial
3425 and/or temporal separation of uses that pose potential conflicts is often the best solution but
3426 requires planning and enforcement. A useful chapter on conflict resolution among lake users
3427 can be found in [Diet For a Small Lake](#) from NYSDEC and NYSFOLA or in the
3428 [Environmental Conflict Resolution Guidebook](#).
3429

5. REDUCED NUTRIENT INPUTS TO LAKES

The most reliable way to prevent algae blooms in a lake is to lower the concentrations of nutrients, especially phosphorus (P), although attention to nitrogen (N) is also important. Most nutrients in lakes come from the watershed, so management of the watershed to limit nutrient inputs is accorded a high priority in most lake management plans aimed at preventing algae blooms. An understanding of the sources of nutrients and the relative magnitude of their contribution is needed, allowing selection of appropriate techniques to keep those nutrients from reaching the target lake. In cases where nutrient loading has been excessive for years, it may be necessary to address recycling of nutrients within the lake, mostly from the sediment, but that is an issue addressed in the next chapter on reducing nutrient availability within the lake. Watershed techniques are addressed here, including control of point sources and non-point sources of nutrients.

Following the adoption of the Clean Water Act in the 1970s, significant achievements were accomplished nationally in the protection and enhancement of water quality. Much of the initial progress resulted from identifying and controlling point sources of pollution through the National Pollutant Discharge Elimination System (NPDES) and Municipal Separate Storm Sewer System (MS4) discharge permit programs. However, pollutant loads from non-point sources (NPS) continue to present problems for achieving water quality goals and maintaining designated uses in many parts of the United States.

While ubiquitous, the presence and quantity of certain NPS pollutant sources and their potential impact on receiving waters is often strongly correlated with specific land uses and the density of land development. In addition to often having a higher prevalence of NPS pollutant sources, more densely developed areas typically have less forest and other naturally vegetated lands that can act as a buffer between NPS pollutants and waterbodies. The major categories of NPS pollution sources in MA include developed areas, transportation, agriculture, forestry, hydromodification, atmospheric deposition, landfills, contaminated areas and waste management sites, and natural resource extraction (GeoSyntec 2013). NPS are generally considered the major cause of water quality problems in MA lakes.

Since the original publication of the GEIR in 2004, there has been extensive expansion and progress in the field, particularly in non-point source control, resulting in the development and deployment of a diverse set of policies, approaches, and technologies. Accompanying the wealth of recent scientific and engineering literature has been the development of comprehensive guides and interactive tools at state and federal levels. Accordingly, the following sections will only serve as a brief introduction to these techniques, providing description and conceptual design but leaving the user to seek out further detail in the identified links and bibliography. Much of the information presented here is adapted from comprehensive information sources including [Stormwater Best Management Practices: Guidance Document](#), the [MA Clean Water Toolkit](#), and the [National Menu of Best Management Practices \(BMPs\) for Stormwater](#).

Federal and State Programs and Regulatory Authority

Points source controls are associated with the treatment or elimination of discharge of wastewater or stormwater into a waterbody. Wastewater (including industrial, municipal, and other sources) is generally regulated through the NPDES permit program. In MA, the United States Environmental Protection Agency (USEPA) Region 1 is the [delegated permitting authority](#) and NPDES permits are typically co-issued by USEPA and MassDEP. While current policy and practices avoid installation of new direct point source discharges into inland lakes, a number of wastewater treatment facilities (WWTF) still pose water quality issues for the receiving waters or, in some cases, legacy nutrient loads in the sediment.

Stormwater is classified as a point source when it is regulated through the [NPDES Stormwater Program](#). A NPDES stormwater permit is required for medium and large MS4s of municipalities and counties with populations >100,000, certain industrial activities, and construction activities disturbing five acres or more. A NPDES permit is also required for small MS4s in “urbanized areas” and small construction activities disturbing between one and five acres of land. MA regulates the issuance of “small” MS4 discharge permits through the [Stormwater Management Standards](#) pursuant to its authority under the Wetlands Protection Act (M.G.L. c. 131, § 40) and the MA Clean Waters Act (M.G.L. c. 21, §§ 26-53).

The Stormwater Management Standards address water quality (pollutants) and water quantity (flooding, low base flow and recharge) by establishing standards that require the implementation of a wide variety of stormwater management strategies. These strategies include environmentally sensitive site design and low impact development (LID) techniques to minimize impervious surface and land disturbance, source control and pollution prevention, structural BMPs, construction period erosion and sedimentation control, and the long-term operation and maintenance of stormwater management systems.

MassDEP oversees the [NPS Management Program Plan](#) and sets strategy for preventing, controlling, and reducing NPS pollution to protect and improve the quality of the Commonwealth's waters. The current Plan covers the NPS Program goals for 2020 to 2024.

Point Source Control

How it Works

Point source water pollution involves pollutants that are discharged from any identifiable, singular source, such as a pipe, ditch, drain, channel, tunnel, conduit, well, container, or vessel. Originally intended to regulate wastewater treatment discharges from industrial or municipal operations, the definition of a point source was extended in 1990 to include storm water 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. Point source discharges are governed by the National Pollutant Discharge Elimination System (NPDES). MA is a so-called “non-delegated” state meaning that NPDES permits are issued by the USEPA New England regional office and not the state itself. However, MassDEP provides considerable feedback on draft permits and offers guidance to applicants on meeting federal requirements.

Historically, manufacturing and other industrial point sources of pollutants were often major water quality concerns as discharges to streams and rivers flowing into downstream impoundments and lakes. Following 50 years of permitting and progress reducing industrial discharges under the Clean Water Act (CWA), most of the nutrients from point sources are from municipal wastewater treatment facilities (WWTF) or Municipal Separate Storm Sewer System (MS4) discharges, which are further categorized as “large” or “medium” or “small” municipal storm sewer systems pursuant to 40 CFR 122.26.



WWTF permitting emphasizes using best available technology to produce effluent concentrations that will protect lakes and other water resources. Domestic wastewater typically enters a WWTF with P in excess of 3 mg/L and sometimes as high as 15 mg/L, while N levels often exceed 40 mg/L, with values up to 70 mg/L not uncommon. Conventional wastewater treatment involves primary (i.e., settling of suspended solids) and secondary (reduction of organic waste, pathogens, and contaminants easily converted to less objectionable forms) treatment and, increasingly, tertiary treatment to meet nutrient effluent goals. Conventional primary and secondary treatment may produce P concentrations 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 WWTF 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 for discharge to lakes. With a target lake P level of <0.02 mg/L and preferably <0.01 mg/L, WWTF inputs currently require substantial dilution or further treatment to avoid eutrophication impacts on lakes.

Point Source Control

Advanced waste treatment, or tertiary treatment, addresses the removal of P and/or N. P compounds are most often removed by coagulation with chemicals, sometimes with an additional filtering step, but biological treatment can also be effective. Achievement of concentrations <0.5 mg/L is routinely possible through tertiary treatment, concentrations close to 0.1 mg/L are often achieved, and some technologies can achieve P concentrations of 0.01 to 0.02 mg/L, albeit at considerable expense.



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 from other contaminants 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 WWTF, and some WWTF are based mainly on biological activity as the mainstay of wastewater treatment. Yet biological processes are not as reliable as physical or chemical treatments, so greater variation in discharge quality is to be expected with biological treatment and more capacity is often needed to ensure compliance with discharge requirements.

Stormwater is classified as a point source when it is regulated through the NPDES Stormwater Program. One provision of the NPDES program for individual facilities is the requirement for a Storm Water 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, and plans focus on 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.



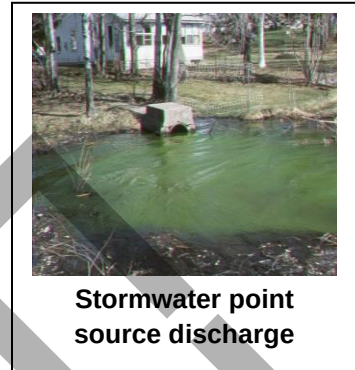
MS4 permits are required for municipalities in areas considered urban by population density. For MS4 systems where the pollution sources are much more diffuse, there is a provision for a Stormwater Management Program (SWMP). The SWMP includes provisions for managing potential pollution by six minimum control measures (MCMs), which include public education and outreach, public involvement and participation, illicit discharge detection and elimination, construction site stormwater runoff control, stormwater management in new development and redevelopment (post-construction stormwater management), and good housekeeping and pollution prevention for permittee operations.

Point Source Control

In some cases, inflows to wastewater treatment plants are combined with urban storm water flow. This is most often a result of inadequate design and capacity 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 or inflow to WWTF beyond the design capacity of the facility. Separating these combined sewer systems (CSS) to avoid Combined Sewer Overflow (CSO) has been a priority for the USEPA and MassDEP for many years. Substantial progress has been made (e.g., cities along the Connecticut River) but the costs of making such improvements in densely populated urban areas is high and the disruption to infrastructure necessary to correct deficiencies slows progress in many areas.

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 P 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 storm water point sources is essential to improving discharge quality in nearly all cases. Nutrient removal from storm water 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 P average 10% for primary, 20-40% for secondary, and 80-99% for tertiary. For nitrogen, removal rates average 5-10% for primary, 10-30% for secondary, and 50-90% for tertiary treatment.



Benefits

- ◆ Control of centralized wastewater collection and treatment can result in a major reduction in loading
- ◆ Improved or upgraded treatment can remove many other contaminants as well as nutrients
- ◆ Storm water management in MS4 permitted systems has great potential for reduced nutrient loading
- ◆ Separation of stormwater from wastewater in conveyance systems can reduce loading to WWTF and lakes and streams

3604 **Detriments**

- 3605 ♦ Even the cleanest treated wastewater may still contain excessive concentrations of nutrients
- 3606 ♦ Centralized wastewater discharge localizes a potentially major impact and may affect the
- 3607 hydrology of contributing watershed areas; water may be transferred among watersheds with
- 3608 impacts to both
- 3609 ♦ Siting, design, permitting and construction of a new WWTF is both a costly and lengthy
- 3610 process

3611 **Information for Proper Application**

- 3612 ♦ An accurate nutrient budget that demonstrates the importance of the point source(s) in
- 3613 determining lake quality
- 3614 ♦ Water quantity and quality data for discharges that supports treatment design
- 3615 ♦ Hydrologic data for receiving waters to evaluate dilution effects
- 3616 ♦ Source analysis for stormwater point sources, to allow minimization of impacts on runoff
- 3617 quality

3618 **Factors Favoring or Disfavoring the Use of this Technique**

- 3619 ♦ Favored when a substantial portion of the P and/or N load is
- 3620 associated with point source pollution
- 3621 ♦ Favored when studies have demonstrated the impact of
- 3622 identifiable discharges on the lake
- 3623 ♦ Favored when water associated with point sources is important
- 3624 to lake hydrology (i.e., diversion is not preferable)
- 3625 ♦ Favored where jurisdiction can be claimed over point sources

Unless dilution by the receiving water is very high (>1000X), tertiary treatment of domestic wastewater is necessary to achieve a phosphorus level that will not harm downstream lakes. Where dilution is low (<10X), impacts may be still occur with current technology from discharges to surface waters.

3626 **Performance Guidelines and Monitoring Needs**

- 3627 ♦ Collect the data necessary to demonstrate the problem and
- 3628 potential for improvement
- 3629 ♦ Meet all requirements of the NPDES program; seek to establish permit limits that meet water
- 3630 quality goals, but with recognition of other pollutant sources to the target lake
- 3631 ♦ Design the treatment system or upgrade to meet demonstrated needs; match treatment
- 3632 processes to water quality goals
- 3633 ♦ Monitor the effluent in accordance with NPDES requirements and at locations appropriate to
- 3634 demonstrating results
- 3635 ♦ Conduct ongoing monitoring to assess impacts and additional management needs; stormwater
- 3636 point source management is usually an iterative process

3637 **Key Considerations for Conservation Commission**

- 3638 ♦ NPDES permit are issued by the USEPA, with input from MassDEP

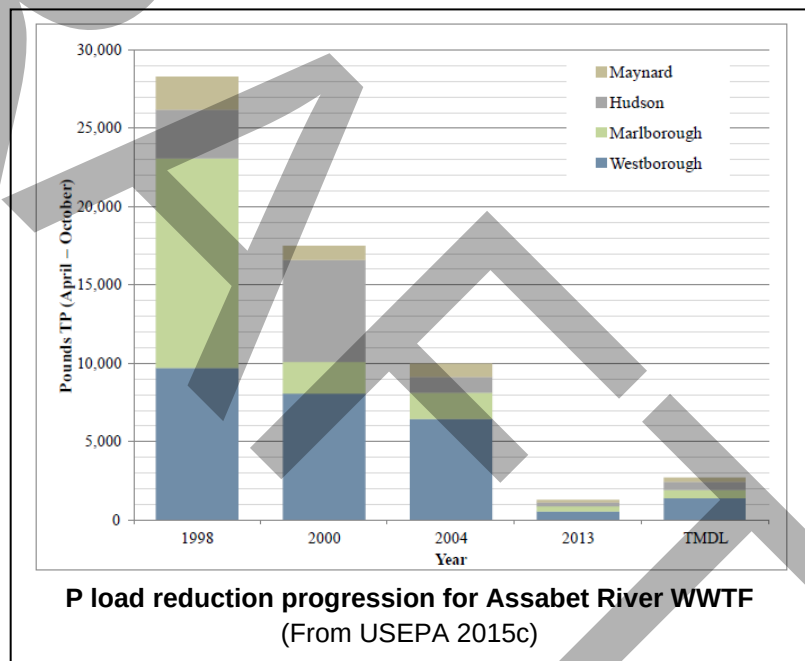
Point Source Control

- ◆ Conservation commissions can offer comments on draft and final permits
- ◆ All interests of the WPA are generally benefited or unaffected by point source controls unless export of water from a watershed (i.e., collection and treatment with discharge outside the watershed) leads to adverse alteration of hydrology
- ◆ Most actual point source controls will occur outside wetland resources and will not be within the jurisdiction of a conservation commission

Massachusetts and Other Experience

Large WWTF generally discharge to large rivers where substantial dilution and assimilative capacity are available. However, there are examples where municipalities discharge to a major tributary of a lake leading to impaired downstream water quality. Many WWTF represent aging infrastructure relying on conventional treatment which is largely ineffective in meeting current nutrient effluent targets. For these WWTF, improvements must be made to bring the facility and its discharge up to current codes and standards and extend the useful life of aging systems to ensure continual operation of the facility to meet discharge permit limits. This usually includes incorporation of advanced treatment technologies to meet currently acknowledged P and N limits.

A major effort over 15 years greatly reduced P concentrations in the effluent from four WWTF discharging to the Assabet River in MA (USEPA 2015c). Multiple impoundments of that river were severely eutrophic and a TMDL called for a >90% reduction of WWTF inputs of P. The target was achieved over sequential upgrades of the four WWTF, applying multiple technologies that varied by WWTF, resulting in P concentrations lower than required by the TMDL. Internal loading remains an issue for these impoundments, but water quality is much better than it has been for many decades.



Another example is Forge Pond in Granby, MA, where in the late 1980s the discharge from the WWTF serving the institutional Belchertown State School flowed into a minor tributary stream and comprised 64% of the total P load to this small, highly eutrophic lake (BEC 1987). WWTF outfall discharge P measurements at that time ranged from 2.25 to 4.7 mg/L. Belchertown State School was closed in 1992 and many of the buildings torn down or retrofitted. In recent years, the WWTF facility was upgraded while sewer coverage has expanded in this developing municipality.

Due to improved P removal, the draft 2022 NPDES permit for the Belchertown Water Reclamation Facility authorized a warm weather (April 1 – October 31) P effluent limitation of 0.10 mg/L and a cold weather (November 1 – March 31) limit of 0.25 mg/L. Similar seasonal limits are now being included in permits for municipal WWTF discharging to nutrient sensitive waters, but even then considerable dilution is needed to lower P concentrations to an acceptable level for lakes. In 2017, the USEPA awarded the town of Belchertown an award for outstanding operations at the municipal wastewater treatment facility. Yet despite these improvements in WWTF effluent quality, Forge Pond remains eutrophic, at least partly due to its shallow depth and its nutrient-rich sediments from legacy inputs.

Onondaga Lake, located in Central New York along the edge of the City of Syracuse, covers 4.6 square miles, has an average depth of 35 feet and a maximum depth of 63 feet. The lake receives water from a 285-square mile watershed located mostly in Onondaga County with the Metropolitan Syracuse Wastewater Treatment Plant (Metro) supplying approximately 20% of the annual inflow. Once a popular tourist attraction with beaches, resorts and amusement parks, industrial development and a growing urban population led to increases in sewage and industrial discharges that severely impaired the water quality of Onondaga Lake. Swimming was banned by 1940 and fishing in 1970. By the end of the 20th century, Onondaga Lake was considered one of the dirtiest lakes in the USA.

Ammonia and P in sewage from Metro contributed to impacts on fish migration and reproduction, led to algal blooms and poor water clarity, and decreased oxygen levels. In addition, stormwater runoff entering the Syracuse combined sewer system routinely overwhelmed the system and sent untreated sewage and stormwater to Onondaga Lake. These CSO were a major source of bacteria, trash, organic material, solids and grit as well as nutrients. To address the ammonia, P and CSO problems, a third-party lawsuit was initiated in 1989 requiring collection system and WWTF improvements.

Under the federal court order, the county spent over \$700 million to reduce the amount and improve the quality of sewage that flowed into the lake during heavy rains. In 2011, Onondaga County submitted the "Metro WWTF Optimization Analysis of Total Phosphorus Treatment" for New York State Department of Environmental Conservation (NYSDEC) approval. This plan detailed recommended actions including modifications to the existing tertiary treatment process and adjustments for hydraulics, operations procedures and maintenance schedules related to optimizing current facility performance. In 2014, Onondaga County achieved a 95% capture rate for CSO and has since increased the rate to nearly 98% (NYSDEC 2023).

By 2019, water quality in the northern two-thirds of Onondaga Lake had achieved public health criteria for swimming. The lake has remained largely free of toxic algae blooms since Metro upgrades have decreased the amount of P going into the water. The aquatic plant community expanded from less than 12% of lake littoral areas to about 80% and the lake now has 65 species of fish documented, up from 9-12 documented in the 1970s (Honeywell 2023).

Point Source Control

MS4 regulated under NPDES are common in urban areas, including Boston, Worcester, Springfield, and Pittsfield in MA. Managing these systems to reduce pollutant loads is challenging, as they were created as public safety measures to avoid flooding problems on roads and residential or commercial properties where expanded impervious surface area greatly increases runoff. Most municipalities in those declared urban areas are charged with reducing pollutant loads from MS4 over an extended period of time, and initial efforts have largely focused on removing illicit connections, limiting exposure of pollutants to precipitation and runoff, and infiltrating stormwater wherever possible. Yet the nature of urban areas creates challenges for improving runoff quality and success is elusive (Osgood 2017). Greater loading reductions are feasible with smaller systems and impacts are lower where only a small portion of the watershed is developed. Management of stormwater point sources is an ongoing concern for improving and protecting MA lakes.

Non-Point Source Controls – Source Management

How it Works

Source management consists of techniques that eliminate or reduce the potential for the release of pollutants from a source that would otherwise enter a downstream lake. While the most reliable way to do this is to eliminate the pollution source, this may not be feasible or practical in many cases. Most source controls are achieved through laws, statewide regulations or local bylaws or ordinances that restrict detrimental product content or use or limit detrimental activities within a watershed. Where a feasible alternative product exists or problematic land uses do not already exist in the watershed, this can be a very successful approach. However, small gains can also be made through advocacy of wise environmental stewardship, particularly by educating shoreline residents.

Eliminating sources of nutrients and other pollutants requires considerable up-front study and evaluation of potential impact. It also requires much public education and a willingness to work with lawmakers to craft effective but fair laws.

Where education reveals both an environmental and economic value through source elimination, greater shareholder acceptance and progress is likely. For example, as established lawns require very little added P, homeowners should be able to save money and protect water quality while maintaining lawns⁶. However, the availability and cost of low-P fertilizer was an issue for many years until enough data had accumulated that demonstrated a direct correlation from the reduction in P in aquatic systems from the use of lower P formulations in lawn fertilizers (e.g., Lehman et al. 2011). Many local bylaws and ordinances followed, with some state laws and regulations, and eventually the fertilizer industry shifted to low P formulations for lawns. Research and education led to a cultural shift that benefits water resource quality.



Fertilized green lawns often translate into a fertilized green lake

Additional, more active methods of nutrient source control include erosion prevention, controlling offsite discharges of stormwater, proper disposal of grass clippings and leaves, use of phosphate-free or low-phosphate automatic dishwashing detergents, waste collection, street sweeping, management of wildlife (e.g., discouraging waterfowl feeding), and water quality-based zoning. On-site wastewater management is addressed in a separate section, but septic tanks should be maintained with regular pumping and inspection at least every 3-5 years.

Phosphorus and nitrogen load reductions, due to source management, are highly variable and may be low (i.e., <10%) where compliance is voluntary. Greater control over inputs can be gained with

⁶ To determine your lawn's nutritional needs, have your soil tested. Call the UMass Extension Soil Testing Lab or download a [soil test order form](#). You may not need to add fertilizer.

Non-Point Source Limitation

3762 municipal ordinances or active participation by town departments (e.g., street sweeping programs).
3763 Use of source controls to prevent loading before it ever starts is the most beneficial use of this
3764 approach and [helpful non-point source control tips](#) are available.

3765 Benefits

- 3766 ♦ Prevention, elimination, or reduction of sources reduces the potential nutrient load
- 3767 ♦ Incremental gains can be multiplied by effective watershed education and stewardship
- 3768 ♦ Costs can be minimal and are spread over the population
- 3769 ♦ Pollutants other than nutrients can be controlled by the same actions

3770 Detriments

- 3771 ♦ Source controls provide some measure of nutrient reduction but are unlikely to be sufficient
3772 by themselves in shifting lake trophic status
- 3773 ♦ Beneficial actions may be at odds with popular cultural values (e.g., green residential lawns)
- 3774 ♦ Compliance is likely to be difficult to track and enforcement of violations may be difficult or
3775 unpopular
- 3776 ♦ Urbanized or agricultural watersheds may contain many existing sources that cannot be
3777 eliminated or even substantially reduced

3778 Information for Proper Application

- 3779 ♦ Accurate estimate of the watershed nutrient load comprised by
3780 the targeted source(s)
- 3781 ♦ Source material for watershed education and voluntary
3782 compliance programs
- 3783 ♦ An understanding of regulatory jurisdiction and limitations
- 3784 ♦ Means to measure progress and, as feasible, provide positive
3785 incentives for compliance



3786 Factors Favoring or Disfavoring the Use of this Technique

- 3787 ♦ Favored when a substantial portion of the nutrient load is associated with an identifiable,
3788 controllable source
- 3789 ♦ Favored where jurisdiction can be claimed over the targeted source
- 3790 ♦ Favored when zoning or other restrictions on land use or products can be properly justified and
3791 are consistent with applicable state and local laws
- 3792 ♦ Favored with a proactive lake association and/or town government

3793 Performance Guidelines and Monitoring Needs

- 3794 ♦ Establish an effective public process for contact and involvement of relevant stakeholders
- 3795 ♦ Collect the data necessary to justify and support the control effort

Non-Point Source Limitation

- 3796 ♦ Focus on education and voluntary compliance before regulatory enforcement
- 3797 ♦ Seek funding to facilitate an incentive program
- 3798 ♦ Monitor at a scale appropriate to the control effort; demonstrate improvement on or from small
- 3799 parcels before seeking to document any overall change in the lake

3800 **Key Considerations for Conservation Commissions**

- 3801 ♦ Conservation commissions can adopt performance standards for shoreline development within
- 3802 jurisdictional limits, including establishment of buffer zones, limited landscape profiles, and
- 3803 mandated use of lower impact products (e.g., pertaining to fertilizers or pesticides)
- 3804 ♦ Enforce existing regulations consistently and equitably, as needed
- 3805 ♦ The impact on all interests of the WPA from source controls should be beneficial or neutral,
- 3806 but be wary of what substitute measures people may take if denied the use of any particular
- 3807 use or product

3808 **Massachusetts and Related Experience**

3809 A prolonged effort in the 1970s lead to a reduction in P in laundry detergents, as that source was
3810 identified as a major component of wastewater P and was not essential to detergent performance.
3811 More recent data (Puijenbroeck et al. 2018) estimate that P emission into wastewater streams from
3812 laundry detergents in North America declined from 69 million kg/yr in 1970 to 45 million kg/yr
3813 in 2010 despite growth in population and detergent use. While that source of P is considered minor
3814 in comparison to urban and agricultural runoff (Maki et al. 1984), reduction in a source at minimal
3815 public cost is viewed as an important step in lake management.

3816 An evaluation of what elimination of P in dish detergent might accomplish (ENSR 2003) found
3817 that no more than 2% of P loading could be attributed to dish detergents but again, the elimination
3818 of any source at minimal public cost seems worthwhile. With a lack of product shift in this sector,
3819 Puijenbroeck et al. (2018) estimate that release of P from dishwasher detergent into the waste
3820 stream has increased from 11 million kg/yr in 1970 to 51 million kg/yr in 2010 in North America.
3821 This does not mean that a large fraction of dishwashing detergent P reaches natural waters, as there
3822 is treatment of most waste streams, but the increase in potential loading is clear and stands in
3823 contrast to that of laundry detergent where lower P formulations were adopted.

3824 As lawn fertilizer has been demonstrated to be a significant P source for streams and lakes, subject
3825 to no treatment before discharge, the lowering of the P content of most residential fertilizer noted
3826 at the start of this review is a better example of what the right combination of research, education,
3827 and regulation can do to protect water resources.

3828 Street sweeping and leaf collection during autumn are additional source control measures that can
3829 reduce nutrient inputs to lakes. In less developed areas, leaves tend to become part of the soil with
3830 less transfer to water resources, but in residential areas with extensive storm drainage systems,
3831 routing to streams and lakes is an issue. Research has demonstrated peak loading to lakes from
3832 residential areas during autumn after leaf fall (Selbig et al. 2020) and collection of those leaves

Non-Point Source Limitation

before they can decay and wash into area streams and lakes can reduce P loading. Weekly cleaning of streets in areas with substantial leaf canopy cover during autumn was found to reduce the associated TP load by 65 to 71%. Cleaning frequency was more important than the method used. Similar issues exist for grass clippings and other yard waste if allowed to enter the stormwater drainage systems, making proper disposal important and suggesting the value of ongoing street cleaning.

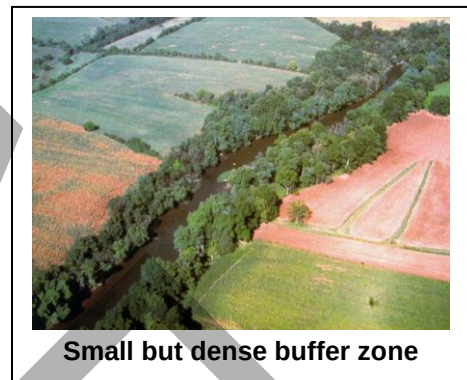
Federal NPDES regulations and many corollary state programs directed at controlling pollutant inputs to water resources focus on pollution prevention measures that include preventing possible contaminants from coming into contact with precipitation or being incorporated into runoff. Stormwater Pollution Prevention Plans, required for certain industries and commercial operations, recommend covered storage of products containing such contaminants (e.g., fertilizers, pesticides, deicers) and require secondary containment around certain liquids. Relatively simple and low-cost measures to prevent the release of contaminants are known but have not been widely applied to residential areas. Where population density is high enough to qualify, municipalities are subject to MS4 regulations that seek to incrementally improve the quality of stormwater through BMPs. Progress has been slow and such regulation is often viewed as an unfunded mandate, but where towns have recognized the value of stormwater management in preserving quality of life for residents and visitors, advances have been made.

Non-Point Source Controls – Agricultural BMPs

How it Works

Agricultural best management practices (BMPs) encompass a wide variety of spatial and temporal practices or features intended to reduce the potential nutrient load of farming on downstream water quality. Agricultural BMPs include conservation buffers, conservation tillage, crop nutrient management, manure management, livestock watering and access practices, as well as other methods. Guidance documents and fact sheets describing each of these BMPs are available from numerous federal and state websites as well as through consultation with the [Center for Agriculture, Food, and the Environment at the University of MA Amherst](#). Descriptions of these practices, adapted from the [MA Clean Water Toolkit](#) (MassDEP 2021), are given below. Performance data can be found in the online database for [BMP performance](#).

Conservation Buffers are small areas or strips of land in permanent vegetation that are designed to intercept and reduce the movement of sediment, nutrients, and pesticides from farm fields. Strategically placed buffer strips, placed between fields and local streams, drainage ditches, wellheads, and other water collection points, can effectively reduce the movement of pollutants into adjacent waters. Buffer strips can also create or enhance wildlife habitat as well as protect biodiversity. When coupled with other upland agricultural BMPs, including conservation tillage, nutrient management, integrated pest management, winter cover crops, and similar management practices and technologies, buffer strips encourage economic and environmental sustainability in farm operations.



Conservation Tillage practices (also known as low-till or no-till practices) are adopted to grow crops with minimal disturbance of the soil. When the amount of soil disturbance (tillage) is reduced, much of the stubble or plant residues remain on top of the soil rather than being plowed into the soil. 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. In general, conservation tillage system is any crop farming system that leaves at least a third of the soil covered after planting, to reduce soil erosion by water. 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. Conservation tillage can also involve contouring, terracing, and related approaches to cultivation of fields that minimize the peak velocity attained by runoff and maximize infiltration of rainwater. Crop Residue Management (CRM) is an "umbrella" term encompassing several tillage systems including no-till, ridge-till, mulch-till, and reduced-till.

Crop Nutrient Management refers to adoption of an integrated set of nutrient management practices to help farmers maintain high yields and save money on fertilizers while reducing NPS pollution (CTIC 1999). With proper planning, the quality of runoff generated from the field can be greatly improved, translating into reduced nutrient loading to area waterways. Key components of a crop nutrient management plan should include creation of a baseline field map, soil testing to determine nutrient requirements, crop sequencing, crop yield estimates, fertilizer sources and forms, determination of fertilization rates and timing of applications, identification of sensitive areas, and an annual review of the effectiveness of the practices and overall productivity.

Manure Management consists of isolating and containing, treating, and disposing of livestock manure. Manure contains large amounts of nutrients, such as P and N, and pathogens, including bacteria, viruses and parasites. Handling manure in a manner that limits interaction with precipitation and incorporation into runoff is essential to protecting aquatic habitats. Pastures with steep and unprotected slopes, lack of vegetative cover, and proximity to receiving water can facilitate entry of manure and associated contaminants into surface water resources. Accordingly, manure application should be kept at a distance from streams and lakes and the application should be avoided during winter months when frozen soils promote runoff. Soil testing to determine assimilative capacity for nutrients is advisable before any manure disposal on open land.



Manure from livestock can be a major source of nutrients

Livestock Watering and Access Limitations. To protect streams, their banks, and riparian zones from physical disturbance, livestock access should be physically limited. Livestock access limitation practices include proper fencing, livestock exclusion, and providing stabilized stream crossing areas. Fencing can protect riparian areas which act as sediment traps and filters along the perimeters of surface waters and wetlands. This practice involves excluding livestock from an area not intended for grazing. Livestock exclusion may improve water quality by preventing livestock from being in the water, preventing access to steep or highly erodible banks, and by preventing direct animal waste deposition in surface waters. Providing a stabilized area for livestock and farm machinery to cross a stream can provide a controlled watering access point for livestock, prevent bank and streambed erosion, reduce erosion and enhance water quality, and maintain or improve wildlife habitat.

Cranberry Farming is a historically and economically significant agricultural interest in MA. Due to the need for readily available water to irrigate and flood bogs for harvesting, these operations are generally located adjacent to bodies of water. 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. Nitrogen is usually in short supply in bogs, and concentrations of readily available nitrogen tend to be low, but dissolved phosphorus may be high, especially in anoxic winter discharges. Microbial processes in lakes may recycle the bog inputs and eventually increase lake fertility, usually over a period of many years. 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. There has been much state-sponsored research over multiple decades into reducing the overall impact of cranberry bogs. Nutrient management BMPs are provided in [Cranberry BMPs. A Handbook for Massachusetts Cranberry Best Management Practices](#) (Sandler 2010).



Cranberry harvest

Overall reduction in nutrient loading from agricultural BMPs is difficult to predict, given the wide range of agricultural activities, local site conditions, and BMPs options. Major reductions (>50%) may be realized from application of an integrated combination of the various BMPs, but application of BMPs will not result in a net zero increase in pollutant loading from agricultural sources compared to natural land uses. Localized monitoring is essential to tracking progress.

Possible Benefits

- ◆ Reduces input of nutrients, pathogens, and other contaminants to streams and lakes
- ◆ Can minimize soil loss and associated economic cost
- ◆ Can reduce fertilizer and pesticide costs
- ◆ May provide health benefits (reduced pesticide use) as well as nutrient loading reduction
- ◆ May provide increased wildlife habitat and diversity

Possible Detriments

- ◆ Can have unfavorable short-term cost-benefit balance from farmer's perspective, unless supporting programs are available
- ◆ Can lead to a reduction in the footprint of productive cropland
- ◆ Soil capacity for adsorbing phosphorus from manure spreading is quickly exhausted, leading to a need for new 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 for control
- ◆ Livestock pasture and sheltering patterns
- ◆ Ongoing monitoring to assess impacts and additional management needs

Given the financial constraints faced by most farmers and the food-producing value of agriculture, successful agricultural BMP implementation often depends upon understanding the agricultural operation and finding funding support for capital improvements that benefit the farm as well as the lake.

Factors Favoring or Disfavoring the Use of this Technique

- ◆ Favored when a substantial portion of the P and/or N load is associated with NPS pollution
- ◆ Favored when studies have demonstrated the impact of identifiable sources
- ◆ Favored when land is available for placement of BMPs
- ◆ Favored when farmers have a vested interest in protecting the aquatic environment
- ◆ Favored when agricultural assistance funding is available
- ◆ Disfavored by limits on directly applicable regulations on agricultural activities

Performance Guidelines and Monitoring Needs

- ◆ Collect 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; focus on upstream vs. downstream loads of key contaminants (e.g., N, P, pesticides, pathogens)
- ◆ Monitor storm inputs more than dry weather conditions

Key Considerations for Conservation Commissions

- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ Many agricultural activities are exempt from provisions of the Clean Water Act but may be subject to the WPA if designated resource areas are impacted
- ◆ If activity involves construction or soil disturbance within or adjacent to a wetland buffer zone (limits set by state and/or town bylaw), review by the conservation commission will be required

- ◆ All interests of the WPA are either benefited or unaffected by agricultural BMPs; greater benefit is usually associated with prevention of pollution and storm damage

Massachusetts and Related Experience

White Island Pond is a 291-acre freshwater natural seepage pond in the towns of Plymouth and Wareham in the Buzzards Bay watershed. The pond has two major basins: the 124-acre West White Island Pond (West Basin) and the 167-acre East White Island Pond (East Basin). Poor water quality prompted MassDEP to add the pond to the state's list of impaired waters in 1992 for non-attainment of its primary recreation designated use. Fertilizer applied on nearby commercial cranberry operations was a likely potential cause. MassDEP awarded a CWA section 319 grant in 2001 to the University of MA (UMass) Cranberry Experiment Station to conduct a multi-year field study of P dynamics in commercial cranberry bogs. Water quality monitoring indicated persistent nutrient-related problems in the pond which experienced elevated levels of TP concentrations, frequent algal blooms, low transparency, and beach closures (due to toxic cyanobacteria).

From watershed TMDL studies, it was determined that 24% of the P load was from direct cranberry bog floodwater discharges and an additional 49% was associated with legacy P inputs being released from the sediments of the pond each summer, those likely derived from past bog inputs. Project partners, including cranberry bog owners, implemented BMPs to reduce nutrient inputs. As a result, P concentration in the lake declined by 41% over 4 years of implementation (Mattson 2015, USEPA 2014). A subsequent P inactivation treatment was conducted to manage inputs from legacy P in the sediments, reducing P concentrations by another 44% (Mattson 2015) from pre-program levels, an overall decline from 82 to 12 µg/L. The MA Year 2016 Integrated List of Waters classified the Pond as "4c" "Impairment not caused by a pollutant – TMDL not required", as aquatic plants are still present at nuisance levels, but cited local sources reporting that White Island Pond water remained clear (MassDEP 2019).

Stafford Pond in Tiverton, Rhode Island, is a water supply and recreational lake that suffered from elevated TP concentrations and summer cyanobacteria blooms in the 1990s (ENSR 1997). Elevated inputs from one tributary subject to inputs from a dairy operation were found to be the largest source of P to Stafford Pond, a situation caused by relocation of the dairy herd some years before. An agricultural management program for the dairy operation resulted in a major reduction in manure inputs and improved conditions in the lake, but eventually past inputs caused an increase in internal loading that had to be addressed by a P inactivation program in 2021 (WRS 2021). In-lake P concentration declined from an average of 115 µg/L to 32 µg/L with agricultural management, a 72% reduction. P concentration declined further to 19 µg/L after P inactivation, an additional 11% reduction from pre-program levels and a 41% reduction from post-agricultural management P concentration.

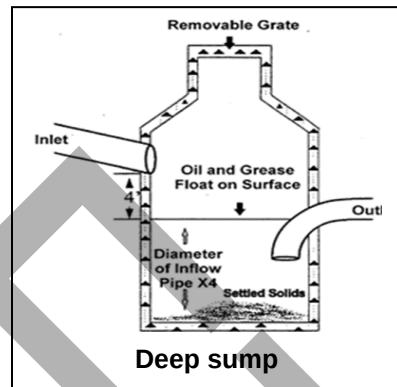
Non-Point Source Controls – Maintained Inlet Devices

How It Works

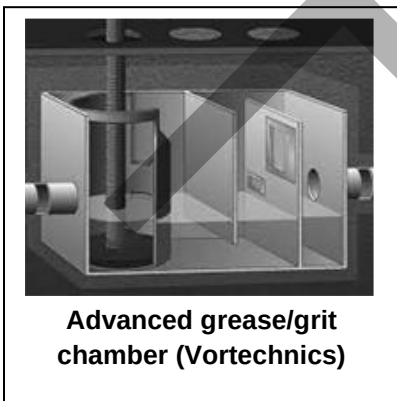
This category covers a wide range of engineered and maintained devices including deep sump catch basins, oil and grease separators, proprietary separators, and other devices designed to provide preliminary filtering or containment of particulate material and petroleum hydrocarbon transported with stormwater runoff. They are less efficient in retaining the fine fraction of the sediment load which usually contains most of the nutrient load. Such systems can trap much of the particulate nutrient load but do not significantly alter dissolved loads. They are generally well suited as retrofits for relatively small areas in developed watersheds. Since they are not generally considered adequate stormwater treatment as a stand-alone system for nutrient reduction, they are typically installed as pre-treatment for other stormwater BMPs. Brief descriptions of the major categories are adapted from the [MA Clean Water Toolkit](#) (MassDEP 2021).

Inlet devices are usually the first structural element in stormwater management and important to overall system function. However, inlet devices are rarely sufficient as the only element of stormwater management where high outlet water quality is desired

Deep Sump Catch Basins, also known as oil and grease or hooded catch basins, are underground retention systems designed to remove and retain trash, debris, and coarse sediment from stormwater runoff, and serve as temporary containment devices for floatables such as oils and greases. Deep sumps provide capacity for sediment accumulation and hooded outlets prevent the discharge of floatables.



Oil/Grit Separators are underground storage tanks with three chambers designed to remove heavy particulates, floating debris and hydrocarbons from stormwater. Stormwater enters the first chamber where heavy sediments and solids drop out. The outflow moves into the second chamber where oils and greases are removed and further settling of suspended solids takes place. Oil and grease are sequestered in this second chamber for removal and disposal. Entering the third outlet chamber, the clarified stormwater runoff is then discharged to a pipe and usually to further treatment by another BMP.



Proprietary Separators are manufactured systems that use a variety of proprietary processes including vortex separation settling, filtration, absorption/adsorption, vegetation, and other processes to meet the MA Stormwater Management Standards to remove sediments and other pollutants. Several rely on a vortex design to enhance sediment removal, using the power of

Inlet Devices

swirling or flowing water to separate floatables and coarser sediments. Other systems rely on filtering mechanisms to augment the settling process. There are a large number of such devices, designed and manufactured by private businesses, and they can be custom sized to accommodate different design storms, drainage areas, and flow conditions. Since proprietary separators can be placed in almost any location on a site, they are particularly useful when either site constraints prevent the use of other stormwater techniques or as part of a larger treatment train.

Inlet devices must be maintained, with periodic clean-out as determined by experience with filling rate. Typically, they must be cleaned regularly, with twice per year (spring/fall) cleaning preferred, but additional cleaning may be required based on device design and runoff load. Street sweeping is complementary and while not essential to device performance, is often integral to pavement management where inlet devices are used as significant pollutant controls.

Possible Benefits

- ◆ Removal of trash, coarse sediments (settleables), oil and grease, and other hydrocarbons (floatables) maximizes discharge aesthetics
- ◆ Credit by the MA Stormwater regulations for 25% TSS removal
- ◆ Greatly extends performance of downstream controls such as detention or infiltration
- ◆ Installation below grade minimizes impacts on land use
- ◆ Proprietary units may be custom-designed to fit site constraints

Possible Detriments

- ◆ Limited pollutant removal; cannot effectively treat soluble pollutants, fine particles or bacteria.
- ◆ Failure to maintain devices may result in little or no removal or clogging and flooding with possible resuspension of pollutants
- ◆ Generally inadequate as the sole nutrient control mechanism
- ◆ Entrapment hazard for amphibians or other small animals

Information for Proper Application

- ◆ Characterization of incoming water quality
- ◆ Proper device size and attributes for expected load and cleaning frequency
- ◆ Assessment of effectiveness in combination with other BMPs in treatment train or as a stand-alone approach
- ◆ Monitoring to assess effectiveness and any need for adjustment

Factors Favoring or Disfavoring the Use of this Technique

- ◆ Favored when a substantial portion of the P and/or N load is documented to be associated with the coarse particulate fraction of runoff load
- ◆ Favored when watershed runoff flows associated with NPS inputs is important to lake hydrology

Inlet Devices

- 4100 ♦ Favored when complementary or supplemental controls (e.g., detention, infiltration) can be
- 4101 incorporated and enhanced by this approach
- 4102 ♦ Disfavored by the absence of proper maintenance

Performance Guidelines and Monitoring Needs

- 4104 ♦ Collect wet and dry weather data necessary to demonstrate the
- 4105 problem, characterize the runoff fractions, and estimate the
- 4106 potential for sediment and nutrient reduction
- 4107 ♦ Design the system to match expected storm flows and account
- 4108 for any site constraints
- 4109 ♦ Develop a stormwater management plan in which inlet
- 4110 devices are one element; do not expect inlet devices to solve
- 4111 all stormwater problems
- 4112 ♦ Develop a maintenance plan including regular catch basin cleaning or street sweeping; regular
- 4113 inspection is necessary with cleaning as needed
- 4114 ♦ Monitor regularly at a scale appropriate to demonstrating results; inlet/outlet sampling may be
- 4115 difficult for subsurface systems and performance of entire system is more important than
- 4116 discrete elements



**Device cleaning is
essential to device
function**

Key Considerations for Conservation Commissions

- 4118 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 4119 Estimated habitat and must be complete before the conservation commission can close any
- 4120 hearing and issue an Order of Conditions under the WPA
- 4121 ♦ If installed as part of site development or if within or adjacent to a wetland buffer zone (limits
- 4122 set by state and/or town bylaw), the device must meet the requirements of the MA Stormwater
- 4123 Standards under the WPA.
- 4124 ♦ A Stormwater Report is required when submitting an application for a Notice of Intent for any
- 4125 project subject to the stormwater-management provisions of the WPA.
- 4126 ♦ Construction outside a wetland resource area creates jurisdictional issues, but if a device results
- 4127 in later impacts on a wetland resource, jurisdiction can be claimed; applicants should be aware
- 4128 of their long-term obligation under the WPA
- 4129 ♦ All the major interests of the WPA are either benefited or unaffected by inlet devices; greater
- 4130 benefit is usually associated with prevention of pollution and storm damage.

Massachusetts and Related Experience

4132 The Town of Wellesley implemented multiple stormwater management techniques with the goal
4133 of reducing NPS pollution in the watershed of Fuller Brook, a tributary of the Charles River. In
4134 2004, Wellesley received funding from MA's CWA section 319 Nonpoint Source Program to
4135 remediate Duck Pond, a small impoundment in a highly developed sub-watershed that had been
4136 identified as a major contributor of pathogens, nutrients and sediment to Fuller Brook. The town

Inlet Devices

4137 implemented several structural and nonstructural BMPs, including 24 deep-sump catch basins with
4138 hoods, five proprietary separators (i.e., Stormceptor® units), and 30 feet of flow distribution pipes
4139 to separate and remove pollutants (e.g., sediment and nutrients) from stormwater runoff. The
4140 completed stormwater structures were estimated to reduce the annual load of sediment by 1,250
4141 tons (USEPA 2010). However, solids loading to Duck Pond have still largely filled this small pond
4142 after about two decades and dredging appears necessary.

4143 A Vortech unit was installed as the first element in a stormwater management system in
4144 Menotomy Rocks Park in Arlington, MA in 1994 to protect the newly dredged Hills Pond. In
4145 conjunction with a wet detention basin built at the edge of the pond, incoming sediment and
4146 nutrient loads were significantly reduced (Fugro 1996). However, space limitations in the park
4147 prevented all stormwater controls from being implemented and limited maintenance reduced long-
4148 term effectiveness. The pond has not refilled with sediment, but algae and rooted plant control has
4149 been necessary in recent years as documented on the website of the Town of Arlington.

4150

Non-Point Source Controls – Buffers and Swales

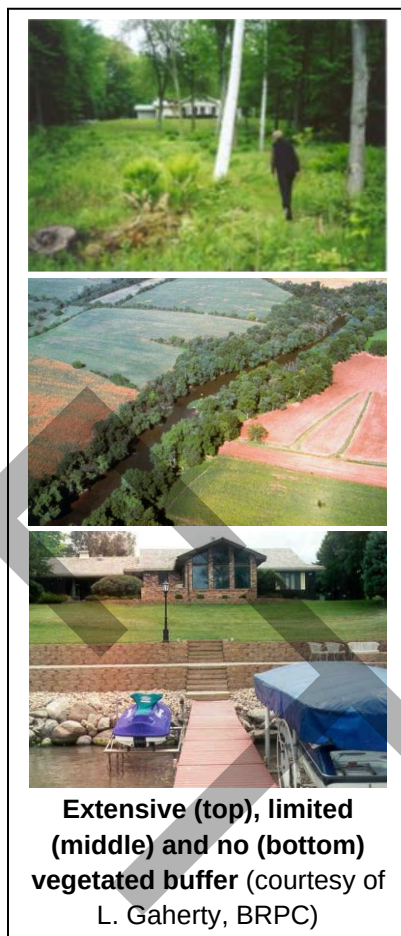
How it Works

Vegetated buffer strips (also known as filter strips) are areas of natural vegetation that treat or mitigate storm runoff from adjacent impervious areas or other intensive land use. They are "living filters," because they capture many of the pollutants that travel through them. Water quality swales, which include both dry and wet types, are vegetated open channels designed to treat the required water quality volume and to convey runoff from a design storm (usually 10-year) without causing erosion. Brief descriptions of the major categories below are adapted from Best Management Practices Fact Sheets available from the [MA Clean Water Toolkit](#).

Vegetated buffer strips

Vegetated buffer or filter strips are uniformly graded vegetated surfaces (i.e., grass or close-growing native vegetation) that typically treat sheet flow or small concentrated flows that can be distributed along the width of the strip using a level spreader. They reduce soil erosion by filtering out a fraction of the particulates, increase infiltration, and decrease the velocity of the storm water. Plant root systems and chemical and biological activity in the soil can capture nutrients and other pollutants and transform them into less harmful forms. Vegetated strips are often placed along streams and other bodies of water that need protection from erosion and sedimentation (see also Agriculture BMP technique section). They are commonly used as pretreatment for other stormwater devices. Vegetative buffer zones can also be used to protect natural swales and be incorporated into natural landscaping of an area. Simply leaving a naturally vegetated area along the stream or lake margin is beneficial, but carefully designed buffers can enhance pollution control.

To be effective the vegetated buffer strips need to be at least 25 ft wide before any appreciable benefit (i.e., 10% TSS removal) is assigned, and superior filtration (i.e., $\geq 45\%$ TSS removal) requires a width of 50 ft or more. Nutrient removal efficiencies are poorly quantified, but filter strips may remove nutrients and metals depending on the length and slope of the filter, soil permeability, size and characteristics of the drainage area, type of vegetative cover, and runoff velocity. Buffers along streams and lakes provide wildlife corridors as well as erosion control, especially on steep slopes. In residential areas, buffer zones can act as a visibility and noise screen and provide aesthetic benefits. Buffers therefore provide a range of



4188 desirable benefits, but nutrient control is not substantial and buffers by themselves are inadequate
4189 to protect lakes from N and P inputs.

4190 **Water Quality Swales**

4191 Water quality swales are vegetated open channels designed
4192 to treat the estimated water quality volume from a site and to
4193 convey runoff from a design storm without causing erosion.
4194 Unlike conventional drainage channels used only for
4195 conveyance, water quality swales and grass channels are
4196 designed to treat the required water quality volume and
4197 incorporate specific features to enhance their stormwater
4198 pollutant removal effectiveness. Roadside swales provide
4199 additional water quantity control benefits, such as reducing
4200 vehicular driving hazards by diverting stormwater flows away from street surfaces, but by
4201 themselves are not likely to provide adequate water quality improvement. There are two different
4202 types of water quality swales that may be used to satisfy the requirements of the MA Stormwater
4203 Management Standards: dry swales and wet swales.



Roadside, vegetated swale

4204 Dry swales are designed to temporarily hold the water quality
4205 volume of a storm in a pool or series of pools created by
4206 permanent check dams at culverts or driveway crossings. The soil
4207 bed consists of native soils or highly permeable fill material,
4208 underlain by an underdrain system. In contrast, wet swales also
4209 temporarily store and treat the storm water quality volume, but
4210 they are constructed directly within existing soils without a soil
4211 filter bed or underdrain system. Wet swales typically store the
4212 water quality volume in pools within the channel, which may be
4213 formed by berms or check dams and may contain wetland
4214 vegetation. The pollutant removal mechanisms in wet swales are
4215 similar to those of constructed stormwater wetlands, which rely
4216 on sedimentation, adsorption, and microbial breakdown.



**Newly established swale
with stabilization mesh
supporting vegetation
growth**

4217 Both vegetated buffers and wet and dry swales are reasonably
4218 effective at removing TSS (50- 70% removal). Reported removal rates for nutrients (total P and
4219 total N) are not as effective. The online database for stormwater [BMP performance](#) provides
4220 average ranges for removal efficiency. For vegetative buffers, removal of P was not significant
4221 and N removal averaged 13.6%. However, buffer width and vegetation details are very important
4222 to performance and better removal can be achieved. For dry grass swales, P removal was not
4223 significant and N removal was 11.3% while for wet swales, P removal averaged 8.5% and N
4224 removal was 17.6%. Swales may also provide some infiltration that is not part of the credited
4225 nutrient reductions. Both buffers and swales can be effective in solids transport reduction.

4226 **Benefits**

- 4227 ♦ Relatively simple to build and maintain
- 4228 ♦ Passively removes sediments and some nutrients without long detention of flow
- 4229 ♦ Processes flow in a way compatible with many other NPS controls that can be added
- 4230 downstream
- 4231 ♦ Can provide substantial wildlife habitat value as well as erosion control
- 4232 ♦ Buffers can blend aesthetically into the landscape and provide noise and visibility screens

4233 **Possible Detriments**

- 4234 ♦ Vegetated buffers require substantial land area to be effective (e.g., 25-50 ft width minimum)
- 4235 ♦ Little or no treatment is provided if the filter strip is short-circuited by concentrated flows
- 4236 ♦ Impractical in areas with steep topography or very flat grades
- 4237 ♦ Wet swales can produce mosquito breeding habitat
- 4238 ♦ Nutrient removal is limited
- 4239 ♦ Maintenance may reduce effectiveness until vegetation re-grows

4240 **Information for Proper Application**

- 4241 ♦ Climatic and drainage area data to provide estimate of maximum hydrologic loading
- 4242 ♦ Water quality data with separation of particulate and dissolved fractions, to allow estimation
- 4243 of needed width or length
- 4244 ♦ Ground slopes, soil types, and planned vegetative cover to allow removal estimation

4245 **Factors Favoring or Disfavoring the Use of this Technique**

- 4246 ♦ Favored when a substantial portion of the P and/or N load is associated with NPS pollution
- 4247 ♦ Favored when studies have demonstrated the impact of roads or lawn areas addressed
- 4248 ♦ Favored where erosion is a major source of contaminants
- 4249 ♦ Favored where land is available for placement of BMPs
- 4250 ♦ Disfavored where additional water quality controls are not planned
- 4251 ♦ Favored where habitat is also a management consideration

4252 **Performance Guidelines and Monitoring Needs**

- 4253 ♦ Collect the data necessary to demonstrate the problem and potential for improvement
- 4254 ♦ Design buffers and swales to meet demonstrated needs; sizing is a key consideration
- 4255 ♦ Consider habitat and aesthetic functions as well as water quality benefits
- 4256 ♦ Use only native species in planting programs
- 4257 ♦ Develop a regular maintenance plan and monitor regularly at scale and locations appropriate
- 4258 to demonstrating results; focus on contaminants of interest, most likely TSS, P, and N.

Key Considerations for Conservation Commissions

- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ Most buffers will be established in the buffer zone and not in an actual wetland resource area
- ◆ Most swales are along roadways and may not be within the jurisdiction of the conservation commission
- ◆ If installed as part of site development or if within or adjacent to a wetland buffer zone (limits set by state and/or town bylaw), the device must meet the requirements of the MA Stormwater Standards under the WPA.
- ◆ A Stormwater Report is required when submitting an application for a Wetlands Notice of Intent for any project subject to the stormwater-management provisions of the WPA.
- ◆ All interests of the WPA are either benefited or unaffected by buffers and swales, with the possible exception of groundwater quality protection if infiltration occurs in the buffer or swale.

Massachusetts and Related Experience

Vegetated buffers and water quality swales are common constituents of watershed-based nutrient reduction plans, typically focusing on reducing and treating runoff from impervious surfaces prior to entry into waterbodies. Vegetated buffers are effective in reducing the ecological and aesthetic impact of shoreline development to the lake edge by reducing soil and nutrient retention and preserving shoreline integrity but engineering the buffer zone immediately adjacent to a lake or tributary may not be desirable for habitat reasons where natural vegetation already exists. Water quality swales are typically used to divert runoff from streets and parking and are a common element incorporated into the design of residential development to meet MA Stormwater Standards. Due to their relatively small size, these BMPs are, individually, unlikely to provide significant reductions of nutrients loads. However, as integral parts of a watershed-based plan, they could provide some reduction of cumulative watershed inputs.

Conservation commissions in MA have usually been sensitive to the need to protect the land immediately adjacent to lakes and streams, mostly buffer zone under the WPA where Bordering Vegetated Wetland is not present. Keeping the buffer zone natural is desirable, and engineered buffer zones are most advantageously applied outside the buffer area as defined by the WPA, Riverways Act, and local bylaws. But where damage has already been done by heavy foot traffic or vegetation clearing, creating an engineered buffer zone may provide acceptable protection, at least from erosion. Swales are especially useful along dirt roads to capture solids while limiting flood hazards but need to direct the water to some additional treatment system to maximize nutrient removal. New development or redevelopment subject to the MA Stormwater Standards will find buffers and swales to be useful elements of a more comprehensive management plan. Likewise,

Buffers and Swales

4296 municipalities subject to Stormwater NPDES permits will also find buffers and swales beneficial,
4297 just not adequate by themselves to meet any nutrient control requirements.

4298 The Berkshire Regional Planning Commission prepared the [Massachusetts Buffer Manual](#) for
4299 MassDEP in 2003 and included examples from around the Commonwealth. While smaller buffers
4300 were noted as valuable for bank stabilization and fish habitat, buffers in excess of 125 ft in width
4301 were viewed as necessary for significant nutrient control and maximum buffer value is not
4302 achieved until a width of 300 ft.

4303 The [LakeSmart Program](#), developed in Maine and applied in New Hampshire as well, focuses
4304 on shorefront properties and finds buffers and swales to be very important to erosion control near
4305 shorelines and along roads, particularly unpaved “camp roads” that may not be regularly
4306 maintained by municipalities.

4307

Non-Point Source Controls – Detention

How It Works

Detention covers a range of engineered structures that are designed to temporarily store and then slowly release stormwater runoff over a defined period of time (usually 12-72 hours). Detention devices include dry detention basins (both conventional and extended), wet detention basins, and bioretention areas (including rain gardens). Pollutant removal is accomplished mainly through settling and biological uptake, although incorporation of infiltration capacity can increase pollutant removal, peak flow control and volume reduction capabilities. Design features are extremely varied and depend on size, pollutant removal goals, regional climate, and localized site conditions. Detention facilities can range from large ponds of several acres with multiple forms of aquatic habitat to micro-level rain gardens. Brief descriptions of the major categories are adapted from the [MA Clean Water Toolkit](#).

Conventional Dry Detention Basin is an impoundment or excavated basin for the short-term detention of stormwater runoff, usually from developed areas, that allows a controlled release downstream from the structure at pre-development flow rates. Their primary function is flood control. Conventional dry detention basins typically control peak runoff for 2-year and 10-year 24-hour storms and will have outlet structures to passively control the rate at which outflow is released from the basin. This can help decrease downstream flooding, erosion and scour. Dry detention basins are not designed to provide extended dewatering times, standing wet pools, or groundwater recharge and have limited pollutant removal capabilities. They may support growth of vegetation, possibly even wetland species, which may provide some additional pollutant trapping. Dry detention ponds have less potential to support mosquito nuisances and provide greater detention capacity per unit cost, but do not improve water quality to the extent that other detention designs can offer.



Dry detention basin (above)
and flow control outlet (below)



Extended Dry Detention Basins are modified conventional dry detention basins, designed to hold stormwater for at least 24 hours to allow solids to settle and to reduce local and downstream flooding. Extended dry detention basins may be designed with either a fixed or adjustable outflow device. Pretreatment is a fundamental design component of an extended dry detention basin to reduce the potential for clogging. Extended dry detention basins may also incorporate other components such as a micro pool or shallow marsh to enhance pollutant removal (see <https://megamanual.geosyntec.com/npsmanual/extendeddrydetentionbasin.aspx>).

Detention

Wet Detention Basins use a permanent pool of water as the primary mechanism to treat stormwater. Wet Detention Basins are commonly also referred to as retention basins. 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. The pool allows sediments to settle (including fine sediments) and removes some soluble pollutants. Wet basins must have additional dry storage capacity to control peak discharge rates. Wet basins have a moderate capacity to remove most urban pollutants, depending on how large the volume of the permanent pool is in relation to the runoff from the surrounding watershed. Continued performance of wet detention basins may require maintenance, as the build-up of sediment will reduce capacity and may cause low oxygen conditions that promote P release.



Wet detention basin

Bioretention Areas and Rain Gardens use soil, plants, and microbes to treat stormwater before it is infiltrated or discharged. Bioretention areas are usually small, shallow depressions filled with sandy soil, topped with a thick layer of mulch, and planted with dense vegetation. Stormwater runoff flows into the bioretention area, percolates through the soil (which acts as a filter) and eventually drains into the groundwater; some of the water is also absorbed by the plants. Overflow may be facilitated in some cases. Bioretention areas are usually designed to hold a small volume of ponded water with an overflow outlet to prevent flooding during larger storm events. Properly designed bioretention areas will remove suspended solids, metals, and nutrients and are effective at pollutant removal and recharge for the "first flush" of stormwater runoff. Distributed around a residential property, bioretention areas can enhance site aesthetics and are often marketed as property amenities. Routine maintenance is simple and can be handled by homeowners or landscape companies.



Small bioretention area/rain garden (above) and larger, more elaborate area (below)



Other Design Considerations an important consideration for installation of basins is that the amount of land required for the installation of effective basins is typically large. For example, 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 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

Detention

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.

Another important consideration for detention facilities is the degree of interaction with groundwater. The [MA stormwater handbook](#) encourages maintaining natural levels of groundwater recharge in developed areas but includes provisions for limiting the impact of infiltrating stormwater on groundwater quality. While passing runoff through soil can be a very effective pollutant removal mechanism, design will need to avoid simply converting a surface water problem into a groundwater issue.

Removal rates for pollutants varies widely among the various design types. Dry detention basins provide little in terms of nutrient reduction, except perhaps indirectly by reducing channel scouring flows that can erode bank sediment downstream. Wet detention basins work more effectively in pollutant retention when properly constructed and maintained. Removal efficiencies reported include: for TSS - 80% with sediment forebay, for TN - 10% to 50%, for TP - 30% to 70%, for metals (copper, lead, zinc, cadmium) 30% to 75%, and pathogens (coliform, *E. coli*) 40% to 90% (see <https://www.mass.gov/doc/MA-stormwater-handbook-vol-2-ch-2-stormwater-best-management-practices/download>). Rain gardens may provide superior removal, but data are scarce. The online database for detention basin performance (see <https://BMPdatabase.org>) provides extensive detail on features, removal mechanisms, and ranges of removal efficiency for a variety of contaminants and indicates that removal of TP or TN removal by detention does not usually average more than 50%. Other treatment processes, such as media filtration, wetland processes, or chemical additives are needed to lower nutrient concentrations to desirable levels.

Possible Benefits

- ◆ Provides flood protection as well as water quality enhancement
- ◆ Can provide significant nutrient reduction (wet ponds)
- ◆ Generally passive removal with potentially limited maintenance needs
- ◆ Bioretention areas can be easily incorporated or retrofitted into residential areas and require small land areas
- ◆ Can provide habitat value and blend aesthetically with landscape

Possible Detriments

- ◆ Adequate basin construction may require substantial land area
- ◆ Construction problems are common in areas of high ground water or abundant bedrock
- ◆ Depth of pool may require restrictive fencing for public safety
- ◆ Wet ponds may become mosquito breeding areas or collect trash

Information for Proper Application

- ◆ Climatic and drainage area data to provide estimate of variability in hydrologic loading

Detention

- 4419 ♦ Water quality data with characterization of particulate, colloidal and dissolved fractions, to
- 4420 allow estimation of needed detention time and supplemental features (e.g., plantings, outlet
- 4421 features, additional treatment)
- 4422 ♦ Soil types, ground water depth and related data for construction planning
- 4423 ♦ Monitoring to assess effectiveness and any need for adjustment

Factors Favoring or Disfavoring the Use of this Technique

- 4425 ♦ Favored when a substantial portion of the P and/or N load is associated with NPS pollution
- 4426 ♦ Favored when studies have demonstrated the impact of identifiable sources
- 4427 ♦ Favored when water associated with NPS inputs is important to lake hydrology
- 4428 ♦ Favored when land is available for placement of sufficiently sized detention system
- 4429 ♦ Disfavored if detention results in groundwater contamination or raises groundwater level in a
- 4430 manner that affects nearby structures (e.g., residential basements, underground utilities)
- 4431 ♦ Disfavored if high degree of treatment is needed to meet water quality standards unless
- 4432 additional treatment processes are included

Performance Guidelines and Monitoring Needs

- 4434 ♦ Collect wet and dry weather data necessary to demonstrate the problem, characterize the runoff
- 4435 fractions, and estimate the potential for sediment and nutrient reduction
- 4436 ♦ Design the system to meet demonstrated needs; consider flood prevention and water quality
- 4437 enhancement, providing appropriate capacity and rate of through-flow
- 4438 ♦ Develop a maintenance plan with short- and long-term provisions
- 4439 ♦ Monitor inflow and outflow concentrations of targeted contaminants to demonstrate results
- 4440 until an adequate track record is established

Key Considerations for Conservation Commissions

- 4442 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 4443 Estimated habitat and must be complete before the conservation commission can close any
- 4444 hearing and issue an Order of Conditions under the WPA
- 4445 ♦ If installed as part of site development or if within or adjacent to a wetland buffer zone (limits
- 4446 set by state and/or town bylaw), the device must meet the requirements of the MA Stormwater
- 4447 Standards included in the [MA stormwater handbook](#)
- 4448 ♦ A Stormwater Report is required when submitting an application for a Wetlands Notice of
- 4449 Intent for any project subject to the stormwater-management provisions of the WPA
- 4450 ♦ A NPDES permit from EPA may be required under special circumstances; consult with
- 4451 MassDEP on possible need
- 4452 ♦ All interests of the WPA are either benefited or unaffected, with the possible exception of
- 4453 groundwater quality protection if infiltration occurs in the detention area

4454 **Massachusetts and Related Experience**

4455 Detention basins are a very common component of the developed landscape, providing valued
4456 flood control and some pollutant loading reduction. Removal rates for N and P do not tend to be
4457 very high and detention areas can actually become a source of nutrients if not maintained, as
4458 nutrient-rich sediment accumulates and is subject to decomposition and redox reactions that can
4459 add nutrients to the water column. Yet the flood control function is quite valuable, and as part of
4460 a more complete stormwater treatment system, water quality of the outflow can be greatly
4461 improved.

4462 Detention basins are routinely created as part of construction projects, often just as temporary
4463 features to capture solids during earth moving activities but sometimes as permanent features of
4464 the developed landscape for post-construction water quality control. Monitoring of detention
4465 facilities in MA as part of the NPDES program for construction permitting has generally
4466 demonstrated much reduced TSS loads, but nutrient control beyond that associated with
4467 particulates has not been a focus of these detention systems. Where fine sediment was not settling
4468 adequately in detention areas, polymers, alum, or other coagulants have been added at the inlet to
4469 enhance settling, and this has been found to depress P concentrations in outflows. Monitoring,
4470 however, rarely focuses on water quality features beyond solids.

4471 Most detention basins created as permanent features of residential or commercial areas are dry
4472 detention facilities, as a permanent wet pool tends to breed mosquitoes. Use of existing natural
4473 wetlands for detention is generally prohibited under the WPA and creation of a wet detention area
4474 in an upland setting requires more engineering to maintain a pool. Where water is retained,
4475 detention areas tend to become treatment wetlands, an approach discussed separately in this guide.

4476 A wet detention basin was built within the boundary of Hills Pond in Menotomy Rocks Park in
4477 Arlington, MA in the early 1990s to receive stormwater after passage through a Vortech until
4478 for solids removal but before entry to the pond. A wetland filter was added on the pond side of the
4479 detention area. Total P reduction from 200 ppb in water entering the detention basin to 20 ppb in
4480 the pond was documented in the first couple of years after installation (Fugro 1996), but this
4481 included dilution as well as any actual P capture.

4482

Non-Point Source Controls – Infiltration/Filtration

How It Works

Water quality impacts to lakes due to storm runoff has been clearly linked to the portion of the watershed that is impervious (USEPA 2021). Some natural surfaces such as clay soil, muck soils, and exposed rock are functionally impervious, while anthropogenic surfaces such as roads, parking lots, driveways, and roofs are major sources of runoff in developed watersheds. A variety of factors influence the magnitude of impact from impervious surfaces, including slopes and level of connectedness between impervious surface and water resources, but general thresholds have emerged after years of research and observation. 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 impacts can be reduced by narrowing roadways, limiting development footprints, preventing soil compaction, eliminating curbs and gutters, and incorporating infiltration methods wherever feasible. Infiltration systems may include infiltration trenches or basins, leaching catch basins, dry wells, porous pavers, or related devices that enhance the infiltration of water into the soil or pass runoff through a filtration medium, usually sand or related porous media. Particles are filtered by the soil matrix and many soluble compounds are adsorbed to soil particles or matrix media. Brief descriptions of these practices, adapted from the [MA Clean Water Toolkit](#) (MassDEP 2021), are given below. TSS and nutrient removal efficiencies for various techniques are available from the [International Stormwater BMP database](#) and infiltration/filtration through porous media provides the highest removal of all watershed BMPs.

Infiltration trenches are shallow excavations filled with gravel or larger stone designed to capture sheet flow or piped inflow. The interstitial spaces in the solid media provides temporary underground storage for stormwater runoff. The stored runoff gradually exfiltrates through the bottom and/or sides of the trench into the subsoil and eventually into the water table. Pretreatment of the runoff is usually advisable as it helps prevent failure of the infiltration system due to clogging and sediment accumulation. Pretreatment may also be necessary to meet discharge requirements under the MA Stormwater Standards. Detention basins may be modified to create greater infiltration, combining the benefits of two management approaches.



Infiltration trench

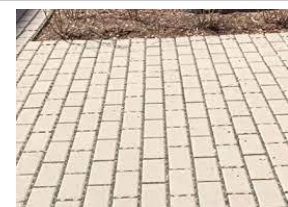
Leaching catch basins are catch basins fabricated of barrel and riser sections that permit the infiltration of runoff into the ground. A leaching basin is a similar device, installed adjacent to a deep sump catch basin that provides pretreatment. Because of this pretreatment, the catch basin/leaching basin combination is preferable to the leaching catch basin, slowing the rate of clogging and limiting the movement of some contaminants into the groundwater. Leaching catch basins and leaching basins are used in areas with highly permeable soils; overflow of these devices in larger storm events is possible and relatively little of the runoff will be infiltrated if the soils are not porous.



Leaching catch basin vaults

Dry wells are small, excavated pits, backfilled with aggregate, and used to infiltrate uncontaminated (“clean”) runoff from impervious areas of limited probability of contamination, like roofs made from relatively inert material. Dry wells should not be used to infiltrate any runoff that could be significantly contaminated with sediment and other pollutants, including parking lot runoff. Dry wells are also generally considered inappropriate in areas of groundwater supply.

Porous pavement is a paved surface constructed from substances with a large percentage of air voids to allow water to pass through it and infiltrate into the subsoil. This porous surface replaces traditional pavement, allowing runoff to infiltrate directly into the soil and receive water quality treatment. Permeable paving materials include porous asphalt, pervious concrete, paving stones, and manufactured “grass pavers” made of concrete or plastic. Permeable paving is widely used for walkways, plazas, driveways, patios, parking stalls, and overflow parking areas.



Porous Pavement
(Source: USEPA)

Porous filter media provide the benefits of infiltration without necessarily putting the water into the soil. The media may be built into an outlet berm for a detention area or any number of “cartridge” configurations that allow insertion into a catch basin opening, channel, or other runoff stream. Media include sand, modified sand (impregnated with highly adsorptive materials), or synthetic materials designed to remove a wide range of contaminants. Runoff passes through the filter media the same way it might infiltrate soil, but emerges as surface or piped flow after passage, not groundwater recharge. There has been considerable advancement in recent years with regard to filter media packaging and use, with high rates of removal for many contaminants, especially P. However, the runoff must pass through the filter medium, creating a challenge under high flow situations. The combination of porous filter media with detention systems appears to work best, allowing more control over the rate of flow and reducing clogging.



Filter berm acting as outlet for a detention area

Infiltration/Filtration

Many media filtration systems are proprietary (for examples, see <https://www.sepro.com/aquatics/eutrosorb>, <https://asfiltermedia.com/stormwater>, and <https://www.conteches.com/stormwater-management/treatment/stormwater-management-stormfilter>).

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 soil characteristics is essential when planning infiltration facilities. In sites with suitable conditions, off-line infiltration systems are generally preferred (i.e., infiltration device is the terminus of treatment process). Media filtration can still be used if soil permeability is low at the site, as the treated runoff is returned to surface flow. As noted above, one key to successful infiltration/filtration is providing adequate pretreatment to remove particles that could otherwise clog the interface at which infiltration/filtration occurs. Another key is having sufficient runoff detention capacity to allow delivery of runoff to the infiltration/filtration surface at a manageable rate that maximizes performance. Both key factors can be met by combining adequate detention facilities with infiltration systems.



Infiltration devices are generally credited with 80% TSS removal but nutrient removal is less effective. Removal rates for P tend to be moderate, with reported averages of 46% and 41% removal by infiltration through sand and porous pavement, respectively, near the actual facility. P removal rates can be much higher if the infiltrated runoff then passes through more soil for a substantial distance before reaching either the groundwater or a lake, much as for an onsite wastewater disposal system. Total nitrogen removal is more limited (e.g., non-significant to 16%) with little reduction of dissolved forms. Filtration through manufactured porous media can improve P removal rates, but P removal in excess of 50% is still uncommon, and N removal usually remains low.

Benefits

- ◆ Removes many contaminants besides nutrients
- ◆ Can be used to minimize runoff and maximize ground water recharge
- ◆ High P removal possible based on multiple processes in soil or artificial media
- ◆ Can include underground leaching galleries to minimize surficial land use
- ◆ Can be combined with detention facilities for extended and improved performance

Detriments

- ◆ Poor removal of mobile dissolved nitrogen in most cases
- ◆ May contaminate groundwater with mobile pollutants present in runoff
- ◆ Requires substantial land area; may interfere with surface uses if not subterranean

Infiltration/Filtration

- 4591 ♦ May require substantial detention capacity or not work at all if soils/media are not sufficiently
- 4592 permeable
- 4593 ♦ May raise the localized groundwater table with possible issues for local structures
- 4594 ♦ May clog if not adequately maintained; pretreatment of influent is often necessary for optimal
- 4595 performance

Information for Proper Application

- 4597 ♦ Drainage area and climatic data to estimate range of expected hydrologic loading
- 4598 ♦ Water quality data of source runoff for evaluating possible impacts on groundwater
- 4599 ♦ Soil conditions, drainage slope, and groundwater table elevation to evaluate efficacy of
- 4600 infiltration and determine design criteria
- 4601 ♦ Selection of appropriate filter media to address contaminants of interest
- 4602 ♦ Maintenance plan with monitoring to assess when maintenance is needed

Factors Favoring or Disfavoring the Use of this Technique

- 4604 ♦ Favored where a substantial portion of the P and/or N load is associated with NPS pollution
- 4605 and studies have demonstrated the impact of identifiable sources
- 4606 ♦ Favored when sizing and pollutant removal functions will make a difference to loading
- 4607 ♦ Favored where land is available for placement of infiltration/filtration facilities
- 4608 ♦ Favored where detention capacity is available to hold excess runoff until it can be
- 4609 infiltrated/filtered
- 4610 ♦ Disfavored where infiltration is limited by soil features or where it could cause local flooding
- 4611 problems, wet basements, or structural damage
- 4612 ♦ Disfavored where infiltration may cause groundwater quality deterioration, especially where
- 4613 groundwater is a source of potable water

Performance Guidelines and Monitoring Needs

- 4615 ♦ Collect the data necessary to demonstrate the problem and potential for improvement
- 4616 ♦ Design the system to meet demonstrated needs; provide trapping for solids that may clog
- 4617 systems and appropriate storage capacity for expected processing rate
- 4618 ♦ Evaluate possible groundwater impacts; adhere to MA Stormwater Policy
- 4619 ♦ Develop a maintenance plan that includes annual or semi-annual inspection and cleaning as
- 4620 warranted
- 4621 ♦ Monitor at locations appropriate to demonstrating results; focus on water quality variables of
- 4622 concern, most often P and N, but potentially solids and bacteria as well

Key Considerations for Conservation Commissions

- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ If installed as part of site development or if within or adjacent to a wetland buffer zone (limits set by state and/or town bylaw), the device must meet the requirements of the MA Stormwater Standards under the WPA
- ◆ A Stormwater Report is required when submitting an application for a Notice of Intent for any project subject to the stormwater-management provisions of the WPA
- ◆ Construction outside a wetland resource area creates jurisdictional issues, but if a device results in later impacts on a wetland resource, jurisdiction can be claimed; applicants should be aware of their long-term obligation under the WPA
- ◆ All the major interests of the WPA are generally benefited or unaffected by properly maintained infiltration/filtration devices but there can be some risk to groundwater quality

Massachusetts and Related Experience

Infiltration has been widely applied where soils were suitable, most notably on Cape Cod and much of southeastern MA. Application is much less frequent in the Berkshires, where soils are much less permeable. Proper sizing, construction, provision of overflow passage, and maintenance, including avoiding compaction of the infiltration area during construction and any subsequent maintenance, have been emphasized in project reviews.

Sunset Lake is a 57-acre lake located in urban Braintree that suffered from bacterial contamination issues, eutrophication, and nuisance aquatic plant growth. Land uses within Sunset Lake's 245-acre urbanized watershed include high-density residential, as well as the local high school and athletic fields. Polluted stormwater runoff from adjacent parking led to high bacteria levels resulting in several beach closings during each swimming season and Sunset Lake was placed on the 1992 Clean Water Act (CWA) section 303(d) list of impaired waters.

In 2011, MassDEP received a USEPA CWA Section 319 grant to improve the water quality of Sunset Lake by reducing stormwater runoff into the lake, particularly bacterial and nutrient pollution. Both structural and nonstructural BMPs were implemented as part of this project. The structural BMPs included many applications focusing on infiltration including one water quality swale, four rain gardens, and three areas of permeable pavers. Installation of the BMPs led to improved conditions. Eroded areas on the beach from the direct discharge of stormwater were eliminated. Despite occasional heavy rains, there has been only one exceedance of bacterial standards since the project was completed in 2012. The reduced frequency of beach closures indicates that bacteria are being removed by the BMPs. The total project cost was \$157,330. (USEPA 2016).

Lake Lorraine in Springfield, MA, is a kettlehole lake in an urban area with very sandy soils. Seven stormwater drainage discharge systems, each serving a long street set perpendicular to the lake, discharge to the waterbody. While water quality remained acceptable for most uses into the 1990s, concern over ongoing loading assessed as part of a diagnostic/feasibility study conducted with state funding led to the installation of leaching catch basins after the most downstream catch basins in each stormwater collection system under the auspices of the Pioneer Valley Planning Commission. There was adequate elevation above the lake and water table and distance to the lake to allow for considerable pollutant removal. The leaching basins overflow to the stormwater discharge pipes, allowing excess runoff from higher intensity storms to overflow to the lake and avoid flooding.

The quantity of runoff was reduced after installation, with the first half-inch of runoff estimated to be infiltrated. Monitoring of storm drain discharges indicated improved quality, as the first flush of stormwater was mostly infiltrated, and dilution improved any overflow quality. However, maintenance of these systems has been minimal, and an assessment of leaching basin condition a decade later indicated that more than half the capacity has been lost to sediment and one manhole access point had been paved over.

Most Cape Cod towns use leaching catch basins or similar infiltration facilities to minimize flow of runoff from roads to surface waterbodies. Most have functioned well, with very little overland runoff reaching most lakes, but impacts on groundwater are not well known and the level of maintenance for facilities varies tremendously and is generally low.

Minneapolis, MN, has documented multiple infiltration projects from the metropolitan area (MN PCA 2022). Reductions in P and sediment input to urban lakes, a priority in that area, have been measured, with a low of 25% P removal and a high of 90% P removal for individual projects. Re-use of some processed water for irrigation minimizes the use of potable water for irrigation of ballfield turf, so benefits extend beyond pollution control.

Filtration through porous media is a newer approach still being advanced, although parking lot drainage from the Bay Colony area west of Hobbs Brook Reservoir in Waltham, a reservoir in the Cambridge water supply system, has had a filter berm at the downstream end of a large detention area for over two decades. In other applications, various media have been packaged in cartridges, layered sheets, “socks”, and other forms for use in catch basins, channels and streams. The greatest drawback has been getting all the flow to pass through the media containment system, as flows can increase rapidly in response to storms in urban areas and clogging remains an issue. Yet removal of contaminants, especially P, is higher for such media than any other structural control method (Clary et al. 2020).

