



# Chemical Management of Hydrilla for Drinking Water Utilities

Project #4747



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# Chemical Management of Hydrilla for Drinking Water Utilities

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## FOREWORD

The Water Research Foundation (WRF) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help water utilities respond to regulatory requirements and address high-priority concerns. WRF's research agenda is developed through a process of consultation with WRF subscribers and other water professionals. WRF's Board of Directors and other professional volunteers help prioritize and select research projects for funding based upon current and future industry needs, applicability, and past work. WRF sponsors research projects through the Focus Area, Emerging Opportunities, Tailored Collaboration, and Facilitated Research programs, as well as various joint research efforts with organizations such as the U.S. Environmental Protection Agency and the U.S. Bureau of Reclamation.

This publication is a result of a research project fully funded or funded in part by WRF subscribers. WRF's subscription program provides a cost-effective and collaborative method for funding research in the public interest. The research investment that underpins this report will intrinsically increase in value as the findings are applied in communities throughout the world. WRF research projects are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. WRF provides planning, management, and technical oversight and awards contracts to other institutions such as water utilities, universities, and engineering firms to conduct the research.

A broad spectrum of water issues is addressed by WRF's research agenda, including infrastructure and asset management, rates and utility finance, risk communication, green infrastructure, food waste co-digestion, reuse, alternative water supplies, water loss control, and more. The ultimate purpose of the coordinated effort is to help water suppliers provide a reliable supply of safe and affordable water to consumers. The true benefits of WRF's research are realized when the results are implemented at the utility level. WRF's staff and Board of Directors are pleased to offer this publication as a contribution toward that end.

Charles M. Murray  
Chair, Board of Directors  
Water Research Foundation

Robert C. Renner, PE  
Chief Executive Officer  
Water Research Foundation



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## EXECUTIVE SUMMARY

### KEY FINDINGS

- Hydrilla is an aquatic invasive plant that can outcompete native species and infest lakes and rivers, causing a variety of impacts to water quality, natural resources, and recreational use.
- Control options for hydrilla include biological controls and herbicides, primarily fluridone and endothall.
- It is important to include a robust public outreach component for any hydrilla management program to maintain public confidence in the safety of the drinking water supply.

### OBJECTIVES

The primary purpose of this project is to explore best management approaches to the control of the aquatic invasive plant *Hydrilla verticillata* (hydrilla) in drinking water sources. As with other aquatic invasive species, once a hydrilla population is established, management alternatives consist of chemical, biological, physical, or mechanical/manual methods (NCAES 1992). However, hydrilla's ability to reproduce from plant fragments, turions, and tubers has made chemical management with herbicides one of the most common methods of control. Hydrilla poses a unique problem in sources of drinking water because of the potential or perceived risks to public health from herbicides. The objectives of this project, therefore, are to:

- Assess the state of knowledge of herbicide application for the management of hydrilla in drinking water reservoirs and its impacts on treatability, water quality, and human and environmental health
- Review lessons-learned from prior hydrilla management efforts
- Provide an example hydrilla risk assessment to identify potential impacts from hydrilla and management options
- Provide recommendations for mitigation of impacts associated with hydrilla management
- Develop communications resources for public outreach

This project included a literature review specific to hydrilla management and associated herbicide research, in-depth analysis of five case studies and follow-up discussions, and the development of an expert workshop to review the New York City Department of Environmental Protection's (DEP's) hydrilla management options for the New Croton Reservoir.

### BACKGROUND

Hydrilla was first introduced into Florida, California, and the Mid-Atlantic states during the 1950s-1980s via the aquarium industry. Over the past decades it has spread throughout the U.S., and it is currently present in 32 states. The Southeast and Texas have the most heavily infested areas, but hydrilla is rapidly expanding into the Midwest and Northeast despite substantial investment in education, management, and control projects. In the coming years it is expected that



more drinking water utilities will be faced with its presence in the rivers, lakes, and reservoirs that serve as sources of drinking water.

Hydrilla is a federally listed aquatic invasive species that has the potential to cause significant economic and environmental impacts once established. Hydrilla is a high priority risk for river and reservoir systems as it can impact water quality, aquatic habitat, and recreational uses. The species forms dense mats of vegetation, outcompeting native species, reducing dissolved oxygen, and raising pH (Langeland 1996). Decay of plant litter can increase natural organic matter in reservoirs, which is a precursor to disinfection byproduct formation. The dense vegetation can also impact flow rates through streams and channels and can clog intake structures. As a result of its ability to reproduce from plant fragments, turions, and tubers, hydrilla spreads easily.

## **APPROACH**

The project team conducted a three-part approach to explore successful hydrilla control methods. First, the team reviewed literature specific to hydrilla life history and control methods to determine the most suitable management options for hydrilla in drinking water sources. The project team then conducted an in-depth review of five case studies in areas of New York, New Jersey, and the tidal Potomac River. Resource managers from the case study partners identified management strategies and lessons learned from unique hydrilla-related challenges. Finally, findings from the case studies and literature review guided the development of a one-day workshop with academic experts, water resource professionals, and case study representatives to review the options under consideration for hydrilla control and identify potential risks to water supplies from hydrilla and hydrilla management.

## **RESULTS/CONCLUSIONS**

Preventing invasive species from becoming established is both the most effective and least costly option for managing hydrilla. Once identified within a waterbody, resource managers must decide between available management options or no action. In most cases, without management hydrilla can be expected to eventually spread to all suitable areas within a waterbody. Shallow, slow-moving waterbodies are at the greatest risk of large-scale infestations that negatively impact beneficial uses. While there are numerous management options available for aquatic plant management, hydrilla's ability to reproduce and spread from plant fragments precludes most options. Benthic barriers and manual removal may work well for small infestations, but biological control with sterile grass carp and chemical management with herbicides are the two most prevalent control options for large-scale management. Specific regulations for introducing grass carp vary between states, but many restrict their use to waterbodies where there is minimal risk of escape. This leaves herbicides as the only feasible option for many locations.

Utilities and water resource managers go to great lengths to protect and improve the quality of drinking water sources. The decision to apply herbicides, even to control a highly invasive plant such as hydrilla, is not taken lightly. Because the primary objective of the drinking water sector is protecting public health, utilities and the public require assurances that the decision to apply herbicides will not result in negative health effects to their customers. Because of the recognition that the negative impacts of pesticides have the potential to outweigh their benefits, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA 1996) requires that all pesticides, including herbicides, undergo extensive, rigorous testing to determine (1) the efficacy for specific use scenarios and target species, and (2) the potential adverse impacts to human and ecological health.

The registration process for pesticides takes years to complete and requires substantial data prior to any environmental release.

While there are recently approved herbicides that are effective against hydrilla, this project focused on two well-established herbicides for hydrilla control: fluridone and endothall. These two herbicides have been registered for aquatic plant management since 1986 and 1960, respectively, have been used extensively, and have undergone multiple registration reviews and independent assessments. For this project, ten independent assessments of the human health and ecological impacts associated with use of the two herbicides were reviewed. These documents repeatedly came to similar conclusions that these two herbicides would result in no significant adverse effects when properly following the label directions, as required by law.

## **APPLICATIONS/RECOMMENDATIONS**

Broadly speaking, no information was identified during the course of this project that would suggest that herbicides should be categorically excluded from sources of drinking water. While the pesticide registration process cannot realistically account for all potential impacts, it is designed to conservatively assess and prevent a broad range of potential negative impacts from pesticide use. However, public perception may remain an obstacle for utilities considering the use of herbicides to manage hydrilla. The case studies reviewed during this project revealed that a focused effort to describe the risks and benefits to the public in advance of the herbicide application was valuable in obtaining stakeholder acceptance. Therefore, it is important to include a robust public outreach component for any hydrilla management program to maintain public confidence in the safety of the drinking water supply. Developing a management plan before hydrilla becomes established will help utilities rapidly respond to the infestation in its early stages, reducing the long-term management costs and improving the potential for success.

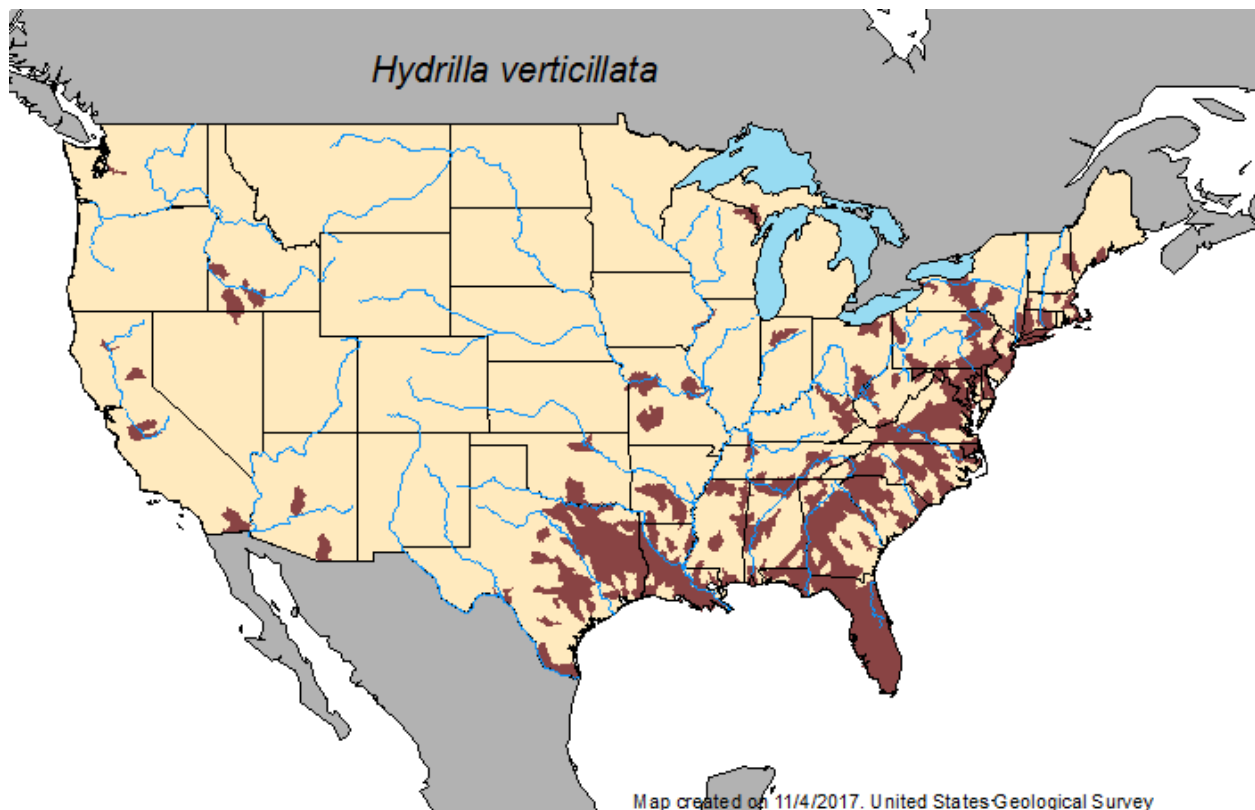
## **RELATED WRF RESEARCH**

- Management of Nuisance Aquatic Species at Pacific Northwest Drinking Water Utilities, project #4364
- Milfoil Ecology, Control, and Implications for Drinking Water Supplies, project #3024
- Workshop on Quagga/Zebra Mussel Control Strategies for Water Users in the Western United States, project #4200



## INTRODUCTION AND BACKGROUND

*Hydrilla verticillata* (hydrilla), an invasive aquatic weed, was first introduced in Florida in the 1950s, and subsequently introduced independently in the Mid-Atlantic and California. It has continued to spread throughout the US and is currently present in 32 states with the Southeast and Texas having the most heavily infested areas (Figure 1). Despite substantial investment in management and control projects, hydrilla continues to spread into new regions. In the coming years, it is expected that more drinking water utilities will be faced with its presence in the rivers, lakes and reservoirs that serve as sources of drinking water.



Source: USGS 2017.

**Figure 1 Hydrilla distribution across HUC8 level watersheds**

Hydrilla, a federally listed noxious weed, is a high priority risk for multi-use reservoir systems. Hydrilla can spread by plant fragments and effectively outcompetes native vegetation. Without management, the species can colonize all viable habitat of rivers and lakes. Growth is limited predominantly by turbidity, high flow rates and light penetration. However, hydrilla can survive well in low light conditions, enabling it to extend into areas that other aquatic plants cannot inhabit.

An infestation can impact water quality, aquatic habitat, and recreational uses. The species forms dense mats of vegetation, reducing dissolved oxygen, and raising pH (Langeland 1996). Decay of plant litter can increase natural organic matter in reservoirs, a precursor to disinfection byproduct formation. Hydrilla is also associated with bald eagle deaths due to toxic cyanobacteria that grow on its leaves (Wilde et al. 2005), as well as fish kills from hypoxic zones due to oxygen

depletion (Cornell Cooperative Extension 2016b). Recreational impacts include difficulty navigating boats through heavily infested waters and risks to swimmers from the dense mats. Small-scale hydrilla infestations may benefit sportfishing, but fish biomass decreases with large infestations (NEANS 2017).

As with other aquatic invasive species, once a hydrilla population is established, management alternatives consist of chemical, biological, physical, or mechanical/manual methods (NCAES 1992). The effectiveness and applicability of each of these options depends on the local environment, regulatory approval, public acceptance, and water supply operations, which must be evaluated to select the proper combination of control methods. Water managers have been battling hydrilla for decades, and chemical management with aquatic herbicides is repeatedly selected as a preferred option for controlling its spread. Applying herbicides in sources of drinking water poses unique risks and requires broad public outreach.

