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HYDRO-RAKING AS A MANAGEMENT OPTION FOR AQUATIC NON-NATIVE INVASIVE AND NATIVE NUISANCE PLANTS IN FRESHWATER PONDS AND LAKES: CASE STUDIES IN MASSACHUSETTS

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And accepted on the recommendation of

Samuel Ratick, Chief Instructor

ABSTRACT

HYDRO-RAKING AS A MANAGEMENT OPTION FOR AQUATIC NON-NATIVE INVASIVE AND NATIVE NUISANCE PLANTS IN FRESHWATER PONDS AND LAKES: CASE STUDIES IN MASSACHUSETTS

DANIELLE LEE DESMARAIS

Hydro-raking is one management option to control non-native invasive and native nuisance plants in freshwater ponds and lakes in Massachusetts. The hydro-rake is a floating pontoon boat with paddlewheels and a long, giant rake that scoops plants from pond or lake bottoms. Analyzing eight case studies in Massachusetts where hydro-raking occurred, this thesis provides a comprehensive overview of when the process would be recommended or not. The results, displayed in a decision tree guide the reader through questions to test for suitability of the water body they manage. The water level needs to be between one and twelve feet, and the pond or lake requires shore access for the machinery. Plants recommended for hydro-raking in Massachusetts are rooted floating plants and emergent shoreline plants. Plants not recommended for removal through hydro-raking include species that spread through fragmentation. Organic debris and trash are also recommended for removal with the hydro-rake.

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Connecticut Valley Mineral Club- Springfield, MA	Educational Committee
Earthroots Field School -Trabuco Canyon, CA	Guest Instructor
Irvine Ranch Outdoor Education Center -Orange, CA	Staff Naturalist
OC Hiking - Irvine, CA	Hike Organizer

DEDICATION

This research is dedicated to anyone who loves ponds and lakes, and their preservation.

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DISCLAIMER

All product and company names are trademarks™ or registered® trademarks of their respective holders. Use of products or companies does not imply any affiliation with or endorsement by them. Hydro-raking as a management option is best evaluated in consultation with an experienced lake or pond management professional.

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1.1 Hydro-raking Research Overview

Hydro-raking is a mechanical means of managing non-native invasive and native nuisance plans by utilizing a pontoon boat with paddlewheels, with a large rake attached to a crane arm, operated by a seated driver, as seen in Figure 1. The machine rakes plant material (living or non-living), leaf litter and other organic debris, from pond and lake bottoms to improve habitat, water quality, aesthetics and nutrient control.

Figure 1. Hydro-raking machinery with seated driver (Foster's Pond Corporation**,** 2007).

The purpose of this thesis is to inform the reader that, under certain conditions, hydro-raking can be a recommended management control option for removing aquatic non-native invasive or native nuisance plants from ponds and lakes in Massachusetts. This research will provide a comprehensive study on the mechanics, limits and successes of hydro-raking, specific to aid decision makers who manage ponds or lakes in Massachusetts.

Section 1.2 in this thesis provides a brief overview of other aquatic plant management methods, to give context to later case studies where multiple methods are combined with hydro-raking. This research is not a comparative guide, the focus in just on hydro-raking. Section 1.3 explains the general problems non-native invasive and nuisance plans can cause, while section 1.4 describes the aquatic plant species discussed in the case study section. The research described in section 1.5 delves into how the hydro-rake works. The literature reviewed is discussed in sections 2.1 through 2.4, where various scientific articles, scientific database findings, and data tables specific to hydro-raking are examined. Section 3.1 through 3.8 explores hydro-raking case studies of ponds and lakes in Massachusetts, where multiple methods of aquatic plant control are often used on a water body, followed by a conclusion of the case study findings.

Costing, legality concerns, permitting fees and the permitting process for hydro-raking are featured in Section 3.10, which leads into sections 4.1 through 4.3 featuring the decision tree, which provides a means for determining the suitability of hydro-raking as a management tool, and provides as example on how the tree is used. Sections 5.1 and 5.2 summarize the benefits and imitations of the hydro-raking and recommends hydro-raking for the removal of trash. Section 6 shows all the materials cited in this thesis, followed by three appendixes. Section 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies*, section 7.2: *Web of Science Database Search Results* and section 7.3 *Letter of Determination from the Institutional Review Board (IRB)*, which serves as proof for approval, for the interviews conducted in this thesis.

The following section 1.2*: Options for Aquatic Plant Management* provides the context for why some plant species need to be managed in lakes and ponds by discussing the various methods that accompany hydro-raking.

1.2 Options for Aquatic Plant Management

Once aquatic plants are dense enough that ponds or lakes exhibit any of the following symptoms: swimming or boating become difficult, the water is giving off a foul odor, it has lost visual appeal for real estate, and fish or other wildlife have died or left the area, a management plan should be developed with professional assistance. These plans often include other methods alongside hydro-raking as a management method, although hydro-raking is the focus of this study. Table 1 shows various management methods for addressing the impacts of non-native invasive and nuisance plants on water bodies, followed by a brief description of each method.

Table 1.

Methods for Aquatic Plant Removal	
Method	**How Method Works**
Dry Dredging	Dry sediment is removed from pond or lake bottom
Wet/hydraulic dredging	Wet sediment is removed from pond or lake bottom
Drawdown- through pumping or dam mechanism	Lowers water level to expose plants to freeze or dry out
Hand-harvesting/pulling	Plants pulled by hand, cut by sickle, dug out with a hoe, rakes or forks.
Mechanical Harvesting	Floating machine with cutting blade. Machine has a conveyor belt to move plants off the water
Hydro-raking	Floating machine with giant rake to scoop and pull plants
Shading by plastic	Reduce sunlight through black plastic sheeting on the water
Shading by dyes	Reduce sunlight through darker chemicals in the water
Shading by Algae	Applying fertilizers to create an algae bloom to shade pond or lake
Sand layering	Adding layers of mineral soils (sand, gravel, clay) to bottom of pond or lake to kill plants
Benthic barriers	Plastic or fabric barriers applied to bottom of waterbody
Biological controls	Introducing a species: fish, turtles, insects, etc. to outcompete or kill plants
Chemicals	Applying herbicides to kill plants
Diver Assisted Suction Harvesting (DASH)	Underwater vaccum with SCUBA divers to remove plant roots, leaves and other debris

Methods of aquatic plant removal. Compiled from (Helfrich, Neves, Libey & Newcomb 2009; Madsen, 2000)

The various methods shown in Table 1 include, dry and wet dredging, a procedure where the pond or lake bottom layer of sediment is scooped out with heavy machinery to lower the water level, remove seed pods in the sediment or change the water chemistry to become undesirable living conditions for the non-native invasive or native nuisance plants. Drawdowns can be accomplished through pumping water out, or using a dam mechanism to lower the water level so the undesired plants can freeze or dry out in the sun. Hand harvesting involves people pulling the plants onto barges, boats or the shore after carefully pulling plants by the roots and collecting seeds.

A mechanical harvester, seen in in Figures 2 and 3, so not to be confused with a hydro-rake, will be explained in detail more than the other management options. The operations of a harvester differ from the hydro-rake through the cutting the plants below the water with a giant saw. The plants are then brought up on a convertor belt similar, to a treadmill, where the plants are then shored and brought ashore for disposal.

Figure 2. Harvester gathering plants onto conveyor belt. Photo credit: (Mystic River Watershed Association, 2010)

Figure 3. Harvester on the water. Photo credit: (Aquarius Systems, 2012)

More techniques to control aquatic plants as seen in Table 1 include, shading to reduce sunlight throughout the water body in an attempt to reduce the non-native invasive or native nuisance plants, which can be achieved using chemical dyes, shade dyes and algae dyes. Sand layering uses sand, clay or other organic rock based material to smother the benthic plants. Benthic barriers are plastic sheeting placed on the bottom with the aid of SCUBA divers in deep areas to also smother plants and prevent growth. Biological controls involve introducing a species such as insects, or fish to eat the non-native invasive or nuisance plants. Herbicides are chemicals that kill plants, and are administered with various chemical strengths and volumes. DASH, (or diver assisted suction harvesting) involves using an underwater vacuum, often with the assistance of SCUBA divers in deep areas, to remove the plants, and then filter and return the water back to the water body.

1.3 Aquatic Non-Native Invasive and Nuisance Aquatic Plants in Massachusetts

Invasive non-native and native nuisance are two common terms used to distinguish aquatic plants that may be targeted for control. The Massachusetts Invasive Plant Advisory Group (MIPAG) defines invasive plants as "non-native species that have spread into native or minimally managed plant systems in Massachusetts, causing economic or environmental harm by developing self-sustaining populations and becoming dominant and/or disruptive to those systems" (MIPAG, n.d). Native nuisance plants are native species that have taken on invasive characteristics by expanding into areas either not previously colonized. An example of nuisance plant problems would be a dense coverage of white waterlily (*Nymphaea odorata*), yellow waterlily (*Nuphar variegatum*) or water shield (*Brasenia schreberi)* growing over the entire surface of a pond or lake making kayaking difficult. These plants are described in appendix 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.* Submerged plants such as spiny naiad *(Najas marina)* or coontail (*Ceratophyllum demersum*), both native to Massachusetts, can also grow too dense and become a nuisance to boaters or swimmers (Wagner, 2004).

The state of Massachusetts estimated that in 2013, one third of the approximately 3,000 freshwater lakes and ponds in Massachusetts were affected by non-native invasive plants (Seltz, 2013). Massachusetts spent about $500,000 on non-native invasive aquatic plant management in 2013, while municipalities and private associations spent about $1.5 million more (Seltz, 2013). Non-native invasive freshwater plants can spread from one ecosystem to another through transport methods such as seeds in bird excrement, wind dispersal of seeds and water transport of plants that reproduce by fragmentation where the new branch fragment establishes in the sediment and a new community grows.

Once an aquatic invasive plant species establishes itself a new community, the plant can spread rapidly, as non-native species bring into new ecosystems structural, physiological, or behavioral adaptations against which native species have no defense (Department of Conservation and Recreation [DCR], 2010b). The impacts include loss of native species, habitat degradation, damage to infrastructure such as houses or boats, disruption of ecosystem function such as species diversity, and impairments to water quality (DCR, 2010b). An excess of the nutrients phosphorus and nitrogen can cause nuisance pond algae blooms, poor water clarity, and unpleasant odors and may affect the health of aquatic life (Solitude Lake Management, 2014a). Water quality issues can also include low dissolved oxygen levels, which can impede plant growth.

Non-native invasive aquatic plants threaten biodiversity from having more effective defense mechanisms against predators, or having no predators at all (Energy and Environmental Affairs, 2016b). Non-native invasive aquatic plants often have a faster growth rate and reproductive success rate, and the ability to out-compete native species for food and habitat (Energy and Environmental Affairs, 2016b). Rooted vascular plants known as macrophytes, such as cattail (*Typha latifolia*) and common reed (*Phragmites australis*), pose the greatest threat to water quality due to the biomass they form from fast growth, causing the displacement of native plants in the littoral habitat zones of waterbodies (DCR , 2010b). These plants are described in appendix 7.1: *Aquatic Plant Species*

Discussed in the Hydro-raking Case Studies. Specific plants mentioned later in the case study sections 3.2 through 3.8 will be briefly discussed in the next section.

1.4 Specific Aquatic Plant Species Discussed in the Hydro-Raking Case Studies

There are four main aquatic plant groups: submerged, rooted floating, emergent, and free floating, seen in Figure 4 (Lembi, 2009). These categories are used to classify the main plants discussed in the case studies on hydro-raking in sections 3.2 through 3.8. None of the non-native invasive or native nuisance plants studied in this thesis fell into the free floating plant category. Water chestnut, one of the plants discussed later can also physically become free floating, but is commonly classified as a rooted floating plant.

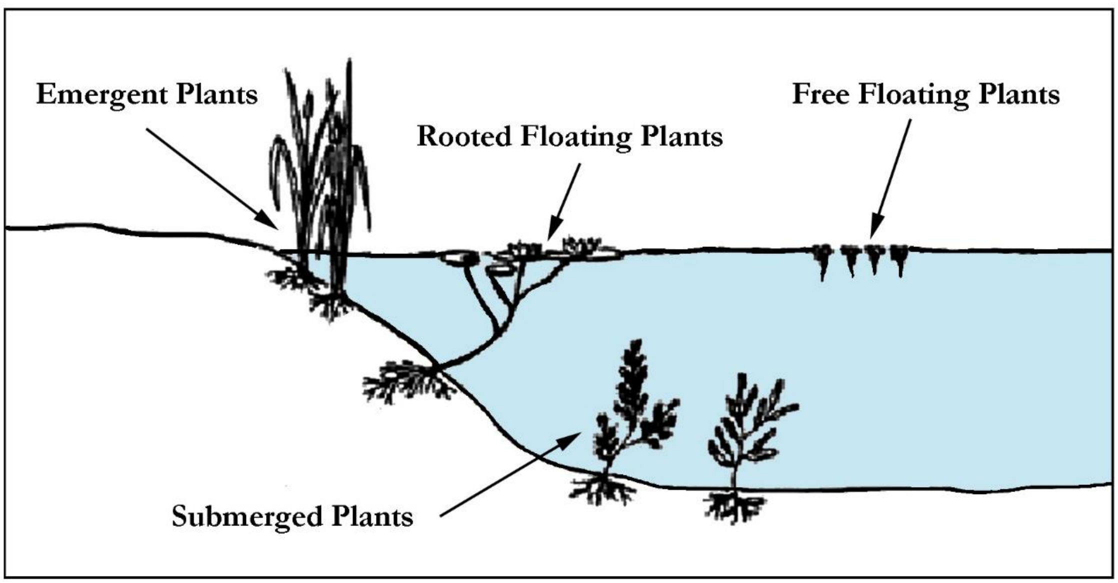

Figure 4. Drawing showing location of submerged, rooted floating, emergent, and free floating plants in a pond or lake. Redrawn from original art by (Lembi, 2009)

Submerged:

- **Fanwort** (*Cabomba caroliniana*) non-native invasive. Discussed in: Warner's Pond, Foster's Pond

- **Variable watermilfoil** (*Myriophyllum heterophyllum*) non-native invasive. Discussed in: Warner's Pond, Spectacle Pond

- **Coontail** (*Ceratophyllum demersum*) native nuisance. Discussed in: Warner's Pond

- **Spiny naiad** *(Najas marina)* non-native invasive. Discussed in: Foster's Pond

Rooted Floating:

- **Water chestnut** (*Trapa natans)* non-native invasive. Discussed in: Warner's Pond, Fiske Pond. (Water chestnut can also become free floating but it commonly classified as rooted floating)

- **White waterlily** (*Nymphaea odorata*) native nuisance. Discussed in: Warner's Pond, Foster's Pond, Red Lily Pond

- **Yellow waterlily** (*Nuphar variegatum*) native nuisance. Discussed in: Warner's Pond, Red Lily Pond

- **Water shield** (*Brasenia schreberi)* native nuisance. Discussed in: Spectacle Pond, Foster's Pond, Lake Elizabeth

Emergent:

- **Purple loosestrife** (*Lythrum salicaria*) non-native invasive. Discussed in: Spectacle Pond, Warner's Pond, Red Lily Pond

- **Water willow** *(Decodon verticillatus)* native nuisance. Discussed in: Warner's Pond, Lake Elizabeth

- **Cattail** *(Typha latifolia)* native nuisance. Discussed in: Spectacle Pond
- **Common reed** *(Phragmites australis)* non-native invasive. Discussed in: Spectacle Pond, Red Lily Pond

The specific plants listed, and later mentioned in the case studies, are explained through a physical description of the plants, how the plant spreads/reproduces, and what the plant does to the ecosystem in appendix 7.1: *Specific Aquatic Plants Discussed in Case Studies.* These plants will or will not be recommended for hydro-raking The next section delves into the mechanics of the hydro-rake pontoon boat, the rake arm the hydro-rake uses and limitations on the use of the hydro-rake.

1.5 Hydro-raking: How the Machinery Works

A hydro-rake is a pontoon boat with paddlewheels, with a large rake attached to a crane arm, operated by a seated driver, seen in Figure 5. The machinery can operate in water from one ft. (.30 m) to 12 ft. (3.65 m) (Solitude Lake Management, 2014a; The Lake Doctor, 2014). There needs to be sufficient water in the pond or lake for the hydro-rake equipment to float and work properly.

Figure 5. Hydro-rake removing plant debris from the water, showing the plastic water-guard up around the operator. Photo credit: (Solitude Lake Management, 2014a).

The purpose of the hydro-rake is to remove non-native invasive and native nuisance vegetation, and in some situations can clear unconsolidated, (loosely arranged) bottom debris such as decaying leaves from pond and lake bottoms (Solitude Lake Management, 2014a). The hydro-rake is powered by a diesel engine, which drives the hydraulically operated paddle wheel propulsion system (Solitude Lake Management, 2014a). Speaking with a manager who oversees hydro-raking at a pond and lake management specialty company, he mentioned there are hydraulic fluid spill protectors on the boat as a safeguard against any leaks (J. Castellani, personal communication, March 8, 2016). The hydro-rake needs to be loaded into the water as a standard boat would, as there are no wheels on the bottom of the boat, which requires shoreline access to the water.

Physical features of the hydro-rake include a long hydraulic arm with a rake attachment. The rake itself is curved, and approximately eight ft. wide, as seen in Figure 6, which shows the one inch prongs called ‘tines”, and one inch spaces between tines to allow the water and sediment to escape from the rake as the hydraulic arm pulls the debris out of the water (SnoVac© & Snow Vac© Metal Fabricating LLC., n.d). It is important to note the size of the rake tines and spaces between them, as some plants will be too small to be caught by the rake, and just stay in the pond or lake.

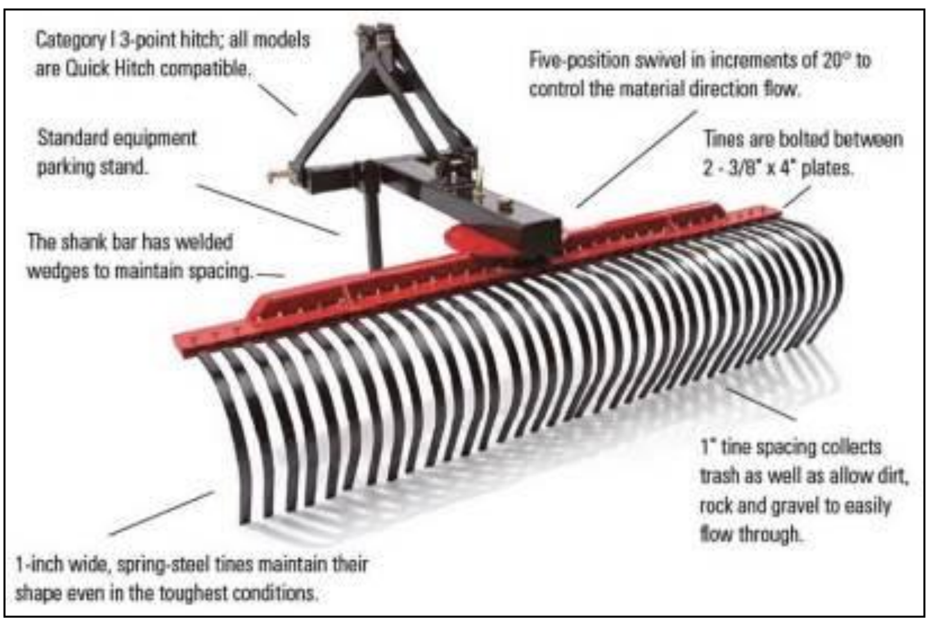

Figure 6. Rake attachment detail on a hydro-rake. Photo credit: (SnoVac© & Snow Vac© Metal Fabricating LLC., n.d.).

The hydro-rake can be used with a variety of attachments (Solitude Lake Management, 2014a). One video of hydro-raking showed water and sediment being sifted and dropped through the rake, seen as a video still image in Figure 7. Speaking with a manager who oversees hydro-raking at a pond and lake management specialty company, he described a rake attachment option with mesh sides, similar to a bucket, to remove finer sediment deposits and designed specifically so that turtles and fish can still escape when hydro-raking (J. Castellani, personal communication, March 8, 2016).

Figure 7. Video still of a hydro-rake of emptying debris onto the shoreline. Video still credit: (Taki161, 2008)

How the plants debris is removed for the pond or lake area to the shore and then moved after out of the wetland area is part of the management and/or restoration process of hydro-raking. The hydro-rake lacks on-board storage for the plants and debris collected. These collected plants and debris need to be off-loaded onto a floating barge or directly onto the shoreline to be removed from the wetland area surrounding the lake or pond.

Each rake, when full of debris can hold a maximum of 500 lbs. of material that can be deposited directly on-shore (Solitude Lake Management, 2014a), as seen in Figure 8.

Figure 8. Hydro-rake unloading on shore. (Aquatic Technologies Inc., 2015).

Speaking with a manager who oversees hydro-raking at a pond and lake management specialty company, he mentioned that plant debris should be moved away from the shore for de-watering to lighten the debris for transport. The plant material de-watering process too close to the shore, can “wear away the surface of the shoreline and cause erosion” (J. Castellani, personal communication, March 8, 2016). Another reason to move the plants is to prevent “seeds, fragments, decaying organic matter and nutrients from moving back into the water” (J. Castellani, personal communication, March 8, 2016) to prevent further regrowth of the removed plants through seed dispersal or rhizome (connected horizontal root) growth discussed in in appendix 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.* Adding nutrients back into the water can provide optimal growing conditions for the non-native invasive and native nuisance aquatic plants to regrow.