Non-point Source Controls - Constructed Wetlands

How it Works

Constructed stormwater wetlands are wetland systems that maximize the removal of pollutants from stormwater runoff through vegetative filtration, nutrient uptake, soil binding, bacterial decomposition, and enhanced settling. Constructed stormwater wetlands temporarily store runoff in shallow pools that support conditions suitable for the growth of wetland plants. Much of the effectiveness of the treatment is related to microbial action; the plants act more as the substrate than the active pollutant removers, but removal rates are higher in the presence of plants.

Constructed stormwater wetlands may be designed as through flow systems with permanent pools for both treatment and storage of peak flows. Types of constructed wetland, in approximate order of decreasing drainage area requirements, include shallow marsh systems, basin/wetland systems, extended detention wetlands, pocket wetlands, and gravel wetlands. Constructed stormwater wetlands can also be designed as off-line systems with first flush stormwater runoff diverted to the wetland or higher storm flows routed around the wetland. To preserve their long-term effectiveness, MassDEP requires incorporation of a sediment forebay as pretreatment for all constructed stormwater wetlands.

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

Importantly for applications in MA, constructed treatment wetlands can function effectively in cold environments, mainly as a function of subsurface flow and related microbial uptake, adsorption, and filtration processes. The 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. Nutrient removal is variable depending on the type of wetland installed. In conventional shallow marsh or basin/wetland systems, total P removal may reach 50-60%. Nitrogen removal is lower but also variable, with averages on the order of 25-30% (Clary et al. 2020). Decay of vegetation in the wetland may raise nutrient export during late summer or fall. Useful information is available from the [MA Clean Water Toolkit](#) and [USEPA constructed wetlands](#) website.

Benefits

- ◆ Combines features of emergent wetlands, ponds, and groundwater for pollutant removal
- ◆ Higher pollutant removal efficiencies for soluble pollutants and particulates than many other structural BMPs
- ◆ Relatively low maintenance needs
- ◆ Provides supplemental wetland habitat area

4729 **Detriments**

- 4730 ♦ Depending upon design, may require more land than other BMPs
- 4731 ♦ Relatively high construction costs compared to other BMPs
- 4732 ♦ Some seasonal component to removal efficiency, although subsurface flow can offset this in
- 4733 many cases.
- 4734 ♦ May have net release of nutrients during hydraulic washout after decay periods
- 4735 ♦ Lower pollutant removal efficiencies until vegetation is well established
- 4736 ♦ May create a potential breeding habitat for mosquitoes

4737 **Information for Proper Application**

- 4738 ♦ Soil conditions and groundwater table elevation, to evaluate
- 4739 efficacy of wetland maintenance and determine design criteria
- 4740 ♦ Drainage area and climatic data to estimate range of expected
- 4741 hydrologic loads
- 4742 ♦ Water quality data for evaluating possible impacts on
- 4743 groundwater and special design needs for maximizing pollutant
- 4744 removal

4745 **Factors Favoring or Disfavoring the Use of this Technique**

- 4746 ♦ Favored when land is available for placement of wetlands and
- 4747 detention capacity can hold a substantial portion of the targeted
- 4748 runoff
- 4749 ♦ Favored when substantial portion of the P and/or N load is
- 4750 associated with NPS pollution and studies have demonstrated the impact of identifiable sources
- 4751 ♦ Favored where maximum nitrogen removal is desired
- 4752 ♦ Disfavored if detention and/or infiltration will cause local flooding problems, wet basements,
- 4753 or structural damage
- 4754 ♦ Disfavored where infiltration may cause groundwater quality deterioration

4755 **Performance Guidelines and Monitoring Needs**

- 4756 ♦ Collect the data necessary to demonstrate the problem and potential for improvement
- 4757 ♦ Design the wetland to meet demonstrated needs; utilize multiple wetland processes, consider
- 4758 flood prevention and water quality enhancement, and provide appropriate capacity and rate of
- 4759 through-flow
- 4760 ♦ Incorporate habitat and aesthetics into design and use only native species in planting programs
- 4761 ♦ Develop a maintenance plan and monitoring program to signal when maintenance is needed



Constructed Wetlands

- ◆ Monitor at locations appropriate to demonstrating results, usually the inflow and outflow locations, but consider inputs to groundwater
- ◆ Focus on nutrients and organic matter leaving the wetland complex

Key Considerations for Conservation Commissions

- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ If installed as part of site development or if within or adjacent to a wetland buffer zone (limits set by state and/or town bylaw), the device must meet the requirements of the MA Stormwater Standards under the WPA
- ◆ Like other stormwater BMPs, constructed stormwater wetlands may not be located within natural wetland areas other than riverfront area, land subject to coastal storm flowage, isolated land subject to flooding or bordering land subject to flooding
- ◆ A Stormwater Report is required when submitting an application for a Notice of Intent for any project subject to the stormwater management provisions of the WPA
- ◆ All the major interests of the WPA are benefited or unaffected by properly constructed wetlands, although there could be some risk of groundwater impacts
- ◆ Wetland creation for stormwater management establishes additional resource area subject to the WPA, but commissions should be mindful of the primary purpose of the wetland and necessary future maintenance and possible adjustments.

Massachusetts and Related Experience

Constructed wetlands were used to mitigate stormwater arising from the construction and operation of the Emerald Square Mall in North Attleboro, MA (Daukas et al. 1989). The 58-acre site drains to the Sevenmile River which flows into Luther Reservoir and Orr Pond, classified as a public drinking water supply. Mitigation of stormwater runoff was necessary to ensure that the water quality of the river and public drinking water supply would be preserved, that the quantity of water flow within the watershed would be maintained, and that stormwater runoff would not cause downstream flooding.



Constructed wetland forebay for a lake

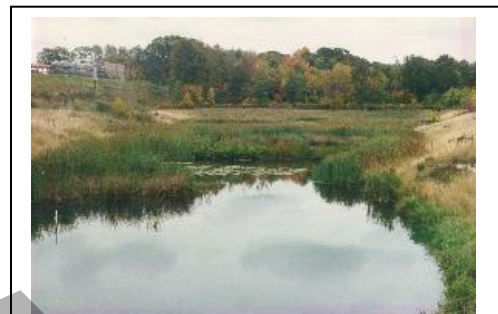


Constructed wetland with multiple chambers
(Courtesy of D. Lowry)

Constructed Wetlands

Stormwater runoff from the shopping mall was divided into two treatment paths with flows from the upper and lower watershed separately routed. Both flows were directed through a sequence of three wetland/detention ponds prior to discharging into tributaries of the Sevenmile River. Wetland basins were established during the first construction phase to provide at least one full growing season prior to receiving parking lot runoff. Additional BMPs were utilized such as catch basins with oil and grease traps, parking lot sweeping, sodium-free deicing salts and the restricted use of herbicides, pesticides and fertilizers. Lastly, long-term monitoring of treated runoff was installed to detect unanticipated water quality problems that may result from the shopping mall operation. No evidence of adverse downstream impacts has been reported or would be expected. The area used for the wetland was upland prior to construction so, while some upland wildlife was likely displaced, new wetland habitat was created for other wildlife.

A constructed wetland for the Crystal Mall in Waterford, CT, has a smaller footprint and more linear design than that of the Emerald Square Mall, but incorporates elements of open water settling, emergent wetland processing, gravel subsurface flow and treatment, and an outlet filter berm.



Constructed wetland with linear configuration
(Courtesy of D. Lowry)

The USEPA reviewed 17 wetland treatment case histories (USEPA 1993) and concluded that removal rates for solids and nutrients could be very high, sometimes in excess of 90%. However, most cases involved wastewater, which tends to have very high initial concentrations of nutrients. In another wastewater application that eventually incorporated stormwater, the 12-acre Tres Rios Demonstration Project in Phoenix, AZ, began in 1993 by treating two million gallons of effluent per day (USEPA 2006). The demonstration project was so successful that in 2000, the U.S. Army Corps of Engineers (ACOE) initiated the Tres Rios Ecosystem Restoration and Flood Control Project which involved the rehabilitation of nearly 700 acres in and around the Salt River, restoring a vital wetland and riparian habitat. Former agricultural fields were graded and contoured into the wetlands and reclaimed water from the wastewater treatment plant was pumped over to the wetlands with eventual discharge to the Salt River. As a result, the lush and scenic Tres Rios wetland complex is now home to more than 150 different species of birds and animals and the lush vegetation attracts many migratory and wintering songbirds (City of Phoenix 2023). The project has also enhanced passive recreation activities.

Constructed Wetlands

Rain gardens can be regarded as small treatment wetlands if they remain wet enough to maintain wetland vegetation. The design of rain gardens typically incorporates many wetland features, but proximity to residential and commercial sites tends to result in the minimization of standing water to avoid mosquito breeding. But if the water table is maintained close to the surface, the valuable water quality features of constructed treatment wetlands can be attained in rain gardens. Often there will be a gradation in vegetation from at least facultatively wetland species in the lowest part of the rain garden to upland species near the periphery.



Rain garden that includes some wetland plants

Non-Point Source Controls – Onsite Wastewater Disposal

How it Works

More than one in five households in the United States depend on individual onsite or small community cluster systems (septic systems) to treat their wastewater. USEPA reports that the New England states have the highest proportion of homes nationwide served by septic systems (see <https://www.epa.gov/septic/about-septic-systems>). Such systems are used to treat and dispose of relatively small volumes of wastewater, usually from houses and businesses located in suburban and rural locations not served by a centralized public sewer system.

Septic systems that are properly planned, designed, sited, installed, operated and maintained can provide excellent wastewater treatment. However, septic systems that are obsolete (e.g., older cesspools leaching directly into subsurface soil) or are not properly sited or maintained may be major contributors of NPS pollution to rivers, coastal waters, groundwater, and surface water.

A typical septic system consists of an underground septic tank, distribution box, and soil adsorption system. Conventional systems accept both graywater (wastewater from showers, sinks, and laundry) and blackwater (wastewater from toilets). Scum and settleable solids are removed from the liquid by gravity separation in the tank with flow to a subsurface drain system where the clarified liquid effluent percolates into the soil. [Guidance for proper operation](#) includes regular inspection of the system with pumping as experience dictates (typically every 3-5 years) or according to calculations based on the number of people served, number of bathrooms, collection tank volume, and other use factors.



**Septic system leachfield
being installed**

In MA, local Boards of Health regulate septic systems with MassDEP oversight in certain situations. [Title 5](#) (310 CMR 15.000) provides specifications for the siting, construction, upgrade, and maintenance requirements of onsite sewage systems. For any new septic systems, the leachfield 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.

P is removed to a substantial degree in both the septic tank and the leachfield, owing to chemical reactions that tend to convert P into particulate forms. Even beyond the leaching field or chamber, most soils adsorb P at high rates and soils are an integral part of an onsite system. Removal rates may be only 20-50% in the actual septic system, but removal rates >90% are expected through soil adsorption in most cases.

When systems are constructed in sites in fractured rock or compacted soil with fissures, high removal rates may not be realized. P removal will also be compromised by a high water table, especially if the groundwater is anoxic, as P will be more mobile in such situations. Likewise, where system failure results in breakout of septic effluent at the ground surface, or the soil capacity for P adsorption is exhausted (which occurs over time), removal of P will be severely reduced. The P load to a lake from septic systems requires careful evaluation. Experience suggests that non-failing septic systems are usually not a major P source to most lakes, but the range of possible inputs is large and local conditions dictate P loading. Additionally, while P adsorption onto soil is a major removal factor, gradual movement of P through soil is possible and results in a very long-term legacy load to receiving waters.



Septic system pump-out



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 of highly mobile nitrate, 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 research and development of a variety of innovative and alternative (I/A) systems. I/A systems are approvable for use in MA to provide higher levels of treatment to treat nitrogen and a better effluent quality, particularly in areas draining to waterbodies sensitive to nitrogen. Advanced onsite 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.

Advanced wastewater systems offer improved removal for a variety of contaminants, depending on included components, and many are proprietary. Most are specifically designed to remove nitrogen, with removal rates >50% and sometimes approaching 90%, although these advanced systems generally do not remove significantly more P than conventional systems.

Tight tanks (i.e., sealed container for temporary storage of septic waste) are an older alternative that eliminates the leaching function of onsite 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.

An important but often overlooked aspect of ensuring the proper long-term operation of onsite wastewater disposal systems pertains to the education of users regarding limiting what goes into the system (e.g., avoiding grease and excess solids loading from garbage grinders), the need for more frequent pump out of sludge from the septic tank, repair or replacement of the leach field or replacement of an old, compromised or failing system with an I/A system. Replacement of onsite

4917 systems with a community sanitary sewer system can enhance treatment and eliminate diffuse
4918 inputs but is very expensive and discharge permitting is no small matter.

4919 **Benefits**

- 4920 ♦ Well-managed onsite wastewater treatment can limit pollution
- 4921 of surface water, provides public health benefits, recharges
- 4922 groundwater, and replenishes aquifers.
- 4923 ♦ Cost-effective and long-term option for treating wastewater,
- 4924 particularly in less densely populated areas
- 4925 ♦ Properly designed, constructed and maintained septic systems
- 4926 minimize P migration and input to lakes
- 4927 ♦ Advanced onsite wastewater disposal systems can reduce
- 4928 nitrogen inputs to groundwater and downstream waterbodies
- 4929 ♦ Tight tanks act to eliminate discharge to the groundwater or lake

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.

4930 **Detriments**

- 4931 ♦ Conventional septic systems do not function well where the
- 4932 groundwater table is high (e.g., <4-6 ft below leachfield
- 4933 elevation); this is an issue near lakes
- 4934 ♦ P removal depends upon soil adsorption; when leachfields are
- 4935 exhausted, increased P mobility and input to lakes is possible
- 4936 ♦ Small residential lots are often classified as non-compliant due
- 4937 to inadequate area for a secondary (backup) leachfield
- 4938 ♦ Maintenance is not required by state law or most local
- 4939 ordinances and voluntary compliance can be problematic
- 4940 ♦ Climate change leading to rising sea levels, warmer
- 4941 temperatures, and more variable precipitation may reduce future
- 4942 effectiveness in some areas

Detailed lake studies in MA (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, 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 P without supporting data.

4943 **Information for Proper Application**

- 4944 ♦ Local soil, climatic, and groundwater conditions to allow proper siting and design
- 4945 ♦ The vertical separation distance from the bottom of the leach field and the estimated high
- 4946 groundwater elevation
- 4947 ♦ Correct use levels and amenities (number of people, presence of dishwashers, garbage grinders,
- 4948 etc.) to allow proper sizing
- 4949 ♦ Consideration of overall density of septic systems in area

4950 **Factors Favoring or Disfavoring the Use of this Technique**

- 4951 ♦ Favored when studies have demonstrated the impact of septic systems on the lake with regard
- 4952 to nutrients or bacteria

On-Site Wastewater Systems

- 4953 ♦ Disfavored where space for properly functioning systems is not available
- 4954 ♦ Disfavored where the groundwater table is near the ground surface or soils are not suitable for
4955 processing effluent
- 4956 ♦ Favored where required changes are justified and consistent with applicable state and local
4957 ordinances
- 4958 ♦ Favored where advantages of upgrading and maintaining systems are well understood by users

Performance Guidelines and Monitoring Needs

- 4960 ♦ Collect the data necessary to demonstrate the problem and potential for improvement
- 4961 ♦ Design systems or rehabilitation programs to meet demonstrated needs; match available
4962 designs to water quality goals
- 4963 ♦ Adhere to Title V regulations in the design and construction of septic systems
- 4964 ♦ Develop an inspection and maintenance plan and encourage owners to follow it
- 4965 ♦ Demonstrate improvement to lake condition, if possible, but recognize the difficulty in
4966 monitoring individual onsite disposal systems

Key Considerations for Conservations Commissions

- 4968 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
4969 Estimated habitat and must be complete before the conservation commission can close any
4970 hearing and issue an Order of Conditions under the WPA
- 4971 ♦ Identify nutrient-sensitive waters and establish that septic system management is needed
- 4972 ♦ Make sure that adequate setbacks to wetland resource areas are maintained.
- 4973 ♦ Verify that a satisfactory percolation test has been completed (refer to Board of Health)
- 4974 ♦ All interests of the WPA are either benefited or unaffected by improved management of onsite
4975 wastewater disposal systems, but the addition of onsite disposal systems could represent a risk
4976 of pollution

Massachusetts and Related Experience

4978 In MA, the influence of onsite wastewater treatment systems on the ecological health of local
4979 waterbodies is perhaps best documented in Cape Cod where most soils are very porous and
4980 treatment of effluent is limited. Pollution of groundwater by nitrogen from local septic systems
4981 with movement into kettlehole lakes and coastal embayment has long been a major water quality
4982 concern. Increasing the nutrient removal performance and long-term stable operation of onsite
4983 systems has been a vital research and technology impetus including the development of I/A
4984 wastewater treatment systems. As part of the acceptance of the I/A systems by local Health Boards,
4985 the owners have the responsibility of keeping their system operating correctly to be in compliance
4986 with state and local regulations. However, once systems have been installed, there has been little
4987 monitoring conducted to make sure they were operating as designed or expected. The diffuse
4988 nature of inputs from onsite wastewater disposal represents a challenge to monitoring and impact
4989 quantification.

In the early 2000s, the Barnstable County Department of Health and Environment identified the need to be able to verify the performance claims being made by technology distributors to homeowners and town health departments. The I/A (Innovative/Alternative) [Septic System tracking database](#) was created in 2005 using funds from USEPA to collect inspection and monitoring records from system operators electronically. All new I/A systems on Cape Cod are now required to have maintenance contracts and are connected to an extensive database. If a particular system doesn't report nitrogen levels into the database (typically quarterly or semiannual testing), local county health monitors are alerted.

Since its inception, more towns have joined this database effort, extending to three additional counties. The program is now financed through user fees to offset administrative costs. To date, there are more than 2,800 active permits being tracked. Currently there are also more than 25,000 sample reports and more than 40,000 inspection reports that have been submitted by operators.

A very extensive and detailed review of onsite wastewater disposal, including the sources, fate and transport of nutrients, pathogens, and organic compounds (Lusk et al. 2017), is consistent with experience in MA. In particular, the cited range for P loading to water resources is 4 to 25% of the total for any given lake and the potential for source controls, maintenance, and advanced treatment alternatives to reduce loading is covered.

The issue of legacy P loading from onsite wastewater disposal was investigated at a MA lake (Schellenger and Hellweger 2019) in very permeable soils. A substantial input of P from wastewater systems was projected and accounted for missing P loading in a separate comparison of total and surface water inputs to the lake. Management efforts over the last two decades, including removal of P from detergents and conversion of cesspools to septic systems under updated Title V regulations, was estimated to have reduced P loading from onsite wastewater disposal by over 30%. Continued P loading from historic onsite wastewater loading to soils after installation of a sanitary sewer system was predicted to be significant but would decline by half every 20 years.

6. REDUCED NUTRIENT AVAILABILITY IN LAKES

Nutrient availability may be controlled by in-lake techniques that include phosphorus (P) inactivation, artificial circulation, hypolimnetic oxygenation, and dredging where watershed management has been unable to reduce nutrient inputs sufficiently to prevent algae blooms or where the main source of nutrients is not the watershed (i.e., as with significant internal loading). Additional techniques that address nutrient availability are included in the alternative technique category, but these additional techniques have limited implementation potential and insufficient documentation of reliability. Additionally, only the use of aluminum products is covered for P inactivation in this chapter. Products with alternative P binders such as Phoslock and EutroSorb, both using lanthanum as the P inactivator, have not been approved for use in MA as of early 2024, although they have been used extensively outside MA.

5030 Phosphorus Inactivation

5031 How It Works

5032 The release of phosphorus (P) stored in lake sediments has become
5033 recognized as a major factor in supporting algae blooms, especially
5034 for cyanobacteria, even after incoming nutrient loads have been
5035 significantly lowered (Steinman and Spears 2020). P may be released
5036 from resuspended sediments, “leaky” plant growth, plant senescence,
5037 bioturbation of sediment by fish or invertebrates, natural decay of
5038 sediment organic matter, or oxidation-reduction (redox) reactions
5039 under low oxygen (strongly hypoxic to anoxic) conditions. The last
5040 two mechanisms appear to be dominant in the vast majority of lakes
5041 where internal recycling of P is a major factor in algal blooms.

5042 When considering P inactivation as a lake management approach, a
5043 useful analogy is a leaky boat, where the boat represents the lake and
5044 water represents P. If there are leaks in the boat, patching them
5045 (watershed management) will be necessary to prevent the boat from
5046 filling with water. However, if the boat is full of water, patching the
5047 leaks will not make the boat useful; the accumulated water must be
5048 removed (P inactivation). If the leaks are very small, removing the
5049 water will restore utility for an extended period of time. If the leaks
5050 are very large, no amount of bailing will improve utility for very long.
5051 Determining where the lake is on that continuum is a helpful exercise
5052 in evaluating project appropriateness. Watershed management can
5053 protect a lake but cannot counter the impact of internal loading.

5054 There are three proven ways to stop P from being released from
5055 sediment: remove the problem sediment (dredging), add oxygen to
5056 prevent low redox reactions from occurring and to encourage natural
5057 inactivation of P (oxygenation), and add alternative P binders that are
5058 not subject to release of P under anoxic conditions (P inactivation).
5059 Additionally, some improvement has been obtained by selective
5060 withdrawal that discharges high P water, but only after many years of
5061 application and never attaining the desired level of loading decrease.
5062 This section covers P inactivation, but it is important to first
5063 understand the relation between internal P loading and algae.

5064 *Understanding how internal P loading supports algae blooms*

5065 With decay under oxygenated conditions, released P is expected to combine with binders naturally
5066 present in the lake (most often iron in MA, but also including calcium, aluminum, and manganese).



Top, middle and bottom of an extruded sediment core showing change from amorphous, high-P material at top to peat and sand with less available P at bottom

P Inactivation

5067 Once bound, it settles back into the sediment in a form not usable by algae, although enough uptake
5068 to support significant algal growth is possible during this process. However, where oxygen is low
5069 enough to allow redox reactions (biochemically mediated reactions in which substitute electron
5070 acceptors replace oxygen), P bound to iron can be released back into the water column from
5071 sediment in a form highly available to algae and can remain in solution until oxygen becomes
5072 available.

5073 The ratio of the key nutrients (i.e., N to P) in redox-mediated P release is low and favors
5074 cyanobacteria over other algae (Ding et al. 2018), as many cyanobacteria can utilize dissolved N
5075 gas not available to other algae. Iron released with P is also more important to cyanobacteria than
5076 other algae (Molot et al. 2021), as it is an essential ingredient in the enzymes critical for conversion
5077 of dissolved N gas into a usable form.

5078 Redox reactions can occur in the sediment even in shallow water if the oxygen demand is high
5079 enough to overcome diffusion and mixing from the overlying water, but as soon as any released P
5080 enters the oxygenated water column it is likely to be naturally inactivated. Algae that grow right
5081 at the sediment-water interface may thrive on this released P and can later rise in the water column
5082 to form mats or planktonic blooms. Yet the deeper the water, the more likely it will be that oxygen
5083 supply will be inadequate due to limited vertical movement, allowing a substantial anoxic zone
5084 with elevated P content to develop.

5085 Oxygen-demanding organic sediment tends to accumulate in deeper water, causing low or no
5086 oxygen conditions and fostering redox reactions and P release, especially during summer when
5087 water temperature is warm enough to foster greater bacterial decay and related oxygen demand. In
5088 many MA lakes anoxia develops by mid- to late summer and in some it can occur as early as June,
5089 leading to substantial P release, a process called internal loading. The P may have originally come
5090 from the watershed but is being recycled in the lake and can become the dominant source of P,
5091 especially during the growing season. P released from sediment may be mixed into the upper
5092 waters by diffusion, wind mixing, or eventual destratification in mid-summer or autumn, becoming
5093 available for algal growth.

5094 Algae can grow at the sediment-water interface to a depth where light becomes limiting, typically
5095 up to three times the Secchi transparency measurement. Cyanobacteria growing this way can take
5096 up excess P, form gas pockets within cells, and rise to the surface where light allows better growth.
5097 Filamentous green algae and some filamentous cyanobacteria will form mats on the bottom, trap
5098 their own photosynthetic gases, and move upward to form surface mats. If P is adequate in surface
5099 waters, the algae may persist. If surface waters are P-poor, the algae will usually die off after a
5100 week or two.

5101 Other algae, most notably some cyanobacteria and golden algae, tend to grow best near the
5102 boundary between upper and lower water layers in a thermally stratified lake, depending on light
5103 from above and P from below, that P having been released from the sediment and migrated upward

P Inactivation

5104 in a low oxygen environment. That layer of algae may or may not move into surface waters,
5105 depending mostly on weather conditions.

5106 *Using P inactivation to control internal P loading*

5107 P precipitation by chemical complexing removes P from
5108 the water column and can control algal abundance until the
5109 P supply is replenished. Inactivation of P in surficial lake
5110 sediments can greatly reduce the release of P from those
5111 sediments, minimizing the internal load. It is essentially an
5112 “anti-fertilizer” treatment. In-lake treatments are most
5113 appropriate when studies indicate that the primary source
5114 of the P is internal (recycled from lake sediments). This
5115 technique is most effective after nutrient loading from the
5116 watershed is significantly reduced, as it is designed to bind
5117 existing sediment P reserves, not new inputs entering the
5118 waterbody post-treatment. However, P inactivation can
5119 also be used to treat inflows to lakes where watershed
5120 management has not been successful in adequately
5121 reducing P inputs or as an interim measure until such
5122 control can be achieved. Such P control can control algal
5123 growths and floating vascular plants (e.g., duckweed,
5124 watermeal) but has little effect on most vascular plants
5125 rooted in the sediment, as the roots extend deeper than the
5126 effect of the treatment.

5127 Iron is the most common natural P binder in MA, but as
5128 noted above, it does not hold the P under anoxic
5129 conditions. Calcium does not release P under anoxia but
5130 will dissolve and release P at pH less than about 8.5
5131 standard units. Except in some Berkshire County lakes the
5132 pH of MA lakes is lower, making calcium addition
5133 ineffective. Aluminum is the most abundant metal in the
5134 crust of the earth, although iron is more locally abundant
5135 in much of MA. Aluminum will hold P under a wide range
5136 of oxygen and pH levels and is readily available in
5137 multiple forms due to its use in water and wastewater
5138 treatment. Aluminum sulfate ($\text{Al}_2(\text{SO}_4)_3 \cdot x\text{H}_2\text{O}$), sodium aluminate ($\text{Na}_2\text{Al}_2\text{O}_4 \cdot x\text{H}_2\text{O}$), and
5139 polyaluminum chloride ($\text{Al}_2(\text{OH})_n\text{Cl}_{6-n}$) (or PAC) are the most common aluminum compounds
5140 applied, but aluminum chlorohydrate ($\text{Al}_2\text{Cl}(\text{OH})_5$) has also been used. Lanthanum, a rare earth
5141 element, is combined with bentonite clay in a product called Phoslock and used for P inactivation
5142 in some other states and countries but has not been approved for use in MA as of 2024.



P Inactivation

Inactivators are applied to the surface or subsurface of the lake, almost always in liquid form from a boat or barge. For aluminum, the P inactivator for virtually all MA treatments to date, a floc, composed of a loosely clumped mass of fine particles, forms and, in settling, removes particulates and at least some dissolved constituents from the water column within minutes to hours. Reactions continue at the sediment-water interface and into the sediment to a depth of about 10 cm (with adequate dosing) for about two months, binding P that could otherwise be released from the sediment. P is transferred from iron to aluminum and where aluminum in the sediment is more than three times the iron concentration or 25 times the redox-sensitive P concentration, P release is sharply curtailed (Lake et al. 2007). Dose can be determined by a target aluminum to iron ratio but is usually set based on an aluminum to redox-sensitive P ratio or a lab assay that generates a curve of reduction in P availability vs amount of aluminum added.

Good candidate lakes for this procedure are those that have had external nutrient loads reduced to an acceptable level and have been shown to have a high internal P load (release from sediment). If the internal P load is more than about 20% of the total P load, with a focus on summer, the internal load will be as important as external loads during the growing season and may require reduction to control blooms. High natural alkalinity is desirable to provide buffering capacity but is not essential to treatment success; buffered treatment can avoid pH change. Highly flushed impoundments are usually not good candidates for sediment P inactivation because of an inability to limit P inputs, but inlet treatments with aluminum at 1-5 mg/L can provide relief until adequate watershed management can be implemented. For lakes with intermediate flushing rates on the order of few months, treatment of the water column with lower doses of aluminum (1-5 mg/L) may remove enough P to avoid blooms and will additively inactivate sediment P with repeat treatments (typically once or twice per year).

The main risk during aluminum treatment is toxicity of certain forms of aluminum to fish and aquatic invertebrates. Those toxic aluminum forms are minimized between pH values of 6 and 8, but some lakes are naturally outside that range, and aluminum sulfate causes pH to decline while sodium aluminate causes pH to rise. After the aluminum product has reacted it is nearly inert but there is some risk during treatment if applications are not properly buffered to prevent large pH swings or if the instantaneous aluminum concentration is too high (>10 mg/L). Low dose inlet or water column treatments rarely cause pH changes of concern, but treatments intended to inactivate surficial sediment in MA lakes have averaged 50 g/m^2 and have been as high as 108 g/m^2 and must be performed gradually to avoid aluminum toxicity. Areal doses (g/m^2) convert to volumetric



P Inactivation

doses (g/m^3 or ppm) by dividing the areal dose by the water depth in meters. Keeping the aluminum concentration <5 ppm has avoided obvious toxicity in past treatments, but that can mean treating a target area several times a few days apart with lower doses to achieve the total dose. It also does not mean that all toxicity has been avoided.

The USEPA has developed a tool for estimating the amount of total aluminum that can be added to water without causing a toxic effect, and water quality standards can be based on that calculation, an improvement over flat values used in the past without regard for the effects of other water quality variables. This [Aluminum Criteria Calculator](#) considers pH, dissolved organic carbon, and hardness, each of which affects aluminum toxicity. There are other factors that also affect toxicity, some of which limit toxicity, so it is not a complete approach, but it does allow an approximation of the maximum dose of aluminum that can be added safely at one time. Experience dictates that this calculator underestimates the amount of aluminum that can be tolerated without toxicity.

The concern over aluminum is focused on the concentration of reactive forms in the water column; aluminum is not known to bioaccumulate and undergoes hydrolysis reactions that make it largely inert after a short time in the aquatic environment. There is no aluminum standard for sediment. A few specific aluminum compounds are listed as hazardous materials, but none are applied to lakes or result from reactions of aluminum in the lake. The lack of indication of toxicity by reacted aluminum compounds suggests that build-up of aluminum over time with sequential treatments does not represent a significant threat to benthic organisms, but more testing may be necessary before that is certain.



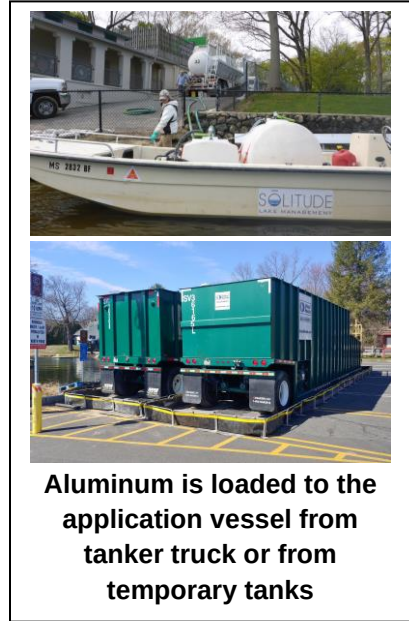
Floc layer visible on top of core samples 3 hours after treatment; layer will migrate into sediment within 2 months

Treatment with alternative chemicals, at such time as they are approved for use in MA, would be similar but there are some differences. Iron can be used only if oxygen is adequate (>2 mg/L); iron is sometimes added in oxygenation projects to ensure adequate P binder is present. Calcium is only effective if pH is maintained at a relatively high level and is mostly available as a solid that would have to be turned into a slurry for application. Raising the pH could have negative impacts on aquatic life. Phoslock is not a coagulant like aluminum, so it will not remove particulate P from the water column. Application when algae or other particles are not abundant in the water will maximize Phoslock results.

P Inactivation

One other treatment option warrants mention. Calcium nitrate treatments are not intended to precipitate or inactivate P directly, but nitrate injected directly into the surface sediments can oxidize sediment, limit anoxia, and maintain the stability of natural iron oxides in the sediments. This approach is not commonly practiced anywhere and has never been tried in MA but has enjoyed some success in Europe. It is more analogous to hypolimnetic oxygenation than P inactivation, but the processes are related.

The benefits of treatment last until the inactivated P has been replaced by watershed inputs or sediment P that is not inactivated migrates upward through the treated zone and can be released into the water column. Review of 114 treatments by Huser et al. (2016) found an average of 6 years of benefit in shallow lakes and an average of 21 years of benefit in stratified lakes. Watershed features, lake morphometry, and detention time greatly affect the duration of benefits, which may be extended through watershed management. When upward migration of P within the sediment allows significant internal loading to resume, re-treatment can restore control that may last longer with each treatment.



Benefits

- ◆ Rapid removal of available P from the water column
- ◆ Minimized internal loading of P from sediment
- ◆ Potential removal (via flocculation) of a variety of other contaminants and bacteria from the water column
- ◆ Higher water clarity and reduced probability of algal blooms, especially cyanobacteria
- ◆ Increased oxygen below the thermocline, as less organic matter is produced, settles, and decays, although anoxia near the bottom has not been eliminated
- ◆ Reduced resuspension of sediment by coagulation and stabilization that limits the impact of sediment disturbance
- ◆ Potential expansion of coldwater fish habitat into upper hypolimnion

Detriments

- ◆ Potential for damage to fish and invertebrates during aluminum treatment with pH outside the range of 6-8 SU or total aluminum concentrations >10 mg/L
- ◆ Possible smothering of invertebrates in the treatment zone by settled floc, although this zone is usually anoxic and not inhabited by a diverse or desirable fauna in most cases
- ◆ Possible loss of zooplankton in treatment zone at elevated doses (can be removed by floc)
- ◆ Greater water clarity may allow rooted plants to grow to at greater depths to greater density

5252 **Information for Proper Application**

- 5253 ♦ An accurate P loading analysis that includes a reliable estimate
- 5254 of internal P load as a fraction of total P load
- 5255 ♦ Sediment testing for available sediment P and calculation of
- 5256 necessary dose of P inactivator, possibly with follow up assays
- 5257 to predict magnitude of inactivation/improvement
- 5258 ♦ Accurate depth and organic sediment maps of the lake to
- 5259 properly evaluate possible target area
- 5260 ♦ Knowledge of lake oxygen regime to further evaluate target
- 5261 treatment area
- 5262 ♦ Where using P inactivation to offset watershed loads, provide an
- 5263 assessment of necessary dose and application timing
- 5264 ♦ Recent information on pH and alkalinity at all depths to properly predict potential changes in
- 5265 pH and to plan for avoiding impacts
- 5266 ♦ Estimates of effectiveness should be made for lake recovery in terms of total P levels and
- 5267 Secchi disk transparency

Toxicity can be avoided by properly buffering inactivator additions, treating repeatedly at a lower dose, or treating parts of the lake sequentially, any one of which may be adequate by itself and together has resulted in no fish kills in MA in over two decades of application

5268 **Factors Favoring or Disfavoring the Use of this Technique**

- 5269 ♦ Favored when >20% of the P load is associated with sediment sources within the lake
- 5270 ♦ Favored when studies have demonstrated the impact of internal loading on the lake
- 5271 ♦ Favored when external P load has been controlled to the maximum practical extent or is
- 5272 documented to be small; historic loading may have been much greater than current loading
- 5273 ♦ Favored when inactivation of P in the water column is expected to provide interim relief from
- 5274 algal blooms and turbidity while a prolonged watershed management program is conducted to
- 5275 reduce external loading
- 5276 ♦ Favored if most inputs are from a single or pair of tributaries that can be treated prior to mixing
- 5277 in the lake
- 5278 ♦ Favored by higher alkalinity (>20 mg/L) that limits pH changes, although buffering can be
- 5279 augmented to prevent major changes in pH during treatment
- 5280 ♦ Disfavored when <10% of the P load is associated with sediment or when the external load
- 5281 includes highly available P (note that most external loads are largely particulate and
- 5282 unavailable until processed in the lake)
- 5283 ♦ Disfavored by very high flushing rates (>12/yr) or very shallow depth (<10 feet) due to
- 5284 decreased longevity of results

5285 **Performance Guidelines and Monitoring Needs**

- 5286 ♦ Determine chemicals to be used; consider oxygen regime and minimize shift in pH unless
- 5287 naturally outside range of 6-8 SU

P Inactivation

- 5288 ♦ Secure appropriate access for equipment and chemicals; adhere to materials handling
5289 regulations in the transfer of chemicals to application equipment
- 5290 ♦ For larger lakes requiring multiple days of treatment, treat non-contiguous sections of the lake
5291 on sequential days
- 5292 ♦ For higher doses of aluminum, split treatment to yield calculated in-lake aluminum level <10
5293 mg/L on any day; restrict total aluminum to about 5 mg/L if feasible
- 5294 ♦ Track the area treated and amount of inactivator applied on a daily basis
- 5295 ♦ Visually assess floc formation, settling, and accumulation on the bottom; determine the extent
5296 of any drift outside the target area and adjust treatment as warranted to minimize drift
- 5297 ♦ Monitor P, the inactivator compound, pH, alkalinity, conductivity, water clarity, temperature,
5298 oxygen, algae, and zooplankton before and after treatment to document changes; post-
5299 treatment monitoring usually extends through two growing seasons on a monthly basis from
5300 at least May through September to properly document success
- 5301 ♦ Monitor pH, alkalinity, conductivity, and turbidity/clarity during treatment, usually at least 3
5302 times per day, with follow-up action if any deviations from the expected range are detected
- 5303 ♦ Survey for stressed or dead fish and invertebrates prior to the start of treatment and daily each
5304 day of treatment, with cessation of treatment if significant kills are noted; for fish in MA, a
5305 fishkill is defined as >100 fish on any day or >50 fish of one species
- 5306 ♦ Set threshold for maximum wind or wave action during days of application and pause or delay
5307 operation if exceeded

Key Considerations for Conservation Commissions

- 5309 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
5310 Estimated habitat and must be complete before the conservation commission can close any
5311 hearing and issue an Order of Conditions under the WPA
- 5312 ♦ Aside from a permit under the WPA through the local conservation commission/MassDEP, P
5313 inactivation treatments require a license to apply chemicals (WM04) from MassDEP, which is
5314 obtained after an Order of Conditions is issued
- 5315 ♦ The effect of P inactivation on the interests of the WPA is neutral or beneficial if the project is
5316 properly conducted; the primary concern is toxicity or smothering of biota during treatment,
5317 neither of which is likely to be a major or lasting influence on lake ecology in a typical project
- 5318 ♦ Commissions may want to understand the P budget fully; it is preferable to use P inactivation
5319 either as a complement to watershed management (minimizing legacy P from past inputs) or
5320 as an interim approach to avoid algae problems while watershed management, often a slow
5321 process, progresses to the point where P loading is acceptable

5322 The most serious impact is the possibility for fish or invertebrate kills during treatment in low
5323 alkalinity lakes, but such impacts are preventable, and no significant fish or mussel mortality has
5324 occurred in over two decades of applications in MA. Reduced hatches of midges have been
5325 observed for a year or two following treatment, suggesting that smothering by floc can occur, but

P Inactivation

effects are temporary. 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 while attaining a marked improvement in water quality.

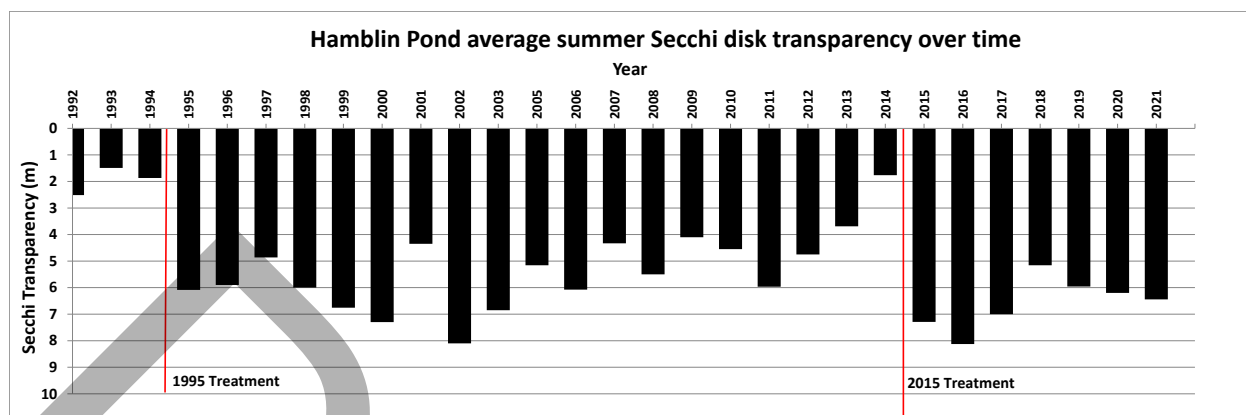
Urban lakes or waterbodies in heavily agricultural watersheds represent a special case for P inactivation; it may not be feasible to reduce inputs to the extent necessary to meet goals and P inactivation becomes a maintenance activity that can at least provide some utility by minimizing harmful algal blooms. Repetitive inlet or low dose in-lake treatments are often proposed for this purpose. The limits to improvement attainable by watershed management (Osgood 2017) will have bearing on how conservation commissions perceive in-lake work and what conditions are imposed as part of an Order of Conditions.

Massachusetts and Related Experience

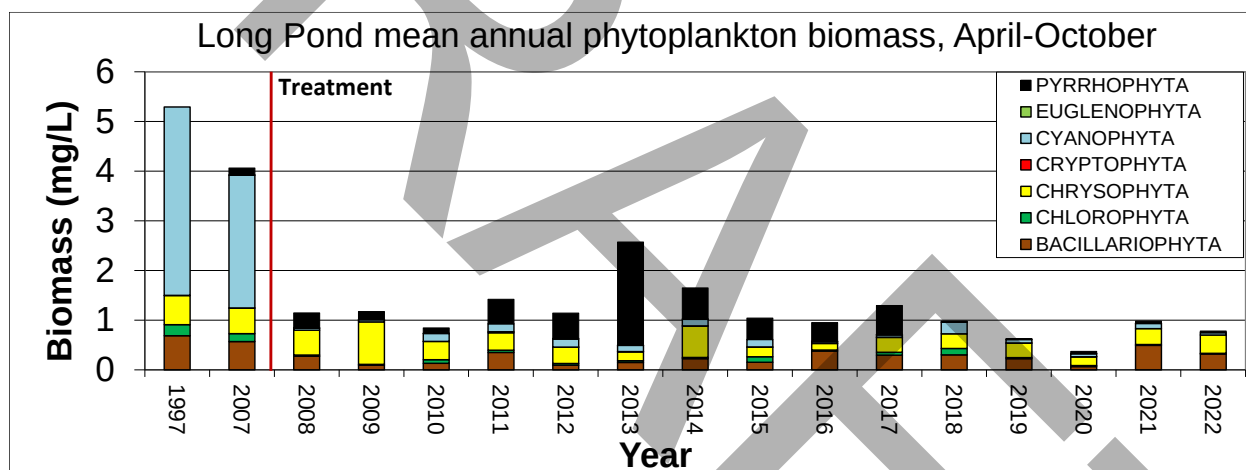
Aluminum treatments have been conducted in MA for over 30 years but improvements in dose determination, application methodology, and protection of aquatic life have enhanced results in that time. At least three lakes have been treated twice; the benefits are not permanent but as much as two decades of improved conditions are possible. Wagner et al. (2017) reported on treatments of a dozen Cape Cod lakes, finding marked improvement in all cases, although not all treated lakes met the goals that were set. Cyanobacteria blooms were reduced in all and eliminated in most, but in several cases the dose was considered too low to provide the full benefit. Cost has limited the dose in some cases, but it has also been found that the presence of abundant planktivorous fish, especially alewife, limits water clarity improvement after treatment, as there are few zooplankton to eat whatever algae are produced.

Kettlehole ponds, dominant on Cape Cod, are prime candidates for P inactivation targeting surficial sediment, having relatively small watersheds that shifted from agricultural to residential over the last century and having accumulated substantial P-rich organic sediment since they were created by the receding glacier over 10,000 years ago. Hamblin Pond in Marstons Mills received inputs from a duck farm for 30 years, ending in the 1950s, and experienced cyanobacteria blooms until P inactivation was conducted in 1995. Water clarity following P inactivation demonstrated a large and immediate increase in clarity, followed by a very gradual decline over 18 years, followed by an abrupt return to cyanobacteria blooms in September 2013 and summer 2014 as P that had been migrating upward through the inactivated zone reached the sediment surface. Retreatment in 2015 regained the high clarity and at least 20 years of desirable conditions are predicted. At least 10 feet of trout water (water <20 C with >5 mg/L of oxygen) was regained by treatment, owing to less organic matter (dead algae) entering the hypolimnion. A holdover trout fishery has been established as a result.

P Inactivation



An extensive algal record for Long Pond in Brewster, also on Cape Cod, demonstrates the shift from cyanobacteria dominance to a lower density, mixed algae community with much greater food web value. Productivity is not necessarily lower, as use of algal biomass is more efficient, but there is less accumulation of algae and higher water clarity. Long Pond has exhibited no cyanobacteria blooms since treatment in 2007.



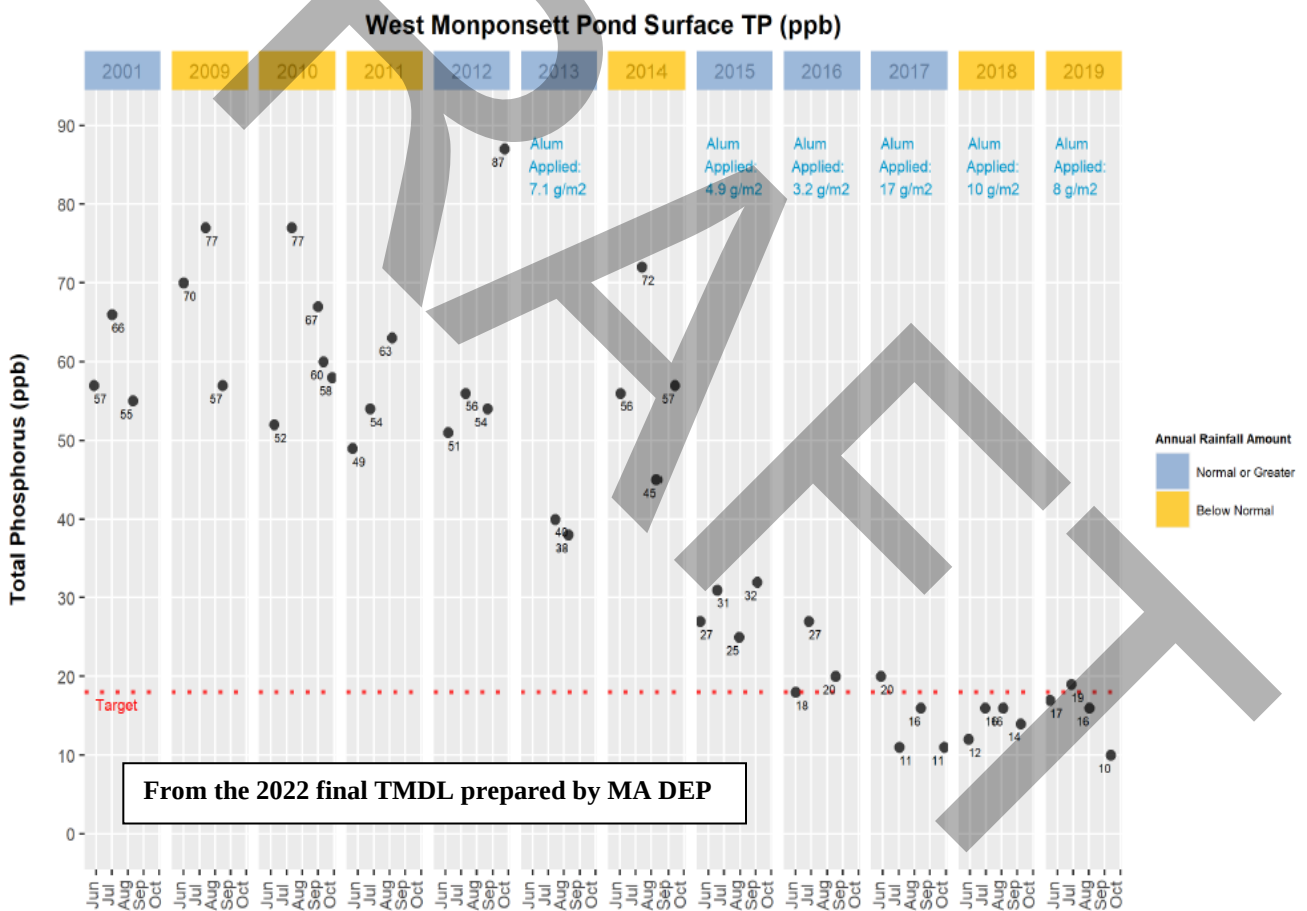
Nearly all treated lakes have experienced a major decrease in cyanobacteria dominance, owing largely to an increase in the N:P ratio that favors non-cyanobacteria, but not all treated lakes have avoided cyanobacteria blooms altogether. Cliff Pond and Lovell's Pond on Cape Cod are two waterbodies that still experience cyanobacteria at levels greater than desired, although both have far less cyanobacteria than prior to treatment. The dose at Cliff Pond was set at the low end of the recommended range for budgetary reasons and additional treatment appears warranted. Treatments are additive and successive treatment can be conducted as funds allow. Lovell's Pond has not responded as positively to treatment, but decades of cranberry bog discharge greatly increased the organic P load and P inactivation with aluminum is less effective on organic P than iron-bound P.

Off Cape Cod, fewer lakes but more lake area overall has been subject to P inactivation of surficial sediment in MA, and lakes in all New England states have been treated. Results have allowed multiple lakes to be removed from state impaired waters lists. Common features of successfully

P Inactivation

treated lakes include detention time >1 year, some degree of summer stratification, and internal loading that represents more than 25% of the total P load. Aluminum doses have ranged from 10 to 108 g/m² with an average close to 50 g/m².

Where the cost of surficial sediment inactivation by a single treatment is not affordable or the dose must be restricted to avoid potential adverse impacts, P inactivation in the water column remains an option. Sediment treatment is additive, and benefits accrue by sequential treatments. Where a very high dose (>75-100 g/m²) of P inactivator is needed, treatment efficiency may be improved by sequential additions a year or more apart (James and Bischoff 2015). Monponsett Pond in Halifax, MA was treated with small sequential doses of aluminum over 8 years to combat internal P loading that fostered cyanobacteria blooms. There was regulatory concern over possible impacts to endangered mussel populations, so individual doses were kept very low but eventually surpassed the targeted minimum of 38 g/m² and achieved the recommended 50 g/m² to provide extended relief.

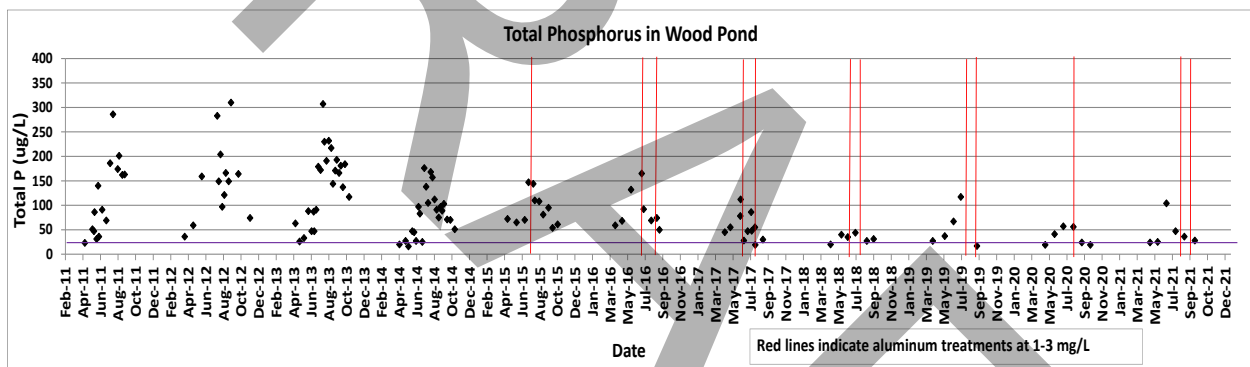


If P loading from the watershed is dominant, it is certainly preferable to address P sources through watershed management, but in highly urban or agricultural watersheds it may not be possible to reduce loads sufficiently and even where possible it will usually take years to achieve significant load reductions by watershed management. P inactivation targeting the water column or tributary

P Inactivation

inputs can provide interim relief or function as a maintenance measure that improves the resource. For urban lakes acting as wildlife oases and serving underprivileged human populations, such treatment can be viewed as ecological and social justice. Such treatments are not common in MA but have been used for many years in FL (Harper et al. 1999) and have expanded into other states (Pilgrim and Brezonik 2005, Churchill et al. 2009).

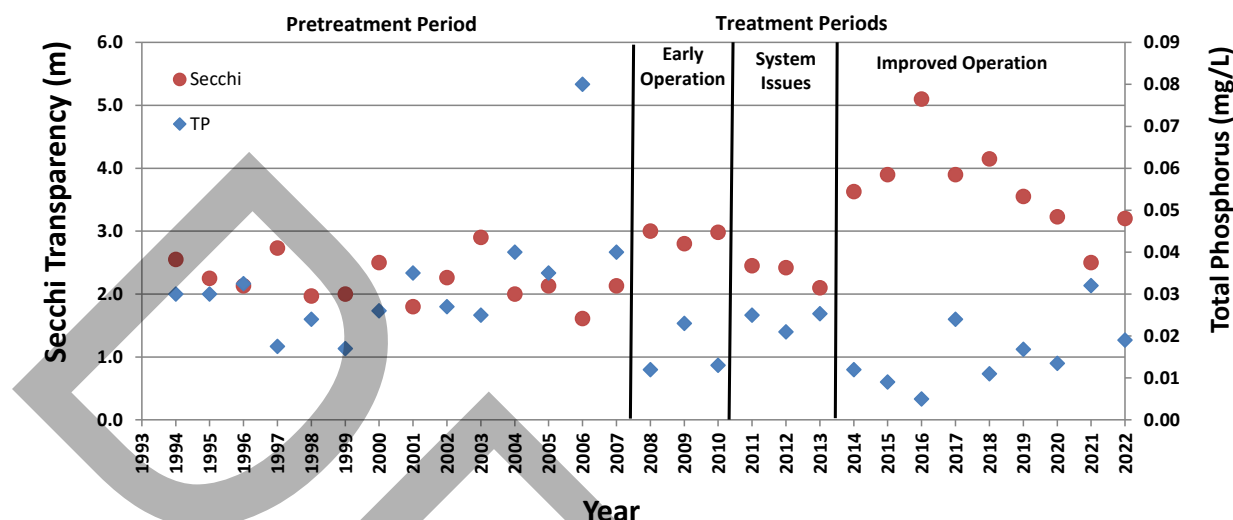
A well-documented example of sequential water column treatments comes from central CT, where Wood Pond in an urban area had suffered from cyanobacteria blooms for over a decade. Watershed management is ongoing but slow, and P inactivation targeting the water column once or twice per summer since 2015 has managed to strongly decrease in-lake P concentration. Doses ranged from 1-3 mg/L over the whole pond and there have been no cyanobacteria blooms since treatment began. Water clarity increased markedly, and rooted plant growth expanded substantially. Summer P concentration peaks, related mainly to internal loading, have been reduced and ongoing watershed loading has been partly counteracted, although the target in-lake P concentration of <25 ppb has only been achieved intermittently. More watershed management is needed, but it may be possible to switch to tributary treatment once internal loads are sufficiently suppressed.



The best MA example of treating inflows to inactivate P comes from Morses Pond in Wellesley, where two tributaries are responsible for >75% of the P input to the pond. Monitoring over a 20-year period determined that P concentrations <20 ppb in the pond do not support algal blooms at levels that impair uses. Treatment of inflows was initiated in 2008 and was managed manually for three years with acceptable results in terms of P concentration and water clarity. Problems with equipment and human resources limited success in the next three years, prompting simplification and automation of the treatment system.

The enhanced system includes a precipitation monitoring station that triggers a pump for each tributary to run at a preset but adjustable threshold for rainfall (normally set at 0.1 inches). Pumps run for 4 hours at an adjustable setting that delivers aluminum polychloride to each of two tributaries at a targeted rate of 1 mg/L. Aluminum product is stored in two tanks, one for each tributary. The system can be controlled by a cell phone interface that allows override of any operational feature. The system can be run whenever desired but is normally operated only from about Memorial Day to just after Independence Day, with a goal of going into summer with an in-lake concentration as close to 10 ppb as possible.

Average summer phosphorus and water clarity in Morses Pond



5429

5430 Results since 2014 have met water clarity goals and facilitated greater swim area use in an urban

5431 waterbody, although the system cannot overcome prolonged wet weather, as in 2021. The amount

5432 of aluminum applied over the last 15 years through the dosing station is comparable to what would

5433 be applied as either annual low-dose water column treatments or a single higher dose sediment

5434 treatment to maintain desirable conditions, but dosing of inlets allows much of the aluminum to

5435 be sequestered in an upstream basin of the lake.

5436 P inactivation has been demonstrated to be a valuable tool for reducing algal blooms in general

5437 and for preventing cyanobacteria blooms more specifically. Environmental risks are limited,

5438 predictable, and largely controllable. Results are usually immediate and benefits can last for many

5439 years under the right conditions of ongoing inputs, dose, and treated area. Benefits can be extended

5440 by retreatment where necessary. While this approach to P control is not preferable to watershed

5441 management where external loads are dominant, it is a valid approach on an interim basis or where

5442 watershed management is stymied by issues of scale and/or jurisdiction. Where internal loading is

5443 the dominant P source, some form of in-lake control will be essential to avoiding algae blooms

5444 and P inactivation is an effective and usually affordable option.

5445 While P inactivation by aluminum is a proven approach to lake management, this field is still

5446 developing, and the experience of the last few decades has led to several insights. Repeated

5447 applications of smaller doses ($<50 \text{ g/m}^2$ or $<3 \text{ mg/L}$) have rarely caused any adverse effects,

5448 provide immediate relief from excessive P concentrations, provide a higher efficiency of P binding

5449 in sediment, and can counter the effects of ongoing release of organic P (which is less inactivated

5450 by aluminum than iron-bound P). This has led some practitioners to spread out larger doses

5451 necessary to achieve greater longevity of benefits over several years. Ongoing monitoring can then

5452 inform adaptive management in relation to later treatments or watershed management approaches.

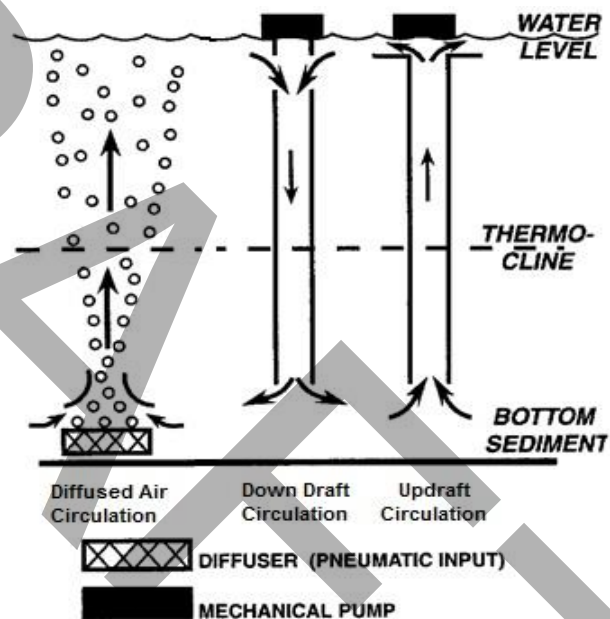
5453

Artificial Circulation

How It Works

Artificial circulation is the movement of lake water by pump or pneumatic force. The intent can vary from avoiding accumulation of bacteria in a swimming area to minimizing internal phosphorus (P) loading by addition of more oxygen in deeper water to homogenization of the water column for more consistent water supply intake quality. For the purposes of this review, artificial circulation is applied to limit internal recycling of P and control algae by mixing that differentially impacts some forms. The process of circulating water can increase oxygen in deeper areas, limiting anoxia and P release from sediment (see details in the review of P inactivation) and causes other water quality changes that favor other types of algae over buoyant cyanobacteria. A detailed review of circulation theory and strategies (Wagner 2015) explains just how complicated this seemingly simple approach can be.

Circulation strategies usually increase turbulence and can prevent or disrupt stratification, although some systems are set up to mix just the top layer of water during stratification and still other systems attempt to induce laminar flow. Whole lake artificial circulation mixes the entire water column, preventing or destroying thermal separation of the epilimnion (top layer) and hypolimnion (bottom layer). Thermal stratification and features of lake morphometry such as coves create stagnant zones that may be subject to accumulation of organic sediment, loss of oxygen, and release of P by redox reactions, thus supporting algal blooms.



Preventing stratification and loss of oxygen may limit internal P loading, but mixing water from different depths can make whatever nutrients are present more available to algae, so the balance between P control and availability becomes very important. If external nutrient loading is substantial, circulation can make conditions worse. If water is circulated to depths about three times the Secchi transparency, light limitation on algae growth can be imposed. However, some portion of any lake will not be deep enough for that mechanism to work. Algae may simply be mixed more evenly in the available volume of water, but avoidance of surface scums and shoreline accumulations of algae may be aesthetically preferable and may limit taste, odor, and toxins. A shift in dominant algal types is common, but a major decrease in biomass is rarely achieved.

Artificial Circulation

Alteration of algal community composition as a function of artificial circulation is partly a function of varied light regime, partly a consequence of changing nutrient ratios, and also a matter of tying up available nutrients in more desirable algae forms that can be consumed by zooplankton and fuel desirable biological productivity without excessive accumulation of algal biomass. Diatoms are normally dominant in spring but decline as the water warms, as they have heavy cell walls that cause them to sink as water density declines with increasing temperature. Circulation can keep diatoms in the water column and delay the seasonal progression of dominance by green algae or cyanobacteria. Diatoms are more edible, produce less taste, odor, and toxicity, and are more easily removed in water treatment. Many of the cyanobacteria with buoyancy regulation capability prefer quiescent waters and microzones with conditions they help establish by metabolic processes. Circulation disrupts those conditions and often favors other algae, many of which are more edible, although some cyanobacteria may persist and may cause taste, odor, or toxicity.

Circulation of water can be accomplished with surface aerators (fountains), bottom diffusers, and water pumps that move water from the bottom up or the top down. The key is to move water at a rate that prevents the development of a thermal gradient, but that is not an easy task. As water warms the energy required to move it across a thermal barrier increases for each unit of temperature increase. In other words, it requires much more energy to mix water at 25°C with water at 30°C than it does to mix water at 20°C with water at 25°C. Circulation systems do not dissipate heat and may even add heat to the lake, mixing water only to the point where the energy needed equals that provided. Unless a very powerful system is installed, warm summer weather in MA will eventually create a thermal gradient that very few circulation systems can overcome. Energetically, it is much easier to maintain mixed conditions than to create them once stratification has set in.

Bubble diffuser (left), downdraft pump (center), and updraft pump (right) used for circulation



Artificial Circulation

Pumps to move water in an aquatic setting tend to fall into two categories: direct drive mixers that typically have small propellers (<2 feet or 0.7 m) that produce a high velocity flow and axial flow pumps that employ larger propellers (>3 feet or 0.9 m) and generate a low velocity water stream. Water can be moved in any direction desired, depending on pump placement and any tube or conduit employed to direct the flow. High velocity, direct drive systems are most often used to send an unconfined stream of oxygenated water from near the surface to whatever depth the thermal gradient will allow. High velocity systems tend to operate on a small scale and are not used to destratify deeper reservoirs, but they can prolong mixed conditions where a strong thermal gradient has not yet developed.

Lower velocity, axial flow pumps are the primary means by which water is moved in updraft or downdraft pump systems used to prevent or destroy stratification. Water is moved through a tube of just slightly greater diameter than the propeller, either upward or downward, at a velocity that minimizes turbulence. There will be some friction loss that increases with tube distance, but these systems tend to be fairly efficient. The amount of water moved is proportional to the size and speed of the propeller and relatively easy to calculate, allowing sizing to ensure that enough water is moved each day to counter the development of a thermal gradient and stratification.

Fountains can be attractive features in small ponds and will provide some oxygenation and mixing functions but are almost never sized to move enough water to make a major difference in water quality except in a limited zone of influence. The depth of intake is especially important to performance, as pulling up deeper water may provide more oxygenation value, but if water circulation is inadequate to eliminate anoxia, surface water quality may degrade.



Pumps may be powered by wind, solar cells, or connection to an electrical line. Consequently, design must consider the availability of power at the site. The thermal resistance to mixing can be calculated for any expected temperature difference, allowing system sizing with a fair degree of reliability, but as noted previously, the cost of a system powerful enough to maintain stratification during prolonged periods of hot, sunny weather is often prohibitive and nearly all users settle for systems that will not be successful all the time.

Unlike most pump systems, where a certain amount of water is drawn into a tube and ejected at the other end, an air-driven mixing system depends on induced water movement through the rise of bubbles released at some depth. While friction, head differential, and other physical factors may affect pump performance, specifications for pump systems should be fairly accurate under known conditions. Water movement induced by air bubbles is much less predictable and tank tests or partial installations rarely mimic the lake environment adequately. Capable vendors have general application rules for their equipment derived from experience, but on-site, air-driven system

Artificial Circulation

adjustment is usually needed. Achieving uniform temperature over the target volume is a reliable indicator of success, but even simple temperature measures present challenges in a large volume of water subject to the daily sun cycle, wind, and inflows.

Beyond the ability of the circulation system to move water, the distribution of that capacity over the target area is a major design consideration. If there is no temperature gradient and therefore no thermal resistance to mixing, water moved from the top to bottom or vice versa is free to move in any direction up to the point where inertial forces overcome directional movement of the water. Lateral movement of up to 20 times the vertical distance of water movement by pumping or pneumatic force is possible, but there is usually some thermal gradient present. Warmer water will rise and colder water will sink such that lateral motion may be no more than five times the vertical distance the water is moved. Claims of colder water brought to the surface or warmer water forced to the bottom moving laterally for hundreds of feet defy physics. Consequently, the number of diffusers for air-driven circulation or discharge points for pumped circulation will be greater for shallower lakes and the circulation process will be less efficient and more costly.

How much water is moved per day is an important design parameter. Most experienced vendors of air-driven circulation systems agree that all water in a target zone should be moved at least every two days, with greater rates of turnover for reservoirs with high heat input, excessive fertility, elevated oxygen demand, or high salt content. Some systems have provided benefits by moving only about 20% of the target volume per day, but those will certainly fail under hot, dry conditions. The general rule is that an air flow rate of at least 1.3 cubic feet per minute per acre of lake ($9.2 \text{ m}^3/\text{min}/\text{km}^2$) will be needed to maintain a mixed system and air flow rates of 2.0 cubic feet per minute per acre of lake ($14.2 \text{ m}^3/\text{min}/\text{km}^2$) are preferred. Insufficient sizing of system capacity is the greatest contributor to failure for this technique, while inadequate distribution of mixing power is another common factor in poor performance (Wagner 2015).

Pump systems are routinely designed to move lesser percentages of the target volume each day than air-driven systems but are rarely successful at maintaining mixed conditions if the target volume is not moved at least every five days (20% per day). Uniform temperature is the best indicator of successful circulation and pumping rates may need to be increased to at least 50% of the target volume per day where lake morphometry is not conducive to efficient mixing (e.g., coves or irregular bottom shape). A thermal gradient of more than 3 C° over the target depth is an indication of inadequate mixing.

Pumping water from the top to the bottom of a lake creates less risk of adverse impacts than bringing water from the bottom of the lake to the top. Moving oxygenated water and any algae in the epilimnion into deep water is completely consistent with goals of elevating oxygen in deep water and moving algae into a light limited area. Partial benefits are possible with underpowered or inadequately spaced downdraft pump discharges. Bringing water from the bottom to the top of a lake, by pumping or aeration, carries the risk of transporting water with low oxygen, high P, and elevated concentrations of reduced substances into upper waters where algae growth, odor, and

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even toxicity may be increased. Design and operation that assures complete mixing is therefore essential for bottom to top circulation systems. Alternatively, mixing only the upper water layer can avoid poor quality water that develops in the lower water layer, but will not provide all the benefits that a well-designed and properly operated whole lake circulation system offers.

While the primary target of most circulation projects is improved oxygen in deeper water with attendant water quality benefits, algal blooms may be controlled by artificial circulation through the following processes:

- ◆ Introduction of dissolved oxygen to the lake bottom may inhibit P release from sediments, curtailing this internal nutrient source where iron is an important P binder.
- ◆ Mixing to the lake bottom will increase the time a cell spends under light-limited conditions, 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 cyanobacteria to less noxious green algae.
- ◆ Turbulence can neutralize the advantageous buoyancy mechanisms of cyanobacteria 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 may be less vulnerable to visually feeding fish. If more zooplankters survive, their consumption of algal cells may also increase.

If circulation provides increased oxygen to a low oxygen zone, oxic chemical reactions may reduce P availability and control algal growth where sufficient P-binders are present. Otherwise, this technique depends largely upon physical disruption and light limitation associated with mixing to control algae. Buoyant cyanobacteria are especially susceptible to such disruption, but most green algae and diatoms are less negatively affected. Surface scums may be avoided, but algal biomass may not decline.

Artificial circulation can prevent winterkills of fish in lakes that become anoxic during winter under the ice. On a smaller scale, artificial circulation can be used to prevent ice formation around docks or other structures. Circulation is also used to enhance water quality in drinking reservoirs as oxygenated conditions created by circulation reduce concentrations of reduced substances such as hydrogen sulfide, ammonium, iron and manganese that must otherwise be removed by treatment. Even where water quality is suboptimal, consistent water quality makes treatment easier for water supply utilities and homogenization by circulation can therefore reduce the cost of water supply.

Possible Benefits

- ◆ Increases mixing and decreases stagnation; may control algae by multiple means and should at least spread out the algal biomass, possibly avoiding surface scums and shoreline accumulations

Artificial Circulation

- 5630 ♦ Increases oxygen levels and enhances habitat accordingly if water is circulated deep enough
- 5631 ♦ Homogenizes water quality, allowing for more consistent treatment by water suppliers

5632 Possible Detriments

- 5633 ♦ Will make whatever nutrients remain in the water column more available to algae, possibly
- 5634 causing or increasing blooms
- 5635 ♦ Mixing may distribute previously localized undesirable substances throughout the lake;
- 5636 inadequate mixing that does not alleviate anoxia and internal P loading may worsen
- 5637 conditions
- 5638 ♦ May resuspend sediment and increase turbidity if circulation is not carefully controlled
- 5639 ♦ The water temperature in deeper water will increase, potentially increasing oxygen demand
- 5640 and related internal P loading unless enough oxygen is supplied to counter that demand
- 5641 ♦ Noise from pumps or compressors may be objectionable and housing to suppress noise may
- 5642 cause overheating and poor performance

5643 Information for Proper Application

- 5644 ♦ An accurate nutrient budget with a detailed analysis of internal P sources
- 5645 ♦ Data related to each of the five possible control mechanisms
- 5646 (oxygenation/P inactivation, light limitation, pH/carbon
- 5647 source adjustment, buoyancy disruption, and enhanced
- 5648 grazing) should be analyzed and evaluated in terms of
- 5649 potential algal control. Specific questions include:
- 5650 ○ Is there internal P loading that can be mitigated by
- 5651 oxygenation of deep waters?
- 5652 ○ Is the mixing zone deep enough to promote light
- 5653 limitation of algae?
- 5654 ○ Is there a large amount of carbon dioxide in the bottom
- 5655 waters that could be mixed to the surface to favor the
- 5656 growth of non-cyanobacteria?
- 5657 ○ Is mixing predicted to counteract the buoyancy advantage of cyanobacteria over other
- 5658 algae?
- 5659 ○ Will a dark, oxygenated refuge be created for zooplankton?
- 5660 ♦ Reliable estimate of the oxygen demand that must be met by the system
- 5661 ♦ Reliable estimate of the amount of air or pumping necessary to mix/destratify the lake under
- 5662 the range of expected temperatures
- 5663 ♦ Lake morphometry data that facilitate choice of circulation method and placement of diffusers
- 5664 or discharge points for maximum effectiveness
- 5665 ♦ Location and details of compressor or pump and power source

Capacity and spatial arrangement of circulation systems are important factors in determining the extent and evenness of circulation. Too little capacity or delivery points can lead to “dead zones” while excess capacity and crowded spacing may resuspend sediment.

5666 **Factors Favoring or Disfavoring the Use of this Technique**

- 5667 ♦ Favored when a substantial portion of the P load is associated with anoxic sediment sources
- 5668 ♦ Favored where external P load has been controlled to the maximum practical extent or is
- 5669 documented to be small; historic loading may have been much greater than current loading
- 5670 ♦ Favored where control of reduced compounds such as hydrogen sulfide, ammonium,
- 5671 manganese, and iron is desired
- 5672 ♦ Favored when adequate P inactivators are available upon addition of oxygen
- 5673 ♦ Favored where shoreline space for a compressor or pump is available where access is
- 5674 sufficient, power is available, and noise impacts will be small
- 5675 ♦ Favored when long-term application of the technique is accepted; effects are temporary and
- 5676 repeated application will be needed
- 5677 ♦ Disfavored where mixing will expand the impact of internal nutrient loading on the lake more
- 5678 than internal loading is reduced
- 5679 ♦ Disfavored when the lake morphometry is highly irregular (multiple separate basins and
- 5680 isolated coves)
- 5681 ♦ Disfavored when the lake is very shallow (<10 ft) if using compressed air, as short vertical run
- 5682 creates inefficiency and the need for more diffuser locations
- 5683 ♦ Disfavored where whole lake circulation limits valued coldwater fishery habitat

5684 **Performance Guidelines and Monitoring Needs**

- 5685 ♦ Determine goals for circulation; if oxygenation is desired, oxygen demand must be met and if
- 5686 destratification is desired, necessary mixing force must be applied
- 5687 ♦ Properly size equipment; especially avoid insufficient capacity
- 5688 ♦ Properly place equipment; space input points based on realistic lateral mixing expectations
- 5689 ♦ Develop a maintenance plan for equipment that includes inspection and cleaning at an
- 5690 appropriate frequency
- 5691 ♦ Operate equipment in accordance with management goals to achieve desired temporal or
- 5692 spatial results
- 5693 ♦ Monitor temperature and oxygen as indicators of mixing and oxygenation, assess other water
- 5694 quality or biological variables as necessary to evaluate success (e.g., water clarity, algae, P, N)
- 5695 ♦ It is recommended that oxygen measurements in larger waterbodies intended to be adequately
- 5696 oxygenated be tracked by in-situ sensors with automation to operate the circulation system,
- 5697 limiting the human role in responding to changing conditions but providing override capability

5698 **Key Considerations for Conservation Commissions**

- 5699 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 5700 Estimated habitat and must be complete before the conservation commission can close any
- 5701 hearing and issue an Order of Conditions under the WPA

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- ◆ If any construction is needed within a Great Pond, even on a temporary basis, a Chapter 91 permit or license is required
- ◆ Construction of onshore support facilities such as a shed to house a compressor or pump may require permitting under the WPA if within the buffer zone
- ◆ Interests of the WPA should not be adversely affected by well-designed and properly operated circulation projects unless planned whole lake circulation will reduce available coldwater habitat.
- ◆ An undersized or intermittently operated system could degrade water quality; design and operation are critical to success and should be properly addressed in submitted materials
- ◆ Circulation of just the upper water layer may alter algal composition but will not increase deep water oxygen or counter internal loading and is unlikely to reduce algal biomass or reduce concentrations of iron, manganese, ammonium, or hydrogen sulfide

Massachusetts and Related Experience

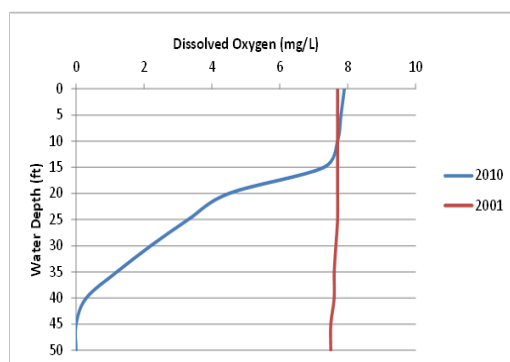
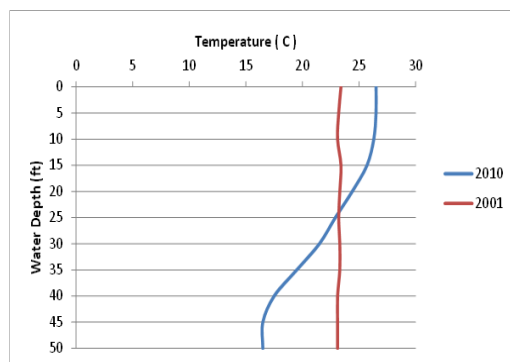
Artificial circulation systems are commonly installed in small ponds in MA but are less often found in larger lakes. Compressed air releases through commercial diffusers, updraft pumps (the best known of which is the Solarbee by Medora), and fountain aerators are all in use. Downdraft pumps are unknown from MA lakes; the primary brand (ResMix from WEARS in Australia) has been installed in some USA lakes but is recommended for lakes that are at least 30 feet deep to avoid stirring up sediment. There are many vendors for compressed air and fountain systems, with a variety of equipment and capacities available.

Results have been highly variable and not especially well documented in many cases. Very few cases can be cited where significantly reduced algal biomass and increased water clarity have been obtained in MA, but surface scums and shoreline accumulations have often been reduced.

A major failure for diffused air circulation occurred at Lovell's Pond in Cotuit (WRS 2014). Years of discharge from cranberry bogs loaded the pond with P-rich organic matter and internal loading supported cyanobacteria blooms in most summers. After the bogs ceased operation, the town sought to rehabilitate the pond. Circulation system design was sufficient in terms of capacity but the building that housed the compressor was inadequately ventilated, and the purchased compressor was from the lowest bidder, not the best quality offering. The compressor shut down due to overheating with some regularity and was not restarted before low oxygen, high-P water developed near the bottom. System restart resulted in mixing of the poor-quality bottom water with the upper water layer, P concentration in the upper waters increased, and cyanobacteria blooms were more frequent and severe than before circulation was initiated. The system could have been operated more effectively but was ultimately abandoned in favor of an alternative management approach.

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Perhaps the best documented MA case of circulation by compressed air release is Fresh Pond, the terminal reservoir in the Cambridge water supply system. Maintenance of adequate oxygen throughout the reservoir was desired for multiple water quality benefits in this water supply that is also the focal point in a large reservation offering outdoor activities to the public. A diffused air circulation system was installed in 1995 and successfully destratified this reservoir with a maximum depth of 50 feet for over a decade, providing all desired water quality benefits at a mixing rate of 53% of the target volume per day. Operation was then cut in half to save on power cost and the system failed to keep the reservoir destratified or to maintain oxygen in deep water until full time operation of the system was restored. Both proper design and operation are essential to success.



