7.0 Alternatives to Renovate ® 3

This section details various alternatives to the proposed action. Specifically, this evaluation considers the advantages and disadvantages of potential macrophyte control treatment alternatives other than use of Renovate® 3. These other potential alternatives to the use of Renovate® 3 include those based on physical control (manipulations of light, water depth, substrate, etc.), chemical control (other aquatic herbicides), and biological controls (herbivorous fish, insects, etc.), as well as the no-action alternative (which entails the lack of any aquatic macrophyte control measure). The no-action alternative does not preclude the ability of an applicant to apply for a permit for the use of those products described in the Final Programmatic Environmental Impact Statement on Aquatic Vegetation Control (NYSDEC, 1981a). Each of the possible macrophyte control treatment alternatives should be evaluated from the standpoint of efficacy, positive and negative environmental impacts, and relative costs. The choice of a particular alternative over the proposed use of Renovate® 3 should be based on the management objectives for the waterbody and the specific characteristics of the problem.

7.1 Identification of Relevant Macrophyte Control Treatment Alternatives

There are a large number of control treatments potentially available for use to control non-desirable macrophyte populations. The various methods typically used to control aquatic plants are summarized in Table 7-1 (adapted from Wagner (2001), categorized by the principal mode of action (i.e., either physical, chemical or biological)). Table 7-1 provides a quick summary of the mode of action, advantages and disadvantages for these alternatives. The three classes of macrophyte treatment control alternatives are introduced briefly below, with additional detailed information on the specific alternatives provided later in this section.

Physical treatment alternatives refer to macrophyte control treatment alternatives that work primarily by altering the light regime, the depth or nature of the benthic substrate, or the elevation of overlying surface water. These macrophyte control treatment alternatives include:

- Benthic Barriers - Placement of materials on the bottom of a lake to cover and impede the growth of macrophytes;
- Dredging – removal of underlying sediment through various methods (dry, wet, pneumatic) to either remove suitable or nutrient-rich substrate or to decrease available light (attenuation);
- Dyes and surface covers – Addition of coloring agents or sheet material to inhibit light penetration and reduce vascular plant growths;
- Harvesting - Multiple methods of mechanical plant cutting, with or without removal, and algal collection; and
- Drawdown - Lowering of the water level to dry and freeze susceptible vegetation.

Table 7-1 Management Options for Control of Aquatic Plants (adapted from Wagner, 2001)

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
PHYSICAL CONTROLS			
1) Benthic barriers	• Mat of variable composition laid on bottom of target area, preventing growth • Can cover area for as little as several months or permanently • Maintenance improves effectiveness • Usually applied around docks, in boating lanes, and in swimming areas	• Highly flexible control • Reduces turbidity from soft bottoms • Can cover undesirable substrate • Can improve fish habitat by creating edge effects	• May cause anoxia at sediment-water interface • May limit benthic invertebrates • Non-selective interference with plants in target area • May inhibit spawning/feeding by some fish species
1.a) Porous or loose-weave synthetic materials	• Laid on bottom and usually anchored by weights or stakes • Removed and cleaned or flipped and repositioned at least once per year for maximum effect	• Allows some escape of gases which may build up underneath • Panels may be flipped in place or removed for relatively easy cleaning or repositioning	• Allows some growth through pores • Gas may still build up underneath in some cases, lifting barrier from bottom
1.b) Non-porous or sheet synthetic materials	• Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand • Not typically removed, but may be swept or "blown" clean periodically	• Prevents all plant growth until buried by sediment • Minimizes interaction of sediment and water column	• Gas build up may cause barrier to float upwards • Strong anchoring makes removal difficult and can hinder maintenance
1.c) Sediments of a desirable composition	• Sediments may be added on top of existing sediments or plants. • Use of sand or clay can limit plant growth and alter sediment-water interactions. • Sediments can be applied from the surface or suction dredged from below muck layer (reverse layering technique)	• Plant biomass can be buried • Seed banks can be buried deeper • Sediment can be made less hospitable to plant growths • Nutrient release from sediments may be reduced • Surface sediment can be made more appealing to human users • Reverse layering requires no addition or removal of sediment	• Lake depth may decline • Sediments may sink into or mix with underlying muck • Permitting for added sediment difficult • Addition of sediment may cause initial turbidity increase • New sediment may contain nutrients or other contaminants • Generally too expensive for large scale application

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
2) Dredging	• Sediment is physically removed by wet or dry excavation, with deposition in a containment area for dewatering/disposal • Dredging can be applied on a limited basis, but is most often a major restructuring of a severely impacted system • Plants and seed beds are removed and re-growth can be limited by light and/or substrate limitation	• Plant removal with some flexibility • Increases water depth • Can reduce pollutant reserves • Can reduce sediment oxygen demand • Can improve spawning habitat for many fish species • Allows complete renovation of aquatic ecosystem	• Temporarily removes benthic invertebrates • May create turbidity • May eliminate fish community (complete dry dredging only) • Possible impacts from containment area discharge • Possible impacts from dredged material disposal • Interference with recreation or other uses during dredging • Usually very expensive
2.a) “Dry” excavation	• Lake drained or lowered to maximum extent practical • Target material dried to maximum extent possible • Conventional excavation equipment used to remove sediments	• Tends to facilitate a very thorough effort • May allow drying of sediments prior to removal • Allows use of less specialized equipment	• Eliminates most aquatic biota unless a portion left undrained • Eliminates lake use during dredging
2.b) “Wet” excavation	• Lake level may be lowered, but sediments not substantially dewatered • Draglines, bucket dredges, or long-reach backhoes used to remove sediment	• Requires least preparation time or effort, tends to be least cost dredging approach • May allow use of easily acquired equipment • May preserve most aquatic biota	• Usually creates extreme turbidity • Tends to result in sediment deposition in surrounding area • Normally requires intermediate containment area to dry sediments prior to hauling • May cause severe disruption of ecological function • Impairs most lake uses during dredging

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
2.c) Hydraulic (or pneumatic) removal	• Lake level not reduced • Suction or cutterhead dredges create slurry which is hydraulically pumped to containment area • Slurry is dewatered; sediment retained, water discharged	• Creates minimal turbidity and limits impact on biota • Can allow some lake uses during dredging • Allows removal with limited access or shoreline disturbance	• Often leaves some sediment behind • Cannot handle extremely coarse or debris-laden materials • Requires advanced and more expensive containment area • Requires overflow discharge from containment area
3) Dyes and surface covers	• Water-soluble dye is mixed with lake water, thereby limiting light penetration and inhibiting plant growth • Dyes remain in solution until washed out of system. • Opaque sheet material applied to water surface	• Light limit on plant growth without high turbidity or great depth • May achieve some control of algae as well • May achieve some selectivity for species tolerant of low light	• May not control peripheral or shallow water rooted plants • May cause thermal stratification in shallow ponds • May facilitate anoxia at sediment interface with water • Covers inhibit gas exchange with atmosphere
4) Mechanical removal (“harvesting”)	• Plants reduced by mechanical means, possibly with disturbance of soils • Collected plants may be placed on shore for composting or other disposal • Wide range of techniques employed, from manual to highly mechanized • Application once or twice per year usually needed	• Highly flexible control • May remove other debris • Can balance habitat and recreational needs	• Possible impacts on aquatic fauna • Non-selective removal of plants in treated area • Possible spread of undesirable species by fragmentation • Possible generation of turbidity
4.a) Hand pulling	• Plants uprooted by hand (“weeding”) and preferably removed	• Highly selective technique	• Labor intensive • Difficult to perform in dense stands
4.b) Cutting (without collection)	• Plants cut in place above roots without being harvested	• Generally efficient and less expensive than complete harvesting	• Leaves root systems and part of plant for re-growth • Leaves cut vegetation to decay or to re-root • Not selective within applied area

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
4.c) Harvesting (with collection)	• Plants cut at depth of 2-10 ft and collected for removal from lake	• Allows plant removal on greater scale	• Limited depth of operation • Usually leaves fragments which may re-root and spread infestation • May impact lake fauna • Not selective within applied area • More expensive than cutting
4.d) Rototilling	• Plants, root systems, and surrounding sediment disturbed with mechanical blades	• Can thoroughly disrupt entire plant	• Usually leaves fragments which may re-root and spread infestation • May impact lake fauna • Not selective within applied area • Creates substantial turbidity • More expensive than harvesting
4.e) Hydroraking	• Plants, root systems and surrounding sediment and debris disturbed with mechanical rake, part of material usually collected and removed from lake	• Can thoroughly disrupt entire plant • Also allows removal of stumps or other obstructions	• Usually leaves fragments which may re-root and spread infestation • May impact lake fauna • Not selective within applied area • Creates substantial turbidity • More expensive than harvesting
5) Water level control	• Lowering or raising the water level to create an inhospitable environment for some or all aquatic plants • Disrupts plant life cycle by dessication, freezing, or light limitation	• Requires only outlet control to affect large area • Provides widespread control in increments of water depth • Complements certain other techniques (dredging, flushing)	• Potential issues with water supply • Potential issues with flooding • Potential impacts to non-target flora and fauna