To prevent regrowth, the plant debris must be removed from the shoreline area, and one method is to place the rakes full of debris directly onto a tractor's loader bucket for upland disposal outside the wetland area, as seen in Figure 9. That is an option to leaving the debris directly on the shoreline.

Figure 9. Hydro-rake loading debris right into a tractor's loader bucket. (Aquatic Technologies Inc., 2015)

The debris raked from the lake or pond bottom can also be placed on a barge, which functioned as a holding station, as seen in Figure 10. A loader bucket attached to a long arm, retrieved the debris off the barge to be deposited in a truck bed for transport.

Figure 10. Hydro-rake loading debris onto a floating barge, collected by a loader bucket and placed into a dump truck bed for transport (Tom Largy, 2015).

The aquatic management company that arranged the hydro-raking can often plan transportation of the plant debris, or the clients (often the homeowners) can handle the removal of debris themselves (Solitude Lake Management, 2014a). After the plant debris is removed from the wetland area, the plants can be used as garden compost. An example of composing is discussed in case study section 3.2: *Campus Pond- University of Massachusetts campus- Amherst, Massachusetts.* Plant debris can also be incinerated and will be discussed in section 3.6: *Fiske Pond-Natick, Massachusetts.*

Preventative methods are important after hydro-raking to prevent any seeds or loose plant pieces from re-growing in the sediment. Fragment barriers, seen in Figures 11 and 12 are floating buoys designed to catch any loose plant pieces or seeds and contain the fragments after the hydro-raking. The barriers in these photos were used after hand-harvesting and a good example of before and after images of where the plant collect along the barriers. Post hydro-raking, the plant fragments and any floating seeds would cling to the buoys, which will then be collected by people on boats or kayaks.

Figure 11. Fragment barrier before hand-harvesting of water chestnuts. (Blackstone River Watershed Association, 2012a)

Figure 12. Fragment barrier after hand-harvesting of water chestnuts. (Blackstone River Watershed Association, 2012a)

The mechanics of how the machinery operated found through a review of aquatic management companies did not show the entire literary scope of hydro-rake research, a thorough literature review was conducted by reading hydro-raking scientific papers.

2. Hydro-raking Literature Background

2.1 Overview of Aquatic Plant Management Literature

Google searches yielded pond and lake aquatic management websites for companies who own and operate the hydro-raking equipment, and often create plant management plans. Database searches through Google Scholar, ResearchGate, and Web of Science, turned up very little in the way of peer reviewed scientific papers. Hydro-raking can also be spelled "hydro raking" and "hydroraking," but the most common spelling is hydro-raking. To be thorough, different spellings were searched for. A phosphorus level study on lakes before and after hydro-raking was reviewed. Data tables of information on hydro-raking from management companies and environmental professionals were studied to see what information was missing. What was missing was a complete overview of when hydro-raking would be an option and when hydro-raking would not. This thesis is intended to fill that research gap by providing a comprehensive study on the mechanics, limits and successes of hydro-raking, specific to aid decision makers who manage ponds or lakes in Massachusetts.

2.2 Hydro-Raking Management Companies

A Google search with the term "hydro-raking" displayed the first 40 results as a mix of aquatic company management websites, a few postings for hydro-raking job requests, and trash hydro-rakes which are not for aquatic plant removal. Running the search term "hydro raking," without the hyphen brought similar results with management companies in Google. Pond and lake management companies presented information that could be biased with their management methods they recommend because the companies own and operate the hydro-raking equipment, and often create plant management plans. Hand-harvesting, for example is usually accomplished by volunteers, not paid aquatic managers, so by recommending a method volunteers complete, the company could face a loss in sales.

Solitude Lake Management pledged their best management practices on their website, "to provide sustainable and renewable lake and pond management solutions to help preserve and, wherever possible, improve the natural ecological balance of our surroundings and the communities we serve" (Solitude Lake Management, 2014d). The company claimed hydro-raking had the ability to "effectively remove all organic debris and muck from the bottom of a pond make it an ideal choice for routine maintenance that will help to prolong or prevent the need for future dredging" (Solitude Lake Management, 2014a). The removal of plants and muck also was claimed to reduce the overall nutrient loading on the water body (Solitude Lake Management, 2014a), which helps to reduce water quality issues like algae, foul odor and low dissolved oxygen. Water quality issues, such as those just listed, can effect aquatic organisms as well as reduce the aesthetics or recreational use of the water body by humans. Advantages of hydro-raking were listed as being able to remove plants, roots systems, muck, sediment, organic debris, and one hydro-raking service typically provides seasonal to 1-3 years or longer of nuisance plant control (Solitude Lake Management, 2014a). Further advantages included: clearing of selective areas including beaches, boating or fishing lanes, no chemical introduction or water use restrictions, minimal disturbance to shoreline landscapes and the cost is far less than dredging (Solitude Lake Management, 2014a).

Another company, The Lake Doctor, based out of Texas commented, “hydro-raking is a common technique used for physically removing small scale infestations of aquatic plants” (The Lake Doctor, 2014). The same company also mentions, “damage to valuable shoreline habitat and waterfront property is avoided with the hydro-rake” and hydro-raking ideal for the removal of floating islands, cattails, waterlilies, leaf accumulation and phragmites (The Lake Doctor, 2014). Phragmites, (also called common reed) is described in appendix 7.1. This company website listed advantages of hydro-raking such as: removing plants and root systems, seasonal control of one to three years of nuisance plants, clearing of selected areas, no chemical introduction or water use restrictions, minimal disturbance to shoreline landscapes and the cost is far less than dredging (The Lake Doctor, 2014).

Another company, Swamp Thing, mentioned that hydro-raking did not use chemicals as a benefit on their website, as they primarily use equipment such as a mechanical harvester and hydro-rake. “Why do think they have warning labels on herbicide treatments, use your own common sense” (Swamp Thing LLC., 2016). The implication they made is that mechanical methods, such as hydro-raking is completely free of any “side-effects” to the pond or lake ecosystem. “Call us today and try something eco-friendly” (Swamp Thing LLC., 2016). The eco-friendly comment again was recommending hydro-raking over using herbicides.

These company testimonials served as a backdrop to the scientific research I was looking for to back up the claims made by the companies. For example, "damage to valuable shoreline habitat and waterfront property is avoided with the hydro-rake" (The Lake Doctor, 2014), prompted research into looking for studies on the limitations and benefits of hydro-raking from an outsider perspective, not a company's viewpoint.

2.3 Scholarly Research Searches

The term "hydro-raking" in Google scholar yielded nine results, mostly journal articles from environmental organizations lacking scientific citations, and the search term "hydro raking" without the hyphen yielded over 8,000 results and displayed results with few scientific studies. Web of Science Core Collection is a database search tool utilized to see what scholarly peer-reviewed research existed on hydro-raking. Web of Science is an online subscription-based scientific citation indexing service maintained by Thomson Reuters. Web of Science Core Collection, has more than 12,000 international journals, scholarly books and conference proceedings representing the main fields of science, social sciences, arts and humanities (Thomson Reuters, 2014). Databases are searched through two criteria: title or topic. Hydro-raking in various spellings resulted in little published research. The titles searches "hydro-raking" and "hydroraking" revealed no results, with the topic search "hydroraking" also revealing none, and the topic search for "hydro raking" yielding one result. The details of this search methods and result are featured in appendix 7.2: *Web of Science Database Search Results.*

Another avenue to find scientific publications to aid this research project was the ResearchGate network, and by searching with the terms “hydro raking” and “hydro-raking” two publications were the search result and neither were about aquatic plant removal. “Hydroraking” brought up three results in Researchgate, where one result was a cancelled conference paper. These results implied there were few scientific studies specific to hydro-raking as an aquatic non-native invasive or native nuisance plant management technique. One search result was research on the changes in phosphorus levels and water turbidity before and after hydro-raking.

A study of hydro-raking effects on phosphorus level was conducted on Lake Wapalanne, located in New Jersey, which has a southern and northern basins connected by a channel. From 2005 to 2015, the southern lobe was shallow, had massive algal blooms, and had become eutrophic prior to hydro-raking (in 2009) based on phosphorus readings (Panja, et. al., 2015). After 11 months of hydro-raking (in 2010) to remove aquatic vegetation and unconsolidated bottom debris from the southern lobe, total phosphorus contents of water collected from various sections of Lake Wapalanne were higher than the samples collected prior to hydro-raking, indicating eutrophication and super-eutrophication, resulting in further algal blooms (Panja et. al. , 2015).

More scientific research on hydro-raking came in the publication *The Practical Guide to Lake Management in Massachusetts*, written by a certified lake manager. The author’s comments noted that hydro-raking can be a “very effective tool for removing submerged stumps, water lily root masses, or floating islands” (Wagner, 2004). Hydro-raking in combination with a harvester can remove most forms of vegetation in ponds or lakes and is particularly effective for water lilies (white or yellow) and other species with dense root masses, and is effective in the short-term because the hydro-rake immediately removes plants (Wagner, 2004).

Some of the more limiting attributes mentioned in *The Practical Guide to Lake Management in Massachusetts*, is that the hydro-rake is "not an especially thorough or selective technique" (Wagner, 2004). That statement means the hydro-rake is not a good option for areas mixed with undesired plant species and desirable species. Another negative attribute of the hydro-rake is the process is "not a delicate operation, however, and will create substantial turbidity and plant fragments," as well as extensive sediment disturbance. (Wagner, 2004). Hydro-raking can also kill and remove some benthic invertebrates during operation (Wagner, 2004). Benthic invertebrates are organisms such as clams, mussels and snails that live in the sediment. With these hydro-raking limitations and benefits deduced from scientific publications, data tables were also explored for information within the review of existing literature on hydro-raking.

2.4 Compiled Research on Hydro-raking

Table 1 consists of hydro-raking information originally distributed at a pond and lake management conference, listed hydro-raking mode of action, advantages and disadvantages.

Table 2.

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
4.b) Cutting (without collection)	♦ Plants cut in place above roots without being harvested	♦ Generally efficient and less expensive than complete harvesting	♦ Leaves root systems and part of plant for possible re-growth ♦ Leaves cut vegetation to decay or to re-root ♦ Not selective within applied area
4.c) Harvesting (with collection)	♦ Plants cut at depth of 2-10 ft and collected for removal from lake	♦ Allows plant removal on greater scale	♦ Limited depth of operation ♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Limited selectivity within applied area ♦ More expensive than cutting
4.d) Rototilling	♦ Plants, root systems, and surrounding sediment disturbed with mechanical blades	♦ Can thoroughly disrupt entire plant	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting
4.e) Hydroraking	♦ Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake	♦ Can thoroughly disrupt entire plant ♦ Also allows removal of stumps or other obstructions	♦ Usually leaves fragments which may re-root and spread infestation ♦ May impact lake fauna ♦ Not selective within applied area ♦ Creates substantial turbidity ♦ More expensive than harvesting
5) Water level control	♦ Lowering or raising the water level to create an inhospitable environment for some or all aquatic plants ♦ Disrupts plant life cycle by dessication, freezing, or light limitation	♦ Requires only outlet control to affect large area ♦ Provides widespread control in increments of water depth ♦ Complements certain other techniques (dredging, flushing)	♦ Potential issues with water supply ♦ Potential issues with flooding ♦ Potential impacts to non-target flora and fauna

Table 2. Management options table, where hydro-raking is highlighted. Modified from (Wagner, 2004, p. 36) adapted from (Wagner, 2001).

Table 2 mentioned that hydro-raking is "more expensive then harvesting", harvesting being mechanical harvesting, another method of non-native invasive and nuisance plant removal. Algae, mentioned in a separate data table discussing various control methods, did not mention hydro-raking as an option, and suggested other managment options instead (Wagner, 2004, pp 27-32).

Table 2, created by a pond and lake aquatic plant management company, was distributed at a management conference in 2000. The hydro-raking section has been highlighted, which lists a description of hydro-raking, plants suitable or not suitable for control with hydro-raking, concerns/issues of hydro-raking and cost of hydro-raking. This data table from the New England Chapter of the North American Lake Management (NEC-NALMS) conference does not have water body criteria, such as depth, access to the water itself to unload the hydro-rake and the actual costing breakdown and permitting process. The costing is also from the year 2000, and could be outdated due to inflation, due to the writing of this thesis in 2016.

Table 3.

PLANT	CONTROL METHOD	DESCRIPTION	CONCERNS/ISSUES	COST
SUBMERSED PLANTS ▪ Eurasian Watermilfoil ▪ Variable or Broadleaf Watermilfoil ▪ Fanwort ▪ Curlyleaf Pondweed	Chemical Treatment Fluridone (Sonar™)	Formulation: Liquid (AS) & Pellet (SRP) Comments: Systemic – selective control of Eurasian watermilfoil, fanwort and curlyleaf pondweed at low application rates. Most effective on contiguous areas ≥ 5 ac. Duration of Control: 2-3 years or longer – except for curlyleaf pondweed.	▪ 30 day irrigation precaution/restriction ▪ May not be effective for shoreline or partial waterbody treatments	$200-$600 per acre
	2,4-D (Navigate®)	Formulation: Granular Comments: Systemic – effective for both species of milfoil. Used for both spot and whole-lake treatments Duration of Control: 1-2 years or longer.	▪ Currently not approved for use in Zone II – Wellhead Protection Areas. ▪ Extended use restrictions for irrigation, watering livestock or drinking/domestic purposes.	$300-$400 per acre
	Diquat (Reward®)	Formulation: Liquid Comments: Contact – fast acting herbicide effective on both species of milfoil and curlyleaf pondweed. Used for both spot and whole-lake treatments. Duration of Control: Typically 1 year.	▪ Seasonal control ▪ May impact more non-target species	$175-$400 per acre
	Cutting / Harvesting	Mechanized cutting to depth of 5-7 feet. Two cuttings per year desirable. Used for maintenance control of larger, established plant infestations.	▪ Non-selective ▪ Typically two or more cuttings required annually. ▪ Care must be taken to contain fragments. ▪ Shoreline disposal operation required.	$350-$600 per acre per cutting
	Hydro-Raking	Mechanical raking of plant and root material to depths of 12 feet. Used for smaller beach/swim areas < 1 acre. Once raking per year is generally adequate. Maintenance technique for established milfoil infestations.	▪ Seasonal control ▪ Temporary disruption of bottom sediments and increases in turbidity. ▪ Care must be taken to contain fragments. ▪ Shoreline disposal operation required.	$1,500-$2,500 per acre
	Bottom/Benthic Weed Barriers	PVC sheeting or PVC coated fiberglass screening. Used for small, dense infestations and beach/swim areas < 1 acre.	▪ Barriers must be removed, cleaned, repaired and reinstalled every 1-3 years ▪ May require SCUBA divers for installations in waters > 4 feet deep. ▪ Cuts off bottom to other aquatic organisms	~$40,000 per acre installed
	Diver Operated Suction Harvesting	Effective in removing sparse growth or beds of rooted plants over smaller areas. Control is generally 1 year or longer.	▪ Seasonal control ▪ Labor intensive ▪ Equipment and operator availability	~$8,000 per acre
	Hand Pulling	Limited to depths of < 5 feet without SCUBA divers. Most effective where plants are widely scattered over small areas. Control is 1 year or longer depending on site.	▪ Seasonal control ▪ Labor intensive	Varies
	Dredging	Control by deepening beyond the plant's photic zone – typically 10 feet or more. Rare to control milfoil by change in substrate type alone.	▪ Considerable short-term disruption ▪ Complex permitting	$5-$10 per cu. yd. or $16,000-$32,000 to remove 2 ft. of sediment over a 1 acre area
	Drawdown	Lower water level in fall and winter to expose plants to freezing and drying conditions. Generally requires 6-8 weeks of sustained freezing/drying for effective control. Control usually 1 year or longer.	▪ Weather conditions and sediment composition may influence effectiveness. ▪ Potential for numerous impacts and constraints.	Varies
	Herbivorous Insects (Weevils)	Specific to Eurasian watermilfoil. Weevils are native to North America and have the potential for long term control. Naturally occurring weevil populations have generally yielded better results than new introductions. Extensive research in process	▪ Slow response ▪ Duration of control variable and cyclical. ▪ Milfoil remains viable	Varies

Handout on control techniques from NEC-NALMS (New England Chapter of the North American Lake Management) conference. (Smith & Ballaud, 2000).

T able 4, also from anoth er aquati c plant mana geme nt comp any, shows an enlarg ed area of a larger data table which details more information than the previous data tables examined in this research. Table 4 lists potential benefits, potential drawbacks, and the costing, which is from 2009. (EcoLogic LLC & Stearns/Wheler GHD, 2009).

Table 4.

	Mechanical Weed Removal
Method	Mechanical removal of weeds, by rotovating (rototilling) or hydroraking.
How does it work?	Removes rooted aquatic plants from targeted areas by means of large cutters that dislodge roots and plants from sediment.
Potential Benefits	More effective than mechanical harvesting, as the roots as well as plants are removed.
Potential Drawbacks	Creates turbidity, disturbs the sediment, may spread some plants by fragmentation. Not selective; cuts all plants.
Data gaps to make decision	Useful for shallower areas where recreational access is limited by weeds
Costs (Relative)	Hydroraking or rotavation services $1,000** to $2,000* per acre
Permitting issues	Turbidity, avoidance of critical habitat areas and spawning/early life stages of fish community Conservation Commission approval needed.
Longevity	Usually needs to be repeated several times year
Ponds appropriate for this alternative	Insufficient data.

Enlarged area of a data table where hydro-raking is highlighted showing the options for mitigating eutrophic conditions through plant removal (EcoLogic LLC & Stearns/Wheler GHD, 2009)

The data tables on hydro-raking did not provide all the information in one table that would be needed to make a decision about using the technique. Missing information included: water depth needed to operate the hydro-rake, species of plants suitable or not suitable for hydro-raking, access to water for unloading the hydro-rake, updated (for 2016) costing and permitting in an easy to understand way. The last section of Table 3 says "insufficient data" next to "ponds appropriate for this method," where that gap is another aspect of hydro-raking this research is trying to fill through the analysis of case studies, in order to provide information on ponds and lakes that would be appropriate for hydro-raking.

Section 3 will detail case studies of hydro-raking in Massachusetts combined with data from the literature from management websites and state-wide environmental assessments to create the final hydro-raking decision tree.

3. Hydro-raking Case Studies in Massachusetts

3.1 Overview of Hydro-raking Case Studies

Eight pond and lake case studies will be examined in this methods section. Red Lily Pond and Lake Elizabeth are connected water bodies, hence why they are grouped together, but counted separately, as each water body had individual plant management challenges. This data collection and analysis was comprised of primary source data collected from personal visits to some of the water bodies to document the aquatic plants with photos and written observations. In an effort to be as thorough as possible, primary data was collected in the form of interview questions, asked to the coalitions, pond corporations, water quality committees or management companies to fill in any data "holes." Secondary quantitative data collected such as environmental baseline reports, town bulletins, conservation commission meeting notes, coalition newsletters, botanical surveys, and water quality reports informed the process of hydro-raking. Qualitative data consisted of comments found on public message boards, comments on uploaded videos, and published secondary interviews. The next step was putting the data from the individual case studies in chronological order to show the start of the plant concerns from the beginning to recent updates, focusing on the hydro-raking that was performed.

The summaries synthesize the process and mention if the hydro-raking was a success or not and the duration of the plant control. Quantifying a successful plant removal can be difficult. The total amount of plants in a water body is difficult to quantify before raking occurred. A reduction in visible plants is one indicator of a successful rake. Tables, maps and photos are included to provide evidence of a successful hydro-rake.

These case studies were chosen to best inform the final decision tree discussed in section 4: A Decision Tree for Hydro-raking. The case studies show a variety of the applications of the hydro-rake are featured in section 3.2 through 3.8. Each case study utilized hydro-raking on their pond or lake, and some have had multiple management methods. Each water body in Massachusetts is unique in regards to biodiversity, water table, topography, slope, depth, land use, phosphorus and oxygen levels, uniform temperature, nutrient loads and the type of life the water body can support. Understanding these variations can assist the decision maker in deciding whether hydro-raking is a viable option to control non-native invasive and nuisance native plants in their pond or lake. Hydro-raking pond and lake case studies chosen across the state of Massachusetts are shown on Map 1, that I compiled through Massachusetts OLIVER online map-making software.