Temperature and oxygen profiles for Fresh Pond with full (2001) and half-time (2010) operation of a diffused air circulation system

Updraft pump systems were installed in Santuit and Skinequit Ponds on Cape Cod over a decade ago. Five units were placed in 166-acre Santuit Pond, which had suffered from cyanobacteria blooms for some years. The pond has a maximum depth of 11 feet so there should be no strong stratification and circulation should eliminate low oxygen zones and limit internal P loading. However, cyanobacteria blooms continued during more than a decade of operation. Water clarity increased somewhat but was still unacceptable for contact recreation. The amount of water circulated by the pumps is simply not enough to maintain mixed conditions and avoid low oxygen at the bottom. A single updraft pump in 18-acre Skinequit Pond with an intake set at 8 feet below the surface was incapable of providing any mixing to the bottom layer that starts at about 13 feet. However, circulation of the upper water layer appears to have shifted the phytoplankton assemblage away from buoyant cyanobacteria, although the dominant algae are still cyanobacteria and water clarity remains unacceptable for contact recreation much of the summer. Problems with internal P loading cannot be overcome by circulation of only the epilimnion of a lake. Alternative P controls are under consideration for Santuit Pond and were implemented in Skinequit Pond in 2023.

In a review of artificial circulation systems in drinking water supplies around the world, Wagner (2015) found that 53% of diffused air circulation systems met program goals and another 42% achieved partial success considered worthwhile. For updraft pump systems, 12% met program goals and another 47% achieved partial success. Dwindraft pump systems were less common but 57% achieved program goals and 43% provided partial success. The potential for problems was

Artificial Circulation

less with downdraft pump systems, owing to high oxygen and algae laden water being forced deeper rather than pulling up water of variable quality from deeper in the reservoirs. The flexibility of air-driven systems was acknowledged, with easier adjustment to enhance performance.

Cooke et al. (2005) reviewed application of artificial circulation to 51 lakes worldwide and concluded that favorable changes in oxygen, pH, ammonium, iron and manganese were commonly achieved. Significant decreases in cyanobacteria were observed in just over half the cases but decreases in algal abundance occurred in only about 25% of cases and increases were noted in almost 25% more. A shift to more edible forms of algae (e.g., diatoms, some greens, many small flagellates) could result in lower accumulated algal biomass where grazing zooplankton are abundant, but water clarity was more likely to decrease than increase from the reviewed cases. For whole lake circulation the hypolimnetic water temperature will increase, which is likely to increase oxygen demand and potentially increase P release from sediment if the oxygen demand is not adequately countered by circulation.

A thesis from the University of Vermont (Kirol 2022) found that artificial circulation of Lake Carmi in VT with diffused air destabilized the water column sufficiently to allow wind to completely mix the lake on an intermittent basis. However, the circulation system did not deliver enough oxygen to the bottom to prevent temporary anoxia and release of P. While overall P release was reduced, the P that was released was made more available in the well-lit upper waters of the lake and caused more frequent and more severe cyanobacteria blooms than prior to installation of the circulation system. A more powerful and better designed system might have been more successful, but keeping the sediment-water interface adequately oxygenated through artificial circulation is challenging. Alternative P control is being evaluated for Lake Carmi as of 2024.

Given variable performance by artificial circulation systems, hybrid systems have sometimes been applied to enhance results. Combining artificial circulation with P inactivation using iron, aluminum, or other P binders can yield improved conditions where the total P load is high. The waterfowl pond in the Brookfield Zoo outside Chicago had malodorous algae blooms and highly discolored water but removing the main P source – the waterfowl – would have eliminated the exhibit. A diffused air circulation system coupled with ferric chloride injection over the diffusers increased oxygen, decreased P, and reduced blooms, color, and odor. A similar system in a private pond in the Hudson River Valley of NY using aluminum as the P binder also greatly enhanced pond conditions. Bacterial products (not yet considered a standard approach in MA) are also often combined with circulation for improved results in other states.

5809 Hypolimnetic Oxygenation

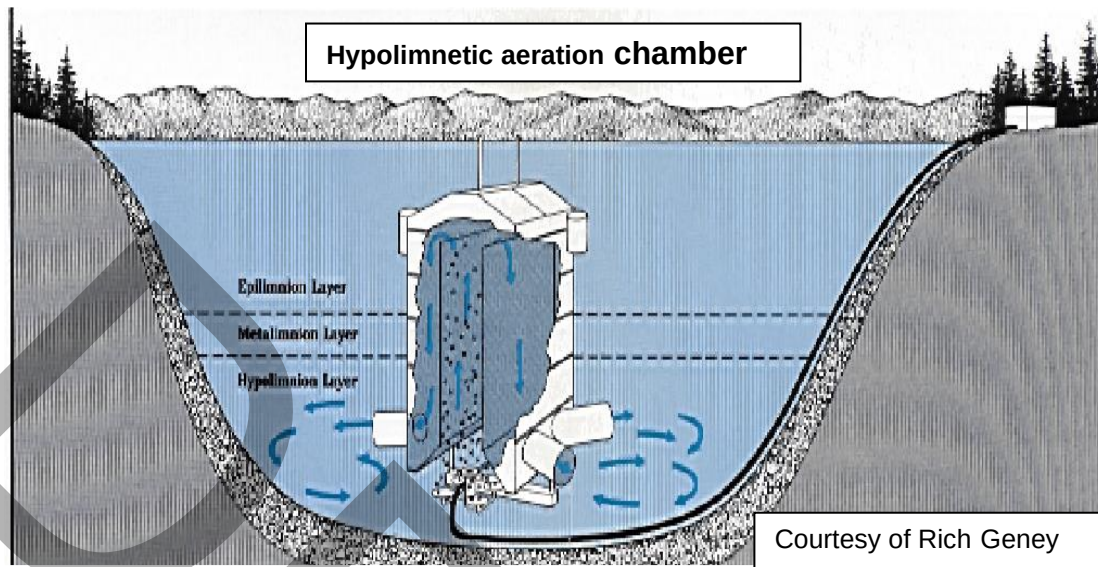
5810 How It Works

5811 As described in the review of phosphorus (P) inactivation, internal loading of P can increase greatly
5812 when oxygen is in short supply as a consequence of chemical (redox) reactions that allow P to be
5813 released from sediment. One approach to preventing sediment P from being a significant nutrient
5814 source for algae is to increase the oxygen concentration between the point of P release and the
5815 water depth at which light is sufficient to support algal growth. Oxygen can be increased by either
5816 vertically circulating water in the lake to move oxygen-rich surface waters to the deeper zone
5817 where oxygen depletion is occurring (artificial circulation), necessarily destratifying a lake, or by
5818 supplying oxygen to that deeper zone without causing enough vertical movement of water to
5819 destratify the lake (hypolimnetic oxygenation). These overlapping techniques are addressed
5820 separately in this manual with hypolimnetic oxygenation addressed here under the acronym HO.

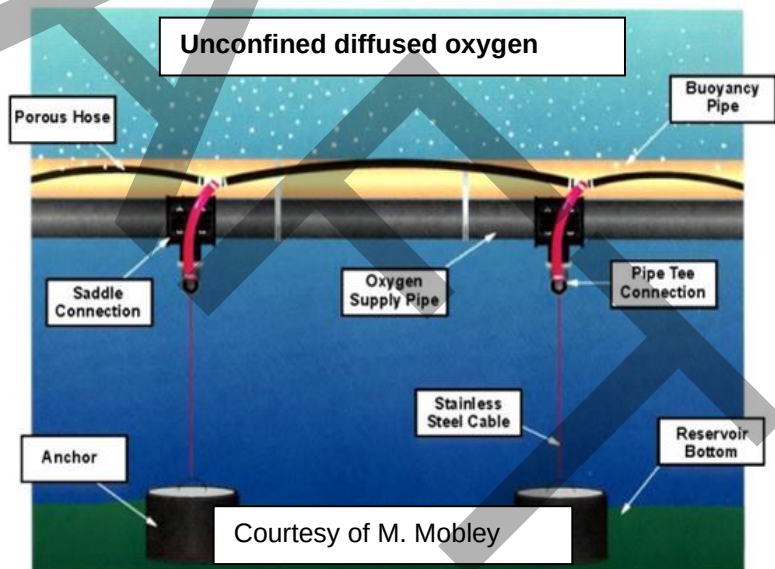
5821 HO systems are intended to add oxygen to deeper water without disrupting thermal stratification.
5822 This maintains the separation of upper and lower water layers in a stratified lake, which can be
5823 important to limiting nutrient cycling and affects other aspects of lake ecology, while addressing
5824 oxygen depression in the lower water layer during stratification. HO systems include diffused
5825 oxygen bubbles released directly into the water column in an unconfined manner, hypolimnetic
5826 aeration chambers that use air to provide oxygen and may also involve mixing with higher oxygen
5827 surface water before return to the deep zone, downflow bubble contact chambers (also called
5828 Speece cones) that mix oxygen and water in a chamber within the deep zone of the lake, and
5829 sidestream oxygenation systems that pull water from the target zone, oxygenate it, and put it back.
5830 Each approach is discussed separately below. No single system type is ideal for all applications.

5831 HO by hypolimnetic aeration chambers is one of the oldest methods for getting oxygen into deep
5832 water without breaking stratification. Compressed air is usually diffused in the inner chamber of a
5833 tube-inside-a-tube tower, rising and pulling water with it, with transfer of oxygen to that water as
5834 it rises. Remaining bubbles exit a small port at the top of the chamber while hypolimnetic water
5835 with added oxygen returns to the hypolimnion through the outer, peripheral chamber. As oxygen
5836 transfer from air is slow, water may need to be cycled through the chamber multiple times to
5837 achieve an oxygen concentration adequate to meet water quality goals and suppress internal P
5838 loading. Chambers can extend from near the bottom to the surface of the lake, creating a longer
5839 bubble rise distance without causing the destratification associated with unconfined bubble
5840 plumes. Such systems are not energy efficient but can effectively oxygenate a hypolimnion.
5841 Further, the use of pure oxygen in such a chamber could overcome the drawback of a hypolimnion
5842 with inadequate thickness to support successful unconfined diffused oxygen application.

Hypolimnetic Oxygenation



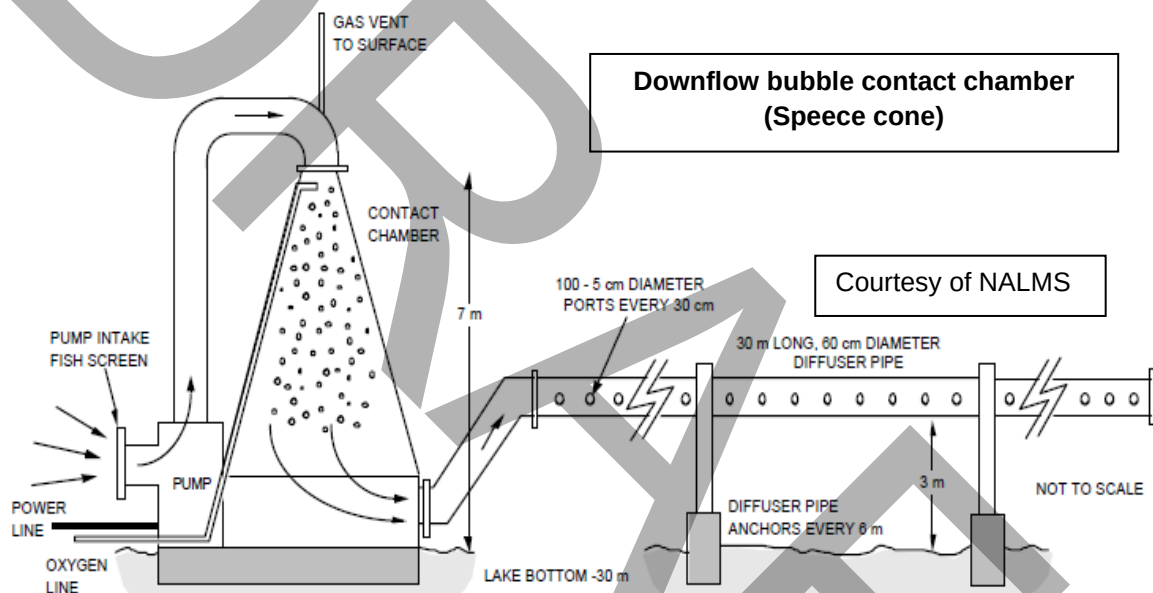
HO by diffused gas mostly focuses on addition of pure oxygen or oxygen-enriched air. The rate of oxygen transfer from normal atmospheric air bubbles is slow ($<1\%$ per vertical foot travelled) and addition of nitrogen gas (78% of air) is generally not desirable. Transfer of oxygen from small bubbles of pure oxygen can result in complete absorption of the bubble over a vertical distance of about 20 feet; the smaller the bubbles the better, as the surface area to volume ratio increases with decreasing bubble diameter and this aids gas transfer. Bubbles released near the sediment-water interface may prevent anoxia but more often create an oxic zone some distance above the bottom that functions as a barrier to upward P migration. Iron and P released by redox reactions will recombine into a precipitant in the oxic zone and settle back to the bottom. This approach will cause mixing if there is not enough vertical run distance within the hypolimnion for bubbles to dissolve but is otherwise the most efficient way to increase deep water oxygen concentrations. No pumping of water or gas is involved. Use of an on-site oxygen generator would require power, but if a liquid oxygen storage tank is used as the oxygen source, the only power requirement is for instrumentation.



HO by downflow bubble contact chambers also involves a chamber in the lake where pure or nearly pure oxygen is added to hypolimnetic water. Ideally, the rise of oxygen bubbles is

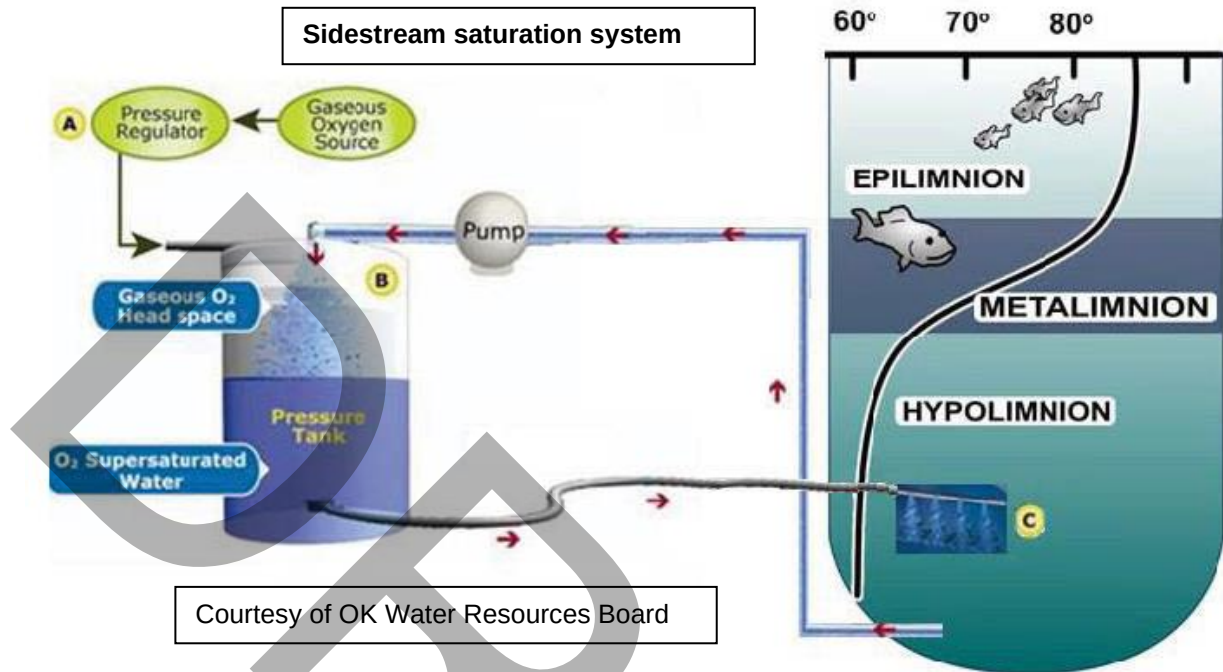
Hypolimnetic Oxygenation

counteracted by the downflow of incoming water, creating a balanced flow that allows all oxygen to be dissolved as the water moves out of the chamber and into a distribution system in the target zone of the lake. If water flow is too high relative to oxygen addition, some bubbles may be carried out into the distribution system, but this should be of little consequence. If the oxygen addition is too high relative to water input, an oxygen pocket may form within the chamber and has to be released (“burping” the system). The oxygen exchange chamber tends to be large and can be on shore but is more often at the bottom of the lake, where the extra pressure allows a higher oxygen concentration to be achieved and the distribution of oxygen laterally in the target zone is very efficient. However, a solid platform is needed for the submerged components, a challenge with the soft, organic sediments of most deep lakes, and maintenance requires either diving or bringing the equipment to the surface, neither of which is easy.

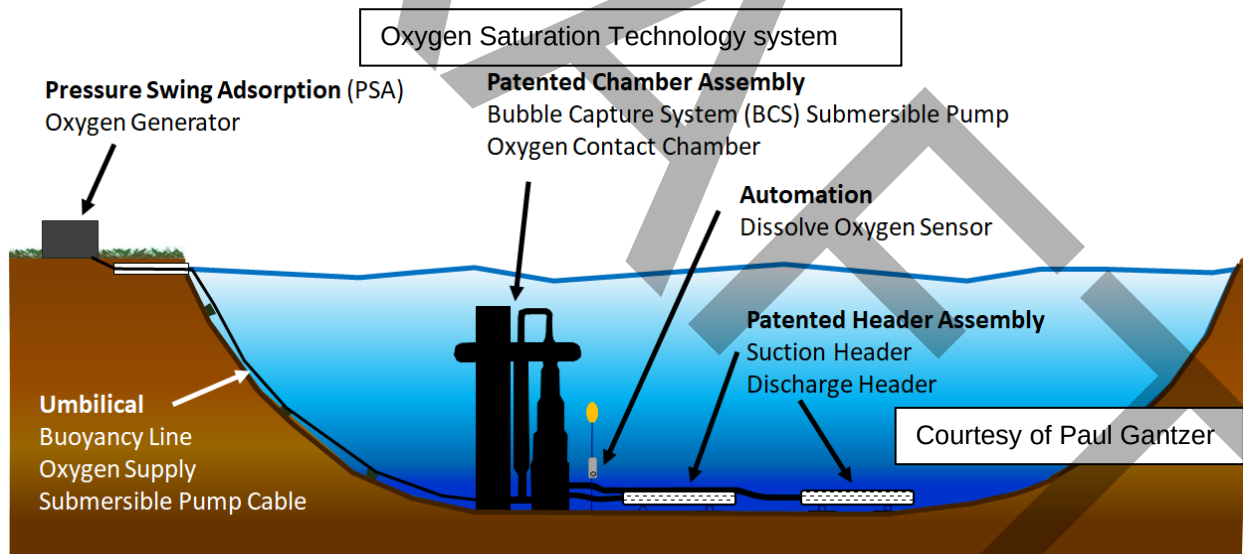


HO by sidestream oxygenation adds oxygen in a chamber, functionally similar to a downflow bubble chamber, but with slightly different processes and a range of chamber sizes. Onshore chambers can be pressurized to allow higher levels of oxygen to be added to withdrawn water before return to the lake. Rapid distribution of highly oxygenated water at the target depth then becomes important to avoid effervescence, the formation of bubbles that will rise and could cause destratification. The current and most advanced version of sidestream saturation, called oxygen saturation technology (OST), can be placed in the lake or onshore and automated to turn oxygen input on and off in response to oxygen sensors in the lake to maintain oxygen in a target zone above an acceptable threshold. OST tends to operate with smaller units that can be placed on shore in a modular arrangement or at varying depths and locations around a lake, more precisely targeting areas and allowing greater operational flexibility.

Hypolimnetic Oxygenation



5895
5896



5897 A derivative of sidestream saturation is called nanobubble technology, in which tiny bubbles are
 5898 formed that are intended to remain in solution without rising as a function of surface charges that
 5899 hold them in place until all gas is dissolved. The bubbles are so small as to qualify as “dissolved”
 5900 by any normal definition and it is not clear what advantage such bubbles convey over a high
 5901 concentration of dissolved oxygen in water placed in the hypolimnion of a lake. Nanobubble
 5902 systems have improved water quality in shallow embayments and industrial water treatment

5903 applications, but do not have a track record of reliability for hypolimnetic oxygenation. Further
5904 development of this approach to hypolimnetic oxygenation may occur.

5905 Various hybrid systems can be employed, applying multiple means of oxygenation and sometimes
5906 crossing over into artificial circulation. A full lift HO system uses air bubbles to bring water to the
5907 surface and then enhances oxygen content with agitation or other adjustments at the lake surface
5908 before returning oxygenated water to the deep target zone. Multiple intake ports can allow water
5909 to be mixed in such a way that an intermediate, thermally stable, third water layer is created, one
5910 with adequate oxygen to act as a barrier to P or other reduced compounds migrating upward
5911 (Kortmann's LayerAir design). Mixing systems are sometimes used to delay stratification into
5912 summer, after which HO systems are used when the energy necessary to keep the lake from
5913 stratifying becomes too great. Oxygenation technology is highly adaptable and offers opportunity
5914 for creativity and flexibility.

5915 Except where liquid oxygen is allowed to evaporate and travel by its own vapor pressure through
5916 pipes to the target zone of a lake, HO systems require some form of pump and/or compressor to
5917 move water and oxygen. Liquid oxygen can be delivered and stored onsite, or an oxygen generator
5918 can be used to provide the needed oxygen. Compressors, pumps, and oxygen generators will
5919 generate heat; proper housing design is essential to cooling and dependable operation. Shore-based
5920 mechanical equipment will require space and power, is usually placed in some kind of protective
5921 structure, and may need noise control to be acceptable to any local residents.

5922 Calculation of the amount of oxygen needed and where it has to be placed are critical elements of
5923 HO project planning. Oxygen demand can be assessed by several methods, including changes in
5924 oxygen concentration over time from lake measurements, measurement within in-situ chambers,
5925 or lab incubation of sediment cores. The movement of water due to gas or water input will increase
5926 oxygen demand, however, and the oxygen input is likely to increase by a factor of up to 2 for pure
5927 oxygen applications and 5 for air applications over demand estimates. The higher induced oxygen
5928 demand from air over pure oxygen is mainly a function of the greater gas input to supply the same
5929 amount of oxygen.

5930 Knowledge of the thermal regime over time and space is important to successful design and
5931 operation of HO systems. Oxygen travels readily from higher to lower concentrations within water
5932 of the same temperature, but as the temperature differential increases that movement is impeded.
5933 A vertical temperature gradient of 3 C° will inhibit water mixing but a difference of just 1 C° can
5934 inhibit oxygen transfer within the dissolved phase. Temperature differential minimizes the
5935 potential for destratification from added gas bubbles but impedes transfer of oxygen.

5936 For P control by HO to be successful there must be adequate P binders present in the sediment
5937 and/or water column. This is often the case, but where there is a history of hydrogen sulfide
5938 production, iron may be sequestered by sulfides and additional P binder may be needed. Extra iron
5939 has been added in some HO applications for improved P binding. HO systems operated for many

Hypolimnetic Oxygenation

5940 years have tended to reduce oxygen demand but do not eliminate it. Operational costs decline but
5941 there is an ongoing need to add oxygen, especially during the last half of summer.

Possible Benefits

- 5943 ♦ Reduces release of P from sediment and accumulation in the hypolimnion without eliminating
5944 stratification
- 5945 ♦ Reduces hypolimnetic accumulations of iron, manganese, ammonium and hydrogen sulfide
- 5946 ♦ Increases hypolimnetic oxygen levels and enhances habitat accordingly
- 5947 ♦ Creates a barrier to upward migration of reduced compounds; if deeper than the depth of light
5948 penetration, reduced algae production is expected
- 5949 ♦ Greater reduction of P than N leads to higher N:P ratios that favor other algae over
5950 cyanobacteria

Possible Detriments

- 5952 ♦ It is possible to induce gas bubble disease in fish, but this is not a documented occurrence from
5953 HO systems; the risk is higher with use of air than oxygen due to accumulation of N₂ gas
- 5954 ♦ System shutdown can allow poor water quality to develop rapidly with resultant habitat
5955 deterioration, and recovery can be slow
- 5956 ♦ Higher oxygen will allow more decomposition with release of nutrients by that process;
5957 adequate P binders must be present to inactivate any released P.

Information for Proper Application

- 5959 ♦ Data requirements for HO as a P control include an accurate P
5960 budget with a detailed analysis of internal sources
- 5961 ♦ The most critical information for designing an HO system is
5962 the oxygen demand that must be met by the system
- 5963 ♦ Lake morphometry and stratification data are needed to
5964 facilitate target area selection and choice of HO approach
- 5965 ♦ Availability of power is a prime application consideration
- 5966 ♦ Knowledge of P binder (especially iron) concentration is
5967 important to verify that P will be inactivated in the presence
5968 of oxygen.

Oligotrophic lakes typically have oxygen demands <0.25 g/m²/day, while eutrophic lake values are >0.55 g/m²/day; values up to 4.5 g/m²/day have been measured in MA lakes and values between 1 and 2 g/m²/day are common in stratified lakes with known oxygen problems.

Factors Favoring or Disfavoring the Use of this Technique

- 5970 ♦ Favored by a substantial portion of the P load being associated with anoxic sediment sources
5971 within the lake
- 5972 ♦ Favored by studies that demonstrate the impact of internal loading on the lake
- 5973 ♦ Favored by an external P load that has been controlled to the maximum practical extent or is
5974 documented to be small; historic loading may have been much greater than current loading

Hypolimnetic Oxygenation

- 5975 ♦ Favored when oxygen demand is high ($>0.5 \text{ g/m}^2/\text{day}$), although cost will rise with increased
- 5976 demand
- 5977 ♦ Favored when in addition to P control, minimization of other reduced compounds such as
- 5978 hydrogen sulfide, ammonia, manganese, and iron is desired (especially in water supplies)
- 5979 ♦ Favored where adequate P inactivators are present for reaction upon addition of oxygen,
- 5980 although this issue can be overcome by binder addition (e.g., aluminum or iron)
- 5981 ♦ Favored when shoreline space for land-based equipment is available where access is sufficient,
- 5982 power is available, and noise impacts can be minimized
- 5983 ♦ Favored where coldwater fishery habitat is an important goal
- 5984 ♦ Disfavored where lake morphometry is highly irregular with multiple separate basins and
- 5985 isolated coves that limit oxygen distribution
- 5986 ♦ Disfavored where ability to sustain long-term operation is limited (most recreational lake
- 5987 associations, as opposed to water suppliers with maintenance staff and ratepayers)

Performance Guidelines and Monitoring Needs

- 5989 ♦ Determine and meet oxygen demand to maintain oxygen $>2 \text{ mg/L}$ for water quality, $>5 \text{ mg/L}$
- 5990 to meet state standard based on support of aquatic life; this may require considerably higher
- 5991 concentrations on an average
- 5992 ♦ Properly size equipment to avoid underperformance
- 5993 ♦ Properly place equipment to ensure adequate coverage of target zone
- 5994 ♦ Incorporate and follow a maintenance plan for equipment
- 5995 ♦ Operate equipment to achieve temporal and spatial oxygen targets; maintaining a substantial
- 5996 buffer of elevated oxygen level will limit impact by occasional system shutdowns
- 5997 ♦ Monitor temperature and oxygen as indicators of mixing and oxygenation, preferably with
- 5998 continuous monitoring sensors
- 5999 ♦ Monitor other water quality or biological variables as necessary to evaluate success (most
- 6000 likely water clarity, P in surface and bottom waters, algal assemblage)

Key Considerations for Conservation Commissions

- 6002 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 6003 Estimated habitat and must be complete before the conservation commission can close any
- 6004 hearing and issue an Order of Conditions under the WPA
- 6005 ♦ If the project involves the installation of any fill or structures within a Great Pond, even on a
- 6006 temporary basis, a Chapter 91 permit or license is required
- 6007 ♦ If any onshore construction (e.g., shed for compressor, oxygen storage tanks, pumps) is within
- 6008 the buffer zone, a permit under the WPA may be needed
- 6009 ♦ No interest of the WPA should be threatened by an HO project and most interests should be
- 6010 protected or enhanced

- ◆ Proper sizing and placement to ensure that oxygen demand is met, and ongoing operation and maintenance of the HO system are critical to success and avoidance of any negative impacts in the future (i.e., loss of oxygen after a desirable biological community is established in formerly low oxygen water)

Massachusetts and Related Experience

Several water supply reservoirs in MA have installed HO systems, but the primary purpose has typically been to minimize the release of iron and manganese from sediment. P release should also be reduced but monitoring data are generally limited. Recreational lakes in MA have rarely undertaken HO projects as the ongoing operational cost and management program have been beyond what most lake groups have felt comfortable supporting. However, this approach to overall lake health improvement is gaining popularity and credibility with many advancements in recent years. While pure oxygen was not commonly used when the 2004 GEIR was developed, this is an offshoot of aeration technology, covered in the GEIR.

The Sarah's Pond project in Orleans, conducted by the Orleans Pond Coalition (OPC) since 2019, has been the first true HO application to a non-water supply lake in MA. Initially a nanobubble system was installed but extensive data from two years of operation did not demonstrate acceptable results. Oxygen was still depressed near the sediment-water interface, P concentrations did not decline, and algal blooms persisted. A sidestream saturation system using oxygen saturation technology from Gantzer Engineering replaced the nanobubble system in year 3 and performed well until early summer when equipment problems allowed low oxygen, elevated P, and a resumption of algae blooms. Adjustment of the HO system for greater reliability occurred through 2021 and 2022, conditions were improved, but overall goals were not achieved until 2023. Many valuable lessons in system design and operation were learned and continued application is planned.

Cooke et al. (2005) reviewed 28 HO projects and noted variable results. A major factor was the availability of P binders when oxygen was added, with improved results where additional binders were added with the oxygen. Disturbance of stratification was found to cause less than desirable results in some cases; decreased P concentration in dark, deep water can be offset by increased P availability through mixing into upper waters with adequate light. Lower algae biomass was associated with a shift away from cyanobacteria and an increase in larger grazing zooplankton in multiple cases, a combined effect of lower P concentration and more consumption of algae facilitated by creation of a deep, oxygenated, zooplankton refuge from fish predation. Benefits to fish growth and survival were also noted, with HO projects supporting coldwater fish populations and improved benthic macroinvertebrate food resources. Reduced iron concentrations were common and valued by water suppliers. The additional benefits of oxygenation exceeded the actual impact on P and algae in many cases.

A detailed review of HO systems (Wagner 2015) in the drinking water industry provides case histories, application tips, and costs. Case histories covered by Wagner (2015) include 5 unconfined diffused oxygen installations, 10 hypolimnetic aeration chamber projects, 4 downdraft

bubble contact system efforts, and 5 sidestream saturation experiences. All provided benefits but oxygenation was not found to consistently reduce algae biomass or shift the assemblage composition away from cyanobacteria. As these case histories are all from water supply or power generation reservoirs and most have major inflows, external loading may override any benefit from internal P load control. In most cases oxygenation was performed to reduce iron and/or manganese in deep source water or to increase oxygen in downstream flows, almost always with substantial success. P control and algae limitation are expected for waterbodies with demonstrated high internal P loading and low summer inflows. Overdesign to provide oxygenation capacity to address anticipated shutdowns was found to be essential to consistent program success, but most users have settled for lower cost systems that function well most but not all of the time.

A review of more recent HO projects by Preece et al. (2019) indicated that reduced internal P loading occurred in almost all cases but that additional management actions were often involved and complicated separation of specific oxygenation impacts. Where internal P loading was a major part of the annual P load and residence time in the waterbody was long, HO reduced cyanobacteria blooms and shifted the algal community to more edible forms. Biological structure then played a major role in overall algae biomass and water clarity, with abundance of larger bodied grazing zooplankton (e.g., *Daphnia*) maximizing water clarity. Shutdown of HO systems after cyanobacteria control has been achieved has resulted in a return of cyanobacteria blooms, suggesting that internal loading is a major factor in such blooms and that HO is an important method for their suppression. Improvement in fish and zooplankton communities were also noted with HO. The reduction in ammonium in deep water was also cited as important to cyanobacteria control and improved habitat for fish and invertebrates.

The duration of monitoring programs for HO projects, typically <5 years in the reported literature, limits our understanding of long-term effects of HO. The oxidation of surficial sediments is not rapid and extended operation of HO systems is expected to lead to more lasting improvements. While complete suppression of oxygen demand and hypoxia in deep water is not expected, more stable lake conditions and reduced need for HO have been demonstrated (Gantzer et al. 2019, Horne and Buetel 2019).

The use of HO systems is not yet a mature science, but advancements of the last two decades have greatly improved the potential for maintaining adequate oxygen in deeper water with suppression of internal P loading and algae blooms. While ongoing operational costs are an issue for recreational lakes, benefits to habitat as well as P control are evident and suggest that wider application of HO technology is warranted.

6083 **Dredging**

6084 **How It Works**

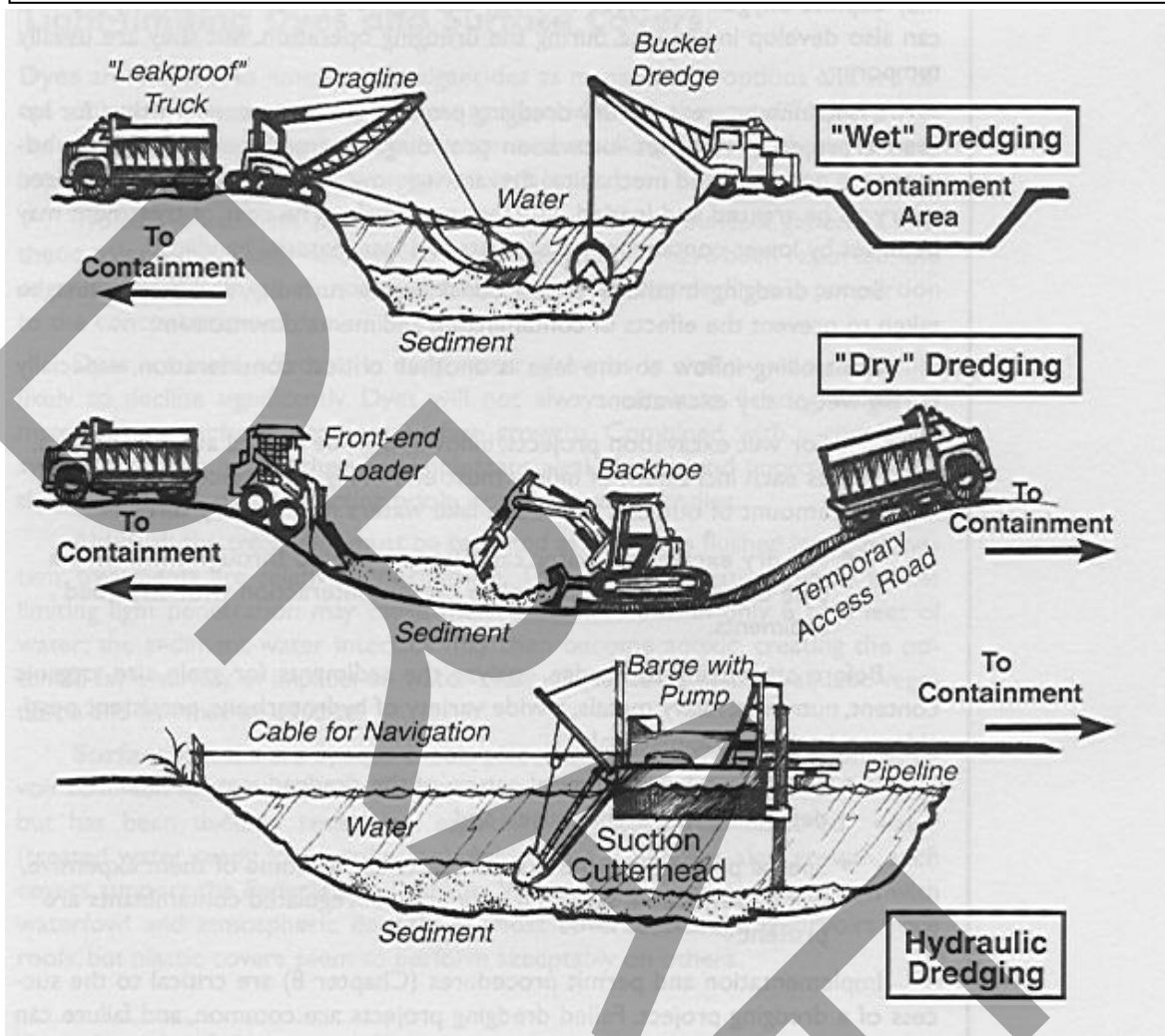
6085 Dredging involves the removal of sediment. Conventional dry, conventional wet, and hydraulic/
6086 pneumatic dredging are each addressed here, although planning and impact considerations will
6087 vary by approach. Dredging increases depth and restores lake volume where infilling from
6088 watershed erosion and organic inputs and/or internal generation of organic matter has occurred.
6089 Dredging can be an effective lake management technique for the control of excessive algae and
6090 rooted vascular plants by multiple mechanisms. Removal of organic sediment can reduce oxygen
6091 demand and improve the overlying water quality in multiple ways. Dredging may be considered
6092 true restoration, as it removes accumulated sediment and “re-sets” the lake to a less eutrophic state,
6093 although it does not address ongoing watershed sources and the collateral damage to lake biota can
6094 be substantial. Dredging of a small part of a lake, such as an inlet area where sediment accumulates,
6095 may have minimal adverse impacts and can prevent later problems as the sediment spreads into
6096 the rest of the lake. Dredging most of a lake could have major effects on biota that have to be
6097 balanced with the benefits of sediment removal.

6098 From the perspective of controlling algae, the release of nutrients that stimulate algae growth from
6099 lake sediments can be reduced by removing a layer of nutrient-rich sediment and exposing
6100 sediments with lower nutrient concentrations. This can reduce internal loading and suppress algal
6101 production if internal sources are dominant. Even where external nutrient loads remain high,
6102 dredging can reduce benthic mat formation and other problems with filamentous green algae and
6103 cyanobacteria, as these forms often initially depend on nutrient-rich substrates for nutrition. P and
6104 iron released from sediment exposed to low oxygen are implicated in many cyanobacteria blooms.
6105 Dredging also removes the accumulated resting stages deposited by a variety of algae.

6106 Additional benefits of dredging that are often sought include reduced plant nuisance impacts and
6107 improved water quality. The removal of sediment by dredging has the potential to limit substrate
6108 suitability for rooted plant growth, will remove seeds, turions, winter buds, and root systems from
6109 which plants grow each year, and could impose a light limitation on plant growth with a sufficient
6110 increase in depth. However, dredging may expose previously buried seeds that can be viable.
6111 Water quality benefits accrue mainly from the reduction in oxygen demand and the release of
6112 various compounds from anoxic sediment. The change in substrate quality will also influence what
6113 benthic invertebrates will be present, which in turn may affect the fish community. Removing
6114 accumulated sediment from a lake offers many benefits but is less commonly applied due to
6115 potential adverse impacts during dredging and usually high cost. Use as an algae control technique
6116 is valid where sediment is the dominant source of nutrients, but there are alternative approaches
6117 (e.g., oxygenation, inactivation) that are less costly. Dredging occurs most often when multiple
6118 benefits are desired or when the lake has become so shallow that it does not support its desired
6119 functions.

6120

Wet, Dry and Hydraulic Dredging Approaches (from Wagner 2001)



6121 Localized dredging projects usually seek to remove sediment from a target area like an inlet, cove,
 6122 swim area or marina, while projects involving most of a lake are usually intended to enhance
 6123 overall lake use, reclaiming depth, removing contaminated sediment, improving water quality,
 6124 and/or controlling rooted plants or algae. It is generally better to remove all problem sediment from
 6125 a smaller area than to remove just some of the material over a larger area, but getting all target
 6126 sediment out of any area can be challenging. Dredging usually targets "soft" sediment, typically
 6127 synonymous with organic deposits or possibly sand or clay inputs from storm drains or tributaries.
 6128 Knowing how much sediment to remove involves careful study and detailed testing of sediments
 6129 for physical and chemical properties. There are many factors that govern dredging success, and a
 6130 dredging feasibility study is usually necessary to cover the range of issues involved with planning,
 6131 designing, and permitting a dredging project. Sediment quantity and sediment quality are the
 6132 overriding influences on cost.

Key Considerations for Dredging

Reasons For Dredging:

Increased depth/access
Removal of nutrients/other contaminants
Control of aquatic vegetation
Reduction in oxygen demand

Volume Of Material Removed:

In-situ volume to be removed
Distribution of volume among sediment types
Distribution of volume over lake area (key sectors)
Bulked/dried volumes (immediately vs ultimate)

Nature of Underlying Material Exposed:

Type of material
Comparison with overlying material

Dewatering Capacity of Sediments:

Dewatering potential
Dewatering timeframe
Containment needs

Regulated Resource Areas:

Wetlands (includes lakes)
MESA listed species
Areas of Critical Environmental Concern
Outstanding Resource Waters
Great Ponds

Equipment Access:

Possible input and output points
Land slopes/elevation gains
Pipeline routing
Property issues

Potential Disposal Sites:

Possible containment sites
Soil conditions
Necessary site preparation
Volumetric capacity
Property issues
Long-term disposal options

Uses Or Sale Of Dredged Material:

Desirable sediment alterations (value enhanced)
Possible beneficial uses
Possible sale

Existing and Proposed Bathymetry:

Mean depth
Maximum depth
Depth contours

Physical Nature of Removed Material:

Grain size distribution
Solids and organic content
Settling rate/residual turbidity
Bulking/drying factors

Chemical Nature of Removed Material:

Metals levels
Petroleum hydrocarbon levels
Nutrient levels
Pesticides levels
PCB levels
Other organic contaminant levels
Other contaminants of concern

Flow Management:

Possible peak flows
Expected mean flows
Provisions for controlling water level
Implications for dredging approach

Relationship To Lake Uses:

Impact on existing uses during project
Impact on existing uses after project
Facilitation of additional uses

Dredging Methodologies:

Dry excavation
Wet excavation
Hydraulic (or pneumatic) options

Other Mitigating Factors:

Protective watershed management
Economic setting
Sociological setting
Political setting

Removal Costs:

Engineering and permitting costs
Dredging and dewatering costs
Disposal and monitoring costs

Dredging

6134 *Dry dredging*

6135 Dry dredging involves partially or completely draining the lake and removing the exposed bottom
6136 sediments with a bulldozer or other conventional excavation equipment and trucking it away.
6137 Projects involving silts, sands, gravel and larger obstructions where
6138 water level can be controlled favor conventional, dry methodology.
6139 Although lakes rarely dry to the point where equipment can be used
6140 without some form of support (e.g., railroad tie mats or gravel
6141 placed to form a road), excavating under “dry” conditions allows
6142 very thorough sediment removal and a complete restructuring of the
6143 pond bottom. The term “dry” may be a misnomer in many cases, as
6144 organic sediments will not dewater sufficiently to be moved like
6145 upland soils. Dry dredging may resemble a large-scale excavation
6146 of pudding, and the more the material is handled, the more liquid it
6147 becomes.

6148 Control of inflow to the lake is critical during dry excavation; water
6149 can often be routed through the lake in a sequestered channel or
6150 pipe, limiting interaction with disturbed sediments. Even then, the
6151 material may need to be placed somewhere outside the lake to dry
6152 before ultimate disposal. If an excavated area or natural upland
6153 depression is available, one-step disposal may be facilitated, but
6154 most projects involve temporary and permanent disposal steps.

6155 *Wet dredging*

6156 Wet dredging may involve partial drawdown, especially to avoid downstream flow of turbid water,
6157 but sediment will be excavated from areas overlain by water. Sediment will be very wet, often
6158 <30% solids unless sand and gravel deposits are being removed. Clamshell dredges, draglines, and
6159 other specialized excavation equipment are used in what is usually a very messy operation.
6160 Excavated sediment must usually be deposited in a sequestered area adjacent to the pond or into
6161 water-holding tanks or other structures until dewatering can occur.
6162 This approach is most often practiced when water level control is
6163 limited. This technique is applicable to ocean harbors, and has been
6164 practiced in Boston and New Bedford, but is usually not preferred
6165 in lakes other than small, isolated ponds unless there is no choice.

6166 Conventional wet dredging methods create considerable turbidity,
6167 and steps must be taken to prevent downstream mobilization of
6168 sediments and associated contaminants. For wet excavation
6169 projects, inflows must normally be routed around the lake, as each
6170 increment of inflow must be balanced by an equal amount of
6171 outflow, and the in-lake waters may be very turbid. It should be noted, however, that some bucket



Dry dredging of Dunn's Pond in Gardner with conventional excavation equipment (above) to a “hard” bottom (below)
(provided by C. Carranza of BEC)



Clamshell dredge used in wet dredging operations
(provided by the Lake Michigan Federation)

Dredging

6172 dredge designs greatly limit the release of turbid water and have been approved for use in
6173 potentially sensitive aquatic settings.

6174 *Hydraulic dredging*

6175 A more advanced form of wet dredging, hydraulic dredging usually involves a suction type of
6176 dredge with a cutter head. Agitation combined with suction removes the sediments as a slurry
6177 usually containing <20% solids by volume. This slurry is typically pumped to a containment area
6178 in an upland setting where the excess water can be separated from the solids by settling that can be augmented by polymer addition.
6179 The supernatant water can be released back to the lake or some other
6180 waterway with proper permitting. The containment area for a
6181 hydraulic dredging project is usually a shallow diked area that is
6182 used as a settling basin. The clarified water may be treated with
6183 flocculation and coagulation techniques to further reduce the
6184 suspended solids in the return water.
6185



Hydraulic dredging: large cutterhead barge

6186 Hydraulic dredging is normally favored for removal of large amounts of highly organic sediments
6187 with few rocks, stumps or other obstructions and where water level control is limited. This type of
6188 project does require a containment area to be available where removed sediments are separated
6189 from water and may involve secondary removal of the dried
6190 sediment from the containment area for ultimate disposal
6191 elsewhere. A slurry can be pumped multiple miles along a suitable
6192 route with booster pumps if there is land to be reclaimed but cost
6193 factors often dictate having the containment area close to the lake.



Hydraulic dredging containment area for Nutting Lake in Billerica: empty (above) and full (below) (provided by J. Walsh of BEC)

6194 Innovations in polymers and belt presses for sediment dewatering
6195 have reached the point where hydraulically dredged slurry can be
6196 treated as it leaves the lake to the extent necessary to load it directly
6197 onto trucks for transport to more remote sites. Solids content of the
6198 resultant material is still too low for many uses without further
6199 drying or mixing with sand, but the need for a large containment
6200 area can be avoided with this technology. The cost of coagulation
6201 and mechanical dewatering may be at least partially offset by
6202 savings in containment area construction and ultimate material
6203 disposal. Likewise, pumping the slurry into geo-tubes (engineered
6204 filter bags) can also enhance dewatering in a limited space.



6205 *Pneumatic dredging*

6206 Pneumatic dredging, in which air pressure is used to pump sediments out of the lake at a higher
6207 solids content (>50%) is possible but not commonly employed and has not been used in New
6208 England. This would seem to be a highly desirable approach, given containment area limitation

Dredging

6209 in many cases and more rapid drying with higher solids content. However, few of these dredges
6210 are operating within North America, and there is little freshwater experience upon which to base
6211 a review. Considerations are much like those for hydraulic dredging.

Possible Benefits

- 6213 ♦ Deepening of the lake for many purposes, including increased flood or water supply storage,
6214 improved recreational uses, enhanced pollutant trapping effectiveness, and dilution of nutrient
6215 loads
- 6216 ♦ Control of rooted plants if a depth (light) or substrate limitation is achieved
- 6217 ♦ Reduced algal mat formation by reduced nutrient supply and elimination of resting cysts
- 6218 ♦ Reduced planktonic algal abundance if internal loading is an important nutrient source and
6219 enough sediment is removed
- 6220 ♦ Removal of toxic substances or other unwanted materials accumulated in the sediment
- 6221 ♦ Reduced sediment-water interactions, especially lowered oxygen demand, for improved water
6222 quality
- 6223 ♦ Opportunity to establish structures to enhance the fish community (dry dredging)

Possible Detriments

- 6225 ♦ All possible negative impacts of drawdown if the lake is lowered to facilitate dry dredging
- 6226 ♦ Reduction or loss of benthic biological components where sediment is removed or disturbed
- 6227 ♦ Altered food web, at least temporarily, but with possible long-term improvement
- 6228 ♦ Potential for downstream turbidity if throughflow is not controlled
- 6229 ♦ Peripheral land disruption for access by equipment
- 6230 ♦ Upland area must be provided for sediment disposal, with temporary alteration
- 6231 ♦ Contaminated sediments potentially subject to many restrictions on disposal

Information for Proper Application

6233 Key factors include:

- 6234 ♦ Sediment quality, which will determine disposal options
6235 and cost
- 6236 ♦ Sediment quantity, which determines disposal volume
6237 needs and greatly affects cost
- 6238 ♦ What type of sediment is underneath the material to be
6239 removed
- 6240 ♦ Sensitive biological resources and regulated resource types,
6241 which affect project goals and permitting
- 6242 ♦ Ability to control the lake level and safely pass inflows,
6243 which affects choice of dredging method
- 6244 ♦ Equipment access and related impacts



Sediment core: dark organic matter on top of a clay base

Dredging

- 6245 ♦ Dewatering and ultimate disposal areas, possible beneficial uses of dredged material

6246 **Factors Favoring or Disfavoring the Use of this Technique**

- 6247 ♦ Favored where there is a justifiable need to increase depth in the lake
- 6248 ♦ Favored where studies have demonstrated the impact of internal nutrient loading on the lake
- 6249 or the presence of other contaminants in the sediment that are impacting lake biota or uses
- 6250 ♦ Favored where the oxygen demand by sediment is causing oxygen impairment in the water
- 6251 column
- 6252 ♦ Favored where rooted plants, algal mats, or planktonic algae dependent on the surficial
- 6253 sediments are impairing recreation and habitat value
- 6254 ♦ Favored where suitable, sufficient containment/disposal areas are available close to the lake
- 6255 ♦ Disfavored where protected species or resource areas make it difficult to avoid adverse impacts
- 6256 from dredging
- 6257 ♦ Disfavored where sediments are contaminated based on
- 6258 MA regulatory concentration thresholds and require
- 6259 special handling and disposal at increased cost

6260 **Performance Guidelines and Monitoring Needs**

- 6261 ♦ Address the many considerations for dredging; pay
- 6262 particular attention to sediment quality and quantity and
- 6263 disposal arrangements
- 6264 ♦ Design the dredging project with local conditions in
- 6265 mind; address water level and flow control, appropriate
- 6266 equipment, access and staging areas, material
- 6267 dewatering and transport for disposal
- 6268 ♦ Excavate in accordance with all permits
- 6269 ♦ Achieve a depth (light) or substrate (hard bottom)
- 6270 limitation if control of plant growth is a project goal;
- 6271 usually this involves removal of all soft sediment or
- 6272 achievement of a water depth in excess of 10 ft
- 6273 ♦ Remove sediment to expose a low nutrient layer if reduction of internal loading is a project
- 6274 goal; usually this involves removal of all organic sediment
- 6275 ♦ Remove sediment to expose inorganic material if reducing oxygen demand is a project goal
- 6276 ♦ Restore or rehabilitate all access, temporary containment, and final disposal areas
- 6277 ♦ Monitor downstream flows and water quality during dredging
- 6278 ♦ Monitor water quality for any discharge from a containment area
- 6279 ♦ Monitor recovery of lake biota and in-lake conditions relative to project goals (e.g., depth
- 6280 increase, water clarity, plant control, water quality enhancement)



Dredging containment area in Menotomy Rocks Park in Arlington when full (above) and when restored (below) to previous activity field status



Key Considerations for Conservation Commissions

- ◆ Dredging could involve over a dozen approval processes; know which ones apply and what agencies will be involved
- ◆ Impacts to interests of the WPA from a specific dredging project are highly dependent upon site-specific features and project design; make no assumptions based on projects elsewhere without careful evaluation of applicability
- ◆ All interests of the WPA could be impaired or benefitted by dredging but the most likely considerations will be short- and long-term effects on fisheries and wildlife habitat

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

Dredging is probably the most complicated lake management activity in terms of planning and permitting. Except at the smallest scale (<100 cubic yards removed), it involves more testing, more approvals, and greater cost than any other in-lake action. Professional help is strongly advised when considering a dredging project, and a dredging feasibility study is almost always essential.

Massachusetts and Related Experience

Dredging is common in the estuarine environment as a means to maintain navigable water or restore eroded beaches but is not commonly attempted on a large scale in freshwater lakes due to cost. Yet major improvements in lake condition and utility have been made by appropriate dredging projects. Dredging technology and material handling were advanced by MA projects in the 1980s and 1990s (e.g., Nutting Lake in Billerica, Dunn's Pond in Gardner, City Hall and Bullough's Ponds in Newton, Hardy Pond in Waltham, Hills Pond in Arlington, Porter Lake in Springfield, among others) and through projects in other New England states in the same timeframe (e.g., Center Springs Pond in Manchester, Silver Lake in Berlin and Meriden, CT).

More recent experience (e.g., Nashawannuck Pond in 2009, Morses Pond in Wellesley in 2012-13, Otis Wood Land Lake in Otis and Sandisfield in 2016-17, Crystal Lake in Peabody in 2016-2017, Sargent Pond in Brookline in 2018) has involved dredging of 12,000 to 45,000 cubic yards of sediment with disposal ranging from beach nourishment to landfill deposit. The primary reason for dredging has usually been to reclaim open water area lost to sedimentation from upstream sources, although organic accumulation from rooted plants accelerated that process in most cases. Control of rooted plants and algae has been an associated and desired result. Dredging reduced oxygen demand and hazardous contaminants as well, providing substantial ancillary benefits.

Dredging

6319 In terms of algal mat control, the dredging of Bullough's Pond suppressed extensive green algal
6320 mats for more than two decades. Similar results have been observed in the portion of Morses Pond
6321 dredged in 2012-13 and throughout Otis Wood Land Lake after dredging in 2016-2017. Planktonic
6322 algae blooms often originate from sediment in 10 to 20 feet of water and are supported by P release
6323 from sediments exposed to anoxia in deeper water, but those areas are rarely dredged as depth is
6324 adequate for most lake uses.

6325 Upstream flow control has been an issue for dry dredging projects, with flow routed around or
6326 through lakes in a sequestered channel or pipe, but not always in a consistently successful manner.
6327 Hydraulic dredging does not require flow control or water level manipulation but is restricted to
6328 the ice-free season and requires a more sophisticated containment area in which to dewater
6329 sediments and a discharge from that containment area that may require additional permitting.

6330 Sediment dewatering has always been a challenge for dredging, as solids content in all but the
6331 sandiest sediment is low and water content must be greatly reduced for almost any disposal
6332 arrangement. Hydraulic dredging takes advantage of the lower solids content to move sediment as
6333 a slurry through a pipe to a containment area. Where a former gravel pit or other landscape
6334 depression is available to be filled and the sediment is clean enough, dewatering and disposal costs
6335 can be reduced and make the project much more affordable if the cost of pumping the slurry to the
6336 site is not extreme. For wet dredging projects a dewatering area very close to the site is essential,
6337 and for dry dredging projects the need for nearby containment capacity is also often high, as
6338 organic lake sediment does not dewater well in the lake. Sometimes it can be pushed to the side
6339 with enough grade to encourage dewatering, but often extended drying time is needed that limits
6340 dredging progress. Belt presses have been used to accelerate dewatering and water-tight trucks
6341 have been employed to haul wet sediment to disposal sites, but each adds cost and is not extremely
6342 effective. Use of large filter bags that can be filled and left to dry has been particularly helpful in
6343 recent years.

6344 In many cases, the need to dredge has been a result of sediment inputs from the watershed, and
6345 unless the sources are curtailed, infilling will continue and may negate the benefits of dredging
6346 within a decade or two. At the cost of most dredging projects, much longer benefit duration is
6347 expected, necessitating watershed management or provision of sedimentation basins near input
6348 points to capture sediment in an area accessible for occasional clean out. Such basins are often
6349 placed at inlets or slightly upstream where a road crossing makes both constriction of flows and
6350 accessibility for clean out easier. Such basins were established on the two tributaries to
6351 Nashawannuck Pond in the 1990s, prior to dredging of the pond, and were cleaned out in 2020
6352 after accumulating about 1500 cubic yards of sediment. Duck Pond in Wellesley was dredged in
6353 1986 and 2006 but has no upstream sedimentation basins and serves a large, urban watershed; it
6354 was largely full of sediment as of 2016 and needs to be dredged again.

6355 Sediment disposal has been a large cost factor in dredging projects, especially when contamination
6356 or physical properties limit beneficial use of dredged material on a local level. Average

Dredging

concentrations of certain metals and hydrocarbons in MA lake sediment exceed standards for unrestricted disposal and often necessitate hauling to an approved disposal facility. Lakes in urban areas are particularly likely to have contaminated sediment, and lakes subject to repeated copper treatments over many years can experience contamination that affects sediment disposal. All dredging projects involving more than 100 cubic yards of material are required to conduct extensive testing of sediment, usually one sample per 1000 cubic yards to be removed. Under MA regulations, lake sediments that exceed standards that could characterize the sediment as hazardous waste do not have to be removed or remediated, but once the sediment is removed from the lake it is treated as hazardous waste and corresponding regulations apply to its handling and disposal. Initial plans for some dredging projects have been dropped as a result of problems with contaminated sediment disposal. Discussion of dredging Wood Pond and the associated Housatonic River in the Pittsfield area, subject to PCB contamination in the past, has gone on for over two decades with limited progress.

Planning and permitting for dredging projects often require multiple years of effort before the dredging can be accomplished. The information needs and multiple permit processes with limited overlap usually result in an extended period of study and regulatory action. It is best to fully understand the quality and quantity of sediment to be removed before getting into the permit process. Funding has also required multiple years to arrange. The Community Preservation Act has been an important source of funds for more recent dredging projects. In some recent cases, a decade or more of time elapsed between the decision to dredge and project completion, a function of permitting and funding processes.

On a more nationwide scale, dredging has been used much as it has in MA, but some projects have been much larger. White Rock Lake in Dallas, TX had lost so much depth from incoming inorganic sediment from a large watershed that sailing clubs were unable to operate. Approximately 3 million cubic yards of sediment were removed by hydraulic dredging in 1998 and used to fill old excavation pits about 8 miles away. That was the fourth dredging operation at White Rock Lake since it was constructed in 1911, with others in the 1930s, 1950s and 1970s. Additional dredging was under consideration in 2020. For impoundments of river systems, dredging is often essential to maintain reservoir capacity for water supply and power generation as well as recreation and aquatic habitat.

After P inactivation stations were established on inlets to decrease available P in runoff entering Lake Seminole in FL, approximately 900,000 cubic yards of organic sediment were removed to reduce the internal load of P, starting in 2019. Over a million cubic yards of sediment were removed from Cedar Lake in IA to restore capacity in a drinking water reservoir that also provides recreational opportunity and valued habitat. Many smaller projects have been completed, often using hydraulic dredges to avoid the impacts to fish and wildlife that can be caused by dry dredging, but partial drawdown or sequestration of parts of lakes to facilitate dry dredging is also common.

7. DIRECT ALGAE REMOVAL

This section addresses only one technique, algaecides. Algaecides are a standard approach to the control of algae in water supplies and recreational lakes when and where nutrient control has been insufficient to prevent blooms. There are other direct algae control techniques, but all have been placed in the alternative technique section of this guide. Some, including flushing and some biological controls, were covered in the 2004 GEIR for Eutrophication and Aquatic Plant Management in MA, while others like sonication, bacterial additives, settling agents, and collection systems were only mentioned as being under development. None of these alternative techniques has received extensive use in MA and while most have substantial applicability to algae problems, they suffer from limited implementation potential and/or insufficiently documented reliability. It is rare to have enough water available during summer to flush any but the smallest ponds, and such flushing moves water of potentially poor quality downstream where it can cause impairment. Bacterial additives are largely proprietary formulations with possible algaecidal properties not yet reviewed by MDAR. Collection systems for algae have only recently been developed but have been tested in MA and show promise. These alternative techniques may be permissible in MA, but it is not possible to offer the level of guidance for use that is possible for algaecides.

Algaecides represent the oldest form of algae control and have been applied for many decades in MA. While not preferable to nutrient control, algaecides are effective and can address an existing problem before it becomes too severe. There are many formulations of algaecides, but copper has been the main active ingredient since the start. More recently developed peroxide-based products have a favorable environmental profile, and a few other compounds have been developed to address algae that are particularly hard to kill. Algaecides are sometimes used to kill algae associated with rooted plants before herbicides are applied to increase the effectiveness of the herbicides.

Treatment with Algaecides

As described in more detail in the Essential Background section, algae are part of a healthy aquatic ecosystem and form a large part of the base of the food web in most lakes. There are many types of algae, only a subset of which are capable of producing toxins harmful to humans or aquatic life. A productive lake may not have excessive algal abundance if those algae are being consumed at a rate commensurate with production. Yet where nutrients are excessive and/or the biological structure is not conducive to rapid consumption of algae, visible accumulations of algae can occur and are called blooms. If the bloom harms people or aquatic life it can be called a Harmful Algal Bloom (HAB). Where the algae involved are cyanobacteria, it can be called a Harmful Cyanobacteria Bloom (HCB). Control of algae through limitation of nutrients is preferred, while limitation of light and increased consumption by zooplankton are desirable but difficult to achieve. Algaecides can be used to reduce algae when other methods have not been successful and the threat from HAB or HCB is perceived as serious enough to warrant action.

How It Works

Algaecides as addressed in this document are exactly what the root elements of the word imply; they are products used to kill algae. By MA regulations, algaecides are a subset of herbicides which are a subset of pesticides and contain an active ingredient applied to water to directly kill target algae.

There are two primary active ingredients used in the vast majority of algaecides applied in MA: copper and peroxide. There are many formulations available and the details of each are important to proper use. A few other herbicides can also be used as algaecides.

Algaecides are applied to waterbodies as solid or liquid products that are expected to interact with algae in the targeted area or volume. Algaecidal action is generally rapid, within a day or two, and products do not remain in the water column for long. It is best to use algaecides to limit the development of an algae bloom rather than to kill algae that are already in bloom mode, as the die off of abundant algae can cause water quality problems that threaten non-target aquatic organisms and potentially human users as well.



Planktonic algal bloom that could be a target of algaecide treatment

Copper-based products

Copper exhibits some selectivity among algae based on dose and exposure. However, almost all algae can be killed at doses allowable by the USEPA-approved algaecide label which specifies application limits that must be followed for legal use. The mode of action of copper is to inhibit photosynthesis and affect nitrogen metabolism, although some cell wall disruption is common with consequent lysing (i.e., “bursting”) of cells.

The GEIR covers the background and use of copper in some detail and MDAR provides a [review of copper-based algaecides](#). There have been many additional formulations developed since the GEIR was finalized in 2004, and while the general guidance in the GEIR remains applicable, consultation with a licensed applicator is advised when choosing a copper-based algaecide. While copper is generally used for the control of algae, in some cases it is also used for macrophyte control, often at a higher concentration than used to control just algae.

Wagner (2020a) provided a review of algaecide use in MA. Key lessons with regard to copper include:

- The label for most copper products limits application to no more than half the waterbody in a single treatment. This may necessitate more than one treatment with a two week pause in between if blooms are severe. It also encourages earlier response to increasing algae, which tends to be more effective, may avoid a bloom, and often causes fewer unintended impacts to non-target biota.
- MA restricts the use of copper for cyanobacteria control when cell concentration for potential toxin producers is >70,000/mL. This is done out of concern for release of water-soluble toxins from cells when lysed by copper, as toxins are not usually excreted and are only liberated into the water upon cell death and membrane rupture. However, those toxins will eventually be released naturally if no treatment is conducted, so this is not a simple solution. Adding to the complexity of the management decision, potential toxin producing cyanobacteria do not always produce toxins and there is no requirement to test for toxins, so the protocol is not definitive and may require follow-up monitoring.
- Tracking of algae and earlier action is advised, with treatment of cyanobacteria at cell counts between 10,000 and 20,000 cells/mL. Review of the most current [MassDPH cyanobacteria guidelines](#) and additional [MassDEP cyanobacteria guidance](#) is advisable when evaluating risk from cyanobacteria and considering algaecide use.
- The dose of copper applied (as copper, independent of formulation) rarely needs to exceed 0.2 ppm in MA lakes. However, although there is variation among algal groups and even between species of the same genus that sometimes necessitates higher doses, and the maximum approved label rate is 1 ppm. With background water quality in MA, nearly all cyanobacteria are sensitive to copper at <0.1 ppm and keeping the copper concentration below 0.1 ppm minimizes damage to non-target organisms, notably zooplankton, macroinvertebrates, and fish. Some algae are resistant to copper, notably certain green algae and a few cyanobacteria, but increasing the concentration of copper to address those algae may harm non-target organisms and alternative control methods are preferable.

- Controlling green algae mats, especially within the *Spirogyra-Mougeotia-Zygnema* group and the *Cladophora-Rhizoclonium-Pithophora* group, is very difficult at any concentration of copper. The outer layer of a mat often protects inner filaments, minimizing copper contact and effectiveness. Green algae mat control by copper depends on treatment before substantial mats develop, which involves treating at the sediment-water interface where light penetrates to the bottom. The logistics of knowing when to treat and getting the algaecide to the bottom without treating the whole water column can be addressed with weighted delivery hoses, chilled solutions, and new pellet formulations that sink before dissolving.



Mats of chlorophyta (green algae) can be very hard to kill with any method; treatment before dense mats form appears essential

Additionally, it is now recognized (Cottingham et al. 2021) that many planktonic cyanobacteria blooms start as growths at the sediment-water interface and timely treatment with copper added near the bottom where both nutrients and light are available can prevent blooms from forming. The same logistics noted above for green algal mats apply and concentrations of copper do not have to be high to be effective.

The water chemistry of the lake is an important consideration for treatment planning and effectiveness. The effectiveness of copper-containing algaecides is affected by basic water quality features. Increasing alkalinity, dissolved or suspended solids, and organic carbon content reduce copper effectiveness and under such conditions chelated copper compounds that maintain more copper in the water for a longer period may be more effective. Additionally, algae do not respond as well to copper treatments at water temperatures less than 10 to 15°C (50 to 59°F), although some success has been achieved. Licensed applicators or Certified Lake Managers can properly assess water quality and plan appropriate treatments.

Toxicity of copper to algae is intentional with the use of algaecides. Copper is potentially toxic to some zooplankton, invertebrates, and fish at concentrations allowable by the federal label and repeated treatments increase the risk of impacts (Scannell 2009). For example, acute and chronic toxicity to the zooplankter *Daphnia* were not observed at doses <0.3 ppm and mostly not until >0.5 ppm, depending on copper formulation (Kang et al. 2022), but the label does allow 1 ppm to be applied. Toxicity to fish was reduced for chelated copper compounds over copper sulfate but increased when surfactants were added, a practice associated with copper use in herbicides but not algaecides (Closson and Paul 2014). Almost all treatments in MA involve doses <0.2 mg/L applied to a fraction of the water column over no more than half the lake area, limiting potential toxicity. Additionally, the uptake of the algaecide by the target algae also mitigates exposure for many organisms (Bishop et al. 2018). There remains valid concern, however, over possible toxicity from

6530 repeat treatments or to organisms more sensitive than those used in testing to develop algaecide
6531 labels.

6532 Some fish, notably species of trout, are sensitive to copper at concentrations less than the maximum
6533 allowable label limit (1 ppm) but the MassWildlife database for fishkills does not indicate any
6534 significant mortality in MA from copper treatments. A review of copper effects on amphibians
6535 (Azizishirazi et al. 2021) suggests that amphibians are less susceptible to acute toxicity than fish,
6536 with virtually no tested species exhibiting mortality at even the maximum label concentration.
6537 Chronic toxicity has been less studied, however, and there is a risk to fish and amphibian eggs
6538 where treatments overlap with spawning or egg laying periods and some indication of
6539 developmental impacts at allowable treatment concentrations and possibly even for concentrations
6540 applied in MA.

6541 Despite direct impacts from multiple treatments at higher doses in other states, the actual copper
6542 in the sediment has generally been considered inert (Hanson and Stefan 1984, Paul et al. 2001).
6543 Benthic macroinvertebrate abundance and diversity were lower in the sediment of some treated
6544 lakes, but that may be an effect of multiple treatments or a result of past algal bloom impacts on
6545 water and sediment quality. Willis (2022) did not find impacts on benthic invertebrates at
6546 application rates typically used in MA but did detect them at maximum allowable rates. Willis
6547 (2022) also found that bioavailability and toxicity were not reliably predictable from sediment
6548 copper concentration. Bioaccumulation has been suggested by some research (Hoang et al. 2011)
6549 for snails that graze on treated sediment but not for fish. Should dredging be considered at any
6550 point, costs will greatly increase where copper concentrations exceed MA regulatory thresholds
6551 relating to sediment disposal.

6552 ***Peroxide-based products***

6553 Peroxide was not included in the 2004 GEIR but is currently registered for use in MA and has
6554 experienced increasing use over the last decade. Peroxide acts mainly on cell walls, either
6555 disintegrating them by oxidation processes or inhibiting transport across membranes. MDAR
6556 provides a [review of peroxide-based algaecides](#) that includes considerable detail on and insight
6557 into this group of algaecides. Hydrogen peroxide and several compounds that generate peroxide
6558 when added to water (e.g., sodium percarbonate and peracetic acid) act on the cell walls of algae
6559 to kill them. As different algal groups have cell walls of different materials and varying
6560 susceptibility to peroxide, this active ingredient tends to differentially control cyanobacteria better
6561 than green algae or diatoms (Matthijs et al. 2012).

6562 A typical dose of hydrogen peroxide for control of algae before dense blooms or mats develop is
6563 0.2 to 1.0 ppm in MA, but the approved label allows application at up to 10 ppm. As with copper
6564 use, tracking the algae community and treating before blooms or mats develop is desirable from
6565 both environmental and cost perspectives. Peroxide-based algaecides are usually sold as a solid
6566 but can be dissolved in water to allow liquid application. Floating granule formulations allow for
6567 dissolution over a period of minutes in surface waters, while application as sinking granules or

6568 tablets can allow the algaecide to sink to the bottom before much dissolution occurs, allowing
6569 treatment of algae growing at the sediment-water interface.

6570 Once reacted, there are no problem compounds remaining, as peroxide quickly degrades to oxygen
6571 and water. Oxidation of cell contents can occur, including cyanobacteria toxins and taste and odor
6572 compounds, a distinct benefit of peroxide application for algae control. Application should occur
6573 before severe blooms or mats form for best control and application is subject to the same cell count
6574 limitations for potentially toxic cyanobacteria as for copper products. Application of peroxide
6575 should also not involve more than half the lake at a time, but most labels require only two to three
6576 days between treatments.

6577 The cost of peroxides tends to be higher than for copper formulations, but the environmental
6578 impact profile is generally regarded as preferable for peroxide, with fewer non-target impacts than
6579 copper within the label limit for dose (Buley et al. 2021). However, peroxides can be toxic to some
6580 aquatic organisms, most notably zooplankton, at doses allowable by the product label but seldom
6581 applied in MA. Weenink et al. (2022) provide an evaluation of peroxide effectiveness and toxicity
6582 to non-target invertebrates, with concentrations <2 ppm greatly reducing cyanobacteria but having
6583 minimal impact on invertebrates. Concentrations up to 4 mg/L were needed to eliminate most
6584 cyanobacteria but had limited effect on green algae and only impacted a few invertebrate species.

6585 Impacts on non-target organisms increased with increasing dose, but only about half the tested
6586 zooplankton and one third the tested benthic invertebrate species were substantially impacted at
6587 the maximum label rate of 10 ppm when forced into 24 hours of exposure. Field tests suggested
6588 minimal impacts after one treatment at 2.5 ppm but increased impact after a second treatment.
6589 There remains valid concern that some non-target species may be more sensitive to peroxide than
6590 those used in toxicity testing to support label development. Peroxides are also listed as toxic to
6591 birds, but mainly through ingestion of pellets; this could be an issue with floating granules until
6592 they are dissolved or with any spillage on land while loading a vessel for aquatic treatment.

6593 Peroxides have not been granted the same regulatory status as copper-based algaecides with regard
6594 to use in water supplies and private ponds without flowing surface outlets. This means that
6595 emergency use of an algaecide to protect public water supplies will likely involve copper until
6596 peroxide is given the same permit exemption as copper products for algae control in water supplies.

6597 ***Other algaecides***

6598 Other algaecides are mostly products developed as herbicides for vascular plants that can be
6599 effective against algae as well. Endothall and flumioxazin are two active ingredients that have been
6600 found to provide control of some filamentous algae mats and are sometimes used for that purpose.
6601 Risks and benefits are covered in the herbicide section of this document.

6602 Barley straw produces algaecidal compounds naturally upon decay and has been used as an algae
6603 control agent in other states. However, barley straw has not been registered with the USEPA as an
6604 algaecide and therefore cannot be evaluated for use by MDAR. Barley straw is covered as an

6605 alternative technique in that section of this document but is not registered for use in MA as of
6606 2024.

6607 **Summary**

6608 While it is preferable to avoid algae blooms and mats by managing nutrients, that is not always
6609 feasible, and algaecides represent a valid control mechanism on at least an interim basis. The need
6610 for algaecides more than once per year should be taken as an indication that a more comprehensive
6611 lake management plan is needed. Where algaecides are used, effectiveness is enhanced and non-
6612 target impacts are reduced through accurate timing of application. Algaecides should be applied
6613 early in the exponential growth phase of algae when algal sensitivity is greatest and the impacts of
6614 lysing cells on the aquatic environment are minimized. Proper timing of application requires
6615 tracking of algal populations, usually on a weekly basis, adding expense to the program but
6616 maximizing benefits while minimizing risks. Once algaecides are applied there is little mitigative
6617 potential and careful planning and implementation are needed to avoid undesirable impacts.

6618 Toxicity is a function of dose and exposure. The low doses of either copper or peroxide products
6619 normally applied in MA can differentially impact cyanobacteria over other algae and minimize
6620 impacts to non-target fauna. Label limits that allow treating only half the area of a waterbody in a
6621 single application reduce exposure for target and non-target organisms. Increasing dose and repeat
6622 applications increase the risk of non-target impacts. Algaecides are therefore best applied at low
6623 concentrations to prevent blooms and not on a regular basis.

6624 **Possible Benefits**

- 6625 ♦ Rapid control of susceptible algae
- 6626 ♦ Potential to avoid an algae bloom or mat formation by well-timed application
- 6627 ♦ Peroxides may oxidize cell contents including taste and odor compounds and toxins
- 6628 ♦ Most algaecides are rapidly eliminated from water column, minimizing prolonged adverse
6629 impacts
- 6630 ♦ Algaecides offer a control option when other methods have been inadequate or where an
6631 interim solution is needed while nutrient control measures are being implemented

6632 **Possible Detriments**

- 6633 ♦ Potential toxicity to non-target organisms; risk increases with dose and treatment frequency
- 6634 ♦ Releases contents of most dead algae cells back into the water column; this may include
6635 nutrients, taste and odor compounds, and toxins, and will increase oxygen demand
- 6636 ♦ Ineffective on some algae; repeated treatments may favor those resistant algae, some of which
6637 are major nuisance species
- 6638 ♦ Copper accumulates in sediments; toxicity and bioaccumulation are not predictable from
6639 copper concentration, but sediment disposal is restricted at elevated copper levels

Information for Proper Application

- ◆ Algal monitoring to determine types of algae in need of control and proper timing of any treatment
- ◆ Water quality data to evaluate dose needs and likely effectiveness (focus on alkalinity, pH, dissolved and suspended solids, temperature)
- ◆ Inventory of non-target biota for potential impact assessment

Factors Favoring or Disfavoring the Use of this Technique

- ◆ Favored when algal monitoring allows early response before bloom formation
- ◆ Favored when dominant algae species are susceptible to algaecides at lower doses
- ◆ Favored when infrequent and unpredictable algal blooms impair recreation or water supply
- ◆ Disfavored where non-target species with high sensitivity to algaecides are present
- ◆ Disfavored if repeated application within a year is needed to reduce blooms or mats



Cyanobacteria scum: treating at such high algae accumulation has potential adverse impacts on water quality and non-target organisms

Performance Guidelines and Monitoring Needs

- ◆ Monitor algae at a frequency appropriate to detection of bloom formation before blooms become dense; know which types of algae are dominant
- ◆ Choose an algaecide appropriate for the quality of water to be treated; pH, alkalinity, organic carbon, and solids content are key variables
- ◆ Algaecides must be applied by licensed applicators with proper permits in place
- ◆ Apply algaecides while algal growth is in its exponential phase; do not wait for a dense bloom to form
- ◆ Apply algaecides in accordance with label instructions and restrictions; justify dose, location and timing of treatment
- ◆ Apply algaecides evenly throughout target area to minimize adverse impacts; target an appropriate water depth to maximize benefits while minimizing adverse impacts
- ◆ Monitor water quality before and after treatment, with emphasis on oxygen and nutrient levels
- ◆ Where cyanobacteria or other algae with potential for toxicity are treated, monitor for toxin level in the water before and after treatment
- ◆ If repeated treatment is necessary in a single growing season, pursue nutrient controls on algal growth as part of a more comprehensive plan
- ◆ Where algaecides are used to aid vascular plant control with other herbicides, use as directed for auxiliary purpose

Proper Use of Algaecides:

- ◆ Applied to prevent a bloom, not remove a bloom, if at all possible
- ◆ Know when algal growth is accelerating and treat on rising part of growth curve
- ◆ Know enough about target lake water chemistry to determine the most appropriate form of algaecide
- ◆ May involve surface or shallow treatment where nutrients are fueling expansion of algae population in shallow water
- ◆ May be most successful with intermediate depth treatment where algal bloom forms near the thermocline
- ◆ Treatment near the sediment-water interface may provide best results where major migration from sediment is occurring
- ◆ Recognize that if repeated treatments are required to maintain control during a year, alternative control methods should be sought

6676

6677 **Key Considerations for Conservation Commissions**

- 6678 ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or
6679 Estimated habitat and must be complete before the conservation commission can close any
6680 hearing and issue an Order of Conditions under the WPA
- 6681 ◆ Aside from the WPA permit through the local conservation commission and MassDEP,
6682 algaecide use requires a [License to Apply Chemicals](#) through MassDEP (WM04 online
6683 process) that occurs after an Order of Conditions has been issued
- 6684 ◆ Application of an algaecide must comply with both the USEPA label and any additional
6685 restrictions given by the MA Department of Agricultural Resources (MDAR), the state agency
6686 responsible for registering algaecides for use in MA
- 6687 ◆ Algaecides must be applied by a licensed applicator
- 6688 ◆ MGL 111 Section 5E, relating to public health, removes jurisdiction from MassDEP and
6689 conservation commissions for the use of algaecides by state and federal agencies while in the
6690 conduct of their official duties, for application in privately owned ponds from which there are
6691 no flowing outlets, and for algaecides approved by the department and used by legally
6692 established water supply agencies in public water supplies. Copper-based algaecides are the
6693 only algaecides approved under this clause as of 2024 and the MassDEP must be notified prior
6694 to treatment. Jurisdiction under MESA remains where Priority Habitat for state listed species
6695 is present and approval by MassWildlife/NHESP is still required
- 6696 ◆ Among the interests of the WPA, algaecide use may not cause any negative impacts but there
6697 is potential to affect the interests of protection of water supply, prevention of pollution,
6698 protection of land containing shellfish and protection of fisheries, especially if oxygen is
6699 depressed or loose algal toxins are increased by cell lysing

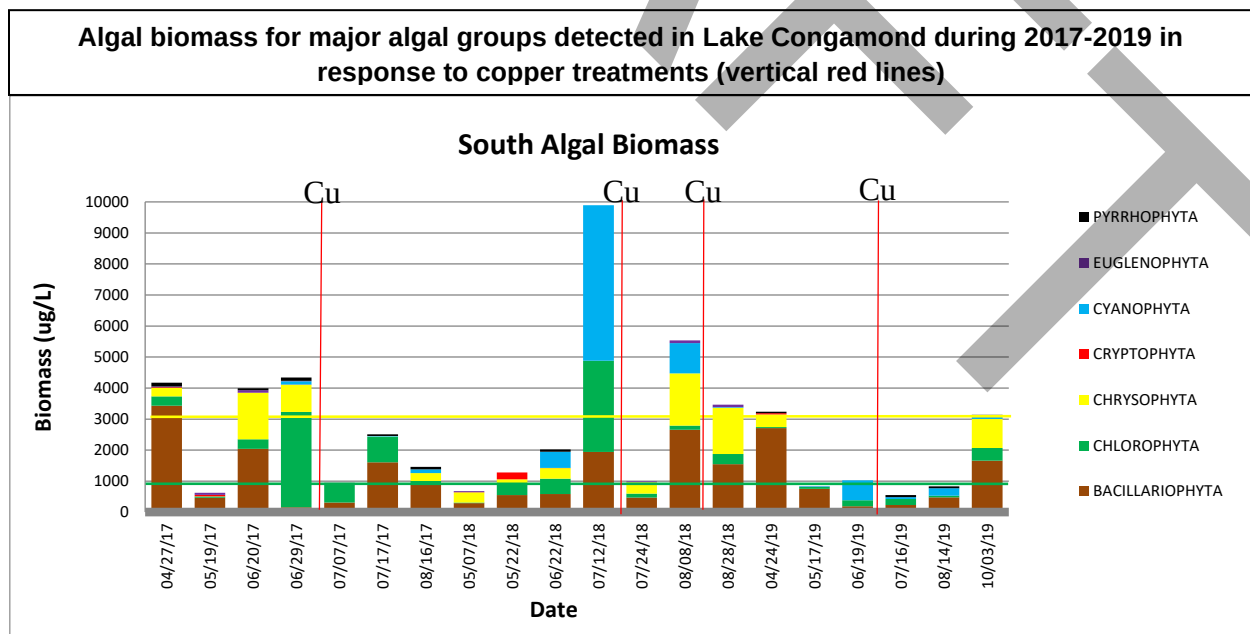
Algaecides

- ◆ The potential benefits of treatment need to be balanced against the risk of any negative impacts; use of algaecides in the early phase of bloom or mat formation can prevent problems while posing limited risk to non-target organisms or water quality

Massachusetts and Related Experience

Algaecides have been used in MA for many years and hundreds of permits are issued each year for such treatments. From 2014 through 2019 the number of treatments with copper-based algaecides increased yearly from 214 to 275. Only a handful of peroxide treatments have been conducted each year according to the MassDEP permit record. The dominance of copper as the active ingredient in algaecides applied in MA is a function of the lower cost of copper and less experience with peroxides. Copper-based algaecides have provided effective short-term control in most cases and have not been implicated in fishkills or other toxic events based on MassWildlife records. The potential for invertebrate mortality is higher than for fish and may go undetected without targeted monitoring. Chronic toxicity impacts are also understudied and could occur at doses allowable by the label, but use of algaecides is not frequent enough in most cases to be a chronic influence.

