Management Options for Aquatic Plants

Option	Permit Needed?	How it Works	PROS	CONS
No treatment	N	Do not treat plants	Protects native species that can prevent spread of invasive or exotic species, enhance water quality, and provide habitat for aquatic fauna No financial cost No system disturbance No harmful effects of chemicals Permit not required	May allow small population of invasive plants to become larger, more difficult to control later
Mechanical Control	Required under NR 109	Plants reduced by mechanical means Wide range of techniques, from manual to highly mechanized	Flexible control Can balance habitat and recreational needs	Must be repeated, often more than once per season Can suspend sediments and increase turbidity and nutrient release
a. Handpulling/Manual raking	Y/N	SCUBA divers or snorkelers remove plants by hand or plants are removed with a rake Works best in soft sediments	Little to no damage done to lake or to native plant species Can be highly selective Can be done by shoreline property owners without permits within an area <30 ft wide OR where selectively removing EWM or CLP Can be very effective at removing problem plants, particularly following early detection of an invasive exotic species	Very labor intensive Needs to be carefully monitored Roots, runners, and even fragments of some species (including EWM) will start new plants, so all of plant must be removed Small-scale control only

b.	Harvesting	Y	Plants are "mowed" at depths of 2-5 ft, collected with a conveyor and off-loaded onto shore	Immediate results	Not selective in species removed
			Harvest invasives only if invasive is already present throughout the lake	EWM removed before it has the opportunity to autofragment, which may create more fragments than created by harvesting	Fragments of vegetation can re-root
				Usually minimal impact to the lake	Can remove some small fish and reptiles from lake
				Harvested lanes through dense weed beds can increase growth and survival of some fish	Initial cost of harvester expensive
				Can remove some nutrients from lake	
Biological Control		Y	Living organisms (e.g. insects or fungi) eat or infect plants	Self-sustaining; organism will over-winter, resume eating its host the next year	Effectiveness will vary as control agent's population fluctates
				Lowers density of problem plant to allow growth of natives	Provides moderate control - complete control unlikely
					Control response may be slow
					Must have enough control agent to be effective
a.	Weevils on EWM*	Y	Native weevil prefers EWM to other native water-milfoil	Native to Wisconsin: weevil cannot "escape" and become a problem	Need to stock large numbers, even if some already present
				Selective control of target species	Need good habitat for overwintering on shore (leaf litter) associated with undeveloped shorelines
				Longer-term control with limited management	Bluegill populations decrease densities through predation
b.	Pathogens	Y	Fungal/bacterial/viral pathogen introduced to target species to induce mortalitiy	May be species specific	Largely experimental; effectiveness and longevity unknown
				May provide long-term control	Possible side effects not understood
				Few dangers to humans or animals	

c.	Allelopathy	Y	Aquatic plants release chemical compounds that inhibit other plants from growing	May provide long-term, maintenance-free control Spikerushes (*Eleocharis* spp.) appear to inhibit Eurasian watermilfoil growth	Initial transplanting slow and labor-intensive Spikerushes native to WI, and have not effectively limited EWM growth Wave action along shore makes it difficult to establish plants; plants will not grow in deep or turbid water
d.	Restoration of native plants	N; strongly recommend plan and consultation with DNR	Diverse native plant community established to repel invasive species	Native plants provide food and habitat for aquatic fauna Diverse native community more repellant to invasive species Supplements removal techniques	Initial transplanting slow and labor-intensive Nuisance invasive plants may outcompete plantings Largely experimental; few well-documented cases

Physical Control	Required under Ch. 30 / NR 107	Plants are reduced by altering variables that affect growth, such as water depth or light levels		
a. Drawdown	Y, May require Environmental Assessment	Lake water lowered; plants killed when sediment dries, compacts or freezes	Can be effective, especially when done in winter, provided drying and freezing occur. Sediment compaction is possible over winter	Plants with large seed bank or propagules that survive drawdown may become more abundant upon refilling
		Must have a water level control device or siphon	Summer drawdown can restore large portions of shoreline and shallow areas as well as provide sediment compaction	Species growing in deep water (e.g. EWM) that survive may increase, particularly if desirable native species are reduced
		Season or duration of drawdown can change effects	Emergent plant species often rebound near shore providing fish and wildlife habitat, sediment stabilization, and increased water quality	May impact attached wetlands and shallow wells near shore
			Success for EWM, variable success for CLP*	Can affect fish, particularly in shallow lakes if oxygen levels drop or if water levels are not restored before spring spawning
			Restores natural water fluctuation important for all aquatic ecosystems	Winter drawdawn must start in early fall or will kill hibernating reptiles and amphibians
				Controversial
b. Dredging	Y	Plants are removed along with sediment	Increases water depth	Expensive
		Most effective when soft sediments overlay harder substrate	Removes nutrient rich sediments	Increases turbidity and releases nutrients
		For extremely impacted systems	Removes soft bottom sediments that may have high oxygen demand	Exposed sediments may be recolonized by invasive species
		Extensive planning required		Sediment testing is expensive and may be necessary
				Removes benthic organisms
				Dredged materials must be disposed of
				Severe impact on lake ecosystem

