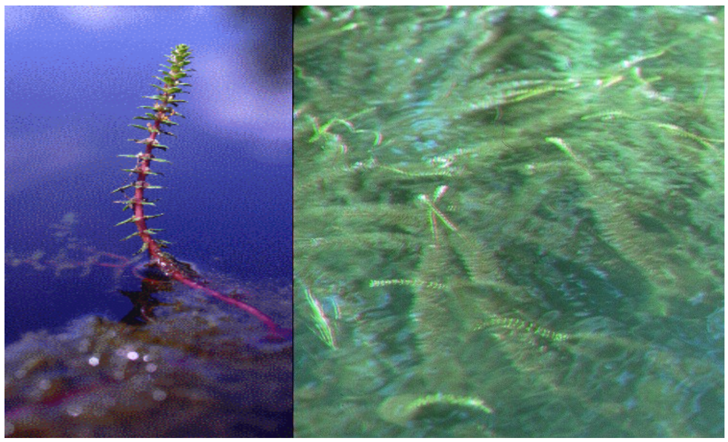
RAPID RESPONSE PLAN FOR VARIABLE WATERMILFOIL (*Myriophyllum heterophyllum*) IN MASSACHUSETTS



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Species Taxonomy and Identification
Variable, or two leaf milfoil, *Myriophyllum heterophyllum* (VWM) is a submerged perennial aquatic herb. The stem of VWM is stout, robust, and typically red in color, with white, thread-like roots which are not always present. VWM can have two distinct leaf types, emergent and submergent. Submerged leaves are featherlike and delicate, usually in whorls of 4-6 around the stem, each with 6-12 segments. The emergent leaves of VWM are small, oval and typically bright green in color. Teeth are sometimes present along the edges of the leaf, and leaves are arranged in whorls around the stem. Emergent leaves are associated with mature plants and may be present during summer months. Winter buds are formed at the base of the plants, and not along the erect stem (Aiken 1981). The flowers of VWM are green to reddish in color, and grow on 2-12 inch spikes above the surface of the water. The floral bracts are whorled, and smaller than the foliage leaves. The fruit is four-lobed, and splits into four distinct sections. VWM is commonly described as having a raccoon-tail or pipe cleaner appearance due to its fine leaves but bushy appearance (Figure 1).

According to Crow and Hellquist 2000, the following taxonomic characteristics are used to identify VWM to species:

1. Leaves pinnately divided, with filiform segments; vegetative stems elongate.
2. Leaves whorled.
3. Uppermost flowers opposite; leaves mostly 8-45 mm long.
4. Spikes with reduced bracteate leaves.
5. Bracts usually more than twice as long as pistillate flowers.
6. Bracts of upper portion of inflorescence serrate, somewhat pectinate at the water line; winter buds developed at base of stems or on rhizomes, usually persisting.
7. Middle leaves with 12 or more segments on each side of rachis; many of the uppermost leaves truncate at apex; stem diameter below inflorescence greater, up to twice the diameter of lower stem; stem tips usually reddish; winter buds not formed among leaves.

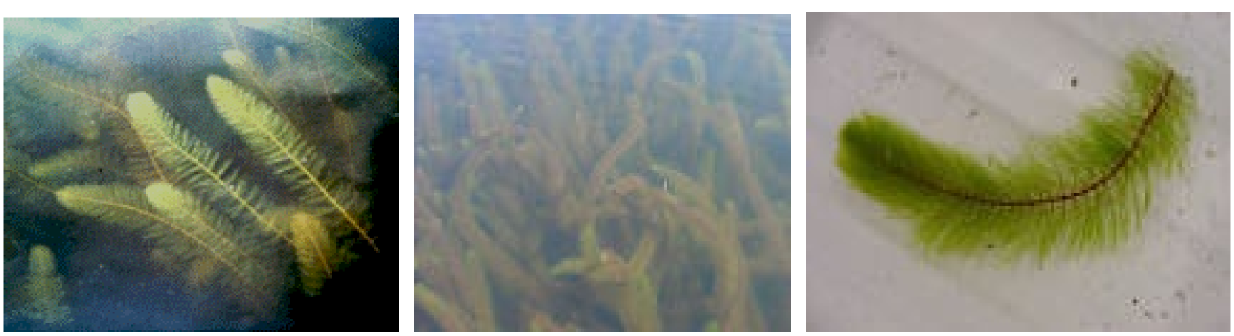


Figure 1. Photographs of variable milfoil. Photos taken from “variable_milfoil.doc” located on the Massachusetts Department of Conservation and Recreation website and the state of Maine website.

Species Origin and Geography

Variable watermilfoil is native to the southern portions of the United States from Florida to Texas. Today, it ranges throughout the eastern United States, westward to North Dakota, south to New Mexico, and as far north as Maine and Quebec (Figure 2). However, to date, VWM has not been located in Vermont. The first specimen collected in New England was collected in 1932 in Bridgeport, Connecticut. Plant fragments are easily transported to new waterbodies by boats, trailers, fishing gear, wind, animals and currents (Aiken et al. 1979). In one study, Minnesota authorities found aquatic plants on 23% of all boats inspected (Bratager et al. 1996). Plant fragments transported to new waterbodies can become rooted and form new shoots. In Massachusetts, is it largely a plant of the eastern coastal plain and the granite belt bordering New Hampshire, both areas with acidic waters, and is absent from the more alkaline Berkshire lakes. It often co-occurs and competes with fanwort (*Cabomba caroliniana*) another invasive plant.

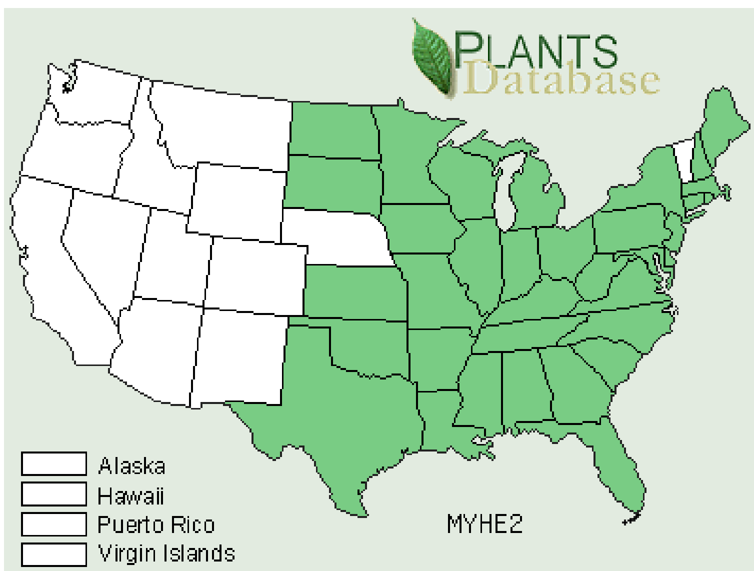


Figure 2. A map indicating the present range of *Myriophyllum heterophyllum*. This map was taken from The USDA Plant Data Base. http://plants.usda.gov/cgi_bin/topics.cgi

