

REPORT

October 2018 - FINAL REPORT

WATERVLIET, NY

City of Watervliet

Normanskill Relicensing – Water Chestnut Control Study



TABLE OF CONTENTS

	Page
TABLE OF CONTENTS	i
LIST OF FIGURES.....	ii
LIST OF APPENDICES.....	ii
EXECUTIVE SUMMARY	ES
1.0 BACKGROUND	1-1
1.1 Taxonomy	1-1
1.2 History	1-1
1.3 Biology.....	1-1
1.3.1 Anatomy	1-1
1.3.2 Life Cycle and Habitat	1-1
1.3.3 Natural Predators	1-2
1.3.4 Dispersal	1-3
1.4 Impacts.....	1-3
1.4.1 Ecological Impacts.....	1-3
2.0 EXISTING CONDITIONS AT THE WATERVLIET RESERVOIR	2-1
2.1 Water Chestnut Distribution in the Watervliet Reservoir	2-1
2.1.1 Current Distribution of Water Chestnut	2-1
2.1.2 Management History	2-1
2.1.3 Impacts to the Watervliet Reservoir.....	2-1
2.1.4 Native Plants.....	2-1
2.2 Other Concerns at the Watervliet Reservoir	2-3
2.2.1 Milfoil	2-3
2.2.2 Algal Blooms	2-4
3.0 WATER CHESTNUT MANAGEMENT	3-1
3.1 Management Options.....	3-1
3.1.1 Hand-pulling	3-1
3.1.2 Mechanical Harvesting and Hydroraking	3-2
3.1.3 Drawdowns	3-3
3.1.4 Hydraulic Dredging	3-3
3.1.5 Benthic Barriers	3-4
3.1.6 Herbicide Treatment.....	3-4
3.1.7 Biological Control	3-5
4.0 WATER CHESTNUT MANAGEMENT AT THE WATERVLIET RESERVOIR.....	4-1
4.1 Recommendations	4-1
4.1.1 Mechanical Harvesting.....	4-6
4.1.2 Herbicide Application	4-1

4.1.3 Hand-pulling 4-2

4.1.4 Estimated Overall Cost..... 4-2

4.1.5 Long-Term Considerations..... 4-3

4.2 Permitting 4-4

5.0 REFERENCES 5-1

LIST OF FIGURES

Figure 1..... *Trapa natans* Distribution and Wetland Boundaries in the Watervliet Reservoir

Figure 2..... *Trapa natans* at the Watervliet Reservoir

Figure 3..... *T. natans* blanketing a large area of the Watervliet Reservoir

Figure 4..... *L. minor* growing at the Watervliet Reservoir

Figure 5..... *N. odorata* growing along the banks of the Watervliet Reservoir

Figure 6..... *P. foliosus* at the Watervliet Reservoir

Figure 7..... *P. nodosus* at the Watervliet Reservoir

Figure 8..... *U. macroriza* at the Watervliet Reservoir

Figure 9..... *M. spicatum* growing near *T. natans* at the Watervliet Reservoir

Figure 10..... Hand-pulling to remove *T. natans*

Figure 11..... Mechanical harvesting

Figure 12..... *S. latifolia* growing near the banks of the Watervliet Reservoir

LIST OF APPENDICES

Appendix A Mapping

Appendix B Reference Materials

EXECUTIVE SUMMARY

The Watervliet Reservoir has become infested with invasive water chestnut (*Trapa natans*), resulting in a shift in species composition that is negatively impacting the native ecology of the reservoir. The reservoir contains 420 acres, 169 of which are infested with *T. natans* (refer to Figure 1). Water chestnut outcompetes a variety of other aquatic vegetation and creates nearly impenetrable mats across wide areas of water (Pfungsten et al, 2018). These mats can be as much as a foot thick, and reduce passage of light into the water, which in turn reduces dissolved oxygen levels and influences nutrient cycling (Pfungsten et al. 2018; Caraco & Cole, 2002). The thick mats offer little in terms of waterfowl habitat, can impede the use of small boats, and the sharp spines on the seed pods can cause injury when stepped on. Water chestnuts provide ideal habitat breeding conditions for mosquitos (CABI, 2018). Ultimately, *T. natans* detrimentally impact water quality and fisheries in the reservoir and downstream resources. They can also result in increased water treatment costs in areas used for municipal potable water supply (CABI, 2018). Numerous control methods exist for managing water chestnut, with variations in cost, effectiveness, and impact to other plants and fish species and overall ecosystem health. This document provides an overview of *T. natans* and options for mitigation and management.

Study Goals and Objectives

The goal of the Watervliet Reservoir Water Chestnut Control Study is to eradicate the invasive population of *T. natans*, with the purpose of improving and maintaining reservoir capacity, water quality, restoring aquatic habitats, and preserving fisheries. The objectives of this study are to create a comprehensive strategy for management options and techniques, monitoring, and control methods to remove the current population of water chestnut and prevent subsequent infestations in the Watervliet Reservoir.

Action Plan

A combination of methods are recommended to remove invasive populations of *T. natans*, including mechanical harvesting, hand-pulling, and herbicide treatment. Factors such as depth of water, distribution of *T. natans*, overall estimated costs, and impacts to the reservoir informed the selection of recommended management options.

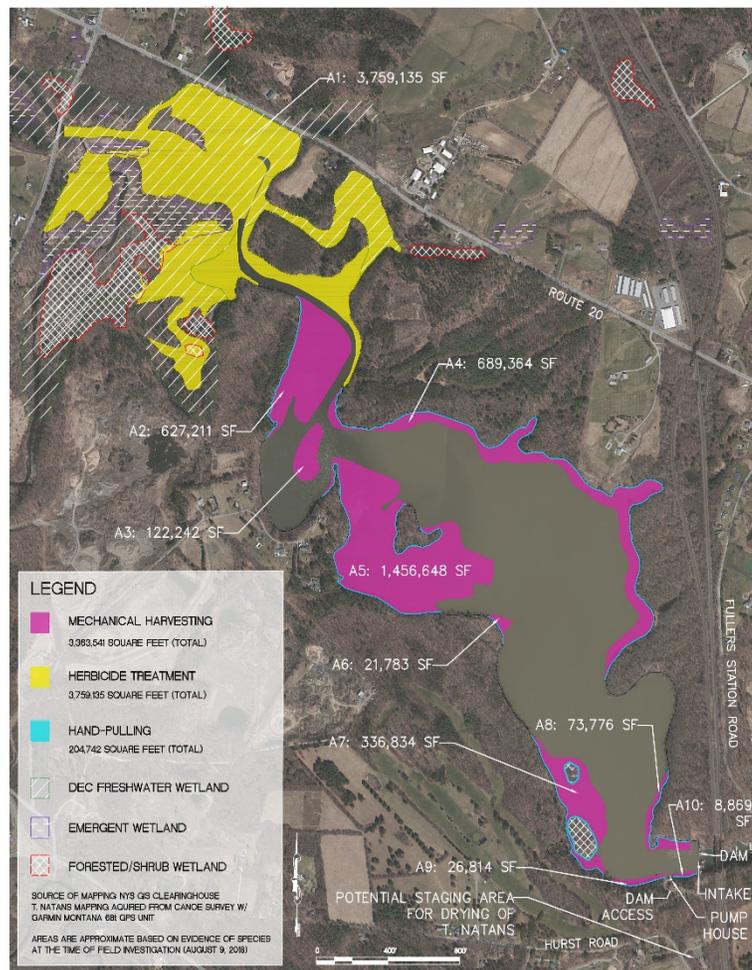


Figure 1: *Trapa natans* Distribution and Wetland Boundaries in the Watervliet Reservoir.

Overall Cost

The approximate costs for treating *T. natans* at the Watervliet Reservoir are \$5,000 for hand-pulling, \$193,382 for mechanical harvesting, and \$69,600 for herbicide treatment. Based on the suggested methods detailed above, and the total area for each management strategy (refer to Appendix A), the overall cost for the initial treatment of *T. natans* in the Watervliet Reservoir would be approximately \$267,982. Costs will decrease over time as populations of *T. natans* decrease. Applying for grants can help minimize overall costs.

Table ES-1 Management Options & Recommendations

Management Options at the Watervliet Reservoir		
Management Option	Recommendation	Cost per acre (Approximate)
Hand-pulling	Recommended for use in small areas of infestation and along the banks in shallow waters. May be used as a follow-up treatment to mechanical harvesting.	\$1,000/acre (assuming a crew of 2 people)
Mechanical Harvesting	Recommended for use at the Watervliet Reservoir at locations where water depths are between 6 and 15 feet.	\$1,233/acre \$3,500 mobilization fee (one-time) \$1,223 disposal fee/acre
Hydroraking	Not recommended for use at the Watervliet Reservoir due to slow pace and need for extensive unloading sites.	\$10,000/acre
Drawdowns	Not recommended for use at the Watervliet Reservoir, due to unpredictability of recharge rates for drinking water supplies.	Pump & siphon materials and appurtenances vary. Labor, fuel, and monitoring costs vary.
Hydraulic Dredging	Not recommended for use at the Watervliet Reservoir due to prohibitive costs and lack of accurate bathymetry.	\$121,005/acre, not including mobilization or disposal fees (Based on an estimate of \$15/cubic yard)
Benthic Barriers	Not recommended for use at the Watervliet Reservoir – not suitable for large areas.	\$45,000-\$65,000/acre installed
Herbicide Treatment	Recommended for use at the northern portion of the Watervliet Reservoir which are over a quarter mile from the reservoir intake.	\$800/acre
Biological Controls	Not recommended at this time. Consider for future management when biological controls are approved for use in New York State.	Costs not available at this time

1.0 BACKGROUND

1.1 Taxonomy

Trapa natans (see Figure 2) is a member of the genus *Trapa* in the *Lythraceae* family. This study focuses on *Trapa natans*, which is an invasive species in North America (OARS, 2017). This aquatic macrophyte is distributed throughout Europe, southern Sweden, European Russia, Asia, and Africa. *T. natans* is also considered invasive in Australia (Gupta & Beentje, 2017).

1.2 History

Trapa natans is indigenous to tropical and temperate regions of Africa and Eurasia. Water chestnut was introduced to North America in the 1870s. Historical records show the plant was cultivated in 1874 at the Asa Gray Botanical Garden in Cambridge, Massachusetts.

From there *T. natans* was introduced to several ponds in Cambridge, including Fresh Pond, by a gardener from the botanical garden. It was intended to be an ornamental species, and its potential to become an invasive species was not recognized at the time, (OARS, 2017).

T. natans was independently introduced to upstate New York in 1886 when plants were placed in what is now known as Collins Lake in Scotia, NY. From there, water chestnut spread into the Mohawk and Hudson Rivers, and from eastern Massachusetts across the region. It was only in 1945 that *T. natans* was noted to have suddenly grown to undesirable levels in the Concord and Sudbury Rivers (OARS, 2017). Because there are no native species that feed on water chestnut populations in North America, it continues to proliferate unchecked (New York Invasive Species Clearinghouse, 2016). Accidental introductions of this plant to water bodies continue to spread it along waterways. Efforts to control *T. natans* have been in effect for several decades. Some have attributed the boom of water chestnut to an increase in alkaline sewage waste, observed as an increase of soluble nitrates in water bodies (OARS, 2017).

1.3 Biology

1.3.1 Anatomy

This floating aquatic plant is made up of leaves which float on the surface of the water and form rosettes by late July, ranging from 10" to 15" in diameter. Small white flowers can be found in the axils of the leaves. These leaves are triangular, alternate, and have toothed edges. The upper surface of the leaves are glossy, while the lower surface is covered with soft hairs. Rosettes surround a central stem and are kept afloat by petioles containing air bladders, while woody nuts develop beneath the rosettes. Each nut has four sharp barbs which can puncture the soles of shoes if stepped on (OARS, 2017; Swearingen & Barger, 2016).

1.3.2 Life Cycle and Habitat

Water chestnut is an annual; it grows from a nut each year and dies back by the end of the growing season. Generally, nuts produced in the growing season sink to the bottom of the water body and overwinter in the soft sediment, emerging the following spring. Those that do not germinate contribute



Figure 2: *Trapa natans*

to a seed bank. These seeds are viable for 10 to 15 years and require a period of dormancy at temperatures below 8°C in order to germinate. Germination occurs in spring when water temperatures reach a range of 10°C to 24°C. Sources differ on the amount of sunlight needed by *T. natans* – some sources indicate a tolerance of partial shade while others state that the plant requires full sun (OARS, 2017).

Seeds germinate in May, and by early to mid-June the first flat leaves reach the water and begin forming a floating rosette. Rosettes and secondary branches appear when the first leaves reach the water and continue to form until around the end of July. As the stem elongates, new leaves are produced from the meristem. From late June to September, inconspicuous small white flowers with four petals can be found in the axils of floating leaves (one flower per axil) (Invasive Plant Atlas of New England, 2018). Pollination occurs via insects, cross-pollination, or self-pollination. Once the plant is fertilized, the peduncle containing the flower bends down into the water, and a green nut begins to form. Each rosette produces between 10 and 15 nuts; the plant continues to fruit and bloom into the fall. The fruits fall off when the seeds reach maturity, usually in early August. They sink down and lodge in the sediment, contributing to the seed bank. The outer fruit layer disintegrates, leaving a black, woody, hard nut with sharp spikes. Rosettes separated from roots can still produce nuts in limited capacities. If the main stem of *T. natans* is broken early in the summer, it can still branch and form new rosettes by late summer (OARS, 2017).

T. natans prefers pH levels between 6.7-8.2 and tolerates calcium carbonate, alkalinity levels of 12-128 mg/L, and salinity of up to 0.1%. (Department of Conservation and Recreation, 2017). This plant thrives in nutrient-rich, slow moving fresh water of lakes, ponds, and rivers with muddy bottoms, and can survive in tidal freshwater marshes. The stems are weak, and the plant is lightly rooted in the sediment by the empty nut hull and thin roots. *T. natans* rarely grows where there is a swift current, or where the substrate has low organic matter. Water chestnut can grow in depths of up to 5 meters but is most commonly found in water depths of about 2 meters.

Water chestnut in high-density plots (over 100 rosettes per square meter), are less productive and shorter-lived than *T. natans* found in low-density plots (5 to 15 rosettes per square meter). Plants found in low-density plots can be much more productive and result in 5 times as many rosettes as plants in high-density plots. Furthermore, rosettes of high-density plants have been seen to experience continuous mortality, while low-density plants have been observed with almost no mortality until September, when the whole plant senesced (OARS, 2017).

1.3.3 Natural Predators

The water chestnut has several natural enemies that could be potential biological controls for *T. natans* in North America. However, because these species are not native to North America, research must be carried out to determine if these species could have a detrimental effect on species other than *T. natans* in North America before it they could be considered a viable option for water chestnut control. These species include insects, mollusks, fungi, and other pathogens in Asia, as well as seven insects from Western Europe. Investigations have shown the beetle *Galerucella birmanica*, to be the most damaging to *T. natans* and the most promising for biological control (New York Invasive Species Clearinghouse, 2016). Research is currently being conducted on the effects of *G. birmanica* on *T. natans* at the Department of Natural Resources at Cornell University. *G. birmanica* is host-specific to *T. natans*, which make it a promising biological control candidate. Furthermore, studies have indicated that *G. birmanica* has a preference for the leaves of water chestnut even after the plant is almost

entirely defoliated. Researchers hope to have USDA approval to release *G. birmanica* in the United States in the near future (OARS, 2017).