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
5.a) Drawdown	• Lowering of water over winter period allows desiccation, freezing, and physical disruption of plants, roots and seed beds • Timing and duration of exposure and degree of dewatering are critical aspects • Variable species tolerance to drawdown; emergent species and seed-bearers are less affected • Most effective on annual to once/3 yr. basis	• Control with some flexibility • Opportunity for shoreline clean-up/structure repair • Flood control utility • Impacts vegetative propagation species with limited impact to seed producing populations	• Possible impacts on contiguous emergent wetlands • Possible effects on overwintering reptiles and amphibians • Possible impairment of well production • Reduction in potential water supply and fire fighting capacity • Alteration of downstream flows • Possible overwinter water level variation • Possible shoreline erosion and slumping • May result in greater nutrient availability for algae
5.b) Flooding	• Higher water level in the spring can inhibit seed germination and plant growth • Higher flows which are normally associated with elevated water levels can flush seed and plant fragments from system	• Where water is available, this can be an inexpensive technique • Plant growth need not be eliminated, merely retarded or delayed • Timing of water level control can selectively favor certain desirable species	• Water for raising the level may not be available • Potential peripheral flooding • Possible downstream impacts • Many species may not be affected, and some may be benefitted • Algal nuisances may increase where nutrients are available
CHEMICAL CONTROLS			
6) Herbicides	• Liquid or pelletized herbicides applied to target area or to plants directly • Contact or systemic poisons kill plants or limit growth • Typically requires application every 1-5 yrs	• Wide range of control is possible • May be able to selectively eliminate species • May achieve some algae control as well	• Possible toxicity to non-target species • Possible downstream impacts • Restrictions of water use for varying time after treatment • Increased oxygen demand from decaying vegetation • Possible recycling of nutrients to allow other growths

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
6.a) Forms of endothall (7-oxabicyclo [2.2.1] heptane-2,3-dicarboxylic acid)	• Contact herbicide with limited translocation potential • Membrane-active chemical which inhibits protein synthesis • Causes structural deterioration • Applied as liquid or granules	• Moderate control of some emersed plant species, moderately to highly effective control of floating and submersed species • Limited toxicity to fish at recommended dosages • Rapid action	• Non-selective in treated area • Toxic to aquatic fauna (varying degrees by formulation) • Time delays on use for water supply, agriculture and recreation • Safety hazards for applicators
6.b) Forms of diquat (6,7-dihydropyrido [1,2-2’,1’-c] pyrazinediium dibromide)	• Contact herbicide • Absorbed by foliage but not roots • Strong oxidant; disrupts most cellular functions • Applied as a liquid, sometimes in conjunction with copper	• Moderate control of some emersed plant species, moderately to highly effective control of floating or submersed species • Limited toxicity to fish at recommended dosages • Rapid action	• Non-selective in treated area • Toxic to zooplankton at recommended dosage • Inactivated by suspended particles; ineffective in muddy waters • Time delays on use for water supply, agriculture and recreation
6.c) Forms of glyphosate (N-[phosphonomethyl glycine)	• Contact herbicide • Absorbed through foliage, disrupts enzyme formation and function in uncertain manner • Applied as liquid spray	• Moderately to highly effective control of emersed and floating plant species • Can be used selectively, based on application to individual plants • Rapid action • Low toxicity to aquatic fauna at recommended dosages • No time delays for use of treated water	• Non-selective in treated area • Inactivation by suspended particles; ineffective in muddy waters • Not for use within 0.5 miles of potable water intakes • Highly corrosive; storage precautions necessary

OPTION	MODE OF ACTION	ADVANTAGES	DISADVANTAGES
6.d) Forms of 2,4-D (2,4-dichlorophenoxyl acetic acid)	• Systemic herbicide • Readily absorbed and translocated throughout plant • Inhibits cell division in new tissue, stimulates growth in older tissue, resulting in gradual cell disruption • Applied as liquid or granules, frequently as part of more complex formulations, preferably during early growth phase of plants	• Moderately to highly effective control of a variety of emersed, floating and submersed plants • Can achieve some selectivity through application timing and concentration • Fairly fast action	• Variable toxicity to aquatic fauna, depending upon formulation and ambient water chemistry • Time delays for use of treated water for agriculture and recreation • Not for use in water supplies
6.e) Forms of fluridone (1-methyl-3-phenyl-5-[-3-{trifluoromethyl} phenyl]-4[IH]-pyridinone)	• Systemic herbicide • Inhibits carotenoid pigment synthesis and impacts photosynthesis • Best applied as liquid or granules during early growth phase of plants	• Can be used selectively, based on concentration • Gradual deterioration of affected plants limits impact on oxygen level (BOD) • Effective against several difficult-to-control species • Low toxicity to aquatic fauna	• Impacts on non-target plant species possible at higher doses • Extremely soluble and mixable; difficult to perform partial lake treatments • Requires extended contact time

Chemical treatment alternatives refer to macrophyte control treatment alternatives that work primarily by application of chemical agents (aquatic herbicides) to directly kill the aquatic macrophytes. These include registered aquatic herbicides which differ in both application and mode of chemical action (general, systemic). For purposes of this analysis we will consider five of the major pesticides registered for use in New York State: Diquat, Endothall, Glyphosphate, 2,4-D, and Fluridone.

Biological treatment alternatives refer to macrophyte control treatment alternatives that work primarily by interaction of other species with the target macrophytes. These may include the stocking or manipulation of phytophagous (i.e., plant-eating) fish and invertebrates to control macrophytes through biological interactions.

7.2 Integrated Plant Management

As described briefly above and discussed in greater detail in the following sections, there is a potentially large selection of possible macrophyte control treatments or technologies that exist. However, not all techniques are appropriate for a given lake and/or to effectively address nuisance macrophyte concerns. Furthermore, techniques may either be non-compatible or may exacerbate the problem (e.g., harvesting of pioneer water milfoil stand leading to fragmentation and widespread colonization of the lake). Given the potentially high costs necessary for extensive whole lake treatments, it is important that the appropriate techniques be used to maximize the benefits that such treatments can provide. In addition, there are potential societal conflicts that can occur between groups of lake users, who may have very different ideas regarding the best use of the lake. Therefore, it is important that the selection of any macrophyte control treatment, including herbicides, be conducted as a result of a well thought-out long-term Integrated Aquatic Vegetation Management Plan (IAVMP). This approach is also consistent with NYSDEC guidance, which endorses the development of an

Aquatic Plant Management Plan as an important component of any strategy to deal with nuisance macrophytes (Appendix A in NYSDEC, 2005).

There are many guidance documents that describe the steps and necessary data to be collected in developing an IAVMP (e.g., Hoyer and Canfield, 1997; WA DOE, 2004; NYSDEC, 2005). These methodologies are roughly equivalent and are likely to include the following components (adapted from WA DOE, 2004):

- **Develop a Problem Statement** – the problem statement summarizes the types, locations, and density of problem aquatic vegetation, and identifies the nature and the extent to which beneficial water uses are being impaired;
- **Describe Past Management Efforts** – summarizes the previous efforts at chemical and non-chemical plant control methods (for last 5 years or longer) and identifies the organizations (e.g., county, lake association, beach association, etc) that sponsored them (this last step is important in identifying possible stakeholders);
- **Define Management Goals** – based on the problem statement and previous experiences in plant control, and the characteristics of the lake, the management goals define what is to be achieved in response to the aquatic plant problems. Defining goals helps in selection of appropriate control treatments. The scope of the management efforts should cover at least 5 years;
- **Determine Waterbody and Watershed Characteristics** – identify geographic limits, land use, potential point and non-point sources, and tributary systems within the waterbody watershed. Provide basic information on the lake size, depth, water quality, residence time, sediment types, water uses, riparian uses (including wetlands), biotic communities (aquatic plants, fish, amphibians, waterfowl), and identify any listed threatened or endangered (T&E) species within or adjacent to the lake;
- **List the Beneficial Uses of the Waterbody** – list the beneficial uses of the waterbody; map their location (this will allow for matching control treatments to within lake habitats and/or recreational focal points);
- **Map Aquatic Plants** – map the approximate location and species of aquatic plants, the sediment depth and type, water depths (bathymetry), locations of wetlands, and location of any T&E species. Correct identification is essential in order to prevent the eradication of rare and endangered species and to document the plant population so that it can be monitored over time (Hellquist, 1993; Crow and Hellquist, 2000). A listing of plants considered rare, threatened or endangered in New York is available in Appendix B. Based on the beneficial uses identified in the step above, indicate whether a high or low level of aquatic plant control is desired. In some cases, no control may be appropriate (i.e., leaving intact aquatic vegetation in selected locations to support fish populations);
- **Identify the Aquatic Plant Control Treatment Alternatives** – identify and screen potential control treatment alternatives, their effectiveness, environmental impacts, human health risks, and costs. For some lakes, several treatment techniques may be immediately eliminated from further consideration, based on the waterbody and watershed characteristics;
- **Select the Aquatic Plant Control Treatment Method(s)** – an IAVMP plan needs to be waterbody-specific and is likely to involve a combination of methods. This step involves choosing the best control treatment (or set of methods) that best achieves the long-term management goals, with least impacts to the environment and is cost-effective;
- **Public Involvement -** the IAVMP should be a consensus document, with support or acceptance by major stakeholders and permitting agencies. The draft IAVMP should be presented in public meeting and public and regulatory comments sought. The final IAVMP will be revised according to this feedback;
- **Develop an Action Strategy** – Based on the final IAVMP, take initial steps or immediate actions (e.g., install BMPs, purchase harvester, etc), provide foundations for later actions, and institute monitoring; and

- **Monitoring and Evaluation of Plan** – monitoring plans should include sampling for concentrations of an applied herbicide, at various time and locations (a pre-treatment sample is recommended). Other field monitoring may be required for other techniques (e.g., turbidity for dredging project). A pre- and post-treatment measurement of plant density and biomass is recommended to evaluate the effectiveness of various treatment alternatives.

The IAVMP should be considered a constantly evolving document. The IAVMP, its supporting information, and management goals should be periodically re-evaluated. The results of the post-treatment monitoring should be evaluated to see how well a particular treatment is controlling nuisance plants or whether unexpected side effects are noted. Quantitative criteria for target plant species reduction are useful benchmarks, but a more important measure of success will be the amount of increase (or decrease) or improvement in the beneficial uses of a waterbody.