Species Ecology

Variable watermilfoil is a hearty plant able to survive a wide range of environmental conditions. VWM prefers slow-moving and still waters of ponds, lakes, streams, ditches, spring-fed swamps and sloughs, and grows in depths up to 10 feet. It thrives in warm waters, but can also over-winter in the colder northern temperatures. VWM grows in acidic and alkaline waters, can tolerate a wide range of calcium concentrations, and prefers fine textured sediments with high ammonium nitrogen levels (Crow and Hellquist 1983). It is most commonly associated with slightly acidic waters with sediments of high organic matter content. Although it sometimes co-occurs with Eurasian watermilfoil, variable watermilfoil tends to occupy the same ecological niche and occurrence of these two species appears to be split mainly on the basis of pH.

VWM produces seeds in the summer, although re-growth from seeds is not common. Similar to Eurasian watermilfoil, the majority of reproduction is through the spread of vegetative fragments and rhizome expansion. Pieces of plant fragments are easily broken off through physical contact with boat props or currents. Plant fragments are easily transported to new waterbodies by boats, trailers, fishing gear, wind, animals and currents (Aiken et al. 1979). Fragments released naturally in the fall root and begin growing in spring. Fragments generated by boats or other disturbances earlier in the year may lead to new plant growths the same year. VWM also reproduces through the formation of winter buds near the base of the stem.

Detection of Invasion

As VWM enters lakes with flow, boats and birds in the vast majority of cases, the logical places to look first are the mouths of tributaries, boat ramps and areas of higher bird concentrations. While mature VWM growths will usually "top out", reaching the surface and forming a canopy, new infestations may be less obvious and often require underwater examination for early detection. Although VWM can grow in water as deep as 15 ft, it is typically found in shallow waters (<10 ft deep) and is likely to be visible from a boat with a viewing tube or by snorkeling if water color is not too high. Use of an underwater video system (Aqua-Vu or equivalent) can be very helpful in scanning large areas of variable depth, but is more expensive and not usually necessary for detecting early invasion.

Sources may not be obvious, but the pattern of occurrence observed during early detection may provide useful clues. Appearance near boat ramps suggests boats as vectors, while appearance in more remote areas with no direct access or inflows suggests birds as the source. Where growths are detected near the mouth of a tributary, it would be appropriate to check the next upstream waterbody or the stream bed itself if conditions are suitable for rooted plant growth.

There are multiple methods of plant survey, and no truly standardized technique. The object is to be as thorough as time and trained manpower allow, maximizing detection probability. To detect a suspected invasion, or simply to monitor for possible invasion, consider the following steps:

1. Acquire a suitable map of the waterbody, showing shoreline features and reference points, and preferably with water depth contours.
2. Use the taxonomic information supplied here, or supplementary information from taxonomic guides, plant keys, or herbarium sheets to identify VWM.
3. As VWM overwinters in a vegetative state, it can be surveyed any time, but is most easily detected and identified in spring as one of the earliest plants to begin growth or in late summer when it may reach the surface.
4. Ideally, space transects around the waterbody, extending from shore to the end of plant growth, with one transect per defined shoreline segment, determining transect location with GPS or readily identified shoreline features. Segments should be of roughly equal length, but this can be based on actual shoreline, straight distance across the water, land use or other features of concern or interest, or encompassed waterbody area. Be sure to cover all boat launch, swimming, inlet, bird congregation, key habitat and intake areas, and any other key access points.

5. Priority can be given to transects of key concern, either based on likely invasion points (access points) or potentially threatened resources (intakes, swimming areas, key habitat) if the number of transects is too great for the manpower and time resources available, but recognize the limitations this will impose on invasion detection.
6. Using a boat with a viewing tube or underwater video camera, or employing snorkeling or SCUBA gear, examine the plant community along transects between the shore and the maximum depth of plant growth (typically <10 ft). Note presence/absence of VWM and extent of coverage and density where VWM is encountered. Record observations for 2 ft water depth intervals, with each observation representing either a defined area within the depth range or the length of the transect between depth intervals (typically 0-2 ft, 2-4 ft, 4-6 ft, and so on). GPS is particularly useful for both transect and point location for future reference.
7. Tabulate all data in a manner that facilitates future comparisons, typically in a spreadsheet or GIS format. Evaluate presence of any VWM, extent of coverage and density, and pattern of occurrence. Map the distribution of VWM in the waterbody for visual reference.
8. Repeat the survey at least once every 3 years (about the time for an invasion to have a detectable impact), and preferably every year to allow the earliest possible detection.

Species Confirmation

Unless the invasion is discovered by individuals trained in plant taxonomy, samples should be sent to competent taxonomists for confirmation. In Massachusetts, the Department of Conservation (DCR), the Department of Environmental Protection (DEP), the Massachusetts College of Liberal Arts (North Adams, specifically Dr. Barre Hellquist), and the University of Massachusetts at Amherst (UMASS) have the expertise to assist in plant identification. Many consulting and lake management firms also possess this expertise, but it will be the responsibility of the DCR to determine where specimens should be sent. Therefore, the DCR at 617-626-1411 or 617-626-1395 should be the first point of contact.

Key steps in confirming an invasion include:

1. Collect complete specimens of the suspected VWM; root systems are less critical for this species, but it is helpful to know that the whole stem has been harvested, and removal of the root crown is necessary for plant control. Place the specimen in a clear container with water for easy viewing (clear 2-L soda bottles without labels work well); keep chilled. Alternatively, specimens can be pressed on a sheet of appropriate (absorbent) paper, covered with wax paper and a stack of books or other suitable weight (an actual herbarium press is useful if available).
2. Contact the DCR representative at 617-626-1411 or 617-626-1395 and inform him/her that a suspected occurrence of VWM has been detected in the waterbody. The DCR contact will assess past records for the waterbody and will instruct the caller where to send a sample for confirmation, if warranted.
3. As soon as possible, preferably within 2 days, send specimens to the identified DCR representative for confirmation, or to a taxonomic expert as designated by the DCR contact. Note in writing that the enclosed specimen is believed to be VWM and include the name of the waterbody, the approximate location in the waterbody (a map is helpful) with water depth and

any other site-specific observations, the date and time of collection, and the name, address, phone number and email for the collector or sender.