3.2
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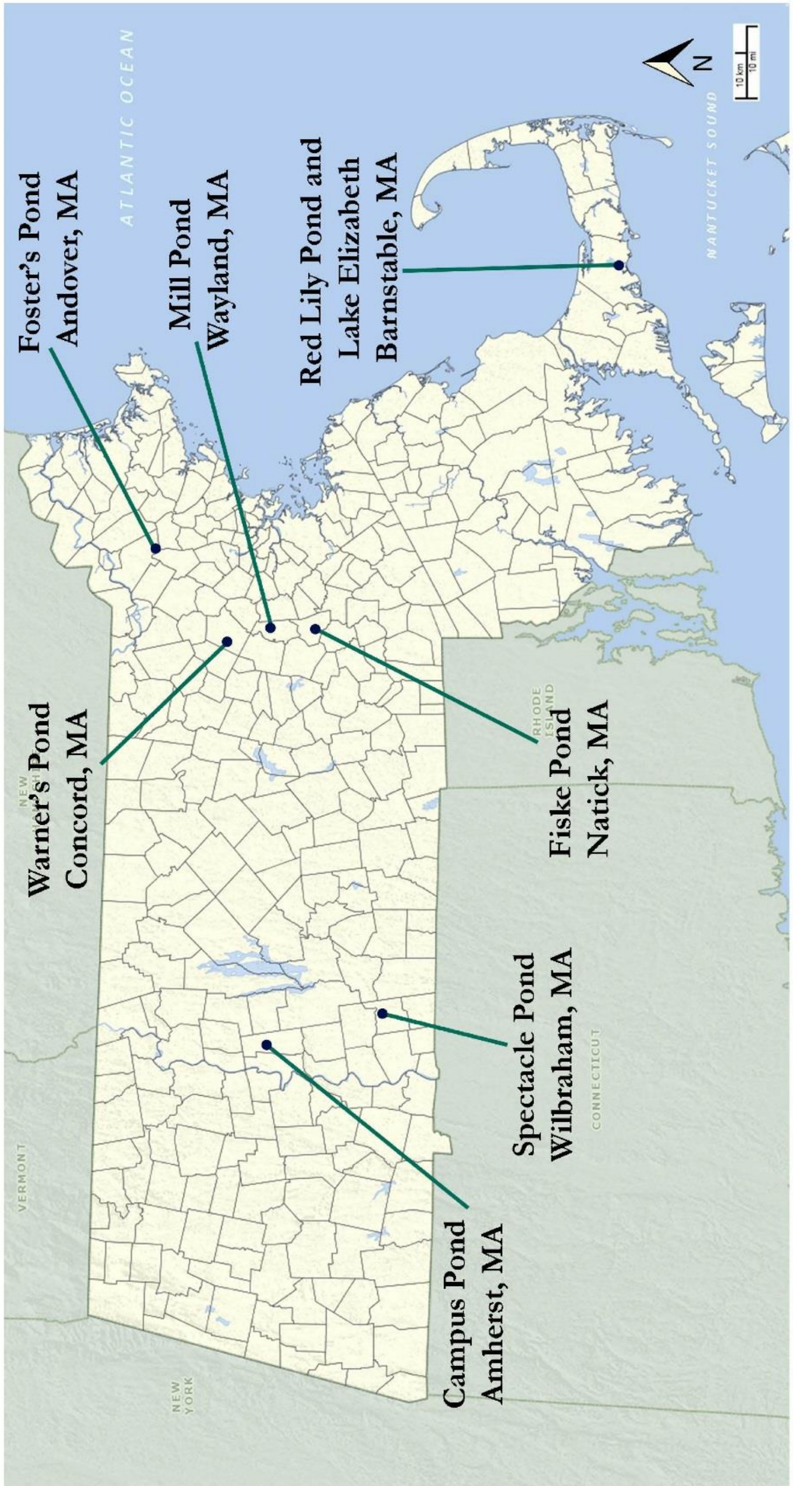


Map 1. Hydro-raking pond and lake case study map of Massachusetts. Map credit: Danielle Desmarais

Map 2. Campus Pond-Amherst MA location.

Map credit: Danielle Desmarais

University Pond- Amherst at a Glance:

Plant of concern: None. Organic debris and trash

Other concerns: many ducks and Canada geese, turtles and fish present

Depth of water body: 5 in. (12.7 cm) to unknown maximum depth

Size of water body: approx. 750 ft. (228.6 m) long by 250 ft. (76.2 m) wide

Land use: Dangerous for human use due to muddy sediment. Bird, fish and turtle habitat

Management methods: Hydro-raking, mechanical harvesting and hand-harvesting

Campus Pond is located in the center of the University of Massachusetts, Amherst campus, surrounded by a large grassy lawn and many buildings. The pond is approximately 750 ft. (228.6 m) long by 250 ft. (76.2 m) wide, shown in the middle of Figure 13.

Figure 13. Campus Pond in the center of the University of Massachusetts, Amherst campus. Photo credit: (Biology Department, University of Massachusetts Amherst, n.d.).

2010-2013

One of the documented hydro-rakings of Campus Pond was in 2010, with a campus news update mentioning the hydro-raking could remove 100 cubic yards of debris after raking was completed (UMass Amherst, 2010a). It is unknown how long hydro-raking had occurred at Campus Pond before that date. The debris raked to the shore was going to be removed by Physical Plant Construction Services staff, tested to be screened into the compost and the loam, (a soil type pulled from the pond bottom) could be used by the Buildings and Grounds Department on campus (UMass Amherst, 2010a). The pond fountains were going to be removed and a spotter on a barge would be keeping watch for any turtles and fish swimming too close to the actual rake (UMass Amherst, 2010a). The environmental company providing the hydro-raking, estimated 40-60 hours of hydro-raking was needed (UMass Amherst, 2010b). After inquiring with a manager who oversees hydro-raking at a pond and lake management specialty company, and managed this pond, he mentioned portions of Campus Pond were hydro-raked in 2013 (J. Castellani, personal communication, March 21, 2016).

2015

I witnessed the hydro-raking of Campus Pond on August 5th, 2015 and noticed immediately the machines were not silent, sounding as though a lawnmower and paddleboat were combined together. The paddle boats maneuvered in reverse, and spun around in a small radius, demonstrating these machines could maneuver in small places. A photo of the pond and both hydro-rake machines, seen in Figure 14, demonstrating the water being expelled high into the air.

Figure 14. Two hydro-rakes working on Campus Pond. Photo credit: Danielle Desmarais.

Two hydro-raking machines were removing bottom debris throughout the visit, although plant material was not visible from my viewing point. The pond debris was placed directly into a truck bed on the shore. After speaking with a manager who oversees hydro-raking at a pond and lake management specialty company, and managed this pond, it was confirmed no plants were removed from Campus Pond. "The primary objective was to remove debris from students, sticks and organic matter buildup" (J. Castellani, personal communication, March 8, 2016). Campus Pond is in the middle of a highly traffic area judging from the extreme erosion on the foot path edges

The water turbidity (cloudiness) was very high as demonstrated in Figure 15, which shows two snapping turtles, each approximately two ft. (.60 m) wide and one was barely visible directly under the surface. The color of the water, due to the suspended sediment was a light brown. Whether or not, this was the average sediment suspension level year-round was unknown.

Figure 15. Two large snapping turtles hidden by shoreline suspended sediment on August 5th, 2015 during hydro-raking. Photo credit: Danielle Desmarais.

Large mats of floating aquatic plants, which appear to be algae, were seen on the surface near the east shore see in Figure 16. The hydro-rake might have had difficulty reaching that area due to the tall rushes and grasses. Those photos of the floating mats are included to show the various plant life, and visually demonstrate some of the limitations of the hydro-rake. Algae are not recommended for removal by hydro-raking due to the ability to slip through the tines (prongs). Three hours were spent observing Campus Pond that afternoon and a hydro-rake never approached the area with the heavy floating plant mats in Figure 16.

Figure 16. Dense floating plant mats in between the shore and the emergent tall grasses. Photo credit: Danielle Desmarais

On August 6th, 2015, the next day after the my first visit to the pond, A University of Massachusetts Amherst student took the photo, seen in Figure 17 from a tall campus building, which showed the two hydro-rake machines still in operation the next day.

Figure 17. Aerial photo showing the hydro-raking of Campus Pond on August 6, 2015. Photo credit: (Kelley, 2015).

Comments responding to this photo included, “They really ought to drain it, remove the mud & organics from the bottom, and then put rocks along the edge to prevent erosion into it” (Kelley, 2015). Another comment was, “The UMass pond is a great asset for the campus landscape and is very important for storm water” (Kelley, 2015). Regarding the August 2015 hydro-raking, another commenter said, “It was a mud hole in 70's and 80's, what took so long” (Kelley, 2015)? These comments demonstrated the pond has aesthetic and water retention value for the campus.

I returned to Campus Pond on October 18th, 2015 to document any changes to the pond since the last visit on August 5th, 2015. I noticed a sign, which stated “Do not enter or the use the pond, shoreline activities only- deep muddy sediment” and another sign that read, “Danger thin ice keep off” which implied this pond is not used recreationally due to dangerous conditions. The mat of floating aquatic plants observed in the August visit was gone, and in its place were tall grasses, rushes, and flowering plants seen in Figure 18. It is inconclusive where or if the hydro-rake was able to maneuver into that tall grassy area, or if the plants died out on their own and water clarity improved.

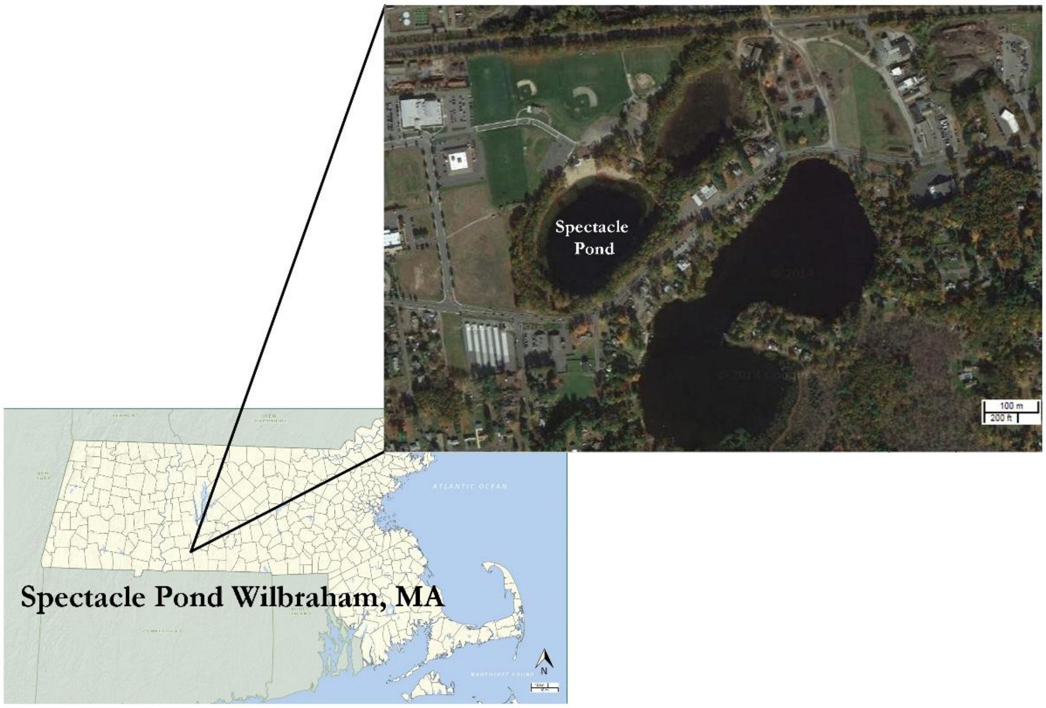
Figure 18. Previous location of a thick mat of aquatic floating plants. Photo Credit: Danielle Desmarais

Another observation from my October 18th, 2015 visit was the abundance of birds: 17 ducks and approximately 205 Canada Geese. The birds were eating non-stop in the middle of the pond, not along the shoreline, suggesting there is plant life for the birds to eat. The water is five in. (12.7 cm) deep in some areas, because the geese could stand up. The turbidity level was slightly lower in October, 2015 when comparing photos from the August, 2015 visit in the same location at the pond. Another observation to note was a fountain operating in the middle of the pond that was not there during the October 2015 hydro-raking. After inquiring with a manager who oversees hydro-raking at a pond and lake management specialty company and managed this pond, he mentioned organic matter buildup was removed to maintain depth where fountains operate to increase the dissolved oxygen levels (J. Castellani, personal communication, March 8, 2016).

During the October, 2015 visit when the hydro-raking was occurring, I could see approximately five in. (12.7 cm) to the pond bottom, in the same vicinity where I took the photo of the snapping turtle seen in Figure 15. In August 2015, in the same spot where the snapping turtle was barely seen, there was now approximately 10 in. (25.2cm) of visibility to the pond bottom. I did not use a Secchi disk, or any scientific equipment to gauge the turbidity. I estimated the turbidity from the vantage point where I was sitting.

In summary, this case study demonstrated the ability of the hydro-rake to operate in a small water body to remove tree litter such as branches and sticks, as well as trash in a heavily trafficked area in the center of a university campus.

3.3 Spectacle "Spec" Pond- Wilbraham, Massachusetts



Map 3. Spectacle Pond- Wilbraham, MA location. Map credit: Danielle Desmarais

Spectacle Pond- Wibraham at a Glance:

Plants of concern: variable watermilfoil (*Myriophyllum heterophyllum*) cattail (*Typha latifolia*), white waterlily (*Nymphaea odorata*) and water shield (*Brasenia schreberi)* These plants are described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies*
Other concerns: rare plant of special concern- terete arrowhead (*Sagittaria teres*).
Depth of water body: Shoreline areas 7 ft. (2.13 m) to a maximum depth 46 ft. (14.02 m)
Size of water body: 9 acres (4.01 ha)
Land use: swimming, kayaking, beach
Management methods: Hydro-raking, benthic barriers, mechanical harvester

Spectacle "Spec" Pond in Wilbraham, MA is approximately 10 acres (4.01 ha) (Padgett, 2008) and located off the heavily trafficked Route 20/Boston Road. Recreational use of the beach include kayaking and swimming, with a dock and beach that is incomegenerating for the Wilbraham Parks and Recreation Department. What makes Spectacle Pond unique and complicated for aquatic plant management of the non-native invasive variable watermilfoil is the presence of a rare plant, terete arrowhead (*Sagittaria teres*). Terete arrowhead was listed in 2008, and is currently still listed, as a species of special concern in the state of Massachusetts (National Heritage and Endangered Species Program [NHESP], 2015). Spectacle Pond is one of the few places in Massachusetts that harbors a population of this rare plant (NHESP, 2015). Threats to the terete arrowhead include soil disturbances from heavy recreational activity such as wading or swimming, along with any changes to water quality or the introduction of an invasive species (NHESP, 2015). Any management activities proposed for areas inhabited by state-listed species must be planned with consultation with NHESP.

2008

A 2008 botanical survey reported populations of very dense, native nuisance white and yellow waterlilies along with water shield at Spectacle Pond (Padgett, 2008). The non-native invasive species, variable watermilfoil was noted as not being plentiful near the rare species (Padgett, 2008). These plants are described in appendix 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.* The NHESP commented, after a request to use chemicals to reduce the non-native invasive and native nuisance plants that chemicals could not be used to control variable watermilfoil at Spectacle Pond because of the risk of chemicals potentially killing the rare species (Commonwealth of Massachusetts Division of Fisheries and Wildlife, 2008). Winter drawdowns to lower the water level were also not recommended, although this was not possible at Spectacle Pond due to two culverts draining into the pond and lack of a means for lowering the pond level. Therefore, manual/mechanical harvesting and/or benthic barriers were recommended as an alternative (Commonwealth of Massachusetts Division of Fisheries and Wildlife, 2008). The abundance of water lilies and cattails in August of 2008, can be seen in Figure 19.

Figure 19: Close-up of waterlilies and cattails along the shore in August, 2008. Photo credit: (Padgett, 2008).

2009

In June of 2009, the total estimated cost was $30,000 to install benthic matting in an area 40 ft. by 50 ft. (12.92 m x 15.42 m) and the hydro-raking would be combined with a mechanical harvesting (Lycott Environmental Inc., 2009b). The plants planned for removal were water shield, variable watermilfoil, cattail and white waterlily, encompassing a space of 75 ft. (22.86 m) by 100 ft. (30.48 m) on both sides of the Spec Pond beach, with the plant debris deposited on the beach after collection (Lycott Environmental Inc., 2009a). The hydro-raking was planned to occur along the beach area and the area without the benthic matting at a depth of at least seven ft. (2.13 m) (Lycott Environmental Inc., 2009b). The use of a mechanical harvester, in conjunction with a hydro-rake, would capture any stray plant fragments and transport the plant debris to the shore, as well as remove any plants from the dock the hydro-rake could not reach due to depths beyond 12 ft. (3.65 m), the limit of the hydro-rake arm (Lycott Environmental Inc., 2009b). The final plans are seen in Figure 20, which detailed the scope of the hydro-raking, seen in cross-hatch and the distance to the rare plants.

Figure 20: Management plan of Spectacle pond showing in cross-hatch the areas of hydro-raking (Lycott Environmental Inc., 2009a)

The hydro-raking occurred the week of August 10, 2009 (Miles, 2009). I asked the parks and recreation manager if the non-native invasive variable watermilfoil, and native nuisance cattail, white waterlily and water shield had retuned. The parks and recreation manager for Spectacle Pond said they all returned in about a year and a half, and mentioned that pond will be one no one can swim or fish in (B. Litz, personal communication, March 1, 2016). That comment also informed that fishing as a sport at Spectacle Pond would longer possibly due to possible fish kills from the over-crowing variable watermilfoil.

2016

I visited Spectacle Pond on February 21, 2016 to see the area previously cleared by the hydro-rake and mechanical harvester in August 2009, and noticed emergent plant stalks growing along the beach in Figure 21. This is the same area seen in Figure 19, which showed a close-up of waterlilies and cattails along the shore taken in August 2008, demonstrating the growth had returned in 2016.

Figure 21. Emergent growth along the shore of Spectacle Pond on February 21, 2016. Photo credit: Danielle Desmarais

On March 10th 2016, a photo was taken at Spectacle Pond showing emergent cattail growth growing taller and encroaching on the beach, seen in Figure 22. This is the same location from Figures 19 and 21, and these three photos demonstrate the progressive regrowth of the emergent plants along the beach after hydro-raking had occurred.

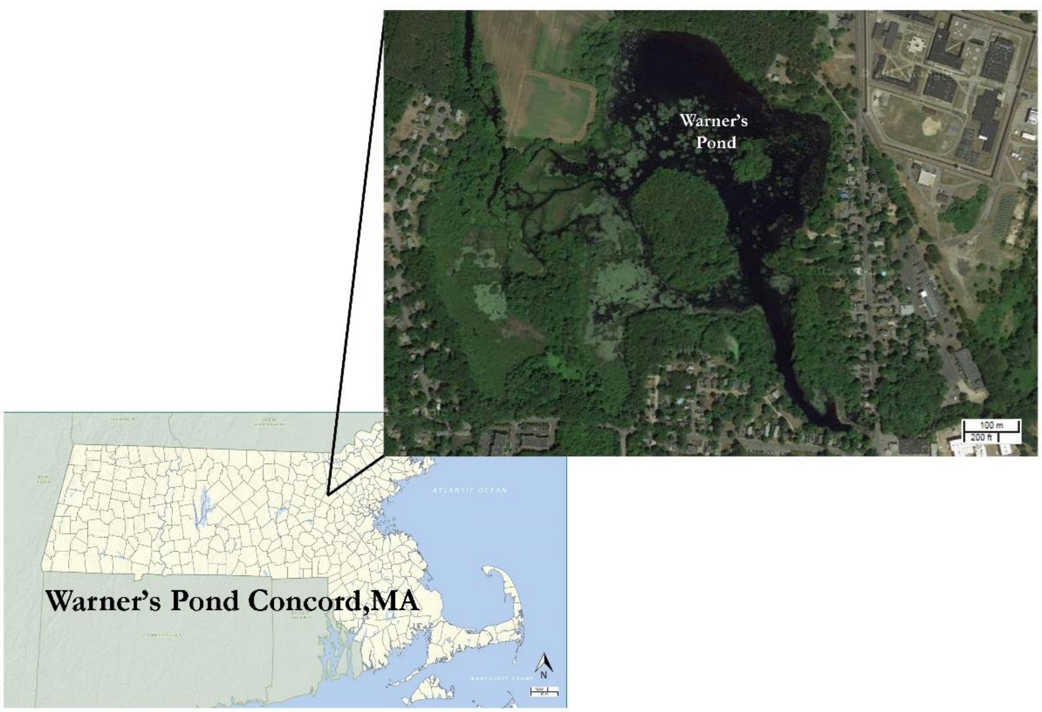
Due to the cold weather in February, it is unknown if the water lilies and water shield populations will return as the same volume, as they appeared in the 2008 photo.

Figure 22. March 10th 2016 photo taken at Spectacle Pond showing emergent cattail growth growing taller and encroaching on the beach. Photo credit: Danielle Desmarais

I asked the Wilbraham Parks and Recreation department about the management plan regarding aquatic plant control in the pond. I was informed they had looked into other remediation techniques, and wanted to spend considerable time over the next several years coming up with a long range (10 - 20 years) master plan for the health of the pond (B. Litz, personal communication, February 26, 2016).

To summarize, the complication of a rare plant did not allow for the use of chemicals or draw-downs at Spectacle Pond, and the final management plan relied on hydro-raking, mechanical harvesting and benthic barriers. All techniques combined were effective at keeping the four undesired plant species under control for approximately a year and a half. Future option management plans are being considered, as hydro-raking was not long term solution for this water body.