7.3 Physical Controls

Physical controls involve the direct alteration of the plant itself, the substrate, water column or general environment in which it depends on for survival. Physical controls for milfoil include benthic barriers, dredging, dyes, surface covers, harvesting, and water level controls. Each of these techniques is described below. Much of this information is adapted from Mattson et al. (2004) and Wagner (2004).

7.3.1 Benthic Barriers

The use of benthic barriers, or bottom covers, is predicated upon the principles that rooted plants require light and cannot grow through physical barriers. Applications of clay, silt, sand, and gravel have been used for many years, although plants often root in these covers eventually, and current environmental regulations make it difficult to gain approval for such deposition of fill. Artificial sediment covering materials, including polyethylene, polypropylene, fiberglass, and nylon, have been developed over the last three decades. A variety of solid and porous forms have been used. Manufactured benthic barriers are negatively buoyant materials, usually in sheet form, which can be applied on top of plants to limit light, physically disrupt growth, and allow unfavorable chemical reactions to interfere with further development of plants. Various plastics and burlap have also been used, but are not nearly as durable or effective in most cases.

In theory, benthic barriers should be a highly effective plant control technique, at least on a localized, area-selective scale. In practice, however, there have been difficulties with the deployment and maintenance of benthic barriers, limiting their utility over the broad range of field conditions. Benthic barriers can be effectively used in small areas such as dock spaces and swimming beaches to completely terminate plant growth. The creation of access lanes and structural habitat diversity is also practical. Large areas are not often treated, however, because the cost of materials, application and maintenance is high.

Benthic barrier problems of prime concern include long-term integrity of the barrier, billowing caused by trapped gases, accumulation of sediment on top of barriers, and growth of plants on porous barriers. Successful use is related to selection of materials and the quality of the installation and subsequent maintenance.

Bottom barriers will eventually accumulate sediment deposits in most cases, which allow plant fragments to root. Barriers must then be cleaned, necessitating either removal or laborious in-place maintenance (Eichler et al., 1995). Despite application and maintenance issues, a benthic barrier can be a very effective tool. Benthic barriers are capable of providing control of rooted plants on at least a localized basis, and have such desirable side benefits as creating more edge habitat within dense plant assemblages and minimizing turbidity generation from fine bottom sediments.

7.3.2 Dredging

Dredging is perhaps best known for maintaining navigation channels in rivers, harbors and ports or for underwater mining of sand and gravel, but dredging can also be an effective lake management technique for the control invasive growth of macrophytes (Holdren et al., 2001). The management objectives of a sediment removal project are usually to deepen a shallow lake for boating and fishing, or to remove nutrient rich sediments that can cause algal blooms or support dense growths of rooted macrophytes.

Dredging can be accomplished by multiple methods that can be conveniently grouped into four categories:

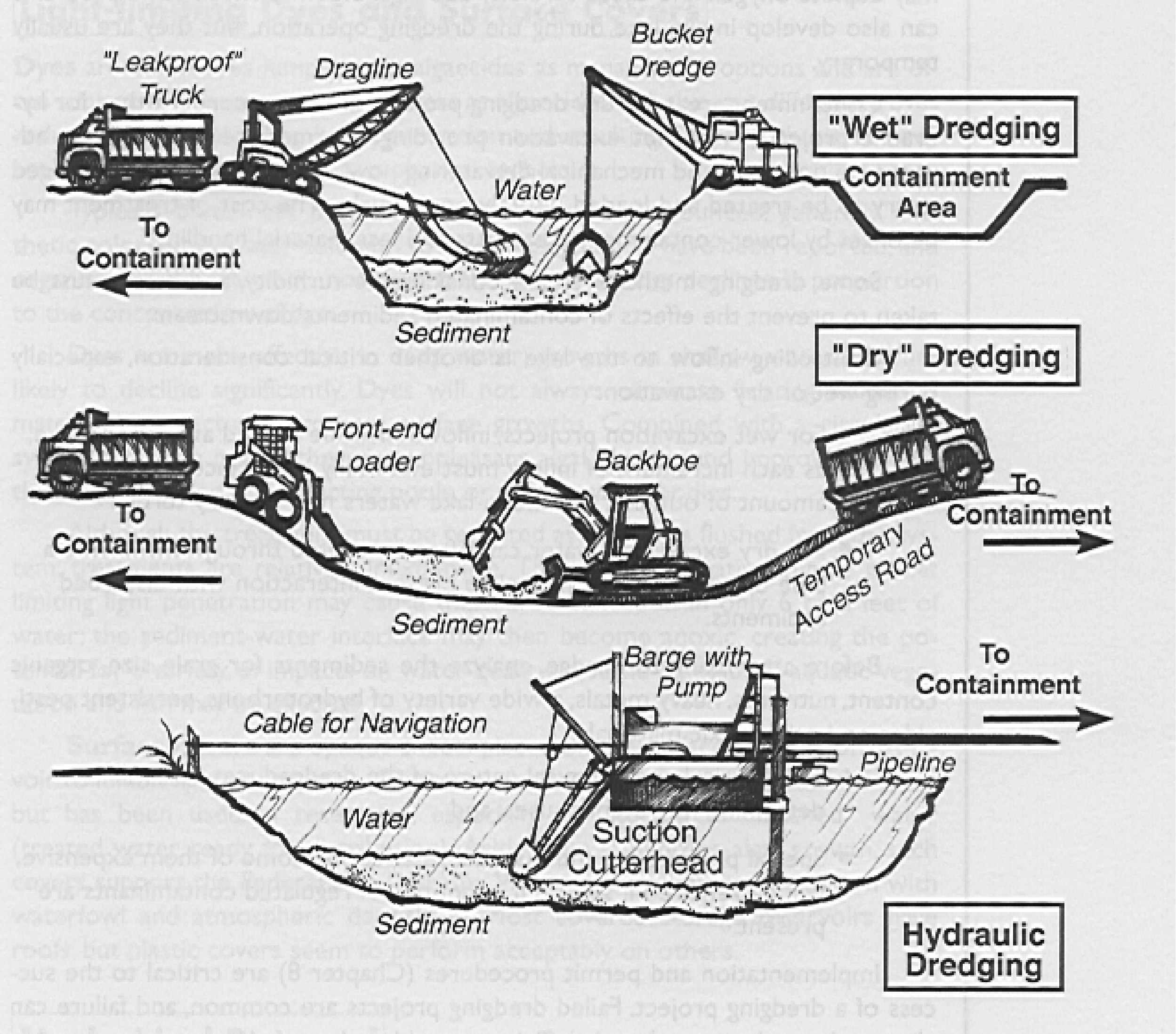
- Dry excavation, in which the lake is drained to the extent possible, the sediments are dewatered by gravity and/or pumping, and sediments are removed with conventional excavation equipment such as backhoes, bulldozers, or draglines.
- Wet excavation, in which the lake is not drained or only partially drawn down (to minimize downstream flows), with excavation of wet sediments by various bucket dredges mounted on cranes or amphibious excavators.
- Hydraulic dredging, requiring a substantial amount of water in the lake to float the dredge and provide a transport medium for sediment. Hydraulic dredges are typically equipped with a cutterhead that loosens sediments that are then mixed with water and transported as pumped slurry of 80 to 90% water and 10 to 20% solids through a pipeline that traverses the lake from the dredging site to a disposal area.
- Pneumatic dredging, in which air pressure is used to pump sediments out of the lake at a higher solids content (reported as 50 to 70%). This would seem to be a highly desirable approach, given containment area limitation in many cases and more rapid drying with higher solids content. However, few of these dredges are operating within North America, and there is little freshwater experience upon which to base a review. Considerations are much like those for hydraulic dredging, and pneumatic dredging will not be considered separately from hydraulic dredging for further discussion.

Dry, wet and hydraulic methods are illustrated in Figure 7-1. Cooke et al. (1993) provides a discussion of dredging considerations that will be helpful to some readers. Recent developments, methods, impact assessment and methods for handling dredged material can be found in McNair (1994). No technique requires more up front information about the lake and its watershed, and there are many engineering principles involved in planning a successful dredging project. No technique is more suitable for true lake restoration, but there are many potential impacts that must be considered and mitigated in the dredging process. Failed dredging projects are common, and failure can almost always be traced to insufficient consideration of the many factors that govern dredging success.

Dredging works as a plant control technique when either a light limitation on growth is imposed through increased water depth or when enough “soft” sediment (muck, clay, silt and fine sand) is removed to reveal a less hospitable substrate (typically rock, gravel or coarse sand). The amount of sediment removed, and hence the new depth and associated light penetration, is critical to successful long term control of rooted, submerged plants. There appears to be a direct relation between water transparency, as determined with a Secchi disk, and the maximum depth of colonization by macrophytes (Canfield et al.,1985). Dredging also removes the accumulated seed bed established by many vascular plants and the resting cysts deposited by a variety of algae.

Partial deepening may limit the amount of vegetation that reaches the surface, but may also favor species tolerant of low light, some of which are non-indigenous species with high nuisance potential, such as Eurasian watermilfoil. Where funding is insufficient to remove all soft sediment, it is more effective to create a depth or substrate limitation in part of the lake than to remove some sediment from all target areas of the lake, if rooted plant control is the primary objective of dredging.

Figure 7-1 Dry, Wet and Hydraulic Dredging Approaches (from Wagner, 2001)



If the soft sediment accumulations that are supporting rooted plant nuisances are not especially thick, it may be possible to create a substrate limitation before a light-limiting depth is reached. If dredging exposes rock ledge or cobble, and all soft sediment can be removed, there will be little rooted plant growth. Yet such circumstances are rare to non-existent; either the soft sediment grades slowly into coarser materials, or it is virtually impossible to remove all fine sediments from the spaces around the rock or cobble. Consequently, some degree of regrowth is to be expected when light penetrates to the bottom. With successful dredging, this regrowth may be only 25% of the pre-dredging density or coverage, and will not contain more recently invading species at a dominant level. Yet some rooted plant regrowth is expected, and is indeed desirable for proper ecological function of the lake as a habitat and for processing of future pollutant inputs.