4. The DCR will confirm the identification or provide an alternative identification either directly or indirectly through a recognized taxonomist, and will be responsible for notifying all appropriate agencies, municipalities and citizen groups either potentially affected or responsible for follow-up actions.

Quantifying the Extent of Invasion

Gaining effective control of VWM depends on detecting all growths, as this species can expand rapidly. The initial discovery may be made during a routine mapping exercise, but mapping approaches suitable for overall plant assemblage characterization (e.g., point intercepts on a grid or transects) may not be appropriate for thorough coverage of recent invasions. Where a growth is detected, it is likely that expansion in the first growing season will be by root crowns, so viewing each discovered growth in concentric circles moving outward from the apparent center will best facilitate mapping of the growth. Detection of additional growths is best accomplished by a thorough visual inspection of the newly infested area, either using tightly spaced transects radiating out from the first discovered growth or focused in the direction of likely current or wind transport.

If the waterbody is large, effort may have to be limited to the most likely locations for invasion. In this regard, examination of any existing plant maps may be helpful. Look for areas of suitable depth (<15 ft, with emphasis on areas 2-10 ft deep) and substrate (moderately organic bottom), known plant and bottom disturbance (marinas, boating lanes, windswept shallows), and plant assemblages of lower density and/or lesser canopy formation.

Evaluation of recent VWM growths should focus on extent of coverage and degree of dominance. Biovolume or biomass measures are useful but time consuming and are not critical to combating new infestations. Careful stem counts are helpful in assessing the efficacy of possible controls, but are also time consuming. An estimate of stems per unit area and the area covered is more valuable in assessing potential controls for new growths. With regard to dominance, it is important to note other species present, as the presence of protected species and the relative abundance of seed producers vs. vegetative propagators are important to planning management actions. A list of plant species with an approximation of the percent of the community each represents is appropriate.

Assessing the rate of expansion may not be necessary if the invasion is detected early and prompt control actions are implemented. However, where VWM has been present for more than a single growing season, information on the rate of expansion may be helpful in planning a control strategy and in garnering support for rapid action. Isolated plants are likely to signal the first year of growth, while scattered plants are likely to represent the second year of growth and well established beds will normally be more than two growing seasons old.

Useful steps in quantifying the invasion include:

1. Use the data generated by the transect method in the section on Detection of Invasion to get a first impression of the extent of invasion, preferably in mapped format. Where VWM is discovered in multiple locations, look for spatial patterns that suggest either transport from the earliest infestation or invasion from multiple sources.
2. If a discovered growth is in a definable cove, examine the entire cove, or at least that portion with a water depth <10 ft.
3. If a discovered growth is associated with a boat ramp, check a suitable area (typically 1-2 acres) associated with that ramp, and check other ramps if present.
4. Where growths occur near a tributary mouth, check area maps for upstream ponds or impoundments on the offending stream and any other tributary and investigate where possible VWM sources seem most likely.
5. When the new growth appears associated with areas of bird congregation, check all such areas in the waterbody.
6. In all cases, note which areas have established beds vs. scattered plants vs. a single plant or just a few stems.
7. Identify all other plants in association with VWM growths, to the limit of areas likely to be targeted for control. Follow the protocols for species confirmation where specimens of unknown identity are encountered, paying particular attention to possible protected species or other invasive species.

Species Threat Evaluation

Threats from VWM are similar to those of both Eurasian watermilfoil (a closely related invasive species typically found in more alkaline lakes) and fanwort (an unrelated invasive plant found in the same acidic habitats). New shoots grow rapidly in the spring and branch repeatedly as they approach the surface of the water. Leaf canopies created by fast growing shoots shade out the germinating seeds or vegetative propagules of understory plants, eventually replacing the native plants and reducing species diversity. Dense and extensive growths of VWM can affect water quality, including oxygen, pH and organic content. Monospecific stands of VWM can negatively affect wildlife, and can alter the predator/prey relationship among fish as well as the overall ecology of an aquatic ecosystem. Fruits of VWM are consumed by aquatic waterfowl, but are not considered a high quality food source. Human uses can be severely impacted by VWM.

The impacts to the aquatic ecosystem due to VWM infestations are similar to those caused by infestations of Eurasian watermilfoil. Dense growths of VWM limit human uses of the waterbody, as these plants can choke channels, clog water intakes, and restrict aquatic activities such as fishing, swimming and boating. Limitations on water uses can negatively impact real estate values (Varney and Christie 2003). The mass of large mats can cause flooding in some waterbodies (www.ecy.wa.gov 2004), and increase sedimentation by trapping detritus (Adams and Prentki 1982).

Oxygen levels can be reduced underneath large VWM mats due to a decrease in wind mixing, and decaying mats decrease oxygen and increase the nutrient load to the waterbody (Honnell et al.

1992; Engel 1995; www.ecy.wa.gov 2004). High levels of photosynthesis elevate pH and day-night variation causes potentially deleterious pH fluctuations at high VWM biomass. Decay of large plant masses puts elevated levels of dissolved and suspended organic matter into the water column.

Aquatic macrophytes can provide food, shelter and spawning habitat for a wide variety of fishes (Lillie and Bud 1992). Intermediate densities of aquatic macrophytes, including milfoils, may enhance fish diversity, feeding, growth and reproduction (Dibble et al. 1996). Yet VWM tends to replace native macrophytes in areas where it is introduced, creating food shortages for fishes (Engel 1995). Dense beds of milfoil can also impede predation, shelter panfishes, and cover spawning areas, leading to potential decreases in sportfish abundance (Engel 1995). Large piscivorous fishes spend more time foraging for prey as density increases, thus reducing growth rates (Savino and Stein 1982). Milfoil beds have been shown to decrease fish abundance compared to native vegetation, and Keast (1983) found that beds of native vegetation supported up to four times as many fish, and up to seven times as many macroinvertebrates. Decreases in macroinvertebrate abundance were observed as Eurasian milfoil coverage increased in one Michigan study examining six lakes (Cheruvelil et al. 2001), and results for VWM are expected to be similar. The depletion of oxygen in waterbodies with dense milfoil coverage can also result in fish avoidance, and in extreme cases could cause fish kills (Holland and Huston 1984, Lillie and Bud 1992, Engel 1995).

Potential spread within the waterbody is governed by the physical features of the waterbody (especially water depth and substrate) and the level of activity of potential vectors of spread for VWM (especially boats, birds, flow and currents). VWM can grow on a variety of substrates, although nuisance densities are most likely to be achieved over fine grained sediments with high ammonium nitrogen levels (Crow and Hellquist 1983). Rocky to gravelly substrates support lesser densities and very loose muck provides an unstable substrate where growths will be variable over space and time; muck sediments or sand with high organic content are the preferred substrates in Massachusetts. The depth range for VWM is from shore to about 15 ft, but in the vast majority of cases, nuisance growths are observed only between 4 and 10 ft (Aiken et al. 1979). Boats and birds can actively transport VWM within a waterbody, but VWM also creates fragments that drift with currents.