A single treatment of algaecides will not provide multi-year control, but well-timed treatments have provided relief for an entire summer in some cases. Treatment of part of Lake Congamond in Southwick as informed by frequent algae monitoring in 2017 and 2019 prevented bloom formation with a single treatment in June of each year. However, delayed treatment in 2018 allowed a bloom to form and it took two treatments in 2018 to maintain desirable conditions. The importance of treating as algae abundance is accelerating and not waiting until a major bloom has occurred is emphasized. Watershed management and P inactivation eliminated the need for algaecides in Congamond Lake as of 2020.



6723 It has been common practice among water suppliers to treat in advance of expected blooms based
6724 on historic algae patterns. The need for pre-emptive treatments may seem speculative in that they
6725 are conducted whether or not there is any evidence of an impending bloom, and it is not possible
6726 to prove that there would have been a bloom in the absence of treatment. However, examination
6727 of detailed algae records for a pair of CT reservoirs with and without treatment has documented
6728 the validity of this widespread approach.

6729 The blooms in question in two reservoirs of the Norwich CT system almost always initiate as
6730 cyanobacteria growing at the sediment-water interface in 15 to 30 feet of water (deep enough to
6731 have P release from sediment but shallow enough to have some light at the bottom). Treatment in
6732 late May can limit the developing colonies and prevent later surface blooms; skipping the treatment
6733 resulted in blooms in June or July in some years (WRS unpublished data). To enhance
6734 effectiveness with minimum risk to non-target organisms, treatment was restricted to the zone of
6735 known algae contribution with algaecide application as a chilled solution delivered through
6736 weighted hoses. No significant cyanobacteria blooms have occurred over the decade of treatment
6737 by this approach and no water quality problems or significant mortality of aquatic fauna has been
6738 detected.

6739 Aquarion Water Company manages multiple reservoirs along the CT coastal region, many of
6740 which have urban watersheds and are subject to high nutrient loads. Both copper and peroxide
6741 have been used with varying success, but over a period of years the staff has developed the
6742 capability to apply algaecides with maximum effectiveness and limited impacts on raw water
6743 quality or biological components of the reservoirs. Peroxides have been found to be effective for
6744 longer than copper, and coupled with bulk ordering of products, has brought the cost of using
6745 peroxide close to that of copper on a multi-year basis. Peroxide has been especially useful in
6746 addressing benthic cyanobacterial mats, with a pelletized formulation applied to sink rapidly to the
6747 bottom where it has caused mats in early stages of formation to disintegrate.

6748 Cooke et al. (2005) review copper as an algaecide and conclude that while it provides potentially
6749 effective short-term control of algal blooms, it has too many possible negative impacts to be a
6750 mainstay of algae management. However, that review includes treatments across North America
6751 and encompasses many treatments at much higher doses and in lakes with very different water and
6752 sediment quality than encountered in MA. A focus on nutrient management is emphasized,
6753 although the value of algaecides for current algae problems where human and ecological health
6754 may be threatened is acknowledged. Used effectively and efficiently, algaecides are a useful tool,
6755 but not one that should be depended upon for long-term algae management.

6756
6757

8. AQUATIC PLANT CONTROL

Standard techniques used to control aquatic vascular plants include dredging, benthic barriers, drawdown, hand pulling, mechanical harvesting, hydroraking, and herbicides, all covered in this chapter. Dredging, while not common as a function of costs and non-target impacts, can reset a lake or some part of one physically and ecologically. Dredging was covered under Reduced Availability of Nutrients in Lakes and is only accorded some additional discussion here in the context of rooted plant management. Benthic barriers have high applicability on a localized basis, can be permitted in MA, and most products have been very reliable. Drawdown is one of the more controversial lake management techniques and is less amenable to guidance that will be applicable in all cases. A general review is provided in this chapter, noting conditions that make drawdown more acceptable to most parties, and an appendix with more detailed discussion of key factors is provided for those wanting to attempt to permit a drawdown outside the limitations suggested in this chapter. Various forms of plant harvesting are commonly applied in MA. Herbicides have been used for many decades, although the products have changed and greater specificity for target species is now achieved by choice of product and timing and location of application.

Additional techniques to remove or prevent plant growth have been assigned to the alternative techniques section (chapter 9) as a consequence of limited documentation of reliability and permitting issues under more recent regulations, but most have been used in MA in the past. See the alternative techniques section for discussion of dyes, surface covers, competition with native plants, reverse layering, addition of herbivores to consume plants, use of pathogens to kill plants, rotoation, and small-scale physical disruption devices. Stocking non-native fish that consume plants, the best known of which is the grass carp, is prohibited in MA.

Dredging

Dredging is mainly conducted to recover depth in a lake, usually after sediment inputs from the watershed have accumulated to the point where habitat and lake uses have become impaired. Dredging on a large scale for other purposes, including reduction of nutrient reserves or plant control, is rarely conducted due to cost, impact, and permitting issues. Dredging is covered as a technique to limit nutrient availability in lakes separately in this manual as a means to reduce problems with algae. The types of dredging, potential benefits and detriments within lakes, and many other application considerations are covered, and the reader is referred to that section on dredging. Additional considerations associated with dredging for rooted plant control are covered here.

Dredging increases depth and potentially changes the nature of the sediment-water interface. With increased depth a light limitation can be imposed, changing the types of plants (based on shade tolerance, pigment composition and related ecology) or the quantity of plants that will grow at the new, deeper depth. A dredging-mediated change to coarser substrate, usually sand and gravel but sometimes rock, will also limit plant growth and shift the assemblage to species able to establish roots in the new, coarser sediment. Where nuisance plant growths occur as a function of accumulation of hospitable sediment, dredging can limit such growths.

When dredging for rooted plant control, it is important to know how deep the water must be to establish a light limitation on plant growth. For northern lakes, the depth to which plants will grow can be estimated as: $\text{Log MDC} = 0.79 \log \text{SD} + 0.25$ where MDC= Maximum Depth of Colonization and SD= Secchi Depth, both in meters.

Dredging for plant control will necessarily occur in the littoral zone, the area where light penetrates to the bottom and allows plant growth. This is a very active biological zone; the sediment is not a barren expanse of lake bottom, but rather a productive area with invertebrates living in or on the sediment, more invertebrates living on or among the plants, fish spawning, feeding, or seeking shelter among plants, and reptiles, amphibians, and birds all using the area as habitat. If the growths are invasive species or native forms at such a high density that human uses and habitat for some aquatic species are compromised, dredging can improve conditions, but the percentage of the littoral zone affected is an important consideration and not all impacts will be positive.

The removal of sediment by dredging can remove the plants themselves along with seeds, turions, winter buds, and root systems from which plants grow each year. This will effectively reset the dredged area in terms of plant community features, and what grows subsequently will be a function of the new conditions of depth and substrate, migration of plants from areas not dredged, new invasions, or active planting and other management to shape the plant community. The key rule in plant management is that where light penetrates to a hospitable substrate, plants will grow. If dredging limits light or makes the substrate less hospitable, fewer plants can be expected. Yet plants are integral to most properly functioning aquatic ecosystems and the encouragement of

Dredging

6819 desirable plants is worth considering. Dredging can be a valuable component of an “aquascaping”
6820 program but does not constitute a complete program by itself.

6821 The changes in types of plants will not always be beneficial. Some invasive species and even some
6822 nuisance native species are able to grow at substantial depth and can grow on sandy to gravelly
6823 substrates. The density of any plant growth will likely be reduced as the water gets deeper and the
6824 sediment becomes coarser, but it is rare to removal all “soft” sediment and some regrowth is to be
6825 expected. The change in sediment features will have a strong impact on the invertebrate fauna,
6826 eliminating or diminishing habitat for some species. Shifts in plant and invertebrate populations
6827 will in turn affect use of the area by fish, reptiles and amphibians. The impact on water-dependent
6828 birds is highly variable; improved access through plant density reduction can be a benefit, while
6829 changing food resources may be a detriment. Habitat is an important consideration under the WPA
6830 and large scale changes may not be acceptable. If any state-listed species is present, the provisions
6831 of MESA apply, and the likelihood of dredging being permitted declines.

6832 As part of an overall plant control program that acknowledges the ecological value of the littoral
6833 zone, dredging must be complemented by additional actions If plants have become overly
6834 abundant due to sediment inputs from the watershed, sources should be identified and addressed.
6835 This will be especially true where a delta forms at an inlet due to inadequate upstream erosion
6836 control. Dredging to remove accumulated sediment, particularly where it supports invasive
6837 species, should be accompanied by upstream work to minimize the need for future dredging. If a
6838 small area is dredged relative to the size of the littoral zone, undesirable impacts can be minimized
6839 unless the dredged area is a critical spawning site or other important and limited habitat type.
6840 Placement of rocks or woody debris in a dredged area can enhance habitat, although it will be
6841 different habitat than what was previously present, and such alteration may not be workable in a
6842 swim area or marina. Knowledge of the fish and wildlife associated with any area targeted for
6843 dredging is important to project planning and impact assessment. Yet where there is ample shallow
6844 water underlain by organic substrates and hosting dense aquatic plant communities, exposure of
6845 coarse substrate and reducing plant density in a limited area through dredging can improve overall
6846 habitat diversity and value.

6847

Benthic Barriers

How It Works

Benthic barriers, or bottom covers, limit light for rooted plants and create a physical barrier that restricts growth. Aquatic plant control by benthic barriers relies on the same concepts as “weed barrier” use in landscaping or gardening. Benthic barrier is usually used for two purposes: 1) to eliminate pioneer infestations of invasive species where localized collateral damage is acceptable and 2) to minimize aquatic vegetation in a small area designated for uses with which plants conflict (e.g., swimming or boat access).

Natural materials including clay, sand, and gravel have been applied to existing lake bottoms to create a layer of substrate less favorable to plant growth, although plants often root in these materials eventually, and environmental regulations make it difficult to gain approval for deposition of fill material. A variety of solid and porous barriers have been used to cover sediment and retard plant growth. Polyethylene, polypropylene, fiberglass, nylon, and various plastics have been developed over the last half century and experience has demonstrated efficient application approaches. Manufactured benthic barriers are negatively buoyant materials in sheet form which can be placed on the lake bottom to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of plants and even mat-forming algae.



**Porous weave benthic barrier
(Aquascreen)**



**Non-porous benthic barrier with
sleeves for rebar weights
(LakeBottomBlanket)
(Courtesy of Paul Grosjean)**

Barriers placed before significant plant growth has occurred can prevent such growths as long as the surface of the barrier does not support rooted plants. Placing barrier after seeds, turions, or winter buds have germinated but growth is limited can help suppress current growth and exhaust plant reserves, eventually leading to fewer plants when the area is uncovered. Placing barrier on mature plant growths may provide control but response is variable by species and there is an increased likelihood that plants will regrow after the barrier is removed.

Benthic barriers can provide highly effective plant control on a localized scale. Benthic barriers are not selective and properly applied barrier can prevent nearly all forms of rooted plant growth and eliminate existing growths over one to two months. Once barrier is removed, recolonization will begin and renewed plant growth varies with time of year, plant species, and presence of seeds, turions or other reproductive forms in the previously covered area. Benthic barriers can be efficiently deployed in small areas such as dock spaces and

Benthic Barriers

swimming areas to minimize rooted plant growth. The creation of access lanes through dense plant growths and enhancement of structural habitat diversity with benthic barriers is also practical. It is unusual to apply benthic barrier to more than an acre or two in any one lake, however, because the cost of materials is high and application effort is substantial.

There have been difficulties with the deployment and maintenance of benthic barriers, limiting their effectiveness over the broad range of field conditions, but these can usually be avoided by proper planning and implementation. Problems of prime concern include long-term integrity of the barrier, “billowing” (i.e., lifting of the barriers off the bottom) caused by trapped gases, accumulation of sediment on top of barriers, and growth of plants on top of or through barriers. Successful use is related to selection of materials, the design and quality of the installation, and ongoing maintenance. Guidance for barrier use can be offered as a result of considerable experience:

- ◆ There is a trade-off between cost and barrier longevity; where a barrier is to be moved or removed for cleaning and replaced it is best to purchase strong material that will last for years
- ◆ Porous barriers will be subject to less billowing, but can still trap gas and will allow settling fragments of some plant species to root and grow; annual maintenance is therefore essential
- ◆ Solid barriers will generally prevent rooting in the absence of sediment accumulations, but will billow after enough gases accumulate if not properly vented and anchored; small slits or holes punched at regular intervals can alleviate gas accumulation
- ◆ Plants under the barrier will usually die within a month, although two months of coverage achieves maximum plant reduction, with solid barriers more effective than porous ones in killing the whole plant; barriers of sufficient tensile strength can then be moved to a new location, although continued presence of barriers restricts recolonization and germination from seeds, winter buds, or turions
- ◆ Maintenance is needed to avoid plant growth on top of barriers; porous barriers will usually need annual cleaning, while non-porous barriers can usually go two years before cleaning is needed.
- ◆ Placing a single barrier panel is relatively easy and will provide plant control within its footprint, but placing multiple panels end to end or side by side greatly increases the needed effort, as lining up the panel edges can be challenging without using divers
- ◆ Use of bricks, stones, small sandbags or other weights will hold the barrier in place but requires individual weight retrieval to remove the barrier for cleaning and maintenance; use of attached or built-in weights supports “one piece” manipulation but will make the barrier heavier overall and require more effort to handle or remove
- ◆ Barrier width in commercially available products has typically been 7 to 14 feet and length has usually been between 25 and 100 feet; smaller pieces are easier to manipulate but having more pieces to place in an area increases the needed effort; balance application ease with desired coverage

Benthic Barriers

- ◆ Currently available barriers are durable and should last at least 10 years with proper installation and maintenance; most can be cut with a knife or scissors or punctured with sharp objects, but few can be ripped and nearly all will support some degree of foot traffic
- ◆ Proper deployment may be difficult to accomplish over dense plant growth, particularly emergent plants with stronger stems; application in spring before plant growth becomes substantial requires less effort but must be conducted in cold water or with lowered water level
- ◆ Unless the panel is in a frame that ensures it remains rigid along its edge, overlapping panels by about 6 inches is necessary to prevent plants from growing between panels
- ◆ Sites with many stumps, boulders or other underwater obstacles are poor candidates for benthic barrier use, while sites with considerable sediment input may also be undesirable candidates.
- ◆ Areas subject to fluctuating water elevations, heavy boat traffic, or strong wave action may pose challenges to keeping the barrier flat and firmly affixed to bottom sediments

MassDCR provides recommended [standard operating procedures for benthic barrier use](#). Important considerations for the installation of benthic barriers include the need for nearly complete elimination of plants, size of the area to be treated, bottom features and possible obstructions, cost of the product, application and maintenance costs, and possible impacts to non-target organisms in the installation area. Proper deployment is a function of manpower and planning by the installer. Careful consideration of site conditions is essential to maximize effectiveness, as barriers must remain in place for at least a month to kill most target plants. Relocated barrier will require less maintenance, especially if flipped on reinstallation, although deployment effort may increase.

Scuba divers normally apply barriers in water deeper than about 8 feet, which greatly increases labor costs. Most applications are in water <8 feet, however, and can be done by boat with support by snorkelers where panels need to be abutted or overlapped. Where drawdown is conducted, barriers can be placed in the drawdown zone prior to refill if the sediment supports foot traffic.

Where the barrier is to be applied and then weighted or staked in place, it can be rolled onto PVC pipe with a slightly longer wooden or metal pole inside the PVC pipe, allowing the barrier to be rolled out like paper towels and then staked or weighted. Where the barrier has attached weights when being deployed (e.g., rebar inserted in sleeves sewn into the barrier), it can often be folded accordion-style and paid out off a boat over the target area. With smaller barrier panels it is possible to flip the barrier in place or onto an adjacent area after at least a month, limiting maintenance and extending coverage within a season.



Benthic barrier with plants growing beyond its edge

Benthic Barriers

How long benthic barrier is left in place beyond the time necessary to kill target plants is a function of the use of the area in which it is installed and the type of barrier. Where barrier is placed in a beach setting in water shallow enough for people to stand, the barrier is often placed at least a month before swim season begins and is removed at the start of the season. People tend to prefer the feel of sandy natural substrate and foot traffic will continue to minimize plant growths, whereas in the absence of the barrier people tend to avoid areas where plants are growing. Where installed in deeper parts of swim areas, or around docks, or to create boating or swimming lanes to deeper water, installation for the whole use season is typical. Where an invasive species is targeted, barrier should be left in place long enough to ensure complete elimination of that target species, often approaching two months, with follow up actions to prevent its recolonization. In some cases, barrier is left permanently and is either cleaned in place or left to have plants grow on top of it where an invasive species has been eliminated and colonizing plants are desirable species.



Benthic barrier in a shallow swimming area in May, to be removed in June

Barriers can usually be removed in early August without significant plant growth before the end of the recreational season, allowing work to occur in warmer water and when lake-related labor is often more available. Some older forms of benthic barriers, such as burlap or felt-like materials, were never meant to be removed and fall apart easily after a few seasons; these and similar materials are not recommended for temporary installations.



Benthic barrier used to create a swimming lane in plant-infested water within a swim area

Benthic barrier can be installed by professional lake management firms but there is nothing especially technical or complicated in the installation and homeowners or knowledgeable members of lake associations, fishing organizations, or other conservation groups can handle installation if well organized. On a lakewide basis, it is best to coordinate among property owners and installation sites to achieve success most efficiently and it is advantageous to have one permit process cover all installations within a given waterbody.

Possible Benefits

- ◆ Complete elimination of plants in target area with proper application and maintenance
- ◆ Most barrier materials are re-useable, allowing coverage of multiple areas over time with the same material
- ◆ Creates edge effect, habitat diversity, and quality enhancement when portions of dense assemblages are covered

Benthic Barriers

- 6998 ♦ May foster an improved plant assemblage after removal, through naturally occurring seeds in
- 6999 the sediment or selective planting, but likely to require follow up actions like hand harvesting

7000 **Possible Detriments**

- 7001 ♦ Non-selective technique; all plants under a barrier will usually be killed
- 7002 ♦ May kill non-mobile invertebrates under barrier
- 7003 ♦ Low oxygen may develop under barriers and may allow release of reduced compounds from
- 7004 sediment, although upward transport is expected to be very limited
- 7005 ♦ Eliminates access to sediment for fish and wildlife; could affect spawning and feeding
- 7006 ♦ Effectiveness usually declines without labor-intensive maintenance
- 7007 ♦ Invasive species may be as likely as native species to recolonize when barrier is removed
- 7008 without follow up effort

7009 **Information for Proper Application**

- 7010 ♦ Mapping of area to be covered by barrier, with information on plant types and density, portion
- 7011 of entire lake plant growth zone targeted, and type of barrier to be installed
- 7012 ♦ Knowledge of sediment features, along with any obstructions or other interference factors
- 7013 ♦ Inventory of biological features of the target area, especially the presence of any protected
- 7014 species
- 7015 ♦ Plan for installation and maintenance

7016 **Factors Favoring or Disfavoring the Use of this Technique**

- 7017 ♦ Favored when the target area has dense plant
- 7018 growths of undesirable species that conflict with
- 7019 designated use of the area (e.g., public swimming
- 7020 or boating access)
- 7021 ♦ Favored when the target area is small (<1 acre) and
- 7022 relatively free of obstructions (e.g., stumps, logs,
- 7023 boulders, pilings, and moorings)
- 7024 ♦ Favored where long-term control is sought over a
- 7025 small area with recognition of necessary
- 7026 maintenance needs
- 7027 ♦ Favored where a desirable plant assemblage is
- 7028 expected to develop or can be encouraged by
- 7029 planting after barrier removal
- 7030 ♦ Disfavored if the target area represents a substantial portion of the plant growth (littoral) zone
- 7031 for the whole lake (>10% is reasonable but the upper threshold may be dictated by the OOC)
- 7032 ♦ Disfavored where barrier placement could negatively impact a protected species
- 7033 ♦ Disfavored where there are many underwater obstructions or high sediment inputs



**Benthic barrier used to suppress
invasive species along shoreline and
in shallow water**

Benthic Barriers

- 7034 ♦ Disfavored in shallow water with strong wave action or intensive boat traffic

Performance Guidelines and Monitoring Needs

- 7036 ♦ Map the vegetation and other resources in the target area; avoid barrier use over protected
7037 species
- 7038 ♦ Select a benthic barrier with properties consistent with project goals and site features
- 7039 ♦ Avoid installation over >10% of lake littoral zone
- 7040 ♦ Lay out and anchor barrier in a manner that maximizes stability in response to wave action or
7041 other influences
- 7042 ♦ Leave barrier in place for at least one month
- 7043 ♦ Develop a maintenance program that monitors and maximizes barrier effectiveness; avoid gaps
7044 in targeted coverage, sediment accumulation, and rooting of plants through porous barriers
- 7045 ♦ Monitor the plant community before and after barrier application
- 7046 ♦ Monitor water quality above and near the barrier if the installation is large (>1 acre or >10%
7047 of littoral zone); focus on oxygen profiles and pH

Key Considerations for Conservation Commissions

- 7049 ♦ Review by the NHESP is required if state-listed species are present, which includes all areas
7050 mapped as Priority or Estimated Habitat; review must be complete and a response received
7051 before a conservation commission can finalize any action under the WPA
- 7052 ♦ Under WPA regulations, installations of benthic barrier covering <5000 square feet of Land
7053 Under Water could be eligible for a negative Determination of Applicability
- 7054 ♦ The effect of benthic barrier on the interests of the WPA has been considered minimal by the
7055 MA DEP when the area covered represents <10% of the area of lake where plants can grow;
7056 smaller areas of application are not considered to measurably change water quality or wildlife
7057 habitat or to detectably alter fish or shellfish resources, but effects can be considered on a lake-
7058 specific basis
- 7059 ♦ The MA DEP endorses issuance of a negative Determination of Applicability under the WPA,
7060 avoiding the more cumbersome process of permit issuance, for use of benthic barrier to address
7061 pioneer infestations of invasive species
- 7062 ♦ Application of barrier should be considered on a lakewide basis; in most cases it is advisable
7063 avoid issuing separate negative Determinations of Applicability or Orders of Conditions to
7064 individual property owners where many separate installations are planned

Massachusetts and Related Experience

7066 Various benthic barriers have been used for many years in MA under a variety of conditions with
7067 a range of results. No single case study is indicative of the range of issues and results, and much
7068 has been learned from experience that can be applied to future installations. Where quick control
7069 of new infestations of invasive species is needed, benthic barriers have proved useful, as approval
7070 for use can often be much faster than for many other control methods and can be very site specific.

Benthic Barriers

7071 Where plant control is necessary in small areas for public safety (e.g., swimming areas), benthic
7072 barriers have been effective.

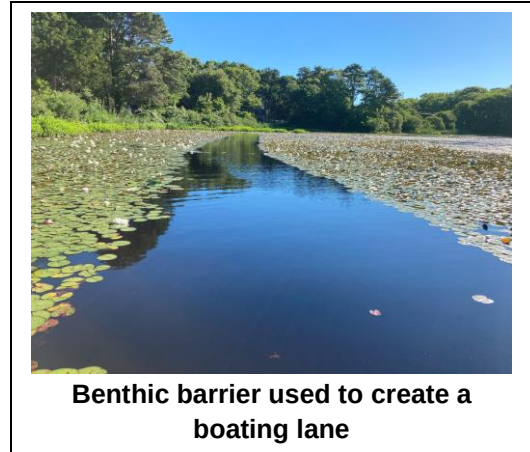
7073 Non-porous barrier (Hypalon, often used as landfill liner) was installed in a swim area within
7074 Stockbridge Bowl in Stockbridge in the late 1980s. While it eliminated all plant growth, gases
7075 trapped underneath caused billowing, with the liner rising a foot or more off the bottom until slits
7076 were cut to allow gas to escape. Addition of sand to weigh down the barrier helped but allowed
7077 plant recolonization, although not at the density encountered before barrier installation.

7078 In Great Pond in Eastham, two large swim areas are heavily used during summer, but plant growths
7079 tend to encroach on those areas. Application of a porous barrier (Aquascreen) to over an acre of
7080 these swimming areas in early May, with removal in early to mid-June, kept the mostly sandy area
7081 open when the swimming season started in this resort town in the early 1990s. Foot traffic
7082 minimized regrowth of vegetation, and the clean substrate was appreciated by lake users. Barriers
7083 were laid out perpendicular to shore from about 3 to 12 feet of water depth. A pair of snorkelers
7084 walked or swam barrier rolled onto PVC pipe with a long rod through the pipe, one snorkeler at
7085 each end, from near shore to deeper water. Panels were pulled sideways as needed to provide a
7086 few inches of overlap and weighted with chain, bricks, patio block or miniature sandbags.
7087 Experimentation with weighting schemes settled on small sandbags as the easiest and most
7088 swimmer friendly weights. Barrier left in place as a test accumulated sand in shallower water and
7089 was colonized by naiad and waterweed in deeper water. Removal was accomplished with a
7090 homemade, portable winch system that rolled the barrier back on the PVC pipe and it was cleaned
7091 with brooms as it was rolled up.

7092 When invasive hydrilla was discovered in Mystic Lake in Barnstable in 2010, treating with an
7093 appropriate herbicide was not an immediate option, given permitting processes and public attitude
7094 at the time. Volunteers from the lake association were able to secure rapid permission to hand
7095 harvest hydrilla and lay down benthic barriers over known patches. A large seine with quarter inch
7096 mesh size was placed around each patch in a horseshoe, with the open end on shore. Volunteers
7097 removed as much hydrilla as possible, then the seine was pulled in to capture any fragments.
7098 Following this procedure, porous benthic barrier in homemade PVC frames was laid on top of the
7099 former patch area, the boundaries of which had been marked prior to harvesting. Framed panels
7100 ranged in size up to about 14 X 20 feet and were weighed down with small sandbags, mostly at
7101 the corners. Panels were removed in autumn and regrowth of hydrilla was monitored the next
7102 spring, with redeployment of barriers where needed. In most cases the hydrilla did regrow from
7103 turions, necessitating barrier redeployment. New patches were discovered each year, although new
7104 growths were small and easily addressed. Still, the inability to eradicate the infestation over a
7105 period of about three years resulted in a change to herbicides for control. The framed approach to
7106 barrier management proved useful and a commercial version has been developed independently
7107 and is currently available as LakeMat.

Benthic Barriers

7108 Elsewhere on Cape Cod, dense water lilies and other
7109 aquatic vegetation prevented use of even kayaks from
7110 a public dock in Lake Elizabeth in Barnstable.
7111 Application of benthic barrier created a boating lane
7112 along shore and out to deeper water with less dense
7113 vegetation. Use of benthic barrier was found to be less
7114 labor intensive than manual harvesting for a greater
7115 duration of benefits. The edge effect is also expected to
7116 enhance habitat for a variety of water-dependent
7117 species.



7118 In Morses Pond in Wellesley a non-porous benthic
7119 barrier (LakeBottomBlanket) was laid out as 10 X 80-foot panels to suppress invasive species
7120 (mostly Eurasian and variable leaf watermilfoil and fanwort) in parts of the swim area between 4
7121 and 12 feet deep. Panels were removed and cleaned after the first year but not found to need much
7122 maintenance. After the second installation, panels were left for 2 years and while cleaning was an
7123 obvious need by the end of the second season, plant growths were limited, and swimming
7124 conditions were safe. Panels have completed their third two-year stint and were easily cleaned and
7125 stored for a fourth two-year application with minimal damage to panels observed after 7 years of
7126 use.

7127 A non-porous barrier was used to control dense growths of parrotfeather in a small pond in
7128 Nantucket in 2017. Growths extended from the shoreline out, much of it emergent, characteristic
7129 of that invasive species. Three panels of non-porous barrier (LakeBottomBlanket) covering 1400
7130 square feet were installed in this 17,500 square foot pond, at least half of which was infested with
7131 parrotfeather. The barrier was removed, and dead plant material was removed from the previously
7132 covered nearshore area. The next year the barrier was redeployed over another area and left for
7133 two summers. It was removed without doing anything more about presumably dead plant matter,
7134 but regrowth was observed, possibly from surviving root systems or seeds but also by
7135 recolonization from nearby growths. At that point an appropriate herbicide became available and
7136 was applied to address parrotfeather throughout the pond and in the downstream channel leading
7137 to a larger lake.

7138 A program of benthic barrier placement in the four ponds under the control of the Sherwood Greens
7139 Road District in Becket was conducted in 2020 and 2021 under a negative Determination of
7140 Applicability that called for <10% of the area in each of these shallow ponds to be covered and for
7141 records to be kept for amount used, location of installation, and user perceptions of results. In 2020
7142 there were 15 shorefront property owners who laid down about 9300 square feet (0.21 ac, <1% of
7143 waterbody area, which is entirely littoral zone) of benthic barrier in 3 of 4 lakes. All participants
7144 offering an opinion found the benthic barrier to be reasonably effective, but only 9 of the 15
7145 property owners applying benthic barrier in 2020 redeployed the barrier in 2021, plus one new
7146 property owner participating, covering about 5200 square feet of area (0.12 ac, 0.05% of littoral

Benthic Barriers

7147 area). Reasons for not participating the second year included conditions remaining improved after
7148 the first year of barrier use and the labor necessary to redeploy barrier being too cumbersome to
7149 warrant redeployment under perceived conditions.

7150 In Otis Reservoir in Otis, non-porous barrier was laid
7151 on areas where invasive *Phragmites* had been cut the
7152 previous summer to prevent regrowth. Otis Reservoir
7153 has an 8-foot drawdown, making it relatively easy to
7154 install barrier in late winter just as refill commences.
7155 The combination of cutting and benthic barriers
7156 eliminated small target stands of *Phragmites*. An
7157 herbicide program was used to address larger stands.

7158 Experience elsewhere tends to mirror what has been
7159 learned in MA. Cooke et al. (2005) provide a brief
7160 review that does not include most of the currently
7161 available, commercially made, benthic barriers. Non-
7162 porous barriers developed in recent years are easier to
7163 use than older forms. Issues with barrier deterioration
7164 were noted, something else that newer materials largely
7165 avoid. Effectiveness in target areas was documented
7166 and the ability to address areas not accessible to
7167 harvesters and some other plant control equipment was
7168 emphasized. Most applications were on a small scale
7169 due to expense and required effort.

7170 A review in Gettys et al. (2014) suggests a one- to two-
7171 month deployment period for best results and suggests
7172 that non-porous barriers can be left in place for up to
7173 three years in some cases with minimal maintenance.

7174 The focus on smaller applications is underscored, with most uses targeting either swimming areas
7175 and docks or pioneer infestations of invasive species. Invasive species most often addressed with
7176 benthic barriers include hydrilla, Eurasian and variable leaf milfoil, curly leaf pondweed, and
7177 Brazilian elodea (*Egeria densa*).

7178 While use in the control of submergent plants is the primary purpose of most benthic barrier
7179 installations, the USACE (2012) cites uses for emergent growth control (including multiple
7180 invasive plant species) and for the elimination of invasive mollusks, whereby low oxygen under
7181 barriers has killed target mollusks such as *Corbicula fluminea*. A program of *Corbicula* control
7182 was conducted in Lake George in NY, although complete or long-term success of such programs
7183 has not been documented.



Benthic barrier laid during drawdown over previously cut *Phragmites* and left for the growing season (above) leading to minimal *Phragmites* growth the next year (below); untreated *Phragmites* remains in the background with a cut area ready for barrier deployment in between
(Courtesy of Paul Grosjean)



Benthic Barriers

Benthic barrier is used in Maine to control pioneer infestations of variable watermilfoil, mostly in the Sebago Lake region, and often in slow flowing rivers. Lakes Environmental Association, the organization that conducts most barrier placement, reports that initial control is typically achieved but that follow up effort, usually hand harvesting, is necessary to support recovery of native plants.

The NHDES uses benthic barriers to control pioneer infestations of invasive species and often leaves the barriers in place. NHDES reports that with complete coverage of detected infestations native plants tend to recolonize the barrier over as sediment accumulates over about two years. Installations are monitored and hand harvesting is conducted when invasive species are detected.

Overall, the conclusions that can be drawn with regard to benthic barrier use can be summarized as follows:

- Benthic barriers have been developed in both porous and non-porous forms, each effective under a range of conditions, with current versions of non-porous barriers having holes or slits to allow gas to escape and minimize billowing
- Benthic barriers can eliminate plants in the applied area, but material, installation, and maintenance costs tend to restrict the total area covered; it is practical to minimize nuisance plants in swim areas and near boat docks or boat launches or to create lanes through dense plants to deeper water
- Addressing pioneer infestations of invasive species with benthic barriers on a small scale is potentially workable but eradication where growths cover more than about an acre or are dispersed lakewide has not proven reliable
- To maximize effectiveness, benthic barrier needs to be maintained, but the frequency of maintenance varies with site conditions and the nature of the barrier; non-porous barrier can often be left in place for two growing seasons without removal for cleaning, but porous barriers routinely need to be removed for cleaning after one growing season
- Benthic barrier should be in place for at least a month during the growing season to effectively kill most plants, but can be moved to a new area or removed well before the end of the growing season with minimal nuisance growths the same season
- Permitting for benthic barrier use is easier in MA than for most other plant control techniques but the portion of the total plant growth zone of a lake managed with benthic barrier may be limited to avoid potential negative impacts

Winter Drawdown

How It Works

Lake and pond water level drawdowns are used nationally to provide storage capacity for flood control, protect dams, outlets, engineered shorelines and other structures from ice damage, facilitate dredging and dam maintenance, and control aquatic perennial vegetation. The focus of this review is on the use of winter drawdown to control aquatic vegetation. The concept of winter drawdown is relatively simple but there are many details to consider. The water level in the lake is lowered in the fall, typically using gravity outflow from boards or a gate in the dam, to allow some portion of the lake bottom to be exposed to drying and winter freezing conditions. Susceptible vegetation that is exposed to freezing or drying conditions for a long enough time will be killed. The boards are then put back in the dam or the gate is closed, and the pond then refills through precipitation and watershed inflows. The waterbody typically reaches full pool by early spring.

Winter drawdown can provide control of plant species that overwinter in a vegetative state, potentially killing the plant by a combination of drying and freezing. Killing the entire root system requires that the plant be exposed to consistently below freezing conditions for two or more weeks with minimal interruption. Annual species that overwinter in the sediments as seeds, turions, tubers, or winter buds are not directly affected by these freezing conditions and the result can be a shift from perennial plants to annual plants. It is important to properly identify the target species for the drawdown as some plants even in the same genus respond differently to drawdown (see table below). Drawdown is used most often in Massachusetts for the control of invasive Eurasian or variable leaf milfoil.



Exposure can kill plants by drying and/or freezing.

Winter drawdown is a weather-dependent technique and the results among years will be variable. The range of conditions along a gradient from the Berkshires to Cape Cod is striking and there is substantial variability among lakes even within the ecoregions of MA. Lakes in southeastern MA rarely freeze in winter while lakes in the Berkshires can have ice cover well into April. Snow cover is similarly variable, less predictable, and can reduce the effectiveness of drawdowns by insulating sediments from below freezing temperatures. Climate change is reducing the extent and severity of freezing conditions across the state. A longer period of drying without freezing temperatures will often kill target plants, but every storm brings the possibility of rewetting the drawdown zone and limiting effects.

Drawdown

7252
7253

Anticipated Response of Common Aquatic Plants to Winter Drawdown
(After Cooke et al. 2005 and Mjelde et al. 2012 as amended by direct experience in MA)

Usually Decreases	Usually Increases
<i>Brasenia schreberi</i> (watershield)	<i>Chara</i> spp. (muskgrass)
<i>Cabomba caroliniana</i> (fanwort)	<i>Gratiola neglecta</i> (hedge hyssop)
<i>Ceratophyllum demersum</i> (coontail)	<i>Hydrilla verticillata</i> (hydrilla)
<i>Egeria densa</i> (Brazilian Elodea)	<i>Juncus</i> spp. (rushes)
<i>Isoetes lacustris</i> (quillwort)	<i>Lythrum salicaria</i> (purple loosestrife)
<i>Lemna minor</i> (duckweed)	<i>Najas flexilis</i> (bushy pondweed)
<i>Lobelia dortmanna</i> (water lobelia)	<i>Najas minor</i> (spiny naiad)
<i>Myriophyllum alterniflorum</i> (alternate milfoil)	<i>Nitella</i> spp. (stonewort)
<i>Myriophyllum aquaticum</i> (parrotfeather)	<i>Nymphoides cordata</i> (little floating heart)
<i>Myriophyllum heterophyllum</i> (variable leaf milfoil)	<i>Nymphoides peltata</i> (yellow floating heart)
<i>Myriophyllum sibiricum</i> (northern milfoil)	<i>Phragmites australis</i> (common reed)
<i>Myriophyllum spicatum</i> (Eurasian milfoil)	<i>Potamogeton amplifolius</i> (bigleaf pondweed)
<i>Myriophyllum verticillatum</i> (whorled milfoil)	<i>Potamogeton epihydrus</i> (leafy pondweed)
<i>Nuphar variegata</i> (yellow water lily)	<i>Potamogeton pusillus</i> (thinleaf pondweed)
<i>Nymphaea odorata</i> (white water lily)	<i>Potamogeton richardsonii</i> (clasping leaf pondweed)
<i>Persicaria amphibium</i> (water smartweed)	<i>Potamogeton zosteriformis</i> (flatstem pondweed)
<i>Potamogeton berchtoldii</i> (small pondweed)	<i>Schoeoplectus</i> spp (bulrushes)
<i>Potamogeton natans</i> (broadleaf pondweed)	<i>Scirpus</i> spp (bulrushes)
<i>Potamogeton robbinsii</i> (Robbins' pondweed)	<i>Sparganium angustifolium</i> (narrow leaf bur-reed)
<i>Ranunculus trichophyllus</i> (threadleaf crowfoot)	<i>Stuckenia pectinata</i> (Sago pondweed)
<i>Sagittaria graminea</i> . (submergent arrowhead)	<i>Typha latifolia</i> (common cattail)
<i>Sparganium emersum</i> (green fruited bur-reed)	
<i>Sparganium natans</i> (small bur-reed)	
<i>Vallisneria americana</i> (water celery)	
Bolded species names are invasive plants. Species not listed here may have insufficient data, but many either exhibit no significant change in response to drawdown or are known to have a range of responses that defies simple classification as increasing or decreasing after drawdown. Included are two major invasive species in MA, <i>Trapa natans</i> (water chestnut) and <i>Potamogeton crispus</i> (curly leaf pondweed), which exhibit no significant or consistent change in response to drawdown.	

7254

7255 Extended use of drawdown can result in long-term changes to sediment coarseness and nutrient
7256 availability that limit plant growth in the drawdown zone (Carmignani and Roy 2021), but these
7257 are very slow processes that can happen over decades. Drawdown as addressed here is intended as
7258 a more immediate control over susceptible vegetation.

7259 Winter drawdowns cause reductions in lake area and volume, leaving less habitat available for
7260 aquatic organisms and specifically impacting the most productive habitat in the waterbody – the
7261 littoral zone or shoreline area. Aquatic organisms that cannot or do not move into deeper water
7262 during drawdown may experience very high mortality. The timing of drawdown and refill may
7263 restrict fish and wildlife breeding and feeding and may impact reptile and amphibian species that

Drawdown

overwinter in a mostly dormant state in the drawdown zone. Fluctuating water level during the winter drawdown period may limit human use of the ice surface for recreation.

During a drawdown, stream flows downstream of the waterbody are also altered from natural streamflow patterns to which aquatic organisms have adapted. Outflows that support autumn drawdown and spring refill tend to reverse the natural spring and autumn flow patterns which naturally involve peaks in the spring and low flows during autumn. All the impacts of drawdown, positive and negative, are highly lake-specific, depending on a wide range of factors that must be considered in the planning and permitting phases.

Refill should commence as soon as freezing and drying goals have been met. The ratio of watershed to lake area is an important determinant of how quickly a lake can be refilled. Lake bathymetry and water clarity will determine how much of the lake will support plant growth (the littoral zone), how far the lake must be drawn down to impact target plants, and how much volume will therefore have to be discharged in the autumn and replaced in the spring. Bathymetry is available for many lakes and ponds in Massachusetts and is available through MassWildlife.



Refill from drawdown in progress

Possible Benefits

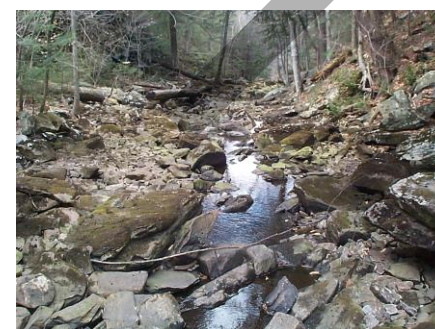
- ◆ Kills vegetative portions of perennial plants by drying, freezing, or physical disturbance.
- ◆ Allows sediment oxidation and compaction, with potential reduction of sediment oxygen demand, sediment volume, and available nutrient content.



High downstream flow in autumn to achieve drawdown

Possible Detriments

- ◆ Will not kill seeds or other non-vegetative overwintering propagules and may stimulate increased seed germination for certain species.
- ◆ Downstream flows will be higher during water lowering and lower during refill, with possible downstream ecological impacts.
- ◆ Nutrient release during exposed sediment oxidation may fuel increased algal production if not flushed from the lake before the next growing season.
- ◆ Fish may not be able to reach spawning areas if refill is later than when spawning occurs.



Low downstream flow during spring refill after drawdown

Drawdown

- 7301 ♦ May restrict habitat access and cover for aquatic mammals and birds.
- 7302 ♦ May strand and kill minimally mobile aquatic fauna (especially mollusks).
- 7303 ♦ May expose and harm hibernating reptiles and amphibians.
- 7304 ♦ Hydrologically connected wetlands could experience changes in species composition and
- 7305 relative abundance if dewatering persists too long.
- 7306 ♦ Will reduce available water for supply purposes and may impair nearby shallow well
- 7307 production or available supplies in fire protection cisterns.
- 7308 ♦ May limit human access and necessitate safety precautions during drawdown.

7309 Information for Proper Application

7310 There are extensive information needs for proper planning, permitting, and implementation of
7311 winter drawdown (see Drawdown Considerations appendix), but these have been simplified
7312 somewhat by the guidance offered below under Performance Guidelines by agency consensus.
7313 Important elements of winter drawdown planning include:

- 7314 ♦ Lake morphometry to allow mapping assessment of area exposed relative to littoral zone areas.
- 7315 ♦ Hydrology to support estimates of drawdown and refill times under the range of potential
- 7316 flows.
- 7317 ♦ Knowledge of outlet features essential to releasing and holding water.
- 7318 ♦ Data (i.e., composition, coverage, density) for aquatic macrophytes in the expected area of
- 7319 exposure
- 7320 ♦ Evaluation of sediment types and slopes in expected drawdown zone
- 7321 ♦ Biological assessments of populations perceived to be at risk from drawdown.
- 7322 ♦ Assessment of downstream channel configuration and resources to facilitate planning to
- 7323 minimize adverse downstream impacts.
- 7324 ♦ Any active local well depths or water supply intake elevations
- 7325 ♦ Evaluation of any ice safety concerns that may result from changes in water levels due to
- 7326 drawdown/refill when there is ice cover

7327 Factors Favoring or Disfavoring the Use of this Technique

- 7328 ♦ Favored when the target plants are susceptible to drying and freezing
- 7329 ♦ Favored when drawdown can reach a depth that impacts the majority of the targeted plants
- 7330 ♦ Favored where drawdown can be achieved by gravity outflow via an existing outlet structure
- 7331 ♦ Favored where areas to be exposed have sediments and slopes that promote rapid dewatering
- 7332 ♦ Favored when drawdown and refill can be accomplished within a few weeks under typical flow
- 7333 conditions and without causing downstream flows outside the natural range
- 7334 ♦ Disfavored where target plants are annual species that produce large quantities of seeds, winter
- 7335 buds, tubers, or turions
- 7336 ♦ Disfavored when the majority of target plants are below the achievable drawdown depth

Drawdown

- 7337 ♦ Disfavored where drawdown will impact survival, migration, and spawning for non-target
7338 organisms
- 7339 ♦ Disfavored where the lake is a potable water supply with a shallow intake or active, nearby
7340 wells are shallow
- 7341 ♦ Disfavored where alteration of the downstream hydrologic regime has significant impacts on
7342 downstream resources

Performance Guidelines and Monitoring Needs

7344 If there is interest in pursuing a winter drawdown which does not meet the criteria outlined below,
7345 a MEPA review process may be required. The appendix of drawdown considerations should be
7346 consulted and the stepwise process for evaluating drawdown potential should be followed.
7347 Performance guidelines currently accepted by the environmental agencies of MA to avoid a MEPA
7348 review as part of the permit process are provided here.

- 7349 1. **Initiation of drawdown** – The drawdown should start between October 1 and November 1,
7350 with an earlier start preferred where possible to allow a slower rate of drawdown and less
7351 impact on aquatic fauna. Public access should be considered on any waterbody open to the
7352 public and the drawdown should not prevent use of public boat ramps or other public facilities.
- 7353 2. **Rate of drawdown** – The decline in water level must be no more than 3 inches per day, with
7354 a slower rate preferred if the target drawdown can be accomplished at the slower rate.
- 7355 3. **Downstream flows during drawdown** – To avoid downstream flooding concerns and
7356 excessive erosion and scouring in the stream channel, the drawdown rate must not result in
7357 downstream flows that exceed one half the flood flow with a 2-year recurrence interval (50%
7358 chance of occurrence in any given year) or the bankfull flow (flow that fills the channel),
7359 whichever is less. The targeted maximum flow should be determined from the [USGS Stream
7360 Stats](#) online application, which provides flood and bankfull flow estimates for any point on
7361 any stream in MA. The lower bound of any estimate should be applied. A default of no more
7362 than 4 cubic feet per second per square mile (cfs/m) of contributing watershed is acceptable as
7363 an alternative approach.
- 7364 4. **Drawdown depth** – The drawdown should be limited to 3 feet or 25% of the littoral zone,
7365 whichever is less, to minimize impacts to valued shallow water resources. The extent of the
7366 littoral zone will need to be determined by plant mapping and reliable bathymetry will be
7367 needed to make calculations.
- 7368 5. **Termination of active drawdown** – The targeted drawdown depth should be achieved by
7369 November 15 to minimize impacts on hibernating fauna that utilize the littoral zone. Active
7370 water level lowering may continue to December 1 if high rainfall delays drawdown progress
7371 in any given year. Minor adjustment based on site-specific data is possible, but drawdown
7372 should be guided by these target dates.
- 7373 6. **Initiation of refill** – Refill after drawdowns for aquatic plant control should begin as soon as
7374 goals for plant control conditions have been attained (at least two weeks of near continuous
7375 exposure to freezing temperatures) and in time to meet a target refill date of April 1. Due to
7376 climate and hydrologic variability, the April 1 refill target should not be a compliance date.

Drawdown

Rather, refill must begin by a date given in the permit, calculated to result in refill by April 1. If refill is not completed by April 1 in two or more consecutive years, the refill initiation date should be reviewed and adjusted as needed to better meet the target refill date.

7. **Consideration of earlier refill start** – If the calculated refill start date is after February 15th, on or around February 15th an assessment should be made to determine if refill can commence earlier than the calculated refill start date. An earlier refill start date would be appropriate in two scenarios: 1) If it is unlikely that two weeks of freezing conditions will occur past February 15th or if existing snow cover will prevent freezing conditions from effectively reaching the plant roots, early refill should be initiated; and 2) If more than 2 weeks of freezing temperatures have occurred prior to February 15, indicating successful plant control, refill should also begin earlier. The earlier start date increases the likelihood of complete refill by April 1 without unduly compromising plant control goals.
8. **Streamflow maintenance during refill** - Downstream flow during the refill period should be maintained at or above the August median flow (the flow exceeded 50% of the time from hydrologic data or appropriate calculations from [USGS Stream Stats](#)). Downstream flow should be guaranteed by passive measures wherever possible, such as valves in flashboards that when open allow enough water to pass downstream, or keeping a subsurface pipe open enough to allow adequate outflow. Even with passive measures, site visits should be made to ensure that outlet flows are not blocked by debris or otherwise impeded. The frequency of visits must be determined based on local conditions.
9. **Monitoring water level and outflow**- Specific plans for how flow will be measured (and by whom) during drawdown and refill should be required for any drawdown. At a minimum, a staff gage (preferably permanent and surveyed) should be installed in the lake at a point where readings can be made at all water levels related to the drawdown. During the period of active drawdown or refill, readings should be obtained whenever outflow is likely to be altered (e.g., flashboard pulled or added, subsurface pipe valve adjusted, pumping rate altered, significant rainfall occurs), with a preference for daily measurement to capture variability and support management decisions. If the water level readings are not suitable to allow calculation of outflow, an additional staff gage or other flow monitoring device should be placed downstream to allow downstream flow assessment and should be monitored at the same time as water level. This need may be eliminated by permanent structures such as valves in flashboards or v-notch weirs that can guarantee the required downstream flow by passive means. Site visits should still be made to ensure that outlet flows are not blocked by debris or otherwise impeded. Additional measurements should be made weekly between active periods of drawdown and refill to allow an assessment of water level stability. Water level and flow measures must be recorded and made accessible and understandable to appropriate agencies.
10. **Biological monitoring and use of data** - A specific set of vegetation control objectives should be established prior to the initiation of winter drawdown. Monitoring to determine when/if those objectives are achieved will include pre- and post-drawdown assessment of vegetation with quantitative comparison and evaluation within the context of management goals. Air

Drawdown

temperature and snowfall from a local meteorological station should be tracked to aid in evaluation of conditions that affect drawdown success as a plant control method and make decisions regarding the initiation of refill. If the proposed drawdown is on a waterbody that has not been drawn down in the previous five years or if the proposal is to increase the drawdown magnitude, surveys of potentially sensitive biological populations (e.g., mussels, early spring-spawning fish, any listed species) should be considered in consultation with MassWildlife.

11. **Continuation of drawdown** – Quantitative evaluation of the vegetation community should be used to determine the value of continuing the use of drawdown. Where the control goal has been achieved, consideration should be given to ceasing winter drawdown until the target vegetation has exceeded an established, quantitative management goal. If drawdown has failed to achieve the goal over a period of five to six years, winter drawdown should be discontinued until other methods of control are evaluated.

Key Considerations for Conservation Commissions

- ◆ Ensure applicant has a plan to implement the Performance Guidelines above.
- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ Drawdown in a Great Pond requires approval under Chapter 91.
- ◆ WPA interests relating to water supply could be affected and must be evaluated.

MA Experience

Drawdown has been used to control aquatic plant assemblages in MA since at least the 1960s with a wide array of impacts, both positive and negative. Regulation of drawdown in MA has also changed over time, leading to varying restrictions and options. Historically, few evaluations were conducted to determine the complete environmental impact of drawdown, leaving the efficacy of drawdown and the approach to regulation open to interpretation. Assessments over the last couple of decades have led to extensive discussions and a revising of the approach to drawdown, reflected in the guidance included in this chapter. Continued data collection, research, and monitoring of drawdowns, as with any lake management technique, are needed to fully understand the overall long-term impacts. This does not mean that drawdowns cannot be performed, but they should incorporate monitoring and data collection into the overall long-term project. Where a proposed drawdown does not meet the performance guidelines provided here, this document provides an appendix of considerations and a stepwise progression for evaluation of drawdown as an option through the MEPA process. Due to the unique characteristics of each drawdown project and the strong possibility that each project would be handled differently if the current guidelines were imposed, state agency proponents of this document have chosen not to include case histories or other summaries of past drawdown projects here.

7454 **Algae Control Techniques Applicable to Floating Vascular Plants**

7455 Some vascular plants either do not have fully functional roots (e.g., bladderwort, coontail) or float
7456 free in the water, unattached to sediment (e.g., duckweed, watermeal). Unlike most vascular plants
7457 that are firmly rooted in the sediment, such plants depend on the water column for nutrients,
7458 particularly N and P. While these non-rooted or free-floating vascular plants can be inhibited or
7459 removed by other vascular plant control techniques in many cases, some of the algae control
7460 techniques are applicable as well. Any reduction in available nutrient concentrations may suppress
7461 growths of non-rooted or floating vascular plants. Accordingly, all watershed techniques for
7462 reducing nutrient inputs to lakes and in-lake techniques to reduce nutrient availability are
7463 applicable. Those techniques have been covered in previous sections. Selective withdrawal or
7464 flushing (from the surface) or collection approaches (skimmers or nets) may reduce free-floating
7465 plant abundance. These are covered under alternative techniques in the next chapter but are less
7466 often applied.

7467 P inactivation efforts in two ponds in Wellesley have minimized duckweed in one and coontail in
7468 the other. Flushing by natural or human-induced means has worked well to reduce free-floating
7469 vascular plants in smaller, linear impoundments with water entering at one end and a surface outlet
7470 at the other. More traditional vascular plant control techniques such as herbicides and mechanical
7471 harvesting will usually work, but techniques such as drawdown and benthic barriers are less
7472 successful with non-rooted and free-floating plants. Dredging may work by both removing
7473 reproductive propagules of non-rooted or free-floating vascular plants and/or by limiting access to
7474 internally generated nutrient loads. However, dredging is rarely conducted unless reclaiming lost
7475 water depth has a high priority.

7476 Hand Pulling

7477 How It Works

7478 Hand pulling encompasses manual
7479 removal of selected plants by a wader,
7480 snorkeler, or diver. Various tools can be
7481 applied under the heading of hand
7482 pulling, such as rakes or cutters used by
7483 hand, but mechanical harvesting and
7484 other removal by machinery are not
7485 included in this approach (see
7486 Mechanical Harvesting). Hand pulling is
7487 highly selective and labor intensive.

7488 Many species- or site-specific
7489 procedures have been developed that
7490 enhance results or efficiency. Hand pulling is well suited to vigilant efforts to keep out invasive
7491 species not yet established in a lake or target area within a lake. Hand pulling can also effectively
7492 address non-dominant growths of undesirable species in mixed assemblages, or small patches of
7493 plants targeted for removal. This technique is poorly
7494 suited to large-scale efforts, especially when the target
7495 species or assemblage occurs in dense or expansive beds.
7496 Hand pulling may be useful, however, to remove
7497 surviving or recolonizing target plants after other
7498 methods of control, such as herbicides or benthic
7499 barriers, have largely removed extensive, dense plant
7500 growths.

7501 Hand pulling can be augmented by various tools,
7502 including a wide assortment of rakes, cutting tools,
7503 nets, and other collection devices. McComas (2002)
7504 provides a brief but extensive review of options. The
7505 most equipment-intensive version of hand pulling is
7506 diver-assisted suction harvesting (DASH), which is
7507 poorly named, as it is the suction that assists the diver,
7508 not the other way around. Hand-pulled plants are fed
7509 into the suction tube for bagging on a vessel at the
7510 water surface. The suction device is not used to directly
7511 harvest plants but allows a higher rate of pulling in a
7512 targeted area, as the diver does not have to stuff pulled plants into a temporary bag and haul that



Diver bagging Eurasian watermilfoil from top down



**Diver Assisted Suction Harvesting:
Diver puts plants into the suction
tube (above) and plants are bagged
at the surface (below)**



Manual Plant Removal

7513 bag to a disposal point. Use of this method transitions into more mechanized forms of harvesting,
7514 but if removal is manual, it is included as hand pulling.

7515 If results are to last more than a few weeks, it is important to remove the entire plant including its
7516 roots. This involves reaching into the sediment or using a tool that gets at the roots, and turbidity
7517 will result from the bottom disturbance. Bagging pulled plants in place will also generate turbidity
7518 in most cases. If individual target plants are too densely clustered, working visibility can quickly
7519 become a problem. In those cases, the work must be discontinuous in an area (i.e., shift between
7520 different locations until turbidity subsides) to result in thorough removal. Less turbidity at the
7521 actual site of plant removal may be created if DASH is applied, as it will pull most of the turbid
7522 water in with the plants, but the area around the processing vessel will likely be temporarily turbid.

7523 If a cutter is used, collection of cut plants is strongly advised unless the area is a small part of a
7524 larger aquatic system and the cut plants are forms that do not spread by fragments. Surrounding
7525 the target area with a net such as a fish seine with quarter-inch mesh size will allow effective
7526 removal of cut plants, although damage may be done to non-target plants in that area when the net
7527 is hauled in. Alternatively, a floating
7528 fragment barrier can be deployed and
7529 cleaned after work is complete. Even if
7530 plants are pulled strictly by hand, some
7531 fragments will likely escape, and some
7532 means of fragment collection is also
7533 strongly advised. Often a person with a
7534 pool skimmer or similar device can
7535 effectively collect fragments from a
7536 paddleboard or canoe. Rigorous fragment
7537 collection is especially important for
7538 plant species that reproduce by
7539 fragmentation, which includes all aquatic
7540 invasive species known from MA as of
7541 2023 except curly leaf pondweed and
7542 water chestnut. Putting a mesh bag over
7543 the plant from the top down then
7544 removing the roots and capturing the
7545 whole plant in the bag will minimize
7546 escaped fragments but is very labor intensive.



Fragment barrier used during hand harvesting to trap drifting plant fragments

7547 The timing of hand pulling may be very important to efficiency and duration of control. It takes a
7548 lot longer to harvest large plants than to pull small sprigs that have just started growing. For annual
7549 species that drop seeds, winter buds, or turions, removal prior to dropping those reproductive
7550 propagules will limit later regrowth (e.g., water chestnut, hydrilla, fanwort). For perennial species,
7551 getting the whole root system is highly advisable, but if the leaves and stems can be removed

before food reserves are transferred to roots, control may last longer. Species with some groups of aquatic plants, like the pondweed genus, can be either an annual or perennial depending on the species, so proper identification is important for proper project planning. Consequently, effective hand pulling is often a spring operation, as early in the growing season as the plants can be found. If work is conducted in early spring when water temperatures are still low, thermal protection (i.e., gloves, boots, suits) for workers is essential, but hand pulling during even summer usually requires at least a wetsuit to work more than an hour. Staffing limits often cause the work to extend into summer, but lower efficiency and less overall benefit are to be expected with later efforts, especially if water clarity declines due to algal blooms or increased boating activity.

There is a trade-off in hand pulling programs between search time and pulling time. The less frequent a target species is encountered, the more efficient it will be to pull plants as they are found. Where growths may be found over a larger area at sometimes higher density, it may be advantageous to survey the area by boat, recording locations by GPS to inform planning and priority setting. In some cases, it is helpful to create some form of underwater grid that divers or snorkelers can follow to find plants and ensure that coverage is thorough. If vegetation is dense, a weighted line attached to shore and a buoy can help divers orient, but the value of hand harvesting in dense vegetation may be limited.



**Bags of hand pulled plants
being ferried to shore**

MassDCR provides recommended [standard operating procedures for use of hand pulling](#) to control non-native species. Hand pulling can be conducted by volunteers, but the best results will be achieved with experience and organization. Getting input from others who have performed hand pulling for target species may enhance programs and hiring competent help to at least design and supervise a hand pulling project is often worthwhile. Care must be taken that the target species is correctly identified and is the only species removed. Involvement by an aquatic botanist to help with plant identification and training of project participants will help avoid non-target impacts.

Possible Benefits

- ◆ Highly selective plant control
- ◆ Limited impact to non-target organisms with proper plant identification
- ◆ Can prevent new infestations from becoming established populations
- ◆ Can follow up other control efforts to maximize benefits
- ◆ Suitable for volunteer efforts with proper training and oversight
- ◆ Some nutrient removal with proper plant disposal, but the actual quantity of nutrients removed is likely to be minimal in comparison with sediment reserves

Possible Detriments

- ◆ Incomplete harvesting may allow regrowth or lead to dispersal of plants
- ◆ Turbidity generation may be substantial
- ◆ Search time may exceed actual removal time

Information for Proper Application

- ◆ Knowledge of plant assemblage, including types, distribution, density
- ◆ Definitive identification of target species
- ◆ Arrangement for sufficient equipment and labor force to accomplish work in targeted area
- ◆ Planning for collection and disposal of hand harvested plants



Bins of hand harvested Eurasian watermilfoil and curly leaf pondweed awaiting disposal at composting facility

Factors Favoring or Disfavoring the Use of this Technique

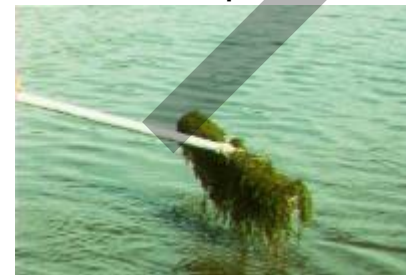
- ◆ Favored when nuisance species are not yet well established; target plant density is low (<500 stems/acre, or about one plant per 10 x 10-foot plot).
- ◆ Favored when target species are in shallow water, or dive crew is readily available
- ◆ Favored when target species are not strongly rooted or prone to fragmentation
- ◆ Disfavored when target plants are in dense patches or cover larger (>1 acre) areas
- ◆ Disfavored where species are prone to forming viable fragments and no fragment collection system is in place

Performance Guidelines and Monitoring Needs

- ◆ Map the distribution of the target species and any protected non-target species in the lake
- ◆ Train all harvesting personnel to recognize the target species and any non-target species of concern
- ◆ Focus hand harvesting on areas of sparse density of the target species (<500 stems/acre in most cases) or small areas of dense vegetation (likely to be removed with some aid by tools)
- ◆ Provide fragment barrier around areas to be harvested and/or deploy people to collect target plant fragments
- ◆ Harvest entire plants; pull out root systems to the greatest extent possible
- ◆ Observe safety precautions in areas where boat traffic may be encountered or other risks exist; provide spotters on the surface for all divers and float a “diver down” flag



Commercially manufactured lake rake used to clear swim area of plants



Manual Plant Removal

- 7622 ♦ Monitor turbidity around the harvest area before, during and after harvest until turbidity returns
- 7623 to background level
- 7624 ♦ Monitor pre- and post-harvest density of target plants
- 7625 ♦ Plan for follow-up inspection and harvesting within the same growing season and in the
- 7626 following growing season

7627 **Key Considerations for Conservation Commissions**

- 7628 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 7629 Estimated habitat and must be complete before the conservation commission can close any
- 7630 hearing and issue an Order of Conditions under the WPA
- 7631 ♦ MassDEP guidance indicates that conservation commissions may issue a negative
- 7632 Determination of Applicability for hand pulling efforts under the WPA, but this does not
- 7633 substitute for NHESP approval where listed species are present, and a separate process still
- 7634 applies before the conservation commission can act
- 7635 ♦ Interests of the WPA are generally benefitted or not impacted by hand pulling; prevention of
- 7636 pollution may be adversely affected for larger operations where turbidity generation is
- 7637 substantial, particularly DASH, but elevated turbidity is expected to be transient
- 7638 ♦ While the federal Clean Water Act, Section 401, does not recognize harvested plants as subject
- 7639 to regulation as dredged material, the MA regulations based on Section 401 can be interpreted
- 7640 to include plant biomass in the same category as sediment; consequently, a 401 permit could
- 7641 be required for hand pulling and the MassDEP should be consulted during the planning phase

7642 **Massachusetts and Related Experience**

7643 Hand harvesting efforts in MA have been varied in terms of target species, area covered, results,
7644 and volunteer vs. contracted service programs. Perhaps the best documented hand harvesting
7645 program has occurred at 125-acre Center Pond in Becket, where the late Mercedes Gallagher
7646 organized both professional divers and volunteers to hand pull Eurasian watermilfoil, curlyleaf
7647 pondweed, and spiny naiad, all invasive species. Eurasian watermilfoil was the most abundant
7648 invasive plant and the focus of most efforts. Acting as a volunteer for over a decade, Ms. Gallagher
7649 surveyed the pond and marked areas with invasive plants, first with small buoys and later with
7650 GPS. She initiated hand pulling as early as April and extended it as late as November, wading in
7651 shallow areas and pioneering several methods of thorough removal while supervising divers in
7652 deeper water. A surface support person, usually in a canoe, received bags of plants from divers
7653 and scooped up any floating fragments with a pool skimmer.

7654 Removed plants were identified and full bags were counted. Time expended on various tasks was
7655 recorded. Costs were carefully tracked. The number of bags of invasive plants removed from the
7656 pond declined markedly and a monitoring program confirmed the reduced abundance of invasive
7657 plants. Hours of effort needed to maintain low invasive plant density declined, but not as strongly
7658 as did the number of bags of plants removed, because search time increased as plants became less
7659 abundant and partially offset the decrease in actual hand pulling time.

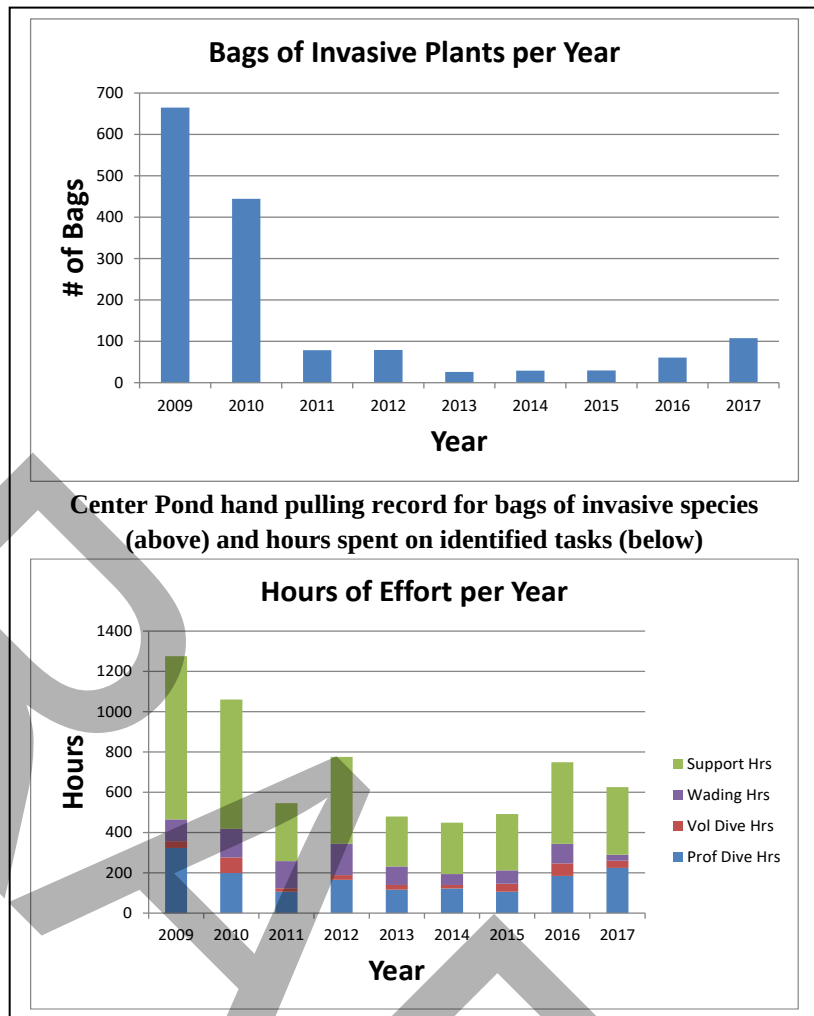
Manual Plant Removal

A combination of reduced effort and a mild winter led to a major increase in milfoil in 2018 and a herbicide program was adopted after Ms. Gallagher passed away with no one able to commit to the level of effort she had put in over the years as a volunteer. Yet the ability of the program to achieve a low density of native plants was clearly demonstrated. A similar program following the Gallagher model was adopted at nearby Yokum Pond and appears to have minimized invasive plants.

Hand pulling of invasive plant infestations in Wachusett Reservoir, a drinking water supply, has included bagging of plants at the point of removal and DASH, with Eurasian and variable-leaf watermilfoil and fanwort as the main targets,

although other invasive species have been detected. Aside from substantial survey time, between 100 and 400 hours of diver time has been logged each year from 2002 to 2020. According to the annual reports for Wachusett Reservoir, this effort has limited the spread and impact of those species but has not eliminated them.

A well-organized hand pulling effort at Dudley Pond in Wayland gained some measure of control over invasive plants, but eventually herbicides were applied as clearing patches was tedious and usually incomplete. Similar stories of partial control of target plants by hand pulling with eventual application of herbicides exist for other MA lakes, including Goose Pond in Lee and Tyringham and the Sherwood Greens ponds in Becket. Use of DASH in Lake Garfield in response to a 10 to 12-acre area of moderate to dense Eurasian watermilfoil growth over the period of 2017 to 2021 has reduced milfoil density in some areas but has not eliminated Eurasian watermilfoil from any area and there is evidence of spread to new areas. Hand pulling has the potential to limit the spread of invasive plant species and can be used on smaller areas of dense growths, but there is a need for sustained effort over multiple years that is hard to maintain with volunteers and can become expensive with paid contractors. Any lapse in effort, especially if combined with favorable growth



Manual Plant Removal

7699 conditions, can allow target plant populations to expand rapidly and overwhelm hand pulling
7700 capacity.

7701 Hand harvesting was applied in Mystic Lake in Barnstable in 2010 as part of an effort to control
7702 invasive hydrilla shortly after discovery of the infestation. Volunteers from the lake association
7703 were able to secure rapid permission to hand harvest hydrilla and lay down benthic barriers over
7704 known patches. A large seine with quarter inch mesh size was placed around each patch in a
7705 horseshoe, with the open end on shore. Volunteers removed as much hydrilla as possible, placing
7706 plants in floating containers, then the seine was pulled in to capture any fragments. Following
7707 this procedure, benthic barriers were laid over the area where patches were found. Removal was
7708 reasonably complete, and the seine captured all observable fragments, but even after benthic
7709 barrier deployment and removal there was regrowth from turions. Herbicide was later applied for
7710 control.

7711 Since 2017, MassWildlife staff have conducted annual hand-pulling of water chestnut in
7712 Threemile Pond in Sheffield. Floating plants have been hand pulled by boat, canoe, or kayak
7713 with plants offloaded on shore for transport to an offsite disposal site. Between 7 and 15 hours of
7714 active pulling per year occurred for the first 3 years of the project, decreasing to less than 3 hours
7715 annually in subsequent years. The optimal timeframe for removal in this region was determined
7716 to be in early July, when most plants have emerged and fruit is beginning to grow yet not mature
7717 enough to be released from plants. From 2017 to 2022, a combined total of 34 hours of active
7718 hand pulling has reduced over 2 acres of dense water chestnut patches to a few sparse clusters of
7719 plants. Annual monitoring and removal of any emergent plants will continue at Threemile Pond
7720 until water chestnut presence dwindles to the point where annual monitoring can transition to
7721 every few years.

7722 In Morses Pond in Wellesley a volunteer group has been hand pulling water chestnut each year for
7723 over two decades. This waterbody is close enough to other sources of water chestnut to be re-
7724 infested periodically, mainly by bird traffic. However, no water chestnut has been detected by
7725 professional surveys in late summer in over a decade, documenting the success of this hand
7726 harvesting program for preventing establishment of water chestnut in Morses Pond.

7727 Results from other states are similar to what has been experienced in MA. Lake George and Lake
7728 Saranac in the Adirondack region of NY have been the subjects of extensive hand pulling
7729 operations. A review of the Lake George program (Fugro East and ACT 1996) found that after a
7730 decade of hand pulling, Eurasian watermilfoil had been eliminated from 68 sites but not from 44
7731 others, with almost all remaining sites displaying denser and/or more expansive growths than
7732 initial conditions. Some use of benthic barrier was attempted but herbicides have not been used
7733 through 2023. The program has continued to the present and was recently re-evaluated by the Lake
7734 George Park Commission, with a recommendation to apply herbicide to longstanding areas of
7735 Eurasian watermilfoil infestation.

7736 Evaluation of the Saranac Lake hand pulling program (Kelting and Laxson 2014) indicated
7737 extermination of Eurasian watermilfoil at 9 of 15 monitored sites over a 10-year period starting in
7738 2004 but an increase at the remaining sites between 2008 and 2010. Density was reduced at those
7739 remaining sites by 2013 and an unmanaged control site exhibited a tripling of abundance over a 4-
7740 year period, suggesting substantial value from the hand pulling, just not complete control. Hand
7741 pulling as the sole means of plant control is best suited to selected species at lower density in
7742 smaller lakes and possibly target areas within a larger lake. Use as a follow up method where more
7743 extensive control has been exercised by other methods (e.g., herbicides, benthic barriers) is also
7744 practical.

7745 While the success of hand pulling has varied, it can be a useful technique for addressing early
7746 infestation by easily identified invasive plants such as water chestnut. Surface hand pulling of
7747 vegetation onto a boat can be relatively easy if time consuming, depending on the area affected.
7748 Use for completely submergent species where divers are necessary has been less successful, mostly
7749 owing to the level of effort required. Hand pulling following other control efforts has been
7750 successful in limiting recolonization by target species. Removal efforts need to be as complete as
7751 possible in any year and must typically be repeated for multiple years to gain control over target
7752 species.

7753

7754 Mechanical Harvesting

7755 How It Works

7756 Mechanical harvesting involves cutting vegetation by a
7757 mechanized process. Hand pulling grades to mechanical harvesting
7758 as tools are added, with the transition generally regarded as
7759 occurring when a person ceases to manually perform the operation.
7760 Towing a cutting bar behind a boat is viewed as mechanical
7761 harvesting, and certainly larger machines on pontoons or barges
7762 that cut and collect vegetation qualify as mechanical harvesting.
7763 Cutting vs. collection is another important distinction, with cutting
7764 involving a blade severing part of the plant from the remaining
7765 stem and rooted portion with no subsequent collection. Collection
7766 involves moving the cut vegetation into some form of container for
7767 disposal outside the lake. Simply cutting plants in a small area of a
7768 much larger lake is unlikely to have major water quality impacts or
7769 other adverse effects. However, collecting cut plants is generally
7770 preferable to avoid potential concerns about oxygen depression,
7771 nutrient recycling, poor aesthetics, and odor sometimes associated
7772 with larger scale operations.

7773 Regrowth after mechanical harvesting is expected, and in some
7774 species that regrowth is so rapid that additional harvesting may be
7775 needed in only a few weeks. If the plant can be cut close enough to
7776 the bottom, or repeatedly, it will sometimes die, but this is more the
7777 exception than the rule. Mechanical harvesting programs tend to
7778 either wait for substantial biomass to be achieved then harvest once
7779 per summer or cut more or less continuously, starting before
7780 nuisance conditions are achieved with the harvester rotating back
7781 to previously harvested areas once all targeted areas are addressed
7782 in a first harvest.

7783 Mechanical harvesting has undergone technological advancement over the last two decades but is
7784 still fundamentally the same concept of mowing an underwater “lawn”. Barges with cutting blades
7785 on a boom of some kind, a conveyor system, and a substantial storage area for cut plants follow a
7786 cutting path, often guided by GPS, fill the storage hopper, then offload at a designated shore
7787 location. A shore-based conveyor facilitates easy transfer of weeds from the harvester to trucks
7788 that haul the weeds to a composting area. Choice of equipment is really a question of scale, with
7789 larger harvesting operations usually employing commercially manufactured machines built to
7790 specifications suited to the job. Some lake associations or municipalities choose to purchase and



Towed cutting bar with a load of plants



Cutting end of a mechanical harvester (above) and loaded hopper after harvest (below)



Mechanical Harvesting

7791 operate harvesters, while others prefer to contract
7792 harvesting services to a firm that specializes in lake
7793 management efforts.

7794 Cutting rates for commercial harvesters tend to
7795 range from about 0.2 to 0.6 acres per hour,
7796 depending on machine size and operator ability,
7797 but the range of possible rates is larger and is often
7798 dictated by the distance to the offloading location
7799 for out-of-lake disposal. Even at the highest



Mechanical harvester offloading to conveyor with transfer to rollaway hopper

7800 practicable rate, harvesting is a slow process that may leave some lake users dissatisfied with
7801 progress in controlling aquatic plants. Weed disposal is not usually a problem, in part because
7802 lakeshore residents and farmers often will use the desiccated weeds as mulch and fertilizer. Also,
7803 since aquatic plants are more than 90 percent water, their dry bulk weight is comparatively small.
7804 Key issues in choosing a harvester include depth of operation, volume and weight of plants that
7805 can be stored, reliability and ease of maintenance, along with a host of technical specifications
7806 regarding the hydraulic system and other mechanical design features. Harvesters require
7807 maintenance and will start to wear out after a decade of use. Keeping an older harvester in
7808 operation for a growing season involves proactive maintenance, an adequate parts supply, and on-
7809 call support for repairs. A competent operator minimizes damage and needed repairs, but the
7810 mechanical nature of the operation and demands on equipment with many moving parts almost
7811 guarantees equipment problems that increase in frequency as the machine ages.