1.3.4 Dispersal

Dispersal of water chestnut in New England has been primarily via human activity. Eleven states, including New York, have listed *T. natans* as an invasive, nuisance or noxious species, but this species is not yet listed at the federal level (OARS, 2017). Forty-three counties in New York have reported infestations of *T. natans*, with many reported in or near the Hudson River (New York State Department of Environmental Conservation, 2018). The nuts of this invasive plant continue to be distributed unintentionally when caught in nets, construction equipment, boats, and excavated sediments. The nuts of water chestnut are further spread when they are washed downstream during storm events. Downstream propagation occurs when broken fragments and rosettes float into new areas with appropriate growing conditions (OARS, 2017).

1.4 Impacts

1.4.1 Ecological Impacts

Floating mats of water chestnut are capable of covering the entire surface of the water (see Figure 3), intercepting more than 95% of the sunlight (OARS, 2017). This results in *T. natans* out-competing virtually all other species, as it shades out other submerged aquatic plants and can create large diurnal changes in the dissolved oxygen concentration of the water column (New York Invasive Species Clearinghouse, 2016). One study of a dense bed of water chestnut in a tidal section of the Hudson River reported dissolved oxygen values below 2.5 mg/L occurring up to 40% of the time in August and varying with tidal cycle. Despite anoxic conditions, impacts of dense *T. natans* populations on fish and macroinvertebrate communities are varied.

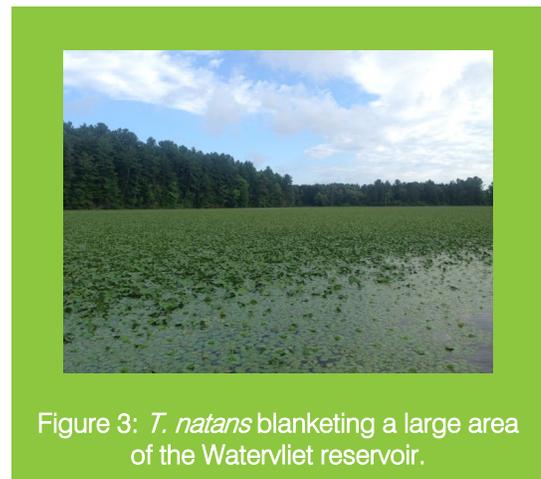


Figure 3: *T. natans* blanketing a large area of the Watervliet reservoir.

Some species of fish inhabit water chestnut beds. Species found to be in the greatest abundance are those with a higher tolerance for adverse conditions. Studies have reported that fish abundance in water chestnut beds in the Hudson was lower than in other vegetation types. *T. natans* has low food value for wildlife, which may contribute to shifts in fish abundance (Capital District Regional Planning Commission, 2003). Most of the macroinvertebrate and fish studies in North America have been conducted on tidal sections of the Hudson River; additional studies in non-tidal rivers must also be investigated, as water bodies not being flushed by tidal action can have longer periods of depleted oxygen conditions.

Large beds of *T. natans* result in deposition of sediments from reduced current velocity, which results in temporary water purification. Water chestnut accumulates cadmium, selenium, and copper in its leaves, nuts, shoots, and roots (OARS, 2017).

2.0 EXISTING CONDITIONS AT THE WATERVLIED RESERVOIR

2.1 Water Chestnut Distribution in the Watervliet Reservoir

2.1.1 Current Distribution of Water Chestnut

Based on the growth cycle of *T. natans*, early August is an ideal time of year in this region to observe the extent of water chestnut as it is fully fledged at the surface of the water. On August 9, 2018 the Weston & Sampson study team measured the extent of *T. natans* at the Watervliet Reservoir. This was done by canoeing the outer extent of all visible areas at the water surface. It was determined that *T. natans* covered approximately 169 acres (40%) of the Watervliet Reservoir, consisting of ten distinct areas (refer to Appendix A: Mapping). The largest areas were located at the northernmost end of the reservoir where the water depths appear to consistently support ideal growing conditions. Areas of the southwestern banks were relatively clear of *T. natans* and any growth was fairly limited to the banks and expanded outward, if at all.

2.1.2 Management History

Water chestnut has long been a problem at the Watervliet Reservoir. In the application for the current license in 1981, a major infestation of *T. natans* covering 60 to 80 acres was documented. Water chestnut removal was performed regularly at the Watervliet Reservoir for several years, but management operations were suspended in 2010. Previous removal efforts were performed by Watervliet staff with a city-owned boat. Removal was conducted continuously throughout the summer months, and accumulated vegetative material was stored in a bay in the reservoir. The northern portion of the reservoir was not managed for *T. natans*, due to difficulty of access and sedimentation concerns. The presence of discarded *T. natans* and sustained presence of the species at the northern portion of the reservoir likely contributed to low removal success rates. Since operations ceased, a steady re-establishment of *T. natans* has occurred over the subsequent years (Capital District Regional Planning Commission, 2003).

2.1.3 Impacts to the Watervliet Reservoir

As *T. natans* decomposes, detritus buildup lowers the retention capacity of the reservoir over time and necessitates additional filtering of these particles from the water. This increases the overall treatment costs for the town and city. (Capital District Regional Planning Commission, 2003). Without appropriate management, *T. natans* will continue to thrive at the Watervliet Reservoir.

2.1.4 Native Plants

Special care should be taken to avoid negatively impacting native plants at the reservoir wherever possible. A full inventory of plant species was not performed for this study. The following species were noted during the field inventory in July of 2018, but should not be considered a comprehensive list:

Lemna minor – Common Duckweed: Belonging to a group of plants known as free-floaters, *L. minor* (see Figure 4) reproduces by budding new leaves attached to the parent plant. Each small greenish-yellow leaf has a single root descending below the water. Very commonly found in eutrophic waters, *L. minor* requires adequate water nutrients to sustain its growth. An important dietary resource for wildlife, *L. minor* can provide up to 90% of the nutritional requirements for ducks and geese and is also an important source of food for muskrat, beaver, and fish. Dense clusters of the plant provide shade for fish and minimize mosquito breeding territory (Minnesota Wildflowers, 2018; Johnson, R.L.).



Figure 4: *L. minor* growing at the Watervliet Reservoir.

Nymphaea odorata – White Water Lily: This commonly found aquatic plant is easily identified by its characteristic round leaves and white, lotus-shaped flower (see Figure 5). Leaves can grow between 4” to 12” with veins radiating from a central axis. Fish enjoy the shade provided by the wide leaves of *N. odorata*, and waterfowl commonly eat the seeds. Rhizomes may be grazed upon by beaver, porcupine, muskrat, and deer (Minnesota Wildflowers, 2018; Johnson, R.L.).



Figure 5: *N.odorata* growing along the banks of the Watervliet Reservoir.

Potamogeton foliosus – Leafy Pondweed: Found in a variety of habitats, *P. foliosus* (see Figure 6) prefers soft sediments but is also tolerant of eutrophic conditions. Leaves are narrow, up to 3” long, and extend from the stem in opposite pairs. The seeds grow in clusters of small flat nutlets and have an identifiable ridge on each seed. *P. foliosus* is an important source of forage for several species of ducks, and the fruits are grazed upon by muskrat, deer, and beaver. Young fish rely upon the plant for cover (Minnesota Wildflowers, 2018; Johnson, R.L.).



Figure 6: *P. foliosus* at the Watervliet Reservoir.

Potamogeton nodosus – Long-leaf Pondweed: More commonly found in flowing water than in lakes or ponds, *P. nodosus* (see Figure 7) can grow in a variety of sediments. It thrives in shady conditions and tolerates turbid water. Stems grow up to 6 feet with leaf stalks in alternate formation. Leaves found on the surface of the water may grow from 3" to up to 10" long. This macrophyte goes dormant in the fall and overwinters as a rhizome. Geese, ducks, fish, and invertebrates forage on *P. nodosus*. Beaver, muskrat, and deer will graze upon its fruits (Minnesota Wildflowers, 2018; Johnson, R.L.).



Figure 7: *P. nodosus* at the Watervliet Reservoir.

Utricularia macrorhiza – Common Bladderwort: A commonly found, often overlooked carnivorous species, *U. vulgaris* (see Figure 8) fills up with air to keep it afloat during the bloom period and re-submerges into the water during dormancy. Yellow flowers resembling snapdragons grow up to 8" above the water line. The flower is globular in shape, with fine red veins on the lower lip. *U. vulgaris* has no true roots, instead, the plant floats on a central stalk with alternating ¾" to 2" long leaves. The flowers are host to a variety of algae, bacteria, and diatoms, and seem to provide habitat for a variety of microorganisms (Minnesota Wildflowers, 2018).



Figure 8: *U. macrorhiza* at the Watervliet Reservoir.

2.2 Other Concerns at the Watervliet Reservoir

2.2.1 Milfoil

Eurasian milfoil, *Myriophyllum spicatum* (see Figure 9) was observed throughout the Watervliet Reservoir, particularly in locations where *T. natans* was found in abundance. This aquatic invader appears to grow in a symbiotically with *T.natans* - rarely extending beyond the plants coverage of the Watervliet Reservoir.

M. spicatum thrives in conditions similar to those favored by *T. natans*, in water depths ranging from 3.2 to 13 feet. *M. spicatum* grows in dense mats and reduces the amount of sunlight able to penetrate the water's surface early in the growing season, contributing to declines in native macrophytes. Fish and macroinvertebrates populations are also found to be negatively impacted by the presence of *M. spicatum*.



Figure 9: *M. spicatum* growing near *T. natans* at the Watervliet Reservoir.

Mechanical harvesting is frequently used to control *M. spicatum* and may be combined with the removal of *T. natans*. Special care must be used to ensure fragments of *M. spicatum* do not float away from the harvester, as they will regrow into new plants. Harvested materials must be incinerated, buried, or composted off site, away from water resources to prevent the regrowth and spread of this species to other water bodies. Promising biological controls include the release of the naturalized pyralid moth *Acentria ephemeralla*; however, further research is needed to ensure the release of the moth will not detrimentally impact native populations (New York Invasive Species Information, 2018).

2.2.2 Algal Blooms

Algal blooms occur when colonies of algae grow rapidly to form very large colonies. Blooms generally occur in areas with nutrient buildups - nitrogen, phosphorus, and carbon are the three principle nutrients that contribute to algal blooms. They accumulate via runoff from areas that use fertilizers and pesticides, such as lawns and farmlands. Algal blooms create dead zones in the water by outcompeting other aquatic vegetation for sunlight and nutrients (National Ocean Service, 2018). No algal blooms were observed in the Watervliet Reservoir at this time.

3.0 WATER CHESTNUT MANAGEMENT

3.1 Management Options

There are a variety of methods for managing *T. natans*, including hand-pulling, mechanical harvesting, hydroraking, drawdowns, hydraulic dredging, benthic barriers, and herbicide treatment, and biological control.

3.1.1 Hand-pulling

Since water chestnut is rooted lightly in the sediment, the entire plant can be easily pulled by hand. Ideally, this should be done when rosettes first appear in mid-June to early July (New York Department of Environmental Conservation, 2018). This management method is commonly performed from small boats (i.e. kayaks, canoes), and is ideal for shallow water (see Figure 10). All parts of the plant should be removed from the site and properly disposed of by incineration or composting. Hand-pulling allows for highly selective control, limited impact to non-target species, and removes plants from the water column (OARS, 2017). Repeated annual hand-pulling of immature rosettes can be an effective means of population control if performed before seed drop (Lake Champlain Basin Program, 2015). For large, dense infestations, this method is not recommended as it is very labor intensive.



Figure 10: Hand-pulling to remove *T. natans*.¹

Methods –

- Obtain proper permitting prior to commencement of the project.
- Appropriately train all personnel on boating safety, plant identification, harvesting techniques, and proper weed disposal. Provide safety equipment.
- Identify boundaries of the work area, and the distribution of water chestnut before treatment.
- Identify access points, disposal site, and disposal method.
- Harvest the entire stem, leaf rosettes, and seed husk. Harvesting must occur before August, when mature seeds begin to drop. Handle rosettes with care to avoid dropping parts of the plant back into the water, especially the immature nuts.
- Weed Disposal: Weeds may be piled near the harvest site and allowed to dry in order to kill the plants and reduce weight and volume of the pile. Refer to Appendix A for recommended location for storing harvested *T. natans* during the drying process. Allow plants to dry between a few days to a few weeks before final disposal. Make sure the pile is kept away from the edge of the water so that no parts of the plant are washed back into the water body. Bring dried water chestnut to a location that can properly incinerate them. If using the composting method, place piles so that the odor is minimized, and plant material will not drift. Composting is generally the most cost-effective disposal technique, if a suitable site is available.
- Use multiple pulls and monitoring to ensure eradication.
(OARS, 2017)

Anticipated Cost: \$1,000.00/acre (with a crew of two people) (SOLitude Lake Management, 2018).

¹Source: <http://www.lakecleanup.com>

3.1.2 Mechanical Harvesting and Hydroraking

Mechanical harvesters cut off *T. natans* rosettes and can remove 1.5 acres of the plant per day. Generally, harvesters need 6 feet of water depth at a minimum. It can be difficult to get the harvester into the target water body, so a large access area (refer to Appendix A) and/or a crane may be required to place equipment and remove water chestnut, increasing overall costs. A second cutting may be necessary later in the season, as *T. natans* may resprout from cut stems.

Hydroraking uproots the entire plant, debris and sediment. A skilled technician can minimize the amount of sediment that is stirred up during the harvesting process. The hydrorake itself is essentially a floating barge supporting a piece of machinery that functions as an industrial-scale rake. Hydrorakes are appropriate for very shallow water (as little as 1.0 to 15 feet of depth) and can remove vegetation up to 10 feet of depth. Weeds must be deposited either on a barge or on-shore, as hydrorakes do not have the capacity to store removed plants (OARS, 2017).

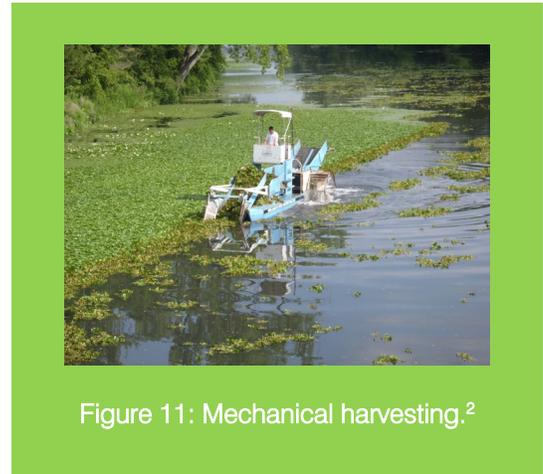


Figure 11: Mechanical harvesting.²

Mechanical harvesting and hydro-raking can remove large, dense infestations of water chestnut (see Figure 11), and can also reduce milfoil populations. However, fragmentation is a concern as it may spread other invasives or impact other aquatic organisms (OARS, 2017). Mechanical harvesting is recommended at specified areas in the reservoir (refer to Appendix A). SOLitude Lake Management,³ a water management company that specializes in the development and execution of customized management programs, noted that they would not recommend a hydrorake for this site, due to the slow pace, high expense, and constant need to unload plant material.