The objectives of this project, therefore, are to:

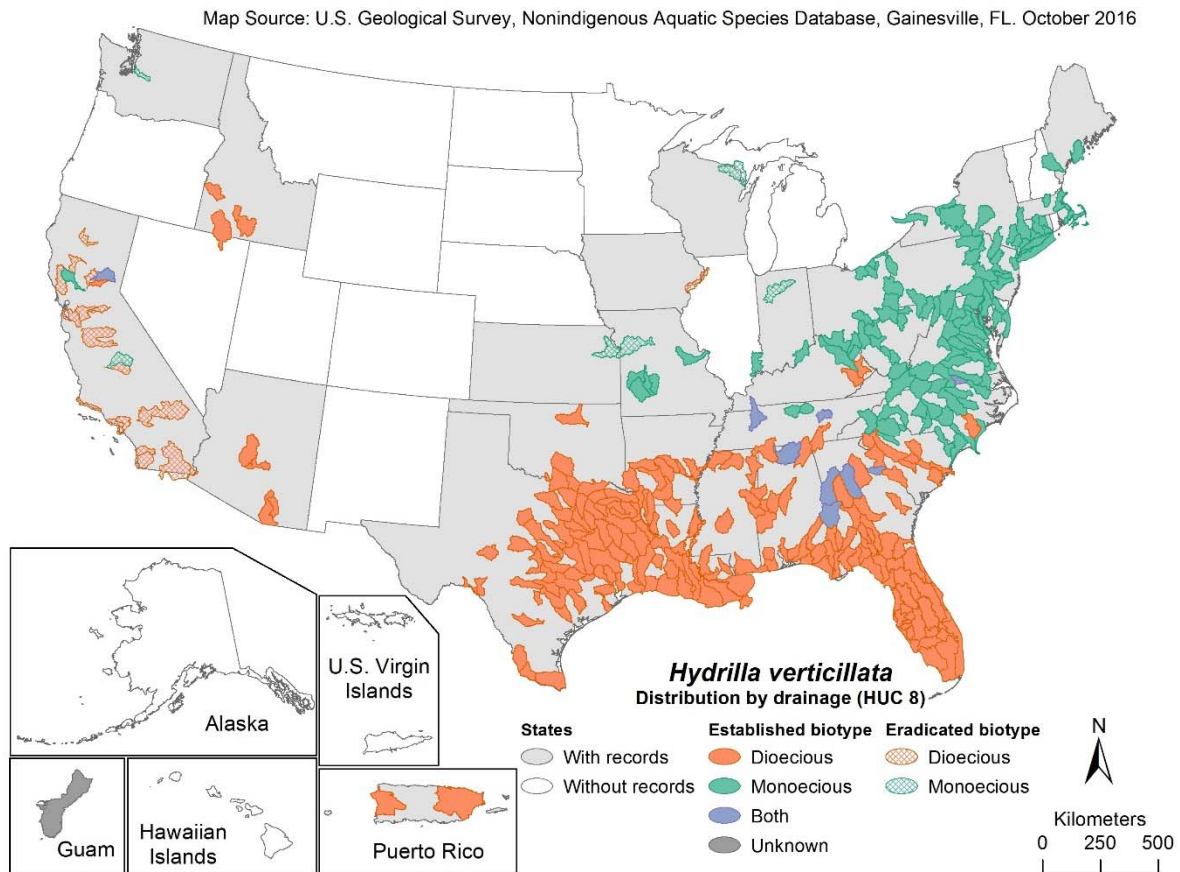
- Assess the state of knowledge of aquatic herbicide application for the management of hydrilla in drinking water reservoirs and its impacts on treatability, water quality and human and environmental health;
- Review lessons-learned from prior hydrilla management efforts;
- Provide an example hydrilla risk assessment to identify potential impacts from hydrilla and management options;
- Provide recommendations for mitigation of impacts associated with hydrilla management; and
- Develop communications resources for public outreach.

By summarizing the state of knowledge, characterizing the range of potential impacts, identifying the considerations for chemical management of hydrilla and documenting the “lessons learned” from water managers, this project can help utilities obtain a better understanding of the potential risks from hydrilla and communicate those risks to stakeholders, so resource managers can respond quickly and effectively to hydrilla infestations.

To achieve these objectives, the project consisted of a literature review of hydrilla management and herbicide research, discussions of hydrilla control experience with resource managers as part of five case studies and organization of an expert workshop to review New York City Department of Environmental Protection’s (DEP) hydrilla management options for the New Croton Reservoir. This report is expected to serve as important guidance for drinking water utilities who must be prepared to respond to the threat of hydrilla now and in the future. This project will help utilities combat this detrimental invasive species, while maintaining the health and safety of drinking water supplies.

## HYDRILLA NATURAL HISTORY

Hydrilla is a submersed aquatic weed with two known biotypes. The dioecious biotype is thought to have originated from India, while the monoecious biotype can be traced to Korea (Masterson 2007). The introduction of the dioecious strain occurred in two locations in Florida in the late 1950s, in Miami and the Tampa Bay area. The introduction of the monoecious strain occurred in Delaware and Washington D.C. around 1980, as well as in North Carolina (Masterson 2007). Hydrilla was also independently introduced in California (Mulholland-Olson 2004). The aquarium trade is likely the primary cause of the original introduction in all locations.



Source: USGS 2016.

**Figure 2 Hydrilla distribution by biotype as of 2016**

The dominant biotype of hydrilla in cooler regions of the United States is the monoecious variety, while the dioecious variety thrives in warmer temperatures and is dominant in the southeastern states and Texas (Figure 2). The primary causes of the spread of hydrilla can be attributed to natural local dispersal and reproduction of the plant, unintentional spread of fragments on boats and intentional spread by uninformed individuals looking to increase wildlife and fisheries habitat (Masterson 2007). Spread of hydrilla by animal vectors, such as waterfowl, which transport reproductively viable parts of the plant between waterbodies, is possible but not well-researched (Langeland 1996).

Due to the reproductive nature of the plant and its adaptability to various environmental conditions, hydrilla has been called the “perfect aquatic weed” (Langeland 1996). Hydrilla is adapted to grow in low light conditions allowing it to grow in deeper water than many other aquatic plants. This allows photosynthesis to occur earlier in the day than many of its aquatic competitors, leading to increased growth of up to an inch each day. Hydrilla can survive out of water in moist conditions for several days, which has been an important means of dispersal via boats and trailers. Hydrilla also thrives in varied water quality conditions, both oligotrophic and eutrophic water systems, a wide range of pH, and salinity up to 7% (Langeland 1996). These advantages allow for growth and rooting at greater depths, commonly up to 25 feet or more (Mulholland-Olson 2004). Hydrilla’s rapid growth results in dense mats on the water’s surface effectively blocking sunlight, making it an aggressive competitor for native species within the US.

Hydrilla is a perennial aquatic plant. The dioecious variety, preferring warmer regions, demonstrates its perennial nature and overwinters. The monoecious variety behaves more like an annual plant, relying on its tuber bank for early spring growth after dying back over the winter (True-Meadows et al. 2016). The primary method of reproduction and spread occurs through the production of tubers, turions, seeds and by fragmentation. Hydrilla stems and fragments can continue to survive, reproduce, and grow roots. Turions, 5-8mm long, are buds capable of forming a new plant. They are located on the leaf axil and will break off and settle on the sediment. Tubers, 5-10mm long, grow on the terminal end of the rhizomes. A single tuber can produce hundreds of plants over the course of a season (Langeland 1996). Hydrilla tuber sprouting includes both synchronous and asynchronous growth patterns.<sup>1</sup> In the Mid-Atlantic states, the tubers of the monoecious biotype typically sprout in late spring and early summer in response to rising temperatures. In the southern states, dioecious biotype tuber germination patterns are more random. Asynchronous sprouting is possible in the monoecious biotype of hydrilla; however, it is less common (Owens et al. 2012).

Tuber banks create challenges for effective management of hydrilla infestations. Once the shoot of the plant is killed, the tuber bank remains. An additional challenge is that tubers can remain dormant for four to six years in dry conditions with the ability to sprout when optimal growth conditions return (True-Meadows et al. 2016). For every square meter of hydrilla, up to 5,000 tubers can be produced (Langeland 1996). The hardiness of the plant leads to difficulties in the management and eradication of infestations from waterbodies. Management of the plant is optimal when the plant is still small and between the period immediately following the tubers sprouting, but before the plants have begun forming new tubers and turions. Effective control measures are required over the course of several years to address the stored reserves within the plant’s tuber bank.

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<sup>1</sup> Synchronous sprouting occurs when most of the plants in a tuber bank sprout at around the same time.



## HYDRILLA CONTROL METHODS

There are a variety of control options available for macrophytes (i.e., aquatic plants). The general management categories are physical/mechanical, biological, and chemical. The focus of this project is chemical control methods, but physical/mechanical and biological methods are also included to provide an overview of available management techniques for hydrilla control. The text below summarizes key points for consideration from Wagner (2004) and other resources, but it is not an exhaustive list. Refer to Wagner (2004) for a comprehensive description of the full range of methods for managing macrophytes, and detailed descriptions of advantages and disadvantages. In addition, regulations vary from state to state, so it is recommended that resource managers discuss hydrilla control options with regulators to identify permit requirements and regulatory restrictions that may be specific to their waterbody.

### PHYSICAL AND MECHANICAL METHODS

Mechanical and physical control techniques interfere with the plant's life cycle through physical removal or by physically disrupting its habitat. Advantages include targeting control measures to specific sites and no addition of chemicals to the waterbody. Disadvantages include a high risk of spreading hydrilla via fragmentation, near-complete disruption of benthic habitat to fully remove the tuber bank and high costs. The disadvantages typically prevent the use of physical and mechanical methods for large-scale infestations. However, these methods have proven successful for small-scale operations. Listed below are some of the physical and mechanical methods used for hydrilla control and key considerations.

- Benthic barriers entail placement of an anchored mat over the location of the infestation to deprive emergent growth of light. Benthic barriers must be removed annually or cleaned to prevent sediment buildup and rooting on top of the barrier. Barriers can deplete the tuber bank over many years as turions and tubers sprout and die off. The cost and labor involved with installing and replacing barriers limits their cost-effectiveness for large areas.<sup>2</sup> Further, rocky substrate or areas with substantial debris may be unsuitable for benthic mats. There are a variety of benthic barriers (porous mats, non-porous mats, and sediment) for use under different environmental conditions.
- Dredging is the physical removal of sediment that contains the root structures and tuber bank. Dredging for aquatic plant control has similar impacts as dredging to deepen a river or reservoir. It is a large-scale construction project that includes staging areas, truck routes and sediment dewatering areas. Hydrilla-contaminated sediment cannot be returned to the waterbody and must be disposed of off-site. Dredging results in an immediate impact on benthic biota and submerged vegetation, and bathymetric changes may result in long-term changes to the aquatic environment.
- Mechanical harvesting is the process by which aquatic plants are cut as close to the sediment as possible. Mechanical harvesting is generally considered a short-term management option for hydrilla and will not address the tuber bank. To prevent further

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<sup>2</sup> NYC Department of Environmental Protection received an estimate of approximately \$3.00 per square foot for materials and installation at New Croton Reservoir.



spread of hydrilla, harvested vegetation must be collected to prevent spread by fragmentation or turions.

- Rototilling and hydroraking (Figure 3) are two methods by which the plant and roots are cut and the bottom sediment disturbed to disrupt rooted plant structures. As with harvesting, all plant materials must be collected to prevent further spread.
- Hand pulling is a manual method to remove plants and root material without impacting non-target species. Hand pulling can be effective for small areas, but the labor-intensive method makes it difficult to cover large areas. Further, divers are needed to access plants in water that is more than a few feet deep. As with other removal methods, hydrilla fragments must be collected to prevent spread of the plants.
- Reservoir drawdown requires lowering the water surface elevation to expose aquatic plants and dry them out. To kill the rooted mass, water levels must be left low for an extended period of time, preferably over the winter as prolonged freezing temperatures can kill the rooted mass. However, mild temperatures, snowfall that insulates the soil or groundwater seepage can help protect tubers. Further, it may be difficult to maintain water levels in a state of drawdown for an extended length of time due to water supply operational constraints.



*Source:* Courtesy of Heather Desko/New Jersey Water Supply Authority.  
**Figure 3 Hydroraking submersed aquatic plants in the D&R Canal**

## BIOLOGICAL METHODS

Biological control is based on the concept that a new introduced species that regulates the life cycle of the invasive species can help provide balance to an ecosystem and prevent negative impacts. Research into biological control for hydrilla is on-going, and a number of species have been introduced to date (Harms et al. 2017, IFAS 2017b). The process for identifying and introducing new species is slow, because there needs to be sufficient prior study to ensure the new introduced species will not cause unforeseen impacts. Further, once introduced, many species are not successful. Of the eight species previously introduced in Florida to control hydrilla (Table 1), grass carp (*Ctenopharyngodon idella*) has been the only success. While invertebrates, viruses and fungi are continuing to be researched and tested experimentally for hydrilla control (Harms et al. 2017, IFAS 2017b), grass carp is expected to be the only commercially available biological control method available for hydrilla for the foreseeable future.<sup>3</sup>

**Table 1**  
**Biological control species previously introduced to control hydrilla**

Common Name	Scientific Name	Status
Hydrilla tuber weevil	<i>Bagous affinis</i>	Failed to establish
Asian hydrilla leaf-mining fly	<i>Hydrellia pakistanae</i>	Limited control
Australian hydrilla leaf-mining fly	<i>Hydrellia balciunasi</i>	Established in Texas, failed elsewhere
Hydrilla stem borer	<i>Bagous hydrillae</i>	Failed to establish
Hydrilla miner	<i>Cricotopus lebetis</i>	Limited control in Florida
Adventive hydrilla moth	<i>Parapoynx diminutalis</i>	Feeding not limited to hydrilla
Chinese grass carp	<i>Ctenopharyngodon idella</i>	Commercially viable, used in many states including Virginia, Texas, Florida, etc.
Fungal pathogen	<i>Micoleptidiscus terrestris</i>	Limited control

Source: Data from IFAS 2017b

Grass carp preferentially consume hydrilla and are expected to provide control for approximately five years. The level of control is dependent on the ratio of fish to the size of the hydrilla infestation. To achieve eradication or to prevent further spread, sufficient fish must be stocked so that their consumption rate exceeds the growth rate of the plants (Sutton and Vandiver 1986). However, this will result in the fish consuming other aquatic plants as well, potentially impacting native species and altering the lake ecology. Grass carp waste can increase nutrient loads in waterbodies, potentially encouraging algal blooms and further changing lake ecology. Other considerations for grass carp include difficulty in removing them once introduced and potential for grass carp to escape from the target waterbody. Because of the risks associated with grass carp, many states, including New York, New Jersey, and Massachusetts, restrict grass carp to small isolated waterbodies to prevent accidental release into the environment.