3.4 Warner's Pond- Concord, Massachusetts



Map 4. Warner's Pond- Concord, MA location. Map credit: Danielle Desmarais

Warner's Pond- Concord at a Glance:

Plants of concern: water chestnut (*Trapa natans)*, fanwort (*Cabomba caroliniana)*, variable watermilfoil (*Myriophyllum heterophyllum*), coontail (*Ceratophyllum demersum*), purple loosestrife (*Lythrum salicaria*), water willow (*Decodon verticillatus*), white waterlily (*Nymphaea odorata*) and yellow waterlily (*Nuphar variegatum*). These plants are described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies*

Other concerns: Inlet and outlet flow

Depth of water body: average depth of 4.5 ft. (1.37 m) with maximum depth at 12 ft. (3.56 m)

Size of water body: approximately 54 acres (21.85 ha)

Land use: canoeing, fishing, ice skating

Management methods: hand-pulling, mechanical harvesting, hydro-raking

Warner's Pond consists of approximately 54 acres (21.85 ha), including three islands with the average depth of 4.5 ft. (1.37 m) and the deepest point being measured at 12 ft. (3.56 m) (Warner's Pond Stewardship, 2008). Warner's Pond has 35 residences along the shorelines, located approximately 100 ft. from pond or more, while a few homes have lawns that extend to the pond edge (Warner's Pond Stewardship, 2008).

A September, 2004 environmental survey found that fanwort accounted for nearly 54% of the total plant growth in Warner's Pond seen in Figure 23, with variable watermilfoil identified in a few locations and secondary to fanwort growth, while water chestnut was being "effectively controlled" with mechanical harvesting and hand-pulling (Bellaud, 2005).

Figure 23. Abundance of water chestnuts in Warner's Pond. Photo Credit: (Town of Concord, MA, n.d)

The survey recommended mechanical harvesting for the fanwort in open water areas to maintain a usable water body, and hydro-raking was advised for clearing individual shorelines of purple loosestrife (Bellaud, 2005). Non-native invasive aquatic plants water chestnut, fanwort and variable watermilfoil, presented the most immediate threat to the loss of open-water at Warner's Pond, as concluded by the survey (Bellaud, 2005). Growth of non-native invasive purple loosestrife and native nuisance water willow was threatening the loss of shallow water areas and shoreline access (Bellaud, 2005). Potential hydro-rake sites were identified in June 2004, on the 44 acre (17.89 ha) open water area of the lake impacted by fanwort, with 25 acres (10.11 ha) identified as the priority harvest area

(Bellaud, 2005). Mechanical harvesting and hydro-raking were both used to control the plant growth. Warner's Pond was mechanically harvested for 13 days in July 2004, which harvested from approximately 21 acres (8.49 ha), and generated 23 truckloads of organic debris (Bellaud, 2005). The harvested organic debris was then transported from the shore to a local plant nursery for permanent disposal as compost (Bellaud, 2005).

The hydro-raking portion of the management program took place in August 2004 over the course of three days, with the goal to remove invasive emergent plants, root mats, and sediment build-up along the shore (Bellaud, 2005). Limited shoreline access in the outlet canal required a transport barge to accompany the hydro-rake and move the plant debris back to a boat launch (Bellaud, 2005). The hydro-rake and transport barge were mobilized for a total of 35 hours and cleared six individual shorelines, all of which were located in the outlet canal at the southern end of the pond (Bellaud, 2005). The cleared shoreline areas acted as a "prudent demonstration of the hydro-raking capabilities, and provide good reference from which budgeting for such activities can be measured for future management of these areas" (Bellaud, 2005).

A late September 2004 survey showed the mechanical harvesting program was relatively effective at controlling the problematic fanwort growth to maintain open-water conditions for the majority of the summer (Bellaud, 2005). The shorefronts that were hydro-raked in the outlet canal remained clear due to the removal of overgrown emergent vegetation, leaf litter and sediment deposits (Bellaud, 2005). The property owners now had open access to the pond and hydro-raking appeared "to be an effective way to reclaim the shoreline access points that have become overgrown with invasive vegetation" (Bellaud, 2005). Figure 24 demonstrates the differences in the plant volume removed from 2003 to 2004 through a photo collage.

Figure 24. Warner's Pond documentation gallery from 2003 to 2004 before and after hydro-raking. Photo credits: (Bellaud, 2005).

The aquatic management company recommended one midseason mechanical harvesting of the fanwort, which provided significant control in helping to maintain open water habitat for the entire summer (Bellaud, 2005). The 2004 report also suggested stockpiling the harvested vegetation in a nearby field, and later the vegetation used as compost (Bellaud, 2005). Control of shoreline emergent plants can be achieved, and water access points can be reclaimed through hydro-raking, furthermore the aquatic management company was hoping for multi-year control of the nuisance shoreline growth through hand pulling any purple loosestrife on a yearly basis (Bellaud, 2005).

2011

A survey conducted in May of 2011, documented that the water was dominated by three species: fanwort, variable watermilfoil and coontail, with coontail being the most abundant plant in the pond, forming a dense blanket in the shallower areas while white waterlily and yellow waterlily were still present (ACT, 2011). These plants are described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies*.

Figure 25 shows submerged plants being caught on a boat oar, demonstrating how navigating the open water could prove difficult with the presence of non-native invasive fanwort, variable watermilfoil and native nuisance coontail.

Figure 25. Photo taken on Sept 2, 2011 showing aquatic plants being pulled from the pond and onto an oar at Warner's Pond. Photo credit: (Environmental Consulting & Engineering Services Group, Inc., 2012).

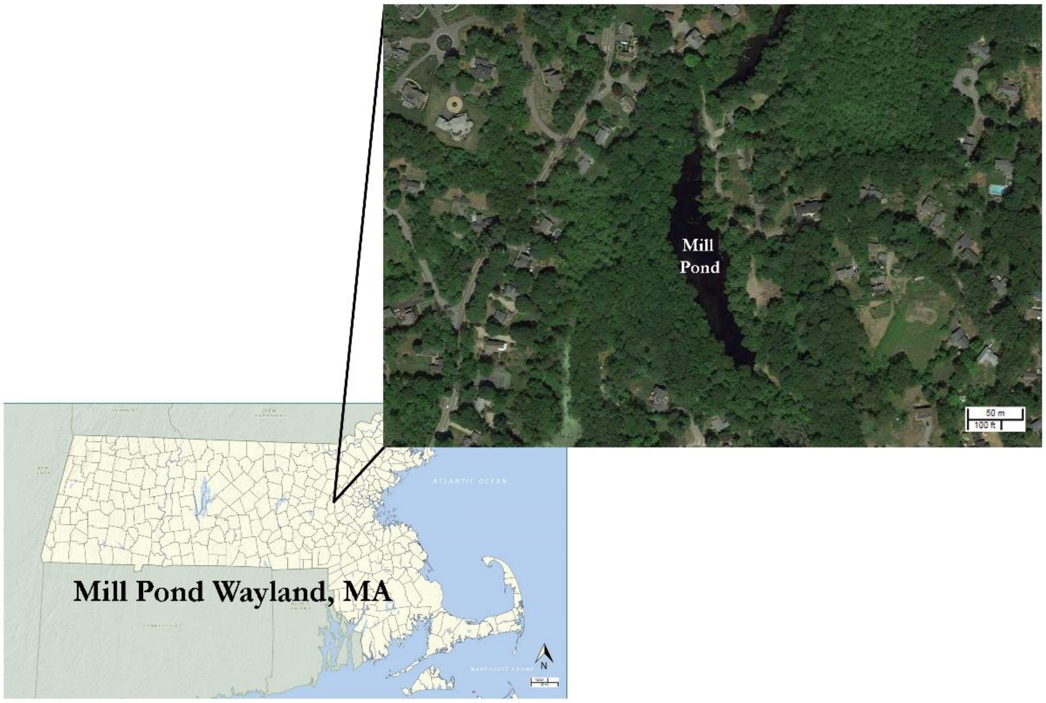
Fluridone, (brand name Sonar[tm]) herbicides, were applied in June through August 2011 at Warner's Pond to control growth of the non-native invasive and native nuisance plants (ACT, 2011). A post-treatment survey conducted on September 2nd 2011, noted fanwort, variable watermilfoil and coontail were all heavily impacted in the treatment area, while an estimated 50% of the waterlilies remained (ACT, 2011). There were also limits mentioned for the duration of control that can be achieved using Sonar^{tm} /fluridone due to the presence of fanwort of the pond, high water flows, and mucky bottom sediments (ACT, 2011).

2012

The 2012 watershed management plan determined that hydro-raking proved to be an effective approach at managing water lilies in selected areas, but would not be recommended against plant species that reproduce through vegetative fragmentation such as fanwort, variable watermilfoil and coontail (ESS Group, Inc., 2012). These plants are described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.* Hand pulling was a continued recommended method to manage the growth and spread of water chestnut and purple loostrife along the shore (ESS Group, Inc., 2012).

In summary, the hydro-raked shoreline areas at Warner's Pond in 2004 acted as a "prudent demonstration of the hydro-raking capabilities, and provide good reference from which budgeting for such activities can be measured for future management of these areas" (Bellaud, 2005). The most abundant non-native invasive plants in 2011 were fanwort, variable watermilfoil, along with a native nuisance plant, coontail, none of which hydro-raking was recommended due to the fragmentation aspect of the plant growth, but were controlled with chemicals. Chemical use, in 2011 did prove effective on reducing fanwort, variable watermilfoil and coontail, while the hydro-rake was preferred to control the shoreline plants: purple loostrife, water willow, and waterlilies at Warner's Pond.

3.5 Mill Pond- Wayland, MA



Map 6. Mill Pond- Wayland, MA location. Map credit: Danielle Desmarais

Mill Pond- Wayland at a Glance:

Plant of concern: None. Organic debris was removed
Other concerns: turtle and fish habitat, downstream flow through dam blocked by debris
Depth of water body: 5.1 ft. average (1.55 m) and 9.6 ft. deepest (2.92 m)
Size of water body: 750 ft. (228.6 m) by 200 ft. (60.96 m)
Land use: Ice skating, fishing
Management methods: Hydro-raking

Mill Pond, also called Wayland Mill Pond, formed when Mill Brook was dammed and is 750 ft. long (228.6 m) by 200 ft. wide (60.96 m) at the widest point commonly used for fishing and ice-skating (Largy, 2014). Mill Pond supports a largemouth bass, sunfish and turtle population (Largy, 2014).

2014

In July 2014, the upper portion of Mill Pond at the opposite end of the dam, "contained several feet of muck" (leaf litter and organic debris) before a hard bottom is reached, with approximately one ft. (.30 m) of water (Largy, 2014), which demonstrated this end of the pond is quite shallow. The middle and lower portions of the pond near the dam are approximately five (1.52 m) to six ft. (1.82 m) deep with one ft. (.30 m) or less of muck on the bottom (Largy, 2014). Three large trees, one with full leaf foilage had fallen into the pond, along with stumps and branches clogging the area above the dam, seen in Figure 26 (Largy, 2014). Figure 26 also shows the duckweed *(Lemna minor)*, a native plant, distributed over the entire water surface (Largy, 2014), and often resembes and algae bloom. Duckweed is not considered a nuisance in this case study as duckweed serves as a food source for aquatic birds and animals. Due to the tiny size of the plants, duckweed would be impossible to hydro-rake, if that was ever desired for aesthetic reasons.

Figure 26. Wood debris in Mill Pond above dam in July of 2014, with duckweed seen on top of the water. Photo Credit: (Largy, 2014).

The hydro-raking of Mill Pond occurred in late June of 2015. The rake scooped material, later placed on a floating barge, pushed down the pond and offloaded into a hauler, as seen in Figures 27 and 28 (Tom Largy, 2015b). Questions were asked of the Wayland Surface Water Quality Committee member about the effects the hydro-rake can have on turtles. They scattered from the noise of the hydro-rake, and if you stop a car they are gone immediately, he said (T. Largy, personal communication, March 7, 2016). He added, after the hydro-raking "The whole pond turned into a deep chocolate color, and after a few days they (turtles) returned and fish and turtles are still there, as of spring 2016 (T. Largy, personal communication, March 7, 2016).

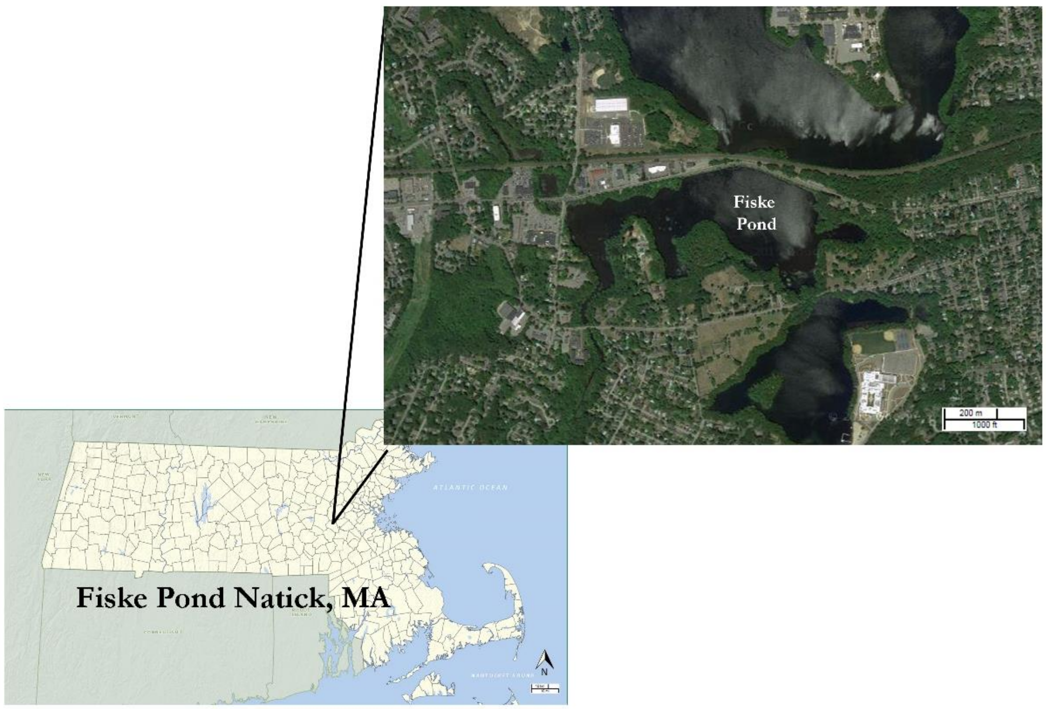
Figure 27. Video still showing the floating barge staging area near the shore. Video still credit: (Tom Largy, 2015a)

Figure 28. Video still showing plant debris removed from the barge by a loader bucket, deposited into a hauler, pulled by a truck. Video still credit: (Tom Largy, 2015a)

At Mill Pond, 1.25 acres (.50 ha) were hydro-raked, for a total of 100 cubic yards of debris collected over the five days (Aquatic Control Technology [ACT], 2015a.) Wayland Surface Water Quality Committee member Tom Largy was asked where the pile of debris was moved. He replied the "pile is still there above the parking lot" (T. Largy, personal communication, March 7, 2016). He also mentioned the debris was not good for composting, due to the high number of large rocks and tree limbs (T. Largy, personal communication, March 7, 2016). The northern section of Mill Pond, where the brook flows in saw results "that were not fully achieved" due to the watery/silty consistency of the debris (ACT, 2015a). With no noticeable improvement, the northern end of Mill Pond began to fill in again with sediment; therefore, hydro-raking was not seen as a practicable option in that area of the pond, due to the silty material and lack of leaf litter (ACT, 2015a).

In summary, the goal of hydro-raking Mill Pond was to remove fallen logs, branches and leaf litter to improve water quality. A Wayland Surface Water Quality Committee member mentioned the committee "might consider hydro-raking again in the future" (T. Largy, personal communication, March 7, 2016). Hydro-raking in this case study was deemed unsuccessful in an northern area due to the lack of leaf litter and containing mostly fine silt.

3.6 Fiske Pond- Natick, MA



Map 7. Fiske Pond- Natick, MA location. Map credit: Danielle Desmarais

Fiske Pond- Natick at a glance:

Plants of concern: Water chestnut (*Trapa natans*).This plant is described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.*

Other concerns: 24 acres (9.71 ha) of 67 acres (26.11 ha) required plant management

Depth of water body: 13 ft. (3.96 m) in deepest areas, unknown shallow depth readings

Size of water body: 67 acres (26.11 ha)

Land use: fishing

Management methods: Hydro-raking, mechanical harvesters, hand-pulling

Natick's Fiske Pond, which flows into Lake Cochituate, is shallow, covers 67 acres (26.11 ha), and supports a wide variety of fish including muskie, northern pike, pickerel, smallmouth bass, largemouth bass and crappie (Hook and Bullet, 2016).

2008

An aquatic plant survey in June of 2008 found that Fiske Pond in Natick had a total of 40 acres (16.18 ha) of water chestnuts, consisting of 34 acres (13.75 ha) of dense growth, 5 acres (2.02 ha) of moderate to light growth, and 1 acre (.40 ha) of light to trace growth (Lycott Environmental Inc., 2010). After 24 days of hydro-raking, mechanical harvesting and hand pulling around the shores, 225 tons of water chestnut plants were removed from the pond and incinerated (Lycott Environmental Inc., 2010).

2009

In June 2009, a survey revealed water chestnut growth inhabiting a total of 40 acres (16.18 ha) of Fiske Pond, with 24 acres (9.71 ha) of dense growth, 10 acres (4.04 ha) of heavy to moderate growth, and 6 acres (2.42 ha) total of light to trace growth (Lycott Environmental Inc., 2010). After 35 days of hydro-raking, mechanical harvesting and hand pulling around the shores, 94.4 tons of water chestnut plants were removed from the pond (Lycott Environmental Inc., 2010). It is important to note the 2009 harvest was 130.6 tons less than the previous year in 2008, meaning the volume of water chestnuts was decreasing. Figures 29 and 30, show a before and after comparison of the removal of water chestnuts.

Figure 29. Photo taken between 2007-2008 of Fiske Pond showing the abundance of water chestnuts Photo credit: (Department of Conservation and Recreation, 2010a)

Figure 30. Photo taken between 2008-2010 of Fiske Pond after removal of water chestnuts. Photo credit: (Department of Conservation and Recreation, 2010a)

Hydro-raking was conducted in the shallow areas primarily along the shoreline in 2008 and 2009 for just a few acres, with mechanical harvesters being utilized from 2008 through 2011(J. Castellani, personal communication, March 21, 2016). The 225 tons of water chestnuts that were removed from the pond in 2008, had decreased by 2013 to "only about a dumpster load" (Seltz, 2013). Hand-harvesting has been the only method used to control the water chestnuts along the shoreline and in the open water since 2011(J. Castellani, personal communication, March 21, 2016; Seltz, 2013). The Massachusetts Department of Conservation said, "It's a pretty good success story" (Seltz, 2013). The state of Massachusetts spent close to $500,000 from 2008 through 2013, on the management plan to remove water chestnuts from Fiske Pond, and protected the more widely used Lake Cochituate (Seltz, 2013).

In summary, after 24 days of hydro-rake operation on Fiske Pond in 2008, 225 tons of water chestnut plants was removed, and in 2009 after 35 days of operation where 94.4 tons of plant material was removed using a combination of hydro-raking, mechanical harvesting and hand pulling. Fiske Pond saw a shape decrease in water chestnuts from 2009 to 2009, with hand-harvesting being the only management method needed since 2011.

3.7 Foster's Pond- Andover, Massachusetts

Map 8. Foster's Pond- Andover, MA location. Map credit: Danielle Desmarais

Foster's Pond- Andover at a Glance:

Plants of concern: fanwort *(Cabomba caroliniana)*, spiny naiad, *(Najas marina*), white waterlily (*Nymphaea odorata*) and water shield (*Brasenia schreberi).* These plants are described in appendix 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies*

Other concerns: Leaf litter, muck, fallen trees, clean-up around dam

Depth of water body: 4.5 ft. (1.37 m) average depth and 13 ft. (3.96 m) maximum depth

Size of water body: 120 acres (48.56 ha) including a cove, main pond, channel and reservoir

Land use: Boating, swimming, shore-line residential area use

Management methods: dam water level draw-downs, hydro-raking, hand pulling, chemicals: diquat/Reward^{tm} and fluridone/Sonar^{tm}

The surface area of Foster's Pond is approximately 120 acres, consists of an outlet cove, main pond, Mill Reservoir and the channel, as seen in satellite imagery in Figure 31 (ACT, 2004). Dug pond is separated from the other water bodies, and is not included in this case study due to a lack of hydro-raking for plant control.

Figure 31. The Foster's Pond system in Andover, consisting of an outlet cove, Main Pond, Mill reservoir and the channel, as seen in satellite imagery. (Foster's Pond Corporation, 2014a).

Starting in 1992, the hydro-raking of shoreline was organized by residents, where each rake load needed to be deposited on the shore's edge and the property owner was responsible for hauling or trucking the material to a permanent, upland disposal site, such as a garden (Foster's Pond Corporation, 2016a). Hydro-raking was conducted every couple of years, with about 20 property owners participating each year and each resident requesting from one to eight hours of raking (Foster's Pond Corporation, 2016a).