c.	Dyes	Y	Colors water, reducing light and reducing plant and algal growth	Impairs plant growth without increasing turbidity	Appropriate for very small water bodies
				Usually non-toxic, degrades naturally over a few weeks.	Should not be used in pond or lake with outflow
					Impairs aesthetics
					Affects to microscopic organisms unknown
d.	Mechanical circulation (Solarbees)	Y	Water is circulated and oxygenated	Reduces blue-green algae	Method is experimental; no published studies have been done
			Oxygenation of water decreases ammonium-nitrogen, which is a preferred nutrient source of EWM, theoretically limiting EWM growth (has not been demonstrated scientifically)	May reduce levels of ammonium-nitrogen in the water and at the sediment interface, which could reduce EWM growth	Although EWM prefers ammonium-nitrogen to nitrate, it will uptake nitrate efficiently, so EWM growth may not be affected
				Oxygenated water may reduce phosphorus release from sediments if mixing is complete	Units are aesthetically unpleasing
				Reduces chance of fish kills by aerating water	Units could be a navigational hazard
e.	Non-point source nutrient control	N	Runoff of nutrients from the watershed are reduced (e.g. by controlling construction erosion or reducing fertilizer use)	Attempts to correct source of problem, not treat symptoms	Results can take years to be evident due to internal recycling of already-present lake nutrients
				Could improve water clarity and reduce occurrences of algal blooms	Expensive
				Native plants may be able to compete invasive species better in low-nutrient conditions	Requires landowner cooperation and regulation
					Improved water clarity may increase plant growth

Chemical Control	Required under NR 107	Granules or liquid chemicals kill plants or cease plant growth; some chemicals used primarily for algae Results usually within 10 days of treatment, but repeat treatments usually needed	Some flexibility for different situations Some can be selective if applied correctly Can be used for restoration activities	Possible toxicity to aquatic animals or humans, especially applicators May kill desirable plant species, e.g. native water-milfoil or native pondweeds Treatment set-back requirements from potable water sources and/or drinking water use restrictions after application, usually based on concentration May cause severe drop in dissolved oxygen causing fish kill, depends on plant biomass killed, temperatures and lake size and shape Controversial
a. 2,4-D (Weedar, Navigate)	Y	Systemic[1] herbicide selective to broadleaf[2] plants that inhibits cell division in new tissue Applied as liquid or granules during early growth phase	Moderately to highly effective, especially on EWM Monocots, such as pondweeds (e.g. CLP) and many other native species not affected. Can be used in synergy with endotholl for early season CLP and EWM treatments Widely used aquatic herbicide	May cause oxygen depletion after plants die and decompose Cannot be used in combination with copper herbicides (used for algae) Toxic to fish
b. Endothall (Aquathol)	Y	Broad-spectrum[3], contact[4] herbicide that inhibits protein synthesis Applied as liquid or granules	Especially effective on CLP and also effective on EWM May be effective in reducing reestablishment of CLP if reapplied several years in a row in early spring Can be selective depending on concentration and seasonal timing Can be combined with 2,4-D for early season CLP and EWM treatments, or with copper compounds Limited off-site drift	Kills many native pondweeds Not as effective in dense plant beds Not to be used in water supplies Toxic to aquatic fauna (to varying degrees) 3-day post-treatment restriction on fish consumption

c.	Diquat (Reward)	Y	Broad-spectrum, contact herbicide that disrupts cellular functioning	Mostly used for water-milfoil and duckweed	May impact non-target plants, especially native pondweeds, coontail, elodea, naiads
			Applied as liquid, can be combined with copper treatment	Rapid action	Toxic to aquatic invertebrates
				Limited direct toxicity on fish and other animals	Needs to be reapplied several years in a row
					Ineffective in muddy or cold water (<50°F)
d.	Fluridone (Sonar or Avast)	Y; special permit and Environmental Assessment may be required	Broad-spectrum, systemic herbicide that inhibits photosynthesis; some reduction in non-target effects can be achieved by lowering dosage	Effective on EWM for 1 to 4 years with aggressive follow-up treatments	Affects many non-target plants, particularly native milfoils, coontails, elodea, and naiads, even at low concentrations. These plants are important to combat invasive species
			Must be applied during early growth stage	Applied at very low concentration	Requires long contact time: 60-90 days
			Available with a special permit only; chemical applications beyond 150 ft from shore not allowed under NR 107	Slow decomposition of plants may limit decreases in dissolved oxygen	Demonstrated herbicide resistance in hydrilla subjected to repeat treatments, EWM has the potential to develop resistance
				Low toxicity to aquatic animals	Unknown effect of repeat whole-lake treatments on lake ecology
e.	Glyphosate (Rodeo)	Y	Broad-spectrum, systemic herbicide that disrupts enzyme formation and function	Effective on floating and emergent plants such as purple loosestrife	Effective control for 1-5 years
			Usually used for purple loosestrife stems or cattails	Selective if carefully applied to individual plants	Ineffective in muddy water
			Applied as liquid spray or painted on loosetrife stems	Non-toxic to most aquatic animals at recommended dosages	Cannot be used near potable water intakes
					RoundUp is often illegally substituted for Rodeo
					Associated surfactants of RoundUp believed to be toxic to reptiles and amphibians
					No control of submerged plants

f.	Triclopyr (Renovate)	Y	Systemic herbicide selective to broadleaf plants that disrupts enzyme function	Effective on many emergent and floating plants	Impacts may occur to some native plants at higher doses (e.g. coontail)
			Applied as liquid spray or liquid	More effective on dicots, such as purple loosestrife; may be more effective than glyphosate	May be toxic to sensitive invertebrates at higher concentrations
				Results in 3-5 weeks	Retreatment opportunities may be limited due to maximum seasonal rate (2.5 ppm)
				Low toxicity to aquatic animals	Sensitive to UV light; sunlight can break herbicide down prematurely
				No recreational use restrictions following treatment	Relatively new management option for aquatic plants (since 2003)
g.	Copper compounds (Cutrine Plus)	Y	Broad-spectrum, systemic herbicide that prevents photosynthesis	Reduces algal growth and increases water clarity	Elemental copper accumulates and persists in sediments
			Used to control planktonic and filamentous algae	No recreational or agricultural restrictions on water use following treatment	Short-term results
				Herbicidal action on hydrilla, an invasive plant not yet present in Wisconsin	Precipitates rapidly in alkaline waters
					Small-scale control only, because algae are easily windblown
					Toxic to invertebrates, trout and other fish, depending on the hardness of the water
					Long-term effects of repeat treatments to benthic organisms unknown
					Clear water may increase plant growth