<sup>3</sup> Grass carp must be US Fish and Wildlife Service (USFWS) certified sterile, triploid fish. (USFWS 2015).



## CHEMICAL METHODS

Chemical control methods are commonly used to manage undesirable submerged macrophytes. Chemical control uses herbicides to kill plants, prevent the germination of seeds or to modify the growth of the plants. There are numerous benefits to chemical control methods including predictable performance based on scientific studies and field trials, suitability for large-scale plant management and low risk of hydrilla spread through fragmentation. Disadvantages to chemical control methods include impacts to non-target species, restrictions on waterbody uses following treatment and potential for negative public perception of herbicide treatment.

The goal of chemical treatment for hydrilla is to treat after tubers have sprouted but before plants have begun forming new tubers or turions, which are not directly affected by herbicides. There are two types of herbicides based on their mechanism for influencing plant growth. Contact herbicides act quickly and kill all plant cells that they contact. Systemic herbicides are absorbed and move within the plant to the site of action. The level of control for both types of herbicides is highly dependent on contact time (e.g., level of exposure of the plant to the herbicide) for each specific chemical. As previously mentioned, hydrilla may exhibit synchronous or asynchronous sprouting, which will affect the length and number of treatments required within the growing season.

Discussed below are the most commonly used herbicides known to be effective in controlling hydrilla. It should be noted that these herbicides are nationally registered for aquatic use under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA 1996). Under the provisions of FIFRA, no herbicide may be legally offered for sale, sold, or used in this country without US Environmental Protection Agency (EPA) registration and approval. Herbicides are approved only after the EPA determines that they will perform their intended function without unreasonable adverse effects on the environment. Once approved, every herbicide must bear a "label" containing basic information about the compound, waterbody restrictions, precautionary statements, and directions for proper use. In addition to federal restriction on the use of herbicides, states may also impose their own standards relative to application of these products in their waters. For example, Florida has approved 14 herbicides for aquatic plant control, while New York has approved nine. Only a subset of these are effective against hydrilla and are described below.

As stated previously, there are two biotypes of hydrilla that largely act as different species. The effectiveness of an herbicide varies between the two biotypes, and the regional experience varies. For example, Florida's experience with the dioecious biotype may not be directly applicable to areas managing the monoecious biotype. Information on the effectiveness on each biotype is provided, if available.

The information below provides a summary of the characteristics of herbicide active ingredients that are important to water resource managers addressing hydrilla. However, there may be multiple manufacturers of herbicide products with the same active ingredients with different formulations (e.g., active ingredient concentration, liquid vs pellet form, various other ingredients, etc.). Each product and formulation has its own label and restrictions, as well as advantages/disadvantages that depend on the local conditions of the waterbody (e.g., rate of water exchange, water quality, sensitive species, uses, etc.) and the extent of the hydrilla infestation. Other considerations include the potential to mix two herbicides or the need to add surfactants to increase plant uptake. Each situation is unique, and there are too many considerations to describe them all in this guidance document. It is recommended that water resource managers pursuing chemical control of hydrilla discuss options with state regulators and licensed pesticide applicators

to review the herbicides permitted in their state that will be most effective for the conditions present at their waterbody.

The active ingredients that have been successful in treating dioecious hydrilla include copper complexes, diquat, copper with diquat, endothall, fluridone, imazamox, penoxsulam, bispyribac and flumioxazin (TAMU 2017, IFAS 2017c). The monoecious biotype has been successfully managed to date with diquat, endothall, fluridone and copper (True-Meadows et al. 2016). It should be emphasized that herbicide development is an active area of research, new products may become registered, existing products may prove effective on hydrilla and states may approve herbicides already registered with the EPA. Further, label restrictions may change over time as well. As such, chemical management options should be revisited periodically to identify products that may be better suited for a given application and to update hydrilla management plans with current label information.

The herbicide summary information below is primarily from IFAS (2017c) along with other sources, such as specific herbicide labels. Drinking water restrictions listed below are from the federal label information; state-specific labels may apply additional restrictions. Any application rate information listed is general to provide an order of magnitude reference for comparison with water quality and/or human health standards. Specific application rates should be developed by a licensed pesticide applicator after sufficient review of water quality conditions and usage of a waterbody.

### **Bispyribac-Sodium**

Bispyribac was registered by the EPA for aquatic uses in 2011 and is sold under the trade name Tradewind. Bispyribac is a systemic herbicide that blocks an enzyme necessary for growth and development specific to plants. The biochemical pathway does not occur in animals. As the herbicide accumulates in plant tissue, the plant dies over a period of weeks to months. Bispyribac has been shown to be effective for dioecious hydrilla in field studies (Petta et al. 2012). Tradewind herbicide may be applied to slow moving or quiescent bodies of water where there is minimum or no outflow; it is not applicable in flowing systems. There is no post-application restriction against use of treated water for drinking or recreational purposes (e.g., swimming, fishing) (Valent 2012).

### **Copper Complexes**

Copper is a fast-acting, broad-spectrum, contact herbicide that kills a wide range of aquatic plants and algae. Although copper is a micro-nutrient required by living plants and animals in small amounts, too much copper kills plants by interfering with plant enzymes, enzyme co-factors and plant metabolism in general. Copper has long been used in natural and industrial waters for algae control, often applied directly to water as copper sulfate crystals. Chelated copper (i.e., copper ion combined with an organic molecule) is typically used for aquatic plant management as it remains active in the water column longer than copper sulfate. Copper is toxic to fish, and because copper is an element, it will accumulate in the sediments regardless of its bioavailability. Drinking water considerations are not typically the limiting factor for copper application. National Primary Drinking Water Regulations include an action level for copper at 1.3 mg/L, but copper applied to lakes and reservoirs tends to quickly bind with sediment and organic matter, settling out of the water column (Haughey et al. 2000). Copper can be highly toxic to mollusks and fish at relatively low doses (approximately 1 to 5 ppm), thus some states, (e.g., Florida and New York) restrict its use to prevent impacts to fisheries. Copper alone may only provide fair control of

hydrilla at application rates of approximately 3 ppm. Copper can be added at lower rates in combination with other herbicides (e.g., diquat or endothall) for better control of hydrilla (NCAES 1992).

## **Diquat**

Diquat, first formulated in the mid-1950s, is a fast-acting contact herbicide that is mainly used to control floating plants such as water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*). On the immersed portions of plants, diquat acts as a systemic herbicide; it enters and diffuses within the plant. Diquat interferes with photosynthesis by forming highly reactive and toxic free-radicals in plant cells. Diquat kills the exposed portions of plants in 24 to 36 hours. It is water soluble and diffuses rapidly through the water, quickly adsorbing into plant tissue. However, diquat is also strongly cationic, so it adsorbs to and is tightly held by negatively charged clay and sediment particles. For this reason, diquat is ineffective in muddy waters where it will bind to the suspended sediment. Diquat dissipates from the water column by adsorption onto soil particles and has a half-life of 1 to 7 days.

Diquat is relatively ineffective when used alone to control hydrilla, but it can be used in combination with chelated copper for quick control. This may be a good option for small scale occurrences, but not for large scale hydrilla control due to accumulation of copper. Diquat also is used in combination with potassium endothall and flumioxazin herbicides for hydrilla control. In each case, the addition of diquat provides more rapid and perhaps more thorough hydrilla control, while introducing a second mode of action to prevent herbicide resistance.

Diquat is restricted for use in public waterbodies and there is a three-day restriction before water treated with diquat can be used for drinking water purposes. Restrictions are necessary so that water does not contain more than the designated maximum contaminant level goal (MCLG) of 0.02 mg/L (ppm) of diquat dibromide (Syngenta Crop Protection 2009).

## **Endothall**

Endothall acid, first available as an aquatic herbicide in the 1960s, was originally used in agriculture as a plant desiccant. The active ingredient is relatively fast-acting and is formulated into two compounds for aquatic use: a dipotassium salt (potassium endothall) and an monoalkylamine salt (amine endothall). Both compounds are available in liquid and granular formulations. Endothall herbicides interfere with plant respiration and photosynthesis by disrupting plant cell membranes. Endothall breaks down in water microbially with a half-life of approximately 4 to 7 days.

Endothall primarily functions as a contact herbicide, but recent research indicates it acts as a systemic herbicide in hydrilla (Ortiz et al. 2017). Endothall is absorbed by submersed plants in lethal concentrations in 12 to 36 hours depending on the concentration applied.

Potassium endothall at typical application rates of 2 to 3 ppm is not toxic to adult fish, eggs, or fry. Amine endothall is more active on plants, but toxic to fish at concentrations greater than 0.3 ppm. Amine endothall is typically not used alone or for large scale hydrilla control. It is usually applied at very low rates with potassium endothall to increase efficacy and to introduce a second active ingredient to prevent herbicide resistance. Potassium endothall is used extensively in Florida, and the Florida Fish and Wildlife Conservation Commission (FWC) is sponsoring research to develop new uses of the product with other herbicide active ingredients (e.g., bispyribac and penoxsulam).

In quiescent waterbodies, endothall products cannot be applied closer than 600 feet to drinking water intakes. In flowing waterbodies, endothall products cannot be applied such that the concentration exceeds 0.1 ppm, the MCL for endothall. Waters treated with endothall may be used for swimming, fishing and irrigating turf, ornamental plants, and crops immediately after treatment (United Phosphorous, Inc. 2016).

### **Flumioxazin**

Flumioxazin was registered by the EPA in 2011 and is sold under the trade name Clipper. It is a contact herbicide that causes chlorosis (yellowing) and necrosis (browning) of exposed plant tissue. It moves within treated leaves, but does not translocate to other areas of the plant. Plants exposed to flumioxazin die because of the disruption of cell membranes. Once inside the plant cell, flumioxazin inhibits a key enzyme, protoporphyrinogen oxidase. Plant necrosis and death is rapid, taking a few days, up to two weeks. In general, at least four hours of contact time is required for good control.

The primary breakdown pathway of flumioxazin in water is by hydrolysis, and it is highly dependent on water pH. Under high pH values (> 9), flumioxazin half-life in water is 15 to 20 minutes. Under more neutral pH values (7 to 8), half-life in water is approximately 24 hours. Flumioxazin controls a wide variety of submersed and floating aquatic weeds and can be tank-mixed with other contact or systemic herbicides.

There is no post-application restriction against use of treated water for drinking or recreational purposes (e.g., swimming, fishing). Treated water is restricted for use for irrigation for up to five days (Nufarm Americas 2017).

### **Fluridone**

Fluridone is a systemic herbicide, developed in the mid-1970s. It was later shown to be effective for the control of submersed plants and was registered by the EPA for aquatic use in 1986. Fluridone is a systemic herbicide used to control underwater plants and is commonly used for hydrilla control. The herbicide is absorbed by plant shoots and roots, where it moves throughout the plant and interferes with chlorophyll. Without chlorophyll, the plant is unable to photosynthesize, shoot tips turn pink or white, and the plant slowly starves and dies. A plant's susceptibility to fluridone is associated with its uptake and translocation rates (Cornell Cooperative Extension 2016a). Photolysis is the primary degradation mechanism, and the half-life is 20 to 50 days (Netherland 2011). There are two potential toxic degradation byproducts, but there have been no documented detections under field conditions (Wisconsin DNR 2012).<sup>4</sup>

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<sup>4</sup> The toxic metabolites from photolysis of fluridone are N-methyl Formamide and 3-trifluoromethyl benzoic acid. The EPA health risk assessment considered these byproducts, and the fluridone label restrictions account for their potential formation (EPA 2004).

### **Herbicide Resistance in Hydrilla**

Herbicide resistance in hydrilla (both fluridone and endothall) is believed to have occurred from repeated application of a single herbicide over many years that selected for individuals that were less susceptible to the herbicide (Giannotti et al. 2014). Utilizing different herbicides over a season with different modes of action is expected to reduce the possibility of resistance emerging within a population. To date, resistance has only been documented in dioecious hydrilla, but there is no evidence that monoecious hydrilla cannot develop resistance as well (Arias et al. 2005).

Fluridone is formulated as both a liquid, and as slow or fast-release pellets. Application rates for plant control are much lower than those for other herbicides – in the parts per billion range compared to parts per million. However, contact time is measured in weeks or months rather than hours or days. Fluridone must be kept at prescribed concentrations for at least 45-80 days for optimum long-term control of hydrilla – even longer exposure is required for more mature plants with high carbohydrate reserves. Fluridone application early in the growing season provides the best selectivity for hydrilla control, as hydrilla exhibits robust growth while most non-target native plants are still dormant.

Fluridone resistance has been documented in dioecious hydrilla in Florida, because of asexual reproduction and sole reliance on fluridone for many years (Arias et al. 2005). Repeated fluridone use effectively removed the more susceptible hydrilla genotypes, leaving the more tolerant plants to expand. In Florida pre-application bioassays are used to determine each hydrilla population's current level of fluridone tolerance. Management strategies to prevent the development of resistance include using fluridone in conjunction with another herbicide to avoid inadvertently selecting for resistance.