Methods –

- Obtain appropriate permitting prior to commencement.
- Identify boundaries of the work area, and the distribution of water chestnut before treatment.
- Identify access points, disposal site, and disposal method (e.g. incineration, composting). Refer to Appendix A for recommended location for storing harvested *T. natans* during the drying process. Refer to weed disposal guidelines in the hand-pulling section.
- Develop a harvester maintenance plan.
- Establish and enact methods for limiting turbidity when possible.
- Create a fragment control plan for non-target invasives that are likely to be spread by fragmentation (e.g. milfoil).
- Timing: Harvest must be performed before nuts mature.
- Incorporate hand-pulling efforts with mechanical harvesting to manage areas of mixed native and invasive plant species and for edge areas.
- Avoid harvesting in areas of sensitive habitat.
- Monitor collection of non-target fauna.
- Repeat as necessary and monitor to ensure eradication.
(OARS, 2017)

²Source: <https://upload.wikimedia.org>

³SOLitude Lake Management was contacted regarding cost and methods of treating and removing *T. natans* from the Watervliet Reservoir.

Anticipated Costs: (SOLitude Lake Management, 2018).

Mechanical Harvester

\$1,233.00/acre

\$3,500.00 mobilization fee

\$1,233.00 disposal fee (per acre)

Hydroraking

\$10,000.00/acre

3.1.3 Drawdowns

There are two options for drawdowns – via pump or via siphon. Pump drawdown transports water over dam crests at large flow rates and at most lift heights. Pumps require a reliable power source and adequate access to the dam. Siphon drawdowns generally require less equipment and material, and are used in areas where access is more difficult. Several small siphons may be placed rather than one large system such as a pump (Morrison Maierle, Inc., 2012). Drawdowns for water chestnut management are usually conducted in the summer - winter drawdowns would allow the seeds to survive in the sediment. Both timing and duration of drawdowns are essential to successfully eradicate *T. natans*. Summer drawdowns should be conducted in late May or early June when the water chestnut has sprouted. Water levels should be drawn down far enough to dry the sediment and kill the water chestnut. This method can be cost effective but can also have wide-spread impacts on other species. Milfoil would also be impacted by drawdowns. The effectiveness of drawdowns has not been verified or adequately studied (OARS, 2017). Because the reservoir is a water supply source, may not be able to be recharged after drawdowns, and would result in a high degree of disturbance to other species, this is not a viable option for control of water chestnut at the Watervliet Reservoir.

Anticipated Cost: Unknown. Pump & siphon materials and appurtenances vary. Labor, fuel, and monitoring costs vary.

3.1.4 Hydraulic Dredging

Hydraulic dredging allows for the removal of sediment, which halts nutrient cycling and reduces the *T. natans* seed bank. It is used in water bodies that do not rapidly re-accumulate sediment. Water depth is also increased by dredging, as the soft sediments are removed, along with rooted aquatic plants. Hydraulic dredging fluidizes sediment, after which the material is pumped into a handling location. Fluidizing occurs when the dredge head mechanically agitates the sediment, drawing the slurry through a suction pipe. Hydraulic dredging is an economical option when large volumes of sediment need to be removed (IRTC, 2014).

Eurasian milfoil may also be removed with this management option. The suction action may reduce the likelihood of fragments escaping into the water body. However, as with drawdowns, hydraulic dredging can be very disruptive, is non-selective, and alters water flows during the management process (OARS, 2017). This method is not recommended as there is not adequate information to accurately calculate reservoir depths, and preliminary estimated costs are prohibitive.

Anticipated Cost: \$121,005/acre (not including mobilization and disposal fees), based on an assumed 5' average depth and \$15/cubic yard (Hudson, 1998). Currently, there is not enough information available to calculate accurate cubic yardage of the Watervliet Reservoir.

3.1.5 Benthic Barriers

Benthic barriers are defined as a bottom cover or barrier placed on top of sediment to prevent the growth of rooted plants. Barriers can be made of gravel, sand, silt, clay, or sheets of polyethylene or other artificial materials. This method can be effective in small areas, where there is no significant water current or wave action. Benthic barriers result in complete elimination of rooted vegetation in the area, so any native species inhabiting the same areas as water chestnut would be impacted. Despite this high success rate, this is not an appropriate option for water chestnut control as the barriers are difficult and costly to install and maintain, are not suitable for large areas, and are non-selective (OARS, 2017).

Anticipated Cost: \$45,000.00-\$65,000.00/acre installed (SOLitude Lake Management, 2018).

3.1.6 Herbicide Treatment

Herbicide chemicals are absorbed into a plant's system or act on plant tissue to disrupt its metabolism. Herbicides can work quickly and be applied selectively, limiting damage to non-target species. Toxicity can be limited by reducing the concentration of herbicide and the timing of application. Negative impacts of using herbicides include the potential for adverse effects on aquatic fauna and non-target plant species, and increased oxygen demands resulting from decaying vegetation (OARS, 2017). Because the Watervliet Reservoir supplies drinking water, selected herbicides must be approved for use in potable water.

Clearcast has been shown to be an effective control measure for *T. natans*. It is approved at concentrations up to 500 ppb in potable water sources, to within a quarter mile of a functioning potable water intake. Clearcast may be applied within a quarter mile of an active potable water intake, but water concentrations of the herbicide may not exceed 50 ppb (SePRO, 2018).

Sonar is used primarily on milfoil (also found in the Watervliet Reservoir) but may only have suppressive effects on water chestnut. (SOLitude Lake Management, 2018). In New York State, Sonar PR is not permitted in waters less than two feet deep, except as permitted under FIFRA Section 24(c), Special Local Need registration. It may be applied at low rates within a quarter mile of a functioning potable water intake (SePRO, 2018).

Herbicide application is a viable treatment method for areas in the northern section of the reservoir, which are over half a mile from the intake point of the reservoir (refer to Appendix A). Herbicide treatment should be repeated in subsequent years as herbicides are not able to penetrate unsprouted seeds of *T. natans*. When seeds sprout the following spring, herbicide or hand-pulling should be conducted to remove new plants (SOLitude Lake Management, 2017; Cayuga County, 2018). With any chemical application, special care must be taken to minimize or avoid impacts to non-target species.

Methods –

- Obtain required permitting before starting project.
- Identify boundaries of the work area and the distribution of non-target species and water chestnut before treatment.
- Take inventory of aquatic organisms, paying special attention to sensitive species.
- Establish a treatment plan. Include areas to be treated, doses and concentrations, expected alteration of plant communities, notifications of water use restrictions, and follow-up activities after initial treatments.

- Identify waterbody and downstream water uses that could be impacted by herbicide treatment.
- Use a licensed applicator and appropriate equipment.
- Monitor and reapply as needed.
(OARS, 2017)

Anticipated Cost: \$800.00/acre (SOLitude Lake Management, 2018).

3.1.7 *Biological Control*

Biological control involves introducing predator species known to feed selectively on the target species. Biological controls work by damaging the target species, or limit their ability to compete or reproduce, or by killing the target outright. The beetle *Galerucella birmanica* has been indicated as a potential biological control for water chestnut. Research has been promising; *G. birmanica* is very likely a host-specific species and may be highly effective for long-term control of water chestnut. This method would also be cost effective. Since it involves the introduction of a non-native species, more research is needed to confirm that the introduced species would not adversely affect native ecology (OARS, 2017). At this time biological control is not a recommended option but should be considered for the future.

Anticipated Cost: Unknown. Awaiting research and approval.

4.0 WATER CHESTNUT MANAGEMENT AT THE WATERVLIET RESERVOIR

4.1 Recommendations

A combination of mechanical harvesting, hand-pulling, and herbicide treatments will be utilized to remove invasive populations of *T. natans*, beginning in the spring of the year that the project commences.

4.1.1 Mechanical Harvesting

For large areas of the reservoir with appropriate depths of 6 to 15 feet, control via mechanical harvesting is a recommended management strategy (refer to Appendix A). This method has had success on the Hudson River, in lakes in Cayuga County, and the Finger Lakes in New York. Despite concerns of fragmentation, non-selectivity in the harvesting process, and high cost, mechanical harvesting is the a viable management option for the Watervliet Reservoir. There are large areas of water chestnut in the Watervliet Reservoir which cannot be effectively managed by hand-pulling efforts alone, and in these instances removal via mechanical harvester will have much greater impacts.

The following cost estimates were provided by SOLitude Lake Management (<https://www.solitudelakemanagement.com>). Mechanical harvesting would be a costly endeavor for a project area of this size. A mechanical harvester would operate at an estimated speed of 1.5 acres per day in shallow water (18" to a few feet), and up to 2.5 acres per day if the water is relatively deep. The billing rate is \$1,233 per acre, in addition to a mobilization fee of \$3,500 when transporting the harvester. This includes cleaning of equipment, transport of the harvester to the site, and other logistic steps. The disposal fee is approximately the same as the on-water fee per acre (\$1,233 per acre). The overall cost for harvesting 77 acres of water chestnut, (refer to Appendix A) is approximately \$193,382.

Since the reservoir will require monitoring and most likely re-treatment over multiple years, the expense involved in mechanical management of *T. natans* is considerable. However, mechanical harvesters bill per acre, and a decrease in acreage of water chestnut in subsequent years will result in a decrease in cost until a minimal level of maintenance is needed to keep the reservoir free of invasives. As populations of *T. natans* decline, it may be suitable to utilize hand-pulling as the primary method of control for areas that have been reduced to small patches.

4.1.2 Herbicide Application

Herbicides may be effective in shallow areas where a mechanical harvester cannot operate (refer to Appendix A). Clearcast and Sonar are two herbicides that may be appropriate for the northern areas of the reservoir, where water is shallow and has high turbidity, making it difficult for mechanical harvesters to operate in (SOLitude Lake Management, 2018). Management of *T. natans* via herbicide will also reduce overall cost of water chestnut removal. Foliar applications of an approved herbicide may be a viable approach for water chestnut management.

Herbicide application is approximately one-third the cost of mechanical harvesting. Some chemicals have been approved for use in potable water. At a cost of approximately \$800 per acre, herbicide treatment would be far less expensive than mechanical harvesting but may not be feasible for all areas of the reservoir, such as those within a quarter mile of the reservoir intake (SOLitude Lake Management, 2018). The estimated overall cost for treating 87 acres of water chestnut with herbicide treatment in the recommended areas of the Watervliet Reservoir (refer to Appendix A) is approximately \$69,600. Herbicide application would be most appropriate in the northern portion of the reservoir,

(which is over a quarter mile from the intake point for the reservoir), where waters are relatively shallow and mechanical harvesting may not be practical. Herbicide application is also a more cost effective means of control.

An integrative approach may reduce cost, if initial herbicide treatment is followed by hand-pulling any plants that are not killed outright by the herbicide. Repeated herbicide treatments will be necessary in following years, as herbicides are not able to penetrate the unsprouted nuts of *T. natans*. Costs will be reduced each consecutive year as *T. natans* populations decline.

4.1.3 Hand-pulling

Hand-pulling is advised for areas with small infestations of *T. natans*, as well as areas that are along banks where mechanical harvesting is not possible, such as along the northeastern edge and along the southernmost bank. Appropriate locations for hand-pulling efforts in the Watervliet Reservoir are those areas within approximately 10 feet of banks where mechanical harvesting is the primary method of treatment (refer to Appendix A). As water depths may be too shallow for a mechanical harvester to operate within 10 feet of shorelines at the Watervliet Reservoir, it is recommended that these areas be treated via hand-pulling efforts. Hand-pulling is also recommended as a follow-up practice to mechanical harvesting and herbicide treatments to remove any displaced fragments or individual plants.

Assuming a crew of two people, the cost per acre of hand-pulling *T. natans* is approximately \$1,000 per acre. The estimated cost for hand-pulling 5 acres of water chestnut in the recommended areas of the Watervliet Reservoir (refer to Appendix A) is approximately \$5,000. If *T. natans* density decreases sufficiently in the larger areas, it may be appropriate in the future to begin managing these areas with hand-pulling as well. Any new patches of *T. natans* should be hand-pulled as soon as possible and monitored closely to prevent further growth. Mechanical harvesting should be followed by hand-pulling of any debris or small patches of water chestnut that were not removed by the harvester.

4.1.4 Estimated Overall Cost

Based on the suggested methods detailed above, and the total area for each management strategy (refer to Appendix A), the overall cost for the initial treatment of *T. natans* in the Watervliet Reservoir would be approximately \$267,982. Costs will decrease over time as *T. natans* population density decreases. Applying for grants can help minimize overall management costs.

Table 1: Overall Cost for Treating *T. natans*

Overall Cost for Treating <i>T. natans</i> at the Watervliet Reservoir		
Management Option	Acreage (Approximate)	Overall Cost (Approximate)
Mechanical Harvesting	87	\$193,382
Herbicide Treatment	77	\$69,600
Hand-pulling	5	\$5,000

Over time, the population of *T. natans* will be significantly reduced if management strategies are consistently implemented. Invasive aquatic macrophytes are not easily eradicated; therefore, proper planning and budgeting for ongoing management of *T. natans* and other invasive species at the Watervliet Reservoir must be conducted.

4.1.5 Long-Term Considerations

Hydraulic Dredging

Significant accumulations of sediment are occurring in the northern portion of the reservoir, in areas with extensive concentrations of *T. natans*. Suspended sediments are visible just below the water's surface, and the depth of water is greatly reduced. Eventually, hydraulic dredging may be necessary in this portion of the site, not only to remove invasive species but to restore the capacity of the reservoir. Biological factors and existing aquatic fish, wildlife, and botanical communities must be evaluated before any dredging measures can be considered. Proper relocation and storage of sediment must be coordinated with regulatory agencies and stakeholders.

Engineering controls may be used to minimize the negative impacts of sediment removal. Turbidity/silt curtains may be installed to prevent downstream contamination of the water body. Turbidity curtains are flexible sedimentation barriers suspended from floats at the water's surface to a depth of 1 to 2 feet above the sediment bed. Turbidity curtains may also be considered to control existing sediment accumulations at the northern portion of the reservoir.

Wetland Restoration

In the past, populations of *T. natans* were left at the northern portion of the reservoir. Concerns that the removal of *T. natans* may increase downstream sediment accumulation are likely valid; however, there is little hope of successful long-term eradication and management of *T. natans* if this significant population is left intact.

The northern portion of the reservoir is a matrix of freshwater forested, shrub, and emergent wetlands (refer to Appendix A). These wetlands are dominated by *T. natans*, with few remaining pockets of cattails (*Typha* spp.) and broadleaf arrowhead (*Sagittaria latifolia*) (see Figure 12). Restoration of native wetland plants may be a viable method to control sediment levels and filter runoff pollutants entering the reservoir via the Normans Kill, Bozen Kill and other tributaries. Existing wetland native plant resources were not evaluated for this study, but more extensive field investigations may yield valuable information about what types of plant species may be suitable for this site.

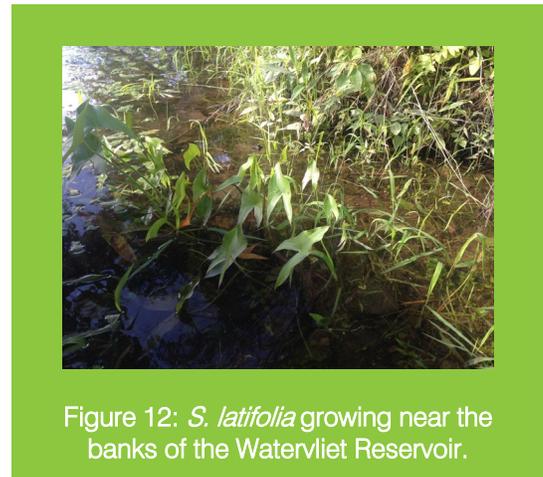


Figure 12: *S. latifolia* growing near the banks of the Watervliet Reservoir.