h.	Lime slurry	Y	Applications of lime temporarily raise water pH, which limits the availablity of inorganic carbon to plants, preventing growth	Appears to be particularly effective against EWM and CLP	Relatively new technique, so effective dosage levels and exposure requirements are not yet known
				Prevents release of sediment phosphorus, which reduces algal growth	Short-term increase in turbidity due to suspended lime particles
				Increases growth of native plants beneficial as fish habitat	High pH detrimental to aquatic invertebrates
					May restrict growth of some native plants
i.	Alum (aluminum sulfate)	Y	Removes phosphorus from water column and creates barrier on sediment to prevent internal loading of phosphorus	Most often used against algal problems	Must not eat fish for 30 days from treatment area
			Dosage must consider pH, hardness and water volume	Improves water clarity	Minimal effect on aquatic plants, or increased light penetration may increase aquatic plants
					Toxic to aquatic animals, including fish at some concentrations

***EWM - Eurasian water-milfoil**
***CLP - Curly-leaf pondweed**
[1]Systemic herbicide - Must be absorbed by the plant and moved to the site of action. Often slower-acting than contact herbicides.
[2]Broadleaf herbicide - Affects only dicots, one of two groups of plants. Aquatic dicots include waterlilies, bladderworts, watermilfoils, and coontails.
[3]Broad-spectrum herbicide - Affects both monocots and dicots.
[4]Contact herbicide - Unable to move within the plant; kills only plant tissue it contacts directly.

Techniques for Aquatic Plant Control Not Allowed in Wisconsin

Option		How it Works	PROS	CONS
Biological Control				
a.	Carp	Plants eaten by stocked carp	Effective at removing aquatic plants	Illegal to transport or stock carp in Wisconsin
			Involves species already present in Madison lakes	Carp cause resuspension of sediments, increased water temperature, lower dissolved oxygen levels, and reduction of light penetration
				Widespread plant removal deteriorates habitat for other fish and aquatic organisms
				Complete alteration of fish assemblage possible
				Dislodging of plants such as EWM or CLP turions can lead to accelerated spreading of plants
b.	Crayfish	Plants eaten by stocked crayfish	Reduces macrophyte biomass	Illegal to transport or stock crayfish in Wisconsin
				Control not selective and may decimate plant community
				Not successful in productive, soft-bottom lakes with many fish predators
				Complete alteration of fish assemblage possible
Mechanical Control				
a.	Cutting (no removal)	Plants are "mowed" with underwater cutter	Creates open water areas rapidly	Root system remains for regrowth
			Works in water up to 25 ft	Fragments of vegetation can re-root and spread infestation throughout the lake
				Nutrient release can cause increased algae and bacteria and be a nuisance to riparian property owners
				Not selective in species removed
				Small-scale control only
b.	Rototilling	Sediment is tilled to uproot plant roots and stems	Decreases stem density, can affect entire plant	Creates turbidity
		Works in deep water (17 ft)	Small-scale control	Not selective in species removed
			May provide long-term control	Fragments of vegetation can re-root
				Complete elimination of fish habitat
				Releases nutrients
				Increased likelihood of invasive species recolonization

c.	Hydroraking	Mechanical rake removes plants from lake Works in deep water (14 ft)	Creates open water areas rapidly	Fragments of vegetation can re-root May impact lake fauna Creates turbidity Plants regrow quickly Requires plant disposal
Physical Control				
a.	Fabrics/ Bottom Barriers	Prevents light from getting to lake bottom	Reduces turbidity in soft-substrate areas Useful for small areas	Eliminates all plants, including native plants important for a healthy lake ecosystem May inhibit spawning by some fish Need maintenance or will become covered in sediment and ineffective Gas accumulation under blankets can cause them to dislodge from the bottom Affects benthic invertebrates Anaerobic environment forms that can release excessive nutrients from sediment

Aquatic Plant Management

Aquatic plants are a critical component in an aquatic ecosystem. Any management of an ecosystem can have negative or even detrimental effects on the whole ecosystem. Therefore, the practice of managing aquatic plants should not be taken lightly. The concept of Aquatic Plant Management (APM) is highly variable since different aquatic resource users want different things. Ideal management to one individual may mean providing prime fish habitat, for another it may be to remove surface vegetation for boating. The practice of APM is also highly variable. There are numerous APM strategies designed to achieve different plant management goals. Some are effective on a small scale, but ineffective in larger situations. Others can only be used for specific plants or during certain times of the growing season. Of course, the types of plants that are to be managed will also help determine which APM alternatives are feasible. The following paragraphs discuss the APM methods used today. The discussion is largely adopted from *Managing Lakes and Rivers, North American Lake Management Society, 2001*, supplemented with other applicable current resources and references. The methods summarized here are largely for management of rooted aquatic plants, not algae. While some methods may also have effects on nuisance algae blooms, the focus is submergent rooted aquatic macrophytes. This information is provided to allow the user to gain a basic understanding of the APM method, it is not designed to an all-inclusive APM decision-making matrix. APM alternatives can be divided into the following categories: Physical Controls, Chemical Controls, and Biological Controls.