Potential spread outside the waterbody is mainly a function of surface outflow, birds and human activities. Overflow can carry viable fragments downstream to additional waterbodies. Birds may transport fragments, but are more likely to carry seeds, either externally or in their digestive tract. Seeds are considered to be a limited source of new plants (Coble and Vance 1987), but even at low viability, this is a potentially important means of invasion. Transport by humans is a known threat, with movement of fragments in or on boats and trailers well documented (Johnstone et al. 1985, Bratager et al. 1996).

All of these factors combine to create a site-specific level of threat. Of primary interest are how great an infestation may become, how readily it may be transmitted to new areas (both inside and outside the infested waterbody), what resources may be impacted to what degree, and what the potential is for eradication or control through rapid response to detection of an invasion. In evaluating the potential threat from a new VWM infestation in DCR parks on a case by case basis, the DCR staff will consider the following:

1. What portion of the waterbody could be colonized (estimate as the area with water depth <15 ft)?
2. What is the potential for dense bed formation (estimate as the area with fine sediments with high organic content, usually in water <10 ft deep)?
3. What is the potential for rapid (<3 years) spread of VWM (estimate as the common area from #1 and #2 above and not densely covered by native plants)?
4. What is the potential strength of vectors of internal VWM spread (boat traffic, flow, currents, open expanses vs. isolated coves)?
5. What is the potential strength of vectors of external VWM spread (trailered day-use boats, daily or seasonally mobile bird populations, outlets without screening)?
6. What resources and uses are potentially threatened (water supply, swimming, boating, fishing, aesthetics, sensitive or protected populations)?
7. What is the potential for eradication (based on extent and density of coverage, vectors of spread)?
8. What is the potential for confinement (based on extent and density of coverage, physical isolation of area affected, vectors of spread)?

By answering these questions, one can characterize the threat according to the following matrix, which can then govern the response to detection of an invasion:

FACTOR	YES	NO	THREAT EVALUATION	HIGH	MEDIUM	LOW
A large area could be affected			Extent and speed of possible infestation			
Plant density could be high						
Spread could be rapid						
Water supply may be impacted			Nature of possible impacts			
Swimming may be impacted						
Boating may be impacted						
Fishing may be impacted						
Aesthetics may be impacted						
Sensitive species may be impacted						
Protected species may be impacted						
Spread by water flow likely			Ability to spread			
Spread by birds likely						
Spread by boating likely						
Spread by other human activities likely						
Eradication is possible			Potential success of rapid response			
Confinement is possible						

Communication and Education
Once the presence of VWM has been confirmed, the town(s) in which the waterbody is situated should be notified, usually through the Conservation Commission, which will have a chairperson or an agent who is reachable through Town Hall. It would also be appropriate to notify all relevant stakeholder groups, but these need to be identified and many will not have a central clearinghouse contact for notification. Groups who should be informed about the infestation include any active lake association, shoreline property owners, boaters, anglers, swimmers, birdwatchers, and water suppliers. Notification through individual contacts is desirable but may be inefficient. Posting a notice in the local paper will help publicize the problem, but the notice may not receive widespread attention. Posting the waterbody at access points is perhaps the most effective approach, as it is the actual users that should be informed and warned to avoid spreading VWM.

It is desirable to post access points with warning signs even before an invasion, displaying a picture or drawing of VWM and asking waterbody users to be on the lookout for this invasive plant. Users, particularly boaters, should be asked to inspect their boats and any trailers prior to launching, and to remove any discovered plants with proper disposal in a manner that prevents the plant from reaching the waterbody. A local contact (name and phone number) for notification should be given, typically either a representative of the lake association or the town's Conservation Commission, or both. Users should be advised to mark the location where the plant was observed if at all possible, but not to pull it out unless they can get the whole plant, including the roots. As most users will not be diving or snorkeling, immediate, effective hand harvesting is probably not a realistic expectation.

After an invasion has been discovered, access points should be posted with a warning to users to avoid any action that could spread VWM. Again, a picture or drawing of VWM should be provided, and any known locations of the plant should be shown on a map of the waterbody. Users should be asked to notify a local contact if VWM is found in other areas not shown on the map, and to avoid motorized boating in areas with VWM. All boats, trailers, fishing equipment, bait buckets or other possible means of transport should be inspected and cleaned prior to leaving the waterbody.

Responsibility for control of VWM does not rest with any one entity under the laws of the Commonwealth of Massachusetts. Approval for control actions is governed by the Wetlands Protection Act, which always involves the town Conservation Commission and the Commonwealth's DEP. Approval for control actions may also involve the Division of Fisheries and Wildlife and/or the Natural Heritage and Endangered Species Program, both agencies of the Commonwealth, depending upon the resources in the waterbody (particularly if protected species are known from the waterbody). Other agencies and approval programs may apply, depending upon the features of the waterbody (naturally large enough to be a statutory Great Pond), the location of the waterbody (e.g., in an Area of Critical Environmental Concern), or the uses of the waterbody (e.g., as a water supply). However, none of these agencies is charged with controlling invasive species, and there is no legislation in Massachusetts that mandates control of VWM. The DCR has taken the lead in Massachusetts with regard to encouraging control of invasive species, and supports control efforts as its budget allows. However, outside of the state parks and reservations, control is largely a function of local desire to protect and maintain the resource.

For waterbodies within DCR parks, the following notification procedures are to be followed when a new infestation by VWM has been confirmed:

1. The DCR contact responsible for confirming the VWM invasion will notify the DCR Regional Director, Park Supervisor and any regional DCR contact charged with managing water resources. A single letter copied to each party is preferred. The letter should briefly state the problem and outline immediate control steps that are needed, indicating an expected date for a follow up visit by Lakes and Ponds Program staff to begin concerted control measures (see posting procedures below).
2. The DCR contact responsible for VWM invasion confirmation will also notify the DEP, the DFW and the NHESP in writing; a copy of the letter sent to DCR parties is sufficient. If a contact for an associated citizens' lake or watershed organization is known, notification should be given to that group as well.
3. The Regional Director or a designated park contact for local affairs will notify the town(s) in which the park and waterbody are situated. The appropriate parties within the town(s) to be notified may vary by town, but should include the Conservation Commission and either the Selectmen, Town Manager or Mayor, depending upon local government structure.