7812 Harvesting is non-selective within the area of operation over the range of depth of cutting. Most
7813 harvesters are built to operate at depths of 2 to 6 feet, so with plants growing to at least 10 feet in
7814 the vast majority of lakes, there will be uncut residual biomass of live plants in some areas by
7815 virtue of depths outside the operating range. Supplemental techniques such as hydroraking or
7816 benthic barriers may be needed to control plants in shallower water. In deeper water, however, the
7817 harvesting operation reduces plant density in the upper part of the water column while leaving
7818 vegetated habitat below, an almost ideal combination for facilitating recreation and retaining
7819 habitat. Some selectivity can be obtained by the timing of harvesting, with certain invasive species
7820 such as Eurasian and variable leaf milfoil and curlyleaf pondweed projecting higher in the water
7821 column than most native species in the spring, allowing for early cutting with less impact to native
7822 species. Harvesting before seeds, turions, or winter buds can be produced and released may provide
7823 longer duration of control for annual species, but except on a very small scale it is difficult to
7824 harvest all areas of a lake before reproduction has occurred.

7825 Harvesting in dense vegetation usually results in small fish, turtles, and other aquatic organisms
7826 winding up on the conveyor. Many will escape if the conveyor is temporarily shut down. If
7827 collected in the hopper, many will die, but few population level impacts have been reported for
7828 mechanical harvesting operations. If operating near the sediment surface or if plants are pulled out

Mechanical Harvesting

7829 of the sediment instead of cut, turbidity may result. Likewise, the paddlewheels that propel most
7830 harvesters can stir up sediment, but turbidity is almost always transient.

Possible Benefits

- 7832 ♦ Clears target area of plant biomass to selected depth (usually up to 6 ft)
- 7833 ♦ Does not kill most plants through single cutting, leaves vegetated habitat well below surface
- 7834 ♦ Repeated harvest may reduce abundance of seed-producing species but has seldom minimized
- 7835 perennial species for more than a season
- 7836 ♦ Can be applied to a target area without impact to adjacent areas
- 7837 ♦ Flexible operation over time and space

Possible Detriments

- 7839 ♦ Minimally selective; only depth of harvest and area addressed
- 7840 is controlled
- 7841 ♦ Will rarely control species that propagate vegetatively, and may
- 7842 help expand their populations if fragments are not collected
- 7843 ♦ Regrowth may overwhelm the ability of harvester to keep target
- 7844 areas clear of plants in larger operations
- 7845 ♦ Harvesting with collection tends to entrain many small fish and
- 7846 other aquatic life forms; overall population impacts are rarely
- 7847 documented, but negative impacts are possible
- 7848 ♦ Cutting without collection may affect water quality through
- 7849 plant decay from larger operations

Mechanical harvesting of species prone to viable fragmentation has been demonstrated to promote the spread of those species and is not desirable when such species are present at low densities or in only a localized portion of the waterbody. However, if such species are already abundant, harvesting may be a useful maintenance strategy.

Information for Proper Application

- 7851 ♦ General plant mapping and knowledge of any sensitive areas,
- 7852 especially where protected species are involved
- 7853 ♦ For large or repeated efforts, more detailed mapping with estimates of cover or biomass aid
- 7854 planning
- 7855 ♦ Fragment control plan, where species that expand by this process are not yet dominant or where
- 7856 downstream movement must be prevented
- 7857 ♦ Harvesting plan to include areas to be harvested, timing and
- 7858 pattern of harvest, and means to dispose of the plant material
- 7859 ♦ Offloading site(s) should be identified and permission to use
- 7860 any area for offloading and/or disposal must be confirmed
- 7861 ♦ Selection of equipment appropriate to the job; cutting width and
- 7862 storage hopper capacity are critical to covering target areas
- 7863 effectively (before regrowth limits benefits)
- 7864 ♦ Information on underwater obstructions, shallow areas, and
- 7865 other possible interference factors

Harvesting repeatedly may be sufficiently disruptive to lower plant biomass for a prolonged period of time. In most cases, however, regrowth to pre-harvest densities is expected within two growing seasons.

Mechanical Harvesting

- 7866 ♦ Understanding of maintenance needs and a plan for keeping the harvester running when needed

7867 **Factors Favoring or Disfavoring the Use of this Technique**

- 7868 ♦ Favored when the overall density of macrophytes is excessive
- 7869 throughout the littoral zone and growths fill the water column
- 7870 ♦ Favored when the target plant community is dominated by
- 7871 undesirable annual species
- 7872 ♦ Favored where a mix of recreational uses and habitat
- 7873 preservation is desired
- 7874 ♦ Favored when suspended sediments resettle quickly and leave
- 7875 minimal residual turbidity
- 7876 ♦ Favored where convenient access for equipment and trucks and a nearby location for plant
- 7877 disposal are available
- 7878 ♦ Disfavored where most target area is very shallow (<3 feet deep)
- 7879 ♦ Disfavored when surficial and underwater obstructions in targeted areas are common and/or
- 7880 have been poorly mapped

Harvesting before seed-producing species such as pondweeds and water chestnut can generate and disperse seeds can reduce the abundance of those species once the existing seed bed has been depleted.

7881 **Performance Guidelines and Monitoring Needs**

- 7882 ♦ Map the distribution of the target species and any protected non-target species in the lake
- 7883 ♦ Develop a harvesting plan that divides the lake into zones and prioritizes which zones will be
- 7884 harvested in what order, designated offloading sites, and any sensitive (no harvest) areas
- 7885 ♦ Select equipment consistent with goals; cutting depth and hopper capacity are important
- 7886 features and auxiliary barges and offloading equipment may improve efficiency
- 7887 ♦ Inspect and clean all equipment before entering or leaving a lake; pressure washing and/or
- 7888 steam cleaning may be necessary in some cases
- 7889 ♦ Avoid areas of known sensitive habitat, especially during active use
- 7890 ♦ Avoid harvesting of plants that spread by vegetative fragmentation when present at low
- 7891 densities unless the collection system is very effective
- 7892 ♦ When harvesting annual (seed-producing) plants, harvest before seeds are formed and
- 7893 dispersed for greatest longevity of results
- 7894 ♦ Harvest as close to the bottom as equipment allows for maximum effect but leave more of
- 7895 submerged plants where habitat is a major interest
- 7896 ♦ Develop a harvester maintenance plan; routine repairs are essential to keeping a harvesting
- 7897 program on schedule
- 7898 ♦ Monitor pre- and post-harvest density of target plants and the plant community in general
- 7899 ♦ Monitor collection of non-target fauna (e.g., fish, turtles) and avoid excessive collection
- 7900 ♦ Monitor water quality over the period of harvesting to detect any significant effects; focus on
- 7901 clarity, oxygen, and nutrient levels

Key Considerations for Conservation Commissions

- ◆ Review by MassWildlife-NHESP is required if the project is located within Priority or Estimated habitat and must be complete before the conservation commission can close any hearing and issue an Order of Conditions under the WPA
- ◆ While the federal Clean Water Act, Section 401, does not recognize harvested plants as subject to regulation as dredged material, the MA regulations based on Section 401 can be interpreted to include plant biomass in the same category as sediment; consequently, a 401 permit could be required for mechanical harvesting and the MassDEP should be consulted during the planning phase
- ◆ Most interests of the WPA are either unimpacted or benefitted by mechanical harvesting; pollution prevention may be an issue if excessive turbidity is created, and fish and wildlife habitat may be compromised if harvesting is extensive (horizontally over the lake and vertically over the water column)
- ◆ Mechanical harvesting offers flexible operation that can be adjusted quickly if issues arise with adequate monitoring and communication

Massachusetts and Related Experience

Mechanical harvesting has long been applied to lakes in MA. Where herbicides are not used, mechanical harvesting is the most applicable approach to larger scale plant control. With operational flexibility over time and space, mechanical harvesting can provide localized relief from nuisance vegetation while maintaining habitat and avoiding sensitive areas. The primary drawback is that the harvesting process is slow; not all target areas can be addressed quickly, and no one wants to have their favorite part of the lake addressed last. Mechanical harvesting in MA has been performed by contractors who bring in equipment and work an agreed number of days or by dedicated operators employed by towns that own their own harvesters. Acceptable results have been reported for many lakes, but, by itself, mechanical harvesting has not eliminated the need for subsequent plant control in any MA lake.

The Town of Monterey operated its own mechanical harvester on Lake Buel for several decades, reducing impacts from Eurasian watermilfoil and a few other species. It had been reported that repeated cuts were favoring dense beds of low growing vegetation, mainly the macroalga *Chara*, but an effort to plant desirable species in harvested areas did not result in a long-term shift away from milfoil. Likewise, planting of Robbins' pondweed (*Potamogeton robbinsii*) in harvested areas of Chandler Pond in Duxbury did not prevent eventual re-infestation by fanwort and variable leaf watermilfoil. Repeated harvest of target areas in Morses Pond in Wellesley led to occasional increases in more desirable species, notably Robbins' pondweed and common naiad, but the shifts have never lasted more than a year or two. Harvesting does not appear to exert enough selective pressure to favor lower growing species on a long-term basis.

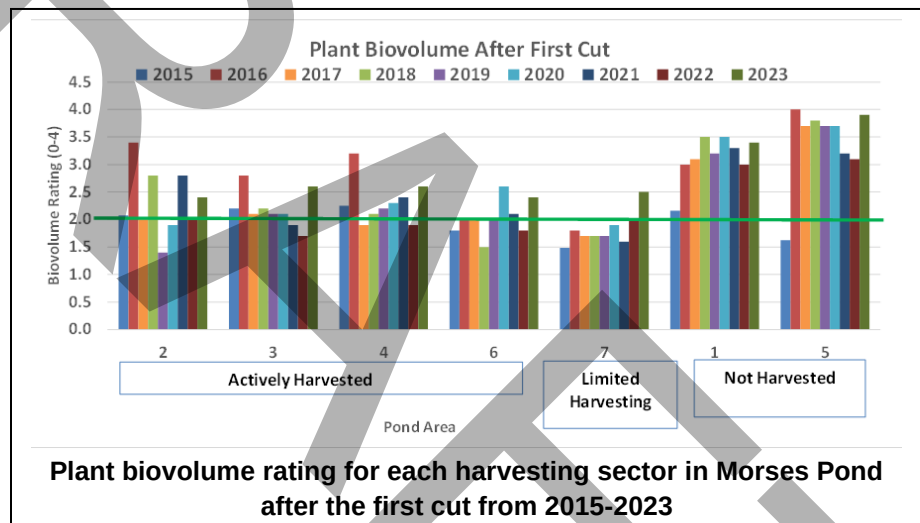
The Morses Pond mechanical harvesting program is one of the better documented examples in MA. The town owns two harvesters, larger (9 ft cutting width) and smaller (6 ft cutting width)

Mechanical Harvesting

versions, that have been used over an approximately 40-acre area since 2007. Both harvesters are not necessarily operated at the same time, but can be, and offer the ability to cut the target area in about 6 weeks. The first cut usually starts in late May and is complete close to the 4th of July holiday weekend. A short break allows the smaller harvester to work on two smaller ponds in town, then a second cut commences and runs into September most years. Hours spent on various tasks and the mass of plants removed have been tracked.

The plant community is assessed before harvesting commences then after the first and second cuts. The goal is to achieve a biovolume rating of <2 for all target areas, with plant biovolume representing the portion of the water column filled with plants in quartiles, such that a value of 2 equates to 25-50% of the water column being filled with plants. Since the harvester cuts from the surface down, that 25-50% is the bottom quarter to half the water column, a desirable situation for recreational use and most fish and wildlife habitat. Two sectors of the pond are not harvested (1 and 5) and one sector (7) is deep enough not to need harvesting over most of its area, leaving 4 sectors (2, 3, 4, 6) that are addressed in sequence in most years.

The data from prior to 2016 nearly always revealed post-harvest values close to or less than 2 but equipment failure in 2016 translated into a very late start on harvesting in a year with a mild winter and early start to plant growth; targets were not achieved except in sector 6.



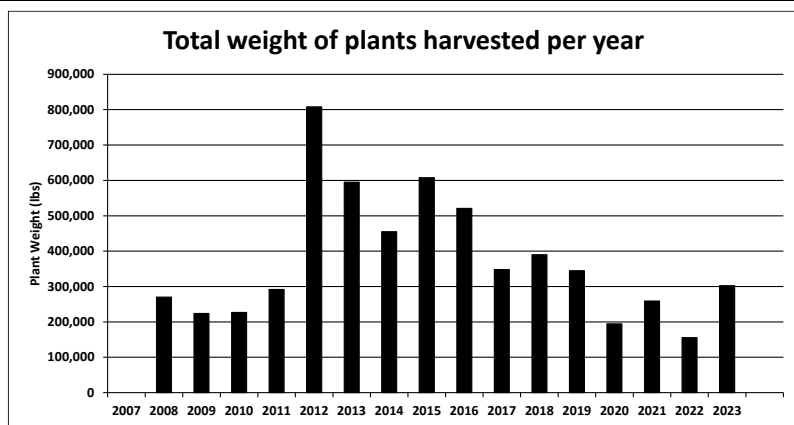
Continued problems with an aging large harvester plagued the program in subsequent years and the target was not always reached. Another mild winter in 2023 allowed early plant growth and the harvesting program was not able to keep up with plant growth. Increased effort compensated to a large degree and the improvement over non-harvested areas is evident in the data.

Extra harvesting was conducted in 2012 and 2013 to support a dredging project, increasing the hours spent and weight of plants removed, but the total plant weight harvested per year has declined since 2015 despite relatively steady cutting hours. The problem lies in the inability of the aging large harvester to handle as large a load as in its early years and the smaller capacity of the smaller harvester, leading to smaller weights per load and more travel time for offloading. As more

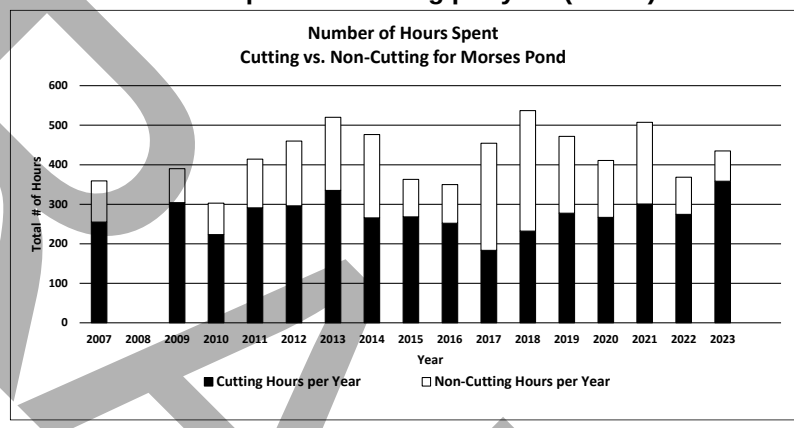
Mechanical Harvesting

hours are devoted to non-cutting tasks such as transport and maintenance, production declines unless considerable extra effort is expended. The importance of harvester age and condition to best operation is underscored. A new, larger harvester was obtained in July 2023 to replace the one put into service in 2007.

Harvesting operations in other states are much like those in MA. Targeted portions of the plant growth zone of a lake are harvested to limit plant interference with swimming, boating, and fishing, sometimes to retard eutrophication and related water quality issues, and usually with no major adverse impacts on habitat or biological resources. Mechanical harvesting is largely a maintenance operation, but one that offers flexibility over space and time and is scalable to meet most lake-specific needs.



Weight of plants removed (above) from Morses Pond and hours spent harvesting per year (below)



8002 Hydroraking

8003 How It Works

8004 Hydroraking involves the equivalent of a floating backhoe, usually outfitted with a York rake that
8005 looks like a farm implement for tilling or moving silage. The tines of the rake attachment are
8006 dragged through the sediment, ripping out thick root masses and collecting associated sediment
8007 and debris. A hydrorake can be a very effective tool for removing submerged stumps, water lily
8008 root masses, or floating islands. Adding fine screening to the tines, sediment can be moved to
8009 contour a swim area or other nearshore site. Hydrorakes can operate to a depth of about 12 feet but
8010 rarely operate in more than four feet of water. Removal of floating islands is an exception but
8011 while the water may be deeper, actual removal of
8012 material is near the lake surface. Such islands are
8013 typically the result of a decaying root mass (usually from
8014 yellow or white water lilies) rising to the surface of a lake
8015 with considerable associated sediment. They may float
8016 anywhere in a lake and a hydrorake can be used to break
8017 up and remove those islands. Use of a hydrorake is not a
8018 delicate operation and will create substantial but
8019 temporary turbidity and generate plant fragments.
8020 Hydroraking in combination with a harvester can remove
8021 most forms of vegetation encountered in lakes.



A hydrorake

8022 Hydroraking of a lake bottom almost always targets shallow areas adjacent to shore where
8023 mechanical harvesters cannot effectively operate, either due to lack of water depth or physical
8024 obstructions like rocks and stumps. A combination of submergent and emergent plants, woody
8025 debris, rocks, and sediment may be removed. Material removed by hydroraking is either placed on
8026 shore adjacent to the work area or on a barge for transport to some other offloading site. The
8027 quantity and nature of that material is important to the permitting process, as hydroraking can be
8028 considered de facto dredging. Hydroraking projects routinely disturb sediment and remove some
8029 sediment with vegetation and other debris, but typically generate less material than the 100 cubic
8030 yard threshold that triggers dredging permitting under Section 401 as administered by MassDEP.

8031 Hydroraking is effective in the short-term in that it removes plants immediately. It is not an
8032 especially thorough or selective technique and is therefore not well suited to submergent species
8033 that can recover from partial root masses or re-root from fragments (e.g., milfoils), or to mixed
8034 assemblages with desirable species present at substantial densities. It is particularly effective for
8035 removal of water lilies (white or yellow), cattails, common reed, yellow floating heart, water
8036 chestnut, watershield, and other species with dense root masses. Adequate removal of roots may
8037 result in reduced plant densities for four to five years. Removal of subsurface obstructions such as
8038 stumps, logs, or rocks may be justifiable for swimming or boating safety, but those features
8039 constitute aquatic habitat for fish and wildlife that must be considered in project planning and need

Hydroraking

8040 to be specifically permitted. The scale of hydroraking is a primary consideration, with most
8041 projects addressing small areas for access improvement, safety, or removing eroded sediment from
8042 the lake after a bank failure.

8043 Hydroraking can kill and remove some benthic invertebrates during operation, especially species
8044 with low mobility such as mussels and snails, and non-target plants will also be impacted in
8045 hydroraked areas. High turbidity is usually generated by hydroraking operations, as there is
8046 extensive sediment disturbance. Nesting birds, spawning fish, and various reptiles and amphibians
8047 may be impacted by hydroraking, especially between late April and early July. This technique is
8048 applied on a very limited areal scale in the vast majority of cases, however, and is not expected to
8049 have lakewide effects on non-target organisms or water quality.

Possible Benefits

- 8051 ♦ Removes vegetation difficult to harvest by other means
- 8052 ♦ Allows removal of stumps, rocks, or other obstructions that may adversely affect water
8053 dependent uses like swimming or boating
- 8054 ♦ Removes sediment adjacent to shore where other equipment may not be able to operate due to
8055 shoreside access or shallow water depth

Possible Detriments

- 8057 ♦ Very disruptive to bottom structure and habitat in areas applied; may generate high turbidity
8058 and drastically alter habitat for some fish and wildlife
- 8059 ♦ May spread plants that reproduce by fragmentation
- 8060 ♦ May remove non-target plants and animals of limited mobility from the work area

Information for Proper Application

- 8062 ♦ Mapping of targeted plant masses or obstructions and knowledge of any sensitive areas,
8063 especially where protected species are involved
- 8064 ♦ Fragment control plan, where species that expand by fragmentation are not yet dominant or
8065 where export from the target area must be prevented
- 8066 ♦ Turbidity control plan, where sensitive receptors are present or a large part of the lake is to be
8067 hydroraked
- 8068 ♦ Calculation of quantity of material to be removed and, if over any regulatory threshold, testing
8069 of material to ascertain quality as relates to allowable disposal

Factors Favoring or Disfavoring the Use of this Technique

- 8071 ♦ Favored when the target species has dense root masses; hydroraking provides effective
8072 removal and control is likely to last longer
- 8073 ♦ Favored when underwater obstructions such as stumps, logs, or rocks are targeted for removal
- 8074 ♦ Favored when the target area is small

Hydroraking

- 8075 ♦ Favored when suspended sediments are coarse, allowing quick resettling and minimal residual
- 8076 turbidity
- 8077 ♦ Favored when convenient access for equipment and trucks and a nearby location for material
- 8078 disposal are available
- 8079 ♦ Disfavored when targeted plants regrow quickly from seeds or remaining root systems or are
- 8080 prone to spread by fragmentation

Performance Guidelines and Monitoring Needs

- 8082 ♦ Map the distribution of the target species or obstructions to be removed; note the distribution
- 8083 of any protected species in the lake
- 8084 ♦ Provide turbidity control (sequestering curtains) if extensive bottom area is to be disturbed or
- 8085 the target area is subject to significant currents
- 8086 ♦ Provide fragment control when working among plants that reproduce by vegetative
- 8087 fragmentation if those plants are not already widespread in the lake
- 8088 ♦ Avoid areas of known sensitive habitat during active use; check area for active bird or fish
- 8089 nests and avoid disturbance if possible
- 8090 ♦ Inspect and clean all equipment before entering or leaving the lake and target area
- 8091 ♦ Monitor turbidity around the hydroraking area before, during and after hydroraking if potential
- 8092 impacts are considered significant
- 8093 ♦ Monitor nutrients and oxygen in the target area before and after hydroraking if potential
- 8094 impacts are considered significant
- 8095 ♦ Monitor pre- and post-hydroraking density of target plants; assess conditions annually after
- 8096 hydroraking to evaluate longevity of benefits

Key Considerations for Conservation Commissions

- 8098 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
- 8099 Estimated habitat and must be complete before the conservation commission can close any
- 8100 hearing and issue an Order of Conditions under the WPA
- 8101 ♦ The normal target area for hydroraking is the interface between Bank and Land Under Water,
- 8102 although Bordering Vegetated Wetlands might also be affected; applicants should provide
- 8103 quantification of impacts to help conservation commissions understand what resources are to
- 8104 be affected and related performance standards
- 8105 ♦ No significant or lasting impacts to water supply, groundwater, flood control, or storm damage
- 8106 prevention interests of the WPA are expected
- 8107 ♦ Prevention of pollution is a possible concern if sediment disruption and resultant turbidity are
- 8108 high over a large enough area, but this is rarely the case
- 8109 ♦ Protection of land containing shellfish, fisheries, and wildlife habitat could be adversely
- 8110 affected or benefitted, depending on the size of the targeted area and resulting conditions; an
- 8111 evaluation should be provided by applicants

Hydroraking

- 8112 ♦ If the hydroraked material volume exceeds 100 cy, the project is likely to be considered
8113 dredging and will require a Section 401 permit from MassDEP

8114 Massachusetts and Related Experience

8115 Hydroraking projects addressing small areas
8116 adjacent to shore where sediment has
8117 accumulated and fostered dense water lilies or
8118 emergent plant growths have been common in
8119 MA. Often hydroraking is used to create an
8120 access point where emergent plants or woody
8121 obstructions are dense. Such access points do not
8122 have to be wider than about 10 feet and can
8123 create valuable edge habitat, and interface
8124 between open water and dense vegetation.
8125 Hydroraking is used as a supplement to
8126 mechanical harvesting where the water is too shallow to allow the harvester to work and where
8127 target plants with heavy root systems like water lilies dominate. Floating islands that popped up
8128 after other means of plant control (sometimes associated with herbicides or drawdown) have been
8129 removed by hydroraking.



Hydrorake placing raked material on a push barge for offloading at a designated site

8130 A MS thesis from Clark University (Desmarais 2016) reviews eight hydroraking projects in MA
8131 and provides a decision tree for application of this technique. The technique can work in water 1 -
8132 12 feet deep, but most projects are in <4 feet of water. Access for the machinery is critical. Plants
8133 recommended for hydro-raking in MA are rooted floating plants and emergent shoreline plants.
8134 Plants not recommended for removal through hydro-raking include species that spread through
8135 fragmentation. Organic debris and trash can be effectively removed by hydrorake but habitat
8136 considerations apply when removing natural materials like rocks and stumps.

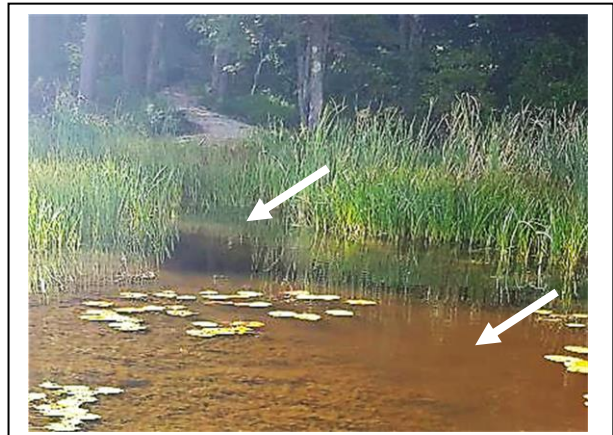
8137 Hydroraking has been applied to Morses Pond in Wellesley on a periodic basis to supplement an
8138 extensive mechanical harvesting program. The harvester cannot work in water <2 feet deep and
8139 shoreline residents find that sediment and debris accumulate over time along their shoreline.
8140 Manual raking covers some areas, but periodically some removal of plants and sediment is
8141 preferred. Small areas are hydroraked for participating shorefront property owners, with the town
8142 facilitating permits but the lake association managing the contractors for hydroraking and material
8143 disposal. Some material has been incorporated into soil on the adjacent properties, but most goes
8144 to the town composting facility. A similar program has been conducted at Foster's Pond in
8145 Andover since 1992.

8146 Also at Morses Pond, a 2012-2013 dredging project in the northern cove produced clean sand that
8147 was placed in the swim area to enhance the substrate at the town beach. That sand was graded by
8148 a hydrorake with a screen attached to the rake tines. A gradual slope to a depth of four feet was
8149 attained, with ropes and docks marking the end of the shallow area, after which the bottom slopes

Hydroraking

8150 steeply to about 12 feet of water depth. The grading enhanced safety in a highly used swimming
8151 area.

8152 Owl Lake in Otis and Sandisfield is a 25-acre,
8153 manmade waterbody with a largely naturally
8154 vegetated shoreline. Dense terrestrial and
8155 emergent vegetation form the transition from
8156 upland to lake. Hydroraking has created small
8157 access points for canoes and kayaks from
8158 multiple properties, each lasting about a decade
8159 before additional hydroraking is needed. No
8160 invasive species have colonized the hydroraked
8161 areas, despite the presence of common reed and
8162 purple loosestrife in other areas. Disruption has
8163 been minimal and with so much of the shoreline
8164 in such vegetated habitat, the edge effects
8165 enhance overall habitat value for wading birds
8166 and furbearing mammals.



Small cut in emergent vegetation and shallow water created by hydroraking to allow boat access from adjacent property

8167 Hydroraking has been used in other states similarly to its use in MA. Hydroraking is a fairly
8168 common plant control technique in New England but does not handle the range of rooted plant
8169 issues and is usually part of a larger plant control program. Hydroraking tends to focus on
8170 accumulated organic sediment and associated plant growths adjacent to the shoreline but is also
8171 commonly used to remove floating islands that arise as decomposing plants trap gases and lift
8172 sediment to the surface of a lake.

8173

8174 **Herbicides**

8175 **How It Works**

8176 ***Types of Herbicides***

8177 Herbicides, along with algaecides, are a subset of what are termed pesticides, substances that can
8178 be used to kill target organisms. Herbicides contain active ingredients that are intentionally toxic
8179 to target plants. Herbicides also contain auxiliary ingredients that aid application or increase
8180 effectiveness, and which may or may not be toxic themselves. Consequently, different
8181 formulations may contain different percentages of active ingredient and various auxiliary
8182 compounds (also called adjuvants) that influence results, both intended and unintended.

8183 Herbicides are typically classified as contact or systemic. Contact herbicides are toxic to plants in
8184 the immediate vicinity of external contact, while systemic herbicides are taken up by the plant and
8185 are translocated throughout the plant. In general, contact herbicides are more effective against
8186 annuals than perennials because they may not kill the roots, allowing perennials to grow back.
8187 Seeds, turions or other reproductive structures are also not likely to be affected, but with proper
8188 timing and multiple treatments, growths can be much reduced.

8189 Systemic herbicides tend to work more slowly than contact herbicides because they need time to
8190 be translocated throughout the plant. Systemic herbicides generally provide more effective control
8191 of perennial plants than contact herbicides, as they kill the entire plant under favorable application
8192 circumstances. Systemic herbicides will also kill susceptible annual species, but regrowth from
8193 seeds, turions, or other reproductive structures will require additional treatments as with contact
8194 herbicides, as previously formed reproductive structures are not impacted.

8195 Many herbicides have both contact and systemic properties; definitive classification as contact or
8196 systemic is not completely reliable. For example, low dose treatment with diquat, considered a
8197 contact herbicide, may result in more complete plant death, while high dose treatment with
8198 triclopyr, a systemic herbicide, may kill the exposed plant tissues before enough herbicide can be
8199 absorbed and translocated to kill the root system.

8200 There were only six active ingredients registered for use in aquatic herbicides in MA as of 2002
8201 and reviewed in the 2004 GEIR, including copper which is mainly used as an algaecide. Six
8202 additional ingredients have been registered by MDAR for MA since then, including another
8203 algaecide, peroxide. Ten herbicidal active ingredients are therefore included here, with algaecides
8204 addressed in the corresponding section of this guide. The 2004 GEIR provided useful information
8205 on those active ingredients approved at that time, and a more recent review by Wagner (2020b)
8206 supplements the GEIR with regard to all active ingredients registered for aquatic use in herbicides
8207 in MA as of 2020.

8208 The MDAR is responsible for the registration of any new herbicide for use in MA and maintains
8209 online information on all registered herbicides, with links provided in this review for each of the

Herbicides

8210 ten active ingredients registered for aquatic use in MA. Any future herbicides proposed for use in
8211 MA will be noticed in the MEPA Environmental Monitor with updated information appended to
8212 this document upon completion of a review by MDAR and MassDEP-ORS.

8213 *Effects of herbicides*

8214 Active ingredients are intended to interfere with essential plant growth processes and cause
8215 structural or metabolic failure. Any plant subject to the process(es) under attack may be impacted,
8216 so herbicides are not highly specific in their targets from the perspective of mode of action. Plants
8217 within a genus and often within a family are likely to respond similarly. Plants of greater taxonomic
8218 dissimilarity may vary in their structural features and metabolic processes, such that differential
8219 impact from an herbicide is possible and therefore some specificity can be attained for some
8220 herbicides. Actual results will depend on many factors including: the concentration applied, the
8221 timing of application, plant density, and the nature of the assemblage where the application is
8222 made.

8223 Results from experimental tanks at a research station where different doses are tested prior to
8224 registration of an herbicide should be a reasonable indicator of field results but cannot replicate all
8225 possible conditions and some variation in response is to be expected. The dilution and flushing
8226 offered by the target waters, the decay rate of the herbicide, and even the genetics of the target
8227 population of plants will affect results. Experience in MA provides practicable knowledge of the
8228 degree of control exerted by specific active ingredients over various target plant species, but
8229 variation is still to be expected.

8230 Herbicides are intended to kill target plants. Advances in selectivity have been achieved through
8231 new or altered formulations, reduced dose, or timing and location of application. However, more
8232 plants than just the target species are normally at risk. In cases of excessive native plant growth,
8233 the herbicide may be intended to reduce the overall abundance of plants without targeting one
8234 species above all others. More often the herbicide is matched to the dominant species, usually an
8235 invasive species, and the dose, timing, and location of application are set to limit inadvertent
8236 impacts to other species. Concern over impacts to non-target flora centers on protected species and
8237 overall impacts to the plant community that may affect habitat for fish and wildlife. Application
8238 decisions are therefore a matter of perceived risk vs. reward and require a careful evaluation of
8239 resources and anticipated effects. Clearly stated and explicitly defined goals should be set with an
8240 appropriate monitoring program to provide actual data for results, determine if goals are met, and
8241 allow program adjustment as warranted.

8242 Impacts to animal life can be direct, as with a toxic effect, or indirect, such as loss of oxygen when
8243 many targeted plants decay at once or the habitat is changed by loss of plants. A presentation by
8244 Richard Hartley of MassWildlife to the Northeast Aquatic Plant Management Society in 2005
8245 reviewed all available data from investigated fishkills in MA over the preceding two decades.

Herbicides

Aquatic herbicides, common target species, and use restrictions

Active Ingredient	Common Aquatic Product Names	Primary Mode	Primary Target Aquatic Plants	Application and Water Use Restrictions
Copper	Komeen, Nautique, Harpoon, Current	Contact	Potamogeton, Vallisneria, Najas, more often for algae control	Maximum application rate = 1 ppm as Cu, treat no more than half the target waterbody with at least 14 days in between treatments. Contact with water and use for irrigation generally discouraged for 24 hr.
Diquat	Reward, Weedtrine, Diquat, Tribune	Contact	Wide range of aquatic plants, Myriophyllum, Potamogeton, Ceratophyllum, Najas, Elodea, Utricularia, Hydrilla	Maximum application rate = 0.5 gal/ac-ft, up to 2 gal/ac maximum = 0.4 ppm diquat cation. Treat no more than half target waterbody at one time with at least 14 days before any additional treatment. No restriction on fishing or swimming but up to 5 days until use for potable supply or irrigation can resume unless concentration is <0.02 ppm.
Endothall	Aquathol, Hydrothol	Contact	Wide range of aquatic plants, Myriophyllum, Hydrilla, Potamogeton, Ceratophyllum, Vallisneria, sometimes Chlorophyta (filamentous green algae)	Maximum application rate = 5 ppm as endothall acid. Treat no more than half the waterbody and not within 600 ft of any active potable water intake. Drinking water standard is 0.1 ppm.
Flumioxazin	Clipper, Propeller, Flumigard	Contact	Lemna, Wolffia, Hydrilla, Cabomba, Ceratophyllum, Najas, Myriophyllum, Potamogeton, Trapa, sometimes Chlorophyta (filamentous green algae)	MA regulations differ from federal label. Maximum application rate = 0.2 ppm as flumioxazin. Treat no more than half the waterbody, previously untreated areas may be treated after 10-14 days, but only one treatment per 4 years. No consumption, swimming, or fishing restrictions, but up to 5 days needed before water can be used for irrigation.
2,4-D	Navigate, Weedar, Clean Amine, Platoon, DMA4, Aquacide	Systemic	Myriophyllum, Trapa, Nuphar, Nymphaea, Brasenia; historically also Ceratophyllum, Persicaria, Utricularia, but rarely used in MA now	Maximum application rate = 2 gal/ac-ft = 1.5 ppm. No more than 2 applications/yr at least 21 days apart. Up to 7 days before water can be used for irrigation or concentration <0.1 ppm. Not allowed in MA waters where any connection to potable water intake or wells is possible.
Fluridone	Sonar, Avast, Fluridone	Systemic	Myriophyllum, Hydrilla, Cabomba, Najas, Elodea, Lemna, Wolffia, sometimes Potamogeton, Nuphar, Nymphaea, Brasenia, Vallisneria to reduce growth	Maximum application rate = 150 ppb, 90 ppb for ponds <10 ac, but most applications are <30% of maximum. Applied concentrations must be <20 ppb within 1320 ft of potable supply intakes. Irrigation of sensitive vegetation after 7-14 days or concentration <1 ppb. No restrictions for swimming or fishing.

Herbicides

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Aquatic herbicides, common target species, and use restrictions (continued)

Active Ingredient	Common Aquatic Product Names	Primary Mode	Primary Target Aquatic Plants	Application and Water Use Restrictions
Glyphosate	Rodeo, Round-Up Custom, Aquaneat, Glyphosate	Systemic	Emergent and floating leaved species, including Phragmites, Typha, Lythrum, Nuphar, Nymphaea, Brasenia, Nelumbo, Persicaria	Applied as a spray, usually 1-8% concentration with sticking agent added, 1 gal provides 4 lbs of glyphosate in acid form with limit of 0.94 gal/ac, equates with maximum applicatio rate of 1.7 kg/ac or 421 mg/m2. Not to be applied within 1/2 mile of potable water intake. No restriction for use of water post-treatment.
Imazapyr	Habitat, Imazapyr, Ecomazpyr	Systemic	Emergent and floating leaved species, including Nuphar, Nymphaea, Nymphoides, Nelumbo, Trapa, Typha, Phragmites, Persicaria, emergent forms of Myriophyllum, but rarely used in MA due to irrigation restrictions and non-target impacts	Applied as a spray, 0.5-5% concentration with sticking agent added, 1 gal provides 2 lbs of imazapyr in acid form with limit of 0.75 gal/ac. Cannot be applied within 1/2 mile of active potable water intake. Treated water cannot be used for irrigation for 120 days or until concentration is <1 ppb. No restrictions for swimming or fishing.
Imazamox	Clearcast, Imox	Systemic	Emergent or floating leaved species, including Phragmites, Typha, Nuphar, Nymphaea, Nelumbo, Nymphoides, Persicaria, Brasenia, Trapa, emergent forms of Myriophyllum	Maximum application rate = 0.5 ppm. Also applied as 1-5% spray for emergent vegetation with limit of 1 gal/ac = 1 lb/ac in acid form. Not to be applied within 1320 ft of active potable intake and concentration must be <50 ppb at any intake for use. No irrigation use until concentration is <1-50 ppb, depending on vegetation type. No restriction for swimming or fishing.
Triclopyr	Renovate, Triclopyr	Systemic	Myriophyllum, Nuphar, Nymphaea, Nelumbo, Brasenia, Lythrum, Phragmites, Persicaria	Maximum application rate = 2 gal/ac/yr = 6 lb active ingredient/ac/yr. Can be applied as spray or injected into water. No irrigation use until concentration is <1 ppb or 120 days after treatment. No restrictions on potable water use, swimming, or fishing.
Florpyrauxifen-benzyl	ProcellaCOR EC	Systemic	Myriophyllum, Nymphoides, Nelumbo, Brasenia, Hydrilla, Trapa, Certatophyllum, but only EC formulation registered for use in MA and applied only for Myriophyllum control	Maximum application rate = 0.13 lb/ac-ft treated (25 prescription dose units), but use in MA is <0.026 lb/ac (<5 PDU). Any additional application to same area after >14 days. No use for irrigation for up to 35 days, but MA waiting period is 1-14 days based on dose and % of waterbody treated. No restrictions for human potable consumption, swimming, or fishing. Use of treated water or composted, treated plants for livestock not recommended.
Information comes from labels for herbicides, MassDAR reviews, and review from 3 applicators with extensive experience in MA				

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Effectiveness of herbicides on algae and non-native vascular plant species in Massachusetts that may be the target of herbicide treatment

Functional Group and Genus or Appropriate Taxon	Total Number of Species in MA	Number of MA Native Species	Number of MA State-Listed Species	Scientific Name of Target Species	Common Name of Target Species	Diquat	Endothall	Flumioxazin	2,4-D	Fluridone	Glyphosate	Imazapyr	Imazamox	Triclopyr	Florpyrauxifen-benzyl
Algae															
Chara/Nitella spp	Many	Many	0	Chara/Nitella spp	Muskgrass/Stonewort	P		P					P		
Chlorophyta	Many	Many	0	Chlorophyta	Filamentous green mats	P		P							
Chlorophyta, Chrysophyta	Many	Many	0	Chlorophyta, Chrysophyta	Planktonic algae										
Cyanobacteria	Many	Many	0	Cyanobacteria	Blue-green algae										
Non-Native Vascular Plants															
Submergent															
Cabomba	1	0	0	Cabomba caroliniana	Fanwort		P	C		C					
Egeria	1	0	0	Egeria densa	Brazilian waterweed	C				P					
Hydrilla	1	0	0	Hydrilla verticillata	Hydrilla	P	C	P		C					
Myriophyllum	10	7	4	Myriophyllum aquaticum	Parrotfeather	C	P	P	C	P		P	P	C	C
				Myriophyllum heterophyllum	Variable watermilfoil	C	P	P	C	P				C	C
				Myriophyllum spicatum	Eurasian watermilfoil	C	C	P	C	C				C	C
Najas	3	2	0	Najas minor	Spiny/European naiad	C	C	P	P	C			P		
				Najas gaudalupensis	Southern naiad	C	C	C	P	C			P		
Potamogeton	30	29	6	Potamogeton crispus	Curlyleaf pondweed	C	C	C		C			C		
Utricularia	12	11	2	Utricularia inflata	Swollen bladderwort	C		C		C					
Floating leaved															
Nelumbo	2	1	0	Nelumbo nucifera	Indian lotus		P	P		C			P	C	C
Nymphoides	2	1	0	Nymphoides peltata	Yellow floating heart	C		P	P			P	P		C
Trapa	1	0	0	Trapa natans	Water chestnut	P		P	C	P	P	C	C	P	C
Emergent															
Lythrum	4	1	0	Lythrum salicaria	Purple loosestrife						C	C		C	
Phragmites	2	1	0	Phragmites australis	Common reed						C	C	C	P	
Key to herbicide effectiveness: C = high level of control with typical application rate. P = partial control or greater with multiple applications and/or higher dose. Blank entry indicates herbicide not generally effective for corresponding species at typical application rates and exposure times. Dose, duration of exposure, formulation and timing of application are all key factors in treatment, causing variation in results.															
Additional Notes: 1) Copper and peroxide, algaecides not typically used for vascular plant control, are covered separately under removal of algae in the corresponding section of this guide. 2) Designations based on herbicide label information and review by 3 applicators with extensive experience in MA. 3) Some herbicides can be mixed or applied sequentially and copper is often used to minimize attached algae on plants and maximize the impact of other herbicides. 4) Most herbicides contain additional compounds, some intended to increase effectiveness; knowledge of additional ingredients can be helpful in selecting an herbicide. 5) Only the EC formulation of florpyrauxifen-benzyl is registered in MA and is used only for Myriophyllum control as of 2023. 6) Native species are those identified in the The Vascular Plants of Massachusetts: A County Checklist; common names are not standardized and will vary between sources.															

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Effectiveness of herbicides on native vascular plant species in Massachusetts that may be the target of herbicide treatment

Functional Group and Genus or Appropriate Taxon	Total Number of Species in MA	Number of MA Native Species	Number of MA State-Listed Species	Scientific Name of Target Species	Common Name of Target Species	Diquat	Endothall	Flumioxazin	2,4-D	Fluridone	Glyphosate	Imazapyr	Imazamox	Triclopyr	Florpyrauxifen-benzyl
<i>Native Species</i>															
<i>Submergent</i>															
Ceratophyllum	2	2	0	Ceratophyllum demersum	Coontail	C	P	C	P	C			P		P
Elodea	2	2	0	Elodea canadensis	Waterweed	C				C					
				Elodea nuttallii	Slender waterweed	C				C					
Myriophyllum	13	10	4	Myriophyllum humile	Low watermilfoil	C	P	C	C	P				C	C
Najas	5	2	0	Najas flexilis	Bushy naiad	C	C	P	P	C			P		
Potamogeton	30	29	6	Broadleaf Potamogeton spp.	Broadleaf pondweeds	P	C	P		P			P		
				Thinleaf Potamogeton spp. (e.g., pusillus, berchtoldii, spirillus)	Thinleaf pondweeds	C	C	P		P			P		
Utricularia	12	11	2	Utricularia spp. (e.g., purpurea, macrorhiza)	Bladderwort	C				C			P		
Vallisneria	1	1	0	Vallisneria americana	Water celery	P	P			P					
<i>Floating leaved</i>															
Brasenia	1	1	0	Brasenia schreberi	Watershield			P	P	P	C	P	P	C	C
Lemna	6	5	0	Lemna spp (e.g., minor)	Duckweed	P		C		C					
Nelumbo	2	1	0	Nelumbo lutea	American lotus			P	P		C	P	P	C	C
Nuphar	3	3	0	Nuphar spp (e.g., variegata)	Yellow water lily			P	P	P	C	C	P	C	
Nymphaea	2	1	0	Nymphaea odorata	White water lily			P	P	P	C	C	P	C	
Nymphoides	2	1	0	Nymphoides cordata	Little floating heart	C		P	P	P		P	P	P	C
Persicaria	20	12	2	Persicaria amphibia	Water smartweed				P	P	C	P	P	P	
Wolffia	3	3	0	Wolffia spp. (e.g., columbiana)	Watermeal	P		C		C					
<i>Emergent</i>															
Pontederia	1	1	0	Pontederia cordata	Pickerelweed	P					C	C	P	P	
Sagittaria	9	9	3	Sagittaria spp. (e.g., latifolia, graminea)	Arrowhead	P					C	C	C	P	
Typha	3	3	0	Typha spp. (e.g., latifolia)	Cattail	P					C	C	C	P	
Key to herbicide effectiveness: C = high level of control with typical application rate. P = partial control or greater with mulitple applications and/or higher dose. Blank entry indicates herbicide not generally effective for corresponding spesces at typical application rates and exposure times. Dose, duration of exposure, formulation and timing of application are all key factors in treatment, causing variation in results.															
Additional Notes: 1) Copper and peroxide, algaecides not typically used for vascular plant control, are covered separately under removal of algae in the corresponding section of this guide. 2) Designations based on herbicide label information and review by 3 applicators with extensive experience in MA. 3) Some herbicides can be mixed or applied sequentially and copper is often used to minimize attached algae on plants and maximize the impact of other herbicides. 4) Most herbicides contain additional compounds, some intended to increase effectiveness; knowledge of additonal ingredients can be helpful in selecting an herbicide. 5) Only the EC formulation of florpyrauxifen-benzyl is registered in MA and is used only for Myriophyllum control as of 2023. 6) Native species are those identified in the The Vascular Plants of Massachusetts: A County Checklist; common names are not standardized and will vary between sources.															

8256

Herbicides

There were no documented instances of direct toxicity from herbicide treatments, consistent with proper use in accordance with herbicide labels which limit allowable dose in consideration of non-target impacts. A few cases of fishkills relating to lowered oxygen from mass die-off of treated vegetation were recorded, all related to contact herbicides (mainly diquat in MA) used on dense plant assemblages. Current treatment protocols have been improved to minimize such risk.

There does remain concern over possible toxicity, especially sub-lethal effects, for fish and wildlife exposed to herbicides at sensitive points in their life cycle. Not all life stages of all species have been studied and detailed monitoring of potentially affected populations is not routine in MA. The impact on organisms with smaller body size (e.g., young birds, fish fry), high preening rates (e.g., muskrat, waterfowl), or high rates of transfer across membranes (e.g., gills for certain aquatic invertebrates) could be more severe than for other organisms and may go undetected. The risk from repeated treatments (i.e., annual or more often) would seem higher than for less frequent herbicide applications. The label dictates maximum rates of application for each herbicide, but caution should be exercised where sensitive life forms might be threatened by a planned treatment.

Where toxicity is not documented, the primary issue for herbicide treatments is change in habitat. There are aquatic and water-dependent organisms that are favored or disadvantaged by any mix of plant species at any given level, so any change in the assemblage from an herbicide treatment will benefit some species and not others. The 8th interest of the WPA was added several years after the initial act was passed and focuses on fish and wildlife habitat. The scientific difficulty of documenting no loss of habitat for any species creates complications, but overall habitat value for the complete suite of species present or appropriate to the water resource can be improved with well-planned herbicide use. The WPA regulations allow for maintenance of boating lanes and management of plants in swimming areas. Where a change in the plant community of most or all of a lake is intended with herbicide use, more evaluation of habitat shifts may be required. It has been the policy of MassDEP that invasive species do not constitute “habitat” for fish and wildlife, but significant change of native plant assemblages must be viewed in terms of habitat alteration.

Time of year of the application is an important consideration for efficacy of treatment for target species and impacts on non-target species. For example, glyphosate is used on emergent and floating leaved plants and will be more effective later in the season when plants are translocating food to the root system. Imazapyr, used on the same species, can be effective over a greater time range within the growing season but has greater non-target species impacts. As another example, fluridone is very effective on invasive Eurasian watermilfoil but requires a long contact time (60-90 days) which may be difficult to achieve near an inlet or in a lake with high flow through and short water detention time at the time of intended application (usually spring). Florpyrauxifen-benzyl (ProcettaCOR) also controls Eurasian watermilfoil and requires only a few days of contact time to be effective, which may limit the impact of flushing and dilution yet minimize impacts to other non-target species. The timing of treatment can matter to certain non-target organisms, such as species of pondweed that begin growth later or die back sooner than many invasive plant species.

Herbicides

8295 or fish that spawn in a narrow time window in spring. Consultation with a licensed applicator,
8296 Certified Lake Manager, and/or MassWildlife can be beneficial in evaluating options.

8297 Control of submergent vegetation vs. nearshore emergent plants requires different approaches and
8298 poses different risks of impact. Submergent species are generally treated by herbicides added to
8299 the water while emergent species are most often treated with herbicides sprayed directly onto plant
8300 surfaces above the water. Different fish and invertebrates, or at least different life stages of each,
8301 tend to utilize submergent species vs. emergent species, so exposure and risk of impacts varies.
8302 More herbicide enters the water with submergent treatments and more herbicide may wind up on
8303 non-target terrestrial vegetation with emergent plant treatment. Most submergent treatments are
8304 done in spring or early summer, while most emergent treatments are performed in late summer.
8305 Treatment of floating leaved vegetation tends to be intermediate to approaches used for
8306 submergent and emergent vegetation, with a wider range of herbicides available. Consideration of
8307 differences in timing and location of treatments for different growth forms of vegetation is
8308 therefore warranted in planning and permitting.

8309 Aquatic plant control can have impacts on water quality, at least in the short-term, but there is no
8310 strong evidence that it leads to long-term impacts to lake water quality. Any impact on biochemical
8311 reactions including oxygen demand, P cycling, and algae bloom formation will be a function of
8312 scale. With a large-scale plant control treatment affecting plant growth over most of a shallow
8313 lake, water quality impacts are more possible. The pH might be lowered by reduced
8314 photosynthesis, P may be temporarily more available, and any control of benthic algae growth
8315 from shading will be reduced.

8316 Oxygen levels are of primary concern in most waterbodies, and the effect of herbicide treatments
8317 can be variable. Lamb et al (2021) found that treatment of a cove infested with dense growths of
8318 little floating heart with ProcellaCOR resulted in major reduction of the target plant species but
8319 also caused a short-term increase in biological oxygen demand and decrease in dissolved oxygen
8320 between 3 and 10 days after treatment, yet oxygen exceeded pre-treatment levels within 42 days
8321 after treatment. A study by Miskella et al (2021) found that treatment of water hyacinth with 2,4-
8322 D or glyphosate did not cause any significant decrease in oxygen, the removal of floating canopy
8323 cover having apparently increased oxygen transfer and offset decomposition of treated vegetation.
8324 Any oxygen impacts are likely to be transient, but if a large portion of a lake with a dense plant
8325 assemblage is treated for overall reduction in plant biomass, the risk of oxygen depression
8326 increases. Treatment planning should minimize the potential to contravene water quality standards
8327 and monitoring should track conditions until post-treatment oxygen stabilizes.

8328 Loss of shading or antagonistic chemical (allelopathic) restriction of algae by plants may foster
8329 greater algae growth, especially by filamentous, mat-forming algae, but sometimes by planktonic
8330 forms. This may lead to significant shifts of primary production from bottom vegetation to
8331 phytoplankton in the water column. This flipping between ecological dominance by vascular plants
8332 and that by algae has been described as alternative stable states and the influence of climate change

Herbicides

has also been implicated (Scheffer and van Nes 2007, Gobler 2020). Yet such shifts are not likely in a lake where the plant growth zone does not cover most of the lake; it is a shallow lake phenomenon. Further, unless plant control targets the whole plant community, the degree of change in plant cover and biomass will be much less than that required to induce major changes in water quality and biological features. Targeted plant control in lakes deep enough to stratify is very unlikely to result in any measurable water quality change, but this remains something to consider in shallow lakes where the plant community occupies most of the lake bottom or where inputs of nutrients from the watershed are high.

Herbicides, like nearly all other plant control options, are unlikely to provide complete control of the target species from a single application. This is akin to taking medicine for some serious ailment – one dose is unlikely to work. Plant control is better viewed as a maintenance activity, hopefully with a decreasing frequency of treatments, but one still likely to be needed from time to time. Many effective plant control programs involve more than one technique in an adaptive manner as the plant community and control needs change.

Permits under the WPA typically last for 3-5 years and can usually be extended at least once, but there should be recognition that plant control may be an ongoing process. Permit applications should include a treatment plan matching the life of the permit, with the option for annual update or revision. The exact combination of herbicides and other techniques to manage a lake will vary with target species, non-target species, target area, lake features, regulatory constraints, and affordability, and can be unique for each lake. There is no “one size fits all solution” and applicants and conservation commissions should work to craft the most appropriate plan. Just because the lake in the next town did “X” and seems to have acceptable results does not mean that “X” is right for the lake in your town, although it certainly bears scrutiny.

There is some potential for aquatic plants to develop resistance to specific herbicides. [Resistance](#) arises from the process of genetic selection for plants with some means to reduce herbicide impact and should not be confused with plant tolerance, which is the existence of traits throughout the population that limit herbicide impact. Resistance was developed by hydrilla to fluridone and a species of duckweed to diquat in Florida where the same area had been treated with the same herbicide every year for many years (Koschnick et al. 2006). Resistance has not been documented to have developed elsewhere to date. Where treatment involves mainly spot applications at locations that change each year and represents a small portion of the plant growth area, development of resistance has not been a significant threat. Additionally, resistance is less likely for herbicides that attack cell membranes and multiple physiological processes as opposed to those that tend to impact one specific process like synthesis of a key enzyme or pigment (Gettys et al. 2020). Yet as the potential for resistance to develop does exist, the simplest advice is not to treat the same area annually with herbicides with the same mode of action for an extended period of years.

8370 ***Regulation of herbicides***

8371 Every registered herbicide has an EPA-approved label, which is more than an identifying sticker
8372 with some instructions for use. Labels are legal and regulatory documents that can be downloaded
8373 from the manufacturer and dictate where, how, and when the specific product can be used, likely
8374 target organisms, appropriate concentrations, and any use restrictions. Herbicides must be
8375 registered for use in MA by the MDAR and may have supplemental labels or other restrictions for
8376 use in MA. Registration signifies that the MDAR finds that the potential benefits of proper use of
8377 the product outweigh possible detriments but does not mean that there can be no negative side
8378 effects.

8379 Aquatic herbicides undergo an additional special review conducted jointly by MDAR and
8380 MassDEP's Office of Research and Standards (MassDEP-ORS). This special review may identify
8381 additional measures that are needed to ensure proper protection of Massachusetts-specific
8382 situations with regard to the use of the product. Upon completion of the joint MDAR/MassDEP-
8383 ORS review, it will be noticed in the MEPA Environmental Monitor. The active ingredient and
8384 product reviews will be included with the MDAR online resource for aquatic herbicides and the
8385 herbicide product will be available for licensed use in lakes and ponds in MA.

8386 Herbicide application in MA is regulated through two permit processes, an Order of Conditions
8387 issued by a conservation commission under the WPA and a License to Apply Chemicals issued by
8388 the MassDEP. If state listed species are present under the MESA, approval from the NHESP is
8389 needed before the conservation commission can act on the Order of Conditions. Application of
8390 herbicides in MA is allowed only by licensed applicators under a project-specific [License to](#)
8391 [Apply Chemicals](#) and must comply with all federal and state label and use restrictions.

8392 ***Herbicide resources***

8393 Reviews of herbicides and their use include Cooke et al. 2005, a book on lake management, and
8394 Gettys et al. 2020, a book on aquatic plants. Cooke et al. 2005 was published not that long after
8395 the GEIR and does not include additional herbicides, but it does summarize control experience and
8396 possible impacts of treatment as understood at the time. [Gettys et al. 2020](#) is the 4th edition of this
8397 aquatic plant control handbook with specific management recommendations for selected invasive
8398 species and a chapter on common concerns expressed about herbicide use with plain language
8399 explanation of risks and related considerations. This publication supports an important point of the
8400 GEIR and the MDAR registration process that the basis for herbicide use is that the herbicide does
8401 not present an unreasonable risk of adverse impacts to human health or the environment when used
8402 in accordance with its label restrictions. That does not mean that there are no risks, only that they
8403 can be minimized while gaining valued control over target plant growths.

8404 Those considering herbicide use should become aware of all possible benefits, known limitations
8405 and constraints, and possible negative impacts, and should carefully evaluate the applicability and
8406 efficacy for the target lake and plant species. Beyond what is included in this guide, the MDAR

Herbicides

8407 maintains online resources relating to each approved active ingredient that are cited in the
8408 following descriptions of those active ingredients. Prospective applicants should consider
8409 consultation with MassWildlife, a Certified Lake Manager, and/or a competent herbicide
8410 applicator when considering options.

8411 As the composition of the plant assemblage is very important to developing a herbicide application
8412 plan and evaluating results, it is critical that plants and in the treatment area are correctly identified.
8413 Aquatic plants can be difficult to identify, although most of the invasive and native nuisance
8414 varieties can be learned. Identification and classification resources include:

- 8415 • [A Guide to Aquatic Plants in Massachusetts](#) - useful general identification reference focused
8416 on MA aquatic plants.
- 8417 • Aquatic Plants of MA by Donald J. Padgett, published in 2021 by Spatterdock Press, ISBN
8418 0578845075 - a more technical taxonomic reference for aquatic plants.
- 8419 • [Aquatic Plants of the Northeast](#) by Emma Kelly and Lindsay Charlop, made available online
8420 in 2023 - developed in collaboration with Chris Doyle and Emily Mayer for the Hudson River
8421 Aquatic Invasive Species Task Force, it provides detailed photos of invasive and native aquatic
8422 plant species.
- 8423 • Flora of the Northeast by Dennis McGee and Harry Ahles, published in 2007 by University of
8424 MA Press, ISBN-13:9781558491892 - technical reference for shoreline and upland species.
- 8425 • Flora Novae Angliae: A Manual for the Identification of Native and Naturalized Higher
8426 Vascular Plants of New England by Arthur Haines, published in 2011, Yale University Press,
8427 ISBN9780300171549, 1008 pages – especially useful for shoreline plants.
- 8428 • [The Vascular Plants of Massachusetts: A County Checklist First Revision](#) by M. Dow
8429 Cullina, B. Connolly, B. Sorrie, and P. Somers, published in 2011 and available from the State
8430 Library of MA - the standard reference for species status as native vs. non-native species in
8431 MA.

8432 Hiring a competent botanist to perform a survey of a lake or target area for herbicide application
8433 may greatly support plan development and the permit process.

8434 **Active herbicide ingredients registered for use in MA**

8435 Some background on active herbicidal ingredients registered for use in MA follows, in alphabetical
8436 order. Readers are encouraged to get more details and possible updates from the MDAR website.
8437 Links to current MDAR/MassDEP-ORS reviews are provided in association with each active
8438 ingredient.

8439 ***2,4-D (2,4-Dichlorophenoxyacetic Acid)***

8440 2,4-D was satisfactorily covered in the GEIR and works to
8441 inhibit cell division in new tissue and stimulates growth in
8442 older tissue resulting in cell disruption. It can have some
8443 selectivity based on the application timing and concentration.
8444 Prohibition of use in water supplies and lakes with substantial
8445 groundwater connection is worth noting. 2,4-D cannot be
8446 applied to lakes where there is a clear groundwater connection
8447 to drinking water supply wells, either public or private. For
8448 areas with porous sandy soils such as Cape Cod a groundwater
8449 connection is logically presumed, while for areas with
8450 minimally permeable glacial or clay soils such as the Berkshires it is very unlikely that 2,4-D will
8451 seep out of the lake into groundwater. However, actually documenting a connection or lack thereof
8452 between lakes and water supply wells can be technically challenging. Accordingly, regulatory
8453 bodies may disallow treatment with 2,4-D if any wells are near the lake rather than seek an
8454 investigation of connectivity.

2,4-D is a systemic herbicide; it is translocated throughout the plant and kills all parts except seeds, turions, and certain winter buds. 2,4-D is very effective against submergent species not otherwise easily controlled but cannot be applied in drinking water or lakes with high groundwater connectivity and nearby wells.

8455 The MDAR and MassDEP-ORS produced a [review of 2,4-D](#) that was incorporated into Appendix
8456 III of the GEIR.

8457 ***Diquat dibromide***

8458 Diquat was satisfactorily covered in the GEIR and its use remains
8459 much as it has for the last two decades. It works as a desiccant and
8460 defoliant against broadleaf and grassy species and is non-selective.
8461 However, one potentially important observation is that diquat has
8462 been able to control certain perennial plants like Eurasian
8463 watermilfoil without direct contact with the root crowns. It was
8464 assumed that recovery of milfoil would occur after application of
8465 contact herbicides like diquat, but diquat appears to have some
8466 systemic properties. Successful control beyond a year or two has
8467 been achieved in multiple MA lakes. Use of diquat as a follow up
8468 to a lakewide treatment with another herbicide such as fluridone
8469 appears to be a highly applicable strategy.

Diquat acts mostly by contact, is relatively non-selective, and will leave many root systems that may generate regrowth. It is often used for spot treatment of limited areas, especially as a follow-up to more selective lakewide treatment with another herbicide, but is also used where other herbicides are less effective.

8470 The MDAR and MassDEP-ORS produced a [review of diquat](#) that
8471 was incorporated into Appendix III of the GEIR.

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8474 ***Endothall***

Herbicides

Endothall was satisfactorily covered in the GEIR and its use has not changed substantially since the GEIR was prepared. Endothall is a largely contact herbicide that limits use of oxygen in plant tissues by disrupting cell membranes and limiting photosynthesis. Endothall can be used for rapid control of hydrilla where pioneer infestations are discovered and can depress native plant assemblages for safety purposes in swim areas. Endothall appears to have some systemic properties despite generally being considered a contact herbicide. Endothall is less frequently used in MA than diquat as a result of greater use restrictions but is a suitable alternative for many target plants. There is a 14-day restriction after application for using treated water for irrigation or stock watering and 3-day post-treatment restriction on fish consumption from treated waters. There is a recommended swimming restriction post-application, and it is not approved for use in drinking water supplies.

Endothall acts mostly by contact, is relatively non-selective, although dose and timing may limit impacts to non-target vegetation in some cases. Endothall is used for spot treatment of limited areas but is used less than diquat in MA.

The MDAR and MassDEP-ORS produced a [review of endothall](#) that was incorporated into Appendix III of the GEIR.

Flumioxazin

Flumioxazin was developed after the 2004 GEIR. Flumioxazin, the common name for N-(7-fluoro-3,4-dihydro-3-oxo-4-prop-2-ynyl-2H-1,4benzoxazin-6-yl)-cyclohex-1-ene-1,2-dicarboxamide, was registered by MDAR for use in MA in 2013. It is a contact herbicide, impacting mainly parts of plants exposed to it. Flumioxazin controls plant growth by blocking biosynthesis in several metabolic pathways, resulting in the accumulation of phototoxic porphyrins in plant tissues. Cell membranes are damaged, and the physical structure of the plant is disrupted. It acts on a wide range of aquatic plants and can be more effective against filamentous green algae than most other registered compounds.

Flumioxazin is minimally selective and is primarily used for spot treatment where vegetation is to be minimized. It is more effective on filamentous algae growths than other herbicides/algacides.

The MDAR and MassDEP-ORS produced a [review of flumioxazin](#) during the registration process.

Fluridone

Fluridone was previously covered in the GEIR, but there have been changes in its use and experience with fluridone that merit updating. Fluridone is a systemic herbicide that interferes with the plant's ability to photosynthesize. The vast majority of fluridone treatments over the last two decades have applied concentrations near the lower end of the labelled rate, often <10 ppb (termed low-dose treatment). A newer pelletized formulation with reliable slow release of fluridone has also provided control in more rapidly flushed areas or in smaller targeted areas, especially for

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8511 Eurasian watermilfoil. As noted in an as yet unpublished study,
8512 Wagner and colleagues evaluated data from over 100 low-dose
8513 treatments for impacts to non-target plant species. In general, native
8514 assemblages recover in no more than 2 years to a single treatment
8515 with fluridone, matching the allowable time for recovery under the
8516 WPA regulations. Data from that study are included in the unofficial
8517 herbicide supplement to the GEIR prepared by Wagner (2020b).

8518 Response of aquatic species richness (the number of species
8519 present.) to low dose fluridone tends to vary with the number of
8520 native species present at the time of treatment. Where invasive
8521 species have depressed native species richness, increases are
8522 observed, while where native species richness is high prior to
8523 treatment there is a slight depression of richness for up to five years
8524 following treatment. In terms of overall native plant assemblages,
8525 low dose fluridone treatments have minimal lasting effect while
8526 depressing target species such as Eurasian watermilfoil, fanwort,
8527 hydrilla, and curlyleaf pondweed.

8528 The MDAR and MassDEP-ORS produced a [review of fluridone](#)
8529 that was incorporated into Appendix III of the GEIR.

8530 *Florpyrauxifen-benzyl*

8531 Florpyrauxifen-benzyl was developed after the 2004 GEIR.
8532 Florpyrauxifen-benzyl, more technically 2-pyridinecarboxylic acid,
8533 4-amino-3chloro-6-(4-chloro-2-fluoro-3-methoxy-phenyl)-5-
8534 fluoro-, phenyl methyl ester, is an arylpicolinate systemic herbicide
8535 intended for use for foliar application to emergent aquatic vegetation
8536 or direct application to water to control submergent vegetation. As a
8537 synthetic auxin it produces effects on the plant including alterations
8538 in cell wall elasticity and gene expression, and non-productive tissue
8539 growth that results in leaf curl and disruption of the plant phloem,
8540 interfering with transport of nutrients and causing death in days to
8541 weeks. Target species include invasive hydrilla, all invasive
8542 watermilfoils, and floating heart. It is marketed under the tradename ProcellaCOR. It was
8543 registered by MDAR for use in MA in 2019, so there is a limited track record for this herbicide,
8544 but it requires only a few days of contact time, making it valuable for more complete control of
8545 aquatic plants in areas with shorter detention time.

8546 The MDAR and MassDEP-ORS produced a [review of florpyrauxifen-benzyl](#) during the
8547 registration process.

Fluridone is a systemic herbicide; it is translocated throughout the plant and kills all parts except seeds, turions, and certain winter buds. It is used at relatively low doses (routinely <20 ppb) and can be used selectively through adjustment of dose, application timing, and duration of exposure. Fluridone is very diffusive and requires extended contact time (>60 days) for best results. Booster treatments or slow release pellets can be applied if the target area flushes too often.

Florpyrauxifen-benzyl is the newest aquatic herbicide approved for use in MA. It is a systemic herbicide and has been very effective against invasive species of watermilfoil with very limited impacts on many native species. It requires a relatively short contact time at a relatively low dose.

8548 ***Glyphosate***

8549 Glyphosate was satisfactorily covered in the GEIR and works by
8550 disrupting enzyme formation, although the exact mechanism
8551 remains unknown. Glyphosate is fast acting and can be somewhat
8552 selective based on method of application (e.g. direct foliar
8553 application). Formulations used in aquatic plant control should not
8554 be equated to terrestrial formulations. The dose, additives,
8555 frequency of application, target area and risk to people are very
8556 different from agricultural use. Application by licensed
8557 professionals cannot be equated to home use. As of publication of
8558 this guide, some towns have banned the use of glyphosate-based
8559 herbicides without distinction between aquatic and terrestrial uses
8560 under local bylaws. It remains to be seen if such actions can
8561 withstand state-level policy for registered herbicides. Applicants
8562 need to be aware of any local regulations when planning plant
8563 control with glyphosate and municipal authorities are encouraged
8564 to consult guidance provided by MassDEP and DPH.

Glyphosate is a common terrestrial herbicide that is also used on emergent and floating leaved aquatic plants but not submergent forms. This herbicide is translocated throughout susceptible species and can kill the whole plant. Uptake is dependent on features of the exposed plant surface and exposure time. It is washed off by rain but requires only a brief contact time.

8565 The MDAR and MassDEP-ORS produced a [review of glyphosate](#) that was incorporated into
8566 Appendix III of the GEIR. In light of recent controversy over possible carcinogenicity of
8567 glyphosate, the MDAR further reviewed available information and in 2022 posted an [updated](#)
8568 [glyphosate fact sheet](#), that includes recent assessments by USEPA that support the conclusion
8569 that there is no evidence that glyphosate causes cancer in humans.

8570 ***Imazamox***

8571 Imazamox was developed after the 2004 GEIR and more recently
8572 registered by the MDAR for use in MA. Imazamox is the common
8573 name for (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-
8574 1Himidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid
8575 and is a systemic herbicide. Imazamox is a member of the
8576 imidazolinone class of herbicides that also includes imazapic,
8577 imazapyr, imazethapyr, imazamethabenz, and imazaquin. It can be
8578 used for control of emergent, floating leaved and submergent aquatic plants. The mode of action
8579 is much like that of the closely related imazapyr, but imazamox is formulated for activity below
8580 the water surface. It is marketed under the tradename Clearcast. Clearcast has proven less effective
8581 overall on many submergent species than other systemic herbicides but is a broad-spectrum
8582 herbicide, impacting a wider range of species than most other systemic herbicides. It has received
8583 only modest use in MA to date.

Imazamox is a broad-spectrum herbicide that is primarily used to provide the mode of action of imazapyr when targeting submergent vegetation. It is approved for use in MA but not commonly used

8584 The MDAR and MassDEP-ORS produced a [review of imazamox](#) during the registration process.

8585

8586 ***Imazapyr***

8587 Imazapyr was developed after the 2004 GEIR. It comes as a salt (2-Propanamine, 2-(4,5-dihydro-
8588 4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylate[Imazapyr) or an acid
8589 (2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-nicotinic acid). Imazapyr is an imidazolinone
8590 herbicide that can control a wide range of emergent and floating leaved aquatic plants but is not
8591 effective against submerged aquatic vegetation. It is the primary
8592 alternative to glyphosate for control of Phragmites and floating
8593 leaved plants like waterlilies. The aquatic formulation is sold under
8594 the tradename Habitat and was registered for use in MA by MDAR
8595 in 2012. Uptake of systemic imidazolinone herbicides is primarily
8596 through the foliage and roots. The herbicide is then translocated to
8597 buds or areas of growth where it inhibits acetohydroxyacid or
8598 acetolactate synthase (ALS), an enzyme involved in the synthesis
8599 of essential amino acids required for protein synthesis and cell growth. Imazapyr disrupts protein
8600 synthesis and interferes with cell growth and DNA synthesis, causing the plant to slowly die. ALS
8601 is not present in mammals, birds, fish, or insects, making imazapyr specifically toxic to plants.

Imazapyr represents a substitute for glyphosate. It is effective on most emergent and floating leaved species and can be used effectively over a longer period of the growing season but tends to have more non-target impacts.

8602 The MDAR and MassDEP-ORS produced a [review of imazapyr](#) during the registration process.

8603 ***Triclopyr***

8604 Triclopyr received federal registration for aquatic habitats at the end of 2002 and became accepted
8605 for use in MA in 2004. It was addressed in the GEIR in light of impending registration in MA but
8606 there was minimal experience with use at that time. The trade name for the aquatic formulation is
8607 Renovate, with 3 pounds of triclopyr per gallon (about 35% triclopyr). Triclopyr is a systemic
8608 herbicide that prevents synthesis of plant-specific enzymes, resulting in disruption of growth
8609 processes. It was expected to provide selective control of Eurasian watermilfoil and other non-
8610 native dicotyledenous species with no anticipated impacts on aquatic animals at concentrations up
8611 to 0.5 mg/L. The MDAR and MassDEP-ORS [review of triclopyr](#) is informative.

8612 Over the last 15 years triclopyr has proven less effective against
8613 Eurasian watermilfoil than fluridone where adequate exposure time
8614 can be maintained, and the newer florypyrauxifen-benzyl appears to
8615 offer better results where exposure time is limited. Yet triclopyr can
8616 control Eurasian watermilfoil and has provided greater control of
8617 the related variable watermilfoil and parrotfeather than fluridone. It
8618 has also provided control of a number of other invasive species including common reed, purple
8619 loosestrife and water chestnut and certain nuisance native species such as water lilies, watershield,
8620 floating heart, lotus and water smartweed.

The greatest value of triclopyr appears to be for spot treatment of invasive milfoil species after lake-wide treatment with other herbicides such as fluridone.

Herbicides

8621 **Possible Benefits**

- 8622 ♦ Can minimize invasive species abundance
- 8623 ♦ Can reduce nuisance growths of native species to facilitate water-dependent human uses and
- 8624 enhance open water habitat

8625 **Possible Detriments**

- 8626 ♦ May harm some non-target species; some non-target impacts can be minimized by proper
- 8627 planning, but some cannot be avoided
- 8628 ♦ Rarely provides extended control of annual species that propagate by seeds, turions, or winter
- 8629 buds
- 8630 ♦ Complete elimination of target species is rare; long-term control requires a multi-year program,
- 8631 usually with multiple control methods applied

8632 **Information for Proper Application**

- 8633 ♦ Correctly identified plant species in the target area, allowing determination of herbicide and
- 8634 dose to be used and planning to minimize non-target impacts
- 8635 ♦ General plant mapping and knowledge of any ecologically sensitive areas, especially where
- 8636 protected species are involved
- 8637 ♦ For large or repeated efforts, more detailed vegetation mapping with estimates of cover or
- 8638 biomass that aid planning and tracking of results
- 8639 ♦ Acreage and volume of the area(s) to be treated to allow calculation of product needed to
- 8640 deliver appropriate dose
- 8641 ♦ Water body uses to facilitate determination of any use restrictions during and after treatment
- 8642 ♦ Consideration of all user groups and any conflicts with intended vegetation control

8643 **Factors Favoring or Disfavoring the Use of this Technique**

- 8644 ♦ Favored where undesirable plant species dominate, especially invasive species
- 8645 ♦ Favored where overall density of macrophytes is excessive throughout the littoral zone
- 8646 ♦ Disfavored where susceptible, state-listed plant species or other sensitive receptors are present
- 8647 ♦ Disfavored where existing vegetation is desired for fish and wildlife habitat

8648 **Performance Guidelines and Monitoring Needs**

- 8649 ♦ Map the distribution of the target species and any protected non-target species in the lake to
- 8650 facilitate assessment of results
- 8651 ♦ Track weather where dilution and flushing are factors in herbicide effectiveness
- 8652 ♦ Apply in accordance with all label instructions and restrictions
- 8653 ♦ Inspect and clean all equipment before entering or leaving the lake and target area
- 8654 ♦ Test for herbicide concentration periodically if intended exposure time is long enough to
- 8655 warrant booster treatment

Herbicides

- 8656 ♦ Compare pre- and post-treatment plant communities; level of detail and duration of monitoring
8657 period depends on size of target area, sensitivity of non-target resources, and plans for follow-
8658 up treatment or other controls, but monitoring should generally occur in the same time period
8659 of successive years for long-term programs at points on established transects or a grid for best
8660 comparison
- 8661 ♦ Monitoring for state-listed rare species, if required by MassWildlife-NHESP, may require
8662 different approaches than those for general vegetation or wildlife purposes, as these may not
8663 be adequately represented in transect or grid surveys and may be harder to identify;
8664 MassWildlife-NHESP can assist with method development
- 8665 ♦ Track oxygen levels if amount of vegetation expected to die within a two-week period could
8666 depress oxygen, often a concern during hot weather or drought where the target area is a large
8667 portion of the lake

8668 **Key Considerations for Conservation Commissions**

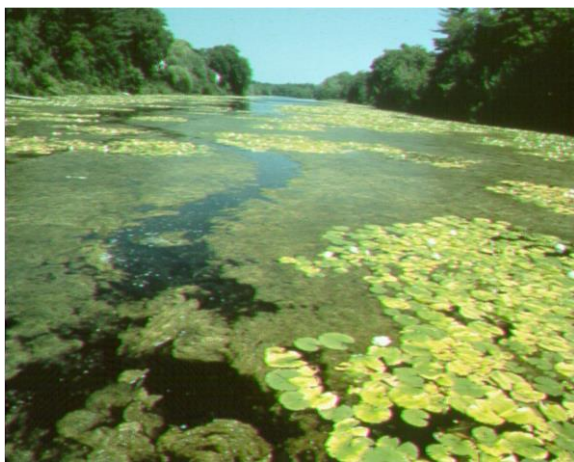
- 8669 ♦ Review by MassWildlife-NHESP is required if the project is located within Priority or
8670 Estimated habitat and must be complete before the conservation commission can close any
8671 hearing and issue an Order of Conditions under the WPA
- 8672 ♦ A License to Apply Chemicals under Sec 401, administered by the MassDEP, is required and
8673 is obtained after an Order of Conditions under the WPA has been issued by the conservation
8674 commission
- 8675 ♦ Flood control and storm damage prevention interests of the WPA should not be affected by
8676 herbicide use
- 8677 ♦ Impact on WPA interests of surface water and groundwater supply, pollution prevention, and
8678 land containing shellfish will depend on lake-specific circumstances, but should be minimal
8679 for an appropriate plan to apply an herbicide registered by MDAR and permitted by MassDEP
8680 for use in the target waterbody
- 8681 ♦ Impact on the WPA interests of fisheries and wildlife habitat will be highly dependent on lake-
8682 specific circumstances and should be evaluated in an appropriate Notice of Intent
- 8683 ♦ Modest reductions in the plant growth zone (the portion of the lake with sufficient light for
8684 plants to grow) of <10% of the area are very unlikely to have significant impacts unless the
8685 target area overlaps with the distribution or habitat of a state-listed species. Treating >10 % of
8686 the plant growth zone may have no measurable impact on the interests of the WPA, but a case-
8687 specific evaluation is recommended.
- 8688 ♦ Whole lake treatments may have minimal non-target impact when selective, but require more
8689 analysis than spot treatments to ascertain the likely level of impact
- 8690 ♦ If there is potential for a significant amount of herbicide to flow downstream of the lake,
8691 additional resource impact assessment may be needed

8692 **Massachusetts and Related Experience**

8693 More permits are issued each year by MassDEP under Section 401 for herbicide application than
8694 any other lake management technique. Over the last decade between 250 and 400 lakes in MA
8695 have been treated with herbicides each year. Since the GEIR was prepared there have been many
8696 treatments with monitoring programs that allow assessment of how well target plants were
8697 controlled and how much impact there was on non-target species, although detailed quantitative
8698 data are often lacking. In general, the desired conditions of fewer invasive species and overall
8699 lower aquatic vegetation density have been achieved, but rarely for more than a few years,
8700 necessitating re-treatment.

8701 Partial lake treatments to keep swimming facilities open or maintain boating lanes have been
8702 common and generally successful, but the mix of annual and perennial species in these shallow
8703 areas with hospitable sediment for growth almost guarantees that treatment will have to be repeated
8704 every year or every other year. Whole lake fluridone treatments have minimized targeted invasive
8705 plant growths (usually Eurasian watermilfoil, fanwort, or hydrilla) in multiple lakes (e.g., Goose
8706 Pond in Lee and Tyringham, Center Pond in Becket, Spectacle Pond in Littleton, Lost Lake in
8707 Groton, Lake Winnecunnet in Norton, Dudley Pond in Wayland, Neponset Reservoir in
8708 Foxborough, Long Pond in Centerville, Mystic Lake in Marstons Mills) for periods ranging from
8709 2 to 10 years. Follow-up treatment on a spot basis, usually involving diquat, has prolonged benefits
8710 in many cases. Supplemental hand pulling or application of benthic barriers has also extended
8711 treatment benefits.