2004

Foster's Pond was overgrown with fanwort in 2004 and of October of that year, Foster's Pond had 78.9% total plant cover and fanwort made up 54.5% of the total plant cover amount (Aquatic Control Technology, Inc.[ACT], 2014). Mechanical harvesting and hydro-raking were not recommended for long-term control of fanwort infestations due to hydro-raking operations inevitably creating plant fragments that cannot be effectively contained and collected because the mechanical control options usually can only provide weeks of effective control before the plants regrow (ACT, 2004).

Although, hydro-raking had been maintaining individual shorefronts in Foster's Pond for many years, the management company stated it was "doubtful that hydro-raking can provide sufficient seasonal control" (ACT, 2004). In October, 2004 hydro-raking was performed over four days on shorefront properties at thirteen sites that pre-signed up at a town meeting including, 17 hours in the main Pond and 12 hours in the channel, for a total of 29 hours (Foster's Pond Corporation, 2004). The hydro-rake also removed a "concentration of invasive plants" in front of the sluiceway of the dam, to prepare for repair work on the dam for the next draw-down (Foster's Pond Corporation, 2004). The invasive plant species were not specified. Hydro-raking would appear to be slightly successful for removing waterlilies at shoreline properties, but not as successful at removing the fanwort.

2005

In 2005 the Foster's Pond Corporation initiated the use of fluridone, (brand name Sonar[tm]) for fanwort control, a winter water draw-down over the 2005-2006 season and hydro-raking remained a part of the management plan due to leaf litter, decomposed plant "muck" and lilies not being controlled by Sonar (Foster's Pond Corporation, 2005a). Hydro-raking commenced in October of 2005 for ten shorefront property owners in the main pond over a three-day period, with the main pond utilizing one day and the area around the dam the other two days for a total of 24.5 hours (Foster's Pond Corporation, 2005b). The targeted plants for removal were lilies, lily roots, and leaf litter as fanwort levels were not a concern at this time (Foster's Pond Corporation, 2005b).

In September 2005, a biologist analyzing Foster's Pond was asked if hydro-raking spread the fanwort, to which he replied, "I doubt very much there are any viable roots which are hardy enough that the hydro-rake uncovering them will stimulate new growth" (Foster's Pond Corporation, 2005a). Foster's Pond Corporation also asked the biologist if they could have gotten these results of the dead fanwort with a big drawdown, to which the biologist commented the water could not be drawn down low enough with the dam mechanism (Foster's Pond Corporation, 2005a). The biologist also added, that with regards to small-scale fanwort coverage, "hand-pulling would be a good option to keep the fanwort at bay," but due to the high density and large coverage of fanwort it would be impractical (Foster's Pond Corporation, 2005a). He added, that people would need to work slowly to get out the roots, without breaking off and pieces and having the plant reproduce (Foster's

Pond Corporation, 2005a). For further explanation of how fanwort reproduces through fragmentation, please see appendix 7.1: *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.*

2006-2007

Hydro-raking continued as part of the yearly maintenance on Foster's Pond. In October of 2006, five properties around the main pond, and four properties in the channel and areas around the dam here hydro-raked accounted for a total of 26.5 hours (Foster's Pond Corporation, 2006). The 2007 hydro-raking spanned three days on five properties on the main pond, three properties on the channel, and for the first time since hydro-raking started in 1992, two properties on the Mill Reservoir for a total of 25.5 hours of raking. (Foster's Pond Corporation, 2007). Lower-than-normal water levels made the hydro-rake machinery difficult to maneuver the rake close enough to the shore to access the plants targeted for removal (Foster's Pond Corporation, 2007).

2008-2010

In August 2008, the Foster's Pond Corporation reported that the native water lilies are virtually gone from the channel and passages between the main pond and the Mill Reservoir, so there was no need for hydro-raking in 2008 (Foster's Pond Corporation, 2008). 2009 saw 20 hours of hydro-raking for five properties on the main pond, one on the reservoir and two on the channel, while hydro-raking was not possible in 2010 due to the water levels being too shallow (Foster's Pond Corporation, 2009; Foster's Pond

Corporation, 2010). Dense colonies of fanwort, and spiny naiad, were found in the channel, the passage and at several spots along the shoreline in the main pond in 2010 (Foster's Pond Corporation, 2010a). In July of 2010, 3.5 acres of the pond was sprayed with the herbicide diquat, (brand name Reward^{tm}) to eradicate the newly discovered spiny naiad, while in 2011, fluridone, (brand name Sonar^{tm}) was used to eradicate the fanwort, which led to the discovery at the end of 2011, that the fanwort was eliminated (ACT, 2012).

2013-2014

Hydro-raking resumed in October in 2013 after a four year gap from 2009 from seemingly successful chemical weed treatments and decline in lily patches, where nine property owners had rooted vegetation and muck removed along with the accumulation of organic debris from falling leaves and decaying weeds (Foster's Pond Corporation, 2013). Active management of fanwort growth was not planned for the 2013 season (ACT, 2014). Hydro-raking resumed for ten properties in October, 2014 for a total of 25.4 hours, along with hydro-raking around the dam to prepare for repairs to stop a leak, and to remove a birch tree a beaver had cut down (Foster's Pond Corporation, 2014b).

There was a mid-summer herbicide treatment in 2014 that reduced weeds throughout the pond, therefore only six property owners signed up for hydro-raking at a total of 16.5 hours following a summertime near drought that caused some problems for the hydro-rake machinery (Foster's Pond Corporation, 2014b). The pond's water level was lower than usual and the hydro-rake could not reach the shore as usual to deposit the plant debris (Foster's Pond Corporation, 2014b). Table 5 shows how the total plant percentage on the water has gone down from 2004 to 2014, although the fanwort had returned from 0% in 2011 to 10.9% in 2014. Figure 32 also demonstrates on satellite imagery, the extent the fanwort has spread visually, shown in the hatched areas, and created from August 2014 data.

Table 5.

Year	Estimated % Total Plant Cover	Estimated % Fanwort Cover
2004	78.9	54.5
2005[1]	25.5	0.1
2008	15.9	0.9
2009	34.2	6.1
2011[1]	19.0	0
2012	21.2	0.1
2014	53.6	10.9

[1]Whole-lake Sonar (fluridone) treatment performed

Foster's Pond total plant coverage percentages decreasing from 2004 to 2014 (Aquatic Control Technology, Inc., 2015b)

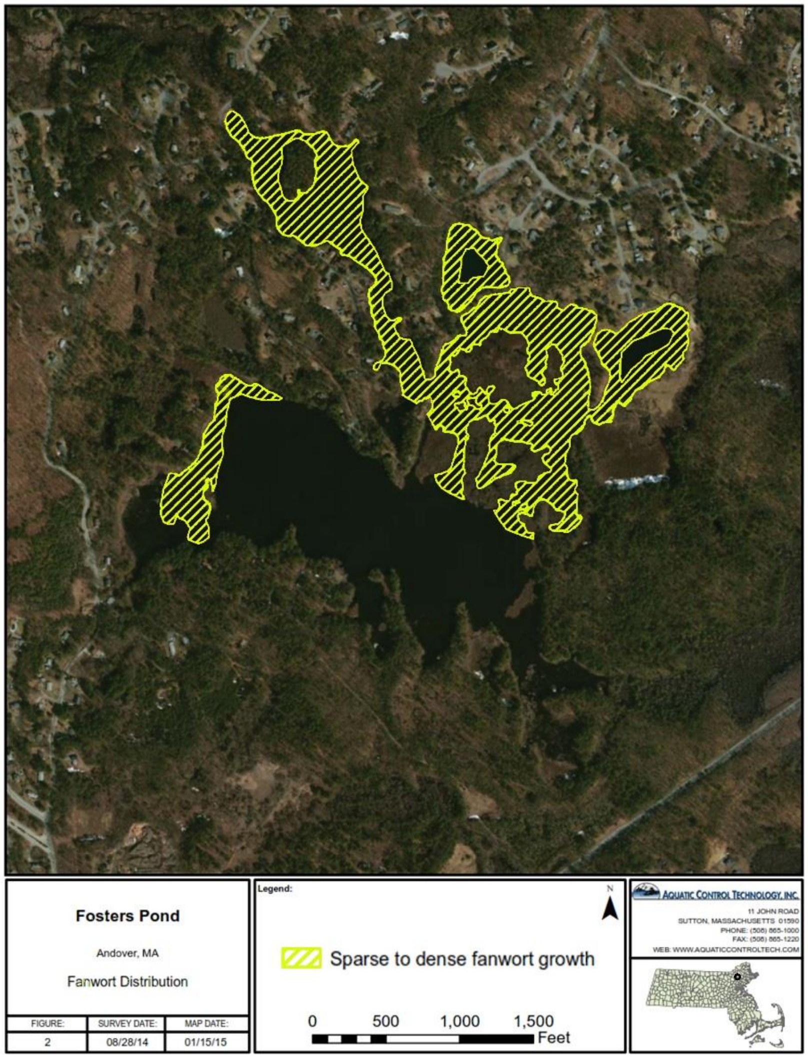


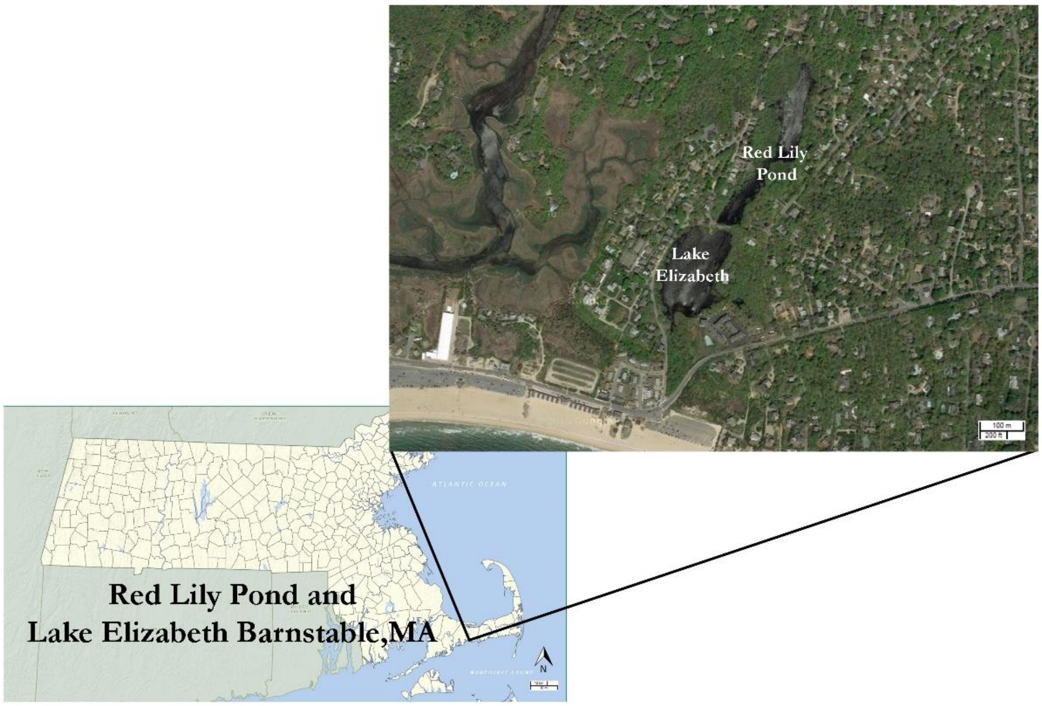
Figure 32. Fanwort distribution from August 2014 survey data, shown as hatch marks (Aquatic Control Technology, Inc., 2014b)

A 2015 report mentioned that the chemicals harmed the growth of the native plants and it was expected that the native desired aquatic vegetation will rebound fairly quickly, with a more diverse vegetative composition by the end of the summer of 2016 (Aquatic Control Technologies, Inc., 2015b). The regrowth of the desirable plants was being possible due to the fact many of the desirable native plants are annuals and as long as seeds existed in the pond sediment (Aquatic Control Technologies, Inc., 2015b).

The order of conditions authorized by the Andover Conservation Commission will allow for hydro-raking and herbicidal treatments for invasive weeds and algae, winter drawdowns through January 2019 (Department of Environmental Protection [DEP], 2015). The future of Foster's Pond, given the long history of aquatic invasive plant control issues, led to this conclusion by the management company's report that given "the presence of invasive, non-native aquatic vegetation, specifically fanwort, it is likely that Foster's Pond will continue to suffer from problematic aquatic weed growth in the future" (ACT, 2015b).

In summary, Foster's Pond has a long history of fanwort and water lilies. For the years 2009 through October of 2013, no hydro-raking was conducted, only chemical treatments were used to control the non-native invasive and native nuisance plants. In October of 2013 after chemical treatments, there was a decline in lily patches only, and not a complete eradication of the fanwort. Plans include further hydro-raking, herbicidal treatments and drawdowns for plant control through January, 2019.

3.8 Red Lily Pond and Lake Elizabeth- Barnstable, MA



Map 9. Red Lily Pond and Lake Elizabeth- Barnstable, MA location. Map credit: Danielle Desmarais

Red Lily Pond and Lake Elizabeth at a Glance:

Plants of concern: water shield (*Brasenia schreberi*), white waterlily (*Nymphaea odorata*), yellow waterlily (*Nuphar variegatum*), common reed (*Phragmites australis)* and purple loostrife (*Lythrum salicaria*)**.** These plants are described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.*

Other concerns: Herring run, restrictions on native waterlily removal

Depth of water bodies: Red Lily Pond's maximum depth: 4.2 ft. (1.28 m)

Lake Elizabeth's maximum depth: 3.9 ft. (1.19 m)

Size of water bodies: 5.1 acre (2.06 ha) northern basin called Red Lily Pond

8.2 acre (3.31 ha) southern basin called Lake Elizabeth

Land uses: scenic, support a diversity of wildlife, herring

Management methods: Hydro-raking, hand pulling

The Red Lily Pond system is approximately 12 acres (5.26 ha), comprised of two connected waterbodies, hence why they are grouped together in this case study. The 8.2 acre (3.31 ha) southern basin is called Lake Elizabeth and a 5.1 acre (2.06 ha) northern basin is called Red Lily Pond. Red Lily Pond's maximum depth in 1988 was 4.2 ft. (1.28 m), a mean depth of 2.1 ft.(.64 m) and Lake Elizabeth's maximum depth was 3.9 ft. (1.19 m) and mean depth of 3.1 ft. (.94 m) (K-V Associates & IEP Inc., 1988). Those were the most updated available depth readings. Red Lily Pond and Lake Elizabeth are home to ospreys, fish, swallows, swans, ducks, geese frogs and turtles (Red Lily Pond Project Association, Inc., 2007).

I personally visited Red Lily Pond and Lake Elizabeth in October of 2015, and I noted there were many houses along the shore in a densely habituated community, along with a fishing line hanging in a tree and a fishing buoy in the water, implying people fish at this pond. Figure 33 shows a close-up of the density of water lilies on Red Lily Pond in October.

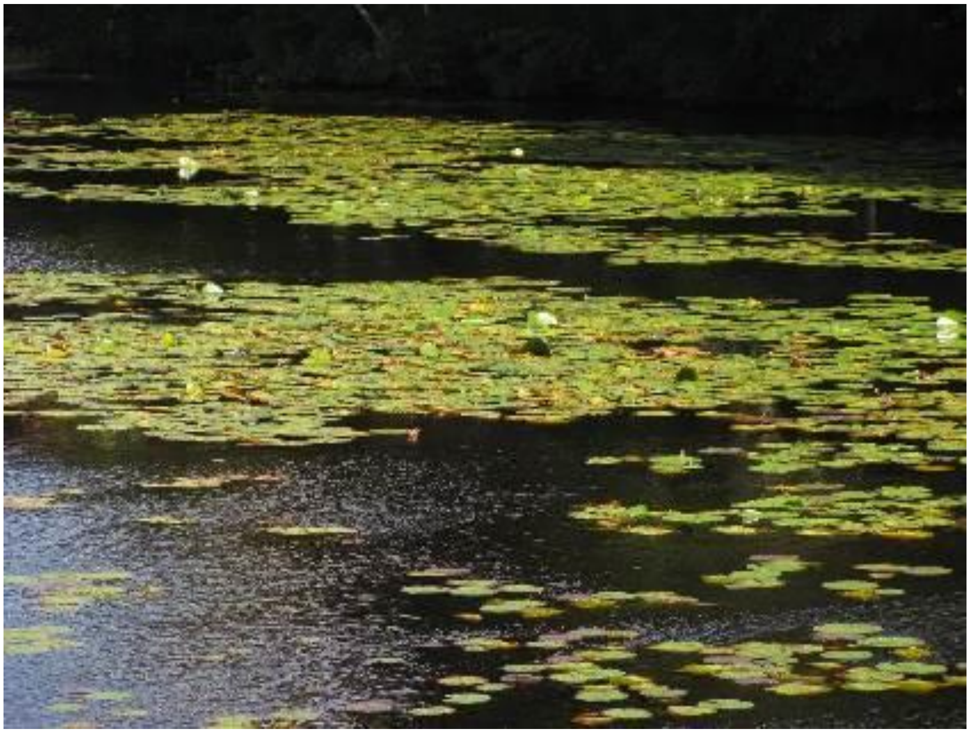


Figure 33. Close-up of water lilies on Red Lily Pond. Photo credit: Danielle Desmarais

The following Figures, 34 and 35 explain the interconnectiveness to the waterbodies because water flows south from Red Lily Pond, under a paved road, and into Lake Elizabeth through a large metal pipe. Any plants that spread through fragemention could theoretically travel from Red Lily Pond through the pipe, and down stream to Lake Elizabeth, to start a new colony.

Figure 34. Road separating Red Lily Pond from Lake Elizabeth. Photo credit: Danielle Desmarais

Figure 35. Large metal pipe running underneath paved road into Lake Elizabeth. Photo credit: Danielle Desmarais

1988-1999

There have been four rounds of hydro-raking at Red Lily Pond in the 1980's and 1990's starting in 1981, 1984, 1991 and 1997, where 1470 cubic yards of plants and root material were removed from Red Lily Pond (Mitchell, 2008). The species removed was unknown. The last hydro-raking project at Red Lily Pond and Lake Elizabeth performed in the 1997 provided more than 10 years of effective target plant control (Gazaille, 2011).

2008

2007 marked a change in the need to return to hydro-raking for plant control. Water quality had improved in 2008 to meet Phosphorus Cape Cod Commission criteria from to the reduction and mitigation of the volume of nutrient runoff and groundwater inputs entering the Red Lily Pond system, however the water quality is still conductive for overgrowth of nuisance plants (Mitchell, 2008). Hydro-raking, harvesting, herbicides or benthic barriers were recommended in a 2008 evalaution to remove the neusance aquaic vegetation (Mitchell, 2008), along with recommened surveillance of common reed (Red Lily Pond Project Association, Inc., 2008). In September of 2008, the Lake Elizabeth/Red Lily Pond herring run was restored through the construction of the fish ladder in Lake Elizabeth (Red Lily Pond Project Association, Inc., 2008).

2011-2013

The Red Lily Pond Project Association had been working for over 8 years to fund another pond restoration project (Red Lily Pond Project Association, Inc., 2012). In October of 2011, a biologist conducted a wildlife habitat evaluation of both Red Lily Pond and Lake Elizabeth, and noted heavy waterlily growth was impairing the important edge effect, which is relationship between vegetated areas and the open water (Gazaille, 2011).

The hydro-raking of Red Lily Pond lasted for 26 days in October of 2011 (Gazaille, 2011). The hydro-raking work for the first week of the project at Red Lily Pond, focused on the removal of water willow in the northern end and white waterlily, yellow waterlily and water shield in the southern part of the pond, for total of approximately 4.0 acres (Gazaille, 2011).

Lake Elizabeth was hydro-raked for nine days in October through November 2011 with a shoreline access clean-up and restoration for one day (Gazaille, 2011). Launching the hydro-rake and removing the aquatic plants in the off-loading area proved to be more difficult in Lake Elizabeth due to the shallow water depths (Gazaille, 2011). The target vegetation in Lake Elizabeth was water willow, purple loostrife, white waterlily, yellow waterlily and water shield (Gazaille, 2011). These plants are all described in appendix 7.1 *Aquatic Plant Species Discussed in the Hydro-raking Case Studies.*

The total amount of days spent hydro-raking should be noted, as some of the other case studies required one or two days of hydro-raking. Red Lily Pond required 100 hours of raking, Lake Elizabeth required 77 hours of total raking. A total of 120 truckloads of aquatic plants (600 cubic yards) were removed from the north and middle section of Red Lily Pond, and in Lake Elizabeth, 92 loads (460 cubic yards) of aquatic plants were removed as detailed in Table 5 (The Red Lily Pond Project, 2012). Table 5 also shows how Red Lily Pond, which is a small water body, actually had more plants removed than Lake Elizabeth did.

Table 6.

Project Variables	*Red Lily Pond*	*Lake Elizabeth*	*Project Totals*
Raking Time Frame	10/3 – 10/29	10/30-11/8	10/3-11/8
Number of Hours Raked	100 hrs	77 hrs.	177 hrs.
Total Number of Truck Loads	120 loads	92 loads	212 loads
Estimated Cubic Yardage Removed	600 yds^3	460 yds^3	1060 yds^3

Red Lily Pond and Lake Elizabeth hydro-raking details. Credit: (Gazaille, 2011).