For waterbodies within DCR parks, the following posting procedures are to be followed when a new infestation by VWM has been confirmed:

1. All access points to the waterbody (e.g., boat launches, swimming areas, fishing piers or obvious shoreline fishing points) shall be posted with a photograph or drawing of VWM and a written notice that this invasive plant has been found in the waterbody.
2. Suggested language is as follows: Warning. Variable watermilfoil (*Myriophyllum heterophyllum*) has been found in this waterbody. This invasive plant represents a threat to this waterbody and its users. Caution should be exercised to avoid the spread of this plant. Do not pick or remove this plant if you encounter it, and be sure all equipment brought to this waterbody is clean before leaving.
3. Include a contact name and phone number on all postings.

Quarantine Options

Both natural processes and human activities can spread VWM, both within an invaded waterbody and to other area lakes. Minimizing the spread of VWM may require some form of quarantine. Making the waterbody off limits to all users is an extreme action not typically justified for new growths that are likely to be limited in areal coverage. However, keeping people out of infested areas may be a valid option. This may be done by signage, buoys, or an actual sequestration curtain, with cost increasing dramatically in the listed progression.

Where the invasion is occurring at a boat ramp, closure of the ramp may be justified; this will both limit the spread of VWM and generate public awareness of the problem and a desire to take action against the VWM. A town may take such an action where the public welfare is deemed to be at stake for a boat ramp owned by the town, but it is not clear that such action is legal for private boat ramps, and towns do not have the authority to close ramps owned by the Commonwealth. Consult with private owners or the Public Access Board of Massachusetts when considering closure of a ramp not owned by the town.

Where the invasion is occurring in a swimming area, closure of that area will have much the same effect and limitations as for boat ramps. If the VWM growths are localized, it may be possible to partition off the infested area by moving the buoyed ropes that usually delimit swimming areas. If the growths are extensive, it may be appropriate to close the swimming area on the basis of public safety; people can get tangled in dense milfoil infestations and drown.

The use of sequestering curtains or screens can both restrict access to an infested area and limit the spread of VWM by vegetative fragmentation. This approach, while often expensive, has been very effective in a number of cases, especially for small areas or coves with a narrow connection to the main body of the waterbody.

Possible expansion routes should be considered and addressed to the extent possible. Sequestration, as noted above, can be highly effective if the infested area is localized and amenable to curtains or screens. Outlets from the waterbody should also be screened to minimize the export of VWM fragments with outflow. This may be problematic where leaves or other debris are abundant enough to clog such screens, necessitating frequent cleaning. Rotating screens or other automated outflow restrictors are effective but expensive. Drawdown may also limit VWM escape, if an appropriate subsurface outlet exists and VWM can be prevented from passing through it. It may be advisable to implement bird controls to limit bird contact with infested areas; scare tactics (e.g., flags or pinwheels on buoys, noisemakers) can be effective for short time periods, which may be all that is necessary for lakes with migratory populations. Greater effort may be needed for lakes with substantial resident bird populations. If boating is allowed, it is advisable to set up a temporary wash station at any ramp; it may be necessary to staff it to maximize use compliance. At the very least, boats and trailers leaving the waterbody should be inspected and cleaned.

Where a VWM invasion is confirmed in a waterbody in a DCR park, the following quarantine steps will be evaluated and implemented as warranted:

1. Screen the surface outlet of the waterbody to minimize downstream movement of VWM, maintaining the screen as necessary to facilitate outflow.
2. Lower the water level to prevent surface outflow; a subsurface drain may be used to continue outflow, but VWM may escape through this exit if not screened, and such screening will require cleaning.
3. Post access points with warnings to avoid the plant and/or certain areas of the waterbody; use marker buoys to identify infested areas.
4. Surround smaller infested areas with sequestration curtain or other enclosing materials that prevent spread and limit access.
5. Curtain off coves or other isolated areas to prevent VWM spread and limit access.
6. Use scare tactics or other approaches to limit bird use of the waterbody.
7. Set up a washing station and inspection point for boats taken out of the waterbody; require inspection and cleaning where needed.

8. Close any access point (e.g., boat ramp, beach, other points of active contact) in close proximity to VWM, where the potential for internal or external spread is considered high.
9. Close the waterbody to human use.

Early Eradication Options

Timelines for necessary action with regard to VWM invasions hinge on stopping the spread of this plant. Root crown expansion occurs throughout the growing season, so the sooner controls are implemented, the smaller the area that must be addressed. As plants fragment in the late summer and early autumn, emphasis should be placed on removing plants before the end of August to limit dispersal of propagules by that mechanism. Once the growing season is over (about October), plants are largely dormant and many collapse or are otherwise reduced in biovolume until the following spring. Detecting and effectively removing VWM plants by physical means will therefore be more difficult outside the growing season.

Management options are covered in The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, available on-line at http://www.mass.gov/dcr/waterSupply/lakepond/lakepond.htm and supplied to all towns in the Commonwealth by the DCR in 2004. A summary of control approaches with the potential to eradicate VWM during the early stages of an invasion is provided below.

Hand Harvesting

Mode of action: Plants are removed by divers by hand; removal includes root crowns.

Probability of successful control: Where density is <500 plants per acre over a small number of acres, control can be complete. At higher densities or area of coverage, risk of incomplete harvest or spread by fragment escape increases dramatically.

Potential non-target impacts: Limited; with training, divers recognize VWM and avoid other plants; risk to non-target plants increases as density of plant community increases. Temporary turbidity increases are expected.

Permitting needs: Can be approved without Order of Conditions under the Wetlands Protection Act through a Negative Determination of Applicability (WPA regulations deemed not to apply, as only the invasive plant is removed).

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage. Monitoring during harvesting to detect and collect fragments is also very important to successful elimination of VWM.

Range of costs: Often done by volunteers, but estimates from professional operations range from \$100 to \$500 per acre.

Other considerations: Use of a fragment barrier around all harvesting areas is highly recommended. Effective hand harvesting requires careful planning and is more difficult that it may appear.

Suction Harvesting

Mode of action: Plants can be pulled directly into the suction apparatus, but for best effect this is a suction aided hand harvesting operation, whereby hand harvested plants are fed into the suction tube and filtered out in an above-water chamber. This speeds up the operation and limits fragment dispersal.

Probability of successful control: High potential for eradication at low to moderate densities of VWM; complete removal probability declines at higher densities.

Potential non-target impacts: May pull in non-target plants and plankton by suction, but effects localized and limited. Turbidity plume at surface from filtering chamber may be substantial.

Permitting needs: Generally requires an Order of Conditions under the Wetlands Protection Act, but may be issued a Negative Determination of Applicability where risk to other species and turbidity is expected to be low.

Monitoring needs: Critical to delineate target area and provide means for divers to stay on course with complete coverage.