The maximum application rate for fluridone is 150 ppb, and fluridone application rates are restricted to less than 20 ppb within ¼ mile of potable drinking water intakes (SePRO 2017).

### **Imazamox**

Imazamox was registered for aquatic use in 2007. Imazamox is a systemic herbicide that works by inhibiting the plant enzyme acetolactate synthase (ALS), which regulates the production of amino acids in plants. When ALS is inhibited, plants die. Animals do not produce these enzymes, so imazamox has low toxicity to animals. Enzyme inhibiting herbicides act very slowly. Imazamox is broken down in the water by photolysis and microbial degradation. Its half-life in water is 7 to 14 days.

Imazamox is absorbed rapidly into plant tissues, and growth of susceptible plants is inhibited within a few hours after application, dying in approximately 1-2 weeks. In Florida, aquatic plant management programs include submersed applications for hydrilla control. At concentrations of 50-150 ppb, imazamox acts as a growth regulator for hydrilla, persisting for up to several months. At concentrations of 150-250 ppb, imazamox acts with herbicidal activity, killing hydrilla in a few weeks after application.

Imazamox application rates are restricted to less than 50 ppb within ¼ mile of potable drinking water intakes, and irrigation is restricted at rates above 50 ppb (BASF Corporation 2010).

### **Penoxsulam**

Penoxsulam was registered for aquatic use in 2009. It is currently sold under the trade name of Galleon. It is a systemic herbicide that is applied to plant foliage to control floating or immersed plants, or to the water column for submersed plant control. Penoxsulam works by inhibiting the plant enzyme acetolactate synthase, similar to imazamox. Treatment must maintain herbicide concentrations at sufficient levels for 90-120 days for optimum performance. Penoxsulam is broken down in water both microbially and through photolysis, and its half-life in water is approximately 25 days. Because of the long contact time, penoxsulam is not generally applied in areas of high water exchange. Penoxsulam needs a surfactant for foliar and exposed sediment applications to increase efficacy by binding the herbicide to the plant.



There are no restrictions on consumption of treated water for potable use or by livestock, pets, or other animals. The label for penoxsulam-containing herbicides includes a number of restrictions on irrigation usage after treatment (SePRO 2012).

## **Topramezone**

Topramezone was registered for aquatic use by the EPA in 2013. It is currently sold under the trade name Oasis. It is a systemic herbicide that is applied to the water column for submersed plant control, directly to foliage of floating and emergent vegetation or to dewatered sites. Topramezone is the first herbicide belonging to new chemical class called pyrazolones. In sensitive plant species, topramezone inhibits the enzyme 4-hydroxyphenylpyruvate dioxygenase, leading to a disruption of the synthesis and function of chloroplasts. Consequently, chlorophyll is destroyed by oxidation resulting in bleaching of the growing shoot tissue (white or pink coloration) and subsequent death of the above ground portion of the plant.

Generally, topramezone is applied at 30-50 ppb and maintained at or near the initial concentration for a minimum of 60 days. Applications are made to actively growing plants early in the growing season before mature plants can build tubers. Topramezone is absorbed into the plant tissue and symptoms generally first appear in 7 to 10 days.

Water with concentrations higher than 45 ppb are restricted for potable uses. There are no restrictions on consumption of treated water by livestock, pets, or other animals up to the maximum concentration of 50 ppb. There are no restrictions on use of treated water for recreational purposes including swimming and fishing up to the maximum concentration of 50 ppb (BASF Corporation 2014).

## **HYDRILLA CONTROL SELECTION CRITERIA**

The goals of the hydrilla management program will drive the best approach and will be unique to each individual situation. It is necessary to first explore potential impacts to a waterbody from hydrilla in the event of no action in order to determine management goals. Hydrilla can make use of low light, low nutrient conditions, thus it can outcompete native vegetation and spread to areas native and other non-native vegetation cannot grow. Uncontrolled, hydrilla can be expected to eventually spread to all suitable habitat areas within a waterbody. For example, within the Eno River in North Carolina, while managers were deciding on an appropriate plan of action for hydrilla control, the infestation was able to spread approximately one mile per year within the river (Rob Richardson, personal communication, November 17, 2017).

The large swathes of vegetation and its impact on recreation (fishing, swimming, and boating) have been well-documented and are the typical driver for control in many locations. Other impacts include reducing flow rates in drainage canals and shallow rivers, clogging irrigation intakes and changing flow patterns in cooling water ponds (Langeland 1996). Research has shown that sport fishing species may be negatively impacted once hydrilla reaches approximately 30% coverage (NCAES 1992). A species of cyanobacteria that grows on hydrilla has been linked to waterfowl mortality due to neurotoxin accumulation (Wilde et al. 2005).<sup>5</sup>

Hydrilla's impacts on water quality and treatment operations are a prime consideration for drinking water utilities. Hydrilla dies back in the fall when water becomes cold, causing the

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<sup>5</sup> Toxins produced from cyanobacteria associated with hydrilla are uncharacterized (Dodd et al. 2016). No studies were found that linked hydrilla to direct human health impacts.



vegetation within the water column to die. This can result in impacts to drinking water utilities because 1) the vegetation can block intake screens or collect on treatment plant equipment and 2) the sudden die-off of large stands of hydrilla can cause a large influx of natural organic matter (NOM), as well as causing buildup of NOM within the waterbody over repeated growth/die-off cycles.<sup>6</sup> NOM is a precursor to regulated disinfection byproducts (DBP), and it is difficult to determine the level DBP formation due to differing types of organic matter reactivity. While no specific studies were identified that evaluated the DBP formation potential of hydrilla, the large volume of biomass hydrilla is capable of producing is sufficient to raise concern.

For waterbodies where the full area is potential hydrilla habitat, typically shallow and slow-moving streams and reservoirs, it is clearly necessary to manage hydrilla actively to prevent it from completely taking over. For waterbodies that could only be partially impacted by hydrilla due to depth or other limiting factors, the amount of potential infestation and the risks to beneficial uses must be weighed against the effort and potential impacts from hydrilla management. Aside from a few exceptions, see Potomac River Case Study, the typical approach has been to actively manage hydrilla to control its spread and reduce the size of the infestation to prevent impacts to native ecology, recreation, fisheries, and other beneficial uses. Further, there must also be a consideration of regional implications when determining the level hydrilla management. For example, if water managers within the larger region are generally following active management, pursuing no action would result in that waterbody becoming a potential source for reintroduction to other waterbodies. Unless compelling information is available that would strongly favor a no action alternative for a waterbody, such as limited potential habitat for hydrilla and low risk of spread to other locations, the general recommendation for drinking water utilities would be to pursue active management to prevent the spread of hydrilla.

- **Physical and Mechanical Methods:** With the goal of reducing the infestation and preventing the further spread of hydrilla, mechanical methods (dredging, harvesting, hydrosucking and rototilling) are not recommended (NCAES 1992). Collecting all fragments, tubers, seeds and turions is too difficult to reliably prevent spreading. Hand removal can be successful for small isolated patches, so long as the fragments are contained. However, hand pulling can be cost prohibitive if the water is deep enough to require divers for the work. Benthic mats are suitable for small areas with good access and suitable substrate, but may not be cost-competitive with herbicides. Reservoir drawdown has proven unsuccessful for hydrilla because the tubers can survive for long periods and remain viable (Langeland 1996). Overall, physical and mechanical methods are not recommended for large-scale control and eradication, but may be appropriate for small scale occurrences.
- **Biological Methods:** Selection criteria for biological control options, which are currently limited to grass carp, are 1) is it allowable under state law and 2) does the risk from hydrilla outweigh the risks to lake ecology? For example, grass carp have been considered successful in the Catawba River system in North Carolina and South Carolina, but there is little native vegetation in the reservoirs because of water level fluctuations from hydropower operations (Ellis 2014). In waterbodies with diverse aquatic plant communities, grass carp can be expected to diminish native plants, particularly those that are preferred by the species. Because grass carp and other

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<sup>6</sup> Studies on hydrilla in the Potomac River estimated approximately 15 tons per acre of vegetative matter in shoreline stands in water up to 6 feet deep (US Army Corps of Engineers 1986).

biological controls are a natural species, performance can be unpredictable. Experience in Washington State, for example, found grass carp performance for aquatic plant management to range from limited control to complete elimination of underwater plants in a waterbody (Washington Department of Ecology 2002).

- **Chemical Methods:** While there are many effective herbicides available for the management of hydrilla, the primary concern among drinking water utilities with respect to chemical management is their foremost responsibility to maintain public health. For a utility or water manager to decide to add chemicals to a source of drinking water, they must be assured that those chemicals are not going to cause harm to drinking water consumers or the general public. The EPA is charged with setting tolerances and registering pesticides. The EPA has a detailed process for determining the potential for adverse effects from aquatic pesticides based on data and modeling (Stubbs 2014). Human health data required during the registration process include acute toxicity studies, subchronic toxicity testing, chronic toxicity and oncogenicity.<sup>7</sup> Human developmental toxicity is based on gene mutation studies, two generation reproduction studies and structural chromosomal aberration studies. Depending on pesticide use pattern and results of studies, additional studies may be required (Stubbs 2014).

EPA uses the data to conduct a human health risk assessment to evaluate the likelihood that an adverse human health risk may occur because of exposure to a pesticide via direct or indirect contact, or by ingestion of treated foods. Using data and models, EPA determines the potential for exposure from a pesticide and its no adverse effect level (NOAEL), which includes a minimum 100-fold factor of safety (EPA n.d.). In addition to human health studies, general ecological risks are determined based on environmental fate and transport studies and ecological toxicity studies, including analysis of bioaccumulation. The goal of the EPA registration process is to provide assurance that using aquatic pesticides as directed per the label instructions will not cause unreasonable adverse effects on human health or the environment (Stubbs 2014). In addition, recognizing that science changes over time, pesticide re-registration is conducted on an approximately 15-year cycle. Review of the EPA pesticide registration process with an independent toxicologist confirmed the process is both comprehensive and conservative, but is often difficult to properly communicate to the public and other stakeholders (Bernalyn D. McGaughey, Personal Communication, 12/13/17).

Despite the level of effort required to register a pesticide and ensure no adverse effects, there may be apprehension amongst stakeholders at the prospect of their use to manage hydrilla. Therefore, it is typically beneficial to develop a robust public outreach program to provide justification for the need to apply herbicides, get feedback from stakeholders and address their concerns. It is beneficial to provide stakeholders with documentation that demonstrates a low potential for risks and a plan that addresses potential contingencies (e.g., accidents and spills). Given the variety of herbicide characteristics, if chemical management is selected, it is recommended that utility staff consult with a licensed pesticide applicator to review the available products and formulations, state restrictions, presence of sensitive species and location specific conditions to identify the most appropriate product to achieve the utility's goals.

- **Combination Methods:** Given the persistence of hydrilla and its difficulty to eradicate, typically a combination of measures is often employed to maximize effectiveness. For

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<sup>7</sup> Tumor-causing

example, when using grass carp with large infestations, applying a contact pesticide is used initially to reduce the plant biomass, decreasing the amount of plant material needed to be consumed by the fish. An additional benefit is that it can improve fish survival, because large hydrilla infestations can cause diurnal swings in dissolved oxygen that could reduce grass carp survival (Sutton and Vandiver 1986). Similarly, a combination of contact and systemic herbicides can provide both immediate and long-term management benefits for hydrilla control. For large-scale infestations, once the bulk of the infestation has been addressed by herbicides and/or grass carp, management strategies could transition to effective small-scale approaches, such as hand pulling or benthic barriers. Typically, there is no single approach that will be fully effective, so it is necessary to keep as many options available to achieve management objectives.

In summary, physical control of hydrilla is generally limited to small infestations that can be managed with hand pulling or benthic barriers. Biological control may be an option depending on state laws and the sensitivity of the aquatic ecology to impacts. Depending on state regulations and local conditions, there may be multiple chemical control options available. Herbicide options should be reviewed with a licensed herbicide applicator to identify the most suitable option based on management objectives and local conditions. In many instances, effective management utilizes a combination of these options to target hydrilla and minimize broader impacts to the waterbody and its beneficial uses. Further, because hydrilla control is a multi-year process, adaptive management that evaluates performance and adjusts the management approach from year to year is often a component of hydrilla control strategies.

## HYDRILLA MANAGEMENT CASE STUDIES

Case studies of prior and on-going hydrilla management programs were reviewed to compile lessons learned that would help guide hydrilla management efforts. Refer to Appendix A for select resources on each case study.

### CROTON RIVER

Hydrilla was identified in the Croton River, downstream of the New Croton Reservoir and upstream of the Croton Bay of the Hudson River, in Westchester County in 2013 and confirmed in 2014. Following the discovery, the New York State Department of Environmental Conservation (NYSDEC) initiated a review to determine an appropriate management response. The following summarizes the potential risks from hydrilla in the Croton River that were used as justification by NYSDEC to use herbicides to manage hydrilla (McGlynn and Eyres 2017).

- 1) Village of Croton-on-Hudson Drinking Water Supply: The village's drinking water supply consists of groundwater wells with direct connection to the Croton River. Hydrilla could eventually impact water quality from decomposing hydrilla contributing DBP precursors to the village water supply.
- 2) Submerged Aquatic Vegetation (SAV): NYSDEC and other organizations have been working to restore SAV beds throughout the tidal Hudson River, which play a vital role in maintaining river dissolved oxygen levels and providing aquatic habitat in the Estuary. Hydrilla could displace native SAV, negatively impacting restoration efforts.
- 3) Waterfowl and raptors: Although not present in hydrilla samples collected at the Croton River to date, a strain of toxic cyanobacteria has been linked to waterfowl mortality and is associated with hydrilla. The cyanobacteria species is a recent discovery and little is known about its potential to spread north.
- 4) Waters in New York and adjacent states: Given the proximity to numerous waterbodies, its direct connection with the entire Hudson River watershed,<sup>8</sup> and state borders nearby, this infestation poses a serious threat to the aesthetic values of many waters in New York, Massachusetts, and Connecticut.
- 5) Fish populations and biodiversity: The dense mats of vegetation will displace native plants, and decomposition of hydrilla vegetation decreases the dissolved oxygen content in the water and can result in fish kills.
- 6) Threat to recreation: The dense mats of vegetation will prohibit swimming, boating, and fishing in infested areas of the river.