A properly conducted dredging program removes accumulated sediment from a lake and effectively sets it back in time, to a point prior to significant sedimentation. Partial dredging projects are possible and may be appropriate depending upon management goals, but for maximum benefit it is far better to remove all “soft” sediment to achieve restoration objectives.

7.3.3 Dyes

The use of dyes as algal or vascular plant control agents is often grouped with herbicides in lake management evaluations, but this can be very misleading with regard to how dyes work. Dyes are used to limit light penetration and therefore restrict the depth at which rooted plants can grow or the total amount of light available for algal growth. They are only selective in the sense that they favor species tolerant of low light or with sufficient food reserves to support an extended growth period (during which a stem could reach the lighted zone). Dyes are generally non-toxic to all aquatic species, including the target species of plants. In lakes with high transparency but only moderate depth and ample soft sediment accumulations, dyes may provide open water where little would otherwise exist. Repeated treatment will be necessary, as the dye eventually flushes out of the system. Dyes are typically permitted under the same process as herbicides, despite their radically different mode of action.

Although dyes can be an effective method of algae and plant control in small ornamental and golf course ponds, dyes have not provided consistently acceptable control in larger systems and are not generally applied as a control method for either rooted aquatic plants or algae in larger lakes. The dye should be applied early in the growing season for greatest effectiveness. Dyes can usually only be used in lakes and ponds without a flowing outlet, making it a logical choice for small, contained ornamental ponds. There is insufficient information available to evaluate field applications of dyes other than AQUASHADE®, but the light attenuating mechanism is the same for other commercially available dyes.

7.3.4 Harvesting

There are several methods of harvesting with varying degree of scale costs. These techniques include hand pulling, suction harvesting, mechanical harvesting (cutting with and without collection), rototivation, and hydroraking. Each of these harvesting methods is described in detail below.

Hand pulling is exactly what it sounds like; a snorkeler or diver surveys an area and selectively pulls out unwanted plants on an individual basis. This is a highly selective technique, and a labor intensive one. It is well suited to vigilant efforts to keep out invasive species that have not yet become established in the lake or area of concern. Hand pulling can also effectively address non-dominant growths of undesirable species in mixed assemblages, or small patches of plants targeted for removal (Eichler et al., 1991). This technique is not well suited to large-scale efforts, especially when the target species or assemblage occurs in dense or expansive beds.

Hand pulling can be augmented by various tools, including a wide assortment of rakes, cutting tools, water jetting devices, nets and other collection devices. McComas (1993) provides an extensive review of options. Suction dredging is also used to augment hand pulling, allowing a higher rate of pulling in a targeted area, as the diver/snorkeler does not have to carry pulled plants to a disposal point. Use of these tools transitions into more mechanized forms of harvesting.

Suction harvesting, or suction dredging, is mechanically augmented hand pulling. The diver hand pulls the unwanted plants and allows them to be transported through a vacuum hose to the surface into a mesh bag or other collection device. This technique accelerates the hand pulling process allowing pulling for denser assemblages but generally does not increase the area of control (Eichler et al., 1991; Mattson et al. 2004).

Mechanical harvesting is most often associated with large machines on pontoons that cut and collect vegetation, but encompasses a range of techniques from simply cutting the vegetation in place to cutting, collecting, and grinding the plants, to collection and disposal outside the lake. In its simplest form, cutting, a blade of some kind is applied to plants, severing the active apical meristem (location of growth) and possibly much more of the plant from the remaining rooted portion. Regrowth is expected, and in some species that regrowth is so rapid that it negates the benefits of the cutting in only a few weeks (Nichols and Lathrop, 1994). If the plant can be cut close enough to the bottom, or repeatedly, it will sometimes die, but this is more the exception than the rule. Cutting is defined here as an operation that does not involve collecting the plants once they are cut, so impacts to dissolved oxygen and nutrient release are possible in large-scale cutting operations.

Harvesting usually refers to more advanced technology cutting techniques involving the use of mechanized barges with harvesting operations, in which plants are collected for out-of-lake disposal. In its use as a cutting technology, the “harvester” cuts the plants but does not collect them. A modification in this technique employs a grinding apparatus that ensures that viable plant fragments are minimized after processing. There is a distinct potential for dissolved oxygen impacts and nutrient release as the plant biomass decays, much like what would be expected from many herbicide treatments.

Harvesting may involve collection in nets or small boats towed by the person cutting the weeds, or can employ smaller boat-mounted cutting tools that haul the cut biomass into the boat for eventual disposal on land. It can also be accomplished with larger, commercial machines with numerous blades, a conveyor system, and a substantial storage area for cut plants. Offloading accessories are available, allowing easy transfer of weeds from the harvester to trucks that haul the weeds to a composting area. Choice of equipment is really a question of scale, with larger harvesting operations usually employing commercially manufactured machines built to specifications suited to the job. Some lake associations choose to purchase and operate harvesters, while others prefer to contract harvesting services to a firm that specializes in lake management efforts.

Rotovation is basically the application of an underwater rototiller to an area of sediment, typically one with dense growths of an unwanted rooted aquatic plant. A rotovator is a hydraulically operated tillage device mounted on a barge. The tiller can be lowered to depths of 10 to 12 feet for the purpose of tearing up roots. On a much simpler scale, cultivation equipment or even old bed springs pulled behind tractors can accomplish much root disturbance. Rototilling and the use of cultivation equipment are highly disruptive procedures normally applied on a small scale. Rotovation has a limited track record, mostly in British Columbia. Use of a variety of cultivation equipment has been practiced in New England for many years, but is rarely documented. Potential impacts to non-target organisms and water quality are substantial, but where severe weed infestations exist, this technique could be appropriate.

Hydroraking involves the equivalent of a floating backhoe, usually outfitted with a york rake that looks like a farm implement for tilling or moving silage. The tines of the rake attachment are moved through the sediment, ripping out thick root masses and associated sediment and debris. A hydrorake can be a very effective tool for removing submerged stumps, water lily root masses, or floating islands. Use of a hydrorake is not a delicate operation, however, and will create substantial turbidity and plant fragments. Hydroraking in combination with a harvester can remove most forms of vegetation encountered in lakes.

Hydroraking is effective in the short-term in that it removes plants immediately. It is not an especially thorough or selective technique, and is therefore not well suited to submergent species that can reroot from fragments (e.g., milfoil) or mixed assemblages with desirable species present at substantial densities. It is particularly effective for water lilies (white or yellow) and other species with dense root masses. Hydroraking is also often used to remove subsurface obstructions such as stumps or logs.

7.3.5 Water Level Control

Control of rooted aquatic plants can be achieved through water level control. Two methods can be used, flooding and drawdown. Flooding, increasing water depth in an effort to achieve light limitation for aquatic plant control, is rarely used since water quantity and potential flooding impacts to urban areas limit the utility of this technique. Drawdown is often used, however, and is described below.

Drawdown is a process whereby the water level is lowered by gravity, pumping or siphoning and held at that reduced level for some period of time, typically several months and usually over the winter. Drawdown can provide control of plant species that overwinter in a vegetative state, and oxidation of sediments may result in lower nutrient levels with adequate flushing. Drawdowns also provide flood control and allow access for nearshore clean ups and repairs to structures. The ability to control the water level in a lake is affected by area precipitation pattern, system hydrology, lake morphometry, and the outlet structure. The base elevation of the outlet or associated subsurface pipe(s) will usually set the maximum drawdown level, while the capacity of the outlet to pass water and the pattern of water inflow to the lake will determine if that base elevation can be achieved and maintained. In some cases, sedimentation of an outlet channel or other obstructions may control the maximum drawdown level.

Several factors affect the success of drawdown with respect to plant control. While drying of plants during drawdowns may provide some control, the additional impact of freezing is substantial, making drawdown a more effective strategy during late fall and winter. However, a mild winter or one with early and persistent snow may not provide the necessary level of drying and freezing. The presence of high levels of groundwater seepage into the lake may mitigate or negate destructive effects on target submergent species by keeping the area moist and unfrozen. The presence of extensive seed beds may result in rapid re-establishment of previously occurring plant species, some of which may be undesirable. Recolonization from nearby areas may be rapid, and the response of macrophyte species to drawdown is quite variable.

Aside from direct impact on target plants, drawdown can also indirectly and gradually affect the plant community by changing the substrate composition in the drawdown zone. If there is sufficient slope, finer sediments will be transported to deeper waters, leaving behind a coarser substrate. If there is a thick muck layer present in the drawdown zone, there is probably not adequate slope to allow its movement. However, where light sediment has accumulated over sand, gravel or rock, repetitive drawdowns can restore the coarse substrate and limit plant growths. Expected response of target species (Table 7-2) is of particular importance when plant control is the major goal.

7.4 Chemical Controls

Chemical treatment is one of the oldest methods used to manage nuisance aquatic weeds, and is still the most frequently applied approach. Other than perhaps drawdown, few alternatives to herbicides were widely practiced until relatively recently. Those considering chemical use should become aware of all possible benefits, known limitations and constraints, and possible negative impacts, and should carefully evaluate the applicability and efficacy for the target lake.