Range of costs: $5,000 to $15,000 per acre, depending upon equipment features, contractor mobilization, VWM density, and total area to be harvested.

Other considerations: Turbidity may be unacceptable where a large area is suction harvested.

Benthic Barriers

Mode of action: Covers target area with a porous or non-porous blanket, limiting light and physically stressing plants.

Probability of successful control: Usually completely eliminates live vegetation from covered area in 30 to 60 days.

Potential non-target impacts: All plants under the barrier will be killed. Some invertebrates are also killed, but many relocate. Fish find the barriers attractive for cover and foraging area, mainly a function of “edge effect” (creation of edges between plants and open water).

Permitting needs: Often approved through a Negative Determination of Applicability (provisions of WPA do not apply) where VWM is the main plant affected. Otherwise permitted with an Order of Conditions with possible restrictions where other species are at significant risk.

Monitoring needs: Careful delineation of areas to be covered is needed. Condition of plant community, especially root crowns of VWM, should be assessed prior to removal.

Range of costs: Materials typically cost $0.50 to $1.00 per square foot. With application and maintenance costs, expect $30,000 to $50,000 per acre. However, some material can be re-used indefinitely, so costs are greatly reduced for subsequent applications.

Other considerations: To enhance performance, benthic barriers should be carefully anchored and periodically cleaned. To minimize hooks and lures getting caught in benthic barriers, mark location with labeled buoys. Barriers may present a safety hazard in swimming areas.

Water Level Drawdown

Mode of action: Lowered water level exposes plants and substrate to drying and freezing action. Ice damage may also be a factor. Where plants can be dried, frozen, or ripped up by ice action, VWM can be greatly reduced in abundance or eliminated. With many years of repeated drawdown, exposed substrate tends to be dominated by coarse sediment less hospitable to VWM invasion.

Probability of successful control: Very high where drying, freezing and/or ice damage occurs. As this is a function of the weather pattern, uncertainty is high; about one out of three years provides effective drawdown conditions in Massachusetts. Where thick organic sediments, spring activity, or other factors limit freezing and drying, success will be lower.

Potential non-target impacts: Other plants that overwinter in vegetative forms are also likely to be harmed. Seed-producing plants may be stimulated. Some invertebrates (especially mollusks), amphibians (most likely frogs), reptiles (particularly wood turtles) and mammals (most probably beaver and muskrat) could be negatively affected. Effects on fish vary, depending upon timing and duration of drawdown and the interaction with feeding and reproduction. Direct water supply and water level in wells may be affected.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act, usually entailing a detailed review of the potential for non-target impacts.

Monitoring needs: Can be extensive. Pre- and post-implementation surveys are needed. Aside from effects on the plant community, effects on susceptible fauna may be required. Water supply must be monitored and a contingency plan is needed if supply is impaired. It should be assumed that at least three years of implementation will be needed to conduct a valid assessment of success and non-target impacts.

Range of costs: Where drawdown is facilitated by existing structures, costs are limited to permitting and monitoring, with potential for mitigation costs if impacts are unacceptable.

Other considerations: A very detailed evaluation of potential drawdown impacts is needed before attempting this technique. Issues of downstream flooding, refill time, and impacts on water supply and non-target organisms must be addressed.

Application of 2,4-D

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, killing susceptible plants by disrupting cellular growth. Uptake is fairly rapid, limiting necessary exposure time.

Probability of successful control: VWM is susceptible to 2,4-D. With adequate dose (around 1 ppm active ingredient) and contact time (1-3 days), VWM can be eradicated or nearly eliminated. Where dilution, flushing or other factors compromise dose and exposure, success declines. Survival of some plants is expected, necessitating follow-up controls.

Potential non-target impacts: Some other plants are susceptible to 2,4-D at doses applied for VWM control. Rapid die off may reduce oxygen levels through decay. Most fauna are not affected at those doses, but there is a health risk to humans if consumed at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP. Application to waters used for drinking water supply, including surface waters with potential interaction with wells, is prohibited unless a detailed hydrologic study is performed to demonstrate minimal risk to water users.

Monitoring needs: Normally the plant community is monitored before and after treatment. Special studies of other populations may be required by permit, depending upon resources.

Range of costs: Typically $300 to $800 per acre.

Other considerations: Not applicable for waterbodies with known interaction with water supplies (surface supplies or wells), but can be used fairly selectively for VWM.

Application of Fluridone

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, inhibiting the synthesis of carotenoid pigments. Lack of these auxiliary (protective) photosynthetic pigments causes susceptible plants to die slowly through reduced food production and damage by sunlight. Uptake must be nearly continuous over an extended period (>60 days preferred), necessitating extended exposure time.

Probability of successful control: Where adequate dose (>10 ppb for VWM) and exposure time (60-120 days) are maintained, VWM may be eradicated, but results have been mixed. Aside from issues with exposure time and maintenance of an adequate concentration to kill the plants, uptake and effects for fluridone operating on VWM appear less than for EWM. Treatment very early in the growing season has achieved the best success, but higher flows at that time limit the value of whole lake treatments. Partial treatment, using sequestration curtains to limit water exchange, may be more effective but is also considerably more expensive. Follow up actions, such as hand harvesting, are often necessary, and re-treatment the next year may enhance control. Consequently, fluridone is not typically the first choice for VWM control.

Potential non-target impacts: Susceptibility of other plants to fluridone varies widely, and lowering of the dose can maintain much of the native community. However, doses <6 ppb are unlikely to control VWM, and complete control is not typically achieved at <10 ppb, if then. At doses >10 ppb, impacts to non-target plants are expected. Slow die-off of affected plants limits oxygen reduction. No impacts to fauna or humans are expected at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.

Monitoring needs: Normally the plant community is monitored before and after treatment. The concentration of fluridone is also commonly tracked on a weekly to monthly basis with an Enzyme Limited Immuno-Sorbent Assay (ELISA).

Range of costs: Costs range from $500 to $2,000 per acre, depending upon the form of fluridone applied, any necessary re-treatment to maintain dose, and any sequestration of the target area.

Other considerations: The combination of dose and exposure time is critical to success; the combination of achievable detention time and degree to which non-target plants must be protected will determine the potential for eradication or extended control.

Application of Triclopyr

Mode of action: This systemic herbicide is absorbed by vegetative tissues and translocated throughout the plant, inhibiting synthesis of key enzymes while stimulating growth, resulting in plant death. Uptake is rapid and exposure time can be less than one to three days. Plants sink from the surface within a week and die within three weeks.

Probability of successful control: Where adequate dose (0.75 to 2.5 ppm, usually about 1.5 ppm) and exposure time (6-12 hours) are maintained, VWM can be eradicated. As this herbicide was approved in November of 2004, however, there is only limited experience under experimental use permits to guide treatment.