The above long-term management considerations have not been evaluated for costs, as these potential strategies extend beyond the scope of this project.

4.2 Permitting

The following permits will be required for the recommended management options listed below, and were informed by a conversation with the NYSDEC (Baker, N., personal communication, October 12, 2018).

NYS DEC Article 24: Freshwater Wetlands General Permit – requires permits for certain activities in and within 100 feet of the boundary of wetlands that are shown on freshwater regulatory maps and are 12.4 acres or larger.

NYS DEC Article 15: Protection of Waters General Permit – prevents undesirable activities on water bodies by establishing and enforcing regulations that preserve, protect, and enhance current and potential values of water resources, are consistent with the social and economic development of New York State, and that protect public welfare and health.

NYS DEC Notice of Intent (NOI) – a request for coverage under the State Pollutant Discharge Elimination System (SPDES) General Permit for Stormwater Discharges from Construction Activities.

NYS DEC Water Quality Certification – certifies that proposed activities will not violate water quality standards (NYS DEC, 2018).

USACE Section 404 – Mechanized land clearing, filling, grading, ditching, other excavation, and piling installation in waters of the U.S. require a U.S. Army Corps of Engineers Section 404 Permit before commencing construction.

USACE Section 10 – regulated activities (including work involving dredging, disposal of dredged material, placement/removal of structures, filling, or excavation), conducted below the Ordinary High Water elevation of navigable waters of the United States must be permitted/approved by the U.S. Army Corps of Engineers.

Hand-Pulling

NYS DEC Article 15: Protection of Waters General Permit
NYS DEC Article 24: Freshwater Wetlands General Permit

Mechanical Harvesting

NYS DEC Article 15: Protection of Waters General Permit
NYS DEC Article 24: Freshwater Wetlands General Permit

Herbicide Treatment

NYS DEC Article 15 Permit
NYC DEC Notice of Intent (NOI)

Hydraulic Dredging

NYS DEC Article 15: Protection of Waters General Permit
NYS DEC Article 24: Freshwater Wetlands General Permit
NYS DEC Water Quality Certification
USACE Section 404
USACE Section 10

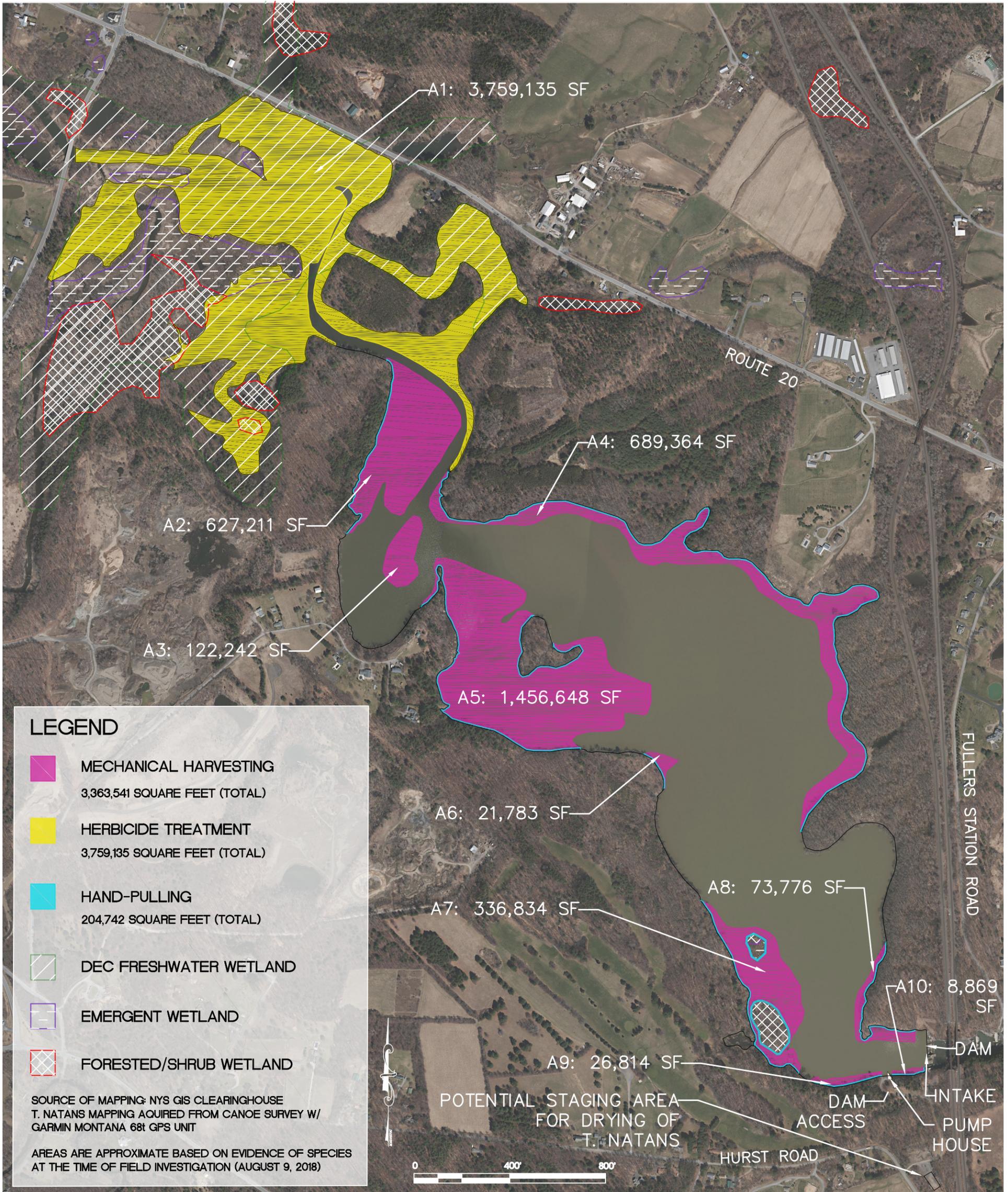
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APPENDIX A

Mapping



Trapa Natans Distribution and Wetland Boundaries in the Watervliet Reservoir

430 Acres

Weston & Sampson
 Weston & Sampson PE, LS, LA, P.C.
 1 Winner's Circle, Suite 130, Albany, NY
 518.463.4400
 www.westonandsampson.com

APPENDIX B

Reference Materials

WATER CHESTNUT MANAGEMENT GUIDANCE & FIVE-YEAR MANAGEMENT PLAN FOR THE SUDBURY, ASSABET, AND CONCORD RIVER WATERSHED

FEBRUARY 2017



FOR THE ASSABET SUDBURY & CONCORD RIVERS

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This work was prepared by OARS staff Suzanne Flint, Alison Field-Juma, and Jessica Furbeck and any errors or omissions are OARS’ responsibility. The Guidance is intended as a living document and we will endeavor to keep it up-to-date with the help of its readers and users.

EXECUTIVE SUMMARY

Lakes, ponds and rivers across the Commonwealth of Massachusetts are being choked by invasive water chestnut (*Trapa natans*). The result is degraded ecology and habitat value, loss of recreational value, and the high cost of control efforts. It can be challenging to figure out how to effectively manage water chestnut due to a lack of life-cycle information, diverse approaches to permitting, cost, and evolving control methods. This Guidance provides the latest research and management experience compiled for Conservation Commissions, communities, researchers and other stakeholders to use in developing effective management approaches and plans. The document reviews the control options and permitting needs for each option and provides model language for permitting under the Wetlands Protection Act for use by both applicants and Commissions. It includes a 5-year Water Chestnut Management Plan for the Sudbury, Assabet and Concord watershed, and extensive references. It is intended to be a living a document.

TABLE OF CONTENTS

ACKNOWLEDGEMENTSII

EXECUTIVE SUMMARYII

TABLES AND FIGURESIV

BACKGROUND 1

 Taxonomy 1

 History..... 1

 Biology..... 2

 Anatomy..... 2

 Life Cycle and Habitat 3

 Natural Enemies..... 8

 Dispersal 8

 Impacts 9

 Ecological Impacts..... 9

 Impacts on Recreation and Aesthetics 10

 Management Options 10

 Hand-Pulling 13

 Mechanical Harvesting and Hydrorake 14

 Drawdowns 16

 Dredging 16

 Benthic Barriers 17

 Herbicide Treatment 18

 Biological Control..... 20

 Funding 21

 Permitting for Control Efforts 21

 Legal Status..... 21

 Responsible Parties 21

 Permitting in Massachusetts 22

Model Permitting Language	27
WATER CHESTNUT IN THE SUDBURY, ASSABET, AND CONCORD WATERSHED.....	30
Distribution of Water Chestnut.....	30
Management History.....	30
WATER CHESTNUT MANAGEMENT PLAN	37
Goals	37
Action Plan.....	37
Objective 1. Establish a Watershed-Wide Water Chestnut Task Force.....	37
Objective 2: Establish Watershed-wide Monitoring & Reporting.....	37
Objective 3: Outreach and Local Participation.....	38
Objective 4: Consistent Wetland Permitting of Control Efforts.....	38
Objective 5: Prevent and Control New Infestations	39
Objective 6: Contribute to Research on Effective Controls.....	39
Objective 7: Support Control Measures.....	39
REFERENCES	44
APPENDIX I: RESPONSES TO OARS/MACC ON-LINE SURVEY.....	51
APPENDIX II: SAMPLE WPA PERMITTING (ON-LINE VERSION ONLY).....	53
Request for Determination of Applicability (RDA).....	53
Notice of Intent (NOI).....	53
Order of Conditions (OOC)	53
APPENDIX III: WATER CHESTNUT MAPS: OARS' 2016 SURVEY.....	54

TABLES AND FIGURES

Table 1: Water Chestnut Control Options	12
Table 2: Thresholds for filing "Limited Projects"	23
Table 3: Survey Responses	24
Table 4: River Sections and Management	41
Figure 1: Water chestnut, Sudbury River, Framingham, 2016 (OARS).....	1

Figure 2: *Trapa natans* (from Crow & Hellquist, 1983). 2

Figure 3: Photos of *Trapa natans* life stages (S. Flint)..... 5

Figure 4: Water chestnut on the edge of dam, Billerica, Sept. 2016 (OARS)..... 8

Figure 5: Water chestnut on Billerica impoundment, 2008 (OARS)..... 10

Figure 6: Water Chestnut Pulling, Framingham, 2016..... 13

Figure 7: Water Chestnut Harvester & Conveyor, Sudbury River, 2014 (OARS)..... 14

Figure 8: Wetlands Protection Act Permitting Flow Chart..... 26

Figure 9: Assabet River Water Chestnut Survey, Gleasondale, 2013 32

Figure 10: Assabet River Water Chestnut Survey, Gleasondale, 2014 33

Figure 11: Assabet River Water Chestnut Survey, Gleasondale, 2016 33

Figure 12: Water Chestnut Survey 2016 - Concord Impoundments..... 34

Figure 13: Water Chestnut Harvested, Heard Pond..... 35

APPENDICES

- Appendix I: Responses to OARS/MACC Survey
- Appendix II: Sample Permitting (On-line Version Only)
- Appendix III: Water Chestnut Maps: OARS’ 2016 Survey (Map Index and Link to On-line Maps)

BACKGROUND

TAXONOMY

The water chestnut genus *Trapa* is currently classified in the *Lythraceae* family (Integrated Taxonomic Information System, 2016). Previously water chestnut was classified as a separate family, *Trapaceae* (Crow and Hellquist, 2000; Muenscher, 1944; USDA, 2016b) or *Hydrocaryaceae* (Gleason and Cronquist, 1963), with one genus, *Trapa*. There are between 2 and 11 species listed by various sources under the *Trapa* genus, the most common being *T. natans* and *T. bicornis*. The focus of this literature review is *T. natans* L., which is invasive in North America. *Trapa* species should not be confused with the “Chinese water chestnut” (*Eleocharis dulcis*) commonly used in Chinese cuisine.

HISTORY

Water chestnut, *Trapa* spp., is native to temperate and tropical Europe, Asia, and Africa. Archeological records suggest that *Trapa natans* was once widespread in northern Europe, but it is now nearly extirpated from the region (Hummel and Kiviat, 2004; Karg, 2006). *T. natans* is still an important agricultural product in China and India where the nuts are used (Kundu and Joshi, 2012). Although reportedly an important food in early European history, the nuts of *T. natans* are not known to be consumed in North America except by squirrels and other wildlife (Hummel and Kiviat, 2004).

While accounts vary, most agree that *Trapa natans* was introduced to North America in Middlesex County, Massachusetts, in the 1870s (Countryman, 1978). By 1874, the plant was cultivated in the Asa Gray Botanical Garden at Harvard University in Cambridge, Massachusetts. Louis Guerineau, the gardener at the botanical garden, introduced it to Fresh Pond and several other ponds in Cambridge, Mass., as an ornamental (Davenport, 1879).

Davenport reported personally bringing nuts to Minor Pratt in Concord, Mass., where they placed the nuts and plants in a pond near the Sudbury River, remarking “but that so fine a plant as this, with its handsome leafy rosettes, and edible nuts, which would, if common, be as attractive to boys as hickory nuts now are, can ever become a ‘nuisance’ I can scarcely believe.” In 1886, Father J. Hermann Wibbe independently introduced the plant to Sanders Lake (now Collins Lake) near Schenectady, New York (Countryman, 1978). Over the last 150 years water chestnut spread from Sanders Lake down the Mohawk River into the Hudson River and from eastern Massachusetts across the region. It was first documented in the southern end of



Figure 1: Water chestnut, Sudbury River, Framingham, 2016 (OARS)

Lake Champlain in the early 1940s (Countryman, 1970), in a tributary to the Chesapeake Bay, Maryland, in 1955 (Allen and Strain, 2013), and in Quebec, Canada by 1998, and in the Connecticut River system in 1999.

Although *T. natans* had been in the Sudbury and Concord Rivers since 1886, it was reported to grow suddenly to nuisance proportions by 1945. Eaton (1947) reported “the still more spectacular explosion of the ... water chestnut (*Trapa natans*) that took place in our part of the river [Sudbury River from Fairhaven Bay to Concord Village] summer before last and which continued during this past summer. ... last summer it so multiplied in our stretch that no water at all was to be seen, except along the thread of the stream.” Eaton attributed the explosion of both *Trapa* and *Lemna* (duckweed) on the Sudbury to the increase in “alkaline sewage wastes,” as measured by soluble nitrates in the river. The plant continues to spread along waterways through accidental introductions. Efforts to control the plant followed in the wake of these introductions, and have been ongoing for several decades.