Herbicides and algaecides contain active ingredients that are toxic to target plants. For convenience, we will refer to this collective group of chemicals as herbicides here, with inclusion of algaecides inferred. Herbicides are typically classified as contact or systemic herbicides based on the action mode of the active ingredient. Contact herbicides are toxic to plants by uptake in the immediate vicinity of external contact, while systemic herbicides are taken up by the plant and are translocated throughout the plant. In general, contact herbicides are more effective against annuals than perennials because they may not kill the roots, allowing perennials to grow back. Seeds are also not likely to be affected, but with proper timing and perhaps several treatments, growths can be eliminated much the same way harvesting can eliminate annual plants. Systemic herbicides tend to work more slowly than contact herbicides because they take time to be translocated throughout the plant. Systemic herbicides generally provide more effective control of perennial plants than contact herbicides, as they kill the entire plant under favorable application circumstances. Systemic herbicides will also kill susceptible annual species, but regrowth from seeds is usually substantial. If annual species are the target of control, additional treatment will be required, normally a year after initial treatment and for as long as the seed bank facilitates new growths.

Table 7-2 Anticipated Response of Some Common Aquatic Plants to Winter Drawdown (adapted from Cooke et al., 1993)

Change in Relative Abundance			
	Increase	**No Change**	**Decrease**
Acorus calamus (sweet flag)	E		
Alternanthera philoxeroides (alligator weed)	E		
Asclepias incarnata (swamp milkweed)			E
Brasenia schreberi (watershield)			S
Cabomba caroliniana (fanwort)			S
Cephalanthus occidentalis (buttonbush)	E		
Ceratophyllum demersum (coontail)			S
Egeria densa (Brazilian Elodea)			S
Eichhornia crassipes (water hyacinth)		E/S	
Eleocharis acicularis (needle spikerush)	S	S	S
Elodea canadensis (waterweed)	S	S	S
Glyceria borealis (mannagrass)	E		
Hydrilla verticllata (hydrilla)	S		
Leersia oryzoides (rice cutgrass)	E		
Myrica gale (sweetgale)		E	
Myriophyllum spp. (milfoil)			S
Najas flexilis (bushy pondweed)	S		
Najas guadalupensis (southern naiad)			S
Nuphar spp. (yellow water lily)			E/S
*Nymphaea odorata (*water lily)			S
Polygonum amphibium (water smartweed)		E/S	
Polygonum coccineum (smartweed)	E		
Potamogeton epihydrus (leafy pondweed)	S		
Potamogeton robbinsii (Robbins' pondweed)			S
Potentilla palustris (marsh cinquefoil)			E/S
Scirpus americanus (three square rush)	E		
Scirpus cyperinus (wooly grass)	E		
Scirpus validus (great bulrush)	E		
Sium suave (water parsnip)	E		
Typha latifolia (common cattail)	E	E	
Zizania aquatic (wild rice)	E		

E=emergent growth form
S=submergent growth form (includes rooted species with floating leaves)
E/S=emergent and submergent forms

Another way to classify herbicides is by whether the active ingredients are selective or broad spectrum. Selective herbicides are more effective on certain plant species than others, with control of that selectivity normally dependent on dose and exposure duration. Plant factors that influence selectivity include plant morphology, physiology and the stage of growth. Even a selective herbicide can kill most plants if applied at high rates. Likewise, contact herbicides may show some selectivity based on dose and plant features, but tend to induce impacts on a broad spectrum of plant species.

The choice of herbicide to manage an undesirable plant population depends on the properties of the herbicide, the relative sensitivity of the target and non-target plants and other organisms that will be exposed, water use restrictions after herbicide use, and cost. Effectiveness in controlling the target plant species is normally the primary consideration. Other factors determine possible choice between two or more potentially effective herbicides, dose, and whether a treatment is actually feasible.

Herbicide effectiveness may be influenced by such factors as timing, rate and method of application, species present and weather conditions (Westerdahl and Getsinger, 1998a,b). Additionally, dose determination should consider hydraulic residence time, morphometry and water hardness to maximize effectiveness. Herbicide treatment can be an effective short-term (and sometimes, longer) management procedure to produce a rapid reduction in algae or vascular plants for periods of weeks to months. Although long-term effectiveness of herbicide treatments is possible, in most cases herbicide use is considered a short-term control technique.

Five aquatic herbicides currently approved for aquatic use by the United States Environmental Protection Agency (USACE 2002) and registered for use in New York State are described below. Information for individual herbicidal active ingredients in use today is further discussed in association with each active ingredient in subsequent parts of review.   Copper is not generally used to control milfoil growth and is therefore not included in this discussion. The relative effectiveness of control by New York-registered herbicides on common nuisance aquatic plants is listed in Table 7-3 (NYSDEC, 2005).

7.4.1 Diquat

Diquat is a fast acting contact herbicide, producing results within 2 weeks of application through disruption of photosynthesis. It is a broad-spectrum herbicide with potential risks to aquatic fauna, but laboratory indications of invertebrate toxicity have not been clearly documented in the field. A domestic water use restriction of 3 days is normally applied. Irrigation restrictions of 2 to 5 days are applied, depending on dose and crop to be irrigated. Regrowth of some species has been rapid (often within the same year) after treatment with diquat, but two years of control have been achieved in some instances.

Diquat is used as a general purpose aquatic herbicide, both as a primary control agent for a broad range of macrophytes and as a follow-up treatment chemical for control of plants (especially milfoil) missed by other herbicides or physical control techniques. Treatment with diquat is recommended early in the season to impact early growth stages, but can be applied any time. Diquat is less effective in turbid, muddy water due to adsorption onto sediments and other particles.

Since diquat is a broad spectrum herbicide, it can be expected to impact non-target plants when they are present. Loss of vegetative cover may have some impact on aquatic animals, but short-term effects are not expected. The acute toxicity of diquat for fish is highly variable depending on species, age, and hardness of water. Young fish are more sensitive than older fish. Toxicity is decreased as water hardness increases.

Table 7-3 Impact of NYS Registered Herbicides on Common Nuisance Aquatic Plants (adapted from NYSDEC, 2005)

Susceptibility to Herbicide:						
Aquatic Plant	**Diquat**	**2,4-D**	**Endothall**	**Glyphosate**	**Fluridone**	**Triclopyr**
Emergent Species						
Lythrum salicaria (purple loosestrife)	low	low	low	high	low	high
Phragmites spp (reed grass)	low	low	medium	high	low	medium
Pontedaria cordata (pickerelweed)	low	medium	low	medium	low	high
Sagittaria spp (arrowhead)	low	high	low	high	low	medium
Scirpus spp (bulrush)	medium	high	low	high	low	low
Typha spp (cattails)	medium	medium	low	high	medium	low
Floating Leaf Species						
Brasenia schreberi (water shield)	medium	medium	medium	low	medium	medium
Lemna spp (duckweed)	high	medium	medium	low	high	low
Nuphar spp yellow water lily)	low	medium	medium	high	medium	medium
Nymphaea spp (white water lily)	low	medium	medium	high	medium	medium
Trapa natans (water chestnut)	low	medium	low	low	low	medium
Submergent Species						
Ceratophyllum demersum (coontail)	high	medium	high	low	medium	low
Cabomba caroliniana (fanwort)	medium	medium	high	low	high	low
Chara spp (muskgrass)	low	low	low	low	low	low
Elodea canadensis (common waterweed)	high	medium	low	low	high	low
Heteranthera dubia (water stargrass)	high	high	medium	low	medium	low
Myriophyllum spicatum (Eurasian watermilfoil)	high	high	high	low	high	high
Najas flexilis (bushy pondweed)	high	medium	high	low	high	low
Potamogeton amplifolius (largeleaf pondweed)	low	low	medium	low	medium	low
Potamogeton crispus (curly-leafed pondweed)	high	low	high	low	high	low
Potamogeton robbinsii (Robbins' pondweed)	low	low	medium	low	medium	low
Stuckenia pectinatus (Sago pondweed)	high	low	medium	low	medium	low
Utricularia spp (bladderwort)	high	medium	low	low	medium	low
Vallisneria americana (wild celery)	low	low	medium	low	high	low

Adapted from Holdren, et al, 2001 and others.

7.4.2 Endothall

Endothall is a contact herbicide, attacking a wide range of plants. The method of action of endothall is suspected to inhibit the use of oxygen for respiration. Only portions of the plant with which the herbicide can come into contact are killed. There are two forms of the active ingredient; the inorganic potassium salt that is found in the products Aquathol® Granular and Aquathol® K and the alkylamine salt formulations of Hydrothol® 191 Granular and Hydrothol® 191. Effective control can range from weeks to months. Most endothall compounds break down readily and are not persistent in the aquatic environment, disappearing from the water column in under 10 days and from the sediments in under 3 weeks.

Endothall acts quickly on susceptible plants, but does not kill roots with which it cannot come into contact, and recovery of many plants occurs. Rapid death of susceptible plants can cause oxygen depletion if decomposition exceeds re-aeration in the treated area, but this can be mitigated by conducting successive partial treatments. Toxicity to invertebrates, fish or humans is possible but not expected at typical doses, but endothall is not typically permitted for use in drinking water supplies.

Endothall is primarily a broad spectrum vascular plant control chemical. Endothall has not been very effective against milfoil, but works well on most species of pondweeds, coontail and naiads. It is used less than most other herbicides, mainly due to dose limits that are observed to avoid impacts to non-target fauna.

Hydrothol® 191 is an alkylamine salt formulation of endothall. This formulation is effective against algae as well as macrophytes, but is much more toxic to fish than Aquathol® K. The environmental hazards listed on the Hydrothol® 191 (Dimethylalkylamine endothall granular and liquid) labels warn that fish may be killed by dosages in excess of 0.3 ppm. Hydrothol® 191 is less toxic to fish in cool water (<65°F). However, Hydrothol® 191 granular is sometimes not used because of potential dust problems and possible toxicity to the applicator. Aquathol® K is much less toxic and is used more frequently than Hydrothol® 191. Aquathol® K application rates vary with water depth. Although usually applied at lower rates, the maximum rate of 269 lbs per 2 acre feet or 6.4 gallons per 2 acre-feet for spot treatment would result in a maximum concentration of 5 ppm according to the product labels.