Potential non-target impacts: Dicotyledonous plants, including VWM, are susceptible to triclopyr, while monocotyledonous species, such as naiad and pondweed, are minimally affected at label doses. Impacts to fauna or humans have not been observed at applied doses.

Permitting needs: Requires an Order of Conditions under the Wetlands Protection Act and a License to Apply Chemicals from the DEP.

Monitoring needs: Normally the plant community is monitored before and after treatment.

Range of costs: Costs are expected to range from $600 to $800 per acre, but there have been too few treatments to date to generalize.

Other considerations: As triclopyr was only registered for use in Massachusetts in 2004, evaluation of its potential is based on experimental use only. However, lower required exposure times make it an attractive choice where detention time is short.

Other Options

Other management options are not listed for one or more of the following reasons:

- impractical on a small scale
- not able to eradicate VWM
- could cause VWM to spread
- not approved for use in Massachusetts

Recommended Options for Early Eradication

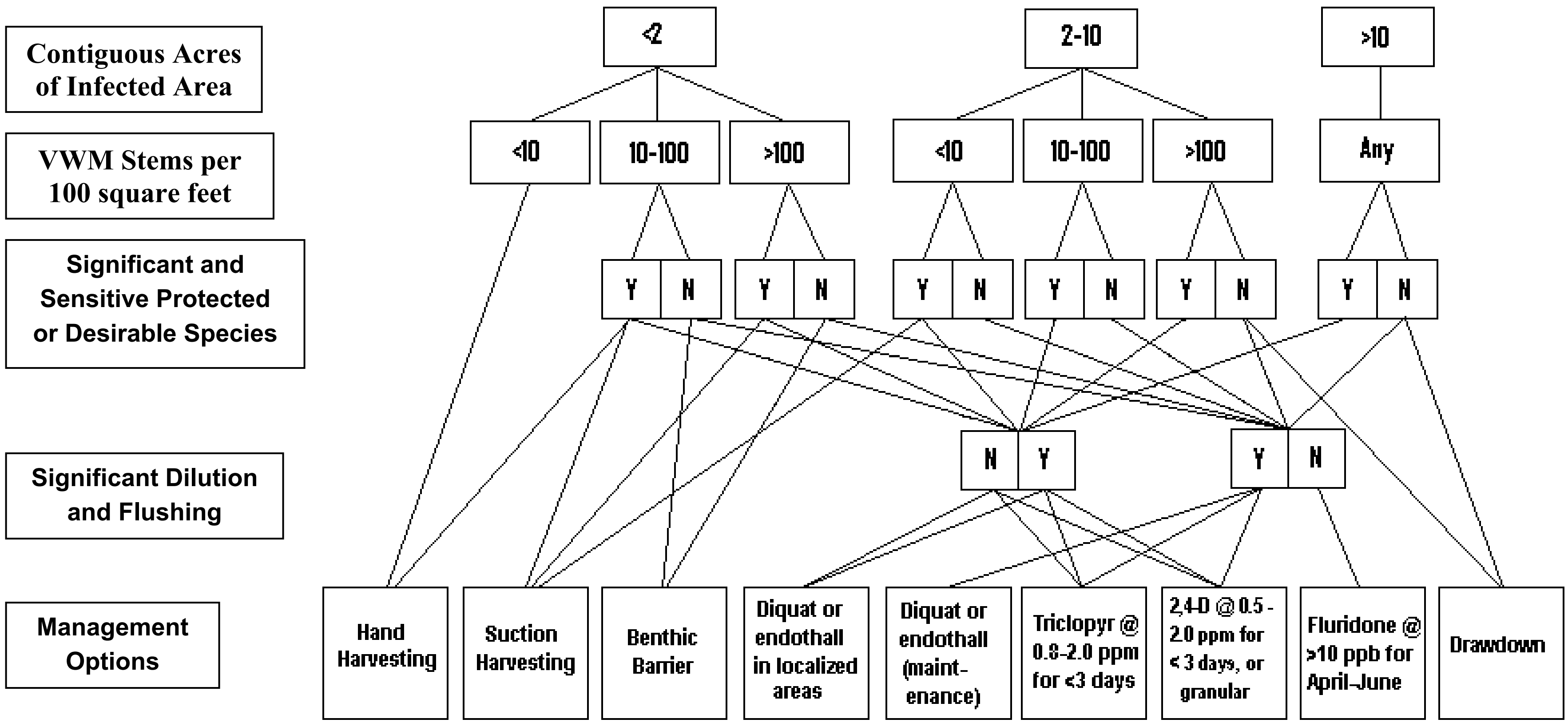
The most commonly recommended early actions are hand harvesting and bottom barriers, each of which has a high potential for success, low cost on a localized basis, and limited permitting needs. Where growths are too dense for effective hand harvesting and too extensive for cost-effective bottom barrier placement, suction harvesting should be considered. Drawdown, where applicable, is perhaps the most widely effective preventive control in cases where repeated invasion is expected or documented, but is not applicable in all cases. On a localized basis, the herbicides 2,4-D and triclopyr have great potential for control of VWM where exposure times are limited and with limited impacts on other native species. However, more experience is needed to make a more definitive recommendation regarding triclopyr, and 2,4-D use is restricted in waters linked to drinking water supply. Success with fluridone has been illusive, but may be improved by early growing season application to sequestered target areas.

A graphic summary of rapid response actions is provided in Figure 3. Most rapid responses will involve sparse growths over a limited area or small, dense beds in a confined area. While the listed techniques may still be applicable after growths have become widespread, addressing them may not qualify as a rapid response, and additional considerations (e.g., impacts to non-target organisms on a lakewide basis) are likely to become more important in the permitting process. The selection pathways shown in Figure 3 represent logical choices based on general features of the aquatic system, and are not intended to provide infallible rules or inflexible options. Practitioners should use a careful process of option review based on site specific data when selecting a rapid response for VWM in any target lake.

Deciding Which Technique to Apply

The following decision tree is provided as an aid to evaluating control options. Thresholds for application are given as guidelines, not rigid rules. Individual circumstances may affect the choice of approach and outcome. Follow up monitoring is considered essential, and follow up control after an initial application is considered likely to be necessary.

Figure 3. Decision Tree for the Control of Variable Watermilfoil (*Myriophyllum heterophyllum*)



Notes: Hand harvesting and suction harvesting must include root system removal. Benthic barrier should remain in place for 30 to 60 days. Triclopyr approved for use in MA in late 2004; experience is limited in MA. Choice of 2,4-D is linked mainly to water uses. Fluridone use may be appropriate for sequestered areas treated early in the growing season. Diquat and endothall will not eradicate populations but can control VWM until other techniques can be applied. Drawdown use is dependent on many factors, including hydrology and use as a water supply. Moderate to dense growth over an extensive area (>10 acres) may not be appropriate for rapid response consideration.