Physical Controls

Physical APM controls include various methods to prevent growth or remove part or all of the aquatic plant. Both manual and mechanical techniques are employed. Physical APM methods include:

- Hand pulling
- Hand cutting
- Bottom barriers
- Light limitation (dyes, covers)
- Mechanical harvesting
- Hydroraking/rototilling
- Suction Dredging
- Dredging
- Drawdown

Each of these methods are described below. The costs, benefits, and drawbacks of each APM strategy are provided.

Hand Pulling: This method involves digging out the entire unwanted plant including stems and roots with a hand tool such as a spade. This method is highly selective and suitable for shallow areas for removing invasive species that have not become well established. This technique is obviously not for use on large dense beds of nuisance aquatic plants. It is best used in areas less than 3 feet, but can be used in deeper areas with divers using scuba and snorkeling equipment. It can also be used in combination with the suction dredge method. In Wisconsin, hand pulling may be completed outside a designated sensitive area without a permit but is limited to 30 feet of shoreline frontage. Removal of exotic species is not limited to 30 feet.

Advantages: This technique results in immediate clearing of the water column of nuisance plants. When a selective technique is desired in a shallow, small area, hand pulling is a good choice. It is also useful in sensitive areas where disruption must be minimized.

Disadvantages: This method is labor intensive. Disturbing the substrate may affect fish habitat, increase turbidity, and may promote phosphorus re-suspension and subsequent algae blooms.

Costs: The costs are highly variable. There is practically no cost using volunteers or lakeshore landowners to remove unwanted plants, however, using divers to remove plants can get relatively expensive. Hand pulling labor can range from $400 to $800 per acre.

Hand Cutting: This is another manual method where the plants are cut below the water surface. Generally the roots are not removed. Tools such as rakes, scythes or other specialized tools are pulled through the plant beds by boat or several people. This method is not as selective as hand pulling. This method is well suited for small areas near docks and piers. Plant material must be removed from the water. In Wisconsin, hand cutting may be completed outside a designated sensitive area without a permit but is limited to 30 feet of shoreline frontage. Removal of exotic species is not limited to 30 feet.

Advantages: This technique results in immediate clearing of the water column of nuisance plants. Costs are minimal.

Disadvantages: This is also a fairly time consuming and labor intensive option. Since the technique does not remove the entire plant (leaves root system and part of plant), it may not result in long-term reductions in growth. This technique is not species specific and results in all aquatic plants being removed from the water column.

Costs: The costs range from minimal for volunteers using hand equipment up to over $1,000 for a hand-held mechanized cutting implement. Hand cutting labor can range from $400 to $800 per acre.

Bottom Barriers: A barrier material is applied over the lake bottom to prevent rooted aquatics from growing. Natural barriers such as clay, silt, and gravel can be used although eventually plants may root in these areas again. Artificial materials can also be used for bottom barriers and anchored to the substrate. Barrier materials include burlap, nylon, rubber, polyethylene, polypropylene, and fiberglass. Barriers include both solid and porous forms. A permit is required to place any fill or barrier structure on the substrate of a waterbody. This method is well suited for areas near docks, piers, and beaches. Periodic maintenance may be required to remove accumulated silt or rooting fragments from the barrier.

Advantages: This technique does not result in production of plant fragments. Properly installed, it can provide immediate and multiple year relief.

Disadvantages: This is a non-selective option, all plants beneath the barrier will be affected. Some materials are costly and installation is labor intensive. Other disadvantages include limited material durability, gas accumulation beneath the cover, or possible re-growth of plants from above or below the cover. Fish and invertebrate habitat is disrupted with this technique. Anchored barriers can be difficult to remove.

Costs: A 20 foot x 60 foot panel cost $265, while a 30 foot x 50 foot panel cost $375 (this does not include installation costs). Costs for materials vary from $0.15 per square foot ($ft^2$) to over $0.35/ ft^2. The costs for installation range from $0.25 to $0.50/ ft^2. Barriers can cost $20,000 to $50,000 per acre.

Light Limitation: Limiting the available light in the water column can prevent photosynthesis and plant growth. Dark colored dyes and surface covers have been used to accomplish light limitation. Dyes are effective in shallow water bodies where their concentration can be kept at a desired concentration and loss through dilution is less. This method is well suited for small, shallow water bodies with no outlets such as private ponds.

Surface covers can be a useful tool in small areas such as docks and beaches. While they can interfere with aquatic recreation, they can be timed to produce results and not affect summer recreation uses.

Advantages: Dyes are non-toxic to humans and aquatic organisms. No special equipment is required for application. Light limitation with dyes or covers method may be selective to shade tolerant species. In addition to submerged macrophyte control, it can also control the algae growth.

Disadvantages: The application of water column dyes is limited to shallow water bodies with no outlets. Repeated dye treatments may be necessary. The dyes may not control peripheral or shallow-water rooted plants. This technique must be initiated before aquatic plants start to grow. Covers inhibit gas exchange with the atmosphere.

Costs: Costs for a commercial dye and application range from $100 to $500 per acre.

Mechanical Harvesting: Mechanical harvesters are essentially cutters mounted on barges that cut aquatic plants at a desired depth. Maximum cutting depths range from 5 to 8 feet with a cutting width of 6.5 to 12 feet. Cut plant materials require collection and removal from the water. Conventional harvesters combine cutting, collecting, storing, and transporting cut vegetation into one piece of equipment. Transport barges and shoreline conveyors are also available to remove the cut vegetation. The cut plants must be removed from the water body. The equipment needs are dictated by severity of the aquatic plant problem. Contract harvesting services are available in lieu of purchasing used or new equipment. Trained staff will be necessary to operate a mechanical harvester. To achieve maximum removal of plant material, harvesting is usually completed during the summer months while submergent vegetation is growing to the surface. The duration of control is variable and re-growth of aquatic plants is common. Factors such as timing of harvest, water depth, depth of cut, and timing can influence the effectiveness of a harvesting operation. Harvesting is suited for large open areas with dense stands of exotic or nuisance plant species. Permits are now required in Wisconsin to use a mechanical harvester.