7.4.3 Glyphosate

Glyphosate is a systemic, broad spectrum herbicide. Glyphosate is used to control emergent vegetation and to create open areas for waterfowl or human use. Its mode of action is to disrupt the plant's shikimic acid metabolic pathway. Shikimic acid is a precursor in the biosynthesis of aromatic amino acids. The disruption in the pathway prevents the synthesis of aromatic amino acids and the metabolism of phenolic compounds. The net effect is that the plant is unable to synthesize protein and produce new plant tissue. Glyphosate penetrates the cuticle of the plant and moves to the phloem where it is translocated throughout the plant, including the roots. Its aquatic formulation is effective against most emergent or floating-leaved plant species, but not against most submergent species. Rainfall shortly after treatment can negate its effectiveness, and it readily adsorbs to particulates in the water column or to sediments and is inactivated. It is relatively non-toxic to aquatic fauna at recommended doses, and degrades readily into non-toxic components in the aquatic environment. The maximum concentration for treated water is typically about 0.7 mg/L, but a dose of no more than 0.2 mg/L is usually recommended.

The most common aquatic use of glyphosate is for control of emergent and floating leaf species, in particular water lilies (*Nuphar spp., Nymphaea spp*.), reed grass (*Phragmites spp*.), purple loosestrife (*Lythrum salicaria*) and cattail (*Typha spp*.). Glyphosate is not effective for control of submerged macrophytes because it is water soluble and the concentration after dilution would be insufficient to damage a submergent plant. It is, however, recommended for control of many wetland and floodplain species that include trees, shrubs and herbs. Glyphosate effectiveness is greater in soft water. Additives such as ammonium phosphate are recommended for hard water glyphosate applications, and non-ionic surfactants are often recommended to increase overall effectiveness.

Because it is a broad spectrum herbicide, glyphosate should be expected to impact non-target emergent or floating leaf plants if the spray contacts them. Control of the spray can therefore greatly limit impacts to non-target vegetation. The LC_{50} levels for fish species vary widely, perhaps due to variations in formulations tested (i.e., with or without surfactant). Most applications would result in aquatic concentrations far lower than any toxic threshold. Invertebrates do not appear to be harmed directly by the herbicide, but may be impacted by the alteration of vegetation.

7.4.4 2,4-D

2,4-D, the active ingredient in a variety of commercial herbicide products, has been in use for over 30 years. This is a systemic herbicide; it is absorbed by roots, leaves and shoots and disrupts cell division throughout the plant. Vegetative propagules such as winter buds, if not connected to the circulatory system of the plant at the time of treatment, are generally unaffected and can grow into new plants. Seeds are also not affected. It is therefore important to treat plants early in the season, after growth has become active but before such propagules form.

2,4-D is sold in liquid or granular forms as sodium and potassium salts, as amine salts, and as an ester. Doses of 50 to 150 pounds per acre are usually applied for the control of submersed weeds, most often of the dimethylamine salt (DMA) or the butoxyethanolester (BEE) in granular formulation. Lower doses are more selective but require more contact time; a range of one to three days of contact time is typically needed at the range of doses normally applied. 2,4-D has a short persistence in water but can be detected in the sediment for months.

Experience with granular 2,4-D in the control of nuisance macrophytes has generally been positive, with careful dosage management providing control of such non-indigenous nuisance species as Eurasian watermilfoil with only sublethal damage to many native species. 2,4-D has variable toxicity to fish, depending upon formulation, dose and fish species. The 2,4-D label does not permit use of this herbicide in water used for drinking or other domestic purposes, or for irrigation until the concentration is less than 0.1 ppm, typically about 3 weeks. While there is overlap in the species to which 2,4-D and triclopyr would be applied, the drinking water use restrictions are much more limiting for 2,4-D.

7.4.5 Fluridone

Fluridone is a systemic herbicide that comes in two general formulations, an aqueous suspension and a slow release pellet, although several forms of pellets are now on the market. This chemical inhibits carotene synthesis, which in turn exposes the chlorophyll to photodegradation. Most plants can be damaged by sunlight in the absence of protective carotenes, resulting in chlorosis of tissue and death of the entire plant with prolonged exposure to a sufficient concentration of fluridone. When carotene is absent the plant is unable to produce the carbohydrates necessary to sustain life. Some plants, including Eurasian watermilfoil, are more sensitive to fluridone than others, allowing selective control at low doses.

For susceptible plants, lethal effects are expressed slowly in response to treatment with fluridone. Existing carotenes must degrade and chlorosis must set in before plants die off; this takes several weeks to several months, with 30-90 days given as the observed range of time for die off to occur after treatment. The slow rate of plant die-off minimizes the risk of oxygen depletion. Fluridone concentrations should be maintained in the lethal range for the target species for at least 6 weeks, preferably 9 weeks, and ideally 13 weeks. This presents some difficulty for treatment in areas of substantial water exchange, and indicates the value of an alternative herbicide for many of the same target species, represented by triclopyr.

The selectivity of fluridone for the target species depends on the timing and the rate of application. Early treatment (April/early May) with fluridone effectively controls overwintering perennials before some of the beneficial species of pondweed and naiad begin to grow. Variability in response has also been observed as a function of dose, with lower doses causing less impact on non-target species. However, lesser impact on target plants has also been noted in some cases, so dose selection involves balancing risk of failure to control target plants with risk of impact to non-target species.

Fluridone is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and mammals, including humans. The USEPA has set a tolerance limit of 0.15 ppm for fluridone or its degradation products in potable water supplies, although some state restrictions are lower. Substantial bioaccumulation has been noted in certain plant species, but not in animals.

7.5 Biological Controls

Interest has grown in biological control methods over the last two to three decades. Most methods are still experimental and have a limited degree of achieved effectiveness. Most methods have the potential to inflict negative impacts on the environment. Biological methods differ from other plant control methods in that there are more variables to consider and usually a longer time span needed to evaluate effectiveness. These methods are unusual in that the treatments consist of either altering conditions to favor certain organisms or introducing live organisms that may be difficult or impossible to control or recall once introduced. For this reason non-indigenous introductions are restricted in most cases. Biological control has the advantage that it is perceived as a more “natural” or “organic” plant control option, but it still represents human interference within an ecological system. The potential for long-term effectiveness with limited maintenance is attractive, but has been largely illusive with biological controls.

7.5.1 Herbivorous Fish

The sterile triploid form of grass carp (*Ctenopharyngodon idella*), also known as the white amur, is a species of fish that is permitted for use in the control of aquatic macrophytes in New York State (Stang, 1994). The native range of grass carp includes the Pacific slope of Asia from the Amur River of China and Siberia, south to the West River in southern China and Thailand. They are typically found in low gradient reaches of large river systems. Grass carp can grow to 4 feet long and attain weights of over 100 pounds, making them the largest member of the cyprinid family. They have a very high growth rate, with a maximum at about 6 pounds per year. They typically grow to a size of 15-20 pounds in North American waters and have adapted quite well to life in reservoirs where they are stocked for aquatic vegetation control.

As with other carp species, they are tolerant of wide fluctuations in water quality including water temperatures from 0 to 35°C, salinities up to 10 ppt, and oxygen concentrations approaching 0 mg/L. Grass carp do not feed when water temperatures drop below 11°C (52°F) and feed heavily when water temperatures are between 20°C and 30°C (68°F and 86°F). Dietary preference is an important aspect of grass carp, as pertains to their use as a plant control mechanism. Grass carp have exhibited a wide variety of food choices from study to study. In some cases grass carp have been reported to have a low feeding preference for *Myriophyllum spicatum*. Yet in a recently completed Connecticut study, grass carp did consume milfoil more readily than other submergent species. Grass carp readily eat other non-indigenous plants such as *Cabomba caroliniana* and *Egeria densa* as well as various native species. In some cases grass carp will also eat and control filamentous algae (e.g., *Pithophora*). Generally, grass carp avoid cattails and water lilies, but the high level of variability in grass carp diet among lakes should be kept in mind.

The major difficulty in using grass carp to control aquatic plants is determining what rate will be effective and yet not so high as to eradicate the plants completely. Effective grass carp stocking rates are a function of grass carp mortality, water temperature, plant species composition, plant biomass and desired level of control. The fish usually live ten or more years but the typical plant control period is reported to be 3 to 4 years with some restocking often required. They are difficult to capture and remove unless the lake is treated with rotenone that will kill other fish species as well. Grass carp may also decrease the density or even eliminate vascular plants, although in a Connecticut study, the carp preferred milfoil to other plants. Algal blooms resulting from nutrients being converted from plant biomass by the grass carp have been common, even without elimination of vascular plants.

7.5.2 Herbivorous Invertebrates

Biological control has the objective of achieving control of plants without introducing toxic chemicals or using machinery. Yet it suffers from an ecological drawback; in predator-prey (or parasite-host) relationships, it is rare for the predator to completely eliminate the prey.

Biological control using invertebrates (mainly insects) from the same region as the introduced target plant species include the root boring weevil (*Hylobius transversovittatus*) and two leaf beetles (*Galerucella calmariensis* and *G. pusilla*) for the control of purple loosestrife (*Lythrum salicaria*). Augmentation of a native insect population has been studied with the milfoil midge (*Cricotopus myriophylli*), a moth (*Acentria ephemerella*) and the milfoil weevil (*Euhrychiopsis lecontei*). Releases in Massachusetts of the native weevil (*Euhrychiopsis lecontei*) for the control of Eurasian milfoil have occurred since 1995, and there are signs of success in two of the original test lakes (Creed and Sheldon, 1994; Sheldon, 1995; Sheldon and Creed, 1995; Sheldon and O'Bryan, 1996a,b)

Euhrychiopsis lecontei is a native North American insect species believed to have been associated with northern watermilfoil (*Myriophyllum sibericum*), a species largely replaced by non-indigenous, Eurasian watermilfoil (*M. spicatum*) since the 1940's. It does not utilize non-milfoil species. In controlled trials, the weevil clearly has the ability to impact milfoil plants through structural damage to apical meristems (growth points) and basal stems (plant support). Adults and larvae feed on milfoil, eggs are laid on it, and pupation occurs in burrows in the stem. Field observations linked the weevil to natural milfoil declines in nine Vermont lakes and additional lakes in other states (Johnson et al., 2000).