Control of Established Infestations

This document deals mainly with early invasion and the new infestations that result, but it is important to note that older infestations, where the VWM has moved throughout the waterbody into all suitable habitats and probably become the dominant plant, can and should be addressed if continued invasion in the region is to be curtailed. The Practical Guide to Lake Management in Massachusetts (Wagner, 2004), a companion guide to the GEIR on Lake Management, provides a review of all available techniques for combating variable watermilfoil (*Myriophyllum heterophyllum*) infestations. On a whole lake basis, herbicide treatment is the most cost-effective means for reducing milfoil coverage and density to levels that can be controlled by physical techniques like hand harvesting or bottom barriers. Drawdown will reduce VWM in the drawdown zone, but it is rare that a waterbody can be drawn down enough to eliminate VWM without unacceptable impacts to non-target species. Techniques suitable for combating new growths are seldom practical or effective on a whole lake scale (e.g., hand harvesting, bottom barriers).

Maintenance techniques that limit the impact of VWM on waterbody uses, but do not typically result in elimination of VWM, include mechanical harvesting, hydroraking, rotovation, and the contact herbicides diquat and endothall. The physical methods may actually spread VWM if it is not already everywhere in the waterbody, after which these are analogous to mowing a lawn. The contact herbicides do not kill the root crowns of VWM, allowing regrowth within two growing seasons.

Dredging can remove VWM along with all other plants and any remaining seeds or other propagules associated with the dredged sediment. The cost is extremely high, however, and resulting substrate conditions are usually still hospitable to milfoil growth. With much bare area to be colonized, invasive species such as VWM are likely to become dominant it more desirable species are not actively introduced. Only if dredging results in a water depth too great for effective colonization by VWM is it likely to be the only method needed to control VWM in the target area.

There are currently no herbivorous insects for the control of VWM. Grass carp can eliminate VWM (and indeed all other submersed plants) when stocked at sufficient density, but are not approved for use in Massachusetts at this time.

Prevention of Re-Infestation

Once an invasion has been repulsed through any of the above methods, it should be apparent that the waterbody is susceptible to VWM. As the cost of prevention is much less than the cost of rehabilitation of an infested waterbody, steps should be taken to reduce the risk of re-introduction of VWM. As VWM most often comes from a local source, control activity is encouraged on a watershed, multi-municipal or regional level. Working across political boundaries with limited funding is difficult, but represents the most sweeping opportunity to limit future invasions. Alternatively, and almost essential as a back-up, steps need to be taken at the individual waterbody to reduce the risk of re-introduction. Key steps may include:

- Education through the lake association or town for all users about the threat of VWM, how to avoid introducing it to the waterbody, how to identify it, and who to contact if it is found. See the other sections in this document for relevant information to be provided.

- Posting of all access points with signs warning of the threat, showing how to identify VWM, and urging that boats, fishing gear and other recreational equipment be cleaned before and after use in the waterbody. See the section on Communication and Education in this document.
- Provision of wash stations at boat ramps, and/or staffing of ramps with inspectors.
- Drawdown where applicable and permitted to minimize overwintering of introduced VWM.
- Monitoring of the plant community to detect VWM, with a focus on boat ramps and inlets.

Summary

1. Variable watermilfoil (*Myriophyllum heterophyllum* or VWM) is an invasive plant normally identified by a reddish stem and whorled leaves in sets of 4-6, with 6-12 thread-like segments on each side of the central leaf axis. Hybridization is possible, necessitating genetic identification in some cases. Hybrid VWM appears to be more aggressive than the non-hybrid VWM.
2. VWM is native to the southern portions of the United States from Florida to Texas. It is most often transported on boats or trailers, by birds, and with water flow.
3. VWM can be transported great distances by fragments that can root and grow. It becomes locally abundant by root crown expansion. Seeds are of limited importance in dispersal, but cannot be ignored completely in evaluating routes of new infestations or regrowth from seemingly eradicated populations.
4. VWM creates canopies that shade out other plant species. At high density it provides poor habitat for most water-dependent fauna, impairs recreational uses, and can have negative impacts on water supply and flood control.
5. VWM is most often detected in the early stages of infestation in water <10 ft deep by visual examination (viewing tube from boat or mask and snorkel). Look first in the vicinity of boat ramps, inlets, and areas of bird congregation. One effective long-term monitoring strategy involves setting up transects representing areas of the lake and searching at discrete depth intervals from shore to the maximum depth of plant growth.
6. When detected, map VWM coverage with notation of density as beds, scattered plants, or solitary stems. Be thorough with visual coverage of potentially infested areas. Record all other species present and their relative abundance. Confirm identification through the DCR.
7. Educate waterbody users by whatever means practical about the threat and presence of VWM. Posting of access points is useful in all cases. Signs should show how to identify VWM, urge that all boats, trailers and other recreational equipment be cleaned before and after use in the waterbody, and provide a contact name and phone number for reporting or correspondence.
8. It is advantageous to quarantine infested areas until removal can be attempted. Closing beaches and boat ramps can be problematic, legally and practically, but can promote greater awareness and support for prompt action. Use of curtains or screens both to keep people out of an infested area and to keep VWM inside is desirable but expensive.
9. Eradication of VWM detected early in an invasion can be accomplished with hand harvesting, suction harvesting, benthic barriers, drawdown, or the herbicides 2,4-D, or triclopyr. Fluridone may be effective if applied very early in the growing season and if the concentration is maintained at a moderate level for about 3 months. Diquat and endothall may keep a populatioin in check, but will not eradicate it. Hand harvesting and benthic barriers are often allowable without an Order of Conditions under the WPA, and can therefore be implemented most rapidly.

Each method has benefits and drawbacks, and the specific circumstances will affect which option(s) can be applied.

10. A range of additional options are available to combat later stage invasions. Those not mentioned as eradication options for new infestations have some feature that prevents effective, rapid use, but these techniques may have applicability under special circumstances.
11. Drawdown, where feasible, can act as a deterrent to invasion on an annual basis at a relatively low cost, through direct impact on invading VWM and by gradually altering the peripheral sediment features to make them less hospitable, but has many possible impacts on aquatic resources and requires a thorough evaluation in each case.
12. Once VWM has been removed after an invasion event, steps are necessary to prevent re-infestation. Education of waterbody users, with a focus on boating, and ongoing monitoring to detect new VWM plants are critical components. It should be assumed that VWM will return, but it is far easier to address new growths than to combat a full infestation.

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