Advantages: Harvesting provides immediate visible results. Harvesting allows plant removal on a larger scale than other options. Harvesting provides flexible area control. In other words, the harvester can be moved to where it is needed and used to target problem areas. This technique has the added benefit of removing the plant material from the water body and therefore also eliminates a possible source of nutrients often released during fall decay of aquatic plants. While removal of nutrients through plant harvesting has not been quantified, it can be important in aquatic ecosystem with low nutrient inputs.

Disadvantages: Drawbacks of harvesting include: limited depth of operation, not selective within the application area, and expensive equipment costs.

Harvesting also creates plant fragments, which can be a concern since certain plants have the ability to reproduce from a plant fragment (e.g. Eurasian watermilfoil). Plant fragments may re-root and spread a problem plant to other areas. Harvesting can have negative effects on non-target plants, young of year fish, and invertebrates. The harvesting will require trained operators and maintenance of equipment. Also, a disposal site or landspreading program will be needed for harvested plants.

Costs: Costs for a harvesting operation are highly variable dependant on program scale. New harvesters range from $40,000 for small machines to over $100,000 for large, deluxe models. Costs vary considerably, depending on the model, size, and options chosen. Specially designed units are available, but may cost more. The equipment can last 10 to 15 years. A grant for ½ the equipment cost can be obtained from the Wisconsin Waterways Commission and a loan can be obtained for the remaining capital investment. Operation costs include insurance, fuel, spare parts, and payroll. Historical harvesting values have been reported at $200 up to $1,500 per acre. A survey of recent Wisconsin harvesting operations reported costs to be between $100/acre and $200/acre.

A used harvester can be purchased for $10,000 to $20,000. Maintenance costs are typically higher.

Contract harvesting costs approximately $125/per hour plus mobilization to the water body. Contractors can typically harvest ¼ to ½ acre per hour for an estimated cost of $250 to $500/per acre.

Hydroraking/rototilling: Hydroraking is the use of a boat or barge mounted machine with a rake that is lowered to the bottom and dragged. The tines of the rake rip out roots of aquatic plants. Rototilling, or rotovation, also rips out root masses but uses a mechanical rotating head with tines instead of a rake. Harvesting may need to be completed in conjunction with these methods to gather floating plant fragments. This application would best be used where nuisance populations are well established and prevention of stem fragments is not critical. A permit would be required for this type of aquatic plant management and would only be issued in limited cases of extreme infestations of nuisance vegetation. In Wisconsin, this method is not looked upon favorably or at all by the WDNR.

Advantages: These methods have the potential for significant reductions in aquatic plant growth. These methods can remove the plant stems and roots, resulting in thorough plant disruption. Hydroraking/rototilling can be completed in "off season" months avoiding interference with summer recreation activities.

Disadvantages: Hydroraking/rototilling are not selective and may destroy substrate habitat important to fish and invertebrates. Suspension of sediments will increase turbidity and release nutrients trapped in bottom sediments into the water column potentially causing algal blooms. These methods can cause floating plant and root fragments, which may re-root and spread the problem. Hydroraking/rototilling are expensive and not likely to be permitted by regulatory agencies.

Costs: Bottom tillage costs vary according to equipment, treatment scale, and plant density. For soft vegetation costs can range from $2,000 to $4,000 per acre. For dense, rooted masses, costs can be up to $10,000 per acre. Contract bottom tillage reportedly ranges from $1,200 to $1,700 per acre (Washington Department of Ecology, 1994).

Suction Dredging: Suction dredging uses a small boat or barge with portable dredges and suction heads. Scuba divers operate the suction dredge and can target removal of whole plants, seeds, and roots. This method may be applied in conjunction with hand cutting where divers dislodge the plants. The plant/sediment slurry is hydraulically pumped to the barge through hoses carried by the diver. Its effectiveness is dependent on sediment composition, density of aquatic plants, and underwater visibility. Suction dredging may be best suited for localized infestations of low plant density where fragmentation must be controlled. A permit will be required for this activity.

Advantages: Diver suction dredging is species –selective. Disruption of sediments can be minimized. These methods can remove the plant stems and roots, resulting in thorough plant disruption and potential longer term control. Fragmentation of plants is minimized. This activity can be completed near and around obstacles such as piers or marinas where a harvester could not operate.

Disadvantages: Diver suction dredging is labor intensive and costly. Upland disposal of dredged slurry can require additional equipment and costs. Increased turbidity in the area of treatment can be a problem. Release of nutrients and other pollutants can also be a problem.

Costs: Suction dredging costs can be variable depending on equipment and transport requirements for slurry. Costs range from $5,000 per acre to $10,000 per acre.

Dredging

Sediment removal through dredging can work as a plant control technique by limiting light through increased water depth or removing soft sediments that are a preferred habitat to nuisance rooted plants. Soft sediment removal is accomplished with drag lines, bucket dredges, long reach backhoes, or other specialized dredging equipment. Dredging has had mixed results in controlling aquatic plant, however it can be highly effective in appropriate situations. Dredging is most often applied in a major restructuring of a severely degraded system. Generally, dredging is an activity associated with other restoration efforts. Comprehensive pre-planning will be necessary for these techniques and a dredging permit would be required.