Lakewide crashes of milfoil populations have generally not been observed in cases where the weevil has been introduced into only part of the lake, although localized damage has been substantial. Widespread control may require more time than current research and monitoring has allowed. As with experience with introduced insect species in the south, the population growth rate of the weevil is usually slower than that of its host plant, necessitating supplemental stocking of weevils for more immediate results. Just what allows the weevil to overtake the milfoil population in the cases where natural control has been observed is still unknown.

Acentria ephemerella is a European aquatic moth first reported in North America near Montreal in 1927 (Sheppard, 1945; as reported in Johnson and Blossey, 2002). While it is considered a generalist herbivore, significant declines in Eurasian watermilfoil populations in Ontario and New York lakes have been associated with population explosions of the species (Johnson et al., 1998; Gross et al., 2001). Cayuga Lake is the best studied of these declines, with a greater than 90% reduction of Eurasian watermilfoil (Johnson et al., 1998; Gross et al., 2001); a reduction that has been maintained for 15 years since the initial decline (R. Johnson, pers. comm.. 12/20/06). This selective suppression of Eurasian watermilfoil has led to a strong recovery by native macrophyte species, which now dominate the plant community (Johnson and Blossey, 2002). Further investigations of the effects of population augmentation and long-term control of watermilfoil by *A. ephemerella* are being conducted in several New York lakes including Chautauqua, Otisco, and Owasco (R. Johnson, pers. comm. 12/20/06).

For the control of purple loosestrife, a measure of success has been achieved with the introduction of two European leaf beetles (*Galerucella calmariensis* and *G. pusilla*) (Blossey, 2002; MA CZM, 2006). Two other potential insect control agents for purple loosestrife (*Hylobius transversovittatus* and *Nanophes marmoratus*) have been identified, but their effectiveness has not been fully established.

Mass releases of the *Galerucella* sp. beetles have been successfully used in the United States to control purple loosestrife infestations since the early 1990s (approved in 1992 by U.S. Department of Agriculture for their use in biocontrol). While these natural beetle predators cannot eliminate purple loosestrife entirely, at several release sites complete defoliation of large stands have been reported with local reductions of more than 95% of the biomass (Blossey, 2002). Published literature indicates that the beetles are host-specific and no significant long-term significant impacts on native plant species have been observed (MA CZM, 2006). Several states and academic institutions have established programs to provide information and guidance on this form of biological control (e.g., MA CZM Purple Loosestrife Biocontrol Project, Cornell University Biological Control of Non-indigenous Plants Species Program). Efforts are also being made to mass-produce the biocontrol bettles to make them available to interested parties or state agencies (MA CZM, 2006).

7.5.3 Plant Competition

Although invasive nuisance plant species are just what the name implies, there is evidence that the presence of a healthy, desirable plant community can minimize or slow infestation rates. Most invasive species are favored by disturbance, so a stable plant community should provide a significant defense. Unfortunately, natural disturbances abound, and almost all common plant control techniques constitute disturbances. Therefore, if native and desirable species are to regain dominance after disturbance, it may be necessary to supplement their natural dissemination and growth with seeding and planting. The use of seeding or planting of vegetation is still a highly experimental procedure, but if native species are employed, it should yield minimal controversy.

Experiments indicate that the addition of dried seeds to an exposed area of sediment will result in rapid germination of virtually all viable seeds and rapid cover of the previously exposed area. However, if this is not done early enough in the growing season to allow annual plants to mature and produce seeds of their own, the population will not sustain itself into the second growing season. Transplanting mature growths into exposed areas has generally been found to be a more successful means of establishing a seed producing population. The use of cuttings gathered by a harvester has not been successful in establishing native species, so it appears that whole, viable plants must be added.

Areas of dense, healthy, indigenous plants tend to resist colonization by invasive species. Resistance may not be complete or lasting, but invasions have been greatly slowed where bare sediment is minimized. More research is needed, but establishment of desired vegetation is entirely consistent with the primary plant management axiom: if light and substrate are adequate, plants will grow. Rooted plant control should extend beyond the limitation of undesirable species to the encouragement of desirable plants.

7.6 No-Action Alternative

The no action or no management alternative for aquatic plants would exclude all active lake management programs, but would include normal monitoring and would also include normal operations such as drawdowns for flood control or dam repair and other activities as permitted or required by law. The normal tendency for lakes is to gradually accumulate sediments and associated nutrients and to generally become more eutrophic. Although macrophytes may be excluded from deeper areas of the lake due to light limitation, as sediments fill in the lake a greater proportion of the lake area becomes suitable for aquatic macrophytes. In consideration of this, the no management alternative would allow lakes to become ever more eutrophic in the future, even if no human additions of nutrients, sediments or non-indigenous plants were considered. In cases where there is development in the watershed leading to increased erosion and sediment transport to the lake, the rate of infilling and expansion of macrophyte beds would be expected to increase more rapidly.

In addition, activities that involve boat transport among lakes may introduce non-indigenous plant species into lakes that previously did not have infestations. One of the major modes of introduction is assumed to be boating activities. The no management alternative would provide neither prevention nor remediation efforts other than those required by current laws, which contain minimal provisions intended to stop the spread of invasive species or preserve the desirable features of lakes.

7.7 Alternatives Analysis

As discussed in Sections 2.0 and 3.0 of the SEIS, the uncontrolled growth of nuisance aquatic macrophyte species can substantially impact the natural diversity, ecological function, and recreational uses of a waterbody. However, as noted in Section 7.2, is important that the appropriate control techniques are selected which are appropriate for effectively removing the nuisance species, which minimize potential adverse ecological effects (or mitigative measures can be included), that are practicable and cost-effective, and which reduces potential societal conflicts that can occur between groups of lake users. Therefore, it is important that the selection of any macrophyte control treatment, including herbicides, be conducted as a result of a well thought-out long-term IAVMP, consistent with NYSDEC guidance (NYSDEC, 2005). Part of the development of the IAVMP is an alternative analysis, which is considered in a series of steps below.

7.7.1 Management vs. No Management

The first consideration is the determination that a problem aquatic infestation is occurring within a waterbody of interest. This primary determination is typically the responsibility of a lake association or lake manager (if applicable) and should be based on current aquatic plant surveys and/or monitoring efforts. This information should include the areal size of the waterbody, the location, nature, and acreage of the infestation, the recreational uses of the waterbody, and the presence of sensitive species. This is analogous to the first step in development of a problem statement for the IAVMP (see Section 7.2) If, through these monitoring and information gathering efforts, the infestation of the waterbody by Eurasian watermilfoil or excessive growths of other potential targets species (see Section 2.4) is detected, then a decision to treat the waterbody is made.

In some cases, no treatment may be elected for the short-term, with a “wait-and-see” attitude taken, using monitoring efforts to keep tabs on the size and impact of the infestation until further information, equipment, funding, etc, may be available. For some waterbodies, the no management approach may also be a long-term strategy, based on factors such as size of the waterbody, current and future uses, the presence of sensitive receptors, proximity to residential or recreational uses, or other factors. However, for many ponds and lakes with important ecological and/or recreational uses, there is likely to be a decision to manage the macrophytes, particularly if this is an initial infestation of exotic invasives and rapid response is vital. As with any IAVMP, any subsequent decisions regarding macrophyte management approaches must consider all permit requirements.

7.7.2 Renovate® 3 vs. Physical Treatment Alternatives

As part of the development of a waterbody-specific IAVMP, the potential usefulness of physical treatment alternatives needs to be considered. As identified in Section 7.3., physical treatment alternatives include benthic barriers, dredging, dyes, harvesting, and water level controls. Any initial screening may be based on the scale of potential treatment required or practicable. Smaller scale treatments include installation of benthic barriers and harvesting (variable scale); while the other alternatives (dredging, dyes, water level control) tend to be conducted over a significant portion or the entire waterbody.

Since Renovate® 3 is anticipated to be used mostly for selective control of Eurasian watermilfoil, several physical treatment alternatives can be easily eliminated from the alternatives analysis. Dredging can be eliminated because it has significant impacts, is very costly, often requires a lengthy permitting process, and low light limitation may not be effective on watermilfoil. Similarly, the use of dyes is inappropriate since they are mostly restricted to small volume waterbodies due to the need to maintain high color concentrations; they may not be able to suppress watermilfoil with light limitation, and could have impact to other vegetation. Conventional harvesting is not appropriate due to the potential for fragmentation and spreading of Eurasian watermilfoil (Painter, 1988).

Physical treatment alternatives that should be considered for control of Eurasian watermilfoil include small-scale harvesting, (hand pulling or diver-assisted), benthic barriers, and water level control (Eichler et al., 1991; 1993; 1995). The first two alternatives are potentially useful in the early invasion phase when the size of the infestation is spatially limited. These alternatives are often considered when formulating a rapid response to aquatic invasives. Both are labor-intensive and need significant involvement of either trained volunteers or hired lake management firms over a significant period of the growing season.

Water level control has been shown to be effective against Eurasian watermilfoil (see Table 7-2) but is dependent on the ability of lake managers to draw the lake down to the areas and depths where the milfoil is present. This may be limited by the lack of an impounding structure, the bottom elevation of the existing outlet or drainage pipe, or secondary restrictions within the lake to free drainage (e.g., internal pooling areas). In addition, the presence of sensitive plant or wildlife species or significant fishery resources in the waterbody or in adjacent wetlands may restrict the amount of drawdown permitted. Therefore, water level control may be considered as a tool for use in an IAVMP for suppression or general control of Eurasian watermilfoil, but will rarely be sufficient as a stand-alone option. It is not generally considered as a rapid response technique for elimination of any early infestation.