Without management existing hydrilla populations would continue to grow and spread to new locations. Each season hydrilla would grow into dense mats that would out-shade and outcompete native plants and then decompose, decreasing dissolved oxygen in the water. The Croton River infestation would be a source of fragments that could establish in the Hudson River, which could be transported to locations where it could become established and grow.

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<sup>8</sup> An overarching goal of the Croton River hydrilla management program is to prevent the establishment of hydrilla in the Hudson River. The Hudson River watershed is over 12,000 square miles, and it is feared hydrilla could spread throughout much of the state once established in the river.

NYSDEC considered the range of potential management options available for the Croton River. Most physical and mechanical methods were screened out because of the potential for further spread by fragmentation. Benthic mats were reviewed and determined to be largely ineffective in flowing streams. Grass carp were screened out because there would be no way to prevent the fish from escaping into the Hudson River, which could impact native SAV populations. Chemical control was determined to be feasible and effective, and NYSDEC staff recommended chemical control as the preferred option. It was determined that while complete eradication may be difficult to achieve, herbicides could greatly reduce the size of the infestation, enabling continued small-scale maintenance to keep the remaining populations in check. Adaptive management was also adopted as a strategy, which would entail assessing treatment outcomes and revising the approach in subsequent years.

A dye study was conducted to assess the efficacy of herbicide treatment in the flowing stream. It was determined that as long as water exchange was maintained below a maximum threshold, there could be enough contact time before dilution reduced herbicide concentrations. Initially a pilot treatment using endothall (1.5 to 5.0 ppm) for a portion of the river, downstream of the Village of Croton-on-Hudson Drinking Water Supply, was planned for 2016, but never initiated due to permitting delays and unanticipated high flows in the Croton River that exceeded the flow threshold.<sup>9</sup> Fluridone treatment was decided upon for the full length of the river with the first application during the growing season in 2017. Fluridone was selected over endothall, because of the potential drinking water risks to the Croton-on-Hudson wellfield and less potential natural resources impacts. The treatment target concentration was 2 ppb of fluridone. A monitoring plan was developed to achieve multiple goals:

- Drinking water safety,
- Environmental protection, and
- Maintenance of adequate herbicide levels for effective treatment.

Monitoring of the wellfield was conducted daily for the first seven days and then weekly to confirm fluridone levels remained below 1 ppm in the drinking water supply. If wellfield levels reached 1 to 4 ppb in wells, daily sampling would be triggered. If wellfield levels exceeded 4 ppb, fluridone treatment would be modified or terminated until measured concentrations in the wells dropped below the trigger limit. Treatment occurred in July through October 2017. Monitoring increased from weekly to the additional daily sampling due to wellfield levels exceeding 1 ppb in late August. Daily sampling continued for most of the duration of treatment through approximately one month after the end of treatment (NYSDEC 2017c).

Throughout the process, NYSDEC worked with multiple stakeholder organizations in the region to facilitate public outreach, workshops, public meetings, fact sheets and messaging to target audiences that include residents, municipalities, recreationists, yacht clubs, marinas, etc. NYSDEC is planning to hold biannual public stakeholder meetings to provide updates on the project as it progresses. An early summer meeting would outline the plan for the coming season, and an end of year meeting would provide the results of the treatment and monitoring conducted by the contractor. The project webpage on the DEC website will be updated regularly with information from the project and will provide resources for residents, municipalities, and

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<sup>9</sup> The upstream watershed for the Croton River is 375 square miles. While the New Croton Reservoir regulates flows in the river to some degree, average annual flows can exceed 1,000 cubic feet per second (cfs), and individual storms can result in flows exceeding 10,000 cfs, resulting in large flows over the spillway and into the river.

environmental stakeholders. Annual reports, work plans, water quality monitoring data and survey results will be made available via the project webpage. Overall, the public outreach for the Croton River project has been well-received (Willow Eyres, personal communication, November 17, 2017).

## **CAYUGA INLET**

In the summer of 2011 hydrilla was found infesting 166 acres in the Cayuga Inlet, which drains to Cayuga Lake's southern end in Ithaca, New York. The following provides a summary of the hydrilla management conducted between 2011 and 2015 as described in the annual management reports (Cornell Cooperative Extension 2016a).

Subsequent to the hydrilla discovery, a Hydrilla Task Force was formed to:

- Research the risks posed by hydrilla and the possible responses;
- Collaborate with agencies at all levels of government and other interested parties;
- Provide recommendations to the entities that could carry out actions; and
- Conduct extensive outreach and education in the Cayuga Lake Watershed.

The task force decided on a goal of eradication from the Cayuga Inlet. An herbicide approach was selected, and stakeholders acted quickly to obtain permits in 2011 to conduct an initial herbicide application using endothall-based Aquathol K.<sup>10</sup> The City of Ithaca restricted access to the inlet area during treatment, and water monitoring was conducted in the vicinity until endothall levels were undetectable. Monitoring was also conducted at the Bolton Point water intake (located 2.5 miles north of the Cayuga Inlet) as a precaution. As required by the label, no application was conducted within 600 feet of drinking water intakes.

After the herbicide application permits were obtained, additional hydrilla was identified outside of the treatment areas. Diver-assisted suction harvesting (DASH) was selected to address these areas. Post removal follow up determined that DASH removal was not effective for hydrilla management in the Cayuga Inlet. DASH efforts resulted in considerable hydrilla fragmentation and increased turbidity, increasing the risk of hydrilla spread and creating difficult working conditions for the diver crew. However, the task force still includes hand pulling as one of its options, and plans to continue to use it for small infestations where fragmentation can be prevented.

Prior to the 2012 growing season, researchers and resource managers from across the country with extensive knowledge on hydrilla, along with representatives from herbicide manufacturers, were consulted to provide information to revise the Cayuga Inlet treatment plan. After taking into consideration local site conditions (flow, temperatures, light, water quality, etc.), a dual herbicide approach (endothall and fluridone) was selected. The dual herbicide application was selected to ensure treatment across potential asynchronous hydrilla tuber growth patterns and reduce the risk of developing herbicide resistance. Endothall was applied once, while fluridone was applied as a sustained liquid application, supplemented with the addition of pellets in areas that had low mixing with the main channel. Monitoring was used to manage chemical concentrations throughout the inlet vicinity.

Dual herbicide treatment was continued in 2013, 2014 and 2015 with modifications to treated area as new populations were identified. Additionally, treatment concentrations were refined based on experience from prior year treatments. When hydrilla infestations were

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<sup>10</sup> Aquathol K uses potassium endothall, which is less toxic to fish than amine endothall.



discovered outside of treated areas, benthic mats were used to suppress growth and prevent further spread, and the areas wrapped into the treatment area in subsequent years.

Throughout the process, stakeholders conducted substantial outreach to generate support for the hydrilla management plan. Outreach consisted of flyers, website, public meetings, information booths at the farmers market and workshops. Public cruises provided by the Floating Classroom provided a venue for updates on the eradication effort. Members of the task force and other stakeholder organizations (Cayuga Lake Watershed Network and the Cornell Cooperative Extension of Tompkins County) gave media interviews (print, radio, and TV), prepared press releases, responded to individual stakeholder concerns and prepared position statements for regulatory/agency staff and articles for news outlets.

An upcoming consideration will be preventing the spread of hydrilla during channel dredging operations needed for navigation. The plan currently being designed will include the use of geotubes to filter out hydrilla fragments and turions (Cornell Cooperative Extension 2016a).

## **DELAWARE AND RARITAN CANAL**

The Delaware and Raritan Canal (D&R Canal) is a manmade waterway that connects the Delaware and Raritan rivers in New Jersey. The New Jersey Water Supply Authority is responsible for maintaining a dependable supply of water throughout the 60-mile canal. The Authority has nine Canal customers with intakes used for irrigation, drinking water and process water. Nuisance aquatic plant growth inhibits the natural flow of water through the Canal and requires active aquatic plant management. In July 2016, hydrilla was discovered during routine aquatic plant management via mechanical removal. It was decided that the extent of the hydrilla needed to be assessed prior to determining the appropriate management strategies. Submerged aquatic plant mapping was conducted by a consultant in September 2016, which documented hydrilla occurring at over 56% of the sample sites in 18 miles of the Canal. The following provides a summary of hydrilla management approaches as documented in the D&R Canal Submersed Aquatic Vegetation Management Plan (SOLitude Lake Management 2017).

The New Jersey Water Supply Authority determined that rapid expansion of hydrilla and shallow canal depths require management to maintain flows through the canal. The canal is regionally important and could become a source for further spread in New Jersey, where hydrilla is not currently widespread. The New Jersey Water Supply Authority conducted a comprehensive review of physical/mechanical, biological, and chemical options to determine the best approach for the D&R Canal. [Table 2](#) provides a summary of the findings from that review.

In 2017, a team of experts assembled by the New Jersey Water Supply Authority determined that a low dose injection of fluridone was the most effective SAV control method to target hydrilla for the D&R Canal. Many factors were considered during the formulation of the SAV Management Plan, including:

- A review of other large-scale Northeast hydrilla control programs (Cayuga Inlet (New York), Erie Canal (New York), the Croton River (New York), as well as a program in the Eno River (North Carolina)
- A review of water use restrictions for low dose fluridone in the D&R Canal
- Several site visits to the D&R Canal by the consultant and team of experts
- A review of the water flow throughout the D&R Canal

- A rhodamine dye study conducted in April 2017 to simulate the movement of an herbicide throughout the D&R Canal
- Bench tests of herbicide residual removal at all four of the water treatment plants that could potentially pull water from the Canal for potable drinking
- An extensive review of other submerged aquatic plant control programs and their applicability to the D&R Canal

The SAV Management Plan was developed to be adaptive; the results from the prior years' actions reviewed to determine changes to the SAV plan and selected control programs for the following year. The initial treatment plan targeted a rate of 4 ppb at the point of injection, which was planned to flow through the treatment area and maintain concentration in the range of 1.7 to 2.3 ppb. The drinking water intakes are located 11 to 26 miles downstream of the fluridone treatment area. Bench tests were conducted to identify the potential removal efficiencies for processes employed at each drinking water treatment plant. Results of the jar tests were used to develop target concentrations during fluridone treatment and to inform dose alteration in the event that weekly monitoring results indicated fluridone concentrations were too high. Results from the first year of fluridone application indicated that full-scale treatment was found to correlate well with jar test results (Heather Desko, personal communication, 11/17/17).

**Table 2**  
**Summary of aquatic plant control options considered for hydrilla in the D&R Canal**

<b>Option</b>	<b>Determination for the D&amp;R Canal</b>	<b>Comments</b>
1) Benthic Barriers	Limited Applicability	Possibly viable once size of infestation is significantly reduced
1.a) Porous or loose weave synthetic materials	Limited Applicability	Growth can occur through pores in fabric
1.b) Non-porous or sheet synthetic materials	Limited Applicability	Possibly viable once size of infestation is significantly reduced
1.c) Sediments of a desirable composition	Not Applicable	Applying sediment to cover hydrilla would reduce canal volume
2) Dredging	Limited Applicability	Too expensive for just aquatic plant control
2.a) "Dry" excavation	Not Applicable	Canal cannot be dewatered
2.b) "Wet" excavation	Limited Applicability	Too expensive for just aquatic plant control
2.c) Hydraulic (or pneumatic) removal	Limited Applicability	Too expensive for just aquatic plant control
3) Dyes and Surface Covers	Not Applicable	Flowing water not suitable for dyes
4) Mechanical Removal ("harvesting")	Limited Applicability	Need to manage fragmentation
4.a) Hand pulling	Limited Applicability	Need to manage fragmentation
4.b) Cutting (without collection)	Not Applicable	Not applicable due to fragmentation
4.c) Harvesting (with collection)	Limited Applicability	Need to manage fragmentation
4.d) Rototilling	Not Applicable	Not applicable due to fragmentation

(continued)



**Table 2 Continued**

<b>Option</b>	<b>Determination for the D&amp;R Canal</b>	<b>Comments</b>
4.e) Hydroraking <sup>11</sup>	Applicable	Need to manage fragmentation
5) Water level control	Not Applicable	Not applicable due to flow requirements in canal
5.a) Drawdown	Not Applicable	Not applicable due to flow requirements in canal
5.b) Flooding	Not Applicable	Not applicable due to flow requirements in canal
6) Herbicides	Applicable	Varies by specific herbicide
6.a) Forms of copper	Limited Applicability	Impacts to sensitive trout species
6.b) Forms of diquat	Limited Applicability	Limited experience in the Northeast
6.c) Forms of glyphosate	Not Applicable	Hydrilla not controlled by glyphosate
6.d) Endothall	Applicable	Effective control, but alternative drinking water supply operations require further review
6.e) Fluridone	Applicable	Disadvantages can be managed for effective hydrilla control
6.f) triclopyr	Not Applicable	Hydrilla has low susceptibility
6.g) flumioxazin	Limited Applicability	Better control options available
6.h) Bispyribac-Sodium	Not Applicable	Limited experience in the Northeast
6. j) Imazamox	Not Applicable	Use restrictions are a limiting factor
7) Biological introductions	Not Applicable	Varies by specific organism
7.a) Herbivorous fish	Not Applicable	NJ Dept of Fish and Wildlife will not permit grass carp
7.b) Herbivorous insects	Not Applicable	Not commercially available.
7.c) Fungal/bacterial/ viral pathogens	Not Applicable	Not commercially available.
7.d) Selective plantings	Not Applicable	Would inhibit water flow.