Figure 36 shows satellite image where the actual hydro-raking took place on Red Lily Pond and Lake Elizabeth in 2011, shown in cross-hatching, and it is clear the majority of Red Lily Pond was hydro-raked, which might explain why more plant material was removed from that water body.

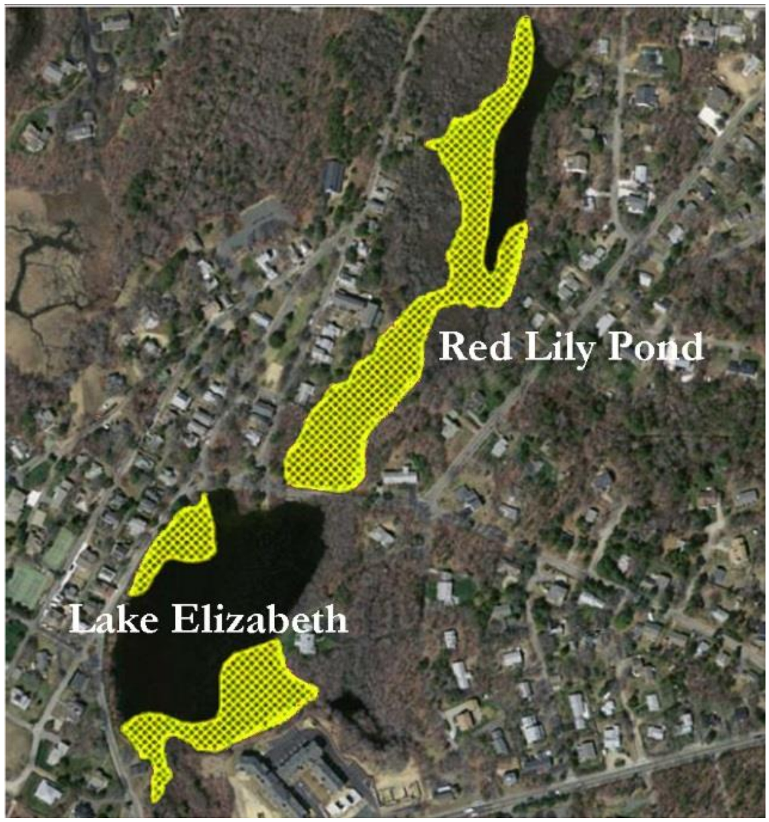


Figure 36. Hydro-raking occurred in the hatched areas in 2011. Credit: (Gazaille, 2011)

Only a portion of water lilies could be removed due to a conservation commission condition that the waterlilies were considered a native plant (The Red Lily Pond Project, 2012). "The ponds have never looked so good!" was a comment from a member of The Red Lily Pond Project, a non- profit organization tasked with the upkeep of the pond system. 2011 year-end report noted that the full extent of waterlily control within the areas hydro-raked will not be known until next summer (of 2012), and the waterlily and aquatic vegetation growth as a whole was significantly reduced as a result of the hydro-raking effort (Gazaille, 2011). A biologist also commented after the hydro-raking areas of diverse native plant growth were being preserved to serve as important fish and wildlife habitat (Gazaille, 2011). The 2011 hydro-raking performed at Red Lily Pond and Lake Elizabeth was successful at reducing the waterlily and emergent plant cover and should provide multiple years of acceptable control (Gazaille, 2011). Acceptable control was not defined. The biologist then also recommended smaller scale hydro-raking on a more frequent basis every three to four years to not disturb the herring spawn, along with biannual vegetation monitoring (Gazaille, 2011).

In a 2013 newsletter, the last update from the Red Lily Pond Project Association, purple loostrife was being hand collected along the shores of Lake Elizabeth, described as a “meticulous and arduous task”, with two truckloads of plant debris cleared in one afternoon through volunteer work (Red Lily Pond Project Association, Inc., 2013). There were still efforts being made to regulate water levels and allow for the migration of herring up through Lake Elizabeth and into Red Lily Pond (Red Lily Pond Project Association, Inc., 2013). The newsletter was not clear on the amount of herring spotted or the success level of the run renovations.

In summary, waterlily and emergent shoreline growth was significantly reduced from the hydro-raking in 2011. Red Lily Pond required 100 hours of raking, Lake Elizabeth required 77 hours of raking. The hydro-raking of Red Lily Pond lasted for 26 days in October of 2011 (Gazaille, 2011). The hydro-raking at Red Lily Pond, focused on the removal of water willow, white water lily, yellow waterlily and water shield, while the hydro-raking at Lake Elizabeth was water willow, purple loostrife, white waterlily, yellow waterlily and water shield (Gazaille, 2011). Overall, the hydro-raking to remove the rooted floating and emergent plants seemed successful., and will hopefully improve the water quality for the herring.

3.9 Conclusion of the Case Study Findings

In concluding the findings of the eight case studies, the main points to take away from each pond or lake aided in the making of the decision tree in section 4.

- The Campus Pond case study demonstrated the ability of the hydro-rake to operate in a small water body to remove tree litter such as branches and sticks, as well as trash in a heavily trafficked area in the center of a university campus.
- The Spectacle Pond case study showed how the complication of a rare plant allowed hydro-raking, mechanical raking and benthic barriers for the removal of variable watermilfoil and emergent native nuisance plants. All three techniques combined were effective at keeping the four undesired plant species under control for approximately a year and a half, while other options are being considered for the future.
- The Warner's Pond case study demonstrated how successful the hydro-rake was at removing emergent plants from shoreline areas. The most abundant non-native invasive plants in 2011 were fanwort, variable watermilfoil, along with a native nuisance plant, coontail, none of which hydro-raking was recommended due to the fragmentation aspect of the plant growth, but were controlled with chemicals.

- Mill Pond's hydro-raking goals were to remove fallen logs, branches and leaf litter to improve water quality. The hydro-raking was deemed successful around the southern end near the dam location, while the hydro-raking was determined unsuccessful in an northern area where the brook feeds into the pond due to that area lacking leaf litter and contained mostly fine silt.

- Fiske Pond in 2008, had 225 tons of water chestnut plants removed, and in 2009, 94.4 tons of water chestnuts were removed, using a combination of hydro-raking, mechanical harvesting and hand pulling. Fiske pond saw a shape decrease in the amount of water chestnuts from 2009 to 2009, with hand-harvesting being the only management method needed since 2011.

- Foster's Pond had a long history of problems with fanwort and water lilies and years of hydro-raking almost every year from 1992 to 2008. For the years 2009 through October of 2013, no hydro-raking was conducted, only chemical treatments were used to control the non-native invasive and native nuisance plants. In October of 2013 there was a decline in lily patches only, and not a complete eradication of the fanwort. Plans include further hydro-raking, herbicidal treatments and drawdowns for plant control through January, 2019.

- The hydro-raking at Red Lily Pond, in 2011 focused on the removal of water willow, white water lily, yellow waterlily and water shield, while the hydro-raking focus at

Lake Elizabeth in 2011 was water willow, purple loostrife, white waterlily, yellow waterlily and water shield (Gazaille, 2011). Overall, the hydro-raking to remove the rooted floating and emergent plants seemed successful.

The physical characteristics of the problems caused by non-native invasive and native nuisance plants has been demonstrated through the case studies. The next section will detail the specific costs and provide permitting fees and information needed to make a feasible decision concerning the use of hydro-raking to address concerns with managing plants.

3.10 Costs and Permitting for Hydro-Raking in Massachusetts

This information provided in this section is based on hydro-raking costing estimates, and some of the permitting fees for hydro-raking ponds and lakes. These costs can assist a decision maker through the estimates and actual costs. A professional environmental consultant with hydro-raking experience should be called upon to investigate, document and advise in any aquatic non-native invasive or nuisance plant situation before even proceeding to the next steps of costing and permitting. The costing figures in this section were provided by management companies, and were obtained through published bids for hydro-raking jobs. If a manager of a pond or lake wanted to proceed with hydro-raking, the first step would be to look into the permitting required in the town in Massachusetts where the pond or lake resides.

Permitting

To demonstrate the complicated process of permitting, here are some general guidelines based on the most updated 2014 laws. Aquatic plant management projects in lakes and ponds are subject to the jurisdiction of the Wetlands Protection Act, MGL Ch. 131, § 40 (Langley, Rhodes & Stroman, 2004). MGL (Massachusetts General Law) Chapter 131, § (section) 40 is the law surrounding the "removal, fill, dredging or altering of land bordering waters" (MGL chapter 131, section 40, 2004). The purpose of that law is to make sure the persons removing the plants have filed a notice of intent (NOI), which will be discussed later on.

Aquatic plant management projects in lakes and ponds are subject to the regulations in 310 CMR 10.00 (Langley, Rhodes & Stroman, 2004). CMR stands for Code of Massachusetts Regulations. "Projects must comply with the general performance standards established for each applicable resource area in the regulations unless the project is "limited" (310 CMR 10.53(4) or 310 CMR 10.53(3)(l))" (Langley, Rhodes & Stroman, 2004). The next paragraphs will explain this language further.

How would one know if a project is "limited"? Those questions would fall under the definition of 310 CMR 10.53(4)- Ecological Restoration Limited Projects. Applicants proposing a limited project 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 of the interests of the Wetlands Protection Act (WPA). 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

> eutrophication, or those that would increase dissolved oxygen or improve overall water quality in a water body. (Langley, Rhodes & Stroman, 2004).

What is interesting to note under the limited project description of 310 CMR 10.53(4) is this next paragraph, which describes when certain projects would not count as an ecological restoration limited project:

> Projects proposing aquatic plant management to improve the natural ability of a resource area to provide recreation, aesthetics, odor reduction, or other similar interests do not qualify under 310 CMR 10.53(4) because those interests are not protected by the WPA regulations (Langley, Rhodes & Stroman, 2004).

For an example in context, under 310 CMR 10.53(4), a limited project, applying to remove waterlilies because they impede recreational activities, by filing the permitting under a limited project, would be problematic and the permitting paperwork could be rejected. Another limited project criteria could be 310 CMR 10.53 (3)(l) Water Dependent Uses. Included in those regulations are "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" (Langley, Rhodes & Stroman, 2004). Examples of water dependent uses and facilities include, (but are not limited to), marinas and public recreational uses. An environmental consultant would help determine if a hydro-raking project would qualify for either of the two limited projects.

A confusing part of hydro-raking permitting was questioning whether hydro-raking is a form of dredging. The actual law language of CMR 10.53(4), Ecological Restoration Limited Projects states, "If the project involves the dredging of 100 cubic yards of sediment or more or dredging of any amount…" (DEP, 2014), the applicant would need to file for Water Quality Certification. Speaking with a manager who oversees hydro-raking at a pond and lake management specialty company regarding dredging permitting, mentioned: "100 cubic yards of plant debris is really 35 or 40 cubic yards on average after dewatering." "If one were to removed more than 100 cubic yards of plant debris, soil core samples would need to be tested for hazardous materials and heavy metal and the debris would need to go somewhere special" (J. Castellani, personal communication, March 8, 2016). The somewhere special mentioned would not be a compost pile, as the debris might need to be brought to a landfill, per individual town or city regulations.

There are questions that a land manager needs to ask before the permitting process can begin. Who owns the land? Who manages the land? Is the pond legally classified as a great pond? What species of plant are causing problems? What specific problems are the plants causing? Examples of problems include impediment to recreational activities such as kayaking and swimming, loss of fish or turtles or the loss of native plants due to invasive plants competing for resources. The actual problem looking to be solved by hydro-raking is important because the process could be considered a restoration. It varies who actually files the permits.

On Foster's Pond, for example, individual property owners do not need to apply for a permit in order to participate in the group program, but their sign-up forms must be included in a package of materials submitted for formal approval prior to the commencement of each year's Hydro-Raking. (Foster's Pond Corporation, 2016a). Another one of the previous case studies, Campus Pond had permitting done through a contractor and not the University itself. "New England Environmental, a contractor, has been charged with securing necessary permits and authorization from the Amherst Conservation Committee" (UMass Amherst, 2010a).

Whether or not the hydro-raking qualifies as a limited project or not, the steps are similar to obtaining the information to proceed with the permit process. A Notice of Intent (NOI) needs to be prepared with the following information.

- Obtain a botany identification of the plants causing problems along with the other native, non-nuisance plants.
- Identify any fisheries and species of fish
- Create a detailed distribution map of the target and non- target plants
- It is important to check if the pond or lake falls under the estimated habitats for rare wildlife, including vernal pools on maps through Natural Heritage and Endangered Species Program.
- Discuss entry and exit points for undesired plants. Are boats entering or leaving being cleaned? Are culverts empting from one water body into another? Is the area prone to flooding?
- Develop a monitoring plan for the unwanted plants pre and post hydro-raking and include long term goals.
- Identify all affected wetland resource areas such as groundwater and wells
- Provide plans of unloading the hydro-rake, staging the plant debris and final disposal site of plant debris.

All steps: (Langley, Rhodes & Stroman, 2004).

The application review process then proceeds in the state of Massachusetts for an

Administrative Completeness Review (Energy and Environmental Affairs, 2016).

With approved permitting, public meetings are then held, abutters have been notified of the plans and the city or town Conservation Commission issues an order of conditions with a three-year time frame until renewal is needed. This information is from my personal experience working with the Wilbraham, MA Department of Public Works on dredging permitting, and attending Conservation Commission meetings for years.

One example from the case study on Red Lily Pond is when the order of conditions from the Conservation Commission specified that only a portion of the water lilies could be removed because they are considered a native plant (The Red Lily Pond Project, 2012). Hydro-Raking was then performed in accordance with those Order of Conditions.

The total time frame the permitting takes from start to finish was investigated. A manager who oversees hydro-raking at a pond and lake management specialty company said, "There are variables that effect the duration of the 'Notice of Intent' process, including timing of client management request, timing of surveys and a Conservation Commission meeting schedule (J. Castellani, personal communication, March 10, 2016). The typical time frame to secure permitting is 6 to 8 months for the hydro-raking permitting process in Massachusetts (J. Castellani, personal communication, March 10, 2016). The surveys mentioned could be botanical or of neighboring wildlife habitats, to name a few.

Some of the specific permitting costs in Massachusetts are as follows:

- The typical Notice of Intent (NOI) filing fee is $550 and spilt between the state and city or Town.
- The city or town the pond or lake resides in may have their own additional by-law fee.
- Additional fee to obtain a certified abutters list from the local Assessor's Office.
- Abutter notification mailings and newspaper ads of the project intention and Conservation Commission public hearing date ads. The pricing is proportional to the number of abutter notifications needed.
- The consultant time is a fee to conduct aquatic vegetation, bathymetric and sediment surveys. The pricing based on water body size and project scope.
- Fees for the consultant's time to prepare the permit application forms with accompanied proposed management plan.
- Fees for the consultant's time to attend/present the proposed management plan at a local Conservation Commission hearing.
- Once an Order of Conditions (OOC) is issued filing fee at regional Registry of Deeds is $75.
- Other factors that may affect permit cost include document preparation and file fees if the water body is within any of these state-supervised area: Natural Heritage and Endangered Species Program (NHESP), Areas of Critical and Environmental Concern (ACEC), Outstanding Resource Waters (ORW) and the Massachusetts Environmental Policy Aquatic Control (MEPA) Office.
- The cost range in the state of Massachusetts would be $2,500 to $10,000 to secure an Order of Conditions (OOC).

The source for all the information contained in those steps: (J. Castellani, personal communication, March 13, 2016).

Hydro-raking costing estimates

Once permitting is secured and approved, the actual hydro-raking activities can be specifically costed, such as the transport of the machine, and the disposal of the plant debris. This section will provide some costing estimates based on the most updated information available in 2016.

- Warner Pond estimated the costs of hydro-raking in 2012 at around $7,000 per acre, plus permitting costs (ESS Group, Inc., 2012). That figure did not include any details such as if transport costs were included.
- Campus Pond at the University of Massachusetts in Amherst mentioned as a case study, published a bid for 2015 hydro-raking in June with an estimate of $55,000 (North American Procurement Council, 2015). The job details did not mention the duration of time hydro-raking was needed for.
- The 2011 hydro-raking project Red Lily Pond and Lake Elizabeth cost a total of $137,000, which encompassed 177 hours of raking and with 212 truckloads of aquatic plants removed from Red Lily Pond and Lake Elizabeth (The Red Lily Pond Project, 2012).
- Niles Pond Conservancy in Gloucester, MA requested funds from the Community Preservation Committee to address shorelines heavily infested with dense growth of common reed, and the open water had sections with dense growths of white water lily (Niles Pond Conservancy, 2012).

- Hydro-raking operation estimates were $8,750 per acre, for a total cost of $103,250 just for the actual hydro-raking on the water (Niles Pond Conservancy, 2012).
- There was an additional fee of $3,600 for the loading, trucking and disposal of plant material, based on the estimated volume of plants at $30 cubic yard, and transport costs based on mileage and number of truck trips in 2011 (Niles Pond Conservancy, 2012).
- The estimated total cost for hydro-raking and material disposal for 11.8 acres on Niles Pond was $106,850.
- The total estimate for the proposal at Niles Pond in Gloucester, did not include any additional costs for permitting under the Massachusetts Wetlands Protection Act (Niles Pond Conservancy, 2012).

One way to figure out a rough costing estimate is the amount of time needed for plant removal. Spectacle Pond, one of the previously discussed case studies had a time estimate for their hydro-raking cost estimation. One average, the rake "can clear a 50 by 50 ft. area in approximately one hour" which shows how fast the raking can be accomplished (Lycott Environmental Inc., 2009).

Foster's Pond research detailed that an average beach area could be cleared of non-native invasive or native nuisance plants in a space that was 75 ft. by 50 ft. in approximately 1 to 2 hours, depending on the weed densities, depth and bottom characteristics (Foster's Pond Corporation, 2016b). Removal of leaf litter, organic debris, or dense vegetation may require considerably more time (Foster's Pond Corporation, 2016b). The environmental company providing the hydro-raking estimated 40-60 hours of hydro-raking was needed on Campus Pond in 2010 (UMass Amherst, 2010b).

In summary, based on estimates in this section, $7,000 to $9,000 an acre is the rough estimate for hydro-raking costing in 2016. That range factors in staging and transportation of the plant debris to the final location, if required. The length of time needed to secure permitting on average, is 6-9 months with permitting fees ranging from $2,500 to $10,000, to secure an Order of Conditions (OOC) in the state of Massachusetts.

The costs of hydro-raking associated with the actual operation of the machine on the water, plus transport fees of the plant debris combined with the permitting fees gives an idea of what the total cost of hydro-raking would be for a pond or lake, that information will be combined with the specific plant species suitable or not suitable for hydro-raking.

4. Decision Tree for Hydro-raking and Discussion

4.1 How to Use a Decision Tree

This decision tree entitled, "A Decision Support System for Evaluating Hydro-raking for Removal or Non-Native Invasive or Native Nuisance Plants from Freshwater Lakes and Ponds in Massachusetts" can fill a gap in hydro-raking research by providing a decision maker a comprehensive guide to determining if a certain water body should be considered for hydro-raking. A decision tree, which guides the reader through a series of questions to consider if hydro-raking is a viable option, is shown in Figure 37. This decision tree helps aid a lake or pond manager by combining all the data from pond and lake management sites (technical information and limitations), environmental reports and the eight case study outcomes.

The decision tree was designed to flow down the page, as each question assisted the decision maker on whether or not hydro-raking was suitable for their pond or lake. One the left side of the chart, four rounded rectangles state the four main categories of questions: depth, access, budget and time. Those categories were chosen to fill the research gap found in existing data tables from section 2.4: *Compiled Research on Hydro-raking* where the access to the water body information was missing along with water depth requirements and permitting fees. Responding 'no' to any of the four main questions leads the decision maker to the right column where a 'no' sign is present, next the words "hydro-raking not an option" surrounded by a dotted box.