Advantages: Dredging can remove nutrient reserves which result in nuisance rooted aquatic plant growth. Dredging, when completed, can also actually improve substrate and habitat for more desirable species of aquatic plants, fish, and invertebrates. It allows the complete renovation of an aquatic ecosytem. This method has the potential for significant reductions in aquatic plant growth. These methods can be completed in “off season” months avoiding interference with summer recreation activities.

Disadvantages: Dredging can temporarily destroy important fish and invertebrate habitat. Suspension of sediments usually increases turbidity significantly and can possibly releases nutrients causing algae blooms. Dredging is extremely expensive and requires significant planning. Dredged materials may contain toxic materials (metals, PCBs). Dredged material transportation and disposal of toxic materials are additional management considerations and are potentially expensive. It could be difficult and costly to secure regulatory permits and approvals.

Costs: Dredging costs depend upon the scale of the project and many other factors. It is generally an extremely expensive option.

Drawdown: Water level drawdown exposes the plants and root systems to prolonged freezing and drying to kill the plants. It can be completed any time of the year, however is generally more effective in winter, exposing the lake bed to freezing temperatures. If there is a water level control structure capable of drawdown, it can be an in-expensive way to control some aquatic plants. Aquatic plants vary in their susceptibility to drawdown, therefore, accurate identification of problem species is important. Drawdown is often used for other purposes of improving waterfowl habitat or fishery management, but sometimes has the added benefit of nuisance rooted aquatic plant control. This method can be used in conjunction with a dredging project to excavate nutrient-rich sediments. This method is best suited for use on reservoirs or shallow man-made lakes. A drawdown would require regulatory permits and approvals.

Advantages: A drawdown can result in compaction of certain types of sediments and can be used to facilitate other lake management activities such as dam repair, bottom barrier, or dredging projects. Drawdown can significantly impact populations of aquatic plants that propagate vegetatively. It is inexpensive.

Disadvantages: This method is limited to situations with a water level control structure. Pumps can be used to de-water further if groundwater seepage is not significant. This technique may also result in the removal of beneficial plant species. Drawdowns can decrease bottom dwelling invertebrates and overwintering reptiles and amphibians. Drawdowns can affect adjacent wetlands, alter downstream flows, and potentially impair well production. Drawdowns and any water level manipulation are often highly controversial since shoreline landowners access and public recreation are limited during the drawdown. Fish populations are vulnerable during a drawdown due to over-harvesting by fisherman in decreased water volumes.

Costs: If a suitable outlet structure is available then costs should be minimal. If dewatering pumps would be required or additional management projects such as dredging are completed, additional costs would be incurred. Other costs would include recreational losses and perhaps loss in tourism revenue.

Chemical Controls

Using chemical herbicides to kill nuisance aquatic plants is the oldest APM method. However, past pesticides uses being linked to environmental or human health problems have led to public wariness of chemicals in the environment. Current pesticide registration procedures are more stringent than in the past. While no chemical pesticide can be considered 100 percent safe, federal pesticide regulations are based on the premise that if a chemical is used according to its label instructions it will not cause adverse environmental or human health effects.

Chemical herbicides for aquatic plants can be divided into two categories, systemic and contact herbicides. Systemic herbicides are absorbed by the plant, translocated throughout the plant, and are capable of killing the entire plant, including the roots and shoots. Contact herbicides kill the plant surface in which in comes in contact, leaving roots capable of re-growth. Aquatic herbicides exist under various trade names, causing some confusion. Aquatic herbicides include the following:

- Endothall Based Herbicide
- Diquat Based Herbicide
- Fluridone Based Herbicide
- 2-4 D Based Herbicide
- Glyophosate Based Herbicide
- Triclopyr Based Herbicide
- Phosphorus Precipitation

Each of these methods are described below. The costs, benefits, and drawbacks of each chemical APM alternative are provided.

Endothall Based Herbicide: Endothall is a contact herbicide, attacking a wide range of plants at the point of contact. The chemical is not readily transferred to other plant tissue, therefore regrowth can be expected and repeated treatments may be needed. It is sold in liquid and granular forms under the trade names of Aquathol® or Hydrothol®. Hydrothol is also an algaecide. Most endothall products break down easily and do not remain in the aquatic environment. Endothall products can result in plant reductions for a few weeks to several months. Multi-season effectiveness is not typical. A permit is required for use of this herbicide.

Advantages: Endothall products work quickly and exhibit moderate to highly effective control of floating and submersed species. This herbicide has limited toxicity to fish at recommended doses.

Disadvantages: The entire plant is not killed when using endothall. Endothall is non-selective in the treatment area. High concentrations can kill fish easily. Water use restrictions (time delays) are necessary for recreation, irrigation, and fish consumption after application.

Costs: Costs vary with treatment area and dosage. Average costs for chemical application range between $400 and $700 per acre.

Diquat Based Herbicide: Diquat is a fast-acting contact herbicide effective on a broad spectrum of aquatic plants. It is sold under the trade name Reward®. Diluted forms of this product are also sold as private label products. Since Diquat binds to sediments readily, its effectiveness is reduced by turbid water. Multi-season effectiveness is not typical. A permit is required for use of this herbicide.

Advantages: Diquat works quickly and exhibit moderate to highly effective control of floating and submersed species. This herbicide has limited toxicity to fish at recommended doses.

Disadvantages: The entire plant is not killed when using diquat. Diquat is non-selective in the treatment area. Diquat can be inactivated by suspended sediments. Diquat is sometimes toxic to zooplankton at the recommended dose. Limited water used restrictions (water supply, agriculture, and contact recreation) are required after application.

Costs: Costs vary with treatment area and dosage. A general cost estimate for treatment is between $200 and $500 per acre.