*Source:* Modified with permission from SOLitude Lake Management 2017, originally based on Wagner 2004.

## **TONAWANDA CREEK/ERIE CANAL**

Hydrilla was identified in an approximately 15-mile section of Tonawanda Creek/Erie Canal near Buffalo, NY in the late summer of 2012. Based on monitoring and delineation during 2013, along with interagency discussions, a plan to conduct herbicide treatment in 2014 was devised (Figure 4). The proximity of the infestation to the Niagara River and the potential for further spread of hydrilla through the canal to numerous key waterbodies across New York and to the Great Lakes were primary factors that drove the decision to initiate the control project.

An important consideration for herbicide treatment in the canal was that during the growth season, when herbicides would need to be applied, typical flow rates are 400 to 800 cubic feet per

<sup>11</sup> Hydroraking is the typical method to manage aquatic plant growth and maintain flows through the canal. However, because hydroraking spreads hydrilla, the NJ Water Supply Authority will avoid hydroraking in hydrilla infested areas, unless needed on an emergency basis to maintain canal flows.

second (cfs). Water exchange rates would be too high at these flow rates for adequate herbicide contact time. However, the NYS Canal Corporation was able to reduce flow rates for a period of 48 hours to facilitate treatment operations. Given the short window of time, a fast-acting endothall-based herbicide, Aquathol K, was selected. Drinking water intakes on the Niagara River, downstream of the Tonawanda Creek confluence, were outside of the 600-foot restriction required for endothall application. The treatment plan consisted of treating approximately seven miles of the canal (213 acres) with endothall at a concentration of 1.5 mg/L (ppm). Tuber monitoring operations identified the period between late June to late August as being the optimal time for herbicide application (i.e., after tubers had sprouted but before new tubers had formed). Tuber monitoring also indicated that sprouting was generally synchronous with 90% or more of the tubers sprouting within the mid- to late- summer. This enabled treatment to occur once during the growing season and have a significant effect on the infestation (Netherland et al. n.d.). Large scale treatment has been effective over the past four years, and treatment is shifting to evaluating effective methods for treating isolated patches of hydrilla within the creek/canal (Great Lakes Hydrilla Collaborative 2018).



*Source:* Kornacki et al. 2014.

**Figure 4 Herbicide application in the Erie Canal, North Tonawanda, NY, July 2014**

## **TIDAL POTOMAC RIVER**

In the early 1980s, hydrilla had become established and spread across approximately 2,000 acres of shallow area within the tidal freshwater portion of the river. The infestation resulted in navigational difficulties in these areas that prompted the State of Maryland and Commonwealth of Virginia to request the US Army Corps of Engineers (USACE) to conduct an analysis of control options to prevent further spread. A series of planning objectives were developed to guide the plan formulation process. The primary objective was to control existing and future growth of hydrilla in public high use areas (e.g., marinas, major navigation channels, watercraft launch areas and waterfront parks or concentrations of residential development) along the Potomac River. Further, it was a goal to maintain the natural balance of plants in the aquatic environment and encourage

the health of the Potomac River and Chesapeake Bay by minimizing the impact of control operations on native SAV.

The USACE developed an Environmental Impact Statement (EIS) that included consideration of physical/mechanical controls (benthic mats, harvesting, rototilling, dredging and hand pulling), biological controls (grass carp) and chemical controls (diquat, endothall, fluridone and copper complexes). The two preferred alternatives from the analysis were mechanical harvesting and chemical control with diquat (US Army Corps of Engineers 1986). Mechanical harvesting was considered beneficial by providing an immediate removal of vegetation to open river access. It was recognized that mechanical harvesting benefits would be temporary and that the risk of further spread by fragmentation was an issue. Grass carp were ruled out because of impacts to native SAV. At the time endothall and fluridone were not labeled for use in flowing waters, and the toxicity of copper complexes on fish were determined to result in unacceptable impacts to Potomac River fisheries. Diquat was determined to be the only available and effective herbicide for hydrilla control in the Potomac River. However, there was concern that the river flows and tidal movement of water would make it difficult to apply herbicides to target hydrilla and not impact sensitive native SAV.

The USACE ultimately selected mechanical harvesting for implementation and elected to conduct further studies on the effectiveness of diquat on hydrilla in the Potomac River. The USACE has continued to conduct selective mechanical harvesting of hydrilla on a small scale to maintain recreational access in specific areas and has not used herbicides. As expected, hydrilla has continued to spread; however, studies have shown that hydrilla has been a benefit by increasing the SAV coverage in the tidal Potomac River without displacing the native SAV populations (Rybicki and Landwehr 2007).

While there are no drinking water intakes in this section of river, this case study was included as it was the only example identified where large scale hydrilla management was not selected. Unlike reservoirs and smaller rivers or streams, the tidal Potomac River has a watershed of approximately 12,000 square miles and average flows of approximately 9,000 cfs. The depth, flow rates, tidal fluctuation and turbidity are all believed to limit hydrilla habitat across much of this section of river. While hydrilla has extended into a number of the Chesapeake Bay tributaries in Virginia, none of the occurrences were attributed to the presence of hydrilla in the Potomac River.

## **NEW CROTON RESERVOIR HYDRILLA MANAGEMENT ASSESSMENT**

As part of this project, an assessment of hydrilla management options for DEP's New Croton Reservoir is included as a guide for other utilities. The New Croton Reservoir is owned and operated by DEP and is formed by impounding the Croton River. It is the terminal reservoir of the Croton System and receives water from eleven other Croton System reservoirs. The Croton System typically supplies approximately 10 percent of NYC's drinking water demands. However, during drought or other conditions, the Croton System yield is sufficient to meet up to 30 percent of the City's demand. All water diverted from New Croton Reservoir by DEP flows to the Croton Water Filtration Plant (WFP) via the New Croton Aqueduct. Spills and releases from the reservoir continue down the Croton River to the Hudson River.

Located in Westchester County, New York, the reservoir is approximately 22 miles north of New York City. It has a surface area of approximately 2,100 acres, a maximum depth of 120 feet and 19 billion gallons of storage capacity. The reservoir is relatively long and serpentine, stretching for approximately eight miles with 34 miles of shoreline. DEP owns the property surrounding the reservoir and controls access to the reservoir. A permit is required for individuals to fish from the shore or from registered, non-motorized boats, which are required to stay onsite. Swimming is not allowed in the reservoir. The reservoir supports numerous fish species and is popular for recreational fishing. The reservoir supports a warm and cool water fishery with large and small mouth bass, chain pickerel, yellow and white perch, black crappie, bullfish, and sunfish predominating. The reservoir itself is not stocked, but its upstream tributaries are stocked with trout.

The water quality classification for the reservoir is Class AA throughout its entire length, which indicates the highest and best use of the reservoir is for drinking water. DEP operates the only drinking water intakes, one of which is located at the dam and the second is located approximately three miles upstream of the dam. The elevation of the reservoir at full pool is 196 feet above sea level. The reservoir is generally kept within two feet of full pool, except during drought conditions and excessive run-off causing the reservoir to spill. The drinking water intakes are located at the upper release (166 ft. elevation above sea level) and lower release (116 ft. elevation above sea level). In addition to the DEP Croton WFP, the Village of Ossining uses the New Croton Reservoir as its primary source of water for its Indian Brook Water Treatment Plant (WTP). Ossining's intake is a tap off the DEP intake at the dam. New Castle's Millwood WTP has a full backup connection to the New Croton Aqueduct between the reservoir and the Croton WFP. A few other local municipalities (Tarrytown, Sleepy Hollow, Ardsley) may still have connections to New Croton Aqueduct, but cannot currently use them because they are not connected to their respective treatment plants. In addition to direct connections, the Village of Croton-on-Hudson has a wellfield along the Croton River downstream of the New Croton Reservoir.

Treatment processes employed at the Croton WFP include stacked dissolved air floatation and filtration with anthracite/sand dual media filter. The filtered water is then disinfected with UV and chlorine. After treatment, the water is dosed with orthophosphate for corrosion control and hydrofluorosilicic acid to add fluoride. Water flows from the treatment plant to Jerome Park Reservoir prior to entering the distribution system for the City.

DEP's reliance on the Croton System will increase in the next few years as DEP implements a series of construction projects that will take portions of the Catskill and Delaware systems

offline.<sup>12</sup> DEP will be shutting down the Catskill Aqueduct for three 10-week periods over a period of 3 years, currently planned for 2018 to 2020. These 10-week shutdowns are required to facilitate the repair and rehabilitation of the Catskill Aqueduct and would generally take place between October and December to coincide with the lowest water demand period of the year. Beginning in October 2022, DEP is planning to shut down the Rondout-West Branch Tunnel, which conveys water to the City from the Delaware System, for a period of eight months to connect a new bypass tunnel. Each of these shutdowns will take a substantial portion of the NYC water supply offline, requiring the Croton WFP to operate up to its maximum rate of 290 mgd. DEP anticipates the Croton WFP will need to remain online continuously, beginning in the spring of 2018 through the completion of the shutdowns in approximately 2023.

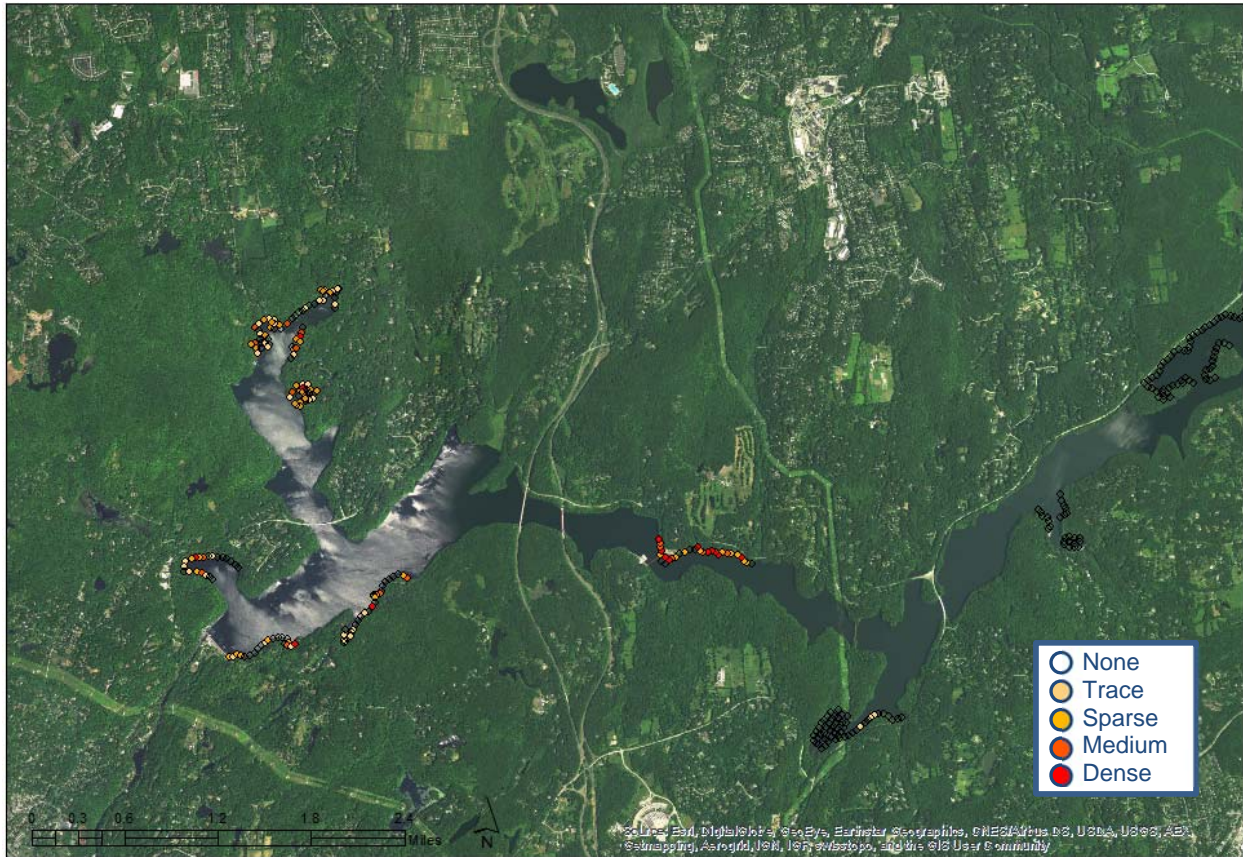
The Village of Ossining's Indian Brook WTP uses the New Croton Reservoir for the majority of its water supply. The treatment processes employed at the plant include coagulation, flocculation, dual media filtration, corrosion control and chlorination. The Town of New Castle's Millwood WTP has a backup connection to the New Croton Aqueduct below the reservoir. The Millwood WTP employs coagulation, flocculation, dissolved air flotation, ozone, dual media filtration, corrosion control and chlorination.

After its discovery in the Croton River below the New Croton Reservoir, hydrilla was identified in the reservoir itself in October 2014. The largest infestation is in proximity to a DEP boat launch that is not open to the public. DEP installed small-scale benthic barriers around the boat launch in 2015 and 2016 to limit its spread, while further study was underway. Surveys of the reservoir in 2016 by SOLitude Lake Management revealed populations of hydrilla at a number of locations within the reservoir (Figure 5). Overall, the survey indicated that approximately 33% of the surveyed sites had hydrilla present, ranging from sparse to dense. Preliminary results from a more widespread survey in 2017 indicated the presence of hydrilla in areas not previously surveyed. DEP's primary goal is to protect public health and the environment, which requires protecting the integrity of the water supply system. DEP reviewed the available options and potential risks from hydrilla to formulate a plan to address the hydrilla infestation in New Croton Reservoir.