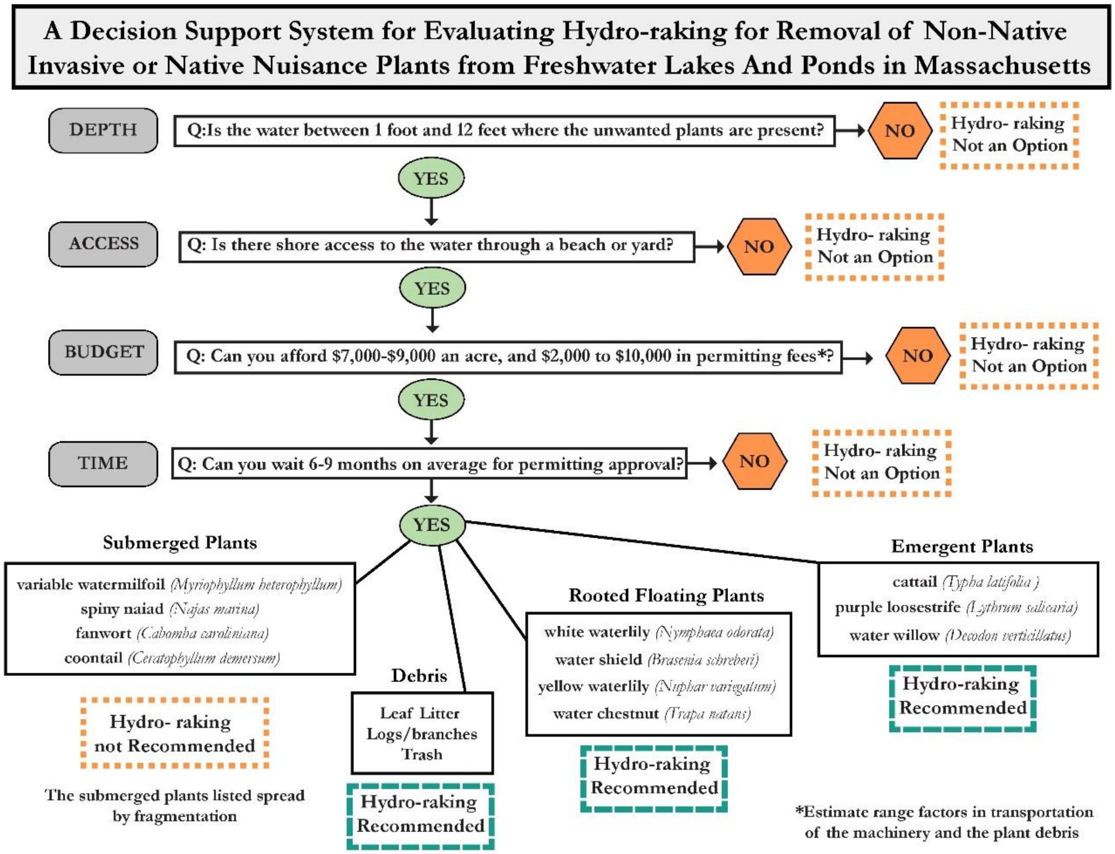


Figure 37. Decision tree to aid in hydro-raking decision making. Design credit: Danielle Desmarais

The next example of the decision tree, in Figure 38 shown in highlighted areas in yellow boxes (or grey boxes if viewing in black and white), shows the path a decision maker would make, in a theoretical example using the tree.

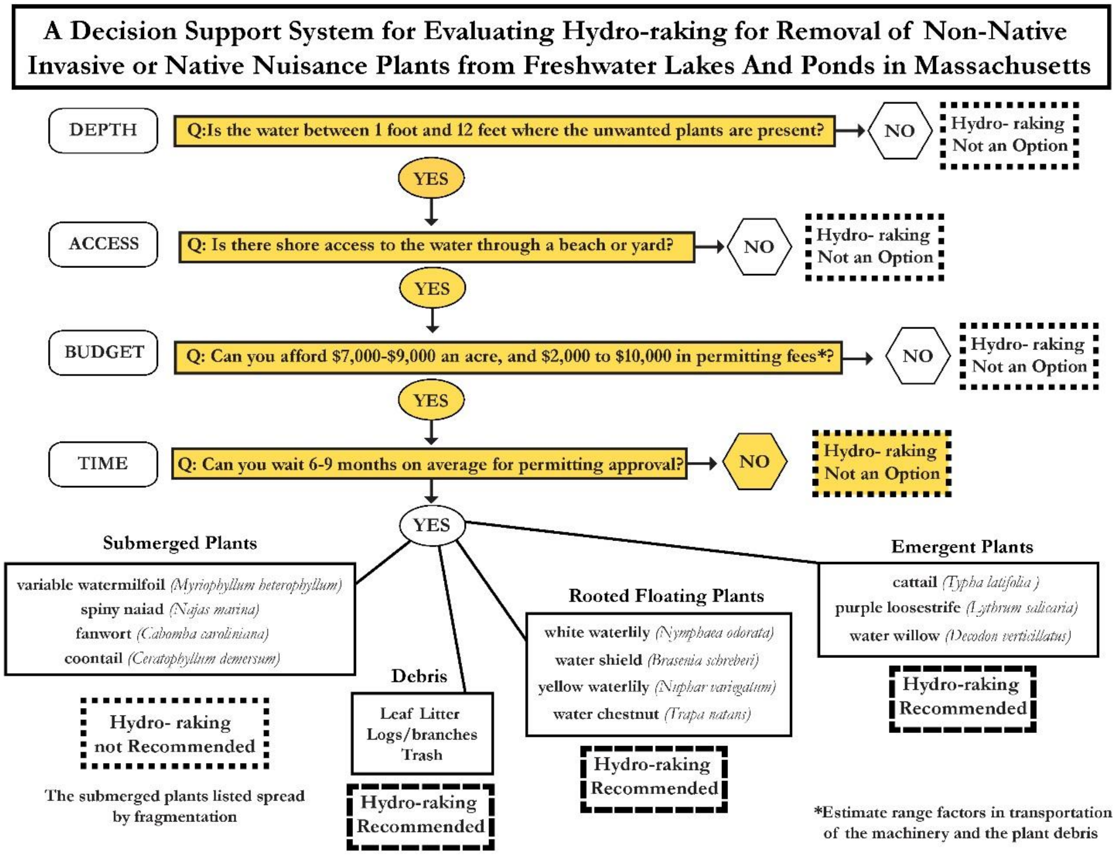


Figure 33. A step-by-step guide through the tree shown in highlighted areas. Design credit: Danielle Desmarais

To step through Figure 33 in a hypothetical situation, a pond manager overseeing a water body that is 5 ft. (1.52 m) deep on average, with a boat dock, with the problematic plant being water chestnuts, and it is the month is July when starting to look into options for removal of the water chestnuts. The first question regarding the water depth, has an answer of 'yes', has the appropriate water depth and then steps down to the next question, where 'yes', there is shore access. The 'yes' answer leads to the questions about the budget, and 'yes' there is room in the budget for hydro-raking. The next question is "Can you wait

6-9 months on average for permitting approval?" The plants are becoming a huge hindrance to the dock where the boats are housed, and the plants need to be removed immediately. Because it is July, and in Massachusetts, the minimum time to procure the proper permits based on the 6 to 9 months of average permit processing would be in December, a time where the plants are dormant and the pond is likely to be frozen over. Hydro-raking would have to wait for the next spring or another management method would have to be chosen.

4.2 Discussion of Decision Tree Results

The decision tree demonstrated that through case study evidence and data from environmental professionals, hydro-raking can be a recommended management option for removing aquatic nuisance plants from ponds and lakes in Massachusetts under certain conditions. All the plant categories were accounted for and added to the decision tree, except the free floating category, due to the fact the rake itself does not appear to be able to scoop algae or duckweed due because the tiny plants would be falling between the tines of the rake.

Another facet of the hydro-rake not mentioned in the decision tree, but is important to consider, is the noise factor. Upon witnessing hydro-raking at Campus Pond discussed in case study section 3.2 *Campus Pond- University of Massachusetts campus- Amherst, Massachusetts* where I can best describe the machinery as a lawnmower underwater. It is not a silent operation to run a hydro-rake all day long. I could see in landscapes where there are a lack of sound buffers, such as trees, the noise of that machinery in the water could travel far and possibly irritate people living nearby.

The conclusion section will summarize this entire thesis and delve more into the benefits/limitations of the hydro-rake, and provide recommendations for future hydro-rake studies.

5. Conclusion of Hydro-raking Research

In conclusion, hydro-raking can be a recommended management control option for removing aquatic invasive or nuisance plants from ponds and lakes in Massachusetts under specific conditions. Finding the specific conditions was accomplished from studying the available scientific literature specifically on hydro-raking, finding technical information through aquatic management company websites, and existing data tables of information regarding the suitability of hydro-raking in various water body conditions.

Eight case studies were analyzed to help develop through this research endeavor. All the information gathered from management companies, Massachusetts state-level reports, and scientific studies on hydro-raking was used to develop a decision tree to help aid decision makers to see if hydro-raking is a viable option for managing non-native invasive and native nuisance plants on their pond or lake. The water needed to be at least one ft. (.30 m) deep to operate the hydro-rake, and undesired plants cannot be deeper than 12 ft. (3.65 m), along with shoreline access being needed to launch the hydro-rake pontoon boat, as it does not have wheels.

5.1 Benefits and Limitations of the Hydro-rake

This section will summarize the finding of this thesis research in simple statements pulled from the various sections of this research and place that information into two categories: hydro-raking benefits and hydro-raking limitations/weaknesses.

Hydro-raking Benefits

- Recommended for the removal of emergent plants with root bundles such as: purple loosestrife (*Lythrum salicaria*), water willow *(Decodon verticillatus)* and cattail (*Typha latifolia*).
- Recommended for the removal of rooted floating plants such as water chestnut (*Trapa natans)*, white waterlily (*Nymphaea odorata*), yellow waterlily (*Nuphar variegatum*) and water shield (*Brasenia schreberi).*
- Hydro-raking can also be effective when combined with other aquatic plant management techniques such as mechanical harvesting or hand-harvesting
- The hydro-rake can navigate shallow water over 1 foot (.30 m) and due to its small size, can travel up river, channels and rotate in tight areas.
- The rake mechanism allows for turtles and fish to escape when plant or organic debris is pulled from the lake or pond bottom
- Can remove plants, roots systems, muck, sediment and organic debris, and sunken or floating trash

- One hydro-raking service typically provides seasonal to 1-3 years or longer of nuisance plant control.
- Can provide clearing of selective areas including beaches, boating/fishing lanes
- Does not cause water use restrictions, people can be active in the water while hydro-raking is occurring

Hydro-raking Limitations/Weaknesses

- Hydro-raking is not recommended for submerged plants that spread through fragmentation such as fanwort (*Cabomba caroliniana)*, spiny naiad *(Najas marina)*, Coontail (*Ceratophyllum demersum*) and variable watermilfoil (*Myriophyllum heterophyllum*).
- The case studies and environmental research also have deduced that thin leaved and delicate plants will slide through the rake, (such as algae and duckweed) making those plant not recommended for control through hydro-raking.
- There also needs to be consideration that undesired plants planned for removal could also be mixed in with desirable plants, in which the desired plants are removed. Another concern with hydroraking, is the removal of the seeds of desirable plants because the rake cannot choose what is it pulling, if there are multiple species in the same area.
- Requires shoreline access to launch boat, and the water needs to be at least 1 ft. (0.30 m) in depth to operate, along with the undesired plants cannot be deeper than 12 ft.. (3.65 m).

- Hydro-raking can be very expensive after permitting and other fees, but as this is not a comparative study, it's up to the decision maker to see the merits beyond the price.
- The machinery is fairly loud, sounding similar to a lawn mower.
- Hydro-raking can increase phosphorus levels and turbidity (cloudiness) temporarily.

A temporary increase in turbidity (cloudiness) levels could be a possible avenue for a long-term study, which will be discussed in the next section.

5.2 Recommendations For Future Hydro-raking Studies

Each time I visited Campus Pond, I had to guess the turbidity level just from viewing the water. Using a Secchi disk could prove helpful in actually measuring turbidity before, during and after hydro-raking, in long intervals of time such as years, taking regular readings to track changes.

More avenues for further research could be a larger study area, perhaps all of New England to see if other states have similar non-native invasive or native nuisance plant control issues. I also wonder if the permitting for the hydro-rake is similar, different or less complicated then the Massachusetts process. The hydro-rake itself is technology that dates back to the early 1980's, (IEP Inc. Consulting Environmental Scientists, 1983), so it's relatively new.

Another application of the hydro-rake is trash removal from highly trafficked areas. A pond in the center of a college campus, discussed in section 3.2: *Campus Pond- University of Massachusetts campus- Amherst, Massachusetts* could open new avenue of studying the hydro-rake's abilities. Trash can sink, and then become imbedded into the sediment, making a giant rake an ideal tool to remove that trash.

Managing nature is a delicate balance, and the hydro-rake can assist in restoration efforts the water body manager and company utilizing the hydro-rake equipment has the same goals. Removing native, plants perceived as a nuisance can have negative effects for the ecosystem. A plant might be blocking a scenic view, be difficult to swim through or cover part of the water surface, but best management practices need to put in place to not remove the entire population of a native plant. Cattails, white and yellow water lilies and water shield are often targeted for removal due to impediments on recreational activities. It is important to remember a pond or lake is not the same as a crystal-clear swimming pool, and a manager need to consider that when deciding to remove a species from their water body, purely because people do not find those plants beneficial to them. Aquatic plant management is not without complications, but it is important to keep an equilibrium between the native plants and the non-native invasive plants.

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7. Appendix

Appendix 7.1 Specific Aquatic Plants Discussed in Case Studies

This section supplements the case studies in sections 3.2 through 3.8: Campus Pond, Spectacle "Spec" Pond, Warner's Pond, Mill Pond, Fiske Pond, Foster's Pond, Red Lily Pond and Lake Elizabeth. This appendix is not an identification guide, but is here to provide a short overview of each major plant mentioned in the case with photos of the plants, descriptions on how the plants reproduce and spread, and what effects the plants can have on an aquatic ecosystem. This condensed guide does not include every non-native invasive or nuisance aquatic plant in Massachusetts, but rather, only the ones causing the biggest concerns in the case studies. The information was compiled from various plant identification books and online guides.

Fanwort (*Cabomba caroliniana*)

Fanwort is a submerged, non-native invasive aquatic with delicate two inch fan-like leaves, as seen in Figure 39. (Robinson, 2002d). Fanwort is native to the southern United States, and was first discovered in Massachusetts in Hatfield in 1930 (Robinson, 2002c). Fanwort tolerates a wide range of pH, temperatures and lives in both oligotrophic (low nutrient) and eutrophic (nutrient rich) lakes and ponds, while also being able to survive in frozen lakes (Robinson, 2002d).

Figure 39. Fanwort, (*Cabomba caroliniana)* with flowers budding above the water. Photo credit: (Foster's Pond Corporation, 2015)

Fanwort reproduce two ways, the first through fragmentation, and due to stems breaking easily, re-sprouting, and growing into new plants with stems up to six ft. in length (Robinson, 2002c) the plant spreads rapidly. The second reproduction method for fanwort is to grow from seed formations remaining in lake or pond sediment (Robinson, 2002c). Floating fanwort fragments can also develop adventitious roots, (tiny roots that replace any dying roots) to absorb nutrients, and then sink to the bottom of the pond or lake to establish new colonies of fanwort. (ACT, 2004).

Fanwort can establish dense mats on the surface capable of rapid growth and spread, shading other submerged plants (Robinson, 2002c), and thus can out-compete native plants for nutrients and sunlight. The loss of native vegetation can lead to a decline in species biodiversity due to loss of organisms that depend on the native plants (Robinson, 2002c). Fanwort can greatly impede human activities such as boating, fishing, water skiing and swimming, and fanwort can negatively impact real estate values (Robinson, 2002c).

Variable watermilfoil (*Myriophyllum heterophyllum*)

Variable watermilfoil (*Myriophyllum heterophyllum*), (also called variable-leaf watermilfoil, variable-leaved watermilfoil and variable milfoil) is a submerged non-native invasive. Variable watermilfoil has delicate green feather-like leaves that average ½ inch to 2 inches across with thick stems that are usually red, seen in Figures 40 and 41. (Robinson, 2002d). This plant is found throughout Massachusetts, but tends to prefer the acidic waters in the eastern part of the state (Robinson, 2002d).

Figure 40. Variable watermilfoil close-up, note the red stem. Photo credit: (Texas A&M AgriLife Extension Service, n.d.).

Figure 41. Variable watermilfoil under water. Photo credit: (Texas A&M AgriLife Extension Service, n.d.).

Variable watermilfoil reproduces by fragmentation, where a new individual develops from a point on the body of the parent organism, and in variable watermilfoil fragments each stem can grow up to one inch per day (Go Botany, 2016b). Another method of reproduction is through rhizome division which, is a continuously growing horizontal underground stem. Variable watermilfoil tolerates a wide range of conditions such as: surviving over winter in frozen water, can thrive in warm water bodies and can live in acidic water bodies (Robinson, 2002d).

Variable watermilfoil can form dense mats at the water surface intercepting sunlight needed by other submerged plants and can grow in depths up to 10 ft. (3.04 m) (Robinson, 2002b). Variable watermilfoil is capable of rapid growth and spread, which displace native species, reduces biodiversity, lessens recreational use such as swimming or kayaking, reduce real estate values and lower aesthetic values (Robinson, 2002d). Once established, the plant can out-compete native vegetation, which causes species that depend on native vegetation to survive to relocate or die off, which results is a less biodiverse ecosystem. When dense mats of variable watermilfoil decay, the available oxygen in the water is depleted, causing low oxygen conditions known as anoxia, which can lead to the death of fish and other aquatic organisms (Robinson, 2002d).

Coontail (*Ceratophyllum demersum*)

Coontail, (also known as raccoon's tail, coon's tail and common hornwort) is a native nuisance, submerged plant found throughout New England. This underwater perennial plant has branched stems with stiff whorls of leaves that vary from dark green to almost black seen in Figure 42. Coontail lacks true roots, and can float freely below the surface and can anchor to the bottom of the lake or pond by modified leaves (Department of Ecology, State of Washington, n.d.-c).

Figure 42. Coontail (*Ceratophyllum demersum*)close-up. Photo credit: Donald Cameron (Go Botany, 2016a)

Coontail spreads vegetatively through seed and plant fragmenting (Go Botany, 2016a) The small (4-7 mm) fruit has three long spines (to 12mm) with stems that are easily broken (Department of Ecology, State of Washington, n.d.-c). The plant is tolerant of hard water (high calcium content) and low light levels, allowing the plant a range of lakes and ponds to grow in (Department of Ecology, State of Washington, n.d.-c).

Coontail, as a plant native to Massachusetts, provides important habitat for young fish, small aquatic animals, aquatic insects and some waterfowl eat the seeds and foliage, although coontail is not considered a primary avian food source (Department of Ecology, State of Washington, n.d.-c). In nutrient rich water, coontail tends to form dense colonies either anchored in the mud or floating freely near the surface, and these colonies can form large monospecific (single species) stands, that block light to plants below, seen in Figure 43 (Department of Ecology, State of Washington, n.d.-c ; Go Botany, 2016a).

Figure 43. Coontail (*Ceratophyllum demersum*) forming a dense mat on the water surface. Photo credit: Donald Cameron (Go Botany, 2016a)

Spiny naiad *(Najas marina)*

Spiny naiad, (also referred to as slender, brittle, European naiad or bushy naiad) is a submerged aquatic plant with heavily-branched stems, giving the plant a bushy appearance, which can grow up to 4 ft. (1.21 m) in length (Rhode Island Department of Environmental

Management [Rhode Island DEM], 2010). Spiny naiad has serrated thin leaves that arch backwards, seen in Figure 44.

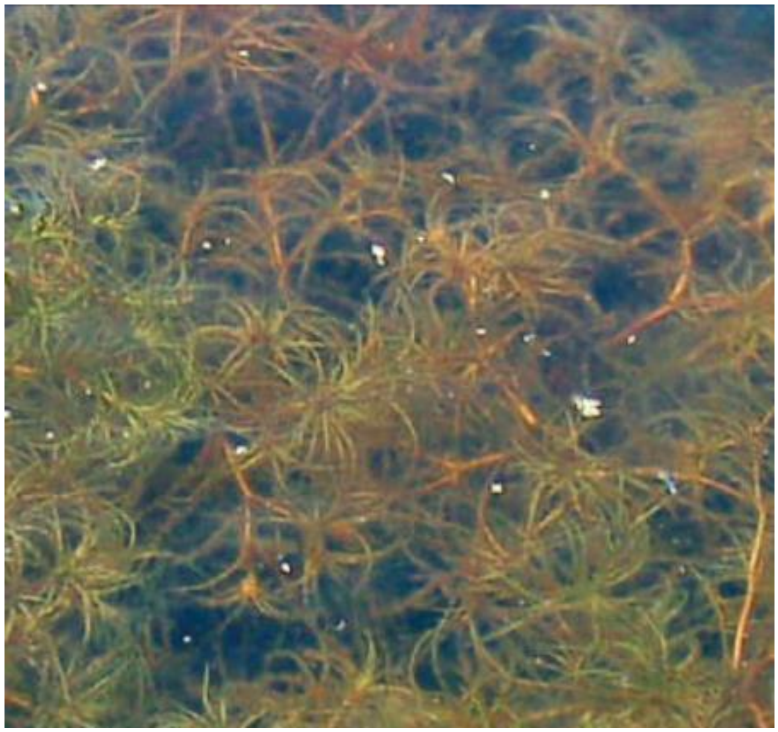

Figure 44. Spiny naiad and its thin serrated leaves. Photo credit: (Rhode Island DEM, 2010).

Spiny naiad is native to Europe, and was first introduced to the United States in the 1930's (Rhode Island DEM, 2010). The plant can spread to a new ecosystem through streams or rivers, migrating waterfowl and human activities due to the plant's ability to break easily into fragments that may become attached to boats, trailers or equipment (Rhode Island DEM, 2010). The small seeds can easily become attached to waterfowl who fly and transport the seeds to a new location (Rhode Island DEM, 2010). Spiny naiad can tolerate a wide range of conditions such as water with high turbidity (cloudiness) and eutrophic (nutrient rich) conditions (Rhode Island DEM, 2010).

Once introduced to a new ecosystem, spiny naiad spreads rapidly and may completely cover the lake bottom, out-competing native plant species for space and light, as seen in Figure 45 (Rhode Island DEM, 2010). If this plant becomes dominant, it may create conditions that are "detrimental to native fish and waterfowl, along with interfering with recreational activities such as boating, swimming and fishing (Rhode Island DEM, 2010).

Figure 45. Spiny naiad growing in a large colony on the bottom of a pond. Photo credit: (Rhode Island DEM, 2010).