Control of purple loosestrife by physical methods has generally proven problematic. Experience has shown that many mechanical and cultural methods (water level management, burning, manual removal, and cutting) have been tried and have proven ineffective in controlling purple loosestrife and are largely impractical on a large scale (MA CZM, 2006). In many cases mechanical methods and controlled burns have resulted in the promotion of further spread of the loosestrife (CDFA, 2006). For early infestations, small patches of young plants can be removed by hand with little effort, but care needs to be taken to remove all root fragments. It is necessary to dispose of plants and roots by drying and burning or by composting in an enclosed area, and important to take care to prevent further seed spread from clothing or equipment during the removal process. It is difficult to remove all of the roots in a single digging, so monitoring of the infestation area for several growing seasons is recommended to ensure that purple loosestrife has not regrown from roots or seed. In summary, physical control of purple loosestrife is possible for small isolated primary infestation areas, but is largely impractical at larger scales (> 0.5 acres).

7.7.3 Renovate® 3 vs. Biological Treatment Alternatives

As part of the development of a waterbody-specific IAVMP, the potential usefulness of biological treatment alternatives needs to be considered. As identified in Section 7.5, biological treatment alternatives include herbivorous fish and invertebrates. For selective control of Eurasian watermilfoil, grass carp do not provide a good alternative treatment because they tend to be general grazers of available macrophytes (see Section 7.5.1) with no specialized preference for the watermilfoil. In contrast, the herbivorous weevils (see Section 7.5.2), have high specificity for that species. However, the effectiveness of these introduced invertebrates is still largely uncertain, with localized success reported in some locales and little or no effect in others. Moreover, keeping weevil populations at levels capable of controlling watermilfoil populations has been problematic. There has been a well-documented rapid reduction and long-term suppression of Eurasian watermilfoil by larvae of the aquatic moth, *A. ephemerella* in Cayuga Lake. Further investigations on the applicability of enhancing ambient populations by stocking of larvae to create a quicker reduction response are being conducted in several other New York lakes (R. Johnson, pers. comm.) , but results will not be available for full evaluation for several years. At the current time, Renovate® 3 would likely be preferred over herbivorous macroinvertebrates in a rapid response plan due to its greater reliability and replicability of macrophyte control. Further investigation and studies with herbivorous weevils in the Northeast may be required to see whether they are an effective long-term solution and/or should be incorporated into an IAVMP.

As discussed in Section 7.5.2, the most likely biological treatment alternative for control of purple loosestrife is the mass introduction of *Galerucella* sp. beetles. Release of these beetles, possibly in combination with the root-eating weevil (*H. transversovittatus*) or the flower-eating weevil (*N. marmoratus*), may prove to be a very effective means of control. While results from early release sites indicate that successful suppression of purple loosestrife can be achieved, it is still not predictable which replacement communities will develop in their place. At several release locations in New York, a resurgence of cattails and other wetland plants has been observed, but this is not always the case as other invasives (*Phragmites australis*, *Phalaris arundinacea*) may expand (Blossey, 2002). Studies are being made to investigate whether a combination of biocontrol coupled with physical means (fire, disking, flooding, mowing, etc) may be useful in accelerating the return of nature plant communities. Nationwide, purple loosestrife biocontrol program are conducting standardized long-term monitoring programs to follow and evaluate the effectiveness of releases and the secondary redevelopment of wetland plant populations (Blossey, 2002). Investigations are also on-going regarding changes in animal communities (insects, amphibians, birds) associated with changes in purple loosestrife populations. At the current time, Renovate® 3 would be a viable alternative to herbivorous macroinvertebrates in a rapid response plan due to its greater reliability and replicability of macrophyte control.

7.7.4 Renovate® 3 vs. Other Chemical Treatment Alternatives

As discussed earlier, aquatic herbicides can be very effective in controlling target plant species in lakes. Herbicides have advantages over most techniques when getting a problem species under control is an immediate goal. No other technique can address infestations over a wider area faster and at lower cost. Herbicides may also be particularly applicable in cases of recent invasions by non-indigenous plants, as more complete control can often be exercised with herbicides before invasive species become widespread.

Renovate® 3 is anticipated to be used mostly for selective control of Eurasian watermilfoil. Comparison of the effectiveness of the five aquatic herbicides registered in New York (Table 7-3) indicates that four are considered to have high effectiveness with *M. spicatum* – diquat, 2,4-D, endothall, and fluridone (NYSDEC, 2005). However, diquat and endothall are considered general purpose, broad-spectrum contact herbicides which are used when removal of most aquatic vegetation is desired and not selective for specific control of watermilfoil. In many cases, this broad-spectrum toxicity may limit application of diquat and endothall to spot treatments of limited area. In contrast, Renovate® 3 is highly selective against Eurasian watermilfoil and other select dicotyledons, and has little to no effect on most common native monocotyledons (e.g., naiads, pondweeds, etc). Therefore, these two aquatic herbicides would not be considered good alternatives to Renovate® 3 for selective treatment of Eurasian watermilfoil.

Renovate® 3 was therefore compared to the two herbicides typically used of control of Eurasian watermilfoil: 2, 4-D and fluridone. When comparing these three herbicides, the factors which would favor selection of Renovate® 3 include: selectivity, requirement of a short contact time, short half-life, and low toxicity.

Both fluridone and 2,4-D are systemic herbicides that are effective against Eurasian watermilfoil, but may also cause collateral damage to other aquatic macrophytes (particularly at higher doses). For fluridone, this is typically avoided by maintaining a low effective concentration (but one which does not impact native pondweeds) for a lengthy period of time. Maintenance of the effective concentration may be problematic if the area to be treated is small, there is potential for dispersion and dilution (e.g., rapid flushing time of the waterbody) and due to unexpected meteorological events. In contrast, Renovate® 3's rapid uptake and short exposure requirement (hours to days) for effective macrophyte control is a useful attribute for selecting an herbicide for treating a waterbody where water quality or hydrology may be dynamic (e.g., impoundment with significant stormwater inputs).

Due to the rapid breakdown (i.e., half-life for triclopyr can range from 12 hours to 29 days), lack of significant bioaccumulation, and low toxicity of triclopyr and its major metabolites (TMP, TCP), Renovate® 3 is considered to pose very little risk of adverse risk to fish and higher wildlife receptors. Due to its selectivity and short-half life, there would be low concern regarding potential overexposure of the vegetation. The low toxicity of Renovate® 3 would be a useful attribute when selecting an aquatic herbicide where there are concerns with potential transport of treated water downstream to habitats of sensitive receptors.

Another potential selective advantage for Renovate® 3 is the distance-based label restrictions for application to waters used for certain uses (e.g., drinking swimming, irrigation). There are some cases where differences in necessary distance of applications from a potable water intake may allow use of Renovate ® 3 (particularly for control of floating or emersed invasives) in locations where other aquatic herbicides would be prohibited. For example, Renovate® 3 may be used for spot-treating floating or emersed invasives at distances from 500 to 1,100 ft from potable water intakes, whereas both 2,4-D (1,500 setback distance for active potable or irrigation intake) or glyphosate (no application within 1,320 feet upstream of a potable water intake) require greater distances. [Note: glyphosate may be considered an alternative for treatment of purple loosestrife].

As with all management techniques, an important selective factor is cost effectiveness. Presently, submersed Renovate® 3 treatments in deep water applications (> 4 ft. average depth) are expected to be a more expensive option for single treatments than for 2,4-D or fluridone. However, the use of Renovate® OTF allows for treatment of aquatic macrophytes in deeper water (depths exceeding 4 feet deep) using less volume and active ingredient and thus a reduced cost over Renovate® 3 (and more comparable to the cost 2,4-D.

Even if a significant cost differential exists betweens these two herbicide, Renovate® 3 may still be used as the primary substitute for 2,4-D or diquat due to use restrictions which prohibit the use of these chemicals in waters with depth >6 ft (see applicable restrictions under Conservation Law 15-0313 Part 327 Pesticide Control Regulations). In addition, the selective properties of triclopyr may result in Renovate® 3 as the primary tool in certain entire littoral specific treatment programs and/or as part of a IAVMP; for example, as a follow-up “spot” management (e.g., < 4 acres) of Eurasian watermilfoil following a lakewide fluridone management program.

Careful use of aquatic herbicide has been reported to be an effective, efficient, and a less destructive (compared with physical techniques) means of removing large purple loosestrife stands in California (CDFA, 2006). Chemical control of purple loosestrife may be accomplished by application of glyphosate or triclopyr. Glyphosate is the only currently- approved herbicide in New York shown to have high effectiveness for this species (see Table 7-3). Control of small purple loosestrife stands is reported by spot treatments with glyphosate commercial products (e.g., Rodeo) typically applied at a 1-1.5 % solution, during early to late bloom (CDFA, 2006). Renovate® 3 also provides an alternative, effective chemical control agent for purple loosestrife. However, as noted in Section 7.4.3, glyphosate is a broad spectrum (i.e., non-selective) herbicide which would potentially affect other emergent species. Application of Renovate® 3, which provides selective control of broadleaf plants with minimal impact to most monocot species, could be used for spot treatment of smaller loosestrife stands, particularly in areas which overlap aquatic waterbodies or where there is a need to protect native monocot species.

As noted earlier, watershed and waterbody specific characteristics, aquatic and/or wetland plant community coverage and composition, water uses and stakeholders’ expectations and preferences will need to be considered when selecting any aquatic herbicide as part of an integrated aquatic vegetation management plan.