Fluoridone Based Herbicide: Fluoridone is a slow-acting systemic herbicide, which is effectively absorbed and translocated by both plant roots and stems. Sonar® and Avast!® is the trade name and it is sold in liquid or granular form. Fluoridone requires a longer contact time and demonstrates delayed toxicity to target plants. Eurasian watermilfoil is more sensitive to fluoridone than other aquatic plants. This allows a semi-selective approach when low enough doses are used. Since the roots are also killed, multi-season effectiveness can be achieved. It is best applied during the early growth phase of the plants. A permit and extensive planning is required for use of this herbicide.

Advantages: Fluoridone is capable of killing roots, therefore producing a longer lasting effect than other herbicides. A variety of emergent and submersed aquatics are susceptible to this herbicide. Fluoridine can be used selectively, based on concentration. A gradual killing of target plants limits severe oxygen depletion from dead plant material. It has demonstrated low toxicity to aquatic fauna such as fish and invertebrates. 3 to 5 year control has been demonstrated. Extensive testing has shown that, when used according to label instructions, it does not pose negative health affects.

Disadvantages: Fluoridine is a very slow-acting herbicide sometimes taking up to several months for visible effects. It requires a long contact time. Fluoridine is extremely soluble and mixable, therefore, not effective in flowing water situations or for treating a select area in a large open lake. Impacts on non-target plants are possible at higher doses. Time delays are necessary on use of the water (water supply, irrigation, and contact recreation) after application.

Costs: Costs vary with treatment area and dosage. Treatment costs range from $500 to $2,000 per acre.

2,4-D Based Herbicide: 2,4-D based herbicides are sold in liquid or granular forms under various trade names. Common granular forms are sold under the trade names Navigate® and Aqua Kleen®. Common liquid forms include DMA 4® and Weedar 64®. 2,4-D is a systemic herbicide that affects broad leaf plants. It has been demonstrated effective against Eurasian watermilfoil, but it may not work on many aquatic plants. Since the roots are also killed, multi-season effectiveness may be achieved. It is best applied during the early growth phase of the plants. Visible results are evident within 10 to 14 days. A permit is required for use of this herbicide.

Advantages: 2,4-D is capable of killing roots, therefore producing a longer lasting effect than some other herbicides. It is fairly fast and somewhat selective, based on application timing and concentration. 2,4-D containing products are moderately to highly effective on a few emergent, floating, or submersed plants.

Disadvantages: 2,4-D can have variable toxicity effects to aquatic fauna, depending on formulation and water chemistry. 2,4-D lasts only a short time in water, but can be detected in sediments for months after application. Time delays are necessary on use of the water (agriculture and contact recreation) after application. The label does not permit use of this product in water used for drinking, irrigation, or livestock watering.

Costs: Costs vary with treatment area and dosage. Treatment costs range from $300 to $800 per acre.

Glyophosate Based Herbicide: Glyophosate has been categorized as both a contact and a systemic herbicide. It is applied as a liquid spray and is sold under the trade name Rodeo® or Pondmaster®. It is a non-selective, broad based herbicide effective against emergent or floating leaved plants, but not submergents. It's effectiveness can be reduced by rain. A permit is required for use of this herbicide.

Advantages: Glyophoshate is moderately to highly effective against emergent and floating-leaf plants resulting in rapid plant destruction. Since it is applied by spraying plants above the surface, the applicator can apply it selectively to target plants. Glyophosate dissipates quickly from natural waters, has a low toxicity to aquatic fauna, and carries no restrictions or time delays for swimming, fishing, or irrigation.

Disadvantages: Glyophoshate is non-selective in the treatment area. Wind can dissipate the product during the application reducing it's effectiveness and cause damage to non-target organisms. Therefore, spray application should only be completed when wind drift is not a problem. This compound is highly corrosive, therefore storage precautions are necessary.

Costs: Costs average $500 to $1,000 per acre depending on the scale of treatment.

Triclopyr Based Herbicide: Triclopyr is a systemic herbicide. It is registered for experimental aquatic use in selected areas only. It is applied as a liquid spray or injected into the subsurface as a liquid. Triclopyr is sold under the trade name Renovate® or Restorate®. Triclopyr has shown to be an effective control to many floating and submersed plants. It has been demonstrated to be highly effective against Eurasian watermilfoil, having little effect on valued native plants such as pondweeds. Triclopyr is most effective when applied during the active growth period of younger plants.

Advantages: This herbicide is fast acting. Triclopyr can be used selectively since it appears more effective against dicot plant species, including several difficult nuisance plants. Testing has demonstrated low toxicity to aquatic fauna.

Disadvantages: At higher doses, there are possible impacts to non-target species. Some forms of this herbicide are experimental for aquatic use and restrictions on use of the treated water are not yet certain.

Biological Controls

There has been recent interest in using biological technologies to control aquatic plants. This concept stems from a desire to use a "natural" control and reduce expenses related to equipment and/or chemicals. While use of biological controls is in its infancy, potentially useful technologies have been identified and show promise for integration with physical and chemical APM strategies. Several biological controls that are in use or are under experimentation include the following:

- Herbivorous Fish
- Herbivorous Insects
- Plant Pathogens
- Native Plants

Each of these methods are described below. The costs, benefits, and drawbacks of each biologic APM method are provided.

Herbivorous Fish: A herbivorous fish such as the non-native grass carp can consume large quantities of aquatic plants. These fish have high growth rates and a wide range of plant food preferences. Stocking rates and effectiveness will depend on many factors including climate, water temperature, type and extent of aquatic plants, and other site-specific issues. Sterile (triploid) fish have been developed resulting in no reproduction of the grass carp and population control. This technology has demonstrated mixed results and is most appropriately used for lake-wide, low intensity control of submersed plants. Some states do not allow stocking of herbivorous fish. In Wisconsin, stocking of grass carp is prohibited.