Water chestnut (*Trapa natans)*

Water chestnut is a rooted floating non-native invasive plant with has air bladders located at the base of the green triangular wide leaves. Water chestnut plants have nuts that are armed with four very sharp barbs, as seen in Figure 46. The sharp barbs can penetrate shoes with leather soles and pose a hazard to bare ft. swimmers and beach visitors (Robinson, 2002a). The stems can Stems can grow up to 16 ft. (4.8 m) long and grow in water up to 16.5 ft. (5 m) deep, but often grows in shallow water one to six and a half ft. (0.3 to 2.0 m) deep (Northeast Aquatic Nuisance Species Panel [NEANS], 2016).

Figure 46. Water chestnut (*Trapa natans)* seed pods with barbs. Photo credit: Leslie J. Mehrhoff, University of Connecticut (National Parks Service, n.d.).

Water chestnut is native to Eurasia and was brought to Cambridge, Massachusetts by a gardener in 1897, where the plant rapidly spread into nearby rivers and ponds, and reached western portions of the state by 1920 (Robinson, 2002a). Water Chestnut reproduces primarily via the production of nuts (seed), where each nut can produce 10-15 plants (Robinson, 2002a). The nuts are released in the fall and quickly sink into the sediments, where they can remain viable for up to 12 years (Robinson, 2002a). Methods of dispersal include: floating downstream or attaching to wildlife, and then establish new colonies after the nuts sinks to the bottom of the pond or lake (Robinson, 2002a; Kaufman & Kaufman, 2007).

Water chestnut can withstand a pH range of 6.7 through 8.2, can survive over winter in frozen water and grow productively in water high in nutrients (Kaufman & Kaufman, 2007; Robinson, 2002a). During a single season, one acre of Water chestnut can produce enough seeds to cover 100 acres the following year (Robinson, 2002a). Water chestnut can grow into dense, floating mats seen in Figures 47 and 48, which restricts light availability to plants below and reduces the oxygen content in the water (NEANS, 2016).

Figure 47. Water body partly covered in water chestnut (*Trapa natans)*. Photo credit: (NEANS, 2016).

Figure 48. Water body completely covered in water chestnut (*Trapa natans)*. Photo credit: Leslie J. Mehrhoff, University of Connecticut (National Parks Service, n.d.).

Water chestnut colonies displaces native species, reduces biodiversity, hampers recreational uses, reduces real estate value and diminishes aesthetic values (Robinson, 2002a). The large, dense mats of vegetation the water chestnut can form on the water surface intercepts sunlight to the exclusion of other submerged plants, along with mosquito populations breeding on the mats (Robinson, 2002a; Kaufman & Kaufman, 2007). The thick mats greatly impede recreational activities for boaters, fisherman, water skiers and swimmers, along with negatively impacting real estate, depleting the available oxygen in the water (Robinson, 2002a). The resulting low oxygen condition (anoxia) can lead to fish kills and harm other aquatic animals as well as plants (Robinson, 2002a).

White waterlily (*Nymphaea odorata*)

White waterlily is a plant native to Massachusetts, with distinct large, 2.3 to 3.9 inch (6 to 12 cm) flowers that float on the water surface seen in Figures 49 and 50, and also emits, what is considered a pleasant fragrance (Department of Ecology, State of Washington, n.d-b). The plant is common in cultivated gardens as well as natural ponds and lakes in Massachusetts.

Figure 49. White waterlily (*Nymphaea odorata*) close-up. Photo credit: Danielle Desmarais

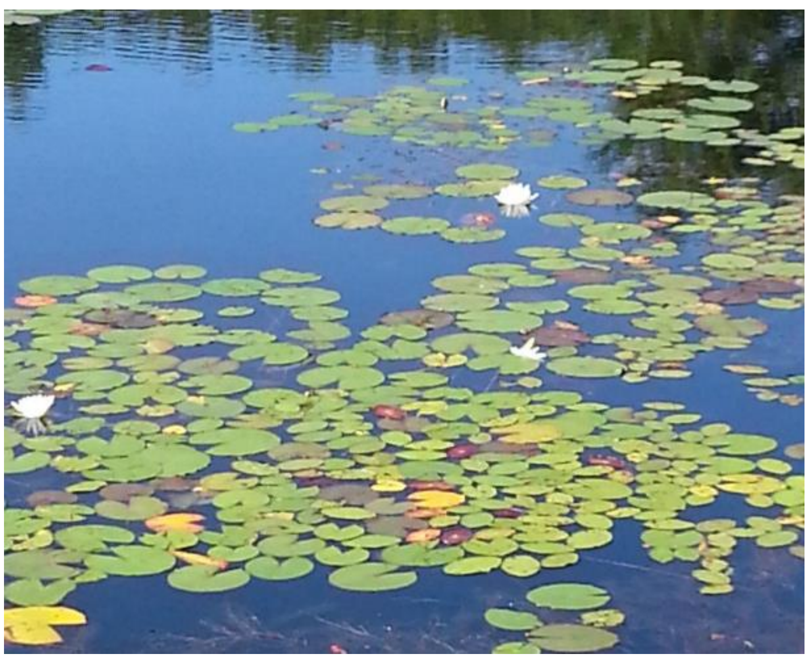

Figure 50. White waterlily (*Nymphaea odorata*) flowers and leaves. Photo credit: Danielle Desmarais

White water lily propagates through thick rhizomes (horizontal underground roots), that grow to 2-3 cm in diameter (Department of Ecology, State of Washington, n.d-b). Rhizomes are continuously growing horizontal underground stems that puts out lateral shoots and adventitious roots at intervals to sprout a new plant. White waterlily also reproduces from small seeds (Department of Ecology, State of Washington, n.d-b). Figure 51 shows the rhizomes are buried in the sediment, and a new plant can been seen growing in a corkscrew shape out of the rhizome.

Figure 51. New white waterlily growing in a cork-screw. Note the length of the stems. Photo credit: Donald Cameron (Go Botany, 2016c).

The leaves and roots are eaten by beavers, muskrats, porcupines, and deer, the seeds are eaten by waterfowl (Department of Ecology, State of Washington, n.d-b). White waterlily can become a nuisance in shallow lakes or ponds (Department of Ecology, State of Washington, n.d-b), due to the difficultly of swimming, boating or kayaking through the lily pads and navigating the long stems.

Yellow waterlily (***Nuphar variegatum***)

Yellow waterlily, (also known as Brandy-bottle, bullhead lily, yellow pond-lily *Nuphar variegatum*, spatterdock and yellow cowlily), has bright green floating leaves accompanied by bright yellow flowers seen in Figure 52.

Figure 52. Yellow waterlily (*Nuphar variegatum*). Photo credit: (Wennerberg, n.d.).

Yellow waterlily is native to the lower 48 states and can grow to be 15 to 60 cm in height from the sediment floor (Wennerberg, n.d.). Rhizomes (continuously growing horizontal underground stems that put out lateral shoots and adventitious roots at intervals to sprout a new plant) anchor into the muddy bottom of a water body and give rise to long, thin stems seen in Figure 53.

Figure 53. Yellow waterlily (*Nuphar variegatum*) rhizomes at the water surface after a storm. Photo credit: (Peterson, 2011)

Another way of reproduction for the yellow waterlily is through seeds, which are produced and deposited on the water surface, and then carried to a germination spot by the current or wind (Wennerberg, n.d.). Yellow waterlily grows in wet, sandy soils in one to three ft. (.30 to .91 m) of water in full sun to part shade, being more tolerant of shade and deep water than the white waterlily (*Nymphaea odorata*) (Wennerberg, n.d.). A Yellow waterlily plant can produce underwater stems that grow up to 6.5 ft. (2 m) long and can slowly spread to form sizeable colonies (Wennerberg, n.d.).

Yellow water lily provides food and shelter for many fish and underwater insects, as well as being an ornamental planting in water gardens and ponds for aesthetics (Wennerberg, n.d.). This plant may become invasive, even though native to Massachusetts, and may displace desirable vegetation if not properly managed (Wennerberg, n.d.).

Water shield (*Brasenia schreberi)*

Water shield, also called dollar bonnet and water target, has floating small, purplish, oval leaves, giving them an umbrella-like appearance seen in Figure 54.

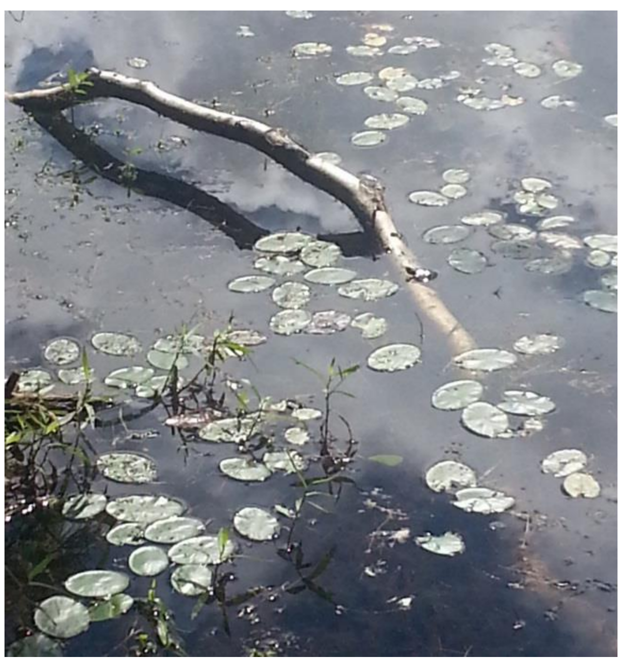

Figure 54. Water shield (*Brasenia schreberi*) shown in shades of green and purple. Photo credit: Danielle Desmarais

Water shield reproduces by rhizomes (underground horizontal roots) and through seed dispersal, where flowers produce 4-18 fruits, each containing two seeds, which ripen underwater and decay to then release seeds (Department of Ecology, State of Washington, n.d.-a).

Water shield provides habitat for fish and aquatic insects while the seeds and vegetation are eaten by waterfowl (Department of Ecology, State of Washington, n.d.-a). The plant, similar to yellow waterlily *(Nuphar variegatum*) and white waterlily (*Nymphaea odorata*) can impede recreation activities such as boating, kayaking or swimming.

Purple loosestrife (*Lythrum salicaria*)

The stems on the purple loosestrife plant can reach 9 ft. (2.73 m) tall, with four 16 inch (40.64 cm) flowering spikes, that are bright magenta, as seen in Figure 55. Purple loostrife can reproduce through root shoots and seed dispersal, with as many as 30 -50 stems rise from a persistent perennial tap root and spreading rootstock and when mature, the taproot and major root branches become thick and woody (Washington State Department of Ecology, n.d.). Disturbance to the plant, such as stomping and breaking off above or underground stems, initiates bud growth (Washington State Department of Ecology, n.d.).

Figure 55. Purple loostrife flowers. Photo credit: (Johnson, 2014)

Purple loosestrife tolerates a broad pH range requiring moist soils (Washington State Department of Ecology, n.d.), often along the shores of ponds and lakes. A mature plant can produce 2.7 million thin-walled, flat seeds and flowering can occur in 8 - 10 weeks after germination, where some seeds sink in the water, and resurface after germination, and seedling densities sharply fall within 34 ft. (10.66 m) of the parent plant (Washington State Department of Ecology, n.d.). Seed distribution methods include: transportation through wetlands by animals, humans, boats, or vehicles and water dispersal through winds or water currents (Washington State Department of Ecology, n.d.).

Native to Europe and Asia, purple loosestrife is classified as a non-native invasive plant in the United States, which can form dense mats along the shores of wetlands and crowd out native aquatic plants (Energy and Environmental Affairs, 2016). Purple loosestrife can quickly adapt to environmental changes and expand its range to replace native plants used for ground cover, food or nesting material driving away native animals and birds (Washington State Department of Ecology, n.d.).

Water willow ***(Decodon verticillatus)***

Water willow, (also called swamp loostrife), has pink flowers and bright green leaves, seen in Figure 56 with common habitats including lake edges, open stream banks and shallow ponds. The plant is native to the continental United States (Flora of New Jersey, 2012).

Figure 56. Water willow flowers and leaves. Photo credit: Flora of New Jersey. (2012, September)

The water willow spreads from pollination and has the ability to extend itself laterally over open water along the aquatic edge of lakeside wetlands (Pennsylvania Natural Heritage Program [PNHP], n.d.) seen in Figure 57, where the plants are overhanging into the water.

Figure 57. Water willow overhanging into the pond or lake. Photo credit: (Smith, 2012)

Nutrient enrichment and the resulting eutrophication in a water body can accelerate the growth of the water willow to become a native nuisance (Flora of New Jersey, 2012). Water bodies downstream of enriched waters can be completed covered by the arching stems of water willow (Flora of New Jersey, 2012). Water willow alters shallow open water habitats by creating areas of sediment deposition leading to new land being slowly built as sediment collects around the ends of the overhanding branches and anchored by new roots (Flora of New Jersey, 2012).

Cattail (*Typha latifolia*)

Cattail, also called broad-leaved cattail are herbaceous, rhizomatous perennial plants with long, slender green stalks topped with brown, fluffy, cigar-shaped flowering heads seen in Figure 58. The plants range from 4.92 to 9.84 ft. (1.5 to 3.0 m) tall.

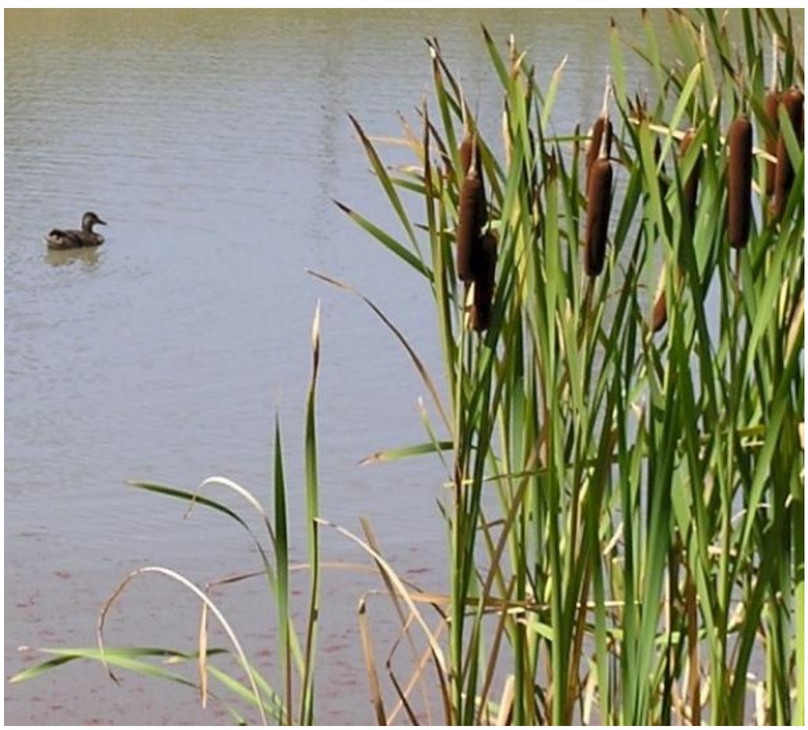

Figure 58. Cattails in the summer on a pond. Photo credit: (Hansen, 2012)

Cattails are common throughout the United States, located in coastal and valley marshes at elevations lower than 2,000 m. and spread both vegetatively and by seed

(Stevens & Hoag, n.d.). The cigar shaped flowering heads bloom and the seeds take on a cotton appearance, as seen in Figure 59, a photo taken in late February in Massachusetts.

Figure 59. Cattails in the winter at Spectacle Pond. Photo credit: Danielle Desmarais

Cattails become invasive to new communities when hydrology, salinity, or fertility changes, causing the cattail to out-compete native species, often becoming monotypic stands of dense cattails (Stevens & Hoag, n.d.). Cattails tolerate perennial flooding, reduced soil conditions and moderate salinity with influxes of nutrients or freshwater to a saline environment, cattails are aggressive invaders in both brackish salt marshes and freshwater wetlands (Stevens & Hoag, n.d.).

Cattails provide food and shelter to the other organisms in an ecosystem, the seeds are eaten by several duck species, geese and muskrats prefer the stems and roots, while moose and elk eat fresh spring shoots (Stevens & Hoag, n.d.). Birds can benefit from cattails, as shelter and nesting cover are provided for long-billed marsh wrens, red-wing blackbirds, and yellow-headed blackbirds (Stevens & Hoag, n.d.).

Common reed (Phragmites australis)

Common reed (also called phragmites) can grow up to 20 ft. (6 m), with leaves 50 in. to 100 in. (20 cm to 40 cm) long that grow in marshes as well as around lake and pond edges as seen in Figure 60 (Kaufman & Kaufman 2007).

Figure 60. Common reed (Phragmites australis) growing in a dense stand. Photo credit: (Kaufman & Kaufman 2007).

Common reed produces a fluffy flower head that initially is purple in color, but turns white and fluffy as it matures, as seen in Figure 61 (Kaufman & Kaufman 2007). Common reed is capable of rapid growth and spread. One way for this spread is when seeds that are dispersed by wind, water and wildlife (Robinson, 2002b). Another method of reproduction is rhizomes, (under-ground roots) that can extend down over 6.5 ft. (2 m) to reach deep ground water, where rhizome fragments can be transported and re-grow in new locations (Robinson, 2002b).

Figure 61. Mature flower head of the common reed (Phragmites australis) Photo credit: (Kaufman & Kaufman 2007).

Common reed survives in stagnant and poorly aerated waters due to the presence of air spaces in the roots above ground and can tolerate high salinity and a wide pH range of 4.8 through 8.2 (Robinson, 2002b). Common reed blocks the sunlight to organisms below in two ways: the plant can grow in tall, dense stands, and stalks break at midpoint but do not fall to the ground (Kaufman & Kaufman 2007). Common reed can form very dense monospecific stands that may exclude native vegetation and not provide ideal shelter or food for wildlife and reduce biodiversity, which is what happens when a dense stand blocks the path of turtles trying to lay eggs in the sandy shore area (Robinson, 2002b; Kaufman & Kaufman 2007). Water flow can be reduced from common reed stems, which can trap sediments, causing the water body to become increasingly shallow therefore leading to the flood retention of the wetland is decreased (Robinson, 2002b).

7.2 Web of Science Database Search Results

Web of Science Core Collection is a database search tool utilized to see what scholarly peer-reviewed research existed on hydro-raking. Web of Science is an online subscription-based scientific citation indexing service maintained by Thomson Reuters. Web of Science Core Collection, has more than 12,000 international journals, scholarly books and conference proceedings representing the main fields of science, social sciences, arts and humanities (Thomson Reuters, 2014). Thomson Reuters focuses on journals that publish full text in English, so that is a considering factor is the total number of journals that appear in my data table (Thomson Reuters, 2014).The web of science perimeters were run at Worcester Polytechnic Institute. Running the Web of Science Core Collection perimeters in November of 2015, the timeframe box was set to all (1980- 2015). All the citation index boxes were checked for selection under Web of Science core collection: citation indexes, to attempt to yield more search results. The boxes were: science citation index expanded (SCI-EXPANDED) 1980-present, social sciences index (SSCI) 1980-present, arts and humanities citation index (A&HCI) 1980-present, conference proceedings citation index-science (CPCI-S) 1990-present, conference proceedings citation index-social science and humanities (CPCI-SSH) 1990 to present and emerging sources citation index (ESCI) 2015 to present.

Databases are searched through two criteria: title or topic. Here are some of the results of the various searches in Table 7. Highlighted at the top of the table, are various hydro-raking spellings and the results were none or one research piece found. As demonstrated by this data table, hydro-raking in various spellings resulted in little published research. The titles searches "hydro-raking" and "hydroraking" revealed no results, with the topic search "hydroraking" also revealing none, and the topic search for "hydro raking" yielded one result. Pond AND plant AND invasive in the title search brought 91 results. Titles with the words pond AND Massachusetts displayed 181 results along with 266 results for lake AND Massachusetts in the title.

Table 7.

Web of Science Search Results		
Search term: Title	**Search term: Topic**	**Number of Results**
	hydroraking	none
	hydro raking	1
hydro-raking		none
hydro raking		none
pond		10,624
	freshwater management	5,312
freshwater AND management		164
pond AND management		206
lake AND management		970
pond AND plant		209
pond AND plant AND invasive		2
	pond AND plant AND invasive	91
pond AND conservation		91
pond AND Massachusetts		33
	pond AND Massachusetts	181
	Lake AND Massachusetts	266
Lake AND Massachusetts		14
	freshwater AND maintenance	771
freshwater AND maintenance		20

Search results from Web of Science showing the search results of all databases. Table credit: Danielle Desmarais

7.3 Letter of Determination from the Institutional Review Board (IRB)

This emailed letter serves as proof of approval from the Clark University IRB for the interviews conducted in this thesis.

RE: Exemption due tomorrow?-Plant and pond questions-Desmarais

From: **Human Subjects Research** (humansubjects@clarku.edu)
Sent: Tue 2/09/16 9:17 AM
To: Desmarais, Danielle (DDesmarais@clarku.edu)

Hi Danielle,

I heard back from the IRB Chair. He has determined that you will need permission from the companies to ask scientific fact questions, but do not need IRB approval. You do not need to submit a proposal for IRB review. The email serves as evidence of that decision.

Best of luck with the research,

Diane