BIOLOGY

ANATOMY

Trapa natans is easily identified by its distinctive floating rosettes of leaves. The leaves on the water surface are alternate, green, and triangular with a toothed edge, a glossy upper surface, and a lower surface covered with soft hairs. The floating leaves form rosettes from 10 to 15” in diameter by late July (Groth et al., 1996; OARS, 2013) with leaves surrounding a central stem, kept afloat by petioles with air bladders. Small white flowers are borne in axils of the floating leaves. The fruits are large woody nuts with four sharp, recurved barbs. Below the water surface is a cord-like stem 2–5 meters long with feathery, leaf-like structures in opposite pairs along the stem. These plume-like structures are variously considered stipules, leaves, or adventitious roots. Further down the stem are black feathery roots which reach down into the

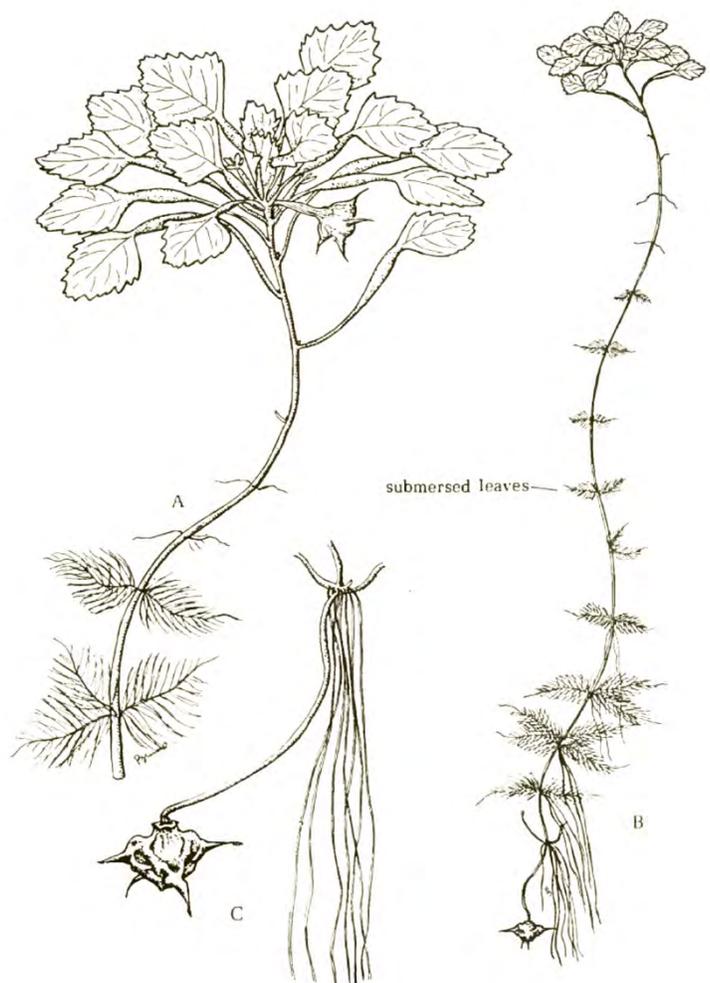


Figure 2: *Trapa natans* (from Crow & Hellquist, 1983, Used with permission by Milne Special Collections and Archives Dept, University of New Hampshire, Durham, NH).

soft sediment. Each stem may produce several branches each terminating in a rosette (Crow and Hellquist, 1983; Crow and Hellquist, 2000; Gleason and Cronquist, 1963; Muenscher, 1944).

LIFE CYCLE AND HABITAT

Trapa natans is an annual, growing each year from seed (nut) and dying back by the end of the growing season. Most nuts sink to the bottom of the water body where they were produced. The nuts overwinter in the soft sediment and generate the bed of *T. natans* at that site the following year (Hummel and Kiviat, 2004). A portion of the seeds produced each year germinate in the following spring, the remainder accumulate and create a seed bank; in the sediments seeds are viable for up to 10–15 years (Methe et al., 1993; T. Largy, pers. comm.). To germinate, seeds must have a period of dormancy at cold temperatures ($< 8^{\circ}\text{C}$) (Kurihara and Ikusima, 1991; Des Jardin, 2015); they germinate in the spring when water temperatures reach about 12°C . Seeds germinate fastest at moderately warm temperatures ($17\text{--}19^{\circ}\text{C}$) but will germinate at a range of water temperatures from 10°C to 24°C and the final overall germination rate was found to be unaffected by these temperature ranges (Des Jardin, 2015). Contradicting earlier reports that the plants require full sun, Des Jardin (2015) reported that they are tolerant of partial shade.

In eastern Massachusetts, seeds generally germinate in May, with the first flat leaves reaching the water surface by early to mid-June, forming the floating rosette. Secondary branches and rosettes appear from the time the first leaves reach the surface until the first nuts are set (usually late July), at which point the number of rosettes per plant stabilizes (Groth et al., 1996). Leaves are produced from the meristem (growing tip of the stem) throughout the growing season as the stem elongates. Submersed leaves drop early and are replaced by pairs of fine, dissected leaves along the stem (Hummel and Kiviat, 2004). Small four-petal, white flowers are borne singly in the axils of floating leaves from late June to September (Hummel and Kiviat, 2004). Pollination occurs via self-pollination, cross-pollination, or by insects. Kadono and Schneider (1986) reported that the flowers are most often visited by beetles and true bugs (*Coleoptera* and *Hemiptera*). After fertilization, the peduncle holding the flower bends down into the water where the one-seeded green nut forms. Each rosette may produce 10–15 nuts. The plant continues to bloom and fruit into the fall or when cold temperatures end the season (S. Flint, pers. observation). When the seeds are mature, usually by early August, the nuts fall off and sink to the bottom of the water body and lodge in the sediment. The outer fruit layer of the nut disintegrates quickly to reveal a hard, black, woody nut with sharp barbed spikes. Although nut production is reduced, a rosette separated from its root can continue to produce nuts (Methe et al., 1993) and a stem can branch and form new rosettes by mid-August if the main stem is broken earlier in the summer (S. Flint, pers. observation).

Plant density affects many aspects of water chestnut growth and vigor, since they compete for two-dimensional water surface space rather than three-dimensional canopy space like terrestrial plants. *Trapa natans* in initially low-density plots (5–15 rosettes/square meter) are larger, more productive, and longer-lived than plants in high density plots (>100 rosettes/square meter). Compared with plants in high

density plots, low-density plants can have 5 times more rosettes and 8–10 times the biomass (Groth et al., 1996). Groth et al. reported that the largest plant from low-density plots bore 27 rosettes, while the largest from high density bore only five rosettes. In addition, low-density plants showed practically no mortality until the entire plant senesced in September, whereas rosettes of plants at high-density suffered continuous mortality, particularly to the secondary rosettes, through the growing season (Groth et al., 1996)

Water chestnut thrives in slow moving, nutrient-rich fresh water of ponds, lakes and rivers with muddy bottoms (Takamura et al., 2003). The plant prefers pH of 6.7–8.2 and tolerates salinity up to 0.1% and alkalinity of 12–128 mg/L calcium carbonate (Crow and Hellquist, 1983). It rarely grows where the substrate is low in organic matter or there is a swift current; the stems are weak and the plant is lightly rooted in the sediments by thin roots and the empty nut hull. It can survive in tidal freshwater marshes, such as the Hudson River (Coote et al., 2001) and can grow in depths up to 5 meters, but is most abundant in water around 2 meters deep (Muenscher, 1944).

Figure 3: Photos of *Trapa natans* (OARS)

Dry nut



Nut sprouting (with roots and underwater leaves)



Flower on short peduncle



Flower in axil of floating leaves



Rosette close up—new leaves from center



Nut under rosette



Immature seed (early July)



Immature seed—bisected



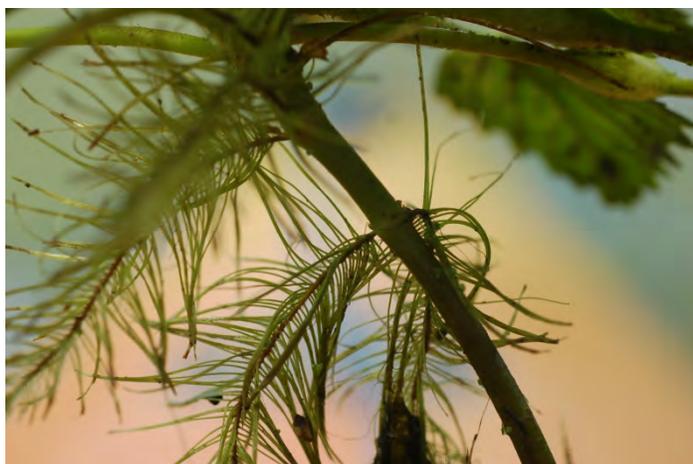
Mature Seed (late August)



Mature seed—bisected



Underwater leaves (late August)



Underwater leaves (late August)



Petioles with air bladders (late August)



Petiole—bisected



Large rosette with secondary rosette (July 20)



Dense patch and OARS Rapid Response Team member



NATURAL ENEMIES

In water chestnut's native range there are a number of natural enemies that could potentially be harnessed to control *T. natans* populations in North America. Field surveys identified 17 species (including insects, mollusks, fungi, and other pathogens) in Asia and 7 insects in Western Europe feeding on *Trapa* species. Several were investigated further: *Galerucella nymphaeae* L. (water lily beetle), *Galerucella birmanica* (beetle), and *Nanophyes japonica* (weevil) (Ding and Blossey, 2005). Of these, *Galerucella birmanica* was the most damaging to water chestnut and the most promising for biological control (Pemberton, 1999; Pemberton 2002; Ding et al., 2006a; Ding et al., 2006b). A North American beetle, *Pyrrhalta nymphaeae*, has also been reported to graze on *Trapa natans* in the Hudson River, but not extensively enough to inhibit nut production (Schmidt, 1986).

Galerucella birmanica is currently being studied by Dr. Bernd Blossey at Cornell University's Department of Natural Resources as a potential biological control for water chestnut. Research started in the early 2000s, but were dropped when studies suggested that *G. birmanica* also grazes on a native water shield (*Brasenia schreberi*). More recent work shows that the beetle *G. birmanica* is host-specific and its preference for the leaves of *Trapa natans* continues even after the plant is almost completely defoliated (Cornell Chronicle, 2016). The beetle is likely able to survive New England's climate, with best reproduction and generation survival occurring at 88–93° F (Zheng et al., 2008). Greater than 50 larvae per rosette were found to be needed to negatively impact the plant. At lower densities (10–50 larvae/rosette) the plant was able to increase leaf production at the expense of reproductive efforts (Ding et al., 2006b). Dr. Blossey hopes to have USDA approval for releasing *G. birmanica* in the United States by 2018 (Cornell Chronicle, 2016).

DISPERSAL



Figure 4: Water chestnut on the edge of dam, Billerica, Sept. 2016 (OARS)

Initially the greatest dispersal vector of *T. natans* in New England was intentional human introduction (Hummel and Kiviat, 2004; Les and Mehrhoff, 1999). *T. natans* has been listed as a nuisance or noxious species in 11 states, including Massachusetts (USDA, 2016a), although not at the federal level. As a result, intentional spread has likely stopped. However, nuts can still be distributed due to human activity by getting caught on nets, boats, construction equipment, and in excavated sediment. The sharply

barbed nuts are thought to cling to the feathers of waterfowl and the fur of animals, which may also play a role in their dispersal, as well as in sediment washed downstream in floods. Propagation downstream can also occur by rosettes and fragments with nuts breaking off the stem and floating with the currents to populate a new area with suitable substrate.

IMPACTS

ECOLOGICAL IMPACTS

Water chestnut can cover nearly 100% of the water surface, intercepting over 95% of incident sunlight (Caraco and Cole, 2002). The floating mats of vegetation shade out other submerged plants and can create large diurnal changes in the dissolved oxygen concentration in the water column (Kornijów et al., 2010). A study of dense water chestnut beds in a tidal section of the Hudson River reported dissolved oxygen values below 2.5 mg/L occurring up to 40% of the time in August and varying with tidal cycle (Caraco and Cole, 2002). Areas that are not flushed by tides may have longer periods of anoxic (depleted oxygen) conditions.

In spite of anoxic conditions, the impacts of dense water chestnut beds on macroinvertebrate and fish communities are varied (Schultz and Dibble, 2012). Studies of *T. natans* and native *Vallisneria* beds in the Hudson River found macroinvertebrate communities of different compositions (Feldman, 2001; Strayer et al., 2003; Teixeira et al., 2014; Kato et al., 2016). Strayer reported that the abundance of macroinvertebrates in the *Trapa* beds was higher than in *Vallisneria* beds. Kornijów et al. (2010) reported that water chestnut beds studied supported a rich community of macroinvertebrates, despite the common occurrence of hypoxia.

Several studies of fish abundance and species composition in water chestnut beds report that although fish do inhabit the beds, the species in greatest abundance are those with a wider tolerance for adverse conditions. Pelczarski (1990) reported that the abundance of fish in water chestnut beds in the Hudson was lower than reported in other vegetation types, but both adult and juvenile fourspine stickleback and carp were present in both beds. Coote et al. (2001) found young-of-the-year blueback herring using some beds. Most of the fish and macroinvertebrates studies in North America have been done on the tidal sections of the Hudson River; addition studies in non-tidal rivers would be warranted.

Water chestnut, like other large beds of aquatic plants, slows current velocity which leads to deposition of sediments, assisting in temporary water purification. Water chestnut has been shown to accumulate copper and cadmium in its roots, shoots, leaves and nuts (Sweta et al., 2015). Water chestnut (whole plants) harvested from the Sudbury River at Framingham, Mass., showed concentrations of cadmium and selenium above common soil concentrations; mercury, a major contaminant of sediments in the Sudbury River, was not detected and other contaminants tested were at low levels (OARS, 2013, pers. comm.). The fate of accumulated metals after water chestnut decomposes is unknown (Hummel and Kiviat, 2004).

IMPACTS ON RECREATION AND AESTHETICS

There is universal agreement that *T. natans* severely affects the recreational use of water bodies by creating impenetrable mats of vegetation that make the river inaccessible to boating, swimming, and fishing. The sharp barbed nuts can penetrate shoes and gloves and pose a hazard to swimmer and beach goers. (Charles River Watershed Association, n.d.; Connecticut River Watershed Council, n.d.; Mystic River Watershed Association, n.d.; Nashua River



Figure 5: Water chestnut on Billerica impoundment, 2008 (OARS)

Watershed Association, n.d.; Robinson, 2002). The decaying vegetation at the end of the growing season, or as a result of herbicide treatment, can create odors. In August 2016 a large mat of rotting water chestnut washed up against the dam on the Nashua River in Pepperell, its strong odor bringing notice in the local press: “The Nashua River flowing over the dam and underneath the Main Street Bridge stinks where a dense mat of bright green vegetation slowly dying to brown floats at the top of the dam.” (Nashoba Valley Voice, 2016). The loss of open water can significantly change the scenery and aesthetic beauty of a water body. These impacts can, in turn, impact real estate values (Robinson, 2002).

MANAGEMENT OPTIONS

An optimal management plan for controlling water chestnut will vary by the size of the infestation, the type of water body managed, any special characteristics of the site (e.g., rare species present or source water protection), the length of time managed, and the resources available for management. Unlike many invasive plants, water chestnut is strictly an annual and has been successfully controlled or eliminated in some water bodies, but only after persistent efforts. The most important aspects of successful water chestnut management are commitment to adaptive management, ongoing monitoring, and long-term maintenance. Below, the most commonly used and successful options for managing water chestnut are listed. Each of these techniques may be suitable as part of an overall adaptive management effort at different times and different locations.

Two points must be noted: First, excessive aquatic plant growth is promoted by nutrient-rich water. Efforts at water chestnut management should be accompanied by systematic efforts to reduce nutrient

inputs to the water body. This may be done by reducing and treating stormwater runoff, fixing or eliminating failing septic systems, eliminating runoff of lawn fertilizer, reducing nutrients in effluent from wastewater treatment facilities, and other means depending on the sources of nutrients. Second, aquatic ecosystems should be managed as complex ecosystems with a goal of maintaining a healthy, diverse system that will continue to evolve. This will require protecting and encouraging native aquatic and riparian plants while discouraging invasive plants. It is important to consider the effects that removing water chestnut will have on the water body, so that successful treatment does not pave the way for a different invasives problem.