8712



**Before fluridone application at Wares Cove,
Charles River; dense cover by fanwort, lilies
and filamentous algae**
(Courtesv of G. Smith)



**After fluridone application at Wares Cove,
Charles River: control of nuisance species
lasted three years**
(Courtesy of G. Smith)

8713

Herbicides

8714 Shallow lakes range from those that are naturally shallow to those that are a result of impounding
8715 rivers and wetlands. Manmade shallow lakes, usually part of development efforts prior to the
8716 passage of the WPA, often develop dense native plant communities that can cover most of the
8717 surface of these waterbodies and restrict the human uses that they were created to serve. As the
8718 WPA and its associated regulations do not discern between natural and manmade waterbodies,
8719 conservation commissions are obligated to apply the WPA to these shallow, generally heavily
8720 vegetated lakes. Treatment to open areas for swimming and boating can generally be allowed under
8721 the WPA, but wholesale destruction of the aquatic plant community should be avoided.

8722 Where dense plant assemblages accelerate eutrophication, native plant control can be justified, but
8723 habitat considerations may restrict how much control can be exercised. With a sufficiently targeted
8724 approach, whole lake treatments do not typically eliminate all vegetation and have provided a
8725 couple of years of relief from dense native plant assemblages (e.g., Sherwood Greens ponds in
8726 Becket, Watson Pond in Otis). This necessitates periodic re-treatment but is consistent with
8727 performance standards under the WPA that call for recovery of damaged vegetative communities
8728 in two growing seasons. Monitoring and documentation of this effect should be an ongoing
8729 requirement prior to issuance of further permits for treatment. Additionally, unintended
8730 consequences for native biota have been less studied and more monitoring may be needed in such
8731 cases.

8732 Based on monitoring in multiple states, papers have been published on the degree of control and
8733 impacts to non-target species (e.g., Wagner et al. 2007, Jones et al. 2012, Nault et al. 2017). A
8734 large database on low dose (<10 ppb) fluridone treatments was developed and the results were
8735 summarized in the unofficial herbicide supplement to the GEIR (Wagner 2020b); those data can
8736 be used to predict what plants are likely to increase or decrease as a result of such treatment.
8737 Variation can be expected as a function of site-specific conditions and treatment details such as
8738 timing of initial treatment and any follow up booster treatments, but such experience can aid
8739 project planning

8740 Additional academic research has provided guidance for maximizing effectiveness of herbicide
8741 treatments while minimizing non-target impacts. For example, Glomski et al. (2009) found that
8742 application of 2,4-D or triclopyr at 0.25 ppm controlled Eurasian watermilfoil without significant
8743 impact on bulrush or yellow water lily. Glomski and Netherland (2013) found that treatment with
8744 flumioxazin at up to 0.4 ppm damaged milfoil species, fanwort, hydrilla, coontail, curlyleaf
8745 pondweed, buttercup, and water stargrass, but not most pondweeds, naiads, or water celery.
8746 Netherland et al. (2016) determined that treatment with florasulam (ProcettaCOR) at 9
8747 ppb was enough to kill even hybrid milfoil species but had little effect on most pondweeds,
8748 waterweed, water stargrass, or water celery. Information like this can inform decisions on which
8749 herbicide(s) to use to maximize control of target species while minimizing impacts to non-target
8750 species. There are other factors beyond the herbicide that induce variation (e.g., weather pattern,

Herbicides

8751 herbivore presence, additional measures such as drawdown or benthic barrier use), but it is rare to
8752 observe widespread loss of species or extremely low vegetation density where not intended. Lake
8753 plant communities tend to be resilient.



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9. ALTERNATIVE TECHNIQUES

Alternative techniques as addressed in this guide are lake management methods that are not currently used in MA or are rarely used in comparison to techniques covered previously in this guide. There are three basic reasons why a technique might not be used regularly in MA:

- 1) The technique is prohibited in MA, either by an outright prohibition under existing laws and regulations (e.g., stocking non-indigenous herbivorous fish) or because it depends on a substance or device that has not yet been fully authorized under federal or MA approval procedures (e.g., Phoslock, barley straw, many bacterial products).
- 2) The technique has limitations on applicability or implementation potential in MA, as with dilution or flushing that requires substantial water that is not available in many cases, or with point source diversion or selective withdrawal, where impacts downstream of the discharge location may be unacceptable.
- 3) The technique has not been used enough to properly evaluate reliability, but with time could develop into an applicable and useful approach, such as with several algae collection systems or floating islands for nutrient removal.

Many alternative techniques fall into more than one of these categories, having narrow applicability, limited implementation potential, highly variable results that limit reliability, or not yet having been approved for use in MA. However, alternative techniques with such limitations could still be of potential use in specific circumstances if approved for use in MA. There is always some uncertainty with regard to the precise results of any lake management technique, but the range of likely outcomes should be clearly understood, and appropriate monitoring should allow adjustment to improve benefits and minimize adverse impacts. Mesocosms and/or lab testing followed by experimental application on a small scale may be possible where not expressly prohibited, and over time the technique may be further developed to the point of general acceptance.

However, applicants cannot expect most alternative techniques to be permitted without sufficient data to support their use. Alternative techniques are likely to be held to high standards of controlled environments for testing before controlled application and rigorous monitoring and reporting of results to minimize undesirable results and aid understanding for possible future applications. Some techniques will require specific testing for impacts on sensitive receptors, which could include state-listed species or minimally mobile organisms like freshwater mussels.

Here the alternative techniques are divided into groupings based on mode of action, including nutrient control, direct control of algae, and direct control of vascular plants, with a few techniques capable of controlling both algae and vascular plants.

8794 **Alternative Nutrient Controls**

8795 **Diversion of Point Sources**

8796 Diversion involves the re-routing of a discharge to reduce impacts to a sensitive waterbody or
8797 resource, likely discharging downstream of the original discharge location or in another drainage
8798 basin. This technique can be permitted in MA and has been used in the past, but there is very little
8799 applicability now and permitting would involve impact assessment that could be significant.

8800 Diverting water from a lake may make sense if the associated nutrient load is undesirable and the
8801 loss of the hydrologic load will not have undue negative impacts. Ideally, this involves the
8802 diversion of a relatively small volume of water conveying a large amount of nutrients. In most
8803 cases, this involves the diversion of a wastewater or stormwater discharge regulated under NPDES.
8804 Diversion from a lake to a river is logical, as the impact of elevated nutrients in flowing, turbulent
8805 water tends to be less than in waterbodies with extended detention times. However, diversion has
8806 the drawback of sending polluted water elsewhere without addressing the source of nutrients and
8807 it may be difficult to permit if treatment to improve discharge quality is not part of the project.
8808 Improved treatment is generally preferred over diversion, but diversion can be a very effective
8809 means of reducing nutrient inputs to a lake.

8810 Diversion was applied to remove wastewater discharges to lakes across the USA in the 1960s and
8811 1970s. Improvement was universal, although not always to the extent desired as a function of
8812 legacy P and ongoing internal loading. The [Lake Washington story](#) is a well-documented case of
8813 diversion results and follow up measures.

8814 In MA, elimination of an industrial discharge high in P to Neponset Reservoir in the mid-1980s
8815 allowed significant improvement of water quality over the next 30 years in conjunction with other
8816 measures. In the case of Quacumquasit Pond, which was impacted by wastewater from the Spencer
8817 treatment facility and runoff from a large watershed during storm-induced flow reversals from
8818 Quaboag Pond (Quacumquasit Pond flows into Quabog Pond under dry conditions), a flow control
8819 gate was installed in 1991 to prevent such backflow, an atypical form of diversion. The Leicester
8820 wastewater treatment facility discharge was rerouted to a point downstream of Dutton Pond in the
8821 early 2000s but was still required to upgrade treatment. Historically, discharges from smaller
8822 wastewater treatment facilities have been diverted to larger, more advanced, regional facilities
8823 which discharge to larger rivers, but the main future use of this technique is likely to be in
8824 association with stormwater inputs.

8825 There are currently few wastewater discharges upstream of lakes in MA. Simply diverting runoff
8826 delivered by pipes classified as point sources under NPDES regulations from a lake to a point
8827 downstream may cause unacceptable impacts, but diverting such runoff to treatment areas with
8828 discharge at a new location can be approved under current laws and regulations.

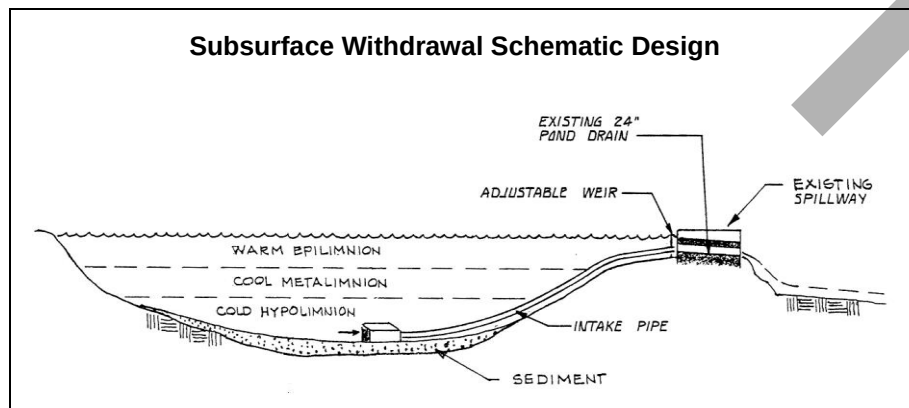
Selective Withdrawal

Background

For recreational lake management, the intent of selective withdrawal is usually to preferentially release the poorest quality water from the lake, which is typically the water at the bottom of the lake (i.e., hypolimnion) unless an intense surface bloom of algae is underway. Where P has accumulated in the hypolimnion through release from the sediments, selective discharge of hypolimnetic waters prior to fall turnover can effectively reduce the amount of P that reaches the upper waters. In some cases, a drawdown is conducted in the autumn after the water column has mixed but nutrient levels are still high, to pass more nutrient-rich water out of the lake, refilling with what could be water of better quality. Over time, the intent is to reduce the internal reserves of nutrients, passing them downstream. A reduction in nutrient concentrations may occur over an extended period of time if P is repeatedly moved from the sediment into the water column and then discharged from the lake. Where hypolimnetic water is discharged and the associated nutrients do not reach the epilimnion, a reduction in algal blooms may be observed in the same year, but major changes usually require many years, often several decades, of selective withdrawal.

If water can be withdrawn at a rate that prevents anoxia from developing near the sediment-water interface, both improved lake conditions and an acceptable discharge quality can be achieved. This can be more easily accomplished in an impoundment with a small hypolimnion and a large inflow. Withdrawal of more water than enters the lake will cause the lake level to decline, so the volume of selective withdrawal may be limited in quantity. This limits the level of benefit that can be attained in any year. In many cases, selective withdrawal will involve water of poor quality and treatment may be necessary before downstream discharge, most often some form of passive oxygenation induced by turbulent flow through a cascade or baffled raceway.

Often an outlet structure must be modified or fully retrofitted to facilitate selective withdrawal, but the one-time capital cost confers permanent control with minimal annual operation and maintenance costs. The most common arrangement is a pipe extending into deep water that exits the outlet below the normal lake surface. Hydraulic head pressure forces water out of the withdrawal pipe such that the discharge is passive (no pumping is required). Siphons have also



been employed but require priming to get the flow started, after which the existing head pressure induces ongoing discharge. Valves can be used to control outflow rate.

Performance and impact considerations

Planning for selective withdrawal to reduce nutrient concentrations in a lake requires a detailed water budget, including variability within and between years, and an accurate bathymetric map is needed to compute depth-specific volumes. Hydrology and physical features of the lake are intrinsically important to the assessment of the viability of withdrawal, rate of withdrawal, and implications of withdrawal for thermal stratification and quality of the discharge. While selective withdrawal can be used in any system, it is most often applied to more strongly stratified lakes.

It is important to determine possible effects on stratification, water level, and related habitat in the lake before attempting selective withdrawal. Downstream effects of any altered flow pattern and water quality are likely to be major determinants of acceptability in the permit process. Monitoring the quality of in-lake and outgoing water is essential to evaluation of results, with a focus on P, N, temperature, and oxygen. Turbidity and conductivity may act as suitable surrogate parameters with site-specific corroboration and are easy to measure in-situ.

Massachusetts and related experience

A well-documented case of selective withdrawal in MA is 314-acre Neponset Reservoir in Foxborough (Godfrey et al. 2003, ENSR 2008). A P-laden discharge from an industrial facility entered the lake for many years, ceasing in the mid-1980s. Internal loading of P through several summers after discharge cessation resulted in P concentrations in excess of 100 ppb by September or October in this unstratified lake and cyanobacteria blooms were common. Approximately half of the lake volume was discharged each autumn during a permitted drawdown, sending water high in P into the Neponset River that leads to Boston Harbor. Over a period of about 20 years the in-lake P concentration declined to an average of 25 ppb and cyanobacteria blooms were minimized. Green algal mats remained a problem and invasive rooted plants became dense, but P concentrations were reduced, and water clarity improved.

Similar results were obtained by fall drawdown of Sebasticook Lake in ME for over 40 years, combined with watershed management to limit P inputs (ME DEP 2022). Average concentrations of P declined from 78 ug/L during the 1980s to 25 ug/L between 2009 and 2018. Chlorophyll-a, indicative of algal abundance, decreased from 34 to 14 ug/L over the same time period. Yet P concentration has not declined to the point where cyanobacteria blooms are prevented, and further management planning is currently underway.

Cooke et al. (2005) discuss selective withdrawal and conclude that the technique is cost effective with potential to reduce P concentrations and increase hypolimnetic oxygen in target lakes, although multiple years of withdrawal have been needed to achieve significant results. As a general guideline for hypolimnetic withdrawal, the entire volume should be exchanged every 2 to 3 months

at a minimum. Avoidance of destratification and substantial water level decline is recommended, and downstream impacts of low oxygen and/or elevated nutrient levels may require mitigation.

Nurnberg (2007) reviewed long-term results from selective withdrawal projects in 48 lakes and found significant decreases in P and chlorophyll-a in the target lakes with a commensurate increase in water clarity. Only 15% of subject lakes achieved a P concentration <20 ppb, however. Hypolimnetic anoxia was reduced but not eliminated. Downstream impacts were the greatest concern and were alleviated by simple treatment in many cases, often increasing oxygen by passive baffles in the discharge location. Drawdown and destratification did not typically occur. As a relatively passive and low-cost technique, selective withdrawal was found to be an efficient means for reducing P load but did not completely meet water quality objectives in most cases.

Sosiak (2022) evaluated a 40-year water quality record with about 20 years of passive hypolimnetic withdrawal from Pine Lake in Alberta, Canada and puts the results in context with many other selective withdrawal projects. The system was operated to avoid significant water level fluctuations, limiting withdrawal volume, but achieved a 30% decrease in P concentration and a 40% decrease in chlorophyll-a, although cyanobacteria blooms still occurred. Hypolimnetic anoxia was reduced but not eliminated. Further improvement was projected for the coming decade, but additional watershed and in-lake work may be necessary to meet all water quality objectives.

Dilution

Lake waters that have low concentrations of an essential nutrient are less likely to exhibit nuisance algal blooms. While it is preferable to reduce total nutrient inputs to the lake, it is possible to lower (dilute) the concentration of nutrients within the lake by adding sufficient quantities of nutrient-deficient water from some additional source. This technique could potentially be permitted in MA, but applicability is very low and the only known current projects using this technique involve well water added to small private ponds.

When water low in P is added to a lake, the actual total P load will increase, but the mean P concentration in the water column will decrease. Dilution to reduce P to no higher than 20 ppb and preferably closer to 10 ppb should minimize algal blooms. Dilution may not prevent blooms that form at the sediment-water interface from nutrients derived from the sediment but will minimize the duration of those blooms as they will not be metabolically supported once the algae rise into the upper waters with lower nutrient concentrations.

Dilution has rarely been applied in MA, mainly as a consequence of inadequate supplies of low nutrient water. The amount of water with virtually no P in it needed to reduce the P concentration by 50% will be at least equal to the average natural inflow to the lake, and any extra inputs from internal loading or wildlife will increase the needed clean water volume. Reliable hydrologic and nutrient loading analyses are needed to evaluate the potential for dilution to make a difference in a waterbody. Any transfer of >100,000 gpd could be subject to permitting by MassDEP under the Water Management Act.

As public water supplies often add phosphates to finished water to meet anti-corrosion standards for distribution pipes, just opening a fire hydrant near a lake may actually increase P concentration. Use of groundwater with low P concentration has potential, but unless there is an artesian well the cost of pumping may be prohibitive. This technique has the greatest applicability for smaller ponds with naturally low inflows, as less clean water will be needed to improve its condition. Addition of well water to private ponds with minimal inflow during summer has accomplished dilution, although the main reason for the well water input has often been to maintain the water level in the pond. Transfer of water for the purpose of dilution may also be regulated under the MA Water Management Act if the quantity exceeds 100,000 gpd.



Water from public distribution systems is often high in P and not suitable for dilution projects

Dilution and flushing are covered in one chapter by Cooke et al. (2005), and the results of these related techniques are difficult to separate. Adding more water of lower nutrient concentrations will increase the flushing rate and adding enough water to decrease concentrations by half will necessitate at least a doubling of the flushing rate. However, flushing (see separate review) is only effective when residence time is reduced to a matter of a few weeks (the time necessary for algae blooms to develop), so dilution is believed to be responsible for most improvements when water of lower nutrient content is added at levels that do not result in rapid flushing.

Welch et al. (2020) summarized application of dilution to Moses Lake in WA over 42 years, finding the dilution effect more important than flushing but acknowledging the value of greater water input. P was reduced from >100 ppb to an average of 24 ppb over the most recent 18 years after a long period of experimentation with the quantity and timing of Columbia River water additions. Chlorophyll-a was reduced by 67% but cyanobacteria remained the dominant algae in Moses Lake. Internal loading was viewed as a major factor in cyanobacteria dominance, but an increase in N:P ratio due to Columbia River water addition was viewed as responsible for some favorable shifts in the algae assemblage.

Phoslock and Other Products for P Inactivation

Phoslock® is a proprietary product consisting of bentonite clay impregnated with lanthanum, a rare earth metal that preferentially binds dissolved phosphates. It represents an alternative to aluminum with some different properties. Use of Phoslock would presumably be permitted by the same process as aluminum (i.e., alum) application, but there has not yet been review and acceptance of this product by appropriate regulatory authorities in MA, so Phoslock currently cannot be applied in MA without some form of MEPA review.

Lanthanum and bentonite clay are not toxic to aquatic life, a possible although avoidable issue with aluminum. Phoslock is not a coagulant, so it will not bind particulate P or clear the water column as aluminum can. The coating of organic sediment by the clay may reduce oxygen demand

Alternative Nutrient Controls

to some degree but may also smother invertebrates. Phoslock is used primarily to prevent release of P from sediment although it will strip dissolved P from the water column. Its higher specificity for P translates into a lower ratio of lanthanum to P being needed than for aluminum to P, although the cost per unit of Phoslock is higher than for aluminum products, so no cost savings are likely. The general rule is to apply 100 lbs. of Phoslock for each pound of P to be inactivated.

European P inactivation projects have sometimes used both aluminum and Phoslock in sequence, a process called “floc and lock,” whereby aluminum strips particulates from the water and Phoslock enhances sequestration of sediment P (Lurling and van Oosterhout 2013). While Phoslock does not have as long a track record as aluminum, it has enjoyed substantial success in Australia, Europe, Canada, and to a more limited degree in the USA (Spears et al. 2016, Lurling et al. 2021).

There are other P-binding products also on the market and under development that may compete with aluminum additions to improve runoff or in-lake water quality. Phosflow® is related to Phoslock but is applied to inlets or discharges, enhancing the quality of urban and agricultural runoff. Products marketed under the name EutroSORB® contain multiple P-binders and are also intended to remove P from inflows. Solid formulations of EutroSORB can be added to filtering “socks” placed in channels and a liquid formulation can be applied to inflows. Products using calcium as a P-binder are also available. A new product called MetaFloc, from Natural Lake Biosciences, with unknown composition, is also being marketed for nutrient control. Other products can be expected as the market for inflow water quality enhancement expands.



Application of Phoslock as a slurry
(courtesy of SOLitude Lake Management)

Phoslock and the other products mentioned here have not yet been approved for use in MA by any overall MEPA process and so cannot be legally applied to MA lakes without individual project review through the MEPA. Some concerns have been expressed for Phoslock regarding possible impacts to benthic biota and bioaccumulation, but no problems have been documented in applications outside MA. Other products do not have enough of a track record anywhere to provide a reliable evaluation. MDAR has stated that as these products are not considered pesticides under its regulations, no review by MDAR is needed to allow application in MA. However, review under MEPA appears necessary, after which project-specific approval under the WPA and likely permitting by MassDEP under the WM04 (License to Apply Chemicals) would be needed. Phoslock from PET and other P-binding products like EutroSorb from SePRO could be useful tools for control of internal P loading in MA lakes based on experience elsewhere.

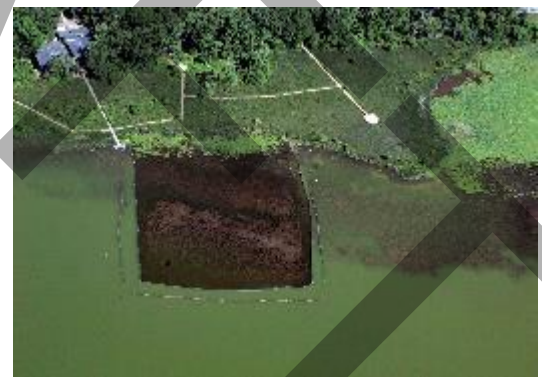
9004 **Removal of Bottom Feeding Fish**

9005 Bottom feeding fish like carp and catfish in shallow lakes can stir up sediment and uproot
9006 vegetation, possibly increasing nutrient availability and leading to water quality impairment.
9007 Removal of such fish can reduce the population and minimize impacts. The methods used to
9008 achieve such reductions are generally not permitted in MA, however, so this technique is unlikely
9009 to be used in MA.

9010 Fishing has generally not proven adequate to achieve control, necessitating alternative methods
9011 for reducing bottom feeding fish abundance such as fish poisons (piscicides such as rotenone or
9012 cyanide) or large commercial netting operations. Use of fish poisons is no longer allowable in MA
9013 and large harvesting operations by net are highly disruptive and not typically permitted in MA.
9014 Draining a lake almost completely will reduce but not eliminate bottom feeding fish (Barr-Milton
9015 Watershed Association 2017), which are remarkably tolerant of stressful conditions, and the
9016 collateral damage to other aquatic life makes such an approach unlikely to be permitted in MA.

9017 Where reductions have been achieved, it can be difficult to maintain control and this approach,
9018 despite clear benefits and some success stories, is not considered reliable. While keeping the
9019 population of bottom feeding fish low is generally desirable, reducing abundance by direct means
9020 is problematic and may not be successful for more than a year or two. Where bottom feeding fish
9021 are very abundant, consideration of their control may be worthwhile, but this is not a common
9022 problem in MA lakes.

9023 Carp removal in a shallow IA waterbody resulted in much greater clarity shortly after removal,
9024 whereas an adjacent control lake remained turbid (Schrage and Downing 2004). Settling of
9025 suspended solids was rapid after carp removal and
9026 large bodied zooplankton greatly depressed
9027 phytoplankton biomass for several months.
9028 However, P concentrations remained elevated and
9029 zooplankton were unable to maintain control over
9030 phytoplankton. Rooted plant diversity and
9031 abundance increased markedly after carp removal,
9032 but low light conditions returned with algae blooms
9033 and carp population resurgence. However,
9034 evaluation of the effects of commercial removal of
9035 bottom feeding common carp and bigmouth buffalo
9036 from multiple shallow IA lakes (Simonson et al.
9037 2023) revealed very few significant differences
9038 between harvested and unharvested lake conditions with harvests <81 lbs/ac.



Carp exclosure area showing much clearer water in Lake Wingra, WI
(photo by M. DeVries, courtesy of NALMS)

9039 After demonstrating benefits by keeping carp out of a sequestered area, carefully coordinated
9040 winter netting in Lake Wingra sufficiently reduced carp to improve water clarity, and abundant
9041 sunfish appear to have preyed on carp eggs, reducing recruitment in later years and extending the

benefits (Lathrop et al 2013). However, the increase in clarity allowed Eurasian watermilfoil to achieve nuisance levels in shallow water, so one problem was traded for another.

Floating Islands/Floating Wetlands/Hydroponics

Floating structures that support vegetative growth can remove nutrients from the water column, provide habitat for various invertebrate and vertebrate species, and provide physical protection for sensitive shorelines. They can be permitted in MA but are potentially subject to Chapter 91 Waterways regulations as well as permitting under the WPA.

Background

Growth of plants and related microbes can take up nutrients, leading to various attempts to lower nutrient concentrations in lakes with concentrated growths of plants over the last 40 years. The use of treatment wetlands, while not without problems and limitations, has been advanced and aids nutrient input control for lakes. Nutripods, which were porous bags of plants floated in lakes and removed to harvest accumulated nutrients, were pioneered in the 1980s but never gained widespread application. The latest iteration of this approach has been floating islands that depend on water column concentrations of nutrients to support plant and microbe growth, functionally a hydroponic system.

Plants with roots extending into the water will draw nutrients out of the water and sequester it in biomass, but a substantial portion of the nutrients can be released back into the water once they die and decay. So, the potential for nutrient removal exists, but would require removing the plants to achieve full benefits. The ability to lower nutrient concentrations substantially and consistently for a prolonged period has not been properly documented and the density of floating islands may be an issue for other aspects of lake ecology and use, including swimming and boating. The scale of application to make a difference in water quality appears greater than many recreational lake users may tolerate, and the process is not just a matter of creating the islands, but managing them, including at least annual removal and harvest.

Floating islands have been constructed from a wide variety of materials. They often have a plastic, mesh or filtration cloth that provides support for living growths. Some systems place plants directly into the mesh for growth while others are sculpted to have higher and lower areas to accommodate a range of plant types. These systems need to have a flotation system that will withstand wind and waves as well as possible exposure to boat wakes. Flotation systems vary among island designs and include marine foam, large diameter drainpipe or PVC pipe filled with empty water bottles, air-filled bladders, and large plastic containers. The floating islands require anchoring and may require



Floating islands in a stormwater pond
(courtesy of Floating Island International)

9079 perimeter fencing to exclude people and any unwanted wildlife but can provide desirable habitat
9080 for a range of invertebrate and vertebrate fauna.

9081 ***Nutrient removal by floating islands***

9082 Commercial websites note proprietary materials in their islands and mixes of plants to maximize
9083 uptake, with before and after photos that suggest great improvement, but few supporting data. Peer
9084 reviewed publications for recreational lake applications are rare, and variation in the support
9085 materials used and plants added creates variability that needs to be understood for best application.

9086 An online search of floating islands for nutrient removal will yield many examples with
9087 remarkably little data. Even the USEPA cites the value of floating islands with minimal
9088 documentation. In most cases, use of floating islands is part of a larger program to control nutrients
9089 in lakes and separation of the effects of various program elements is difficult, although such
9090 separation has been achieved in some wastewater and stormwater studies.

9091 The USEPA (2015b) describes a \$1.7 million project intended to reduce nutrients by 22% in 659-
9092 acre Harvey's Lake in PA. A 10% decrease was achieved; floating islands were just one part of
9093 the program. The Stormwater Management Academy at University of Central Florida (2012)
9094 reports on testing of floating islands in research ponds and recommends coverage of about 7% of
9095 the water surface and the need to remove islands for maintenance after 7 months. A report from
9096 Lund and Polifka (2020) did not find any significant improvement of water quality with floating
9097 islands covering 5% of the surface of a small waterbody with an 89-day detention time, while a
9098 report by Hunt et al. (2012) found N and P removal in the 40-50% range with 18% surface
9099 coverage, albeit with final concentrations still high enough to support algae blooms. Direct
9100 experience by Princeton Hydro (Lubnow, pers. corresp.) suggests about 10 lbs (4.5 kg) of P
9101 removal per 250 square foot island per year.

9102 A presentation by Masters (2015) with a full text version reviews the science behind floating
9103 islands and covers most available literature at that time. The importance of the biofilm formed on
9104 and around roots extending down from the floating island is covered and the role of the plants in
9105 enhancing that biofilm is noted. Use in wastewater lagoons results in up to 27% less P in the
9106 effluent than for the lagoon alone. Similarly, a review by Reinsel (2014) suggests about 50%
9107 removal of N but only about 6% removal of P in stormwater. Nitturkar and Bhosale (2019)
9108 achieved as much as 21% P removal and 36% N removal from a highly eutrophic small pond with
9109 thickly planted islands with selected vegetation in very shallow water but cautioned that increasing
9110 the density of islands could affect oxygen transfer from the atmosphere to the pond. Borne et al.
9111 (2015) review the potential for floating islands to improve water quality but emphasize the many
9112 considerations and general lack of design and maintenance guidance. Use in wastewater and
9113 stormwater applications with high nutrient levels and minimal human use appears less problematic
9114 than use in recreational lake scenarios.

9115 ***Habitat value of floating islands***

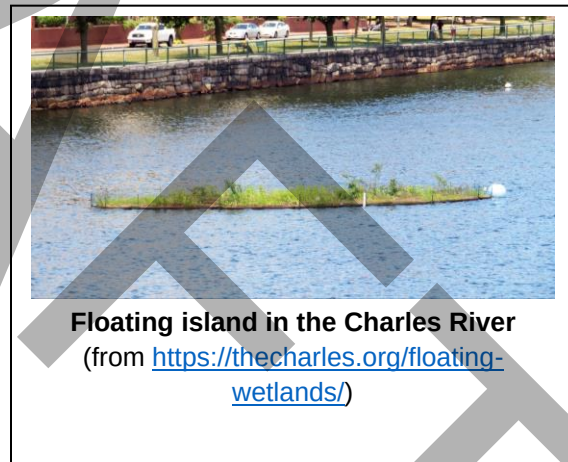
9116 There is clearly value in floating islands as habitat and some organizations have programs for that
9117 purpose, most notably in Chicago to enhance overall habitat and create a [kayak park on the](#)
9118 [Chicago River](#) and in Maine for [loon population enhancement](#). Many water-dependent birds,
9119 mammals and invertebrates will find such islands attractive, and this may not always be a benefit
9120 if unwanted species (e.g., excessive Canada geese) are attracted to the lake.

9121 The [Bio-Barge pilot project](#) was deployed in 2020 in the Port of Seattle, WA, to provide marsh
9122 habitat to replace the habitat lost due to bank development and hardening with goals to provide
9123 chinook salmon estuary habitat through reduced temperature, increased prey availability, and
9124 physical habitat complexity. No results have been reported yet, but each site must be assessed to
9125 determine if species-specific goals are met; both benefits and detriments are possible and require
9126 evaluation.

9127 Additionally, floating islands can be used to mitigate wake impacts to shorelines, a benefit
9128 independent of nutrient uptake and under exploration as part of the “[Emerald Tutu](#)”. A large
9129 series of small islands have been installed in an estuarine area in East Boston where the islands are
9130 primarily providing physical protection benefits for sensitive shoreline.

9131 ***Massachusetts experience***

9132 Aside from the Emerald Tutu for shoreline
9133 protection, the only known active floating island
9134 project in MA as of 2024 is a [pilot floating wetland](#)
9135 deployed in the Charles River north of the
9136 Longfellow Bridge in 2020. This project will be
9137 evaluating cyanobacteria response to the floating
9138 wetland as well as tracking zooplankton
9139 (consumers of algae) around the floating wetlands
9140 relative to control areas. The pilot system deployed
9141 in the Charles River was constructed of coir rolls
9142 lashed together and planted with 19 native plant
9143 species, creating about 700 square feet of wetland floating. The system is anchored with an 800 lb
9144 weight in about fifteen feet of water. Provision of refugia for zooplankton is expected to increase
9145 consumption of algae; direct nutrient removal is not a primary goal.



9146 ***Summary***

9147 The potential for nutrient uptake by engineered floating islands is clear, but there are no
9148 documented cases of nutrient reductions large enough to prevent algal blooms in the literature.
9149 Floating islands can create potentially valuable habitat and as a nutrient control technique they
9150 may be a valuable part of a more complete nutrient control program. However, floating islands
9151 cannot yet be considered reliable in terms of results, particularly as the sole nutrient control

9152 technique. Concerns have been expressed by MA environmental agencies regarding construction
9153 materials, anchoring, and choice of plants. Permitting is possible in MA, but it will be important
9154 to establish clear conditions for application that limit possible adverse impacts and to conduct
9155 monitoring that demonstrates results.

9156 **Sediment Oxidation**

9157 Treating sediment in place to oxidize and limit undesirable interactions with overlying water has
9158 the potential to limit internal nutrient loading but involves compounds that have not been approved
9159 for use in MA. No oxidation products are currently approved for aquatic use in MA, so this
9160 technique is not currently approvable without a project-specific MEPA process.

9161 Addition of compounds to oxidize sediment and minimize P release has been attempted for over
9162 40 years in lake management, but has never enjoyed widespread, frequent application and is not
9163 known to have been attempted in MA. Oxidized sediments are less likely to release available P
9164 and can aid prevention of algal blooms. Cooke et al. (2005) review the application of calcium
9165 nitrate to the upper 6 inches of sediment to provide an alternative source of oxygen (nitrate),
9166 preferred over iron oxides, thereby leaving P bound to iron. In some cases, lime had to be added
9167 to raise the pH and stimulate denitrification, thus minimizing the impact of added N. In some cases,
9168 ferric chloride was also added to increase the supply of iron as a P binder. This process also
9169 suppressed hydrogen sulfide production.

9170 Application of oxidants may impact benthic biota and may not provide lasting control of P release
9171 from sediment. Such application has potential to reduce internal P loading but has largely been
9172 replaced by aluminum additions as the science of sediment P inactivation has developed. Oxidant
9173 application could be permitted in MA if the compounds were approved for use or a project-specific
9174 MEPA review was conducted, but it seems unlikely that this would be a first choice for internal P
9175 load control.

9176 **Selective Nutrient Addition**

9177 While P control is most likely to lead to algae control, multiple nutrients affect algal production
9178 and the ratios of available nutrients to one another determine which types of algae are dominant.
9179 It has long been known that additions of silica will tend to promote diatoms (Kilham 1971). High
9180 nitrogen will tend to shift algal assemblages from cyanobacteria to green algae (Harris et al. 2014).
9181 Adding nutrients to change ratios can shift algae composition to more desirable assemblage of
9182 species, although it may not reduce algal biomass. Addition of nutrients to lakes in MA would
9183 appear to contradict the thrust of multiple permitting programs and is not likely to be acceptable,
9184 and there are no known cases of this approach being attempted in MA.

9185 If the zooplankton community is comprised of large-bodied grazers, there can be less algae in the
9186 water as a function of filter feeding after the phytoplankton assemblage is shifted toward more
9187 edible forms through manipulation of nutrient ratios (Harris et al. 2014). Productivity can be

Alternative Nutrient Controls

9188 maintained or even enhanced while avoiding accumulation of algae that could constitute blooms,
9189 even at moderate nutrient concentrations.

9190 However, addition of more nutrients to water already considered enriched raises permitting issues
9191 in MA and could be considered at odds with the federal Clean Water Act. Water quality standards
9192 may be exceeded, counter to multiple interests of the WPA and necessitating approval under the
9193 Section 401 program, which considers consistency between proposed actions and water quality
9194 standards. Additionally, as control by zooplankton is often unpredictable, never complete, and may
9195 be inadequate, algae blooms may still result, just by potentially less objectionable forms such as
9196 small, gelatinous, green algae or large dinoflagellates. Selective nutrient addition can provide
9197 benefits but is not considered reliable and permitting issues are expected to prevent application in
9198 MA.

9199 **Alternative Direct Algae Controls**

9200 **Flushing**

9201 Flushing for algal control occurs when the water moves through the lake fast enough to prevent
9202 bloom formation or at least minimize the duration of blooms. Adding water to a lake or pond to
9203 increase the flushing rate could be permitted in MA but has logistic constraints and is only likely
9204 to be applicable to very small waterbodies. Prevention of blooms by flushing should be acceptable,
9205 while flushing a bloom downstream raises export and impact issues that might prevent approval.

9206 ***Background***

9207 Free-floating algae (i.e., phytoplankton) in the water column may have some movement capability
9208 but can only maintain a spatial position (horizontal or vertical) in a lake in the absence of
9209 substantial water movement. If enough water passes through a lake to reduce its detention time to
9210 less than about three weeks, algae blooms are less likely to persist and may be largely prevented
9211 because not enough algae biomass accumulates in the lake. Flushing simply moves algae out of
9212 the lake faster than they can reproduce. The shorter the detention time the better the suppression
9213 of a bloom, and this technique is most effective in smaller, linear, impoundments.

9214 In contrast, algae blooms originating from the sediment-water interface, notably many of the
9215 buoyant cyanobacteria, can develop in as little as a few days when those filaments or colonies
9216 synchronously rise in the water column. Consequently, a flushing
9217 rate of 15 to 25% of the lake volume per day may be needed to
9218 minimize algal biomass build-up. Yet many blooms can be
9219 minimized by keeping detention under one to two weeks and some
9220 benefit may be derived by flushing the lake every three weeks. With
9221 a lower flushing rate (higher detention time), blooms may develop
9222 and persist long enough to cause lake impairment, so cutting a six-
9223 month detention time in half has little value for algae control. A
9224 reliable hydrologic loading analysis is needed to properly assess the
9225 potential value of this technique. Transfer of water for the purpose of
9226 flushing may be regulated under the MA Water Management Act if the quantity exceeds 100,000
9227 gpd.

Successful flushing requires a resultant detention time of less than three weeks on a consistent basis during the growing season and preferably closer to one week. This technique is primarily limited by reliability of water supply for this purpose.

9228 The quality of the water used to increase flushing may have an impact on the lake beyond
9229 increasing the flushing rate. If the quality of the added water is better than that in the lake, some
9230 benefit via dilution may accrue, but that technique is covered separately as a means to limit nutrient
9231 availability to algae. If the quality of the added water is poor in some respect, there could be
9232 negative impacts on the lake even with successful flushing. For example, adding a lot of organic
9233 matter may lead to low oxygen levels and adding a lot of sediment-laden water may decrease depth
9234 in some portion of the lake due to settling.

The natural flushing rate for lakes in MA varies considerably among and within lakes. Kettlehole lakes typically flush only once a year or even less, making them poor candidates for flushing as an algal control technique. Impoundments on rivers draining an area 25 times or more larger than the lake will often flush every week on average. However, the seasonal variation within more rapidly flushed lakes can be large, with summer flushing much less frequent than in spring. Lake Massasoit in Springfield has an average flushing rate of once per week, but water can stay in the lake for a month or more during summer when algae blooms are most likely to occur. Flushing must therefore be increased on demand to be effective, and application of this technique is most often limited by the lack of an adequate supply of additional water when it is needed.

Performance and impact considerations

To get more water into a lake, water may be released from an upstream impoundment, diverted from a stream not normally leading to the lake, or pumped from groundwater sources. Upstream releases may compromise water uses in the contributing reservoir if water level declines by a significant amount and groundwater pumping is only viable as a source for small ponds. The ideal situation for increased flushing is when a lake is near a stream or river that does not normally flow through the lake but can facilitate diversion when needed to increase the flushing rate. Such cases are not common but do exist in MA.

Outlet structures and downstream channels must be capable of handling the added discharge for this approach to be feasible. Where detention time is low enough for flushing to be a valid approach, high flows are likely to occur naturally, and the system is likely to support temporary, managed increases in flow when needed. Yet quantitative (e.g., flooding) and qualitative (e.g., bank erosion or other substrate disturbance) downstream impacts must be considered, and attention to any water level fluctuations in the target lake is warranted.

If the lake is stratified, the temperature of the water added to increase the flushing rate is likely to be important. Colder water may dive into the deeper water and either cause destratification or flushing of just the hypolimnion, and this may not provide the benefits sought. Warmer water will ride on the lake surface and may not mix adequately within the epilimnion, the normal target zone for increased flushing.

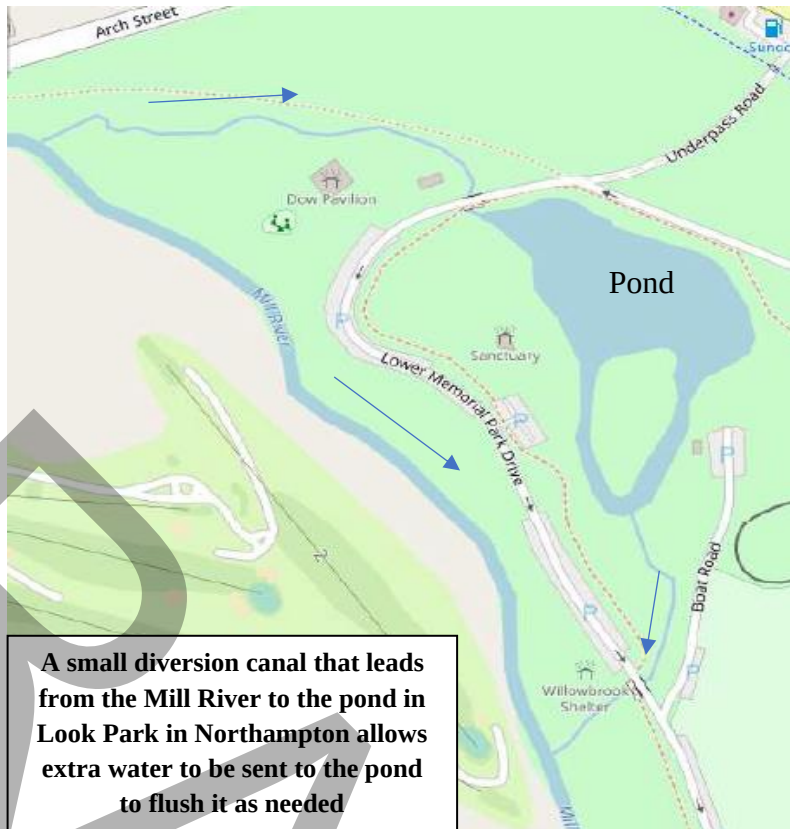
Massachusetts and related experience

Flushing is not a commonly applied technique in MA but has applicability to small ponds with adequate sources of water (e.g., nearby streams, groundwater wells). Some small ponds in MA and other New England states have been flushed with groundwater pumped from wells. For small, manmade ponds with no significant drainage area, wells provide make up water to counter evaporation during hot summers but can also be used to flush such ponds. A series of ornamental ponds on an estate in western CT is fed by two deep wells that flush the water through them on a regular basis in the summer. A small watershed dominated by horse paddocks drains to the ponds and related runoff is nutrient rich. The flushing prevents stagnation and algae problems.

Alternative Direct Algae Controls

9272

9273 The paddleboat and waterfowl
9274 pond in Look Park in
9275 Northampton can be flushed
9276 with water from the adjacent
9277 Mill River if there are algae,
9278 odor, or other water quality
9279 issues. The Mill River has an
9280 average flow of about 108 cubic
9281 feet per second (cfs) and a
9282 summer flow averaging about
9283 30 cfs, while the volume of the
9284 pond is about 500,000 cubic
9285 feet. Diverting just 3 cfs from
9286 the river would flush the pond in
9287 2 days. The Mill River has
9288 generally acceptable water
9289 quality that will not harm the
9290 pond. The diversion of 3 cfs into
9291 the pond with return to the river
9292 about 2000 feet downstream



9293 represents a small (<10%) and temporary reduction in flow that is likely to have a negligible impact
9294 on the river. Flushing is only conducted when water appearance declines in the pond, usually on
9295 the basis of color or clarity.

9296 Rainbow Lake in Connecticut is an impoundment of the Farmington River where inflows from the
9297 very large watershed are usually adequate to flush the lake within 5 days, preventing most algal
9298 blooms (FRWA 2022). Cyanobacteria can develop near the sediment-water interface and rise
9299 synchronously to form blooms, and nutrient concentrations in the lake are high enough to support
9300 extended blooms, but the high rate of flushing minimizes accumulation. Yet during extended
9301 summer dry periods there have been cyanobacteria blooms in recent years. Operation of the power-
9302 generating facility at the outlet coupled with alteration of the water level can increase flushing
9303 under low flow conditions, but no additional release of water from upstream impoundments has
9304 yet been attempted to increase flushing.

9305 Algae Collection Systems

9306 Algae can be collected by multiple means and removed from a lake, but this is not a common
9307 practice, given the challenges associated with collecting and removing algae. Yet such systems
9308 can be permitted in MA and have been recently advanced to the point where algae collection is

Alternative Direct Algae Controls

9309 worth considering as both an interim solution to excessive growths and a possible long-term
9310 solution to high internal P loading.

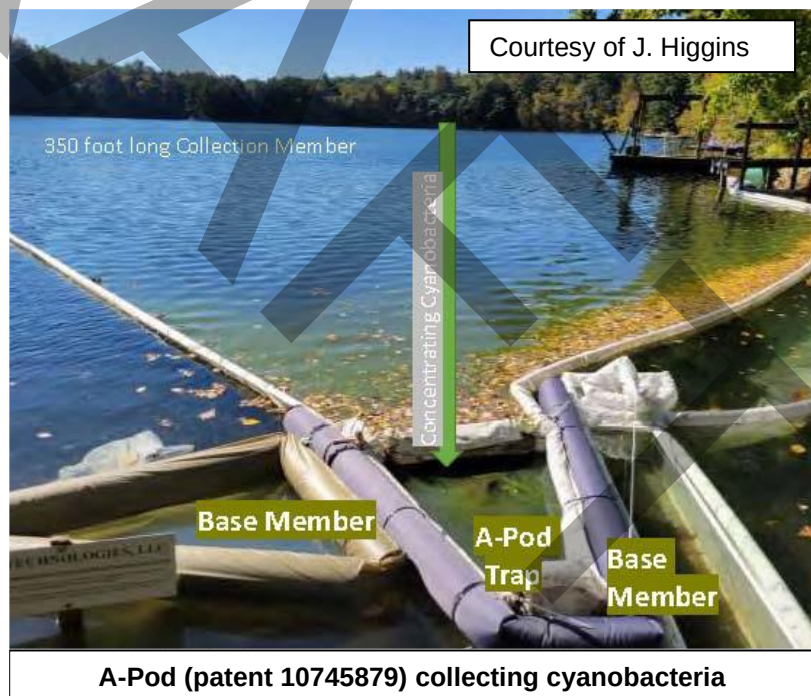
9311 **Background**

9312 Two forms of algae are usually targeted by collection systems: filamentous mats and microscopic
9313 planktonic growths. Of particular interest is the collection of cyanobacteria, as removing them
9314 from the system can minimize potential taste, odor, and toxicity issues. Removal of associated
9315 nutrients may be significant as well and may reduce favorability for further cyanobacteria bloom
9316 generation.

9317 Filamentous mats, which are typically green algae but include some cyanobacteria, can be
9318 collected once they move into the water column or reach the surface with a harvester, especially
9319 one modified to have a finer conveyor system to collect and move mats. Filamentous algae are
9320 often collected with harvested aquatic plants, but the algae collection is mostly incidental to
9321 vascular plant harvesting. Collecting algae mats from the bottom before they rise into the water
9322 column seems preferable but is difficult to do without stirring up the bottom, a disruption that leads
9323 to high turbidity, potential addition of nutrients into the water column, possible fragmentation of
9324 the mats into smaller colonies in water column, possible destruction of fish eggs, and disturbance
9325 of benthic invertebrates. Frequent harvesting of algal mats from the water column is possible but
9326 tedious.

9327 Collecting planktonic algae is a
9328 bit more complicated than
9329 harvesting mats but has been
9330 accomplished both passively
9331 and actively. The A-Pod® by
9332 Higgins is a funnel-like system
9333 with a collection trap that allows
9334 wind or flow currents to
9335 passively concentrate
9336 planktonic algae, especially
9337 floating cyanobacteria, although
9338 it is not just surface scums that
9339 are collected. Additional
9340 collection extensions can be
9341 used to actively direct
9342 planktonic algae into the trap.
9343 Additional chambers allow

9344 separation and protection of zooplankton or other desirable aquatic organisms before release (so-
9345 called Zoop Farm) and storage of accumulated algae before removal (C-Pod). Algae can be



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9346 concentrated up to 2000 times the average in the waterbody, making the material potentially useful
9347 once any toxins have degraded, and the system is portable and scalable.

9348 Where wind and current concentrate cyanobacteria in certain parts of a lake, harnessing those
9349 forces to direct the cyanobacteria into a collection trap allows removal of a bloom with limited
9350 labor and power requirements. The same process may work for floating filamentous algae mats as
9351 well. Knowledge of where algae tend to accumulate in a lake and the prevailing wind and current
9352 patterns will therefore be of importance to the layout and efficiency of collection.

9353 Dissolved air flotation (DAF) technology from the water treatment industry has been used to
9354 remove algae from water withdrawn from a lake with discharge of clean water back to the lake.
9355 DAF has been adapted to be portable within a barge-mounted system, allowing treatment of
9356 targeted areas on a lake. Alternatively, an electrode system has been developed that attracts and
9357 coagulates cyanobacteria for collection or localized electrochemical treatment. The primary
9358 limitation on these types of systems is the rate of processing of lake water, but removal of algae is
9359 efficient.

9360 Collecting algae removes both biomass and associated nutrients, although the actual quantity of
9361 nutrients may be minor, given that algae are mostly water. Yet collection may provide immediate
9362 benefits in terms of improved water clarity and reduced successional blooms. While it may take
9363 years to minimize sediment P reserves, shifting nutrient ratios in the water column may affect the
9364 types of algae present and drive the lake toward a more desirable assemblage. Disposal of collected
9365 biomass could be an issue, particularly where toxic cyanobacteria are involved, but the toxins can
9366 rapidly degrade, allowing beneficial use of the material. Additionally, any addition of structures
9367 to Great Ponds is likely to require permitting under Chapter 91.

9368 *Massachusetts and related experience*

9369 Algae collection techniques are not in widespread use and have been applied mostly in smaller
9370 waterbodies, but there is no technical limit on scale. Application has been hindered mostly by
9371 funding limitations and lack of awareness of these options. Some collection systems have been
9372 scaled up to handle larger lakes and there is potential for longer fetch on bigger lakes to more
9373 efficiently move and concentrate algae. The A-Pod technology was developed through work in
9374 eastern MA lakes including White Pond in Concord and Lake Attitash in Amesbury. A barge-
9375 mounted DAF system for algae removal is in the demonstration stage in MA. Algae mat removal
9376 with harvesters has been accomplished on multiple MA waterbodies with tracking of results for
9377 Morses Pond in Wellesley, but in these cases the main focus has been on vascular plant harvesting.
9378 Specially designed harvesters target floating algal mats on the ponds of the Chicago Botanical
9379 Garden. Most applications have been on a relatively small scale, however, even where a larger
9380 waterbody is involved. This is an approach to algae management that is in an expansion phase, but
9381 there is not enough of a track record to evaluate reliability or compare it to other options in terms
9382 of results for long-term application.

Sonication

Sonication has long been used to break up algal clumps in samples for better lab analysis or water treatment for better removal, but in this field application sound waves are applied to disrupt algal cell membranes and kill the cells. While there are concerns over non-target impacts, none have been documented in aquatic environments and this technique can be permitted in MA. It is mostly used on a smaller scale, either in ponds or limited target areas of larger lakes.

Background

Sound waves over a range of non-audible frequencies will interfere with key algal cellular processes and can kill algae. Multiple frequencies of sound waves can be applied at once to maximize impact on target algae. There is variation in results among and within algal groups based on cell wall composition, shape, gelatinous coatings, and other structural features. Many cyanobacteria, particularly those that utilize gas vesicles within cells for buoyancy, seem to be susceptible to sonic disruption. Diatoms and green algae, with sturdier cell walls, may be less impacted, but separation of interior membranes from the outer cell wall in these forms can prevent transport of materials into or out of the cell and may still result in cell death. The key appears to lie in direct exposure to the sound waves, which have a wave frequency usually slightly higher than 20 KHz and overlapping with the fishfinder sonar range.

Sonication units can be suspended from a buoy or attached to a stake or other anchor within the target waterbody. They can be powered by connection to an onshore power source or run off solar power incorporated into a buoy. In its simplest form, a sonication unit is a single direction sound wave emitter transmitting sound in a cone-shaped field expanding out from the unit and covering a variable area that depends on obstructions or other interference with the sound waves. Susceptible algae within the zone of influence of the sound waves should be killed with adequate exposure. That zone of influence may be substantial where there is a long, open run for the sound waves, but in smaller, irregularly shaped ponds it can take several units to cover the whole pond. The maximum possible distance of impact is about half a mile, but this can be considerably reduced by any obstructions, including rooted plant growths, rocks, any structures in the lake, and perhaps even suspended solids in the water column.

More sophisticated sonicators are available with multiple sound wave emitters arranged to cover a 360-degree area and covering a range of wave frequencies, some with sensors that detect fluorescence from ambient algae and allow adjustment of the sound wave frequency to maximize impact on the dominant type of algae present. These units are usually positioned well away from shore under buoys to maximize coverage and are often deployed in water supply reservoir intake



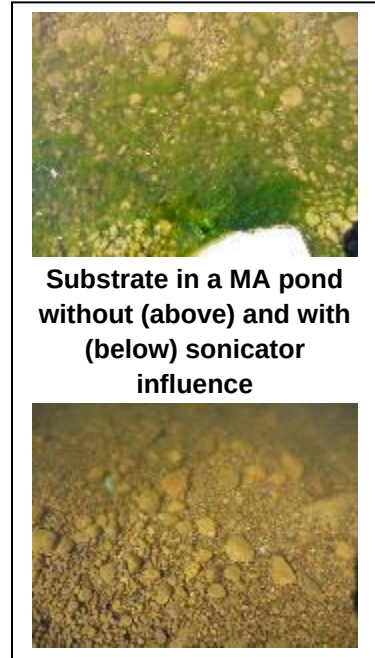
**WaterIQTech (above) and
buoy-mounted LG Sonic
(below) sonicators**
(courtesy of WaterIQTech
and LG Sonics)



9421 forebays or holding areas to reduce algae being transferred to a treatment facility. Such units could
9422 be placed in recreational lakes as well but would represent navigation hazards and would require
9423 a network of power lines in the water if not run by buoy-mounted solar power.

9424 ***Performance and impact considerations***

9425 If nutrients are abundant, some form of algae that is resistant to
9426 sonication can be expected to become dominant, but an overall
9427 reduction in algal abundance is often observed and cyanobacteria
9428 have been reasonably well controlled within the zone of influence
9429 of a sonicator. Control of attached growths has been achieved,
9430 limiting accumulations on tank walls in water treatment facilities
9431 and on rocks or other substrates in shallow water. Yet dense green
9432 algal mats that start their growth on the bottom and float up into the
9433 zone of influence of buoy-mounted sonicators in slightly deeper
9434 water are harder to control. Many of the small green algae with
9435 thick cell walls and/or gelatinous sheaths have exhibited resistance
9436 as well.



9437 The primary issue with sonication is that it does not control the
9438 nutrients that represent the primary driver of algae blooms. With
9439 adequate units in place, bloom generation might be prevented, at
9440 least by susceptible species, but with abundant nutrients still in the
9441 water column, growth of resistant algae would eventually be expected. Additionally, it is hard to
9442 get complete coverage in a waterbody, allowing some algal growth. Yet where nutrient control is
9443 extremely difficult, such as farm ponds, golf course water hazards, and lakes with urban or
9444 agricultural watersheds, sonication provides potential relief from algal blooms.

9445 Few adverse impacts have been reported despite concerns over what sound waves might do to
9446 organisms other than algae. Getchell et al. (2022) report no impact to multiple species of fish or
9447 tadpoles in an extensive lab and field study. Klemenčič and Klemenčič (2021) reported no impacts
9448 on the zooplankter *Daphnia magna* in 48-hr lab tests; possible long-term impacts were not tested.
9449 No loss of zooplankton or fish has been evident in ponds with sonicators that have been assessed
9450 by WRS, Inc. (unpublished data). However, Holm et al. (2008) reported that high intensity
9451 ultrasound at a wavelength close to that used in lake applications was able to kill larger
9452 zooplankton in ballast water.

9453 Despite a substantial body of lab studies, mesocosm work, and pond assessments documenting
9454 control of many types of algae by sonication, there are virtually no peer-reviewed assessments of
9455 sonication results for larger lakes. Large scale application of this technique is rare, although
9456 applications covering key parts of larger lakes are known. The Skaneateles Lake Watershed
9457 Protection Program in NY found that sonication significantly reduced cell counts of algae, most
9458 notably cyanobacteria, in water moved from Skaneateles Lake to a holding reservoir prior to

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withdrawal for potable water treatment, minimizing the need for chemical control by the water district (Abbott 2020). Installation of a pair of large, sophisticated sonication units in the intake forebay of a large reservoir in VA does not appear to have greatly changed algae composition or abundance, but the water utility has documented less use of algaecides since installation (WRS 2023a). WRS, Inc. has analyzed algae samples from many sonication installations and has observed a very wide range of results. Where performance has been inadequate to control algae to the desired level, the issue has been resistant algae in some cases, but there have been problems with sonication units in many cases. Current manufacturers continue to advance the performance and reliability of sonication units.

Summary

Sonication of algae in aquatic environments can kill many types of algae and preemptive use can often prevent bloom formation. No harm has been documented from any sonic device installed for algae control on any aquatic or water dependent species, although testing for long-term impacts is lacking. However, the reliability of algae control with sonication is not consistently high. Where nutrient control is difficult, sonication offers an alternative to algaecides that is worth considering on at least a small scale. Future performance of sonication units may increase as development of this technique continues.

Ecological Management for More and Larger Zooplankton

Zooplankton are tiny animals that live in the water column, the most common groups being Cladocera, Copepoda, and Rotifera (see Figure 8 in Essential Background Information). They consume a variety of particles, some by active selection but mostly by filtration. Large filter feeders consume a lot more algae than small ones but are also a favored food resource for small fish. Adjustments of habitat or the fish community to favor more large herbivorous zooplankton can reduce the standing crop of algae in a lake and actually improve energy flow in the food web. Achieving the right conditions is challenging and sustaining those conditions can be very difficult. Permitting certain adjustments is possible in MA, but success tends to be restricted to smaller waterbodies where controls can be more reliably implemented. Improved zooplankton grazing cannot replace nutrient controls to avoid blooms but can be a helpful supplement.

Background

The amount of water zooplankton can filter in a given amount of time is related to the cube of body length, so larger zooplankters (the biggest Cladocera) provide far more filtering capacity than smaller ones (nearly all Rotifera). Additionally, the maximum size of particles that can be consumed increases with body length, so bigger filter feeding zooplankters filter much more water per unit



***Daphnia*, a large-bodied cladoceran zooplankter with high grazing capacity and value as food for small fish**

time and remove larger algae than smaller zooplankters. A dozen or so of the large-bodied cladoceran *Daphnia* can filter a quart of water in a day, removing the edible algae. Consequently, having a substantial population of large-bodied, filtering zooplankton will provide the greatest water clarity for any given level of fertility (Carpenter et al. 1995, Drenner and Hambright 1999).

Conceptually, it is very attractive to convert high algal productivity into more and larger zooplankton, which in turn are consumed by fish that eat zooplankton (planktivores), which in turn are consumed by fish that eat other fish (piscivores). Productivity is not undesirable, only an accumulation of algae that are not being eaten. Yet not all algae are edible, some occurring in particles too large for even the largest filter feeding zooplankton to consume (e.g., many cyanobacteria) and some having defenses like gelatinous coatings that prevent digestion in the zooplankton's digestive tract (certain small green algae). As lake fertility increases, the algal community tends to be dominated by cyanobacteria and other less edible forms of algae (Canfield et al. 1989, Watson et al. 1998). High lake fertility will therefore tend to counter the potential effect of increased grazing, and while the standing crop of algae may be less than if there were no large, filter feeding zooplankton present (Carpenter et al. 1995), water clarity may not be acceptable to most human users. Research indicates that as P concentration rises through the range of 50 to 100 ppb the potential for fertility to be overcome by grazing by zooplankton will diminish (Jeppesen et al. 1999).

With lower P concentrations there is greater potential for zooplankton to make a difference and a variety of approaches have been employed to enhance grazing on algae. Carpenter et al. (1985) described this change in a lake's community structure as the "trophic cascade" effect. Higher piscivore predation reduces planktivorous fish (e.g., sunfish, alewife, minnows) that cascades into increases in zooplankton size and biomass and ultimately reduce algal biomass. Most biological approaches have been termed "biomanipulation" since some change in biological components (e.g., plants, fish) is induced, but the interactions can be quite complex, and the term "ecological management" may be more appropriate. Projects typically seek to reduce predation pressure on large, herbivorous zooplankton by directly removing planktivores, stocking more piscivores to eat planktivores, or providing some refuge for zooplankton (e.g., dense rooted plants, maintaining oxygen in deep, dark water). Substantial research supports this approach (Hilt et al. 2010, Jeppesen et al. 1997, Shapiro 1990), but in practice the necessary conditions have been difficult to maintain.

Performance and impact considerations

The theory is generally sound, but in practice the desired conditions are hard to establish and maintain. Almost all fish consume zooplankton at an early life stage, so there will be planktivores present if there are fish in the lake. Strong predation on planktivores by piscivores limits food supply for those piscivores and sets up an oscillating progression of abundance and scarcity; biological populations are rarely stable. The zooplankton best suited to life among dense rooted plant assemblages are not the same as those best suited for open water feeding on algae. In a review of ecological management projects, Drenner and Hambright (1999) found that 61% provided some

Alternative Direct Algae Controls

9534 lasting success but that continued management effort was necessary. Over 85% of projects
9535 produced initially positive results, but results were not sustained for more than 5 years without
9536 repeat actions, entirely consistent with expected biological cycles, particularly for fish.

9537 The greatest success has been achieved with smaller (<60 acres) and shallower (<10 ft) lakes that
9538 are not excessively fertilized (P <50 ppb) and for which increased *Daphnia* abundance and rooted
9539 plant coverage has been substantially increased (Drenner and Hambright 1999, Mehner et al. 2002,
9540 Olin et al. 2006, Ha et al. 2013). Ongoing management of fish populations has been necessary and
9541 can be difficult.

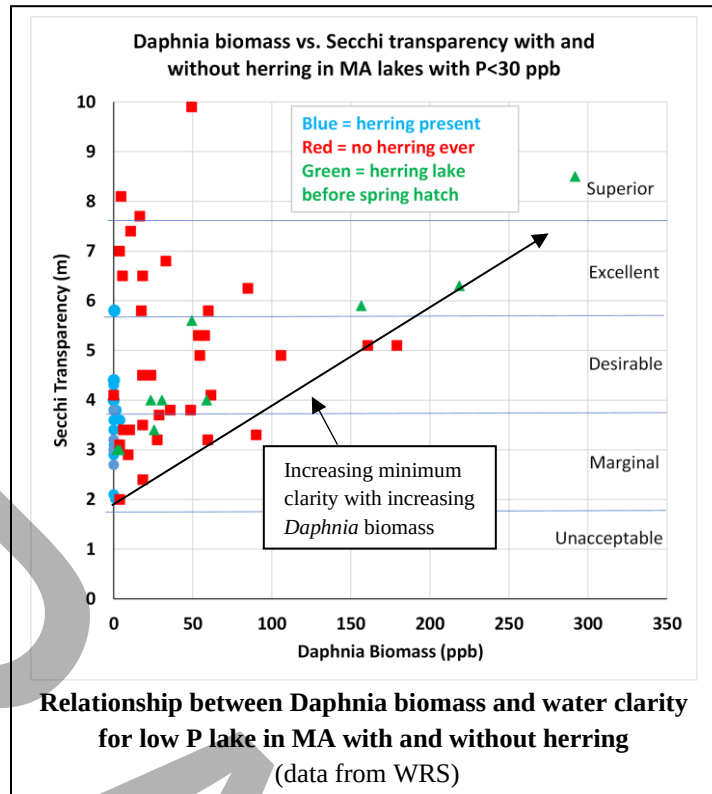
9542 The use of piscicides (fish poisons) to eliminate fish is no longer practiced in MA and fishing or
9543 netting operations are not efficient in most cases, even if permitted. Stocking of piscivores (most
9544 notably largemouth bass) can be permitted in MA and may have potential in shallow, warmwater
9545 lakes, but private stocking is subject to permit and requires a piscivore source, usually from out of
9546 state. Further, if there are piscivorous fish already in the lake, adding more may not produce the
9547 desired effect and it is essential to understand the fish community before any attempt to manipulate
9548 it. Maintaining plant cover over a substantial portion of a shallow lake may be perceived by some
9549 lake users as counter to desired uses like swimming and boating. Yet if predation pressure on
9550 zooplankton can be reduced, it is possible for *Daphnia* to flourish and clarity to increase.

9551 Morses Pond in Wellesley, MA covers just over 100 acres and is managed for reduced P input by
9552 tributary treatment and rooted plants are controlled by mechanical harvesting (WRS 2023b). P
9553 concentrations are routinely <30 ppb in this urban lake and while surficial plant coverage is
9554 reduced, plants are still common several feet below the water surface and are often dense in
9555 unharvested areas. The piscivore population is dominated by largemouth bass and while sunfish
9556 are plentiful in the lake, the zooplankton community is robust and dominated by *Daphnia*. Clarity
9557 rarely drops below 3 m in the summer and algae blooms have been rare for over a decade under
9558 the current management program. Control of available P is viewed as the most influential
9559 management action, but the nature of the zooplankton community is considered beneficial for both
9560 water clarity and fish production.

9561 Otis Wood Land Lake in Otis, MA, covers 25 acres and had no significant piscivore population
9562 until 2019 when largemouth bass were stocked (WRS 2021, ARC 2022). Prior to bass stocking,
9563 the fish community was dominated by sunfish and golden shiners and the zooplankton community
9564 was minimal with only small-bodied individuals present. Since bass were stocked, zooplankton
9565 abundance and mean size have risen, although water clarity in this highly colored lake has not yet
9566 increased significantly. This underscores the importance of understanding the sources of low water
9567 clarity in any effort to increase clarity, although bass stocking in Otis Wood Land Lake was mainly
9568 for recreational opportunity, not water clarity management.

Alternative Direct Algae Controls

While P concentration will tend to be the most relevant factor for predicting water clarity, minimum clarity as measured by Secchi disk in MA lakes with low to moderate P concentrations will rise with increasing *Daphnia* biomass. Clarity is lower for lakes with extremely abundant planktivores and no *Daphnia*, usually by 3 to 7 feet. The importance of zooplankton abundance and average size to water clarity is illustrated by coastal lakes used by herring to spawn in May, with juveniles living in the lake until late summer or early autumn. Spring zooplankton are often abundant and dominated by *Daphnia* while summer zooplankton will be minimized as the young herring feed. In such lakes, the decline in summer clarity is more than would be expected based on P concentration alone.



Summary

Control of nutrient concentrations remains the preferred approach to limiting algae blooms and may be essential if starting concentrations are too high, but enhanced zooplankton grazing capacity can improve water clarity. Data from MA lakes with P concentrations <30 ppb (WRS unpublished data) suggest that the relationship between P and water clarity measured as Secchi transparency is stronger than the relationship between *Daphnia* biomass and water clarity, but clarity does increase with increasing *Daphnia* abundance. Encouraging a healthy zooplankton community, much like other communities within the aquatic environment, appears beneficial for lakes on multiple fronts, but by itself it is not likely to provide consistently acceptable water clarity and is very hard to accomplish and sustain on any but the smallest waterbodies.

Barley Straw

The decay of barley straw produces compounds with algicidal properties, but the complete range of compounds and their effects have not been adequately assessed (Ball et al. 2001, Iredale et al. 2012). As barley straw has not been registered with the USEPA or approved by MDAR for use as an algaecide in MA, this technique cannot be applied in MA.

Compounds produced by the decomposition of barley straw do tend to preferentially reduce cyanobacteria. Decay of barley straw appears to produce peroxides, now a common registered

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algaecide, but many of the compounds produced by decaying barley straw do not directly kill algae. Some of the compounds inhibit growth, possibly by inactivation of P or other essential growth elements. Barley straw is therefore potentially both an algaecide and algal growth inhibitor, a distinction that does not change the registration process at the federal level or the need for approval by MDAR.

The decay process produces substantial oxygen demand and available nutrients, with potential adverse impacts on water quality and even stimulation of algal growth, so use of barley straw has potentially significant drawbacks. Shore-based digesters can limit the amount of organic matter added to the target waterbody, but most applications involve adding the straw directly to a pond. Application of barley straw has worked in some cases and is not particularly expensive, although it has also not been very reliable (McComas 2002). Advances in copper and peroxide as algaecides have minimized the use of barley straw in recent years and its status as an unregistered algaecide is expected to continue in MA.

Bacterial Additives

The addition of bacteria or bacterial products to lakes is a diverse set of technologies, most of which are proprietary; the details of contents and mode of action are usually not public. The standard claim is that the added products allow bacteria to outcompete algae, usually by tying up essential nutrients, or that the product adds enzymes that decompose organic sediment. Enzymes added or produced by added bacteria may also attack algal cell walls and function like an algaecide. Yet there has not yet been review and acceptance of any of these products by appropriate regulatory authorities in MA, under the MEPA process applied to the GEIR, so these products cannot be applied to MA lakes at this time. Absent algaecidal claims, these products might be used after acceptance under a MEPA review. Any algaecide would require registration through the USEPA and approval by MDAR.

Control of algae

Many products appear to focus on N, which would not prevent cyanobacteria capable of utilizing dissolved N gas from becoming abundant. If bacteria did outcompete algae, one would still expect poor clarity as a function of bacteria concentration in the water column, but most available case studies suggest much clearer water. It is possible that the enzymes added or produced by added bacteria attack the cell walls of algae, functioning like algaecides. However, as these products are not registered as algaecides, no algaecidal claims are made in any product literature.

A bacterial additives practitioner described the use of bacterial products as part of a four-step process: 1) kill existing algae, 2) add enzymes that break down long-chain hydrocarbons, 3) add bacterial that incorporate available nutrients, and 4) add settling agents to remove the bacteria (P. Simmsgeiger, pers. comm.). Any product that fosters only one of these steps may be helpful but is not likely to provide consistently acceptable or lasting results. Yet the vast majority of bacterial products available appear to be single step products; add it and await a result. There is therefore a

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9644 lack of public information that makes sound use of these products challenging and creates
9645 permitting issues in MA.

9646 There have been claims of substantial success stories using bacterial products, but documentation
9647 is scarce. WRS analyzes algae samples for project managers and can attest to shifts in algal
9648 composition and declines in algal abundance after addition of bacterial products in some cases.
9649 But given the uncertain mechanisms of algae control, approval under MA regulations may not be
9650 possible without disclosure of product contents and a monitoring program to ensure consistency
9651 with state water quality standards.

Digestion of organic sediment

9653 Use of bacterial products for digestion of organic sediment represents a related and slightly better
9654 understood application. Enzymes are added or produced by added bacteria that can enhance the
9655 breakdown of organic sediment, a process pioneered in the wastewater sludge management
9656 industry, where minimizing the volume of biosolids for disposal has high financial value.
9657 However, sludge management involves frequent and extensive testing with additives intended to
9658 enhance the decomposition process, whereas the products offered for lake applications are simply
9659 added at some prescribed concentration and left to take some hypothesized effect.

9660 The only peer reviewed study of lake application did not find any significant loss of sediment
9661 (Kindervater et al. 2022). While some breakdown of organic matter might be expected with active
9662 enzymes, it is rare for sediment to contain more than 50% organic matter, so the potential reduction
9663 is limited. Further, the fate of nutrients in digested organic matter has not been adequately assessed,
9664 and it is possible that a portion of those nutrients will enter the water column in forms available to
9665 algae.

Summary

9667 Bacterial products are intended to either control algae or digest organic sediment, but it is not clear
9668 that such additives can be approved under existing MA regulations with the current state of
9669 knowledge regarding mode of action and potential impact on water quality. This is an area of lake
9670 management that is still maturing, and future research and closely monitored applications appear
9671 necessary to advance proper use. Yet until specific products are approved for use in MA under the
9672 MEPA process and added to the GEIR, they cannot be used in MA without a project-specific
9673 MEPA review.

Settling Agents

9675 Settling agents are polymers or other coagulating compounds added to water to bind with and settle
9676 out particulates, including algae, or even to precipitate dissolved substances and create particulates
9677 that can settle out of the water column. The coagulation fostered by aluminum added for P
9678 inactivation will settle out most algae, but that is not the primary intent of those treatments.
9679 Polymers have been used to reduce color in some ponds affected by high inputs of humic

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substances, but the effect is only temporary. Settling agents are part of many water and wastewater treatment systems and are a recommended component of comprehensive bacterial additive approaches, but direct application to lakes is not common and such application has not been performed in MA lakes in many years. There has not been a review and acceptance of any of these products other than aluminum by appropriate regulatory authorities in MA, under the MEPA process applied to the GEIR, so these products cannot be applied to MA lakes without a project-specific MEPA review.

9688 **Alternative Direct Algae and Aquatic Plant Controls**

9689 **Dyes**

9690 The addition of dye to a lake will reduce the penetration of
9691 light and potentially limit rooted plant and algae growth.
9692 Dyes can be permitted in MA but are treated as pesticides in
9693 the permitting process, requiring approval under the WPA
9694 and a License to Apply Chemicals from MassDEP (WM04
9695 process). Restrictions apply and use outside small, private
9696 ponds with limited outflow is rare.



**Dye being added to a pond; it
diffuses readily**

9697 In some of the original lake applications, dyes were used to
9698 limit the growth of rooted plants in water that had become
9699 very clear as a result of the impacts of acid precipitation in the Adirondack Mountains of NY.
9700 These days dyes are mainly employed in ornamental ponds and golf course water hazards to
9701 enhance appearance of water that might otherwise suffer algae blooms.

9702 The addition of dye causes the sunlight to be absorbed in shallower water, making that shallow
9703 water warmer and sometimes causing stratification at very shallow (<10 feet) depths. Loss of
9704 oxygen in shallower water is therefore also possible with attendant water quality impacts. Algae
9705 and rooted plant growth in very shallow (<3 feet) water is not likely to be significantly impacted,
9706 but the coloration does often mask algae blooms. Submergent vegetation is more likely to be
9707 controlled than emergent or floating leaved forms. Dyes will either be flushed from the lake or
9708 photodegrade over time, necessitating reapplication at an unpredictable frequency.

9709 Although no toxic responses or direct mortality of target organisms is expected, dyes are persistent
9710 and are best used in ponds with no outflow. For small, artificial, isolated ponds where control of
9711 nutrients in the water column and sediment is difficult or impractical, dyes can provide a more
9712 appealing appearance. Application on a whole lake basis to larger systems with significant
9713 throughflow is generally not advisable, given the potential adverse impacts on thermal and oxygen
9714 regime.

9715 **Surface Covers**

9716 Surface covers have historically been used mainly in water supply reservoirs to limit use by
9717 waterfowl and other wildlife that add contamination, with particular applicability to open storage
9718 of finished water awaiting distribution to customers. It is also possible to use surface covers
9719 temporarily at access points to recreational lakes to retard plant growth, much like benthic barriers
9720 but at the surface of the lake. This technique can be permitted in MA on a small scale but has
9721 limited applicability and has rarely been used.

9722 Preventing light from penetrating the water surface can limit plant and algae growth but may also
9723 impede atmospheric exchange and create access issues. Changes in the regulations for drinking

Alternative Direct Algae and Aquatic Plant Controls

water have altered the way finished water is handled and largely eliminated open storage and the use of surface covers in the water supply industry. Most covers are either floating, opaque sheets or loose balls that float in a surface mass. Use in recreational lakes has mostly been restricted to peripheral application over small areas to minimize plant growths in the spring, prior to the start of more intense recreational use. Access for human users as well as wildlife is impeded by surface covers, so more than seasonal use is unlikely and any use might be counter to some interests of the WPA. There has been very little demand for this technique in recreational lakes, as benthic barriers can supply rooted plant control with less impact on human and non-human lake users.

Algae or Vascular Plant-Eating Fish

The introduction of any vertebrate species to waters of MA is under the direct control of MassWildlife through a permit process. The introduction of non-native species is not allowed and all fish that eat algae or rooted plants as a major portion of their diet are non-native, so stocking herbivorous fish is prohibited in MA at this time.

Best known of the herbivorous fish is the grass carp (*Ctenopharyngodon idella*), which consumes a wide range of rooted aquatic plants and is used in some states for plant control. As described below, the highly variable results, the non-selective nature of herbivory, and the potential for fish to move to other waters and survive for an extended period of time, causing damage to non-target plant populations, is why grass carp and other non-native herbivores are prohibited by state law and regulations as administered through MassWildlife.

Only seven states allow stocking of sterile, diploid grass carp and a genetic triploid version, incapable of reproduction, is most often specified where stocking is allowed. Outlet controls are usually mandated to minimize escape from the target waterbody but are rarely completely effective. Aquatic vegetation control results have been highly variable (Bonar et



Grass carp, *Ctenopharyngodon idella* (courtesy of Chesterfield County Water)

al. 2002, [USGS 2023](#)) and fish abundance or biomass along with dietary preference are the primary factors in degree of plant control. Projects with a goal of complete plant control will involve enough grass carp to virtually eliminate all plants (usually 20/vegetated acre), leading to starvation or escape by the grass carp and a resurgence by plants unless grass carp are restocked.

Projects intending to control just certain species or to reduce plant abundance without elimination will involve an intermediate number of grass carp and have proven very difficult to manage successfully. Intermediate grass carp abundance does not guarantee that fish will not congregate and eliminate plants in certain areas while not impacting other areas. Grass carp do have dietary preferences, and while they will consume nearly all aquatic plants if alternatives are lacking, a

Alternative Direct Algae and Aquatic Plant Controls

9761 focus on invasive or unwanted plant species is not to be expected. Managing a biological control
9762 mechanism is quite complicated.

9763 The use of grass carp for plant control in Lake Gaston on the NC and VA border is one of the
9764 better documented cases. Targeted invasive species have been much reduced but not eliminated
9765 and some native plant species remain, although areas of native species are fenced off to prevent
9766 consumption by grass carp (NCWRC 2019). However, drawdown and herbicides have also been
9767 used in the plant control effort at Lake Gaston and considerable effort goes into tracking results
9768 and making adjustments to enhance control.

9769 Use of grass carp in Ball Lake in CT controlled Eurasian watermilfoil but the plant community is
9770 minimally diverse, with coontail becoming dominant after grass carp were stocked (June-Wells et
9771 al. 2017). Water clarity was poor before grass carp stocking and remained poor after stocking. In
9772 four other CT lakes where grass carp were stocked (Waubeeke, Taunton, Candlewood, and
9773 Squantz), vegetation was dramatically reduced, including both targeted invasive species and native
9774 plants (CAES 2021, 2023a, 2023b). A substantial decrease in water clarity was observed in one of
9775 the four lakes. The conversion of plant biomass into grass carp biomass comes with high release
9776 of nutrients into the water column that can support algal blooms (Cooke et al. 2005).

9777 Fish that consume plants have appeal in a control program as a function of seemingly lower cost
9778 and prolonged control, but the disruption of lake ecology and unreliable results justify the current
9779 MA prohibition on herbivorous fish introduction.

Algae or Rooted Plant Pathogens

9781 Pathogens to kill algae or rooted plants have been isolated and developed over the last 50 years,
9782 but none have ever received widespread application. In most cases the pathogens have only been
9783 partially effective, for example cutting the density of an algal bloom but not enough to make the
9784 water appealing for swimming. Conversion to commercial products has been challenging.
9785 Bacterial and fungal pathogens for mosquito control have been commercialized and are widely
9786 applied, but no pathogen product to control rooted plants or algae is currently commercially
9787 available. If such a product is developed and approved for use in MA, this might be a valid
9788 approach to algae or rooted plant control, but currently there are no options in this category.