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<sup>12</sup> The Catskill System typically provides approximately 40 percent of the City's daily water supply, and the Delaware System typically provides approximately 50 percent of the City's daily water supply.





Source: Courtesy of NYCDEP.

**Figure 5 New Croton Reservoir hydrilla survey results from 2016**

### NO ACTION ALTERNATIVE

Based on Secchi depths for New Croton Reservoir, hydrilla could potentially become established in water depths up to 15 to 30 feet (Hoyer and Canfield 1997). While much of the reservoir is deeper, approximately 400 to 1200 acres (19 to 55%) of reservoir surface area has depths within this range. Without management, as described previously, hydrilla can be expected to colonize a large portion of the reservoir. Water supply impacts from an extensive hydrilla infestation in New Croton Reservoir will consist of increased NOM and potential spikes in disinfection byproducts annually when the plants die back. Sufficient vegetation may enter the intake to clog screens and treatment plant equipment. Natural resources impacts would be anticipated to include a reduction in fish biomass over time (Langeland 1996).

Perhaps of greatest concern is that, without action, the hydrilla infestation at New Croton Reservoir would become a source of spread and re-infestation across the region. At highest risk is the downstream Croton River, which would receive the bulk of hydrilla fragments each year. This influx of viable fragments would severely impact current management efforts to remove hydrilla from the Croton River to prevent further spread into the Hudson River downstream. The upstream Muscoot Reservoir would also be at high risk. Muscoot Reservoir is immediately upstream of New Croton Reservoir and is only separated by a low dam that is often submerged (Figure 6).<sup>13</sup> Unlike

<sup>13</sup> While the predominant flow path is downstream, winds can push water upstream, facilitating the spread of floating fragments.

New Croton Reservoir, Muscoot reservoir is shallow with a maximum depth of 30 feet. Once established in Muscoot Reservoir, hydrilla could potentially colonize nearly 100% of the reservoir surface area. All water from the Croton System must flow through Muscoot Reservoir to be available to DEP for water supply. A substantial hydrilla infestation in Muscoot Reservoir could obstruct flows through the reservoir, resulting in water supply problems for DEP. Uncontrolled, hydrilla would be expected to continue to spread through the Croton System, compounding water supply and ecological impacts in the watershed. While not in the same watersheds, New Croton Reservoir is less than ten miles from Kensico Reservoir, the terminal reservoir for the unfiltered Catskill and Delaware systems. Impacts to the NYC water supply system from hydrilla infestation in Kensico Reservoir would be more severe because the system typically provides 90% of the City's supply and is unfiltered, limiting control options for water quality impacts. Possible routes for the movement of hydrilla from the Croton System to Kensico Reservoir include accidental spread by recreational users, waterfowl vectors and system interconnections.<sup>14</sup> In conclusion, there are substantial risks to the water supply system from hydrilla in New Croton Reservoir. Impacts to the water supply system and its many regional benefits will only grow as the infestation continues to spread.



*Source:* NYCDEP 2018.

**Figure 6 Muscoot Dam**

## **PHYSICAL, MECHANICAL, AND BIOLOGICAL CONTROL OPTIONS**

Because of the risk of spreading via fragmentation, mechanical methods for hydrilla control are not viable. Reservoir drawdown conducted at other reservoirs has been shown to be ineffective

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<sup>14</sup> Delaware System diversions mix with water in the Croton System West Branch Reservoir under certain operational conditions, and there are interconnections between the Croton System and the Delaware Aqueduct at Croton Falls and Cross River reservoirs that are used in emergency situations.

for hydrilla, and long-term drawdown in New Croton Reservoir needed for hydrilla control is infeasible.<sup>15</sup> Biological control with grass carp at New Croton Reservoir is not allowable by state regulators, and is was not an option (NYSDEC 2017b). Given the large-scale extent of hydrilla in New Croton Reservoir, benthic barriers and hand pulling would be cost-prohibitive across the full extent of the infestation. Once the majority of the hydrilla infestation has been eradicated, benthic barriers and hand pulling may prove effective for managing hydrilla long-term, but the current infestation is too extensive for these measures to be feasible and cost-effective.

## **HERBICIDES AVAILABLE FOR HYDRILLA CONTROL APPLICATIONS IN NEW YORK**

There are numerous potential herbicide options available for aquatic plant management in New York. While EPA has the authority to register pesticides and set application restrictions, NYSDEC is responsible for permitting pesticide use within the state. In New York State, most projects or activities proposed by a state agency or unit of local government, and all discretionary approvals (permits) from a NYS agency, require an environmental review under the State Environmental Quality Review Act (SEQRA) to determine if an environmental impact assessment (EIS) is required. A Generic Environmental Impact Statement on Aquatic Vegetation Management (GEIS) was completed in 1981 satisfying EIS requirements for the issuance of Article 15 Aquatic Pesticide Permits for all the aquatic herbicide active ingredients registered for use in waters of the State at the time. Supplemental Environmental Impact Statements (SEIS) were subsequently submitted for additional herbicides. Currently, the following herbicides are allowed for aquatic applications in New York: 2,4-D, copper sulfate, diquat, endothall, fluridone, glyphosate, hydrogen peroxide, imazamox and triclopyr. The text below summarizes screening for applicability of each herbicide for New Croton Reservoir.

- 2,4-D - Blackburn and Weldon (1970) found 2,4-D to have limited effectiveness for hydrilla control and (IFAS 2017a) listed 2,4-D control of hydrilla as variable. However, both resources are related to dioecious hydrilla, no documentation of treatment for monoecious hydrilla was identified. 2,4-D was removed from further consideration due to limited information on the effectiveness for monoecious hydrilla.
- Copper complexes - Previously used for monoecious hydrilla (True-Meadows et al. 2016). Copper can be used either by itself or as a mixture with diquat or endothall. However, application rates may be too high for hydrilla control, because the maximum application rate for copper is 200 ppb in class AA waters per 6 NYCRR 703.5 (NYCRR n.d.) surface water quality standards. Copper complexes were removed from further consideration due to limited effectiveness for hydrilla at maximum allowable rates in New York.
- Diquat - Previously used for monoecious hydrilla (True-Meadows et al. 2016). However, not effective by itself, must be mixed with either endothall or copper. Max application rate of diquat is 20 ppb per 6 NYCRR 703.5 surface water quality standards. Label restrictions require no use for drinking water for three days following treatment

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<sup>15</sup> The upstream watershed is approximately 375 square miles. While DEP has control over releases, there is no bypass around the reservoir, so there would be no way to maintain the reservoir in a drawdown state under typical hydrologic conditions.



and there is a MCL of 20 ppb for drinking water. Diquat removed from further consideration due to restrictions on use in sources of drinking water.

- Endothall - Previously used for monoecious hydrilla (True-Meadows et al. 2016) and has a precedent for use in New York in Erie Canal and Cayuga Inlet. Endothall products cannot be applied within 600 feet of drinking water intakes and there is a drinking water MCL of 0.1 ppm (100 ppb).
- Fluridone - Previously used for monoecious hydrilla (True-Meadows et al. 2016) and has a precedent for use in New York in Croton River and Cayuga Inlet. Fluridone application rates are restricted to less than 20 ppb within ¼ mile of potable drinking water intakes.
- Glyphosate - Glyphosate is not recommended for hydrilla (Wagner 2004) and is removed from further consideration.
- Hydrogen peroxide - Hydrogen peroxide is only approved for use as a fungicide and algacide in New York per the SEIS and is removed from further consideration.
- Imazamox - There are limited studies on the effectiveness of imazamox on monoecious hydrilla. Getsinger et al. (2011) found good control of monoecious hydrilla at application rates up to 200 ppb at one to three months after treatment, but recommended additional studies to confirm observations and evaluate improvements from mixing imazamox with a contact herbicide. Label restrictions on imazamox limit application rates to less than 50 ppb within ¼ mile of potable drinking water intakes. Imazamox removed from further consideration due to limited information on the effectiveness for monoecious hydrilla and restrictions on use in sources of drinking water.
- Triclopyr – Few sources of information were identified indicating triclopyr for hydrilla management. The SEIS for triclopyr indicates it provides a medium level of control for hydrilla, but there was no distinction made for biotype. Label restrictions for triclopyr limit concentrations to less than 50 ppb within ¼ mile of drinking water intakes. Triclopyr removed from further consideration due to limited information on the effectiveness for monoecious hydrilla and restrictions on use in sources of drinking water.

Based on the combination of regulatory constraints in New York and documented herbicide effectiveness for monoecious hydrilla, endothall- and fluridone-based herbicides appear to be the best available options for chemical control of hydrilla in New York for sources of drinking water. There may be specific instances that might favor other options, such as low-level copper or diquat with endothall, but these formulations require consultation with a licensed herbicide applicator. Further, aquatic herbicide development is an active area of research, and additional information may become available over time that eases current restrictions or demonstrates increased effectiveness for available herbicides. As described previously, there are a number of other herbicides approved by EPA, but not currently allowed in New York and/or with limited testing on monoecious hydrilla. These options may become available to DEP in the future, at which time should be considered to determine their potential efficacy for New Croton Reservoir.

A detailed comparison of the two available options for New Croton Reservoir is provided below.

## **Endothall**

Two types of endothall are available, potassium and amine. The potassium endothall, sold as Aquathol K, is considered for New Croton Reservoir because of its prior use in New York for hydrilla control and lower toxicity to fish and aquatic invertebrates as compared to amine endothall (Wisconsin DNR 2012). Typical application rates referenced in literature for hydrilla control range from 1.5 to 5.0 ppm. Endothall is fast-acting, for example contact time at 1.5 ppm for the Erie Canal treatment was 48 hours. Endothall breaks down by microbial degradation and is faster in warmer conditions and slower in cooler conditions. The half-life averages five to ten days, with complete degradation within 30 to 60 days (Wisconsin DNR 2012). Endothall is effective on plants with one treatment per season, unless sprouting occurs again later in the season, in which a second treatment is needed to address the second round of tuber sprouting during the growing season.

Endothall cannot be applied within 600 feet of active drinking water intakes due to the EPA MCL of 0.1 ppm. Therefore, the Croton intake would need to be shut down, or a second herbicide employed, to address infestations around the intake locations. These precautions should be sufficient to protect drinking water quality, but to provide a treatment barrier for endothall, DEP would need granular activated carbon, which has been identified as the best available treatment technology (EPA 2009). Chamberlain et al. (2011) found the degradation potential of endothall to be low (less than 20%) for typical water treatment oxidation chemicals (free chlorine, monochloramine, chlorine dioxide, hydrogen peroxide, ozone, and permanganate) and UV treatment.

While there are risks from inhalation and dermal contact, from a drinking water perspective, the 2015 EPA Human Health Risk Assessment for endothall (EPA 2015) determined the following:

- Acute toxicity is low for ingestion;
- Endothall is classified as "not likely to be carcinogenic to humans;"
- It has no mutagenic potential; and
- There is no evidence of neurotoxicity, developmental or reproductive toxicity.

The primary effect from ingestion is the formation of stomach lesions. The short-term/chronic oral NOAEL was listed as 9.4 mg/kg/day (EPA 2015). At the MCL of 0.1 ppm, it would require a daily intake of 5,600 liters of water for an adult and nearly 1,000 liters of water for a child to reach the NOAEL. Typical daily drinking water intake is one to four liters, resulting in a factor of safety of approximately 1,000 or more for endothall ingestion from drinking water.

The ecological toxicology impacts have been reviewed by the Washington State Department of Ecology as part of its Final Impact Assessment. The findings from that study indicated endothall would not affect aquatic biota acutely or chronically when applied at concentrations less than 5.0 mg dipotassium endothall salt/L recommended on the label.

## **Fluridone**

Typical application rates for hydrilla treatment with fluridone range from 2 to 4 ppb, which is well below the label limit of 20 ppb within ¼ mile of drinking water intakes and the NYS MCL of 50 ppb. While much lower than endothall, treatment must be maintained for much of the growing season (45 to 80 days) to get sufficient contact time for effective control. Additionally, the degradation of fluridone is slower with a half-life of 20 to 50 days.

The 2004 EPA Health Risk Assessment for Fluridone (EPA 2004) determined the following:

- The acute toxicity of fluridone is moderate to low;
- Fluridone was negative for inducing mutations in all guideline studies of the standard mutagenicity tests;
- No neurotoxicity was reported in any of the studies; and
- Fluridone did not significantly affect any of the reproductive parameters.

The drinking water NOAEL was listed as 15 mg/kg/day for short/intermediate term and chronic exposure (EPA 2004). At a treatment level of 4 ppb, it would require a daily intake of 225,000 liters of water for an adult and over 35,000 liters of water for a child to reach the NOAEL. Typical daily drinking water intake is one to four liters, resulting in a factor of safety of approximately 35,000 to 50,000 or more for fluridone ingestion from drinking water. Further, the fluridone SEIS conducted for registration in New York found no adverse public health impacts from fluridone application at rates less than 50 ppb.

Fluridone does not have an established best available treatment technology. Further, little to no specific data was identified in the literature that determined treatment efficacy for typical water treatment processes. The following provides a brief overview of the potential for removal of fluridone from water based on available literature.

### ***Chlorine Disinfection***

No studies were identified that assessed chlorine treatment of fluridone. Croton River monitoring in 2017 detected fluridone in some of the Croton-on-Hudson wells at a concentration of 1 to 1.4 ppb, but measured reduced levels of 0.4 to 0.8 ppb in the distribution system (NYSDEC 2017c). The village only treats the well water with chlorine (Croton-on-Hudson 2017). While these results indicate there could be some fluridone degradation by reaction with chlorine, there could be other factors that affected the fluridone concentrations.