Advantages: This technology can provide multiple years of aquatic plant control from a single stocking. Compared to other long-term aquatic plant control techniques such as bottom tillage or bottom barriers, costs may be relatively low.

Disadvantages: Sterile grass carp exhibit distinct food preferences, limiting their applicability. Grass carp may feed selectively on the preferred plants, while less preferred plants, including milfoil, may increase. The effects of using grass carp may not be immediate. Overstocking may result in an impact on non-target plants or eradication of beneficial plants, altering lake habitat. Using grass carp may result in algae blooms and increased turbidity. If precautions are not taken (i.e. inlet and outlet control structures to prevent fish migration) the fish may migrate and have adverse effects on non-target vegetation.

Costs: Costs can range from $50/acre to over $2,000/acre, at stocking rates of 5 fish/acre to 200 fish/acre.

Herbivorous Insects: Non-native and native insect species have been used to control rooted plants. Using herbivorous insects is intended to selectively control target species. These aquatic larvae of moths, beetles, and thrips use specific host aquatic plants. Several non-native species have been imported under USDA approval and used in integrated pest management programs, a combination of biological, chemical, and mechanical controls.

These non-native insects are being used in southern states to control nuisance plant species and appear climate-limited, their northern range being Georgia and North Carolina. While successes have been demonstrated, non-native species have not established themselves for solving biological problems, sometimes creating as many problems as they solve. Therefore, government agencies prefer alternative controls.

Native insects such as the larvae of midgeflies, caddisflies, beetles, and moths may be successful APM controls in northern states. Recently however, the native aquatic weevil *Euhrychiopsis lecontei* has received the most attention. This weevil has been associated with native northern water milfoil. The weevil can switch plant hosts and feed on Eurasian watermilfoil, destroying it's growth points. While the milfoil weevil is gaining popularity, it is still experimental.

Advantages: Herbivorous insects are expected to have no negative effects on non-target species. The insects have shown promise for long term control when used as part of integrated aquatic plant management programs. The milfoil weevils do not use non-milfoil plants as hosts.

Disadvantages: Natural predator prey cycles indicate that incomplete control is likely. An oscillating cycle of control and re-growth is more likely. Fish predation may complicate controls. Large numbers of milfoil weevils may be required for a dense stand and can be expensive. The weevil leaves the water during the winter, may not return to the water in the spring, and are subject to bird predation in their terrestrial habitat. Application is manual and extremely time consuming. Introducing any species, especially non-native ones, into an aquatic ecosystem may have undesirable effects. Therefore, it is extremely important to understand the life cycles of the insects and the host plants.

Costs: Reported costs of herbivorous insects rang from $300/acre to $3,000/acre.

Specifically, the native milfoil weevils cost approximately $1.00 per weevil. It is generally considered appropriate to use 5 to 7 weevils per stem. Dense stands of milfoil may contain 1 to 2 million stems per acre. Therefore, costs of this new technology are currently prohibitive.

Plant Pathogens: Using a plant pathogen to control nuisance aquatic plants has been studied for many years, however, plant pathogens still remain largely experimental. Fungi are the most common pathogens, while bacteria and viruses have also been used. There is potential for highly specific plant applications.

Advantages: Plant pathogens may be highly species specific. They may provide substantial control of a nuisance species.

Disadvantages: Pathogens are experimental. The effectiveness and longevity of control is not well understood. Possible side effects are also unknown.

Costs: These techniques are experimental therefore a supply of specific products and costs are not established.

Native Plants: This method involves removing the nuisance plant species through chemical or physical means and re-introducing seeds, cuttings, or whole plants of desirable species. Success has been variable. When using seeds, they need to be planted early enough to encourage the full growth and subsequent seed production of those plants. Transplanting mature plants may be a better way to establish seed producing populations of desirable aquatics. Recognizing that a healthy, native, desirable plant community may be resistant to infestations of nuisance species, planting native plants should be encouraged as an APM alternative. Non-native plants can not be translocated.

Advantages: This alternative can restore native plant communities. It can be used to supplement other methods and potentially prevent future needs for costly repeat APM treatments.

Disadvantages: While this appears to be a desirable practice, it is experimental at this time and there are not many well documented successes. Nuisance species may eventually again invade the areas of native plantings. Careful planning is required to ensure that the introduced species do not themselves become nuisances. Hand planting aquatic plants is labor intensive.

Costs: Costs can be highly variable depending on the selected native species, numbers of plants ordered, and the nearest dealer location.

Aquatic Plant Prevention

The phrase "an ounce of prevention is worth a pound of cure" certainly holds true for APM. Prevention is the best way to avoid nuisance aquatic plant growth. Prevention of the spread of invasive aquatic plants must also be achieved. Inspecting boats, trailers, and live wells for live aquatic plant material is the best way to prevent nuisance aquatic plants from entering a new aquatic ecosystem. Protecting the desirable native plant communities is also important in maintaining a healthy aquatic ecosystem and preventing the spread of nuisance aquatics once they are present.

Prolific growth of nuisance aquatic plants can be prevented by limiting nutrient (i.e. phosphorus) inputs to the water body. Aeration or phosphorus precipitation can achieve controls of in-lake cycling of phosphorus, however, if there are additional outside sources of nutrients, these methods will be largely ineffective in controlling algae blooms or intense aquatic macrophyte infestations. Watershed management activities to control nutrient laden storm water runoff are critical to controlling excessive nutrient loading to the water bodies. Nutrient loading can be prevented/minimized by the following:

- Shoreline buffers
- Using non-phosphorus fertilizers on lawns
- Settling basins for storm water effluents