Several sources have detailed discussions of treatment methods suitable for all invasive aquatic plants (Gettys et al., 2014; Mass. EOE, 2004; Wagner, 2004). This discussion is intended as a general guide; detailed Standard Operating Procedures and guidelines should be consulted in preparation for starting any remediation project. The “guidelines” listed for each option here are primarily drawn from The Practical Guide to Lake Management in Massachusetts (Wagner, 2004).

Table 1: Water Chestnut Control Options

Water Chestnut Control Options				
Type	Mode of action	Advantages	Disadvantages	Potential permitting
Hand-pulling	Physical removal of plants before seeds drop; hand-pulling from small boats	highly selective control; limited impact to non-target organisms; good for shallow sites; removes plants from water column; can involve volunteers (lower cost)	Not good for large, dense infestations; labor intensive	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP
Mechanical Harvesting	Physical removal of plants before seeds drop; requires mechanical harvester, conveyor, and truck	Capable of removing large/dense infestations; removes plants from water column	Minimally selective; not useable in shallow sites; fragmentation may spread other invasives; may impact aquatic fauna; requires larger access or use of crane; higher cost	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP
Hydroraking	Physical removal of plants before seeds drop; requires hydrorake, barge, and truck	Capable of operating in shallower areas than mechanical harvester, removes stump and debris	Minimally selective; very disruptive in areas applied; may generate high turbidity; fragmentation may spread other plants; requires larger access or crane	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP
Drawdown	Winter drawdown to kill seeds by freezing; summer drawdown to kill emerging vegetation before seeds set; timing duration are critical	Low cost; opportunity for shoreline cleanup or structure repair; needs outlet control	Non-selective; very disruptive; alteration of flows downstream during drawdown & refill periods; more information needed on effectiveness of summer drawdown	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP
Dredging	Sediment removal to reduce seed bank, reduce nutrient recycling, increase water depth	Removes the soft sediments, deepens the waterbody, effective on all rooted plants	Non-selective; very disruptive; alteration of flows during management; potential release of sediment; high cost	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; 401 Water Quality Certificate from DEP; Chapter 91 and/or 401 permit from ACOE
Bethic Barriers	Placement of barrier or bottom cover to prevent growth of rooted plants	Effective on growth of rooted plants in limited areas or create access lanes; complete elimination of plants in area	Non-selective; High cost of installation and maintenance; not suitable for large areas; difficult to install	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP
Herbicides	absorbed or membrane-active chemicals that disrupt plant metabolism	Limited toxicity; rapid action; can be selectively applied	Potential toxicity to aquatic fauna; water use restrictions for varying time after application; increased oxygen demand from decaying vegetation	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; license to apply chemicals from DEP.
Biological Control: Herbivorous insects	Introduction of insects that feed selectively on target	Research on <i>Galerucella birmanica</i> ongoing; potentially very selective control; lower cost of application and potentially long-term control achieved	Involves introduction of non-native species; more research needed	WPA Request for Determination of Applicability, Notice of Intent; review by NHESP; permit to import and release biological control agents if bred out-of-state USDA Animal and Plant Health Inspection Service

Abbrev: DEP, Department of Environmental Protection; NHESP, Natural Heritage and Endangered Species Program; WPA, Wetlands Protection Act; ACOE, Army Corps of Engineers.

HAND-PULLING

Pulling water chestnuts out by hand or with a rake can be done easily. The technique is well suited for working in shallow water, controlling small infestations, selective control where they are intermixed with other wetland or aquatic plants, or long-term maintenance when an infestation has been brought under control with other techniques. It is frequently used alongside a mechanical harvester to get to plants the harvester cannot reach or pick up dropped rosettes. Because minimal training and equipment is needed, hand-pulling is well suited for volunteer efforts, which can help build community investment in long-term management of the problem (Mass. DCR, 2007). The technique is not good for large-scale efforts when the target plants occur in dense and extensive beds (Wagner, 2004).

Guidelines:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Identify the access points (boat launch and weed off-loading), disposal site(s), and disposal method (e.g., composting or incineration).
- File for and receive appropriate permitting before the start of the project. (See permitting section.)
- Train all personnel on plant identification, boating safety, harvesting techniques, and proper disposal of the weeds. Supply safety equipment: PFDs, bailers, and gloves.
- Work from canoes, kayaks or small boats, using laundry baskets to collect the weeds.
- Harvest as much of the plant as practical. In the early summer the entire stem and seed husk (sharp barbed) will come up easily. Later in the season, when the plants have long stems and multiple attached rosettes, the stems will have to be broken off. Handle the rosettes carefully to avoid dropping nuts back into the water. Leave the roots in the sediment to minimize stirring up silt which may damage the local ecosystem.
- Set up a sturdy and safe offloading point (e.g., a small dock is ideal)
- Some groups advocate multiple pulls (early and late) in a season to ensure full removal.
- Conduct follow-up monitoring in the same and following season.



Figure 6: Water Chestnut Pulling, Framingham, 2016

MECHANICAL HARVESTING AND HYDRORAKE

“Aquatic weed harvesters are like lawnmowers for aquatic weeds.” Aquamarine describes their mechanical harvesting process thus: “aquatic plant harvesters are hydraulically driven with reciprocating knives mounted on the harvesting head to cut the aquatic vegetation. The vegetation is then transferred onto the conveyor system located on the closed deck barge. The storage conveyors are gradually filled up with tightly packed plants and this harvested biomass is then transferred to the shoreline or into a dump truck via a shore conveyor” (Aquamarine, n.d.).

Mechanical harvesting is faster (0.2–0.6 acres per hour) than hand pulling and requires fewer people (Wagner, 2004). However significant amounts of time can be involved shuttling to and fro to offload the weeds. It can be challenging to find a suitable launch and offloading site, and often a crane is used at a bridge to lower the harvester into a river. Harvesters generally need a minimum of 2–3 feet of water depth. Harvesters cut off the rosettes, which may allow resprouting from the stem and the need for a second cutting later in the season.



Figure 7: Water Chestnut Harvester & Conveyor, Sudbury River, 2014 (OARS)

Hydroraking involves the equivalent of a floating backhoe; the tines of the rake are pulled through the sediment, uprooting plants, sediment and debris. SOLitude describes their hydrorake: “The hydro-rake can best be described as a floating barge upon which is mounted a backhoe with several different size and functioning rake attachments. The hydro-rake can operate in water as shallow as 1.0–1.5 feet and can remove nuisance vegetation and bottom debris from water depths ranging from 18 inches to 10 feet.” Hydrorakes don’t have on-board storage so they deposit weeds either on-shore or require a barge.

The hydrorake pulls the entire plant with roots out of the sediment and tend to stir up a lot of silt, some of which can be minimized by a skilled operator.

Guidelines:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Identify the access points (harvester launch and weed off-loading), disposal site(s), and disposal method (e.g., composting or incineration).
- File for and receive appropriate permitting before the start of the project. (See permitting section.)
- Identify methods for minimizing turbidity during harvesting and implement when feasible.
- Develop a fragment control plan for non-target invasive species likely to spread by fragmentation (e.g., milfoil).
- Schedule harvesting to take place before nuts mature.
- Plan hand-pulling to work in tandem with harvesting for edge areas and areas of mixed invasive/native plants.
- Avoid areas of known sensitive habitat during active use.
- Monitor collection of non-target fauna (e.g., fish, turtles).
- Develop a harvester maintenance plan.

WEED DISPOSAL FOR HAND-PULLING AND MECHANICAL HARVESTING

Once harvested, the weeds (sometimes large volumes) must be disposed of by composting or incineration. The weeds may be piled near the harvest site and allowed to dry for a few days to weeks before final disposal. The weight and volume of the pile will decrease significantly when it is allowed to drain and dry, making subsequent transportation and disposal easier. The pile should be kept away from the water's edge to avoid washing back into the water in the event of heavy rain. Care in handling the piles is advisable, since the sharp-barbed nut husks of germinated plants commonly accompany the root. Viable nuts are heavier than water and sink to the bottom; floating nuts are husks of nuts that have already germinated and can penetrate rubber-soled shoes.

Composting is usually the least expensive option when a suitable site can be found. In OARS' survey, of the towns reporting water chestnut harvesting in their area, most (13) reported composting the weeds, one reported incinerating the weeds, and the remaining towns (10) reported "do not know" because someone else was managing the harvesting (see Appendix I). In accordance with Massachusetts' Department of Food and Agriculture regulations (330 CMR 25.00) compost piles should be placed in such a way as to minimize odors, the drift of materials and risk to humans and the environment. Due to the presence of the sharp nuts, reuse of the compost may be limited. Incineration as part of the municipal waste stream is sometimes used but is only efficient if the plants have had an opportunity to dry out naturally as much as possible prior to incineration.

Because of concerns about potential contamination, particularly mercury contamination, the heavy metal content of whole water chestnut plants from the Sudbury River was tested. Plants were pulled from the Fairhaven Bay and Saxonville impoundment sections of the Sudbury River, both areas suffering from significant mercury contamination. The samples were dried and sent for analysis by the Cornell Nutrient Analysis Laboratory. Mercury was undetectable in all samples (OARS, unpublished). The results were also compared with compost guidelines for application on food crops and reported typical soil levels (Brinton, 2000). Of the metals tested, cadmium, chromium, copper, manganese, nickel, selenium, and zinc exceeded the guidelines for application on food crops; only cadmium and selenium exceeded reported typical soil values (OARS, unpublished).

DRAWDOWNS

Winter drawdowns are not generally used for control of water chestnut because the seeds are likely to survive in the sediments (Wagner, 2004). Summer drawdowns have been used occasionally to control water chestnut. To be effective, a summer drawdown should be conducted after late May/early June when water chestnut has sprouted, and water levels are drawn down far enough to dry the sediment and kill the vegetation. Summer drawdowns used in the Concord Impoundments of the Concord River to improve habitat for migrating birds, were effective in reducing the water chestnut (see Concord Impoundments below). Drawdowns can be cost effective, depending on the ability to control water levels in the section of interest, but may have broad impacts on other plant and animal species. Recolonization from nearby areas may be rapid, depending on species, and the response of macrophyte species is quite variable (Wagner, 2004). Summer drawdowns have the potential to affect nearby wells and fire-fighting ponds, which could be critical during the lower-flow summer months.

Guidelines:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Evaluate the potential risks to non-target flora and fauna.
- Apply for and secure permitting from local Conservation Commission.
- Limit the drawdown to 3 ft or contract the Mass. Division of Fish and Game for help evaluating impacts of a greater drawdown.
- Keep outflow during drawdown below 4 cfs/square mile of watershed; once the drawdown is achieved, match outflow to inflow.
- Monitor water levels and water quality during the drawdown, and monitor the recovery of the water body.

DREDGING

Sediment dredging has been used successfully for weed control, but its utility is limited to areas that will not rapidly re-accumulate sediment. *The Practical Guide to Lake Management in Massachusetts* (Wagner, 2004) includes an extensive discussion of conventional wet, conventional dry, and hydraulic

dredging. Dredging can control water chestnut by physically removing its seed bank along with the soft sediment that support its growth, by removing nutrients and internal loading stored in the sediment, and/or increasing the depth of the water body. Dry dredging involves drawing down the waterbody to expose the sediment, controlling inflows during the process, and using conventional excavation equipment. Wet dredging may involve a partial drawdown (especially where water level control is limited) and use of specialized excavation equipment. Conventional wet dredging creates considerable turbidity and requires steps to limit downstream movement of the sediments and to de-water dredged sediments before they are removed for disposal. Hydraulic dredging involves a suction type of dredge to remove a slurry of sediments. The slurry is pumped into a containment area to remove excess water. Hydraulic dredging can work well for large volumes of sediments in areas that cannot be drained and contain relatively few rocks and stumps.

Permitting requirements and costs for dredging are generally higher than for other management options. Permitting required may include: Wetland Protection Act permit; MEPA review; Chapter 91 permit; 404 permit through Army Corps of Engineers; 401 Water Quality permit through Department of Environmental Protection (for projects involving dredging greater than 100 cubic yards of sediment).

Guidelines:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Project planning should address: reasons for dredging, volume and nature of material to be dredged, any protected resources, equipment access, disposal site or use/sale of material, site bathymetry, flow management, dredging methodologies, regulatory process, and costs.
- Apply for and receive all applicable permits (see permitting section).
- Conduct all work in accordance with permit conditions.
- Achieve depth or substrate limitation (depending on project goals).
- Restore or rehabilitate all access, temporary containment, and final disposal areas.
- Monitor containment area, downstream flows and water quality during dredging.
- Monitor recovery of the water body.

BENTHIC BARRIERS

Benthic barriers are used to prevent growth of rooted aquatic plants by limiting light and disrupting growth of all the rooted plants in the application area (Mass. DCR, 2007). Barriers may be clay, silt, sand, gravel, or sheets of artificial material (e.g., polyethylene, polypropylene, fiberglass, or nylon) manufactured to be negatively buoyant. Because of the expense, difficulty of application, non-selectivity, and need for maintenance, benthic barriers are usually used in limited areas and in areas without significant current or waves.

Guidelines:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Select a barrier with properties consistent with the project goals and site features.
- Apply for and receive all applicable permits (see permitting section).
- Install and anchor the barrier so that it is stable in response to waves, currents, and billowing up from sediment gasses.
- Post the area to inform potential users of the barrier's presence.
- Leave in place for a least a month; check for movement and sedimentation.
- Monitor the barrier's effectiveness and plant community before and after installation.

HERBICIDE TREATMENT

Several herbicides can be used to manage water chestnut. Herbicides can be classified by their chemical family, mode of action, or time of application (e.g. pre-emergence or post-emergence). They can also be classified as “contact” or “systemic.” Contact herbicides injure only the plant tissue that they come in contact with and are relatively fast acting (hours to days). Contact herbicides are applied in relatively high concentrations and have a short half-life in water. In contrast, systemic herbicides move from leaves into the roots and rhizomes and kill the plants within days to weeks; they are applied at lower concentrations (Haller, 2014; US Army Corps of Engineers, 2012). A surfactant is added to many contact herbicides to improve adhesion and absorption by the plant leaves. The surfactants are also chemicals, and should be specified and assessed as well.

Herbicides have three names: a trade name, a common name, and a chemical name. The trade name is trademarked by the manufacturer and is specific for each formulation of the herbicide. The common name and chemical name are assigned by the American National Standards Institute and are unique to the active ingredient (US Army Corps of Engineers, 2012). For example the active ingredient of Clearcast™, a trademark of BASF Corporation, is ammonium salt of imazamox, chemical name: 2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 *H*-imidazol-2-yl]-5-(methoxymethyl)-3-pyridinecarboxylic acid (SePRO, 2015).

Aquatic herbicides must be registered with the EPA (under the Federal Insecticide, Fungicide, and Rodenticide Act) and the Massachusetts Department of Agriculture and approved for legal use in Massachusetts. The Massachusetts Pest Product Registration (Mass. DAR, 2016a; Mass. DAR, 2016b) currently lists nine herbicide formulations specifically approved for control of water chestnut in Massachusetts: Aquacide Pellets (2,4-D), Arsenal (imazapyr, isopropylamine salt), Clearcast (imazamox), Habitat (imazapyr, isopropylamine salt), Navigate (2,4-D), Navitrol DPF (triclopyr), Renovate Max G (combination 2,4-D and triclopyr), Renovate OTF (triclopyr), and Sculpin G (2,4-D).