9789

9790 **Alternative Direct Aquatic Plant Controls**

9791 **Plant Competition**

9792 A healthy native plant community is an integral part of nearly all properly functioning lake
9793 ecosystems. Aquatic vascular plants provide food and shelter for many organisms and stabilize
9794 sediment in the nearshore zone. A healthy native plant community also limits possible colonization
9795 areas for invasive species. Protecting native plant communities is important, but natural and
9796 human-induced disturbances will sometimes remove native plants. Replanting after a disturbance
9797 can be permitted in MA but is rarely practiced in the submerged lake environment. Replanting
9798 native vegetation is largely a missing link in lake management that may be appropriate after
9799 invasive species control efforts or natural disturbances create open areas for colonization.

9800 ***Background***

9801 While some native species can become
9802 nuisances, many species grow low to the
9803 sediment (e.g., Robbins' pondweed, Chara,
9804 and Nitella) at a high enough density to
9805 minimize the probability of a fragment of an
9806 invasive species (e.g., Eurasian
9807 watermilfoil) from rooting and growing.
9808 Actively planting areas of lakes that have
9809 been subject to disturbance, either natural or
9810 human-induced, could be a valid means of
9811 minimizing colonization or expansion by
9812 invasive or other nuisance species. Such
9813 planting is conducted in emergent wetlands
9814 as part of rehabilitation efforts and can be permitted in lakes for submergent species, with
9815 restrictions to minimize undesirable introductions. If light penetrates to a hospitable substrate,
9816 plants will grow, but determining which plants will colonize can be aided by actively planting
9817 native species that are suitable to the habitat and location.



Robbins' pondweed, *Potamogeton robbinsii*, a common native plant in MA lakes that grows low and dense, limiting colonization potential by invasive species

9818 Actively planting areas of lakes that have been subject to disturbance, either natural or human-
9819 induced, could be a valid means of minimizing colonization or expansion by invasive or other
9820 nuisance species. It would be unusual to dig up a terrestrial area and then just wait for plants to
9821 colonize; landscapers plant in accordance with a plan. Yet in lake management plants are often
9822 removed with little consideration of what will grow there next. Planned planting of appropriate
9823 native species is therefore a logical extension of aquatic plant control projects and can limit the
9824 potential for undesirable species to grow in a target area. This was termed "aquascaping" in the
9825 literature, but that term has largely been coopted by the aquarium trade to denote underwater
9826 gardening in a closed tank. While there have been many attempts to plant lakes with desirable
9827 vegetation across the USA, this discipline has not progressed to a mature state of development.

9828 ***Performance and impact considerations***

9829 The primary weaknesses in this approach are the ability to get desirable plants to grow where they
9830 are wanted and the tendency of many invasive species to be superior competitors for space.
9831 Experimental planting programs in several New England lakes following invasive species control
9832 actions have resulted in healthy native plant communities taking over in areas previously occupied
9833 by invasive species, but rarely have the planted species become dominant. Instead, other native
9834 plants, presumably from seeds, have assumed dominance. And unless growth by native species is
9835 rapid, colonization by invasive plants on open substrate is possible. Even where a native
9836 assemblage can be re-established, recovery or re-invasion by invasive species is possible and often
9837 occurs. Most invasive species grow higher in the water column and have more of a canopy than
9838 the submergent native species they replace, shading out the desirable species. Competition by
9839 desirable native plant species may slow the colonization of undesirable vegetation but has not
9840 completely stopped it in the vast majority of cases. Still, putting desirable native plant species into
9841 an area that has been disturbed may be better than waiting to see what shows up.

9842 Plants under consideration for movement must not be on the [prohibited plant list](#) for MA. Note
9843 that all federally prohibited plants would also be prohibited even if not on the state list. Plants must
9844 be native to the area, preferably from the subject waterbody (moved within the lake) or from other
9845 lakes in the watershed. While political boundaries often have no ecological significance, keeping
9846 the source within the county where the lake lies is usually appropriate and [The Vascular Plants
9847 of MA; A County Checklist](#) should be helpful.

9848 In any planned movement of plants among lakes, care must be taken to correctly identify the target
9849 plant and to avoid bringing unintended passengers to the recipient lake, particularly invasive plants
9850 or animals. A qualified botanist or aquatic horticulturist can help the project develop measures to
9851 minimize such risks. Harvesting plants for replanting in a target area is possible but creates
9852 disturbance in the area from which those plants are removed. Consequently, care should be taken
9853 to minimize disturbance and take plants from dense patches, leaving plenty of plants behind. Use
9854 of seed stock collected during the growing season and deposited in a target area in spring is an
9855 approach with considerable merit and is widely used in wetland and upland rehabilitation but has
9856 rarely been performed in relation to submergent plant communities. Sequestration of newly planted
9857 areas by temporary fencing may be necessary to minimize consumption by herbivores and give
9858 young plants a chance to grow.

9859 ***Summary***

9860 A healthy native plant community resists invasive species and provides many habitat benefits to
9861 aquatic fauna. Planting open areas with desirable native species may be advantageous in many
9862 cases where disturbances have created open substrate. Paired with other control measures for
9863 invasive species, active planting with native species should play a greater role in rehabilitating
9864 lake habitats. With proper planning, this technique should have greater application in MA.

9865 **Reverse Layering**

9866 Reverse layering was developed at Red Lily Pond/Lake Elizabeth in Barnstable in the late 1990s
9867 by Dr. William Kerfoot and has not been tried elsewhere as far as available documentation shows.
9868 The concept is simple; hydraulically pump a slurry of sand from beneath an organic sediment layer
9869 to the top of that layer, functionally burying the organic layer under cleaner sand that is intended
9870 to provide a less hospitable substrate for plant growth and would lower both oxygen demand from
9871 the sediment and possible nutrient inputs to the water column. While such a project could in theory
9872 be permitted in MA today, it would be subject
9873 to all the regulations relating to dredging and
9874 the deposition of fill in a wetland resource.

9875 Many coastal ponds have substantial sand
9876 deposits that have been covered by organic
9877 muck over the last 10,000 years, so the theory
9878 seems sound, but in practice it did not work
9879 very well. Clay and rock deposits that were
9880 not anticipated impeded pumping of sand and
9881 the resultant new surface layer was not as
9882 thick as desired. Additional sand was brought
9883 in and spread by equipment designed for such
9884 use in cranberry bogs (Town of Barnstable
9885 2004). Long-term plant control benefits were negligible. At the time, the movement of sediment
9886 within the lake was not considered to constitute a dredging project, thus minimizing permit needs,
9887 but interpretation of regulations since has focused on sediment disturbance rather than removal as
9888 the trigger for most permits, so there is no regulatory advantage to reverse layering.



Equipment for reverse layering on Lake Elizabeth
(courtesy of Red Lily Pond Protective Association)

9889 The idea of covering organic sediment with a more inorganic layer remains appealing but is not
9890 easily permitted in MA and reverse layering has not been advanced further.

9891 **Herbivorous Invertebrates**

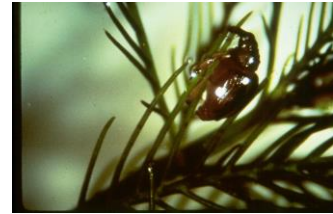
9892 Insects and other invertebrates that eat vegetation or otherwise disrupt plant growth processes have
9893 been introduced to wetlands and lakes to control specific plant species in MA and elsewhere. These
9894 can reduce target plant abundance, have been used and can be permitted in MA, but control is
9895 rarely complete and typically does not last. Basic ecological principles are at work here; predators
9896 that minimize prey (e.g., insects that minimize target plants) will suffer food shortages and
9897 population crashes, allowing recovery of the target species. This tends to set up cycles of scarcity
9898 and abundance that lead to periodic high densities of the target plants that impair habitat or human
9899 uses.

Alternative Direct Aquatic Plant Controls

The purple loosestrife beetle (*Galerucella* spp.) and the milfoil weevil (*Euhrychiopsis lecontei*) are two examples of herbivorous insects used to control targeted invasive species in MA. Despite some initial success, there are no active programs using either species in MA now. The milfoil weevil was pioneered partly in MA where it is native and feeds on a range of watermilfoil species. When Eurasian watermilfoil becomes abundant, the weevil tends to target that species and population crashes were observed in some lakes (Sheldon and Creed 1995), although recovery also occurred. A weevil density of at least 0.5 weevils per milfoil stem and preferably >2 per stem is needed to kill the plant, often equating to >100 weevils per square yard. Stocking at such a density is not practical, but natural population increases often occur and some stocking can boost the response time.



The milfoil weevil,
Euhrychiopsis lecontei
(courtesy of R. Johnson)



Crashes of invasive watermilfoil populations occurred and may be linked to natural expansion of weevils or other invertebrate herbivore populations (Creed 1998). However, once the weevil has reduced the abundance of milfoil, its sole food resource, it must travel further through open water to reach new watermilfoil plants. This migration makes them very susceptible to predation by fish, especially sunfish that tend to be abundant in those areas (Miller 2017). After two decades of active weevil stocking, including rearing of weevils in State of Vermont labs and a commercial facility in OH, this technique is no longer applied. The University of MN offers a detailed primer on the [milfoil weevil](#) that covers the issues.

Similar stories can be found for a range of invertebrate herbivores on a variety of nuisance or invasive aquatic plants. Initial collapses of the target species are followed by resurgence and eventual establishment of an oscillating pattern of abundance. If the high end of target plant density is not acceptable for intended lake uses, biological controls will not be adequate. Invertebrate herbivores could be part of an overall control program, but implementation of supplementary control techniques will almost certainly be needed and can conflict with invertebrate effectiveness (Sheldon and O'Bryan 1996).

A more recent example involves crayfish, which have a highly varied diet, including plants and invertebrates, and readily switch food sources when one is diminished. Lakes with abundant crayfish populations often have fewer rooted plants reported (Rosenthal et al. 2006), and this has been observed in MA as well. Otis Wood Land Lake in Otis had a very large population of the northern crayfish, *Faxonius virilis*, and very few submergent plants. The lake was nearly drained for a dredging project in 2016 and crayfish declined, leading to much higher submergent plant density in 2017 and 2018. The crayfish population recovered naturally by 2019 and submergent plants were again minimized (WRS 2020).

Alternative Direct Aquatic Plant Controls

While control of rooted plants by crayfish may be attractive, crayfish also limit other invertebrates (McCarthy et al. 2006), reducing overall biodiversity, and are subject to predation by many fish species, such that plant control is not guaranteed. Not all plants are consumed by crayfish and some crayfish species are considered invasive, so even though a plant control project using crayfish can be permitted in MA, not all species can be used and not all plants will be controlled. Most peer reviewed papers on crayfish control of vegetation come from lakes where there are active efforts to reduce crayfish abundance to restore some balance to the system (Hein et al. 2007). More research is needed to evaluate crayfish as an aquatic plant control agent within the context of overall lake function.

The primary drawback of this sort of ecological management lies in having incomplete information on how each lake will react to an introduction of a new species or increase in abundance of a species already present. Intended results cannot be guaranteed and unintended consequences are distinctly possible. The story of many biocontrol programs is one of failing to understand the flexibility and adaptability of species, leading to limited success and often unintended consequences (Schulz 2019). The variation in biological controls is inherently larger than for physical or chemical methods, making biological controls less reliable. Application is possible in MA and may have merit, but as the mainstay of plant control, herbivorous invertebrates are unlikely to provide the desired conditions on a consistent basis.

Rotovation

Rotovation is basically the application of an underwater rototiller to an area of sediment, typically one with dense growths of unwanted rooted aquatic plants. A rotovator is a hydraulically operated tillage device mounted on a barge. Rotovation is a highly disruptive procedure that would be unlikely to be permitted in MA due to undesirable impacts to the aquatic environment, but no rotovation projects have ever been attempted in MA.

The tiller on a rotovator can be lowered to depths of 10 to 12 feet for the purpose of tearing up vegetation, including root systems. It is an engineering advance over use of conventional cultivation equipment, but any such approach will disturb sediment, create very high turbidity, and likely have negative impacts on benthic invertebrates. The disturbed plants are not collected as they are with hydroraking, creating oxygen demand with decomposition and potentially spreading species that reproduce by fragmentation. The tilled sediment would seem ideal for colonization by more rooted aquatic plants and would seem to favor invasive species.

Rotovation has a limited track record, mostly in British Columbia. Use of a variety of cultivation equipment has been practiced in New England but has rarely been documented and mostly occurred prior to passage of the WPA. Rotovation has not been used in MA or other New England states. The availability of alternatives with at least equal effectiveness and lesser adverse impacts suggests that no effort is likely to be invested in approving rotovation in MA.

9973 **Physical Plant Disruption Devices**

9974 A variety of mechanical equipment can be found online that disrupts aquatic plant growth over a
9975 small area, usually mounted on a dock or other shoreline structure and requiring electric power.
9976 Items include plastic and metal strips that are dragged over or through the substrate to prevent
9977 plants from growing and propeller- or jet-driven water circulators that are aimed slightly above or
9978 at the sediment surface. A few devices are handheld and possibly battery operated. Where
9979 movement of just water is the goal, these are best considered as mechanical circulators, but nearly
9980 all of these devices are intended to minimize plant growth and tend to disturb sediment. These
9981 might be permissible in MA but would likely be subject to Section 401 permitting as well as the
9982 WPA. Disturbance of a small area to support a water dependent use such as swimming or boat
9983 access might be allowable but impacts on larger areas would likely be counter to the intent of
9984 multiple MA regulations.

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11. APPENDICES

These appendices provide supplemental information that will aid readers and better inform lake management decisions. Included are a list of abbreviations and acronyms used in this guide, a glossary of aquatic and lake management terms used, an evaluation of the cost of lake management, a review of issues involved with drawdown for those seeking to permit drawdowns through the MEPA process, and a set of sample conditions that could be applied to specific lake management Orders of Conditions.

Appendix A: Acronyms and Abbreviations Used in this Guide

10547	
10548	
10549	ACEC – Area of Critical Environmental Concern
10550	AFS – American Fisheries Society
10551	AIS – Aquatic Invasive Species
10552	ALMS – Alberta Lake Management Society
10553	ALS – acetolactate synthase
10554	APMS – American Plant Management Society
10555	As – Arsenic
10556	AWQC – Ambient Water Quality Criteria
10557	AWWA – American Water Works Association
10558	BDL – Below Detection Limit
10559	BMP – Best Management Practice
10560	BOD – Biological Oxygen Demand
10561	C° – Degrees Celsius or Centigrade
10562	C – Carbon
10563	Cd – Cadmium
10564	CERO – MassDEP Central Regional Office.
10565	CFR – Code of Federal Regulation.
10566	CFR – Coldwater Fish Resource (MassWildlife)
10567	Chapter 91 – MA Public Waterfront Act
10568	CMP – Conservation and Management Permit
10569	CMR – Code of MA Regulation.
10570	Co – Cobalt
10571	Cr – Chromium
10572	CRM – Crop Residue Management
10573	Cu – Copper
10574	CWA – Federal Clean Water Act
10575	CWF – Cold Water Fishery
10576	DAF – Dissolved Air Flotation technology
10577	DDT – Dichlorodiphenyl trichloroethane
10578	DDE – Dichlorodiphenyl dicloroethene
10579	DEIR – Draft Environmental Impact Report
10580	DMF – Division of Marine Fisheries
10581	DO – Dissolved Oxygen
10582	DQO – Data Quality Objectives
10583	EIR – Environmental Impact Report
10584	EIS – Environmental Impact Statement
10585	ENF – Environmental Notification Form
10586	EOEEA – MA Executive Office of Energy and Environmental Affairs

Acronyms and Abbreviations

10587	ePLACE – clearinghouse website for submission of environmental forms
10588	ERLP – Ecological Restoration Limited Project
10589	ERP – Ecological Restoration Project
10590	Fe – Iron
10591	FEMA – Federal Emergency Management Agency
10592	FGEIR – Final Generic Environmental Impact Report
10593	FS – Feasibility Study
10594	GEIR – Generic Environmental Impact Report
10595	GIS – Geographic Information System
10596	GPA – General Permit Areas (NHESP)
10597	HAB – harmful Algae Bloom
10598	HCB – Hexachlorobenzene
10599	Hg – Mercury
10600	HRT – Hydraulic Retention Time
10601	HW – Hazardous Waste
10602	I/A – Innovative and Alternative (septic systems)
10603	IWPA – Interim Wellhead Protection Area
10604	kg – Kilogram
10605	L – liter
10606	LID – Low Impact Development
10607	LLRM – Lake Loading and Response Model
10608	LMP – Lake Management Plan
10609	LUWW – Land Under Waterbodies and Waterways
10610	LUST – Leaking Underground Storage Tank
10611	MA – Commonwealth of MA
10612	MACC – MA Association of Conservation Commissions
10613	MassBWR – MassDEP Bureau of Water Resources
10614	MassBWSC – MassDEP Bureau of Waste Site Cleanup
10615	MassDCR – MA Department of Conservation and Recreation
10616	MassDEP – MA Department of Environmental Protection
10617	MassDEQE – MA Department of Environmental Quality Engineering (former name of
10618	MassDEP)
10619	MassDMF – MA Division of Marine Fisheries
10620	MassDPH – MA Department of Public Health
10621	MassDWPC – MassDEP Division of Water Pollution Control
10622	MassDWP – MassDEP Drinking Water Program
10623	MassDWW – MassDEP Division of Wetlands and Waterways
10624	MassGIS – MA Geographic Information System
10625	MassOWM – MA Office of Watershed Management
10626	MassWildlife – MA Department of Fish and Wildlife

Acronyms and Abbreviations

10627	MDAR – MA Department of Agricultural Resources
10628	MDL – Method Detection Limit
10629	MEPA – MA Environmental Policy Act
10630	MESA – MA Endangered Species Act
10631	mg – Milligram
10632	MGL – MA General Law
10633	Mn – Manganese
10634	MS4 – Municipal Separate Storm Sewer System
10635	N – Nitrogen
10636	NALMS – North American Lake Management Society
10637	NAWQA – National Water Quality Assessment
10638	NERO – MassDEP Northeast Regional Office
10639	NHDES – New Hampshire Department of Environmental Services
10640	NHESP – Natural Heritage and Endangered Species Program
10641	Ni – Nickel
10642	NLA – National Lakes Assessment
10643	NOI – Notice of Intent
10644	NPDES – National Pollutant Discharge Elimination System
10645	NPS – Non-Point Source
10646	NRCS – Natural Resources Conservation Service
10647	O&M – Operation and Maintenance
10648	OHM – Oil and/or Hazardous Material
10649	OOB – Order of Conditions
10650	ORW – Outstanding Resource Waters
10651	P – Phosphorus
10652	PAH – Polyaromatic Hydrocarbons
10653	Pb – Lead
10654	PCBs – Polychlorinated Biphenyls
10655	PFAS – Per- and PolyFluoroAlkyl Substances
10656	PGP – Programmatic General Permits (USACE)
10657	PGP – Pesticide General Permit (MDAR)
10658	pH – Relative measure of acidity/alkalinity
10659	PVC – Polyvinyl Chloride
10660	QAPP – Quality Assurance Project Plan
10661	QC – Quality Control
10662	RFP – Request for Proposals
10663	SDT – Secchi Disk Transparency
10664	SDWA – Federal Safe Drinking Water Act
10665	Se – Selenium
10666	SERO – MassDEP Southeast Regional Office

Acronyms and Abbreviations

10667	SOW – Scope of Work
10668	SPCC – Spill Prevention Control and Countermeasures plan
10669	SWQS – State Water Quality Standards
10670	TMDL – Total Maximum Daily Load
10671	TOY – Time of Year
10672	TPH – Total Petroleum Hydrocarbons
10673	TSS – Total Suspended Solids
10674	TSI – Carlson’s Trophic State Index
10675	µg – Microgram (equivalent to part per billion)
10676	USACE – United States Army Corps of Engineers
10677	USDA – United States Department of Agriculture
10678	USEPA – United States Environmental Protection Agency
10679	USFWS – United States Fish and Wildlife Service
10680	UMass – University of MA
10681	USGS – United States Geological Survey
10682	VOC – Volatile Organic Compound
10683	WBP – Watershed-Based Plan
10684	WERO – MassDEP Western Regional Office
10685	W:L – Watershed to Lake Area Ratio
10686	WM04 – License to apply chemicals to water
10687	WPA – MA Wetlands Protection Act
10688	WPP – Watershed Planning Program
10689	WQC – Section 401 Water Quality Certificate
10690	WWTF – Waste Water Treatment Facility
10691	Zn – Zinc

10692 **Appendix B: Glossary of Aquatic Terms Used in this Guide**

10693 **Abiotic** – Pertaining to any non-biological factor or influence, such as morphometric, geological
10694 or meteorological characteristics.

10695 **Acid precipitation** – Atmospheric deposition (rain, snow, dryfall) consisting of free or combined
10696 acidic ions, especially sulfates and oxides of nitrogen and sulfur from industrial and transportation
10697 sources.

10698 **Adverse Effect** – Significant negative impact on wetland wildlife species or their habitat under
10699 the WPA, a determination made with regard to acceptability of a proposed action.

10700 **Algae** – Aquatic single-celled, colonial, or filamentous plants containing chlorophyll, capable of
10701 photosynthesis, and lacking roots, stems, and leaves.

10702 **Algaecides** – Chemicals applied to waterbodies to prevent or control algal populations.

10703 **Algal bloom** – Heavy growth of algae in and on a body of water as a result of high nutrient
10704 concentrations; visible algal accumulations.

10705 **Alkalinity** – The acid combining capacity of a solution, also describes its buffering capacity,
10706 controls pH.

10707 **Ammonium nitrogen (NH₄)** – A dissolved form of nitrogen present in sewage and also generated
10708 from the decomposition of organic nitrogen. It can also be formed when nitrites and nitrates are
10709 reduced. Ammonium is particularly important since it has high oxygen and chemical demands, can
10710 be toxic to many aquatic fauna in un-ionized form (NH₃) and is an important aquatic plant nutrient.

10711 **Anadromous** – A species that spawns in freshwater but spends most of its life cycle in saltwater.

10712 **Anoxic** – Without oxygen.

10713 **Anthropogenic** – Pertaining to human influence or causal factor (e.g., anthropogenic
10714 contaminants).

10715 **Aphotic zone** – Dark zone, below the depth to which light penetrates. Generally equated with the
10716 zone in which most photosynthetic algae cannot survive due to light deficiency.

10717 **Aquatic plant survey** – A systematic mapping of types and location of aquatic plants in a
10718 waterbody, usually conducted by means of a boat, with survey information usually presented on
10719 an aquatic plant map.

10720 **Area of Critical Environmental Concern (ACEC)** – Area designated for special recognition
10721 because of the quality, uniqueness, and significance of its natural and cultural resources and which
10722 is afforded additional protection under environmental laws.

Glossary

- 10723 **Attenuation** – The process whereby light is reduced as it passes down into the water column due
10724 to a combination of absorption and back reflectance, or the process whereby the availability of
10725 nutrients or other contaminants is reduced by various processes.
- 10726 **Bathymetric map** – A map showing depth contours in a waterbody. Bottom contours are usually
10727 presented as lines representing equal depth in meters or feet.
- 10728 **Bathymetry** – The measurement of depths of water or the information derived from such
10729 measurements.
- 10730 **Benthic barriers** – Synthetic or natural fiber sheets of material used to cover an area and prevent
10731 or kill plant growths; also called bottom barriers or sediment covers.
- 10732 **Benthos** – Bottom-dwelling organisms living on, within or attached to the sediment. The
10733 phytobenthos includes the aquatic macrophytes and bottom-dwelling algae. The zoobenthos
10734 (benthic fauna) includes variety of invertebrate animals, particularly mollusks and larval forms of
10735 insects.
- 10736 **Best Management Practices (BMPs)** – Practices or methods used to prevent or reduce amounts
10737 of nutrients, sediments, chemicals, or other pollutants from entering water bodies from human
10738 activities. BMPs have been developed for agricultural, silvicultural, construction, and urban
10739 activities (e.g. stormwater treatment).
- 10740 **Bioavailable** – Able to be taken up by living organisms, usually refers to plant uptake of nutrients.
- 10741 **Biocontrol** – Management using biological organisms, such as fish, insects or micro-organisms
10742 like fungi or bacteria.
- 10743 **Biological Oxygen Demand (BOD)** – The demand for oxygen expressed by substances in water.
10744 BOD is related to the organic content of water, with water high in organic content consuming more
10745 oxygen than water low in organic content due to the decomposition activity of bacteria. BOD is
10746 routinely measured for wastewater effluents and is often important near the bottom of lakes.
- 10747 **Biotic** – Pertaining to biological factors or influences, concerning biological activity.
- 10748 **Buffers** – Small areas or strips of land (usually with permanent vegetation) that are designed and/or
10749 used to intercept and reduce the movement of sediment, nutrients, and toxic materials into adjacent
10750 waterbodies.
- 10751 **Catadromous** – A species that spawns in saltwater but lives most of its life cycle in freshwater.
- 10752 **Chlorophyll-a (Chl-a)** – Major light gathering pigment of all photosynthetic organisms imparting
10753 the characteristic color of green plants. Its relative measurement in natural waters is indicative of
10754 the concentration of algae in the water. Other types of chlorophyll exist but only chl-a is common
10755 to all plants.

- 10756 **Cold Water Fishery (CWF)** – Designated waters suitable for supporting cold water fish such as
10757 trout, defined by having adequately low temperature and sufficiently high oxygen.
- 10758 **Color** – Color is determined by visual comparison of a sample with solutions of known
10759 concentrations of colored solutions and is expressed in standard units of color. Color in lake waters
10760 is related to solids, including algal cell concentration, and dissolved substances.
- 10761 **Concentration** – The quantity of a given constituent in a unit of volume or weight of water.
- 10762 **Conductivity** – The measure of the total ionic concentration of water. Water with high total
10763 dissolved solids (TDS) level would have a high conductance. A conductivity meter tests the flow
10764 of electrons through the water which is heightened in the presence of electrolytes. Conductivity
10765 is proportional to dissolved solids but does not indicate the nature of those solids.
- 10766 **Conservation and Management Permit (CMP)** – A permit issued under the MESA that allows
10767 a project to occur when there is potential for loss of individuals of a listed species (a Take). A
10768 CMP sets the approach and conditions to be applied to avoid or minimize harm to listed species.
- 10769 **Contact herbicide** – An herbicide that causes localized injury or death to plant tissues with which
10770 it comes into contact. Contact herbicides do not usually kill the entire plant, often leaving root
10771 systems intact.
- 10772 **Cubic Feet per Second per square Mile (CFSM)** – A measure of water yield from a watershed
10773 as a longer term average, typically between 1.3 and 17 cfsm for watersheds in MA.
- 10774 **Decomposition** – The metabolic breakdown of organic matter, releasing energy and simple
10775 organic and inorganic compounds which may be utilized by the decomposers themselves (e.g.,
10776 bacteria and fungi).
- 10777 **Detritus** – Settleable material suspended in the water or at the surface of the sediment. Mostly
10778 organic particulates from the decomposition of the remains of organisms, more rarely refers to
10779 inorganic mineral materials.
- 10780 **Diadromous** – spending part of a life cycle in freshwater and part in saltwater; anadromous fish
10781 spawn in freshwater but spend most of their lives in saltwater, while catadromous species spawn
10782 in saltwater but spend most of their lives in freshwater.
- 10783 **Dissolved Oxygen (DO)** – A measure of the amount of oxygen gas dissolved in water and
10784 available for use by aquatic life. Water temperature significantly affects the amount of oxygen
10785 which water can contain with an inverse relationship (higher temperature means lower oxygen).
10786 Biological activity also affects localized DO levels, with photosynthesis raising oxygen and
10787 decomposition lowering it.
- 10788 **Dissolved Phosphorus (DP)** – Soluble or filterable fraction of phosphorus in a waterbody.

Glossary

- 10789 **Drainage basin** – The area drained by, or contributing to, a stream, lake, or another waterbody
10790 (see watershed).
- 10791 **Drawdown** – Decreasing the level of standing water in a waterbody to expose bottom sediments
10792 and rooted plants. Water level drawdown can be accomplished by physically releasing more water
10793 through a controlled outlet structure than enters from inlets.
- 10794 **Dredging** – Physical methods of digging into the bottom of a waterbody to remove sediment or
10795 other material. Dredging can be performed using conventional excavation or hydraulic equipment.
- 10796 **Ecological Restoration Project (ERP)** – A project that has as its primary purpose the restoration
10797 or enhancement of resource areas as defined under the WPA that support the interests of that act.
- 10798 **Ecological Restoration Limited Project (ERLP)** – An ERP that may have temporary or
10799 permanent adverse impacts on resource areas or interests of the WPA but qualify for consideration
10800 based on overall benefit under the WPA.
- 10801 **Ecology** – Scientific study of relationships between organisms and their surroundings
10802 (environment).
- 10803 **Ecoregions** – Defined areas of common climate, geophysical origins, and environmental
10804 similarities.
- 10805 **Ecosystem** – A dynamic association of communities of living organisms and their physical
10806 environment. Boundaries are arbitrary and must be stated or implied, but the components of an
10807 ecosystem interact.
- 10808 **Emergent plants** – Aquatic plants that are rooted or anchored in the sediment around shorelines,
10809 but have stems and leaves extending well above the water surface (e.g., cattails and bulrushes).
- 10810 **Epilimnion** – The upper water layer in a thermally stratified lake, typically the upper 15 to 20 feet.
- 10811 **Eradication** – Complete removal of a specific organism from a specified location, usually refers
10812 to a noxious, invasive species. Under most circumstances, eradication of a population from a site
10813 is very difficult to achieve.
- 10814 **Estimated Habitat** – Habitat for wetland wildlife species that are listed species under the MESA.
10815 A subset of MESA Priority Habitat established under the WPA which includes vertebrates that
10816 utilize wetland resources.
- 10817 **Erosion** – The removal of soil from the land surface, typically by stormwater runoff.
- 10818 **Eutrophic** – High nutrient, high productivity trophic state generally associated with unbalanced
10819 ecological conditions and poor water quality, but high productivity is not inherently undesirable if
10820 biological communities are structured to process production through the food web.

Glossary

- 10821 **Eutrophication** – Process by which a body of water ages, most often passing from a low nutrient
10822 concentration, low productivity state to a high nutrient concentration, high productivity state.
10823 Eutrophication is a long-term natural process, but it can be greatly accelerated by human activities,
10824 in which case it is called cultural eutrophication.
- 10825 **Exotic** – Refers to species of plants or animals that are not native to a particular region into which
10826 they have moved or invaded (e.g., fanwort, Eurasian watermilfoil, Brazilian elodea), also referred
10827 to as non-indigenous or non-native. Exotic species are not necessarily invasive (see invasive).
- 10828 **Fecal coliform bacteria** – Bacteria of the coliform group that are present in the intestines or feces
10829 of warm-blooded animals. They are often used as indicators of the sanitary quality of water. Their
10830 concentrations are expressed as number of colonies formed in a lab per 100 ml of sample and
10831 standards are set based on those results.
- 10832 **Fetch** – The longest linear dimension in a lake basin that wind can affect and which is often
10833 correlated to wave heights.
- 10834 **Fishkill** – An event when a large number or concentration of dead fish are observed in a location
10835 and which may be due to either natural or anthropogenic causes or a combination of both. In MA,
10836 a fishkill is defined as 100 fish in total or 50 of any one species found at one time in a waterbody.
- 10837 **Floating-leafed plant** – Plants with leaves floating on the water surface, yet are rooted or attached
10838 to sediments by long, flexible stems. Waterlilies are examples of rooted floating-leafed plants.
- 10839 **Flushing rate** – Term describing rate of water volume replacement of a waterbody, usually
10840 expressed as the number of times per year the volume of a waterbody is replaced. The inverse of
10841 the flushing rate is the (hydraulic) detention time. A lake with a flushing rate of 2 lake volumes
10842 per year has a detention time of 0.5 year.
- 10843 **Food Chain** – A linear characterization of energy and chemical flow through organisms such that
10844 the biota can be separated into functional units with nutritional interdependence. Can be expanded
10845 to a more detailed characterization with multiple linkages, called a food or trophic web.
- 10846 **Free-floating plants** – Plants that float on or under the water surface, unattached by roots to the
10847 bottom. Some have small root systems that simply hang beneath the plant. Water hyacinth,
10848 duckweed, and bladderwort are examples of free-floating plants.
- 10849 **Grass carp** – Also known as white amur, grass carp (*Ctenopharyngodon idella*) is a large,
10850 vegetation-eating member of the minnow family. Introduction of grass carp is prohibited in MA.
- 10851 **Great Pond** – In MA, any pond or lake which is greater than 10 acres in its natural (original) state.
- 10852 **Groundwater** – Water in the soil or underlying strata, subsurface water.
- 10853 **Habitat** – The physical place where an organism lives, encompassing all the features that interact
10854 with the organism.

- 10855 **Hardness** – A physical-chemical characteristic of water that is commonly recognized by the
10856 increased quantity of soap required to produce lather. It is attributable to the presence of alkaline
10857 earth elements (principally calcium and magnesium) and is expressed in calcium carbonate
10858 (CaCO_3) equivalents.
- 10859 **Herbicide** – A chemical used to suppress the growth of or kill plants.
- 10860 **Humic substances** – Compounds that form much of the organic matter of sediments and water.
10861 They consist of amorphous brown or black colored organic complexes.
- 10862 **Hydraulic Retention Time (HRT)** – The period of detention of water in a basin. The inverse of
10863 detention time is flushing rate. A lake with a detention time of 0.5 year has a flushing rate of 2 lake
10864 volumes per year.
- 10865 **Hydrologic cycle** – The circuit of water movement from the atmosphere to the earth and return to
10866 the atmosphere through various stages or processes such as precipitation, interception, runoff,
10867 infiltration, percolation, storage, evaporation, and transpiration.
- 10868 **Hypolimnion** – The cold, denser layer of water found at the bottom of a thermally stratified lake,
10869 below the thermocline.
- 10870 **Impervious** – Not permitting penetration or percolation of water. Concrete and asphalt are
10871 manmade impervious materials, but natural clays or dense organic matter can also be impervious.
- 10872 **Integrated aquatic plant management** – Management using the best combination of plant
10873 control methods that optimizes target species control, maximizes beneficial uses, minimizes
10874 environmental impacts and optimizes overall costs.
- 10875 **Intermittent** – Discontinuous flow, usually referring to the seasonal flow of a stream or swale
10876 through a drainage path that may be dry at times.
- 10877 **Internal loading** – Process by which nutrients, especially phosphorus, are released from sediments
10878 into the water column and which can available to sponsor algal growth. For some lakes, internal
10879 loading is a significant portion of the lake's annual phosphorus budget. There are multiple modes
10880 of internal loading, but release of iron-bound phosphorus under low oxygen conditions is a primary
10881 pathway in many lakes.
- 10882 **Invasive** – A plant or animal species that is not native to a region, invades, and causes ecological
10883 or economic damage. Not all non-native species are invasive, but those that are can cause
10884 impairment of uses and loss of species diversity, among other problems.
- 10885 **Kettlehole lake** – A kettlehole lake is a waterbody formed by a topographic depression produced
10886 by the melting of a stagnant block of glacial ice and the subsequent downward and inward collapse
10887 of deposited material.

Glossary

- 10888 **Leaching** – Process whereby nutrients and other substances are removed from matter (usually soil
10889 or vegetation) by water. Most often this is a chemical replacement action, prompted by the quality
10890 of the water.
- 10891 **Legacy contaminants** – Toxic or nuisance materials in lake sediments which are present due to
10892 historical inputs from watershed activities, particularly industrial pollutants or stormwater runoff.
- 10893 **License to Apply Chemicals (WM04)** – The permit issued by MassDEP that allows herbicides,
10894 algaecides or any other chemical substance (e.g., P inactivators) to be applied to water in MA.
10895 Application requires prior approval of an OOC under the WPA.
- 10896 **Limiting nutrient** – Essential nutrient needed for growth of plants which is the scarcest in the
10897 environment relative to the needs of the plant. Oftentimes, in freshwater systems, either
10898 phosphorus or nitrogen may be the limiting nutrient for plant growth. The chemical form in which
10899 the nutrient occurs and the nutritional requirements of the plants involved often determine whether
10900 a nutrient is limiting or not. Not all plants and algae are limited by the same nutrient at the same
10901 time.
- 10902 **Limnology** – The comprehensive study of lakes, encompassing physical, chemical and biological
10903 lake conditions and related processes.
- 10904 **Littoral Zone** – Shallow zone occurring near the land-water interface of aquatic ecosystems. It
10905 extends from the shoreline outward to the greatest depth occupied by rooted aquatic plants (usually
10906 due to light limitation), generally defined as two to three times the Secchi transparency depth,
10907 rarely beyond 20 feet (6 m) in MA.
- 10908 **Loading** – Inputs into a receiving water that may exert a detrimental effect on water quality and
10909 some subsequent use of that water.
- 10910 **Macroalgae** – Large, easily seen (macroscopic) algae. The macro-alga *Nitella* sp. sometimes
10911 forms dense plant beds and can be a conspicuous member of the aquatic macrophyte community.
- 10912 **Macrofauna** – A general term which refers to animals which can be seen with the naked eye or
10913 without the aid of a microscope.
- 10914 **Macrophyte** – Higher plant, macroscopic plant, usually a vascular plant that may bear flowers
10915 and seeds, but also including some more advanced algae (e.g., Chara, Nitella) or even filamentous
10916 algal mats large enough to be easily visible..
- 10917 **MA Endangered Species Act (MESA)** – The regulatory basis for the identification and protection
10918 of rare plant and animal species and their priority habitats as well as procedural review and
10919 assessment of potential impacts that proposed projects may pose.
- 10920 **“MegaManual”** – Interactive guide and MassDEP website to help facilitate prevention and
10921 control of nonpoint source pollution in MA.

Glossary

- 10922 **Mesocosm** – An experimental chamber, either in a controlled environment or under field
10923 conditions, but separate from the overall system which it is intended to represent and allowing
10924 testing of some influence (e.g., effect of an herbicide) without risk to the whole system represented.
- 10925 **Mesotrophic** – An intermediate trophic state, with variable but moderate nutrient concentrations
10926 and productivity, typically with healthy plant and fish populations and supportive of multiple water
10927 uses.
- 10928 **Metalimnion** – The water layer exhibiting rapid temperature transition found in a thermally
10929 stratified lake and zone between the upper epilimnion and lower hypolimnion. The thermocline is
10930 the point of greatest temperature difference between any two depth increments within the
10931 metalimnion.
- 10932 **Micrograms per liter (ug/L)** – A unit expressing the concentration of chemical constituents in
10933 solution as mass (micrograms) of solute per unit volume (liter) of water. One thousand micrograms
10934 per liter is equivalent to one milligram per liter.
- 10935 **Micronutrients** – Elements typically found in low concentrations in natural waters (e.g., iron,
10936 silicon, cobalt, magnesium) which are critical to sustaining growth of primary producers,
10937 particularly algae but are not needed in large quantities. Micronutrients can be limiting nutrients
10938 in some cases.
- 10939 **Million Gallons per Day (MGD)** – Million gallons per day, a measure of flow. 1 MGD = 1.54
10940 cubic feet per second.
- 10941 **Mitigation** – Actions taken to replace or enhance animals or plants that may have been damaged
10942 or removed by certain prior activities.
- 10943 **Morphology** – Study of shape, configuration, or form, often used to describe plant or animal
10944 features.
- 10945 **Municipal Separate Storm Sewer System (MS4)** – A collection system for stormwater that does
10946 not include domestic or industrial wastewater, regulated under the NPDES program.
- 10947 **National Pollutant Discharge Elimination System (NPDES)** – A program established under
10948 federal law to reduce the discharge of pollutants into waters of the United States. Permits may be
10949 granted for a variety of discharges, subject to restrictions, with authority delegated to many states
10950 but not MA.
- 10951 **Natural Heritage and Endangered Species Program (NHESP)** – MassWildlife unit responsible
10952 for administration of MESA regulations.
- 10953 **Nitrate (NO₃)** – A form of nitrogen used by plants as a source of nitrogen to build amino acids
10954 and proteins, end product in the aerobic decomposition of nitrogenous matter. Nitrogen in this
10955 form is stable and readily available to plants.

- 10956 **Nitrite (NO₂)** – A form of nitrogen that is the oxidation product of ammonium. It is rapidly
10957 converted to nitrate in the presence of oxygen by certain bacteria. The presence of nitrite-nitrogen
10958 usually indicates that active decomposition and conversion of nitrogen forms is taking place (i.e.,
10959 fresh contamination).
- 10960 **Nitrogen (N)** – A macronutrient which occurs mainly in the forms of organic nitrogen, ammonium
10961 nitrogen, nitrite nitrogen and nitrate nitrogen. Form of nitrogen is related to a successive
10962 decomposition reaction, each dependent on the preceding step, and the progress of decomposition
10963 can be determined in terms of the relative amounts of these four forms of nitrogen.
- 10964 **Non-point (pollutant) source (NPS)** – A diffuse source of water pollution that does not discharge
10965 through a pipe or other readily identifiable structure. Non-point pollution typically originates from
10966 activities on land or water. Examples of non-point sources include agriculture, construction sites,
10967 marinas, urban streets, and residential properties.
- 10968 **Non-target species** – A species not intentionally targeted for control by any method applied to
10969 control some target species.
- 10970 **Notice Of Intent (NOI)** – Forms and documents proposing activities in areas identified as
10971 resources under the MA WPA, subject to review by local conservation commissions, MassDEP,
10972 and possibly other state agencies prior to approval or denial of the proposed action(s).
- 10973 **Noxious weed** – Non-native plant species that, because of aggressive growth habits, can threaten
10974 native plant communities, wetlands, or agricultural lands, or any designated use of a waterbody.
- 10975 **Nutrients** – Elements or compounds which act as fertilizers or growth stimulants for aquatic
10976 organisms. Small amounts are necessary to the ecological balance of a waterbody, but excessive
10977 amounts can upset the balance by causing excessive growths of algae and aquatic vascular plants.
10978 Sewage discharged to a waterbody usually contains large amounts of carbon, nitrogen, and
10979 phosphorus. Stormwater runoff often contributes substantial nutrient loadings to receiving waters.
- 10980 **Oligotrophic** – Low nutrient concentration, low productivity trophic state, often associated with
10981 very desirable water quality, but not necessarily an ideal condition, since often only minimal
10982 aquatic life can be supported.
- 10983 **Order of Conditions (OOC)** – The set of generic and project specific conditions associated with
10984 implementation of an approved Notice of Intent (NOI) application, forming the basis of an
10985 approved project under the MA WPA.
- 10986 **Organic** – Containing a substantial percentage of carbon derived from living organisms; of a living
10987 organism.
- 10988 **Outstanding Resource Water (ORW)** – Any lake, stream, or other waterbody designated by
10989 MassDEP as a high quality aquatic environment with high sensitivity to pollutant inputs and
10990 therefore accorded additional protection under the law.

- 10991 **Overtturn** – The vertical mixing of major layers of water caused by seasonal changes in
10992 temperature. In temperate climate zones, overturn typically occurs in spring and fall.
- 10993 **Oxidation** – A chemical process that can occur through the uptake of oxygen.
- 10994 **Oxygen deficit** – A situation in lakes where respiratory demands for oxygen exceeds its production
10995 via photosynthesis or its input from the drainage basin or atmosphere, leading to a decline in
10996 oxygen content.
- 10997 **pH** – The negative logarithm of the hydrogen ion concentration. A hydrogen concentration scale
10998 from 0 (acidic) to 14 (basic) is used to characterize water solutions. Pure water is neutral at pH
10999 7.0.
- 11000 **Phosphorus (P)** – A macronutrient which most often appears in waterbodies in combined forms
11001 known as ortho- and poly-phosphates and organic phosphorus. Stormwater runoff from highly
11002 urbanized or agricultural areas, septic system leachate, and lake bottom sediments all may
11003 contribute phosphorus. A critical plant nutrient which is often targeted for control in eutrophication
11004 prevention or mitigation plans.
- 11005 **Photic Zone** – Illuminated zone, surface to depth beyond which light no longer penetrates at an
11006 intensity adequate to support photosynthesis. Generally equated with the zone in which
11007 photosynthetic algae can survive and grow, based on adequate light supply.
- 11008 **Photosynthesis** – Process by which primary producers make organic molecules (generally
11009 glucose) from inorganic ingredients, using light as an energy source. Oxygen is released by this
11010 process as a byproduct.
- 11011 **Phytoplankton** – Algae which are suspended, floating or moving only slightly under their own
11012 power in the water column. Often this is the dominant algal form in standing waters.
- 11013 **Plankton** – The community of suspended, floating, or weakly swimming organisms that live in
11014 the open water of lakes and rivers, including algae and small fauna.
- 11015 **Point (pollutant) Source (PS)** – A source of pollutants or contaminants that discharges through a
11016 pipe, culvert, or other identifiable but confined delivery mode. Point sources, such as industrial or
11017 sewage outfalls, are usually readily identified. Stormwater discharges via pipes on designated
11018 urban areas are defined as PS under the federal Clean Water Act.
- 11019 **Pollution** – Undesirable alteration of the physical, chemical, or biological properties of water,
11020 addition of any substance into water by human activity that adversely affects its quality. Prevalent
11021 examples are thermal, heavy metal, nutrient, and bacterial pollution.
- 11022 **Pollutant** – A contaminant, a substance that is not naturally present in water or occurs in unnatural
11023 amounts that can degrade the physical, chemical, or biological properties of the water. Pollutants
11024 can include human-derived chemicals, disease-producing organisms, silt, toxic metals, or oxygen-
11025 demanding materials.

- 11026 **Potable** – Water usable for drinking purposes, fit for human consumption.
- 11027 **Primary production** – Conversion of inorganic matter to organic matter by photosynthesizing
11028 organisms, typically the creation of biomass by plants (macrophytes and algae). It involves the
11029 formation of organic matter or sugars in plant cells from light, water and carbon dioxide.
- 11030 **Priority Habitat** – Mapped habitat for listed species under the MESA, afforded protection and
11031 necessitating review and approval of projects proposed within such habitat.
- 11032 **Public awareness/outreach** – Programs designed to share technical information and data on a
11033 particular topic, usually associated with activities (such as management) on or around a waterbody.
- 11034 **Rapid Response Plan (RRP)** – An approved program of treatment (physical or chemical) to
11035 eradicate or limit the spread of a recently detected, non-indigenous aquatic species to a waterbody
11036 (can be plant or animal).
- 11037 **Riparian** – Of, or related to, or bordering a watercourse.
- 11038 **Runoff** – Water and its various dissolved substances or particulates that flow over the surface of
11039 land in an unchanneled path toward channeled and usually recognized waterways (such as a stream
11040 or river).
- 11041 **Secchi disc** – Typically a 20-cm (8-inch) diameter disc painted white and black in alternating
11042 quadrants. It is used to measure light transparency in lakes. Secchi Disk Transparency (SDT) is
11043 the average of (1) the depth at which the disk lowered into the water is no longer visible and (2)
11044 the depth at which it is visible again when raised.
- 11045 **Secondary productivity** – The growth and reproduction (creation of biomass) by herbivorous
11046 (plant-eating) organisms, the second level of the food web or trophic system.
- 11047 **Sediment** – Solid material and substrate deposited in the bottom of a lake basin.
- 11048 **Sedimentation** – The process of settling and deposition of suspended matter carried by water or
11049 other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below
11050 the point at which it can transport the suspended material.
- 11051 **Sensitive areas** – Critical areas in the landscape, such as wetlands, aquifer recharge areas, and fish
11052 and wildlife habitat conservation areas. In MA, the Natural Heritage Endangered Species Program
11053 (NHESP) identifies priority habitats for threatened or endangered species as sensitive areas in need
11054 of protection.
- 11055 **Sewage** – Human wastes from residences, industrial/commercial establishments or other places
11056 used by humans, typically routed to treatment facilities as a slurry with water in pipes. Sometimes
11057 applied to animal wastes, which are more often called manure.
- 11058 **Specific conductance** – The measure of a water sample's capacity to convey an electric current
11059 providing a generalized measure of the inorganic dissolved substance content of the water. It is

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11060 dependent on temperature and the concentration of ionized substances in the water. Distilled water
11061 exhibits specific conductance of 0.5 to 2.0 microSiemens per centimeter (uS/cm), while natural
11062 waters tend to yield values from 50 to 500 (uS/cm). In typical New England lakes, specific
11063 conductance usually ranges from 100-300 (uS/cm).

11064 **Stakeholders** – The collective group of individuals, businesses, agencies, and organizations who
11065 have an interest in the condition and/or management of a particular waterbody.

11066 **Storm sewer** – A pipe or ditch which carries storm water and surface water but excludes sewage
11067 and industrial wastes.

11068 **Submersed plant** – An aquatic plant that grows with all or most of its stems and leaves below the
11069 water surface. Submersed plants usually grow rooted in the bottom and have thin, flexible stems
11070 supported by the water. Reproductive parts may protrude above the water surface. Common
11071 submersed plants are milfoils and pondweeds.

11072 **Substrate** – The base of material on which an organism lives, such as cobble, gravel, sand, muck,
11073 and silt.

11074 **Surface water** - Refers to lakes, bays, sounds, ponds, reservoirs, springs, rivers, streams, creeks,
11075 estuaries, marshes, inlets, canals, oceans and all other natural or artificial, inland or coastal, fresh
11076 or salt, public or private waters at ground level.

11077 **Susceptibility** – The sensitivity or level of injury demonstrated by a plant to effects of a control
11078 agent such as an herbicide.

11079 **Suspended Solids** – Materials which can be removed by passing the water through a filter. The
11080 remaining solids are called dissolved solids. Suspended solids loadings are generally high in
11081 stream systems which are actively eroding a watershed. Excessive stormwater runoff often results
11082 in high suspended solids loads to lakes. Many other pollutants such as phosphorus are often
11083 associated with suspended solids loadings.

11084 **Systemic herbicide** – An herbicide in which the active chemicals are absorbed and translocated
11085 within the entire plant system, including the roots. Depending on the active ingredient, systemic
11086 herbicides affect certain biochemical reactions in the plant that can cause complete plant death.

11087 **Take** – Loss of any individual of a listed species under the MESA. MESA regulations require
11088 proposed projects to avoid or minimize such loss of protected species, with review and
11089 determination of impacts by the NHESP.

11090 **Taxon** – Any hierarchical division of a recognized classification system, such as a genus or
11091 species. The plural is taxa.

11092 **Thermal stratification** – Horizontal layering of water in a lake caused by temperature-related
11093 differences in density. A thermally stratified lake is generally divided into the epilimnion
11094 (uppermost, warm, mixed layer), metalimnion (middle layer of rapid change in temperature and

- 11095 density) and hypolimnion (lowest, cool, least mixed layer). In most lakes, seasonal changes in
11096 temperature will reverse this process after summer, resulting in the mixing of the entire water
11097 column.
- 11098 **Thermocline** – Boundary level between the epilimnion and hypolimnion of a stratified lake, the
11099 point of maximum temperature change within the metalimnion, and generally approximating the
11100 maximum depth of mixing by wind. Light may penetrate beyond the thermocline.
- 11101 **Title 5** – MA regulations (310 CMR 15.000) that provide specifications for the siting, construction,
11102 upgrade, and maintenance requirements of onsite sewage disposal systems.
- 11103 **Topographic map** – A map showing elevation of the landscape in contours of equal height
11104 (elevation) above sea level. This can be used to identify boundaries of a watershed.
- 11105 **Total Maximum Daily Load (TMDL)** – The calculation of the maximum amount of a pollutant
11106 allowed to enter a waterbody so that the waterbody will meet water quality standards for that
11107 particular pollutant. A TMDL is often developed for use in management planning in the
11108 rehabilitation of lakes.
- 11109 **Total Phosphorus (TP)** – all fractions (organic + inorganic) of phosphorus in a waterbody
- 11110 **Tributaries** - Rivers, streams or other channels that flow into a waterbody.
- 11111 **Trophic state** – The stage or condition of an aquatic system, characterized by biological, chemical,
11112 and physical parameters. Overall term used to describe the productivity of the lake ecosystem and
11113 classify it as oligotrophic (low productivity), mesotrophic (moderate productivity), or eutrophic
11114 (high productivity).
- 11115 **Trophic State Index (TSI)** – A convenient semi-quantitative way to classify the trophic state of
11116 a lake through comparison of ambient values of key indicators (i.e., phosphorus and/or nitrogen
11117 fractions, chl-*a*, and Secchi transparency) to previously established criteria or thresholds.
- 11118 **Turbidity** – Measure of the clarity of a water sample, typically expressed in Nephelometric
11119 Turbidity Units which are related to the scattering and absorption of light by the water sample.
11120 Turbidity is usually related to total dissolved solids in a water sample.
- 11121 **Vascular plant** – A photosynthetic organism with specialized cells that conduct fluids and
11122 nutrients throughout the plant. The xylem conducts water and the phloem transports food. Most
11123 vascular plants have roots, stems, and leaves.
- 11124 **Water quality** – A term used to describe the chemical, physical, and biological characteristics
11125 of water, usually with respect to its suitability for a particular purpose or use.
- 11126 **Water Quality Certification** – The process under Section 401 of the federal Clean Water Act
11127 as administered by MassDEP whereby projects can be approved as being consistent with state

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- 11128 and federal water quality standards. This is mostly applied to dredging projects and links to
11129 Section 404 of the Clean Water Act, administered by the USACE.
- 11130 **Water quality swales** – Vegetated open channels designed to process the estimated water
11131 quality volume from a site, conveying runoff from a design storm without causing erosion and
11132 allowing processes to reduce pollutant content of the conveyed water.
- 11133 **Watershed (or drainage basin)** – A geographical area or region that contributes surface water to
11134 a stream or lake. Watershed slopes and contours carry surface flows by gravity to a common outlet.
11135 The definition can also be applied to subsurface flow in groundwater, although boundaries are
11136 harder to delineate.
- 11137 **Watershed-Based Plan (WBP)** – Conceptual framework and process to address water quality
11138 problems and identify potential watershed activities to be managed to improve currently impaired
11139 waters.
- 11140 **Watershed management** – The management of land within a drainage basin for the protection or
11141 rehabilitation of water-based resources.
- 11142 **Wetland** – A generalized term for a broad group of wet habitats. Wetlands are areas of vegetation
11143 that are transitional between land and water bodies and range from being permanently wet to
11144 intermittently water covered. In MA, lakes are defined as a type of wetland and subject to
11145 regulation under the WPA.
- 11146 **Wetland Protection Act (WPA)** – MA legislation that protects aquatic environments and
11147 authorizes related regulations that establish procedures for conservation commissions and
11148 MassDEP to follow in issuing permits for work in resource areas protected under the WPA.
- 11149 **Zooplankton** – Microscopic animals suspended in the water, including mainly protozoa, rotifers,
11150 cladocera, and copepods, but incorporating other small invertebrates with limited swimming
11151 ability as well.
11152

Appendix C: The Cost of Lake and Watershed Management

Developing representative cost estimates for the application of lake and watershed management techniques is a complicated process with many factors to consider. Yet beyond applicability of a technique to a particular lake problem, public acceptability, and attainability of permits, cost is a major factor in technique selection. It is best to cost out techniques with full awareness of the site-specific conditions and/or limitations and how those will affect cost, as the dollar range for any given technique can be quite large (Table C1). Factors that are likely to have a major impact on cost include:

- Project scale – Larger projects will cost more than smaller projects, although they often have a lower cost per unit area addressed, an economy of scale.
- Project area and in-lake location – The size and configuration of the project area (e.g., one large contiguous area vs. several smaller, separated plots) will affect application efficiency and schedule. The distance between the actual target zone and any input or loading site within the lake will also affect cost for actions like plant harvesting or P inactivation.
- Water depth – The depth of the water column affects the cost of techniques such as circulation, dredging, and water column P inactivation.
- Plant density – The density of the plant community will impact the effort needed for control, especially for forms of harvesting.
- Oxygen demand – The higher the oxygen demand, the more oxygen must be supplied, affecting oxygenation costs.
- Outlet configuration – Any need to modify an existing outlet structure to support techniques like drawdown or selective withdrawal can greatly increase costs.
- Choice of chemical – Which herbicide or P inactivator is chosen affects product cost and there may be tradeoffs between effectiveness, duration of control, and cost.
- Dose – The amount of any chemical needed per unit area will substantially affect costs.
- Frequency of application – How often an action is needed will impact cost over any standardized time period (e.g., a decade as used in Table A1).
- Travel distances – Cost will be a function of how far an essential piece of equipment or service provider must travel to reach the project site or how far any removed materials (e.g., sediment, plant biomass) must be transported for disposal.
- Material quality – The quality of any material that must be disposed, most often sediment or plants, after removal from a lake can affect disposal options and related cost.
- Labor – Prevailing wage rates may vary geographically, seasonally, and by availability for the skills necessary to perform a project. Volunteer programs are not considered here but can certainly reduce costs where the work can be done by volunteers.
- Land purchase – Buying land either to preserve key watershed features or install pollution control devices can greatly add to project cost.
- Site work – Many watershed techniques require site work for proper installation or maximum performance, and the initial state of the land on which the BMP is to be installed affects cost.

11192 Table C1. Cost of application of lake and watershed management techniques

		Capital Cost							
Technique		P Removed (\$/kg)	Areal Basis (\$/ac)	Other Listed Unit	Cost per Listed Unit (\$/unit)	Operational or Follow Up Cost (\$/ac or unit/yr)	Duration of Benefits (yr)	Cost for 10 yr program to address 100 ac (\$)	Notes
Techniques to reduce nutrient inputs									
Point source controls		500-5000		MGD treated	500,000-3,500,000	150-500	Indefinite	NA	Cost largely dependent on treatment method and target discharge concentration, limited economy of scale; cost independent of lake area but may be tied to development density in a watershed.
Non-point source controls									
	Source limitation	0-50,000	0-20,000			0-1500	Indefinite	0-2,000,000	Extreme range; regulatory restriction is least expensive, street sweeping is intermediate, buying out the land use is most expensive. Cost independent of lake area but linked to abundance of target source in watershed.
	Agricultural BMP - non-structural	0-100	0-50			0-50	1 (usually annual)	0-5000	Non-structural measures like nutrient management can actually reduce cost, while some practices have at least an opportunity cost (e.g., not growing crops on an area)
	Agricultural BMP - structural	100-2000	200-3000	Ac covered	5000-50,000	500-5000	5-10	7000-55,000	BMPs for agricultural land can be as simple as maintaining vegetative cover or buffer strips of appropriate width or as complicated as manure handling facilities, but carry labor and opportunity costs
	Inlet trapping - catch basin inserts	3000-10,000	2000-20,000	Installed system	500-10,000	100-500	Indefinite	25,000-250,000	Must be sized for drainage area, expensive to install, must be maintained
	Inlet trapping - hydrodynamic units	7000-25,000	5000-50,000	Installed system	10,000-200,000	500-2000	with maint.	15,000-220,000	
	Buffers and swales	1200-5500	150-1000	Ac covered	20,000-30,000	100-300	Indefinite with maint.	16,000-510,000	Engineering and maintenance essential for maximum and continued performance, cost greatly affected by land availability
	Detention	400-3500	1000-5000	Ac covered	25,000-75,000	500-1000	Indefinite with maint.	105,000-750,000	Need at least 2% of watershed area in detention, cost greatly affected by land availability. Failure to maintain will result in loss of benefits within 10 yr
	Infiltration	2000-7500	2000-42,000	MGD handled	1500-10,000	500-1000	Indefinite with maint.	205,000-4,000,000	More expensive if soils have to be amended to improve porosity; front end controls may be needed to avoid clogging and ground water contamination. Failure to maintain will result in loss of benefits within 10 yr
	Constructed wetlands	5000-25,000	2500-10,000	Ac covered	4000-100,000	300-1000	Indefinite with maint.	250,000-1,000,000	Engineering combines physical, chemical and biological processes for effective treatment; cost a function of land availability and prep needs and treatment of wastewater more expensive than for stormwater.
				MGD handled	150,000-250,000				
	On-site wastewater management	1000-1500	NA	Installed system	10,000-75,000	100-200	>50	210,000-4,000,000	Well sited and constructed septic systems remove all particulates, most P, but little N; engineering for maximum performance can be expensive
Techniques to reduce nutrient availability									
	Selective withdrawal	<100-1000	<100-2000	MGD capacity	0-250,000	0-200	Indefinite w/continued use	5000-500,000	Cost depends on existing outlet configuration, usually need to at least extend pipe into deeper water; any required treatment of discharge is also a cost factor
	P inactivation with Al - sediment	100-200	1000-5000	g/m2 per ac treated	45-60	NA	5-20	150,000-250,000	Cost per unit area varies mainly with dose; larger doses tend to be applied less frequently, evening out per unit cost over extended time period. \$/kg removed based on internal load prevention. Normally performed on contract basis, so equipment and labor combined under capital cost.
	P inactivation with Al - water	300-1000	500-2000	Ac-ft treated	50-150	NA	<1-4	150,000-500,000	Cost per unit area depends on depth and volume treated; treatment of water less efficient than for sediment. \$/kg removed based on actual removal from water. Normally performed on contract basis, so equipment and labor combined under capital cost.
	Artificial circulation	500-6500	1000-2500	Ac-ft addressed	100-300	100-300	Indefinite w/continued use	200,000-550,000	By pump or compressed air, more power and distribution needed for shallower lakes, power costs are main operational expense. \$/kg removed based on internal load prevention.
	Hypolimnetic oxygenation	1000-5000	2000-10,000	Ac-ft addressed	200-2000	200-500	Indefinite w/continued use	400,000-1,500,000	Cost depends mainly on oxygen demand and logistics of getting oxygen into deep water; main operational cost factor is ongoing power and/or oxygen supply. \$/kg removed based on internal load prevention.
	Dredging	70-200	30,000-250,000	Cubic yard	30-100	0-3000	20-50	1,000,000-25,000,000	Cost determined largely by quantity and quality (for disposal) of dredged material. Normally performed on contract basis, so equipment and labor combined under capital cost. Operational cost relates to any forebay cleaning to extend benefits.

11194 Table C1 (continued). Cost of application of lake and watershed management techniques

		Capital Cost							
Technique		P Removed (\$/kg)	Area Addressed (\$/ac)	Other Listed Unit of Cost	Cost per Listed Unit (\$/unit)	Operational or Follow Up Cost (\$/ac or unit/yr)	Duration of Benefits (yr)	Cost for 10 yr program to address 100 ac (\$)	Notes
Techniques to directly remove algae									
	Algaecides	NA	50-300	Ac-ft treated	10-30	NA	<1	50,000-300,000	Many formulations lead to variation of cost, peroxide more expensive than copper on unit basis
Techniques to inhibit vascular plants									
	Dredging	70-200	30,000-250,000	Cubic yard	30-100	0-5000	20-50	1,000,000-25,000,000	Cost determined largely by quantity and quality (for disposal) of dredged material. Normally performed on contract basis, so equipment and labor combined under capital cost. Operational cost relates to any forebay cleaning to extend benefits.
	Benthic barriers	NA	30,000-60,000			500-3000	10+	3,250,000-7,000,000	Material and labor costs can be substantial, but material lasts years so cost per unit area over time is not high; usually applied to small area
	Drawdown	NA	<50-200	Ac-ft removed	<10-50	<10-25	1-2	10,000-50,000	As long as an outlet structure capable of supporting drawdown is present, this is relatively inexpensive; drawdown is rarely conducted if pumping is involved or a new outlet has to be constructed, options not costed here.
Techniques to directly remove vascular plants									
	Hand harvesting	50-300	10-50			100-300	1-3	50,000-300,000	Cost is mostly a function of labor, usually by divers
	Diver-Assisted Suction Harvesting	400-4000	75-150			2000-3000	1-3	800,000-3,000,000	More equipment cost than for unaided hand harvesting, but diver labor is still the main cost factor
	Mechanical harvesting	650-4000	300-500			750-2500	<1-2	1,000,000-3,000,000	Capital cost of harvester amortized over 10 yr; operational cost mostly dictated by labor and equipment maintenance and is larger factor over 10 yr
	Hydroraking	2000-10,000	10,000-20,000	Cubic yard	30-100	NA	1-5	3,000,000-6,000,000	Range of cost largely a function of distance to offloading site and material disposal cost. Normally performed on contract basis, so equipment and labor combined under capital cost.
	Herbicides	NA	200-1300			NA	1-5	150,000-500,000	Varies by herbicide, formulation, dose, and area treated. Normally performed on contract basis, so equipment and labor combined under capital cost.
Alternative Techniques with Adequate Cost Info									
	Nutrient control								
	P inactivation with Phoslock	350-440	1500-8000	g/m2 per ac treated	15-20	NA	5-20	300,000-400,000	Cost related mainly to dose and area treated, usually more expensive than aluminum on basis of units of P addressed. Normally performed on contract basis, so equipment and labor combined under capital cost.
	Direct control of algae								
	Sonication	NA	350-1000	Installed system	10,000-100,000	50-100	5-10	100,000-250,000	Cost of units varies with areal coverage, power source, telemetry option; cost of power is ongoing factor unless solar buoy included, must be continuously operated for best results
	Direct control of algae and vascular plants								
	Dyes	NA	100-300	Ac-ft treated	25-80	NA	<1	100,000-300,000	Cost is largely dependent on depth of water treatment and degree of light reduction desired
Cost estimates are based on recent projects and extrapolations from some older ones; costs are considered valid as of 2023. For 10-yr, 100-ac application, capital and operational costs at necessary frequency are included.									
Costs do not include permitting, design engineering, or monitoring. Costs do not reflect any savings from volunteer labor; professional installation, application, and operation assumed.									
Efficiencies of scale will affect costs, with smaller projects tending to have higher unit costs while larger projects tend to have lower unit costs; a range of typical application scenarios is embodied in these estimates.									

The above factors contribute to the substantial range of costs within and among management techniques. Accordingly, an accurate cost estimate is only possible with considerable site-specific information. For that reason, one cannot usually declare that any technique applicable to a given lake problem is universally more or less expensive than others. For example, drawdown could be less expensive than herbicides for control of susceptible species, but only if the outlet does not need costly repairs or modifications to conduct the drawdown. And while multiple herbicides may control a given target species, the duration of control per herbicide application may vary among herbicides such that the cost differential decreases over time.

Not all techniques apply to all lake problems, and even within a group of applicable techniques there can be variation in effectiveness that overshadows any cost differential. Some techniques are focused on localized, small-scale application (e.g., benthic barriers) while other techniques are more geared for lake-wide application (e.g., certain herbicides, drawdown). Cost is clearly not the only factor in technique selection and should not be the first consideration, but having some idea what different techniques cost is necessary for realistic budgeting for proposed lake projects.

While using benthic barriers or hydroraking to control vascular plants in a swim area may provide results preferable to herbicides or mechanical harvesting, extrapolating application of these techniques to the hypothesized 100-acre application area used in Table C1 would be cost prohibitive, even if permits could be obtained. Hand harvesting carries a lower unit cost than diver-assisted suction harvesting, but a dense patch of target plants in deep water may not be amenable to effective hand harvesting, whereas diver-assisted suction harvesting was created for just that purpose. However, the manpower necessary to harvest a very large area over a short time period by either hand harvesting method may not be readily available, while mechanical harvesting or herbicides can be more rapidly and effectively applied, albeit at higher cost per unit area.

Where management focuses on reducing P input or availability in a lake, cost can be compared on the basis of amount of P removed or prevented from entering the lake, usually expressed as \$/kg or \$/lb. Most reliable estimates come from actual projects where costs were tallied and the actual P reduction was measured by pre- and post-implementation monitoring. These results indicate there are substantial differences in costs among techniques (Table C1). Non-structural actions (e.g., regulations, education, behavioral modification) are often inexpensive, as with regulations to restrict activities in sensitive areas, but can also carry very high costs where land or development rights must be purchased to preserve desirable qualities or future taxbase reduction may occur. Opportunity costs, as with farmers forgoing tilling land to create buffer strips near streams or lakeshores, are not considered here and can be substantial.

Among structural practices, the cost range can also be wide and both capital and operational expenses must be considered. In general, the cost of watershed management techniques is higher than for in-lake actions in terms of \$/kg P removed. Techniques such as buffers, swales, detention, infiltration, and constructed wetlands often carry capital costs greater than \$1000/kg and require periodic maintenance to maintain peak function, often on the order of hundreds of dollars per acre

of facility per year. In comparison, some in-lake techniques such as selective withdrawal, P inactivation of sediment, and dredging are far less costly per kg of P removed. Similarly, the minimum costs for many other in-lake techniques are often low but the range of cost is quite wide, indicating that many additional factors must be considered in developing cost estimates.

Cost information can be helpful in assessing whether a nutrient management program is least expensive, but such information can be secondary to consideration of the magnitude of various sources and the overall desirability of establishing control at the source. For example, one should not decide to address excessive loading with in-lake methods where a reasonable program of watershed management can be constructed, although for highly urban or agricultural watersheds maintenance measures in the lake may be needed even with aggressive watershed management. However, it makes little sense to embark on an expensive watershed management program if the original historic sources are much reduced or no longer exist and internal recycling is the dominant P source. In many cases, multiple methods must be applied to achieve desired load reductions.

Costing out a lake management program will need to consider capital cost, operational cost, frequency of application, and the duration and nature of all benefits. While not all techniques are equally appropriate to the same lake problems, calculating a cost range for a hypothetical area over a set period of time helps put the techniques on a comparable scale. In Table C1 a 100-ac target area and 10-yr timeframe (both arbitrarily selected) are uniformly applied. The range for each technique is still quite wide and there is considerable overlap between many techniques that could be applied to the same problem. Inexpensive lake management is elusive, but careful planning for cost-effective treatment is often the key to successful funding and implementation of lake improvements.

Techniques and associated costs can be grouped according to the problem they address. Where reduction in available P is desired to prevent algal blooms, a variety of in-lake and watershed techniques apply and can be compared based on cost per unit of mass of P made unavailable to algae (Figure C1). This figure is based on average costs and the many factors that can cause significant deviation from the average have already been discussed, but this figure provides a general comparison. However, this comparison does not reflect the effectiveness of the techniques. For example, the cost per kg of P removed is less for detention than infiltration, but detention will not remove as much dissolved P as infiltration and detention basins become sources of P faster than infiltration basins without maintenance. Source limitation (i.e., eliminating the source of the P) has an average cost that exceeds the graphic scale applied, mainly because land must be purchased or some use of it must be controlled or limited. Yet source limitation is the most effective way to limit P inputs to a lake and can sometimes be implemented by regulation at reasonable cost. Dredging is among the least costly techniques in terms of \$/kg P removed, but more P is removed than necessary, as only the upper inch or two of sediment interacts with the overlying water and dredging rarely removes <1 ft of sediment.

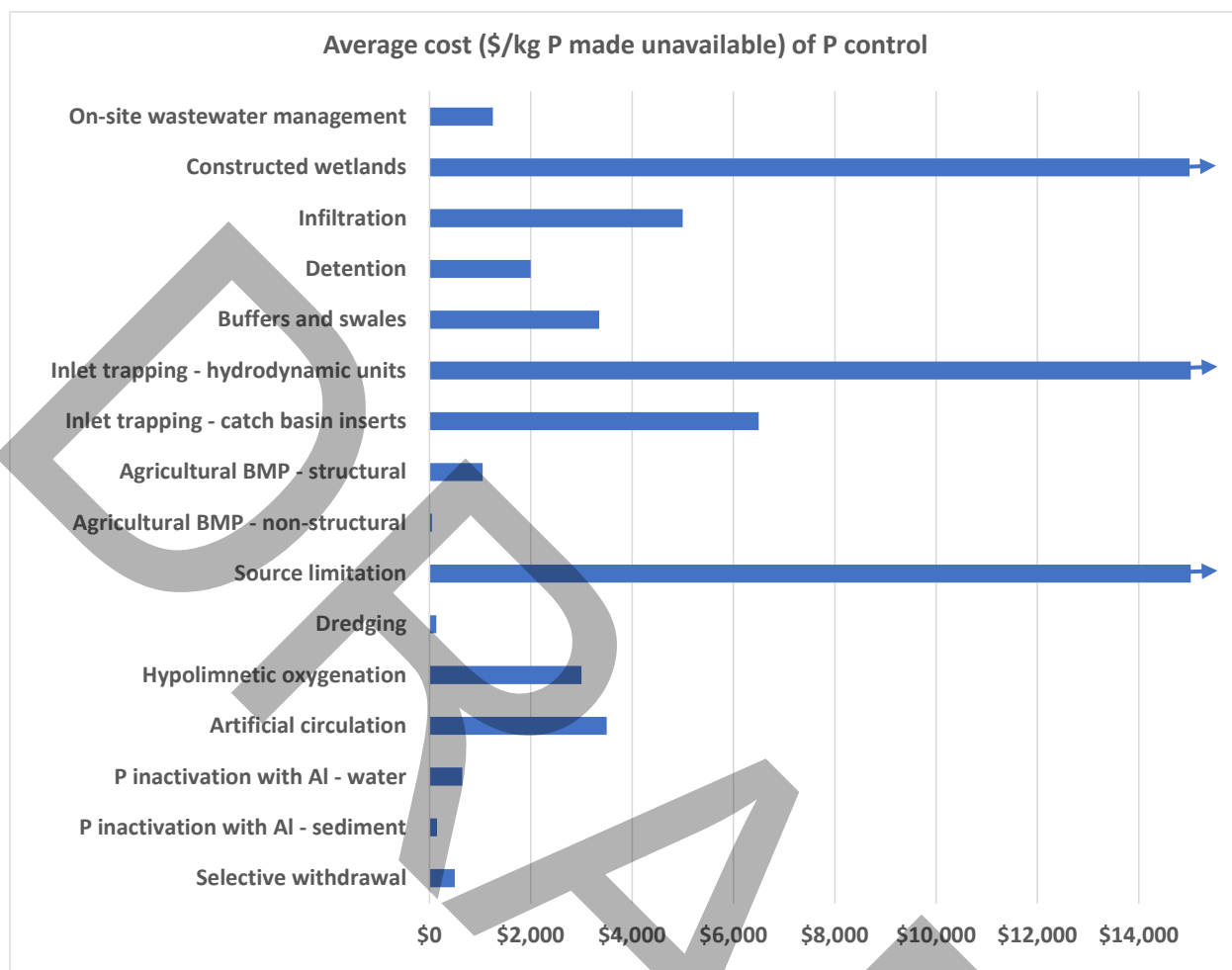


Figure C1. Average cost for phosphorus control by various techniques

Where internal loading of P must be reduced to prevent algal blooms, choices can be compared based on the cost per unit area over a set time period (Figure C2). Average costs suggest that selective withdrawal is the least expensive approach, but this comparison does not reflect effectiveness or additional constraints. Selective withdrawal takes many years to reduce internal loading P reserves, rarely removes enough P to eliminate blooms, and has potential downstream impacts that can make permitting difficult. Inactivation of P in surficial sediment with aluminum is typically a one-time event over at least a 10-yr period, while inactivation of P in the water column is repeated as needed based on flushing rate, usually annually, resulting in higher operational costs. Yet inactivation of P in the water column can counter external P loading and eventually inactivates enough sediment P to reduce internal P loading.

Figure C2 also does not reflect additional benefits of the listed techniques. Artificial circulation and hypolimnetic oxygenation are more expensive than inactivation of P in surficial sediment but add oxygen to deeper waters, limiting the accumulation of reduced substances such as iron,

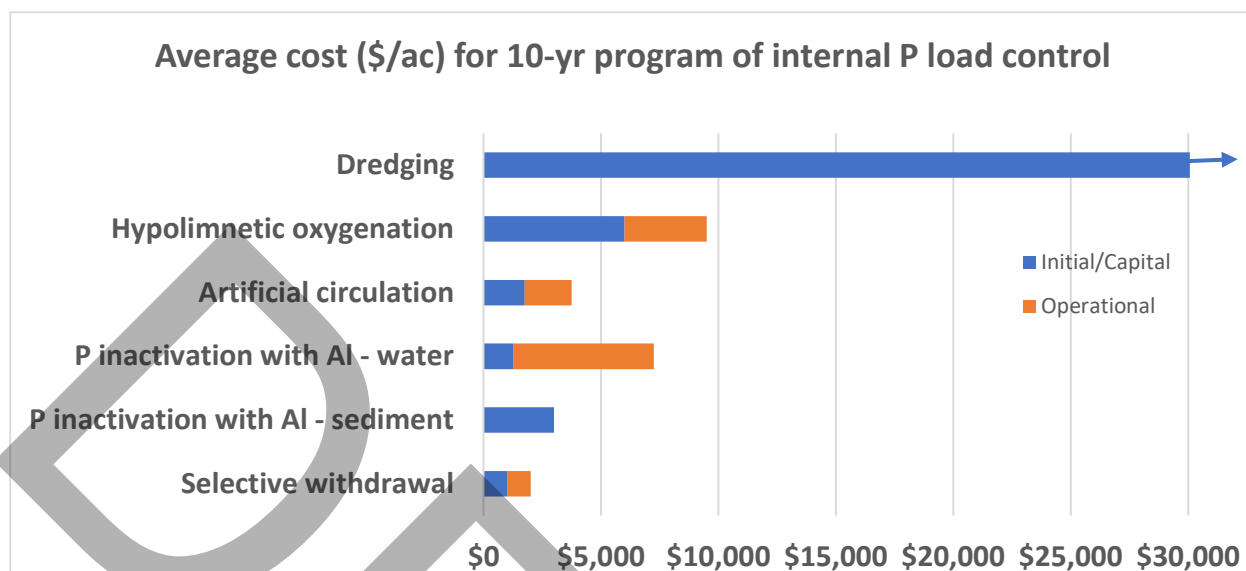


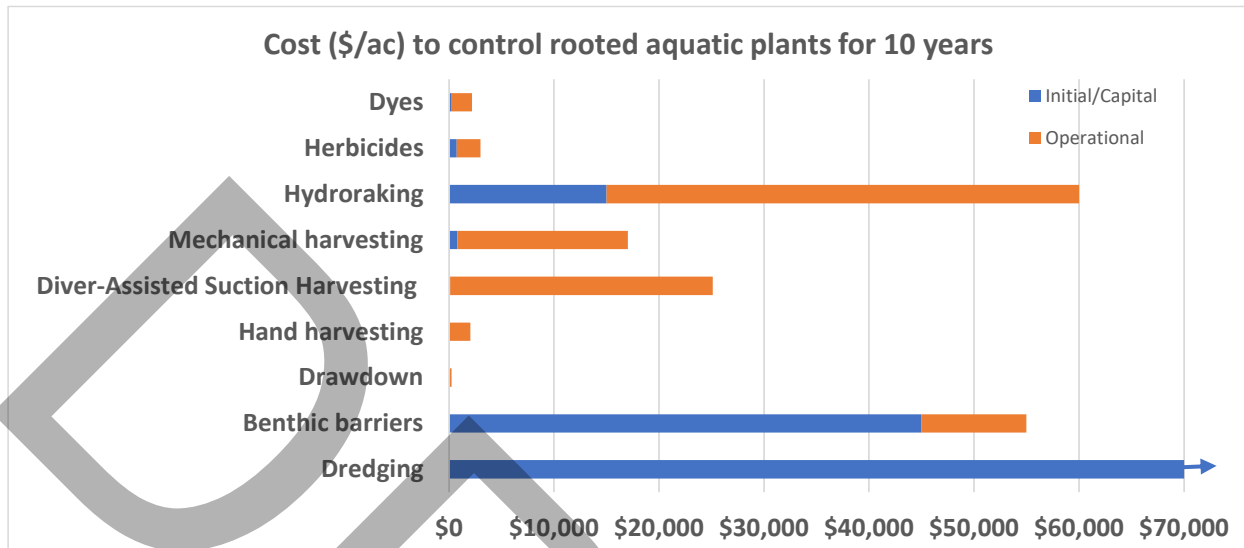
Figure C2. Average cost per unit area to control internal phosphorus load for 10 years

manganese, hydrogen sulfide, and ammonia, and potentially enhancing habitat for fish and invertebrates. Dredging, which was least costly per unit of P mass removed, is the most expensive technique on an areal scale, as more P is removed than is normally involved in internal loading. Yet dredging can remove oxygen-demanding organic sediment and plants (including root systems and seeds), resetting a severely impacted aquatic environment. Beyond cost, the goals of the entire lake management program figure into choice of technique.