In the past, the most widely used herbicide had been 2,4-D (Hummel and Kiviat, 2004; Poovey and Getsinger, 2007; Kishbaugh, 2014; Rector et al., 2015). More recently other chemicals have been used.

Since Clearcast was approved for control of water chestnut, imazamox has been used with initial good results (Nemecek and DeHollander, 2014; DeHollander, pers. comm.). SOLitude Lake Management reported using Clearcast and Renovate Max G to clear water chestnut in several small ponds in Fairfax, Virginia (SOLitude, 2016). The Perkiomen Watershed Conservancy reports using a combination of Habitat and Rodeo (glyphosate) to successfully clear a section of water chestnut on Perkiomen Creek (pers. comm.). The Onondaga County Health Department applied for aquatic permits to chemically treat 147 acres of water chestnut infestation on the Seneca River in 2016 using Clearcast and Rodeo (pers. comm.).

After 24 years of mechanical harvesting and unable to keep up with growth using one harvester, Oswego County Soil and Water Conservation District turned to a combination of methods including treatment with a variety of herbicides and hand-pulling to control water chestnut on the Oswego River and in the district. In 2004–2005, they expanded chemical treatments with special use permits from the New York Department of Environmental Conservation for Aqua-Kleen (granular 2,4-D), Rodeo (glyphosate) and Weedar 64 (2,4-D) at sites in Oneida Lake, Oneida River, Ox Creek and the Seneca River to compare the effectiveness of the herbicides. They reported that results using 2,4-D and glyphosate on large patches of water chestnut were “erratic at best.” In 2009–2013, they attempted undercutting without weed removal in conjunction with chemical treatments. In 2012–2016, large patches of water chestnut in the Oswego and Seneca Rivers were treated using Clearcast. By 2016, the over-220 acres of water chestnut were reduced to about 20 acres and chemical treatment was combined with hand-pulling to control the remaining population on the Oswego River (John DeHollander, pers. comm.; DeHollander, 2015; The Nature Conservancy, 2012; Nemecek and DeHollander, 2014)

General guidelines for chemical control:

- Map the distribution of water chestnut and non-target species before treatment, and identify the boundaries of the work area.
- Identify waterbody and downstream water uses that may be impacted.
- Inventory aquatic biota with emphasis on sensitive species.
- Develop treatment plan including does, areas treated, expected alteration of plant community, follow-up activities, and notifications about any water use restrictions.
- File and receive appropriate permitting before the start of the project (see permitting section).
- Application must be done by a licensed applicator.
- Monitor effectiveness and results, with emphasis on oxygen and nutrient levels if more than 10% of the waterbody area is treated.

2,4- D

2,4-D is a somewhat selective, systemic, broadleaf herbicide used to control a variety of submersed and floating aquatic plants. It has been registered by the US EPA for use in aquatic environments since 1959 (US Army Corps of Engineers, 2012). The chemical prevents the elongation of stems and roots, keeping

tissues juvenile. Depending on the form, the compound acts like the plant hormone auxin, affecting cell wall plasticity and nucleic acid metabolism in plants.

Amine and butoxy-ethyl ester formulations in liquid and granular formulations of 2,4-D can be used against water chestnut effectively (US Army Corps of Engineers, 2012; Rector et al., 2015). These go by the trade names of Navigate (2,4-D ester) and Platoon, DMA-4, and CleanAmine (liquid 2,4-D amine) (ACT, 2015). The liquid amine formulation of 2,4-D is typically used to control both emergent and submersed plants, and granular butoxy-ethyl ester formulation is used for submersed plants only (ACOE 2012). Though widely used as a water chestnut herbicide, updated regulations lowered the allowable dose concentration for 2,4-D, and it may be less effective on water chestnut (pers. comm.). All 2,4-D products are prohibited in Zone II wellhead protection areas due to toxicity and concerns about migration into groundwater (Aquatic Control Technology, 2015a).

TRICLOPYR

Triclopyr is a selective systemic herbicide and auxin mimic that has been shown to be effective on water chestnut (Poovey and Getsinger, 2007). Although triclopyr is not as effective as 2,4-D, it can be used in public waters where 2,4-D use is not allowed (Netherland, 2014). Liquid and granular formulations of triclopyr amide are available to control submersed, floating and emergent dicotyledonous (and some broadleaf monocotyledonous) aquatic plants (Wagner, 2004; US Army Corps of Engineers, 2012).

CLEARCAST

Clearcast is a liquid herbicide containing the ammonium salt of imazamox. It is active on many submerged, emergent, and floating broadleaf and monocot aquatic plants, applied as a foliar (onto the leaves) spray on emergent or floating plants, or applied directly to the water to control submerged plants.

Study of Clearcast for aquatic vegetation management began in 2004, with aquatic Experimental Use Permit (EUP) programs conducted in some 16 states starting in 2006, and the treatment of up to 4,750 acres per year. Clearcast received full EPA approval in 2008 (AECOM, 2009). In the spring of 2015, the Massachusetts Department of Agriculture registered Clearcast for controlling vegetation in and around aquatic sites and terrestrial non-crop sites (Aquatic Control Technologies, 2015a). A foliar application of Clearcast with a surfactant is used for treatment of water chestnut. It should be noted that control will be reduced if spray is washed off foliage by wave action or rain, and repeat applications may be necessary.

BIOLOGICAL CONTROL

“Successful biological control depends on the ability of host-specific herbivores to suppress populations of their host plant” (Ding et al., 2006b). Biological control agents can kill the target plants outright or damage them thus limiting their reproduction or ability to compete with other plants. Research on *Galerucella birmanica* as a biological control for water chestnut is ongoing (see Natural Enemies, above). Any biological control agent must be thoroughly studied for host-specificity and effectiveness and approved for use by the US Department of Agriculture and individual states. A Plant Protection and

Quarantine (PPQ) 526 permit from the USDA is required to transport biological controls across state lines and for release into the environment.

FUNDING

At the state and federal level, most funding for water chestnut control comes through annual budget appropriations or Environmental Bond funding to DCR (Mass. Department of Conservation and Recreation) or US Fish and Wildlife Service. Mass. DEP does not currently have funding for circuit riders for invasives control. At the local level, municipal budgets have provided funds, sometimes drawing on Community Preservation Act money. Local land trusts and watershed organizations have been able to secure funds through grants, donations, and environmental penalties. Volunteer contributions in surveying and hand-pulling are invaluable.

Possible grant programs for invasives control include: Section 106 of the Clean Water Act (EPA), Section 319 of the Clean Water Act—Healthy Watershed Initiative, and DCR matching funding for areas abutting or sharing DCR land.

PERMITTING FOR CONTROL EFFORTS

LEGAL STATUS

In Massachusetts, the sale, planting, transport, and traffic in water chestnut is specifically banned by Massachusetts general law Title XIX Ch. 128 Sec. 20A (Commonwealth of Massachusetts, 2016) and water chestnut is on the Massachusetts Prohibited Plant List (Mass. EOEEA, 2016). The Massachusetts Invasive Plants Advisory Group (MIPAG) lists water chestnut as a “Category 1” early detection priority species; Category 1 species should be reported and eradicated if found anywhere in Massachusetts (MIPAG, 2011). The Mass. DCR Lakes and Ponds Program lists water chestnut on their Rapid Response List.

In 1949 New York State enacted a law prohibiting transport, transplant or traffic in water chestnut. The National Invasive Species Act of 1996 specifically mentioned *Trapa natans* as a species of concern, but imposed no restrictions or penalties (Hummel and Kiviat, 2004). Currently, it is not on the federal noxious weed list. As of 2016, *Trapa natans* is listed as a “noxious weed” in 11 states, including Massachusetts (USDA, 2016).

RESPONSIBLE PARTIES

Control of aquatic invasives is not legally mandated, and, thus, not the responsibility of any agency or municipality. Various groups have taken the lead in managing aquatic invasive plants, depending ownership/management, municipal involvement, and the existence of lake or watershed associations. For example, the Department of Conservation and Recreation (DCR) through their Lakes and Ponds Program manages invasives on DCR-owned properties has taken the lead in Massachusetts to provide

information and training to support control efforts statewide. DCR's Division of Water Supply Protection manages invasives in the water supply reservoirs, including the Sudbury Reservoir (Mass. DCR, 2010). US Fish and Wildlife Service takes the lead managing water chestnut on the Sudbury River within the Great Meadows National Wildlife Refuge in coordination with the Town of Lincoln, Town of Concord, and the Concord Land Conservation Trust. Outside of the state parks and reservations, control of invasive plants is largely a function of local desire to protect and maintain the resource.

PERMITTING IN MASSACHUSETTS

A key guide to the permitting process is DEP's *Guidance for Aquatic Plant Management in Lakes and Ponds as it Relates to the Wetlands Protection Act* (Langley et al., 2004), available on the DEP website. This guide is specific to lakes and ponds, but can generally be applied to rivers as well. Another key resource is *Protecting Wetlands and Open Space: MACC's Environmental Handbook*, which is available on-line for a fee. The local Conservation Commission will be involved due to the Wetlands Protection Act. It is highly recommended that anyone considering water chestnut control discuss their proposed activities as early as possible with the Commission so that they, or the conservation agent, may advise on the best approach. The DEP's Wetlands Circuit Rider (Central, Southeast and Western regions only) is a great resource for applicants and Commissions alike.

All water chestnut control projects fall under the permitting requirements of the Massachusetts Wetlands Protection Act (MGL Ch. 131, Sec. 40) primarily because they may "alter" (change the condition of) "land under water" and may also require approval under local wetlands bylaws/ordinances. "Alterations" include sedimentation, flow patterns, vegetation, or the physical, biological or chemical condition of the water. In some cases, "bordering vegetated wetlands" may also be affected. Conservation Commissions have the discretion to determine that minor hand-pulling efforts to remove water chestnut plants that do not significantly disturb the sediment may go ahead without permitting. Where large equipment may need to access the waterbody, projects may also alter "banks" or "floodplains" or other resource areas, potentially creating erosion or sedimentation. Plants removed by harvesting (whether by hand or machine) will need to be disposed of properly. See Figure 8 describing the permitting process. All forms and instructions for filing under the Wetlands Protection Act can be found at: www.mass.gov/eea/agencies/massdep/water/approvals/wetlands-and-waterways-forms.html#4. Sample permitting is provided in Appendix II.

Water chestnut control projects may also fall under other regulations. The site location, funding sources, scope, and methods will define the regulatory requirements. Permitting can take several months so it should be started during the winter for the following summer. For projects that will require obtaining funding and an Order of Conditions and any other permits, getting started the preceding fall is advisable.

Under the Wetlands Protection Act, water chestnut control may be considered an "Ecological Restoration Limited Project." Such a project must meet the definition: "a project whose primary purpose is to restore or otherwise improve the natural capacity of a Resource Area(s) to protect and maintain the interests identified in M.G.L. c.131 § 40, when such interests have been degraded or destroyed by

anthropogenic influences.” (310 CMR 10.04). To be considered a “Limited Project,” the activity must exceed the thresholds for the three resource areas shown in the table below. If it is less than those thresholds, it goes through the same process as any other project under the Act.

Table 2: Thresholds for filing “Limited Projects”

Resource Area	Threshold for Wildlife Habitat Evaluations in Inland Resource Areas
Bank	50 linear feet or 10% of Bank on the property, whichever is less (310 CMR 10.54(4)(a)(5))
Land Under Waterbodies and Waterways (LUW)	5,000 square feet or 10% of LUW on the property, whichever is less (310 CMR 10.56(4)(a)(4))
Bordering Land Subject to Flooding (BLSF)	5,000 square feet or 10% of BLSF presumed significant for wildlife habitat, whichever is less (310 CMR 10.57(4)(a)(3))

Source: MACC (2015), p. ST 6.4.

The project *cannot* be Dam Removal, Freshwater Stream Crossing Repair and Replacement, Stream Daylighting, Tidal Restoration, Rare Species Habitat Restoration, or Restoring Fish Passageways. These six project types are considered “Ecological Restoration Projects” and require a different form (Form 3A) and process (310 CMR 10.13 (2-7)).

Under the “Limited Project” type, the applicant must show that a project improves the natural capacity of a specific resource area. This includes projects proposed primarily to enhance fisheries habitat, address eutrophication, or increase dissolved oxygen or improve overall water quality in a water body. Ecological Restoration Limited Projects fall into five categories; #5 is “Other Restoration Projects.” According to the MACC Handbook (2016, p. 18.7.4), this category applies to projects designed “to enhance biodiversity through the removal and/or management of invasive species and through native plantings. It can also be used to justify removal of aquatic nuisance vegetation, and thinning or planting of vegetation to improve habitat value.” DEP’s Guidance (2004, p. 1) notes that “projects involving removal of aquatic nuisance vegetation must demonstrate that the vegetation is a ‘nuisance’ to the interests of the act.” Water chestnut, as a non-indigenous invasive plant species, fits the definition of nuisance vegetation.

As an Ecological Restoration Limited Project, the environmental impacts are reviewed at two levels: the local Conservation Commission, which has jurisdiction under the Wetlands Protection Act and any local wetland bylaw/ordinance, and the Massachusetts Environmental Policy Act (MEPA) Unit, which has jurisdiction over state-funded or state-authorized projects of a certain size or scope. Mass. DEP may choose to review projects as part of the Wetlands Protection Act and other regulations. If there are rare species in or adjacent to the waterbody, approval for control actions will be needed from the Natural Heritage and Endangered Species Program (NHESP). Other agencies and approval programs may apply, depending upon the features of the waterbody (e.g., naturally large enough to be a statutory Great Pond), its location (e.g., in an Area of Critical Environmental Concern), or its uses (e.g., as a water supply) (ENSR, 2005; Langley et al., 2004). Provided there is no discharge of dredge or fill materials, the

federal Clean Water Act (Section 404) should not apply. The Clean Water Act’s Sec. 401 Water Quality Certificate should not be required for the same reason unless a herbicide is used.

Small-scale hand-pulling efforts may not need formal approval, at the discretion of the Conservation Commission. However, organized larger-scale hand-pulling may significantly disturb sediment (resource area = “land under water”) and generate quite a lot of pulled material and may need to be reviewed through a Request for Determination of Applicability (RDA). This is at the discretion of the Conservation Commission so meeting with the Conservation Agent well in advance of any planned work is advisable. For organized hand-pulling that is seen to disturb “land under water,” a Request for Determination of Applicability is submitted to the municipal Conservation Commission. The Commission may issue a *negative* Determination (thus not requiring a Notice of Intent), with the provision that DCR’s Standard Operating Procedures are used (Mass. DCR, 2007), and other conditions as needed. This process enables the Commission to confirm that proper methods are being used for the hand-pulling and disposal of the weeds. If a *positive* Determination is issued, the next step is for the applicant to submit a Notice of Intent.

There were differences of opinion about permitting hand-pulling among the towns responding to OARS’ survey question: “What type of permitting would be needed for hand-pulling?” (see Appendix I). The Request for Determination should probably be used more frequently than it is currently because it provides information to the Conservation Commission and provides a record in case of local complaints or concerns. Using equipment such as harvesters and hydrorakes to remove water chestnut, on the other hand, will generally need permitting through an Order of Conditions.

Table 3: Survey Responses

Permitting for Handpull (49 responses)	Number
Administrative or none	13
Request for Determination	18
Order of Conditions	12
Emergency Order	2
Unsure	4

To obtain an Order of Conditions, the applicant must submit a Notice of Intent that specifies the scale and scope of the project, location(s), and equipment and disposal methods. The forms for the Limited Project are the Wetlands Protection Act (WPA) Form 3 (Notice of Intent) and Appendix A (Ecological Restoration Limited Project Checklists). These cannot be filed electronically. The Limited Project application requires submitting a plan, a determination letter from the Natural Heritage and Endangered Species Program (if there is an endangered plant or animal species habitat mapped in that area), and publication in the Environmental Monitor (www.mass.gov/eea/agencies/mepa/submitting-notices-to-the-environmental-monitor.html), and abutter notification. While there is a fee for the filing for most applicants, town departments are exempt from the fee.

If the project does not exceed these thresholds for a Limited Project (Table 2), a regular Notice of Intent without Appendix A is appropriate. This can be filed electronically and does not need publication in the

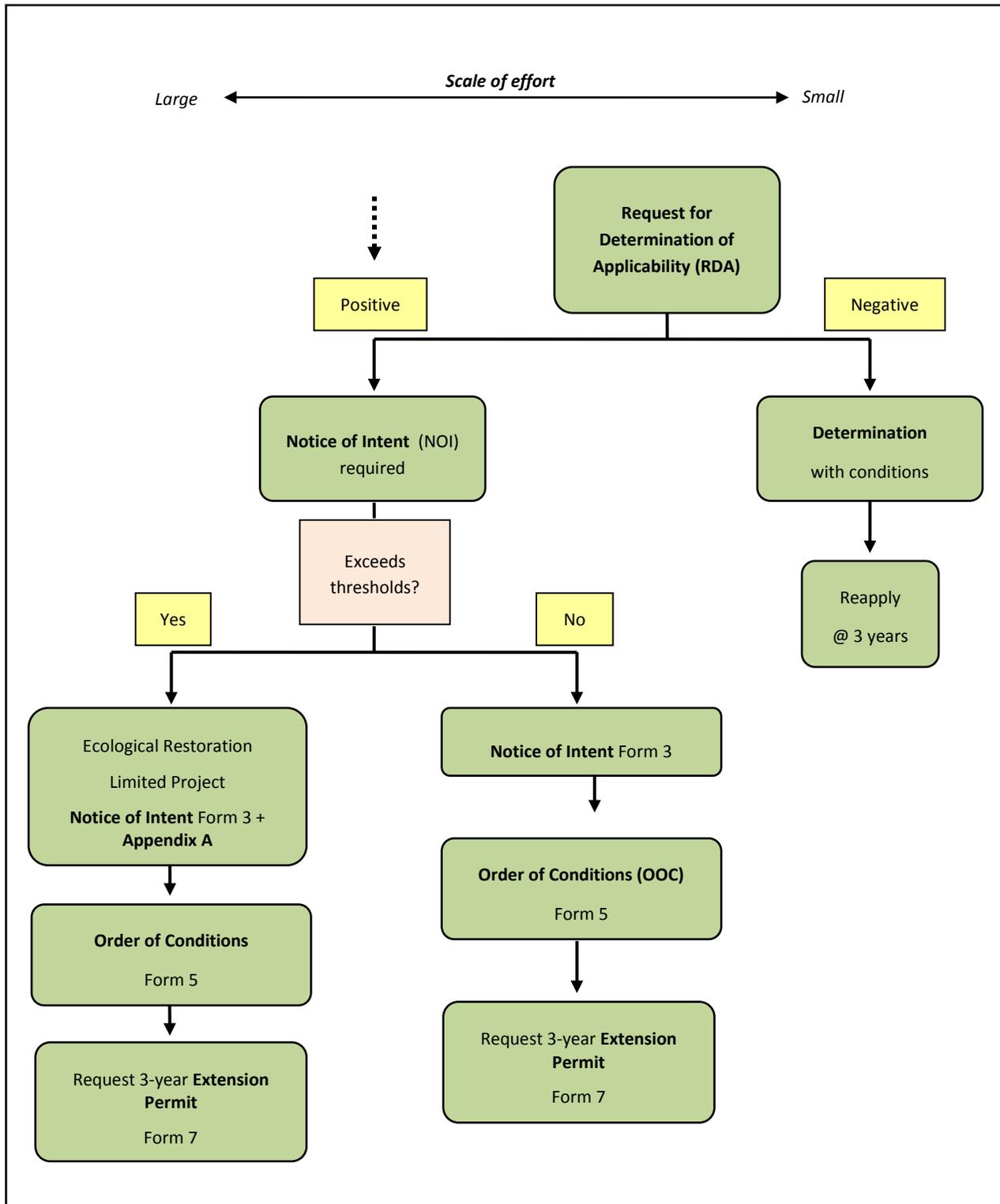
Environmental Monitor. It does require abutter notification. The Order of Conditions may be written to cover similar efforts elsewhere in the municipality (a “generic” Order of Conditions) if so requested in the Notice of Intent. In this case it is preferable to have one town entity or person designated as the coordinator who can delegate the work to other groups, departments, consultants or individuals in order to maintain accountability and compliance with the Conditions. This is often a municipal department, such as Public Works.

The Order of Conditions should include erosion control at the location where equipment is put in the water, proper plant disposal, and minimizing disruption of bottom sediments, particularly where they may be contaminated. These aspects should be thought through in advance by the applicant and included in the Notice of Intent where possible. Orders of Conditions may be issued for 3-5 years and be extended upon request an indefinite number of times. Applicants and Commissions should review the *Guidance for Aquatic Plant Management in Lakes and Ponds as it Relates to the Wetlands Protection Act* (Langley et al., 2004). Useful procedures are described in DCR’s *Standard Operating Procedures: Using Hand Pulling and Benthic Barriers to Control Pioneer Populations of Non-Native Aquatic Species, A Guide for Volunteers* (2007, on the DCR website), and in the much more detailed document *Final Generic Environmental Impact Report: Eutrophication and Aquatic Plant Management in Massachusetts* (Mass. EOEAA, 2004), available on the EOEAA website.

Herbicide application to water bodies or aquatic plants requires permitting under the Wetlands Protection Act through a Notice of Intent. The herbicide must be applied by a licensed applicator. Herbicide licenses issued by the Mass. DEP, Office of Watershed Management (Bureau of Resource Protection) using Form BRP WM 04 are also required to apply chemicals for the control of nuisance aquatic vegetation in waterways. No herbicide license is required for treating a privately-owned pond with a single owner from which there are no flowing outlets, although this activity will still require approval from the Conservation Commission.

Dredging permitting is more complex. Typically a study is done first to determine what native species are present and how dredging will affect them. This requires the Department of Fish and Game to look at the proposed location and ensure it will not be harmful. An Order of Conditions will be required from the local Conservation Commission. Restrictions may then be put on the extent of drawdown and dredging and other elements of the project. The Army Corps of Engineers must also issue a permit under the Clean Water Act, Section 404 which requires a permit before dredged or fill material may be discharged into waters of the United States. Depending on the amount of material dredged, a Section 401 Water Quality Certificate from Mass. DEP may also be required.

Figure 8: Wetlands Protection Act Permitting Flow Chart



REQUEST FOR DETERMINATION OF APPLICABILITY (RDA)

An RDA is made to the Conservation Commission to determine whether the proposed work requires filing a Notice of Intent and issuance of an Order of Conditions, or not. In this case, the question is not whether the work is in a resource area, as by definition it is in “land under water,” but rather whether the proposed work will affect the resource such that it needs a more complete review and Order of Conditions under the Act or a local bylaw/ordinance to ensure protection of resource areas. An applicant can skip the RDA and go directly to filing a NOI if they prefer. The applicant uses WPA Form 1. There are instructions on the same web page. There is no fee or abutter notification under the state Wetlands Protection Act, although local bylaws/ordinances may require one or both. The applicant must pay for a legal notice of the application in a local newspaper that is published at least five days prior to the hearing. The Conservation Commission can advise regarding placing the public newspaper notice. The RDA should include a narrative describing the work to be done and at least a sketch plan showing the areas where removal is proposed, along with any other proposed activity

DETERMINATION OF APPLICABILITY

The outcome of an RDA filing will either be a positive or a negative Determination of Applicability, using Form 2. A *positive* Determination means that the applicant must file a Notice of Intent for the proposed work. A *negative* Determination means that the work does not require permitting, and can be issued with or without conditions. While a Negative Determination with conditions is has fewer procedural requirements, the commission retains the right to require an NOI if the conditions are not followed. Note, however, that no abutter notice and no public hearing is required for an RDA/Determination under the state Wetlands Protection Act. So the public doesn’t get official notice, other than the request being listed on a Conservation Commission’s agenda. Members of the public may feel uninformed if they subsequently observe control activities. A negative Determination expires after three years, after which a new RDA must be submitted. It cannot be extended. See sample RDA in Appendix II.

Possible conditions could be:

1. A preconstruction site visit shall be held to review work and inspect the erosion control barrier.
2. A report shall be submitted after the project has been completed documenting that the work has been conducted in accordance with all conditions of this Determination of Applicability.
3. Invasives shall be disposed of at an appropriate off-site location or covered with a tarp and “cooked.”
4. Hand-pulling of invasives is permitted site-wide in perpetuity.

NOTICE OF INTENT (NOI)

Applicants for Ecological Restoration Limited Projects use WPA Form 3 plus Appendix A for the NOI. Appendix A is an Ecological Restoration Limited Project Checklist that “guides the applicant in determining if their project is eligible to file as an Inland or Coastal Ecological Restoration Limited Project” MACC, 2016, p. 18.7.4). Applicants for Ecological Restoration Projects (not “limited”), such as larger dredging projects, use an Ecological Restoration NOI form, WPA Form 3A, instead.

Before filing an NOI for an Ecological Restoration Limited Project, an applicant must: (1) submit notification to the *Environmental Monitor* 14 days prior, and (2) if the project will occur within “Priority Habitats of Rare Species” (shown on the most recent Estimated Habitat Map of State-listed Rare Wetlands Wildlife as yellow cross-hatching, http://maps.massgis.state.ma.us/PRI_EST_HAB/viewer.htm), the applicant must receive a written determination from the Natural Heritage and Endangered Species Program (NHESP) that Preliminary Massachusetts Endangered Species Act Review has been met (see 310 CMR 10.11). Similarly, if the project will occur within “Estimated Habitats of Rare Wildlife” (shown on the same map as green cross-hatching), the applicant must receive a written determination from NHESP as to whether or not the project will have long- or short-term adverse impacts.

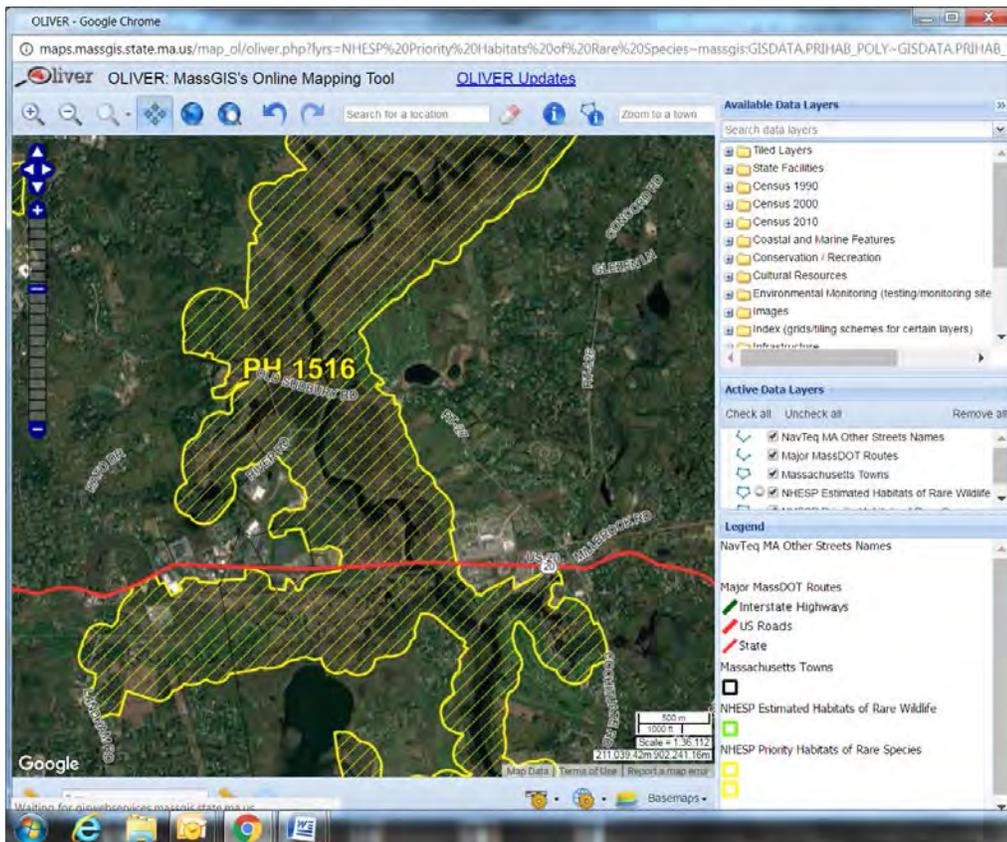


Figure 9: Sample Priority Habitat Map of State-listed Rare Species

Additionally, if there are time-of-year restrictions in a coastal water body, or the project will affect a diadromous (migratory) fish run, a determination from the Division of Marine Fisheries is required. Work that generates silt, or involves dredging of over 100 cu. yds., also has specific requirements. These requirements are spelled out in the Wetlands regulations at 310 CMR 10.11 and 10.12 and must be met.

Because water chestnut control always requires several years of continuous work, it is advisable for the applicant to seek an Order of Conditions for the maximum duration, 5 years, and that provides for adaptive management. Adaptive management allows adjustment of the control method based on the actual conditions. This approach should include annual monitoring and reporting to the Conservation Commission. The Commission should approve any adjustment of the control approach, e.g., moving from mechanical to hand harvesting when population densities are significantly reduced. An adaptive management approach will be more effective, and save time and money over permitting one single approach without monitoring and adjustment. See sample NOI in Appendix II.

ORDER OF CONDITIONS (OOC)

Orders of Conditions use WPA Form 5; these can be issued for a maximum 5 year duration, and be extended upon request. As noted above, there are many advantages to issuing a 5 year permit which covers all desired methods, with monitoring and switching of method as needed. The schedule for monitoring and reporting to the Conservation Commission should be made clear and be in sync with the seasonal growth patterns of the plant and the work to be performed. See sample OOC for mechanical harvesting in Appendix II.

GENERAL/GENERIC TOWN-WIDE PERMIT REQUIRING CC NOTIFICATION OF SPECIFIC ACTIVITIES

If there are many sites within a municipality where water chestnut control is needed, or can be anticipated, it may be more efficient for the applicant to apply for a town-wide “generic” permit. This is best done when a single NOI applicant will be managing all of the covered waterbodies, such as a municipal department, or is able to delegate or contract the management to others, such as community groups or lake management consultants. This should also take an adaptive management approach, recognizing the different stages and needs of each waterbody in the community, and include monitoring.

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