Organizing techniques and associated average costs for addressing rooted plant problems on an areal basis over a 10-yr period reveals a wide range of costs (Figure C3). Effectiveness over time is an important factor, resulting in re-application of techniques at variable frequency over the chosen 10-yr period and affecting the split between initial/capital and operational costs. Applicability is another important variable. Drawdown is the least expensive approach per unit area considered but only addresses a subset of possible target plants over a portion of the lake area. Hand harvesting is relatively inexpensive but not really workable for large expanses of dense plant growths. Dyes are also inexpensive for small, shallow waterbodies, but costs may increase disproportionately for larger, deeper lakes. Additionally, dyes only shrink the littoral zone through light limitation and will not prevent plant growth in the shallowest water. Herbicides provide the greatest flexibility of options at the lowest cost, but the cost for different herbicides can vary substantially and is not adequately reflected in the average cost applied in Figure C3.

The relative cost of plant control techniques greatly affects scale of application. Benthic barriers can be extremely effective but the cost limits how much area can affordably be addressed. Likewise, hydroraking can address plants in very shallow areas where mechanical harvesters cannot operate, but at a cost that limits the affordable area addressed. Dredging is the most expensive approach, with a cost per acre exceeding the scale applied in Figure C3 and is rarely used without multiple reasons for sediment removal, not just plant control.

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Figure C3. Average cost per unit area to control rooted plants for 10 years

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Figure C3 also does not reflect non-target impacts, which can determine what techniques can be permitted under varying circumstances. Each technique can have impacts beyond the target vegetation that limit its application. This can be a major issue for permitting drawdown or lakewide herbicide use, techniques with favorable cost per unit area. Cost is just one of many factors to be considered when choosing lake management techniques.

Appendix D. Winter Drawdown Considerations for Projects Subject to MEPA

Applicability

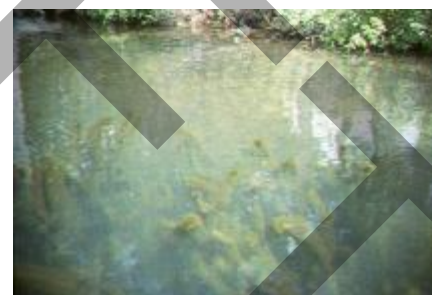
Lake and pond water level drawdowns are used for many purposes outside of the scope of this document, including to provide storage capacity for flood control, to protect dams, outlets, engineered shorelines and other structures from ice damage, and to facilitate dredging and dam maintenance. This appendix provides additional data needs and considerations for drawdowns to control aquatic vegetation when the proposed drawdown exceeds the parameters outlined in Chapter 8. In situations where a lake drawdown is proposed for purposes other than control of aquatic vegetation, consultation with the appropriate agencies is recommended and often required to minimize environmental impact or public safety concerns. In those cases, much of the guidance in Chapter 8 and this appendix may be useful, but the guidance offered here is meant to apply strictly to drawdown for aquatic vegetation control.

For applicants wanting to conduct a drawdown for aquatic vegetation control outside the parameters specified in Chapter 8, greater scrutiny can be expected, more justification will be needed, and a review process prior to any permitting under the WPA is to be expected. The considerations offered here should be addressed through the MEPA process for drawdowns not conforming to the guidance in Chapter 8.

Winter Drawdown Intent and Fundamentals

Winter drawdown can be used to control susceptible aquatic vegetation. For inhibition of plant growth, drawdown involves lowering the water level by gravity, pumping, or siphoning, and maintaining that reduced level for an extended period of time, at least a couple of weeks and typically several months and almost always over the winter.

Winter drawdown can provide control of plant species that overwinter in a vegetative state, potentially killing the plant by a combination of drying and freezing. Annual species that overwinter in sediments as seeds, turions, tubers, winter buds or other reproductive structures are not directly affected and killing entire root systems is difficult without adequate drainage of target areas and freezing temperatures for several weeks. Results are variable from year to year and largely weather dependent.



**Milfoil control within nearshore
drawdown zone with dense
growths beyond that zone**

The draining of water from the lake translates into less lake area and volume during the drawdown. Aquatic organisms that cannot or do not move into deeper water are likely to be killed. The timing of drawdown and refill may restrict fish and wildlife breeding and feeding and may impact species that overwinter in a mostly dormant state in the drawdown zone. Outflows that support autumn drawdown and spring refill tend to reverse the natural spring and autumn flow patterns, which

Drawdown Considerations for MEPA Review

naturally involve peaks in the spring and low flows during autumn. Fluctuating water level during the winter drawdown period may limit human use of any ice surface for recreation.

Yet all the impacts of drawdown, positive and negative, are highly lake-specific, depending on a wide range of factors that must be considered in the planning and permitting phases. A review paper by Carmignani and Roy (2017) lists many possible adverse impacts of drawdown. Carmignani (2020) found some of those impacts in a suite of studied MA lakes, but many were undetected. Winter drawdown to greater depth, greater duration, with different timing, or with other aspects not conforming to the guidance in this document may therefore be possible but can be expected to require greater consideration of the site-specific details and review under the MEPA process.

Key Considerations for Drawdown

Essential Drawdown Planning Information

Target level of drawdown – depth of water after withdrawal
Pond bathymetry – detailed contours for calculating exposed area and decrease in volume
Area to be exposed – portion of whole lake and littoral 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 – type of outlet and method for controlling outflow
Climatological data – frequency of sub-freezing weather, precipitation, and snow cover data
Hydrology – expected distribution of flow over time, likely peaks and low flows
Outflow during drawdown – provisions to avoid downstream channel flooding or other impacts
Outflow during refill – provisions for maintaining minimum downstream flow
Time to drawdown/refill – rate of water level change, days to achieve target level, start and end dates

In-Lake and Downstream Water Quality

Possible change in nutrient levels – any expected increases due to oxidation or remobilization of sediment
Possible change in oxygen levels – any expected increase through oxidation and reduced sediment demand or decrease under ice through decomposition and limited resupply
Other water quality issues – any expected changes as a function of drawdown

Water Supply

Use of lake water as a primary or secondary potable supply – dependence on water availability
Presence/depths of shallow groundwater wells – possible supply impairment
Alternative water supplies – options or supplying water to impacted parties
Emergency response systems like fire suppression – ability to detect and address supply problems during drawdown

Sediment

Sediment in drawdown zone – solids and organic content, particle size distribution, dewatering potential
Drawdown zone slope – potential for fine sediment to move offshore and out of the drawdown zone
Sediment coarsening potential – Over many years the movement of fine sediment and movement of rocks to the surface by freeze-thaw cycles can coarsen sediment in the drawdown zone and limit plant growth
Shoreline features – threat of erosive impacts or ice damage to bank resources
Potential for odors – emissions from exposed area

Key Considerations for Drawdown (continued)

Stream Flow Considerations

Effects on peak flows – dampening effect on downstream velocities and discharge

Effects on low flows – lowering of downstream flow during lake refill

Protected Species

Presence of state listed 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 along transects from shallow to deep water

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

Sediment features – potential for slumping, opening of areas for plant colonization

Macroinvertebrates, Fish and Wildlife

Composition of fauna – types of invertebrates, fish, and wildlife present

Association with areas to be exposed – spatial and temporal overlap between drawdown and habitat use

Breeding and feeding considerations – drawdown interaction with use of drawdown for breeding or food

Magnitude of potential impacts – drawdown zone as portion of habitat used within lake

Downstream Resources

Erosion or flooding potential – susceptibility to impacts from varying flow

Direct biotic impacts – possible scour or low flow effects on biota

Possible habitat alterations – potential for impacts, including from flow regime change

Water quality impacts – potential for alteration and related impacts

Recreational impacts – effects on downstream recreational uses

Supply impacts – effects on downstream supply uses

Access to the Lake

Alteration of wildlife accessibility – issues for use of lake by wildlife during drawdown

Alteration of human accessibility – issues for use of lake by humans during drawdown

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 projects (dredging, shoreline stabilization) – additional actions may require separate permitting

Overall feasibility of using winter drawdown to control rooted plants will depend primarily on the susceptibility of plants in the lake, the bathymetry of the lake and how it relates to area exposed for each increment of depth decrease, watershed hydrology as relates to drawdown and refill, and outlet features that support drawdown. If an initial analysis of those factors is favorable, then the other considerations listed below must be addressed, almost any of which could limit the value or conduct of drawdown, most notably any unacceptable impacts on state-listed species or interests of the WPA.

Species of vascular plants considered susceptible to control by drawdown are listed in the drawdown review section of this document in Chapter 8. Standardized targets or limits for drawdown on a statewide basis to minimize adverse impacts and avoid the MEPA process are also provided in that review. Yet the range of conditions along a gradient from the Berkshires to Cape Cod is striking and there is substantial variability among lakes even within the ecoregions of MA. Climatologically, lakes in southeastern MA do not always freeze while lakes in the Berkshires can have ice or snow cover well into April. Temperature is the primary control for when many animals go into hibernation or fish initiate spawning and varies over space and time. Depth contours will dictate how much of the lake will support plant growth (the littoral zone), how far the lake must be drawn down to impact target plants, and how much water volume will therefore have to be discharged in the autumn and replaced in the spring. Projects that seek to operate outside the limits of the standardized guidance offered in this document will have to be reviewed individually (i.e., MEPA process) and a stepwise process of evaluation and program development is recommended.

MA Experience with Drawdown

In many historic cases, drawdown was primarily conducted in summer or other times of low flow to operate mills or supply water for downstream uses, not for the actual management of lake features, and many MA lakes were expressly created or expanded for the purpose of impounding water for such purposes. As of the passage of the WPA in 1983, that added capacity is treated as an expendable commodity only where specific water rights were retained by an individual or organization. Outside of those private water rights, changing water level is now regulated independently of the natural or manmade status of the waterbody, and wetlands associated with those waterbodies are now protected. Transition to winter drawdown for the management of plants and sediment features occurred mostly in the 1960s, when many of the previously licensed water rights were no longer needed.

The rules governing drawdown have changed several times since the 1960s. Up until the WPA was promulgated, drawdown could not start until mid-October, mainly to be sure that fishermen had unimpeded access to lakes that in some cases was diminished by drawdown. Then it was determined that achieving the drawdown depth by mid-October was preferable, as this would limit exposure of fauna that could enter a period of dormancy in the drawdown zone. This policy was later altered and the 2004 GEIR established what has been the recommended protocol for about two decades, with water level lowering mainly in November with a cutoff of December 1, subject

11491 to maximum outflow rates, and refill targeted for completion by April 1, subject to minimum
11492 outflow limits.

11493 Today, winter drawdown application varies across MA lakes and ponds with several
11494 commonalities as informed by a 2013-2014 email survey to municipalities. Based on responses
11495 from 37 to 46 waterbodies reporting use of winter drawdown, the typical winter drawdown is
11496 applied annually at drawdown depths ≤ 3 feet. The frequency can vary from annual to ≥ 2 -year
11497 intervals and drawdown depths from 1-8 feet. Aquatic vegetation control is the most common
11498 reported use of winter drawdown (56%), followed by shoreline infrastructure protection and
11499 maintenance (37%), which are typically reported together (Carmignani 2020) but are not addressed
11500 here.

11501 Since the GEIR and original Practical Guide were developed, lake managers have almost two
11502 decades of monitoring experience as well as a research program at the USGS Cooperative Fish
11503 and Wildlife Research Unit (Co-op Unit) that resulted in a Ph.D. dissertation (Carmignani 2020),
11504 scientific publications (Carmignani and Roy 2017, Carmignani et al. 2019, Carmignani and Roy
11505 2021, Carmignani et al. 2021, He et al. 2023), and multiple presentations at professional meetings
11506 (e.g., Carmignani 2018). This experience and research have been reviewed by Wagner (2020a)
11507 and lead to the conclusion that the conduct and regulation of drawdown in MA should change.
11508 Recommended changes are incorporated into this guidance document in the drawdown section in
11509 Chapter 8. Research performed by the Co-op Unit aimed to understand the relative influence of
11510 annual winter drawdowns on aspects of littoral ecology, including non-target taxa, and document
11511 the water level characteristics of winter drawdown performance in MA lakes. Prior to this work,
11512 little rigorous field research had been conducted in MA and few prior studies directly assessed
11513 drawdown effects on MA lakes.

11514 Carmignani et al. (2021) continuously monitored water levels in 18 winter drawdown lakes for 2-
11515 4 years to document drawdown magnitude/depth, rates, and timing. From 69 individual
11516 drawdowns they found that drawdown depths remained consistent across years for a given lake
11517 and adhered to the 2004 GEIR guidelines unless otherwise permitted. Most water level reduction
11518 rates were below the 3 inches per day GEIR guideline. However, the guideline for rate of water
11519 level decline was exceeded at some point in 55% of drawdowns and more consistently in 7 lakes.
11520 The timing of winter drawdowns, particularly timing of refill, varied widely across lakes and years.
11521 Drawdowns were initiated between Oct. 1 and Dec. 1 and reached stable water levels between Oct.
11522 7 and Jan. 9, compared to GEIR guidance calling for drawdown initiation starting on Nov 1 and
11523 reaching the target depth by Dec 1. Refill to normal pool levels was achieved between Jan. 13 and
11524 June 26, while the GEIR called for refill to be completed by April 1. Many drawdowns were
11525 therefore operating outside the recommended parameters from the GEIR, although adverse
11526 impacts from such deviation were often not evident.

11527 Research performed by Carmignani and colleagues documented some of the postulated impacts of
11528 drawdown in MA lakes, but many possible effects were not detected. Reassessment suggests that

the GEIR guidance should be adjusted based on more recent research and experience, and that alternative performance guidelines are warranted. For example, initiating drawdown in October instead of November likely enables water levels to reach the target drawdown depth before freezing occurs while maintaining a slower drawdown rate with less potential adverse impact on fauna (He et al. 2023). Other deviations, such as late refill, are not viewed as providing any benefit to aquatic fauna and should be avoided. The variability in drawdown and refill timing highlights the dependence on weather conditions and the unique combination of watershed and lake physical features that mediate hydrological inputs (e.g., precipitation, surface flows, and groundwater). Refill rates, in particular, are dependent on these weather and physical conditions.

Simple metrics like the drainage ratio (watershed area:lake area) can be particularly informative, such that lakes with lower values will take longer to refill. For example, Lake Boon (Hudson), Goose Pond (Tyringham and Lee), and Otis Reservoir (Otis and Tolland) have relatively low drainage ratios (i.e., <10:1) and indeed take longer to reach normal pool levels during spring refill (He et al. 2023). Furthermore, increases in drawdown depth will increase the time to reach target water levels during active drawdown. A hydrological model in development at UMass-Amherst can aid lake managers to meet timing guidelines (He et al. 2023).

Research from the Co-op Unit investigated the potential influence of annual winter drawdowns on ecological components of the littoral zone including substrate composition and macrophyte assemblages (Carmignani and Roy 2021), distribution and density of freshwater mussels (Carmignani et al. 2019), and composition and abundance of macroinvertebrate assemblages (Carmignani 2020). Across a gradient of drawdown depths in 18 annual winter drawdown lakes, Carmignani and Roy (2021) showed that lake sediments are coarser with reduced macrophyte biomass at depths exposed during drawdowns. Drawdowns further structure the composition of macrophytes, such that species primarily propagating from seeds or oospores (tolerant of drawdowns, such as *Najas* spp. and *Chara*) become dominant, while species primarily reliant on vegetative structures (drawdown-sensitive, such as *Nymphaea odorata*, *Potamogeton robbinsii*, *Vallisneria americana*, *Myriophyllum spicatum*, and *Myriophyllum heterophyllum*) are reduced in abundance. This supports previous research and underscores the necessity of proper identification of macrophyte species within a given lake assemblage to determine how species and the assemblage may respond to winter drawdown.

Outside of sensitive, non-target macrophyte species, macroinvertebrates that are minimally mobile and long-lived (i.e., >1-year aquatic stage) are negatively impacted by annual winter drawdowns. Freshwater mussels are particularly sensitive such that mussels are much reduced in abundance within drawdown exposure zones (Carmignani et al. 2019). Other affected macroinvertebrates include groups of aquatic beetles (e.g., *Ectopria*, *Oulimnus*), snails (e.g., *Amnicola*), and caddisflies (e.g., *Polycentropus*) (Carmignani 2020). These sensitive organisms may not represent a significant portion of the overall population in a lake but monitoring to determine the distribution of organisms at risk, notably mussels, over the range of lake depth is an appropriate permit condition. The changes in littoral conditions did not translate into significant differences in

assessed fish community features (Carmignani 2018), but the range of drawdown depths and timing, data limitations, and the fact that many drawdowns may have been occurring for decades may have obscured some changes.

There are many potential ecological impacts of winter drawdowns (reviewed by Carmignani and Roy 2017). While this new research in MA increased our understanding of the influence and impact of winter drawdowns on littoral zone ecology in MA lakes, many knowledge gaps remain (e.g., population dynamics of fish populations) and drawdown influence may be difficult to untangle from historic and ongoing human activities (e.g., herbicide treatments, riparian deforestation, nutrient loading) often present in waterbodies where winter drawdowns are performed. Despite this, research shows that increasing drawdown depths or the % littoral zone exposure can have greater impacts to sensitive, non-target populations (Carmignani and Roy 2017).

Drawdowns for plant control have managed to reduce the density of target plants in the drawdown zone in most cases in most years. Nabnasset Lake in Westford (ESS 2017), Laurel Lake in Lee and Lenox (WRS 2017), Lake Garfield in Monterey, and Bare Hill Pond in Harvard (ARC 2019) have used drawdown almost exclusively to control invasive species of milfoil in shallow water. Indian Lake in Becket (WRS 2020) and Owl Lake in Otis and Sandisfield (WRS 2021) have used only drawdown to control native species that reached nuisance densities in swimming areas and boat launches until very recently. Yet there is substantial variation among years, mainly weather-related, and the trade-off with adverse impacts to non-target species often goes undocumented. It is also true that recovery by target plants can be rapid, necessitating annual drawdown on an ongoing basis.

It is therefore essential that people or organizations proposing drawdowns follow a careful evaluation procedure for assessing if drawdown can provide adequate benefits and minimize adverse impacts to an extent that makes the drawdown worthwhile.

Process for Evaluating Drawdown Efficacy and Limitations for Aquatic Plant Control

A review of drawdown guidance was conducted within the context of 17 years of experience since the GEIR was developed (Wagner 2020a, incorporating multiple sources, including a Co-op Unit thesis by Carmignani in 2020) and resulted in some recommended changes in the way drawdowns should be planned, permitted, conducted, and monitored in MA. Further discussion among the environmental agencies of MA resulted in guidelines provided in the drawdown section of this document (Chapter 8) for aquatic plant control projects that, if followed, would avoid the need for review under the MEPA. Those restrictions could be altered with proper documentation through the MEPA process. The following stepwise evaluation is offered to aid this process.

1. Goals –The goal of plant control, the primary focus here, can be achieved mainly where the target vegetation is susceptible and exposed. An analysis of vegetation that will be affected by drawdowns of increasing depth is therefore required. Evaluation of the potential for winter

drawdown to achieve any goal requires an accurate bathymetric map, with measurement of how much area will be exposed and how much volume will be lost for each increment (usually 1 foot) of drawdown. This is best accomplished as a GIS exercise, but superimposing a bathymetric map image on Google Earth Pro free software will allow areas to be obtained by software functions. Other goals not necessarily benefitted by drawdown should also be considered here, including access for people, use by fish and wildlife, and water quality.

2. Target plants – Perennial species, including multiple species of watermilfoil, coontail, fanwort, various water lilies, and a few pondweeds, can be controlled by the drying and freezing action of drawdowns. Annual species that produce seeds, turions, or winter buds but do not overwinter vegetatively are unlikely to be controlled and germination of reproductive propagules may even be stimulated by drawdown; many pondweeds and naiads fall into this category. Potential coarsening of peripheral substrate after many drawdowns (more than a decade) will tend to reduce the abundance of all rooted plants. Winter drawdown is most often used in MA for control of invasive species of watermilfoil. To evaluate the potential for winter drawdown to control a target species, a map of plant distribution should be compared with any potential drawdown zone. The same GIS or Google Earth Pro process described in item #1 applies here and allows the portion of target and non-target populations potentially impacted by any level of drawdown to be estimated.
3. Target depth of drawdown – From the above analyses, establish the depth of drawdown that will best meet goals. A maximum depth should be set for consideration as well as a minimum depth, that if not achieved, would render the drawdown ineffective. This depth range may not be achievable or sustainable, depending on the outlet structure, and may not be permissible depending on impacts to non-target resources, but it sets the endpoints for an initial evaluation of possible constraints on target drawdown depth.
4. Outlet structure – The structure of the outlet control system will affect the depth of drawdown that is achievable and sustainable. Many outlets control water level by removing wooden or metal slats (also called flashboards or stoplogs) that insert incrementally in a slotted portion of a structure. As each slat is progressively removed, outflow increases and the water level can decline, up to the point where there are no more slats to be removed. The water level that can be attained is determined by the lowest elevation of the structure with all slats removed, but the water level that can be sustained is dependent on how much water the structure can pass. If the opening is only a few feet wide, higher flows may cause the water level to rise again since only so much water can exit at a time. Other outlet structures have subsurface pipes controlled by valves operated from the top of the structure, thus allowing water to exit the pipe at a rate determined by the diameter of the pipe, the degree to which the valve is open, and the depth of water over the bottom elevation of the pipe. Such outlet pipes are often set deeper than flashboard structures but require more monitoring and adjustment to maintain a water level above the bottom elevation of the pipe, as the valve must be periodically adjusted to match outflow to inflow. As with flashboard structures, the water level may rise with higher inflows even with the valve fully open, as the pipe offers only so much flow capacity. Knowing

what water level can be achieved and what maximum flow can be passed to maintain a drawdown may alter the target drawdown depth as determined by the goals discussed above. Pumping or siphoning water is possible to achieve or maintain a drawdown where the existing outlet structure cannot support the target drawdown depth, but at greater operating cost.

5. Listed species protection – Under the MESA, listed species are accorded special protection and the potential impact of drawdown on those species is evaluated by the NHESP within MassWildlife. Loss of protected individuals or their habitat, formally termed a “take”, is only allowable under certain circumstances, generally as part of a plan that will ultimately enhance habitat and the wellbeing of listed species. If the current online NHESP map for Priority Habitat shows one or more listed species present in a waterbody, the NHESP should be consulted before any further planning is conducted, as the constraints on drawdown (and any lake management activities) could be substantial. A formal application, often including the NOI to be submitted under the WPA, will need to be reviewed by NHESP and approved before a conservation commission can take any action under the WPA. It will be necessary to obtain a Conservation and Management Permit (CMP) through NHESP if there are potentially significant impacts to listed species. MESA considerations are likely to be critical to any review under the MEPA.
6. Interests of the WPA – WPA interests of flood control, pollution prevention, and storm damage prevention are generally supported by drawdown, while interests of water supply protection, fisheries, shellfish protection, and wildlife habitat could be negatively impacted. An analysis of what impacts might be expected should be performed. Primary concerns relate to direct impacts on water supply and less mobile aquatic organisms (e.g., mussels) and indirect impacts on fish and wildlife, mostly through habitat loss during the period of drawdown. The magnitude, timing, duration, and frequency of drawdown are important and need to be considered. Mussels will often be stranded and killed in the drawdown zone but recolonize from deeper populations in many cases. Other shifts in invertebrate fauna can be expected. Failure to refill by the time of fish spawning, which can occur shortly after ice out for a few fish species, can limit reproductive success for those species. Drawdowns deeper than about 3 feet may impact beaver populations. Changes in vegetation and substrate in the drawdown zone may affect fish communities, although the magnitude of change is difficult to predict. Itemization of what could happen vs what can reasonably be expected to happen is warranted, and monitoring will likely be needed to document potential changes. Assessments of key populations or entire communities may be necessary to allow risk assessment and ongoing monitoring will almost undoubtedly be needed to document actual impacts.
7. Depth of drawdown – From all of the considerations above, set the target drawdown level or range of levels that will provide maximum benefit while minimizing adverse impacts. It may be determined that drawdown is not appropriate for a given lake where the attainable benefits do not appear to outweigh the likely negative impacts. Where the target drawdown is expected to achieve set goals, but the extent of adverse impacts is less certain, an incremental approach to drawdown may be appropriate, starting with a lesser initial drawdown with annual increases

in drawdown depth as supported by monitoring and analysis. Adjustment over time based on experience and the knowledge provided by an appropriate monitoring program is to be expected. The depth of drawdown should be linked to the amount of total lake area exposed, the portion of the littoral zone (plant growth area) exposed, and the portion of total lake volume to be lost and replaced. While there is no clear threshold value for each of these features that favors or disfavors drawdown, the lower the area exposed and volume lost, the easier it is to conduct a drawdown and the lesser the adverse impacts.

8. Start of drawdown – The recommended start date for drawdowns in MA has shifted several times over the last four decades and a range of dates is justifiable depending on circumstances. Key factors in past recommendations have included not lowering after hibernating animals settle in for the winter, letting the growing season end and allowing emergent and wetland vegetation to go dormant before drawdown, waiting until migratory species such as many waterfowl have moved on, not sending excess warm surface water downstream in coldwater streams, and maintaining access for anglers into fall. There may be cases where each factor is valid, but the needs are not consistent across lakes, and influence is more tied to temperature than date. Natural seasonal water level fluctuations of at least a foot and often two feet are to be expected in most MA lakes, so starting a drawdown earlier when there has been more rain and higher water is possible, while starting later after a hot, dry summer may be preferable. The hydrology of the contributing tributaries and receiving stream should be considered as well as any other drawdowns within the same river basin, trying to avoid creating sharp peak flows or even flooding with simultaneous drawdowns. Each case should be considered individually, but the start of drawdown could be as early as late-September or as late as early November and should focus on limiting the deviation in downstream flow from the natural flow regime as much as possible and keeping the rate of water level decline low. Starting after thermal stratification has broken down may be a useful benchmark as it is linked to water temperature, the trigger for many of the biological events of interest for timing of the drawdown to protect fish and wildlife interests.
9. Rate of drawdown – Organisms with limited mobility (e.g., mussels, some snails) are subject to mortality from drawdown, but many aquatic animals can move to deeper water if not trapped in a shallow area. Keeping the rate of water level decline <3 inches per day and preferably even slower was the guidance given in the GEIR and remains a valid approach to minimizing impacts. At 2 inches per day, a drawdown of 3 feet could be achieved in 18 days while a drawdown of 6 feet would require 36 days. If outlet structures support sufficient discharge and downstream flooding is not an issue at that rate of drawdown, the vast majority of drawdowns in MA can be completed in not much more than a month. Slower rates of drawdown, due either to outflow capacity limits or elevated inflows from precipitation, will necessitate a longer drawdown period but are consistent with the guidance to lower the water level slowly. The rate of water level decline does not need to be constant, but an average somewhere between 1.5 and 2.0 inches per day is desirable. The primary limitation on keeping the rate of drawdown low will be where boards must be pulled from a spillway. Depending on the height of

individual boards, initial outflow may be high enough to cause the rate of drawdown to exceed 3 inches per day, although this is not common and doesn't last long, as decreasing hydraulic head reduces outflow rate. Research to date does not suggest that occasional higher rates of drawdown have detectable impacts, so targeting an average rate of drawdown between 1.5 and 2.0 inches per day is appropriate, but daily variation is to be expected and might result in occasional water level decline close to 3 inches per day. Instantaneous rate of drawdown should not be a compliance issue, but rather the average over the period of active drawdown with a maximum target of no more than 3 inches per day.

10. Maximum outflow – The rate of outflow necessary to sustain an average water level decline of up to 3 inches per day will depend on the area of the lake. For every 10 acres of lake, 0.84 cfs must be discharged to lower the water level by 2 inches in a day. Yet this assumes no additional inflow to the lake, so the necessary discharge is 0.84 cfs/10 acres of surface area plus inflow. Flows tend to be lowest in the late summer and early fall in MA but can still be substantial with a large watershed or a storm. Drawdown of a 100-acre lake at 2 inches per day will require 8.4 cfs on top of whatever inflow is occurring at the time, rain or shine. Whether or not this will cause downstream channel scour or flooding depends on channel configuration and total flow. The USGS [StreamStats](#) online program can help determine an appropriate maximum downstream flow rate. Based on data from many MA stream systems, this interactive program allows users to delineate a watershed and generate a report with various flow statistics, including downstream bankfull flow (the amount of water the channel can hold without flooding) and peak flows expected at different recurrence intervals, ranging from once every two years to once every 500 years, all with confidence intervals representing the range of error possible with predictions like these. It is recommended that the maximum downstream flow be no higher than the lowest of either the lower bound of the probable bankfull flow or the lower bound of the peak flow expected once every two years (Annual Exceedance Probability of 50%), whichever is less. Where flow can vary substantially and quickly due to watershed features and storms, setting the maximum outflow at half the lower bound of bankfull or two-year peak may be justified. This is a more scientifically sound approach than past guidance calling for no more than 4 cfs per square mile of watershed regardless of watershed characteristics. It is more likely that keeping the rate of water level decline to less than 3 inches per day will be the key criterion for outflow determination, but the recommended approach will minimize the probability of downstream impacts where the lake is large and water level decline of up to 3 inches per day translates into high outflows. It is an inherent feature of winter drawdown that outflows during the period of active water level decline will be higher than naturally experienced by the receiving stream at that time of year. This alteration of hydrology is unavoidable, although minimization or mitigation of adverse impacts may be possible.

11. Achievement of target depth – The date by which the target depth of drawdown is reached is a function of the rate of water level decline, which in turn is determined by inflows, maximum outflows, and/or outlet capacity. If a target rate for water level decline can be maintained, the

time it will take for the target depth to be reached is easily calculable, but there will be variation in multiple factors, most notably weather, that will affect this process and its predictability. There is no clear date by which a target drawdown depth must be reached, but it is preferable to reach the target depth by the time freezing temperatures occur, usually in November. And while the onset of snow cover varies by year and location within MA, the month of December historically offers the greatest chance of sub-freezing temperatures without significant snow cover. However, ice will insulate the sediment to some degree, so there is little value for plant control in lowering a lake further once ice has formed. Hibernating reptiles and amphibians will seek winter resting locations as the weather turns cold, usually by sometime in November. A target date of December 1 is therefore appropriate as the latest date that the target drawdown depth is achieved, but reaching the target drawdown depth earlier is preferable. Water level lowering should cease when the target level is reached or the weather dictates that there is either minimal value or increased risk of adverse impacts associated with lowering the water level further. Extending the drawdown period into December may be acceptable in an unusual weather year but should be avoided. Early cessation may be desirable where temperatures drop below freezing earlier than expected. Flexibility should be maintained in permit conditions to foster the best results, with proper monitoring to inform decisions. A recent model developed at UMass-Amherst for evaluating drawdown in MA (He et al. 2023) can help assess the probability of achieving drawdown by December 1 and presumably could be adjusted to accommodate alternative target dates.

12. Choosing a refill completion date – Refill should be timed to achieve full status of the waterbody by the time key ecological processes are expected to occur but must also consider any flood control or ice damage prevention goals that apply in late winter and early spring. The depth of drawdown and relative size of the watershed will vary among lakes and there will be variation in refill rate among years and between geographic regions of MA, so no one date for the start or completion of refill can be reliably recommended for the entire Commonwealth. The 2004 GEIR recommended April 1 as a target date for achieving full status, but fish spawning may have already commenced by that time in some southeastern MA lakes and there is still ice on most Berkshire lakes into April of most years. Water temperature is the key determinant for fish spawning and many other ecological processes and will vary between years for any given date at any given lake. It is recommended that the target date for completion of refill be set as the day on which average temperature of the surface water enters the range for the earliest spawning fish in the lake, if that date can be determined. Yellow perch are the earliest spawners commonly found in MA at water temperatures of 7 to 12°C (44 to 54°F), while smallmouth bass start spawning at about 15°C (59°F) and largemouth bass at 20°C (68°F) (Scott and Crossman 1973, Smith 1985). Fish may begin to utilize shallow water habitat before the spawning temperature is reached, but spawning does not occur under the ice and should be facilitated by completion of refill within the temperature range for spawning. A target date of two weeks after the average ice out date is offered as an alternative where such records are available. A lake-specific target will therefore have to consider many possible factors, and an

appropriate analysis should be part of the planning process. Consultation with MassWildlife is recommended in selecting the target date for refill completion. However, as control over the rate of refill is limited, that target date for refill completion is not a compliance threshold, but rather the basis for calculation of when refill must start.

13. Choosing a refill start date – The refill start date should be back calculated based on achieving full status by the chosen date in at least 4 out of 5 years (80% probability). For any given lake it is possible to calculate the rate of refill from regional hydrologic records. A flow curve can be derived for any location and period of time, allowing estimation of how likely the lake will be full by any given date and facilitating selection of a start date that provides a high probability (but not a guarantee) of refill by any selected date. The various USGS tools listed previously are applicable to this evaluation, as is the Umass-Amherst model (He et al. 2023). Analysis should focus on estimating how long it will take to fill the lake under the range of likely spring conditions while allowing appropriate downstream flow, culminating in selection of a date on which refill will be initiated. Refill must commence by the specified start date and records of refill progression and full status achievement must be kept. It is highly unlikely that a water level a few inches below full on the target date for refill completion will cause significant impacts, but if the differential is substantial or refill is late more than once in five years or in consecutive years, the refill start date should be revised if annual drawdowns are to continue. Where flood control and ice damage prevention are not factors, refill can commence as early as mid-February with no loss in plant control function. If some measure of flood control or ice damage prevention must be maintained but the drawdown is deeper than needed to meet those goals, refill can commence and then be suspended when the level needed to preserve all protective drawdown functions is reached or until that capacity is no longer needed.
14. Rate of refill – Refill can be as fast as inputs allow, as long as erosive forces do not come into play as the water rises. Yet unless there is a controllable upstream source of water, little control can be exercised over the rate of refill. Snowmelt, rain, and runoff will enter the lake in accordance with the weather pattern and it is unlikely that refill can be accelerated to any significant degree. Outflow controls may be able to slow the rate of refill if necessary, and some downstream flow should be maintained, but inputs will not be dependable on a day to day basis and the rate of refill may vary considerably. As described above, calculation of the probability of adding enough water to refill the lake by some chosen date is possible and should be reliable as a long-term average, but the rate of refill can only be predicted and not controlled.
15. Minimum outflow – It is an inherent feature of drawdown that downstream flows will have to be limited to attain refill. Natural flows in the absence of drawdown would be higher and this alteration of hydrology is unavoidable. Impacts will be a function of the deviation of flows during refill from the natural regime and the distance downstream that hydrology is significantly altered. To minimize adverse impacts, maintenance of some downstream flow is essential, but just how much flow is needed depends on channel configuration and the resources at risk. The guidance in the GEIR, based on Aquatic Baseflow Policy, is to allow 0.5 cubic feet per second per square mile (cfs/m) of watershed area, a value that roughly equates to

low flows in late summer and early autumn and represents minimum flows for limited protection of aquatic resources. While there is geographic variation in this value and it is far less than what would naturally be passed downstream in the spring, it provides some protection for downstream aquatic resources while allowing refill of the lake. A more site-specific and recommended alternative would be to use the August median flow (50% occurrence probability) as the minimum downstream flow during refill, and that value can be determined from the USGS [StreamStats](#) online program. Maintenance of a desirable downstream flow can be accomplished several ways, including a separate outflow pipe that discharges the necessary flow based on diameter and vertical position relative to the water level, leaving any subsurface pipe used for drawdown open enough to pass enough water, or setting flashboards in a manner that promotes water passage by leakage at an appropriate level. Valved pipes can be installed in flashboards to allow controlled flow during refill, and such passive downstream flow approaches are recommended to maximize the probability that downstream flows are achieved during refill. It is also possible to set up a siphon or pump water beyond the outlet. While some flow should always be discharged, studies to date have not indicated that it is necessary for the targeted flow to be constant. Compliance should be based on continual flow averaging out to the target value.

16. Frequency of drawdown - Drawdown should be planned and permitted as an annual activity, as multiple years of annual drawdown may be needed to control target vegetation and repeated drawdown is likely to be necessary to maintain that control. Yet those conducting drawdowns should be prepared to cancel or terminate drawdowns when conditions are not suitable or where the need is not evident. Weather prediction is not reliable enough to be used months ahead of time, but where monitoring indicates that drawdown is not likely to provide the desired benefits in any given year, programs should be adjusted or paused accordingly. Where monitoring indicates that target objectives for plant inhibition have been satisfied, consider reducing the magnitude and/or frequency of drawdown. If drawdown has failed to provide the desired plant control over the life of the permit, consider implementing different controls and abandoning drawdown. Avoid set patterns of drawdown variation, such as two years of shallower drawdown and one year of deeper drawdown, as this is a highly weather-dependent technique, and the weather is not predictable over a timeframe of years. Build flexibility into permits to allow adaptive management and incorporation of new information as it becomes available.
17. Water level and flow monitoring – In order to know the rate of drawdown and magnitude of downstream flow, some form of monitoring is needed. The simplest approach is to install a staff gauge at the outlet (preferably permanent and surveyed), typically on a wall of the outlet structure on the upstream (lake) side, allowing visual measurement of lake level at any time. At a minimum, the lake level should be recorded whenever a flashboard is removed or any subsurface pipe valve is adjusted, facilitating calculation of the rate of water level change. With proper outlet dimension measurement, this also allows calculation of outflow just before and just after a board is pulled or a valve is adjusted. If flows are erratic, more frequent

measurement is advisable and may need to be daily in some cases. Automated measuring systems are available and can be installed, providing instantaneous data, recording of data over the period of drawdown, and allowing anyone with access to check lake level and outflow status at any point in time. Automated approaches are much more expensive (usually >\$10,000) and may require an accessible power source. Measurement frequency somewhere between instantaneous and weekly is likely to be needed and may vary by lake. More frequent measurement may be needed in the first few years of drawdown to develop a water elevation track record and may allow less frequent measurement later. During refill, the same water level measurement will allow calculation of net inflow and facilitates projection of the date of refill achievement, although variations in the weather introduce variability into such predictions. Measurement of downstream flow can be accomplished with a staff gage at a point where the channel is stable or by direct periodic measurement, but it is best to set up a passive outflow system that guarantees the desired downstream flow without frequent measurement or adjustment. More sophisticated flow measurement systems can be installed at higher cost but should not be necessary in most cases.

18. Additional monitoring needs – A plan should be crafted for each lake based on the resources that may be affected, and applicable state programs (e.g., DCR Lakes and Ponds Program, MassWildlife, NHESP) may be consulted for guidance depending on the resource. Any required monitoring should be carefully targeted to provide information that supports proper evaluation of impacts with some reasonable probability of occurrence. Where plant management is the main goal, an annual summer survey of the plant community should be conducted to evaluate how well drawdown is meeting quantifiable goals (e.g., targeted species absent in drawdown zone, <10% of sites with the targeted species dominant, other clearly stated quantitative goals). If state-listed species are present, it may be necessary to document any impact on them through appropriate surveys. For rare listed species this can be a difficult task and the NHESP should be involved in development of the monitoring program. If mussels are present, a population survey is advisable to determine the distribution of the population over the range of water depth; mussels in the drawdown zone will experience elevated mortality and recolonization will depend on how abundant mussels are outside the drawdown zone. Water quality monitoring is important in any lake management effort and assessment of the typical parameters (e.g., temperature, oxygen, pH, nutrient levels, water clarity) in at least a spring-summer program is recommended. For drawdown it is also advisable to check the oxygen level under the ice throughout the remaining water column in mid- to late winter to be sure that adequate oxygen remains to support biological communities. Tracking water and air temperatures over the whole year will help with evaluation of impacts (e.g., freezing of plants) and determine the range of dates when key events (e.g., fall turnover, hibernation, spawning) are likely to occur. Recording ice-in and ice-out dates will also be useful. Downstream of the lake, potentially sensitive populations may need to be monitored up to the point where the contribution of flow from the drawdown lake is suitably diminished. As a general guideline, downstream studies might be extended to where flow from the subject lake represents less than

**Drawdown Considerations for
MEPA Review**

11925 about 20% of the total flow in the stream, as determined by any flow records or proportional
11926 land area in the watershed.

11927 19. Permit duration and data evaluation – MassDEP recommends that Orders of Conditions for
11928 drawdowns be issued for five years. This provides enough experience to evaluate compliance
11929 with appropriate targets, as the results in any one year may not be indicative of all impacts,
11930 positive or negative. Where a three-year permit duration is applied, it may be necessary to wait
11931 for two permit cycles to analyze results. Avoid drawing strong conclusions from any one year
11932 of drawdown and do collect the necessary data to evaluate drawdown results over the permit
11933 period. Goals and acceptable levels of impact for drawdown should be stated as quantitatively
11934 as possible and the evaluation should objectively assess achievement and compliance. If the
11935 permit is to be extended or a new permit issued, adjustments should be made as needed to
11936 enhance goal achievement and compliance, such as altering the start date for drawdown, the
11937 depth or rate of drawdown, the refill start date, or the outflow during drawdown or refill.

11938 By following the above evaluation process in a stepwise progression, it may become evident that
11939 drawdown is not appropriate for the waterbody or that there are too many unknown factors to allow
11940 approval within the MA regulatory system. But where drawdown appears appropriate and a
11941 program can be developed that meets the qualifications described above, this program can be
11942 proposed within the MEPA review system and potentially be accepted as a valid approach. That
11943 review process will likely involve all MA agencies with a stake in the outcome, may be protracted,
11944 and may result in adjustments or rejection, and applicants should be prepared to engage in the
11945 process. If a drawdown project is approved under the MEPA, it must still go through all relevant
11946 permitting processes, including filing an NOI under the WPA. If the performance guidelines
11947 established in the drawdown review section of this manual can be met, that will be an easier path
11948 to follow.

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Appendix E: Sample Conditions to Cover Lake Management Activities in an Order of Conditions

As part of the Notice of Intent (NOI) regulatory process under the MA Wetland Protection Act (WPA; M.G.L. Chapter 131, S. 40), successful permit applications for work in wetland resource areas are approved by local conservation commissions with an accompanying Order of Conditions (OOC). The OOC provides a list of required elements which regulate, guide, and/or set limits on these activities under the WPA and, as appropriate, under any town wetland bylaw. When finalized, the OOC is part of the permit application file and recorded in the Registry of Deeds or Land Court.

The general purpose of the OOC is to protect the enumerated interests of the WPA, guide the applicant and contractors in the implementation of the permitted activities, and delineate performance standards that govern work in affected resource areas. Conditions provide the basis for measuring compliance and/or enforcement needs. A properly written OOC guides the applicant and gives the conservation commission a standard to enforce if required measures fail. A successful lake management activity should achieve the stated lake management objectives while protecting the WPA interests. This success is very often dependent on careful crafting of the scope, detail, and specificity of the OOC.

Due to the large range of potential lake management activities and the unique characteristics of each lake, lake management OOC will differ from lake to lake. There is no “one size fits all” template that serves this purpose. However, there are common elements that are often included for a particular technique that provide an initial framework that can be further refined by the conservation commission to produce an effective and protective lake-specific OOC. Some of the characteristics of an effective OOC include:

- Must be based upon WPA regulations and be defensible and enforceable
- Comprehensive coverage of proposed activities
- Straight-forward and clearly written
- Specific to the site and work to be done
- Reasonable in terms required activities and cost to applicants
- Timeframes that are appropriate to the work, protective of WPA interests, and reasonable in terms of applicant and contractor adherence

The final OOC should provide a workable set of conditions that are neither too vague nor overly prescriptive and which are flexible enough to accommodate potential minor changes or deviations that often arise during actual lake work. The more detailed the plans, plan notes, construction sequence, and related implementation steps, the fewer conditions may be needed.

The following sections provide information and recommendations on overall General Conditions, ancillary information useful to include, and common Special Conditions which pertain to specific lake management techniques. Emphasis will be on OOC associated with in-lake management with

lesser coverage on non-point source watershed techniques, as these are usually adequately covered under MA Stormwater Standards (see below) and may occur outside the jurisdiction of the conservation commission. Much of this information is drawn from language in prior NOI or OOC that incorporate appropriate performance standards. In addition, this section provides practical tips drawn from professional experience to help make OOC easier for the conservation commission to oversee and monitor the proposed lake management activity and fair to project participants, given a wide possible range of activities at highly variable spatial scales.

General Conditions Under Massachusetts Wetland Protection Act

Every approved NOI contains a list of General Conditions Under MA Wetland Protection Act (i.e., Conditions #1 - #19). This generic list of Conditions provides necessary regulatory and administrative requirements for any project including topics such as compliance with relevant regulations, duration of permit, compliance with approved site plan, wetland flagging, sedimentation barrier controls, signage requirements, field inspections, and the Certificate of Compliance. Most of the General Conditions are applicable to lake management activities although some may not be necessary (e.g., flagging requirements don't really apply to lakes).

General Condition #19 is reserved for any work that is subject to MA Stormwater Standards. While this may not be applicable to many in-lake management techniques, it will pertain to most watershed non-point source (NPS) control techniques. If applicable, General Condition #19 contains a comprehensive list of conditions and performance standards (outlined in the Stormwater Standards) to which projects must adhere. Given these existing regulatory requirements, it is unlikely that conservation commissions will need to devise additional Special Conditions to cover such activities, except for requirements under a local wetland bylaw or ordinance (see below). For additional information, consult the [MA stormwater handbook](https://www.mass.gov/guides/MA-stormwater-handbook-and-stormwater-standards) (<https://www.mass.gov/guides/MA-stormwater-handbook-and-stormwater-standards>).

Findings under Municipal Wetlands Bylaw or Ordinance

Some municipalities have adopted additional regulations or protections for work in wetland resource areas that are incorporated into local wetland bylaws or ordinances. These local regulations are distinct from MA WPA requirements but are equally applicable to the approval process managed by the local conservation commission. For example, it is possible that a permit may be approved under WPA but denied under local bylaws. Such municipal bylaws expand protection through a variety of means, such as larger buffer zones (e.g., increasing distance from 50 to 100 ft.), more stringent performance standards (e.g., no fertilizer application in proximity to the lake), or other requirements. The MA WPA requirements and local bylaws must be both addressed by OOC Special Conditions and should be segregated to explicitly indicate which regulation a condition pertains to. It is typical to use separate pages clearly identifying which Special Conditions refer to compliance with the WPA vs. those pertaining to the local bylaw or ordinance.

Statement of Fact Section

A well-constructed NOI contains a Statement of Fact section that briefly summarizes the environmental setting, background, rationale, and purpose of the proposed activity. This section provides the conservation commission with the bulk of the information to be considered when rendering an opinion in the approval process. It is also very important should the permit decision be appealed or when an Adjudicatory Review is conducted.

Special Conditions for Lake Management Techniques

This section provides recommendations and exemplary language to be considered as an initial basis for constructing Special Conditions for lake management activities permitted under the WPA. Many of the suggested Special Conditions will not apply to all projects and may need to be modified to suit the particulars of any specific permitted activity. This section is divided into suggested Special Conditions that are generic to most lake management activities and those that pertain to specific lake management techniques described in this guide. Techniques listed as “alternative” in the guide are not covered here, as they have not been approved as part of the Generic Environmental Impact Report, a process through which likely Special Conditions might be assigned.

Generic Special Conditions

The initial Special Conditions generally include language identifying the approved NOI, plans and specifications, and delineating the general applicant responsibilities, conservation commission oversight duties, and provisions for dealing with project changes or non-compliance with the Order of Conditions. These topics and information include:

- Listing of key project plans and documents integral to the activity
- Mandating adherence of all project participants to the approved OOC
- Protecting private property rights (can be an access issue)
- Ensuring the approved NOI and OOC are included as part of any contract or sub-contract dealing with proposed work
- Retaining field inspection opportunities by the conservation commission during any stage of a project as well as the right to halt work if the project is not meeting performance standards
- Immediate reporting of unforeseen problems to the conservation commission and scheduling of a project meeting to discuss how to resolve minor project changes
- Directive for determining whether potentially significant deviation from proposed work triggers the need for an Amended OOC or new NOI.

Example Generic Special Conditions

1. The work shall conform to the following plans, documents, and Special Conditions:
 - a. Approved NOI (with DEP number) and OOC.
 - b. Site plan or map (dated).

Sample Conditions

- 12061 c. Project specifications.
12062 d. Other relevant supplemental information (letters, reports, and documents listed separately
12063 as needed).
- 12064 2. All work shall be performed in accordance with the approved NOI application and supplemental
12065 information submitted to the conservation commission. To the extent that the following
12066 conditions modify or differ from the plans, specifications, or other proposals submitted within
12067 the NOI, these conditions shall supersede as final authority.
- 12068 3. This OOC shall apply to all successors in control or successors in interest of the property
12069 described in the approved NOI and accompanying plans.
- 12070 4. Prior to the commencement of project activities at the site, adequate erosion and sediment
12071 control measures will be implemented as needed and/or as specified in the NOI, the approved
12072 plans, and this OOC. A Certificate of Compliance shall not be issued until the erosion control
12073 measures have been removed after authorization by the conservation commission.
- 12074 5. Any changes in the plans affecting wetland resources, wetland buffer zone, vernal pool buffer
12075 zone, or the riverfront zone, or any deviation in work activity from the plans shall require the
12076 applicant to file a project change request with the conservation commission with a written
12077 inquiry as to whether the change is substantial enough to require filing a new NOI.
- 12078 6. The conservation commission will either determine that the proposed change is an insignificant
12079 project change or that the applicant would need to submit either an Amended NOI or new NOI
12080 application for review.
- 12081 7. A conservation commission member or agent shall have the right to halt all work on the site if
12082 the commissioner or agent determines that any of the work is not in compliance with the Order.
12083 Work shall not resume until the conservation commission is satisfied that any continuing
12084 project work will comply and has so notified the applicant in writing.
- 12085 8. This Order does not authorize the invasion of private property rights or any injury to private
12086 property.
- 12087 9. Any damage caused as a direct result of this project shall be the responsibility of the applicant
12088 to report, replace, or otherwise compensate the injured party.
- 12089 10. This document shall be included in all construction contracts and subcontracts dealing with the
12090 proposed work and shall supersede any conflicting contract requirements.

12091 **Orders of Conditions for Watershed Non-Point Source Techniques**

12092 As noted above, specifications and performance standards for individual watershed NPS control
12093 techniques are generally addressed under General Condition #19 which draws upon information
12094 in the [MA stormwater handbook](#), including MA Stormwater Standards to which such projects
12095 must adhere. The MA Stormwater Standards address water quality (pollutants) and water quantity
12096 (flooding, low base flow and recharge) by establishing standards that apply to implementation of
12097 a wide variety of stormwater management strategies. Given this existing regulatory structure,
12098 conservation commissions will rarely need to devise additional Special Conditions to cover the
12099 performance standards of individual NPS control components.

Sample Conditions

12100 However, the conservation commission should be concerned with ensuring the long-term
12101 performance of watershed NPS devices through specifying that an operation and maintenance plan
12102 be provided, and that inspection and maintenance be documented for the life of the permit.
12103 Typically, some measure of the removal efficiency of the device is tested (e.g., nutrient levels in
12104 inlet and outlet flows). Since structural NPS techniques can rapidly fail without regular, proper
12105 maintenance, the conservation commission may want to consider extending the period (e.g., 3-5
12106 years) before a Certificate of Compliance is issued beyond the simple completion of construction
12107 or vegetation stabilization. If possible, eventual transfer of long-term maintenance duties to
12108 appropriate local municipal departments (e.g., Department of Public Works or Recreation) or lake
12109 associations is also recommended but this must be independently pursued since the original
12110 applicant may no longer be involved or responsible.

12111 In many cases, a series of individual watershed techniques are collectively or sequentially linked
12112 to improve overall water quality entering a waterbody. Therefore, the OOC should facilitate
12113 evaluation of removal efficiency and cost-effectiveness of various techniques, to provide a better
12114 estimate of the reduced total loading to the waterbody and monitor the progress towards defined
12115 regulatory targets (e.g., TMDL). In most cases, this involves monitoring at key watershed locations
12116 with a focus on upstream vs. downstream loads of target contaminants (e.g., N, P, solids,
12117 pathogens). MassDEP envisions that, as monitoring program improvements are implemented,
12118 future goals, objectives, and milestones of watershed management will rely more heavily on water
12119 quality monitoring data to demonstrate program successes.

12120 A watershed-scale assessment is a challenging task for a conservation commission, but much of
12121 this information should be available from project monitoring reports, particularly if the project was
12122 funded by CWA Section 319 monies. Required project reports should summarize the work that
12123 was done, detail the modeled pollutant load removals achieved by each BMP, make
12124 recommendations for follow-up, and discuss lessons learned from the project. Water quality data
12125 are essential to truly document improvements but the current approach under Section 319 grants
12126 does not necessarily require such data. It is likely that additional technical or regulatory support
12127 may be required by the conservation commission to put this information together in a meaningful
12128 review, but such analyses are critical in determining what is effective, reliable, and practicable for
12129 informed watershed management.

12130 ***Example Special Conditions for Watershed NPS Techniques.***

- 12131 1. The Applicant will provide the metrics used to evaluate compliance with stormwater
12132 performance standards to the conservation commission each year, including but not limited to:
12133 a. Results of required water quality monitoring data.
12134 b. Calculation of amount of pollutant removal (e.g., nutrients, sediment).
12135 c. Updates on any required operation and maintenance activities performed during the past
12136 year.
12137 d. Photo documentation of current conditions.

Sample Conditions

- 12138 2. The Applicant will provide the conservation commission with copies of any required project
12139 monitoring reports that are required under CWA Section 319 funding regulations.

12140 **Orders of Conditions for Reduced Nutrient Availability in Lakes**

12141 ***Dredging***

12142 Removal of accumulated sediment is perhaps the most restorative lake management action but is
12143 technically and regulatorily complicated and challenging. Multiple permits will be needed that will
12144 dictate how and when dredging is conducted and where the sediment must go for disposal.
12145 Removal may involve draining part or all of the lake but can also be accomplished hydraulically
12146 with the lake full. Most dredging projects involve an intermediate drying step (i.e., dewatering
12147 process) of dredged materials in a containment area, followed by ultimate disposal elsewhere and
12148 some form of restoration of the containment area. Dredging is likely to impact many forms of
12149 aquatic life during the process and an extended period of recovery within the lake is to be expected.
12150 Change in sediment may selectively favor different biota, leading to some shifts in the benthic
12151 community. Where sediment-water interactions have previously degraded water quality,
12152 conditions in the post-implementation water column should improve markedly. Most conditions
12153 imposed by conservation commissions will be intended to minimize impacts during dredging,
12154 although many may be unavoidable, and to document recovery with respect to the interests of the
12155 WPA.

12156 Example Special Conditions for dredging may include:

- 12157 1. Dredging shall be in accordance with the approved NOI and OOC, as well as all other permits
12158 granted for the dredging project, and will be guided by best management practices and
12159 supporting information as provided in the 2025 Guide.
- 12160 2. Applicant shall submit the following information to the conservation commission as part of
12161 any dredging program prior to implementation:
- 12162 a. List of all participating organizations with contact information.
 - 12163 b. Current and expected bathymetric maps reflecting the result of sediment removal.
 - 12164 c. Map of planned staging area(s) and location of expected final disposal site(s) for dredged
12165 sediment.
 - 12166 d. Monitoring plan for assessing any impacts on areas of the lake not subject to dredging and
12167 any downstream resources.
- 12168 3. During the dredging project, applicant shall submit monthly reports including:
- 12169 a. Area dredged and volume of material removed.
 - 12170 b. Results of all monitoring.
 - 12171 c. Any issues that require resolution or project adjustment.
- 12172 4. Following completion of the dredging project, all staging and containment areas will be
12173 rehabilitated in accordance with plans and permits.
- 12174 5. Two years following dredging, applicant will provide a summary report including monitoring
12175 of water quality and relevant biological components of the system.

12176 ***Phosphorus Inactivation***

12177 Inactivation of phosphorus (P) can reduce the ability of a waterbody to support algal blooms by
12178 binding P from the sediment or water column and making it unavailable to algae. Aluminum is
12179 most commonly used for this purpose but there are other options in use in other states but not yet
12180 approved for use in MA. Treatments may be very infrequent (a decade or more) in the case of
12181 direct sediment P inactivation, once or twice per year in the case of water column P inactivation,
12182 or on demand as with tributary input treatments, usually associated with storms. There are possible
12183 impacts during treatment, but these can largely be mitigated by proper planning and
12184 implementation. Adverse impacts more than a few days after treatment are extremely rare.
12185 Conditions therefore tend to focus on the treatment and minimizing the potential for adverse
12186 impacts.

12187 Example Special Conditions for P inactivation may include:

- 12188 1. P inactivation shall be in accordance with the approved NOI and OOC, as well as the License
12189 to Apply Chemicals, and will be guided by best management practices and supporting
12190 information as provided in the 2025 Guide.
- 12191 2. Applicant shall submit the following information to the conservation commission as part of
12192 any P inactivation program prior to implementation:
 - 12193 a. Products to be applied to bind P and the quantities of each.
 - 12194 b. A list of all project participants with contact information.
 - 12195 c. Dates of expected application.
 - 12196 d. Map of location of any staging area(s).
- 12197 3. Monitoring will be conducted prior to treatment to establish the concentration of P and
12198 proposed P binder in the water column, including at a minimum near surface and near bottom
12199 locations within the treatment area. Monitoring will also include alkalinity and pH, water
12200 clarity, and algal types and abundance.
- 12201 4. During treatment, pH will be assessed at least before and after treatment on each day, with
12202 results used to adjust treatment as necessary to avoid impacts on biota. A daily survey of the
12203 treatment area and any downwind area will be conducted to detect any distressed or dead
12204 organisms.
- 12205 5. Appropriate measures will be taken to minimize the chance of any product, fuel, or related
12206 spills and ensure that adequate spill control devices or techniques are available.
- 12207 6. The conservation commission shall be notified immediately of any leakage of contaminants
12208 and spills or leaks must be cleaned up immediately with waste materials disposed of properly.
- 12209 7. The conservation commission and MassWildlife will be notified immediately if a fish kill
12210 occurs. A fish kill is defined as 100 dead fish of any species or 50 dead fish of any one species
12211 detected within 24 hours of any treatment.
- 12212 8. Treatment will not occur on any day when weather conditions prevent accurate delivery of the
12213 P binder to the target area. This usually translates into days with wind in excess of 20 mph.

Sample Conditions

9. Following treatment, the pre-treatment monitoring will be conducted within a month of treatment and monthly between the months of May and September for two years following treatment.

10. A summary report of treatment and all monitoring data will be supplied to the conservation commission at the conclusion of post-treatment monitoring.

Artificial Circulation

Movement of water in a lake can distribute oxygen to areas that may experience oxygen depression and will often disrupt the growth of problem algae such as cyanobacteria. Thermal differences over depth resist such mixing, and the energy necessary to break stratification is much greater than that necessary to maintain mixed conditions. System design and operation are therefore critical to success of any artificial circulation system. There are multiple types of circulation systems available, and the scale of operation may affect the need for Special Conditions.

Example Special Conditions for artificial circulation may include:

1. Artificial circulation shall be in accordance with the approved NOI and OOC and will be guided by best management practices and supporting information as provided in the 2025 Guide.
2. The system will be operated to prevent low oxygen conditions from being developed within the target area.
3. A monitoring program will be conducted, including at a minimum:
 - a. Oxygen and temperature profiles at 1 m depth increments will be monitored in the target area at least weekly during system operation.
 - b. Total P, total N, and algal types and abundance will be assessed at least monthly during system operation.
4. A report detailing the actions taken and results of the project will be provided to the conservation commission annually.

Hypolimnetic Oxygenation

Addition of oxygen to deep water in a lake can counter internal P loading and support greater use of that water layer by aquatic biota such as fish and invertebrates. Adding oxygen without breaking stratification maintains the natural thermal condition of the lake and can be accomplished by multiple approaches. There is little risk to any interest of the WPA from a properly functioning oxygenation system, but equipment failure that allows a return to anoxic conditions could cause a fish kill or other mortality of aquatic organisms and rapid release of P from sediments exposed to anoxia. Conditions therefore tend to focus on monitoring to ensure that oxygen remains in the targeted range.

Example Special Conditions for hypolimnetic oxygenation may include:

Sample Conditions

1. Oxygenation shall be in accordance with the approved NOI and OOC and will be guided by best management practices and supporting information as provided in the 2025 Guide.
2. The capacity of the oxygenation system will be sufficient to counter oxygen demand and provide oxygen near the sediment in the target area in excess of 5 mg/L.
3. A monitoring system will be in place to track oxygen in the target area on at least a daily basis; it is essential to track oxygen at a frequency that allows intervention when oxygen declines.
4. A report detailing the actions taken and results of the project will be provided to the conservation commission annually.

Orders of Conditions for Algae Removal

Algaecides

Algaecides are a subset of herbicides which are a subset of pesticides and are used to kill and/or mitigate the growth of algae, both in the water column (phytoplankton) or attached to plants or substrate (periphyton, filamentous mats). Algaecides are often applied in response to existing algae blooms of concern (e.g., cyanobacteria) but are more effectively deployed earlier in the bloom cycle to prevent problematic conditions from occurring. The goal is usually to increase water clarity and improve the suitability of water for contact recreation or potable consumption. Where algaecides must be repeatedly used to maintain desirable conditions, consideration of alternative control methods, usually relating to nutrient management, is warranted.

Example Special Conditions for algaecide application may include:

1. Application of algaecides shall be in accordance with the approved NOI and OOC, as well as the License to Apply Chemicals, and will be guided by best management practices and supporting information as provided in the 2025 Guide. All label restrictions must be followed.
2. Applicant shall submit the following information to the conservation commission as part of any algaecide application program prior to implementation:
 - a. Copies of the product names and active ingredients to be applied.
 - b. The name of the applicator or company contracted to apply the algaecide and the name and contact information for the project supervisor(s) responsible for ensuring compliance with the OOC.
 - c. A copy of a current License to Apply Chemicals (BRP WM 04 license) for this project.
3. Algae will be monitored at a frequency that informs treatment decisions and treatment may be conducted as warranted and allowable by the algaecide label for the life of this permit. However, if more than one treatment of the entire waterbody per year is needed, a plan that includes practical alternative controls must be submitted prior to any permit extension or new filing that includes algaecide use.
4. Prior to treatment, notification will be provided to the conservation commission with appropriate justification for why the treatment is to be conducted, when, and where actual application will occur.

Sample Conditions

5. If there is any reason to avoid downstream discharge of water during treatment, a plan for minimizing discharge will be provided to the conservation commission and appropriate actions will be taken in association with the application.
6. The treatment area will be visually surveyed for any dead or distressed organisms prior to and within 24 hours of treatment. Any adverse impacts such as fish kills or impacts to non-target wildlife observed during or shortly after treatment shall immediately be reported to the conservation commission and MassWildlife.
7. Appropriate measures will be taken to minimize the chance of any algaecide, fuel, or related spills and ensure that adequate spill control devices or techniques are available.
8. The conservation commission shall be notified immediately of any leakage of contaminants and spills or leaks must be cleaned up immediately with waste materials disposed of properly.
9. A water quality monitoring program shall be established for the purpose of assessing baseline conditions in the waterbody as well as to provide information to support management decisions regarding future algaecide treatments. Focus on nutrient concentrations, temperature, oxygen and water clarity.
10. A report will be filed with the conservation commission within the calendar year of any algaecide treatment. The report will include what algaecide was applied, where and when it was applied at what dose, and any monitoring data and observations obtained as part of the treatment program.

Orders of Conditions for Plant Control

Drawdown

Lowering the water level to expose some portion of the lake bottom can dry and/or freeze exposed plants. Perennial submergent species are most susceptible to impact and may be controlled by drawdown in the target zone. Annual plants are likely to return quickly from seeds, turions, or winter buds, but gradual coarsening of the exposed substrate over years may lower overall plant density. Interests of the WPA that may be impacted include water supply and fish and wildlife habitat. Special Conditions usually focus on meeting the guidelines that maximize desired impacts on plants while minimizing adverse impacts on non-target uses and organisms.

Example Special Conditions for algaecide application may include:

1. Drawdown shall be conducted in accordance with the approved NOI and OOC and will be guided by best management practices and supporting information as provided in the 2025 Guide.
2. Applicant shall submit the following information to the conservation commission as part of any drawdown program prior to implementation:
 - a. Plan for achieving the prescribed rate of drawdown, targeted date of refill completion, and minimum outflow during refill.
 - b. Monitoring program to track water level changes and outflow at a frequency appropriate to guiding the drawdown and meeting regulatory requirements.

Sample Conditions

3. The plant assemblage will be monitored in summer following any drawdown to quantify changes induced by drawdown.
4. If mussels or other minimally mobile organisms are present, populations will be assessed along transects from shoreline to any point of summer anoxia before and after drawdown.
5. A report will be filed with the conservation commission at the end of the permit period. The report will include records of water level and outflow measurement, magnitude and duration of drawdown attained, start and end date for active drawdown and refill periods, an assessment of the impact on the plant community, an assessment of any impact on other biota for which monitoring has been conducted, and an assessment of compliance with quantitative targets for water level, flow, and plant assemblage features.

Benthic Barriers

Benthic barriers, or bottom covers, limit light for rooted plants and create a physical barrier that restricts growth. Barriers placed before significant plant growth has occurred can prevent such growths if the surface of the barrier does not support rooted plants. Placing barrier after seeds, turions, or winter buds have germinated can help exhaust reserves and eventually lead to fewer plants when the area is uncovered. Benthic barriers are typically used to provide a small vegetation-free zone around shoreline access, docks, or swimming areas and can be precisely located. Some localized impacts to underlying flora and fauna will occur but they are generally negligible given the small area relative to lake area. The total lake area covered may have some bearing on Special Conditions assigned, with larger areas warranting more assessment and reporting.

Example Special Conditions for benthic barriers may include:

1. Application of benthic barriers for control of nuisance aquatic macrophytes shall be in accordance with the approved NOI and OOC and be guided by best management practices and supporting information as provided in the 2025 Guide.
2. Applicant shall submit the following information to the conservation commission as part of any benthic barrier vegetation management program prior to implementation:
 - a. Site plan of treatment area with location, dimensions, and total area to be treated.
 - b. Description of lake bottom in treatment area, including any potential obstructions to the barrier.
 - c. Photograph(s) with recognizable landmarks or other documentation of area to be treated.
 - d. Information on the product (tradename) and/or type of material to be utilized.
 - e. Description of how barrier will be placed in the water body (e.g., shoreline vs. boat) and who will be responsible for application and maintenance.
 - f. Timing of application (e.g., usually late spring) and whether material is to be recovered and redeployed after or during the growing season or is to remain in place for multiple seasons.
 - g. Maintenance program to maintain barrier effectiveness.

Sample Conditions

3. Applicant shall be responsible for maintaining proper placement of barriers to avoid nuisance or safety concerns. The applicant may need to reinstall barriers and/or replace weights if they are dislodged or floating due to wave action or build-up of gases beneath materials.
4. An annual report will be submitted to the conservation commission with a summary of the program and monitoring data or photographic evidence of the results of benthic barrier use.

Dredging for plant control

Dredging for plant control may differ from dredging for internal P load control in that the dredging for plant control will be in the shallow, plant-supporting (littoral) zone, whereas dredging for P control may extend to deeper water. The same permits apply and the impacts are likely to be similar, but impacts to aquatic plants may be greater by design. The same Special Conditions applied to dredging for nutrient control apply, but additionally the applicant should be required to provide a plant community assessment suitable for comparing conditions before and after dredging.

Hand Harvesting

Hand harvesting (or hand pulling) is the selective removal of unwanted plants by hand, sometimes with handheld tools. Hand pulling is typically conducted by volunteers from local lake associations or beach clubs or by private shoreline owners, but some companies offer such services with divers. Hand pulling of localized populations can be extremely effective in removing small populations of nuisance plants, particularly invasive species, provided the root systems are harvested and the plant fragments are removed from the water. In areas where just a few plants are established, pulling those plants by hand can be an effective approach with minimal impact to any non-target organisms. Hand pulling over larger areas or when the target plant population is dense is more challenging, presents the risk of more non-target impacts, and may require more Special Conditions.

Example Special Conditions for hand harvesting may include:

1. Application of hand harvesting proposed for control of nuisance aquatic macrophyte shall be in accordance with the approved NOI and OOC and be guided by best management practices and supporting information as provided in the 2025 Guide.
2. Applicant shall submit the following to the conservation commission as part of any hand harvesting program prior to implementation:
 - a. A survey of plants in any target area, noting any listed species or other species with high habitat value to be avoided.
 - b. A list of plant species to be removed with target removal goals. Plant identification sheets to identify target species are recommended for any volunteer training.
 - c. Site plan of treatment area with approximate dimensions and depths and total area to be addressed [Note: an informal inspection of area by the conservation commission prior to

Sample Conditions

- 12397 harvesting may be useful for clarification of scope and objectives of project]. Inclusion of
12398 photographs of target area with recognizable landmarks is recommended.
- 12399 d. Timing and expected duration of hand harvesting program.
- 12400 e. Procedures for processing harvested plants for eventual disposal and location of that
12401 disposal.
- 12402 3. The Applicant will install a fragment barrier (e.g., fine mesh netting or erosion control
12403 material) around the limits of work areas or have people assigned to fragment collection during
12404 harvesting operations.
- 12405 4. The applicant is responsible for proper removal and disposal of all harvested materials.
- 12406 5. An annual report will be provided to the conservation commission, including an accounting of
12407 hand harvesting effort and documentation of results.

12408 ***Mechanical Harvesting***

12409 Mechanical plant removal operations involve machinery designed to cut and potentially collect
12410 vegetation. Mechanical harvesting is successful in producing temporary relief from nuisance plants
12411 and in removing living organic matter and associated nutrients. Harvesting can be an effective
12412 short-term treatment to reduce the biomass of aquatic plants at shallow depths (usually 3-7 ft depth)
12413 that potentially limits lake uses such as boating and swimming or impacts the quality of fish and
12414 wildlife habitat. Simply cutting plants in a small area of a much larger lake is unlikely to have
12415 major water quality impacts or other adverse effects, but collecting cut plants is usually necessary
12416 in larger harvesting programs to avoid oxygen depression, nutrient recycling, poor aesthetics, and
12417 possibly odor. Turbidity generation during cutting can be substantial but is almost always a short-
12418 term (about a day) phenomenon. Mechanical harvesting is minimally selective, removing all
12419 vegetation in the targeted area up to the depth of cutting, and may remove some fish. The scale
12420 and frequency of mechanical harvesting therefore has bearing on the need for Special Conditions.

12421 Example Special Conditions for mechanical harvesting may include:

- 12422 1. Application of mechanical harvesting shall be in accordance with the approved NOI and OOC,
12423 as well as any other permits required, and be guided by best management practices and
12424 supporting information as provided in the 2025 Guide.
- 12425 2. Applicant shall submit the following information to the conservation commission in
12426 association with any program of mechanical harvesting of aquatic vegetation prior to
12427 implementation:
- 12428 a. Site plan of harvesting area with approximate location, dimensions, and total area to be
12429 treated. Any designated “no harvest” areas should be clearly marked.
- 12430 b. Any potential bottom hazards such as rocks, woody debris, shallow depth, and other
12431 obstructions potentially affecting harvester performance or safety need to be clearly
12432 identified.
- 12433 c. Map of existing aquatic vegetation with identification of major species and general
12434 appraisal of relative abundance, biomass, and coverage. Quantitative collection of plant

Sample Conditions

- 12435 community data, most often from an established network of monitoring sites, will facilitate
12436 pre- and post-harvesting conditions assessment.
- 12437 d. Harvesting plan delineating the primary target species, harvesting depth, planned timing
12438 and frequency of harvesting, and in what order areas are to be harvested.
- 12439 e. Process for harvested plant disposal, including the location of drying and disposal site(s).
- 12440 3. Operators must inspect and clean all equipment before entering or leaving the lake. The
12441 operator will be responsible for providing adequate spill control devices or techniques at
12442 staging areas and be prepared to address any spills in open water.
- 12443 4. The operator will take special care when harvesting aquatic vegetation which spreads by
12444 vegetative fragmentation. Such vegetation fragments should be collected to prevent further
12445 spread.
- 12446 5. Water quality will be monitored over the period of harvesting to detect any significant effects;
12447 focus on clarity, oxygen, and nutrient levels.
- 12448 6. Any observed collateral impact to non-target fauna (e.g., fish, turtles) during harvesting shall
12449 be noted and means to avoid excessive collection will be implemented.
- 12450 7. Applicant shall complete pre- and post-treatment monitoring of plant composition and density
12451 in the harvesting area to evaluate program effectiveness.
- 12452 8. An annual report summarizing the harvesting program and documenting results will be
12453 submitted to the conservation commission. Hours or days of effort, dates of harvesting, amount
12454 of vegetation collected, associated water quality and plant data, and an appropriate impact
12455 assessment should be included.

12456 ***Hydroraking***

12457 Hydroraking involves the use of the equivalent of a floating backhoe, usually outfitted with an
12458 extendable arm and a York rake. The tines of the rake attachment are dragged through the
12459 sediment, ripping out thick root masses and often collecting associated sediment and debris.
12460 Hydroraking of a lake bottom typically targets shallow areas adjacent to shore where mechanical
12461 harvesters cannot effectively operate, either due to lack of water depth or physical obstructions
12462 like rocks and stumps. When employed properly, a hydrorake can be a very effective tool for
12463 removing submerged stumps, water lily root masses, or floating islands. Adding fine screening to
12464 the tines allows sediment to be moved to contour a swim area or other nearshore site. Material
12465 removed by hydroraking is either placed on shore adjacent to the work area or on a barge for
12466 transport to some other offloading site. Hydroraking is functionally a form of dredging and may
12467 be permitted as such, with attendant sediment testing and related regulatory scrutiny, if the quantity
12468 of material removed exceeds 100 cy.

12469 Example Special Conditions for hydroraking may include:

- 12470 1. Application of hydroraking shall be in accordance with the approved NOI and OOC, as well
12471 as all other permits granted for hydroraking, and be guided by best management practices and
12472 supporting information as provided in the 2025 Guide.

Sample Conditions

2. Applicant shall submit the following information to the conservation commission in association with any hydroraking project prior to implementation:
 - a. Site plan of project area with location, depth, and total area and volume to be hydroraked with description of target plants or obstructions to be removed.
 - b. Any potential bottom hazards such as rocks, woody debris, shallow depth, and other obstructions potentially affecting hydroraking performance or safety need to be clearly identified. Any such obstruction designated as habitat and not to be removed will be properly noted on the site plan.
 - c. Provisions for controlling turbidity and measures to minimize impacts to fauna and water quality.
 - d. Provisions for offloading sediment to shore, measures for minimizing offloading impact, and ultimate disposal location.
3. The operator must inspect and clean all equipment of dirt and vegetation before entering or leaving the lake. The operator will be responsible for providing adequate spill control devices or techniques at staging areas and will be prepared to address any spills in open water areas.
4. Applicant shall complete pre- and post-treatment survey of treatment area to evaluate the removal of material and resulting conditions.
5. Water quality monitoring will be conducted where more than temporary, localized impacts are plausible; focus on turbidity, oxygen, and nutrient concentrations.
6. An annual report summarizing the hydroraking program and describing results will be submitted to the conservation commission. Amount of material removed, any related water quality alteration, and changes to target areas will be documented.

Aquatic Herbicides

Treatment of aquatic vegetation by chemical herbicides is commonly used in MA for reducing expansive growths of nuisance aquatic vegetation and especially for control of invasive species. Herbicides can be an effective means to reduce unwanted biomass and facilitate recreational use. Habitat rehabilitation is also possible with herbicides, especially where invasive species have become dominant. However, treatments do not often produce long-term results and there may be concerns over direct and indirect effects on non-target organisms. Therefore, any treatment must be carefully planned and implemented. Since repeat treatment is very likely over a period of years, monitoring becomes very important in adaptive management. Treatment can address an entire lake or a small portion of the waterbody; assignment of Special Conditions may be dependent on scale and frequency of treatment.

Example Special Conditions for aquatic herbicide application may include:

1. Application of herbicide treatment for control of nuisance aquatic shall be in accordance with the approved NOI and OOC, as well as the License to Apply Chemicals, and be guided by best management practices and supporting information as provided in the 2025 Guide.

Sample Conditions

- 12510 2. Herbicide treatments shall be conducted only with EPA registered and MDAR approved
12511 aquatic herbicides.
- 12512 3. Applicant shall submit the following information to the conservation commission in
12513 association with any herbicide application prior to implementation:
 - 12514 a. The applicant shall provide the trademark product name(s) and active ingredient(s) of
12515 aquatic herbicide products to be used.
 - 12516 b. The applicant must provide the name of the applicator responsible for applying the
12517 herbicide and the name and contact number for all parties responsible for compliance with
12518 the OOC.
 - 12519 c. A copy of a current License to Apply Chemicals (BRP WM 04) for this project.
 - 12520 d. An aquatic vegetation treatment plan including target area, species to be treated, dose
12521 calculations, timing of application, any mitigation to avoid non-target in-lake and
12522 downstream impacts, and potential follow-up activities, including further herbicide
12523 application.
 - 12524 e. If multiple treatments are permitted, the applicant should establish criteria or “trigger”
12525 metrics to justify repeated herbicide use (e.g., target cover or density limit, threshold active
12526 ingredient concentration). Goals and criteria for further action should be quantitative and
12527 measurable.
- 12528 4. If there is any reason to avoid downstream discharge of water during treatment, a plan for
12529 minimizing discharge will be provided to the conservation commission and appropriate actions
12530 will be taken in association with the application.
- 12531 5. Appropriate measures will be taken to minimize the chance of any herbicide, fuel, or related
12532 spills and ensure that adequate spill control devices or techniques are available.
- 12533 6. The conservation commission shall be notified immediately of any leakage of contaminants
12534 and spills or leaks must be cleaned up immediately with waste materials disposed of properly.
- 12535 7. Signage indicating restrictions on any use of the lake during and following treatment shall be
12536 posted at least 48 hours in advance of the planned treatment. Signage shall be displayed at boat
12537 launch/access locations, public beaches, other common lake access points, and along streets
12538 with parcels with direct frontage on the lake shoreline, as needed to ensure that all potential
12539 users are informed.
- 12540 8. The treatment area will be observed before treatment and again within 24 hours after treatment
12541 with assessment of any distressed or dead organisms. Any adverse impacts such as fish kills
12542 or impacts to non-target wildlife observed shall immediately be reported to the conservation
12543 commission and MassWildlife. A fish kill is defined as 100 dead fish of any species or 50 dead
12544 fish of any one species detected within 24 hours of any treatment.
- 12545 9. Pre- and post-implementation water quality should be monitored where more than localized
12546 treatment is involved; focus on temperature, oxygen, pH, and water clarity.
- 12547 10. Pre- and post-treatment data for aquatic vegetation features will be collected. Measurements
12548 should be suitable for quantitative comparison of pre- and post-treatment conditions with
12549 respect to vegetative composition, coverage, and density.

Sample Conditions

12550 11. The applicant shall submit an annual report to the conservation commission within the year of
12551 treatment. The report will provide a description of project work, pre- and post-implementation
12552 aquatic vegetation conditions, any water quality data, an evaluation of aquatic vegetation
12553 reduction, and any relevant observations.

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