### ***Other Oxidants***

Chamberlain et al. (2011) evaluated the degradation potential of 62 pesticides and herbicides from typical water treatment oxidation chemicals (free chlorine, monochloramine, chlorine dioxide, hydrogen peroxide, ozone, and permanganate). While fluridone was not included, the majority of the pesticides evaluated in the study exhibited low (less than 20%) removal. However, some pesticides did experience medium (20% to 50%) or high (greater than 50%) removal for various oxidants. There were no clear trends in the data, but ozone (O<sub>3</sub>) tended to provide better removal for many, but not all compounds. Based on the variation of removal efficacy between different pesticides and oxidants, additional study is needed to identify the specific reactivity of fluridone to water treatment oxidants.

### ***Advanced Oxidation Processes (AOP)***

AOP is a set of processes designed to oxidize organic compounds through the creation of hydroxyl radicals. No information was identified in the literature search related to the effectiveness of AOP on fluridone.

### ***Ultraviolet Light (UV)***

No studies were identified that assessed UV treatment of fluridone in a drinking water treatment context. However, photolysis is the primary mode of degradation of fluridone. Mossler et al. (1989) determined the change in half-life of fluridone due to different wavelengths of UV radiation and found that wavelengths in the range of 297 to 325 nm had more rapid degradation than wavelengths above approximately 350 nm.

The Croton UV system is designed for disinfection to target *Giardia*. The UV reactors are low-pressure high-output (LPHO) and operate at a wavelength of 254 nm. Prior studies indicate fluridone photolysis occurs at the UV B range of 280 to 315 nm, which is outside the range of the Croton UV system. Additionally, the exposure time in the UV facility is on the order of seconds, not hours needed per Mossler et al. (1989). Without further information, no treatment can be assumed for fluridone from UV disinfection systems.

### ***Granular Activated Carbon***

Activated carbon can bind with herbicides (Sun et al. 2011). However, no studies were identified that quantified removal rates using commercially available granular and powdered activated carbons used in water treatment plants. The utilities that use the D&R Canal as a source of supply conducted jar tests to simulate fluridone removal during typical treatment processes. Further, the plants monitored fluridone at their intakes and following treatment during the fluridone application in the canal during 2017. As is typical with activated carbon treatment of synthetic organics, the level of removal varies based on type of carbon, dosage rate, contact time, background water quality and other factors. Results have not been published, but, as stated previously, full-scale treatment was found to correlate well with jar test results for the utilities using the D&R Canal as a source of supply (Heather Desko, personal communication, 11/17/17).

### ***Sedimentation, Flocculation, Filtration***

The organic carbon partition coefficient ( $K_{oc}$ ) for fluridone is 260 to 740  $\text{cm}^3/\text{gm}$  (EPA 2004), which is indicative of low to moderate soil adsorption (NCBI 2017). Some removal of fluridone, therefore, may occur in turbid waters as particles are removed from the water column via sedimentation, flocculation, and filtration.

### ***Aeration***

Volatilization from water surfaces is not expected to be an important fate process based upon estimated Henry's Law constant for fluridone (NCBI 2017).

### ***Ozone with Biologically Active Filtration***

Ozone with biologically active filtration ( $\text{O}_3/\text{BAF}$ ) uses ozone to break down organic matter and has a granular filter that is primed with living organisms to consume organic matter. Activated carbon is a typical media for  $\text{O}_3/\text{BAF}$ . There is no data available as to the effect of ozone on fluridone. Further, it is difficult to determine whether the  $\text{O}_3/\text{BAF}$  microorganisms would acclimate to fluridone as a source of carbon over time. The activated carbon filter bed is not expected to provide substantial removal, as it is not optimized for synthetic organic removal in

O<sub>3</sub>/BAF. Unless O<sub>3</sub> is determined to be reactive with fluridone, O<sub>3</sub>/BAF is not expected to achieve any greater removal than that of a typical granular media filter.

### ***Impacts***

From an ecological toxicology perspective, a number of independent toxicological assessments have ranked fluridone as being relatively low risk when following label instructions (ENSR International 2005; Durkin 2008). Wagner et al. (2017) reviewed the impacts of low dose fluridone treatment across 64 lakes over 20 years of treatment for Eurasian Watermilfoil. The findings indicated short-term impacts on non-target aquatic plants and aquatic plant species richness, but that most species recovered within one or two years. The fluridone SEIS conducted for registration in New York determined no adverse impacts based on label application rates. The California Division of Boating and Waterways (CADBW) uses fluridone to control invasive aquatic plants in the Sacramento-San Joaquin Delta, which is home to numerous threatened and endangered fish species. CADBW develops environmental impact reports of its submersed aquatic invasive species control program approximately every five years (CADBW 2012). The plans are reviewed for concurrence by the USFWS and National Marine Fisheries Service to ensure no impacts to threatened and endangered species or critical habitat (Jeff Caudill, personal communication, 11/13/17).

### **NEW CROTON RESERVOIR HYDRILLA WORKSHOP**

In addition to the review in this report, a workshop was held on November 17, 2017 with outside experts and case study representatives to review the options under consideration for hydrilla control by DEP and identify potential risks to the water supply system from hydrilla and hydrilla management. DEP had preliminarily selected fluridone as the preferred option for treatment of the New Croton Reservoir due to the lesser restrictions on application near drinking water intakes and to be consistent with the treatment determined by NYSDEC for the Croton River. As such, there was a focus on fluridone application for hydrilla control, fluridone fate and transport and fluridone removal. However, the advantages and disadvantages of other herbicides as well as physical, mechanical, and biological control methods were also discussed.

The workshop included variety of professionals with expertise relevant to managing hydrilla in New York and nationwide (Table 3). The range of expertise enabled the group to broadly explore the important considerations for a hydrilla management program.<sup>16</sup> The goal of the workshop was to collect information for DEP decision-making, and the group was not charged with making recommendations. It was decided the project team would distill recommendations for DEP from workshop discussions as detailed below. This was decided beforehand to maximize the limited workshop time available and to enable the participation of industry experts without creating a conflict of interest. Refer to Appendix C for all workshop materials, including agenda, participant bios, background material, etc., and refer to Appendix D for workshop presentations. The discussions and information shared during the course of the workshop have been integrated into this report. Refer to Appendix E for a summary of the workshop discussions.

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<sup>16</sup> A number of people with herbicide toxicology expertise were invited to the workshop, but the schedule of the meeting did not enable them to attend. The project team reached out to them separately to discuss the EPA human health risk assessment process and prior experience with human and ecological toxicology of fluridone.

**Table 3**  
**Workshop participants**

Case Study Representatives	
Heather Desko	New Jersey Water Supply Authority
Mike Greer	US Army Corp of Engineers
Angel Hinickle	Tompkins County Soil and Water Conservation District
Cathy McGlynn	NYSDEC Invasive Species Coordination Unit
Outside Experts	
Rob Richardson	NC State University Dept of Crop Science
Dave Mitchell	Independent Lake Management Consultant
Industry Representatives	
Chris Doyle	SOLitude Lake Management
Mark Heilman	SePRO
Regulator Representatives	
Anthony Lamanno	NYSDEC Bureau of Pest Management
Utility Operations and Treatment Experts	
Linda Diebolt	Hazen and Sawyer
Matt Valade	Hazen and Sawyer
Josh Weiss	Hazen and Sawyer
Facilitators	
Ben Wright	Hazen and Sawyer
Heather Landis	Hazen and Sawyer
Tina Nelson	Hazen and Sawyer
Water Research Foundation Staff	
Alice Fulmer	Water Research Foundation
Jennifer Warner	Water Research Foundation
Water Research Foundation Project Advisory Committee	
Willow Eyres	NYSDEC
Orren Schneider	American Water
Meredith Taylor	NYC DEP
DEP Staff	
Mike Usai	NYC DEP
Dale Borchert	NYC DEP
Ira Stern	NYC DEP
Paul Lenz	NYC DEP
Adam Bosch	NYC DEP
Jim Keesler	NYC DEP (by phone)
Lori Emery	NYC DEP (by phone)



## RECOMMENDATIONS FOR DEP

The first documented case of hydrilla in New York was in 2008, and it has since spread to 11 counties in less than ten years (NYSDEC 2017a). Without management, hydrilla is expected to continue to spread through the state. Given the need to control the spread of hydrilla in New Croton Reservoir and the lack of effective non-chemical options available for managing a large-scale infestation, herbicide treatment is the only available option to DEP. At this time, only two herbicide options appear feasible for the New Croton Reservoir: endothall and fluridone. Based on available data from EPA and from independent risk assessments for fluridone and endothall, when following label restrictions, herbicide treatment of hydrilla in New Croton Reservoir would likely be effective and feasible without resulting in significant adverse impacts to human or ecological health.

Both options have advantages and disadvantages. Additionally, activated carbon is the only confirmed treatment process that would provide a treatment barrier for the removal of either herbicide, but no WTP that uses New Croton Reservoir as a source of drinking water has activated carbon as part of its plant.<sup>17</sup> However, appropriate application of either herbicide could be conducted so as not to require drinking water treatment to maintain compliance with regulations. Further, while dilution and natural degradation will reduce the concentration of either herbicide, the application plan and monitoring should be coordinated with NYSDEC to ensure no adverse impacts on herbicide application in the Croton River downstream.

Below is a discussion of the considerations of the two herbicide options for New Croton Reservoir.

- Endothall - The shorter treatment period and quicker degradation is a major advantage for endothall. However, endothall application would require intake shutdown to apply herbicides within 600 feet of the intakes. DEP has limited ability near-term to shut down the intakes given upcoming repair activities in other parts of the water supply system. Impacts to other systems that rely on New Croton Reservoir would also need to be taken into consideration. If DEP cannot reliably plan around endothall application in the reservoir to allow for herbicide contact time and subsequent degradation, it is not recommended that DEP pursue endothall for treatment in proximity to the drinking water intakes. However, endothall treatment of areas outside of the 600-foot intake buffer is not expected to result in adverse impacts. Because it took nearly six to eight weeks for fluridone to show up in the Croton-on-Hudson wellfield during Croton River fluridone application (NYSDEC 2017c), endothall would not be expected to impact the downstream wells following a 24 to 48 hour treatment of the reservoir.
- Fluridone - Fluridone application would allow for continuous operation of the intakes, regardless of application location, because of the lack of drinking water restrictions at the dosages allowed in New York. The long-duration treatment is a disadvantage because it increases the potential the herbicide could eventually enter the intake. While this would not be a public health concern at the concentrations needed to control hydrilla, it could result in negative public perception. It should be noted that treatment would occur when the reservoir is typically stratified. Stratification reduces vertical mixing of the reservoir, which would make it unlikely for fluridone to mix with deeper

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<sup>17</sup> The Croton WTP was designed to be able to convert to GAC in the future. Indian Brook WTP is currently being upgraded and may have the same option in the future.



water at the elevation of the intakes. However, stratification cannot be relied upon to prevent fluridone from reaching the intake. Large storms can mix the reservoir vertically, and large drawdown conditions, such as during droughts or the RWBT shutdown, can drop the thermocline below the intake level.

Given the operational constraints on the reservoir, fluridone is the best available herbicide for treatment in proximity to the intakes. Either fluridone or endothall could be used elsewhere in the reservoir. If DEP pursues herbicide treatment of New Croton Reservoir, it is recommended that DEP develop a comprehensive public outreach program to educate the public on the need for treatment and risks of hydrilla to justify the use of herbicides in New Croton Reservoir. The public outreach program for herbicide treatment should address the potential for minor exposure, and put the level of incidental exposure in context with the EPA-derived NOAEL.

The health of the reservoirs is critical for DEP to manage water quality and maintain recreational opportunities. Invasive species are a recognized threat, and DEP has enacted strict rules and regulations to prevent the introduction and spread of invasive species. For example, DEP requires all recreational users to obtain an access permit, and all boats used on DEP property are required to be registered, inspected and steam cleaned by DEP. Boats must be stored on-site and transfer between reservoirs is not allowed without a new permit and cleaning/inspection (NYCDEP 2010). While it may be possible for boaters to spread hydrilla within the reservoir, DEP only allows non-motorized boats, which greatly reduces the ability of boaters to traverse great distances in the reservoir. Aside from natural movement of hydrilla fragments on the currents, DEP's New Croton Reservoir access restrictions are expected to prevent further spread of hydrilla both within/outside of the reservoir.



## INVASIVE SPECIES CONTROL AND SOURCE WATER PROTECTION

Source water protection (SWP) is an established component of the multi-barrier approach to protecting the health and safety of public drinking water supplies. While invasive species may not result in acute water quality impacts the same as other threats (e.g., chemical spills, wastewater discharges, non-point source pollution, etc.), they do result in a range of impacts to water supplies that must be addressed by utilities. Managing invasive species consumes staff time and budget, increasing costs and taking away from other pressing water supply needs. Therefore, invasive species management can be included as part of a utility's SWP planning efforts, giving decision-makers a roadmap for engaging with the public and other stakeholders on this important issue.

There are a range of resources on SWP and community engagement from the EPA, AWWA, Water Research Foundation and state agencies. These resources are directly applicable to invasive species. The American Water Works Association (AWWA) management standard G300-14, for example, describes the generally recognized elements of an effective SWP protection plan.

1. Source water protection program vision stakeholder involvement;
2. Source water characterization;
3. Source water protection goals;
4. Source water protection action plan;
5. Implementation of the action plan; and
6. Periodic evaluation and revision of the entire program.

These components of a SWP plan can be used both for preventive measures and active management of invasive species. The following describes some of the additional considerations when applying these concepts to invasive species.

- Source water protection program vision – The visioning process is an important first step in the SWP process. The vision is a statement of commitment and provides the over-arching guidance for setting priorities into the future. Depending on the level of detail in the vision statement(s), invasive species can specifically be addressed or simply referenced under the umbrella of threats to the water supply/watershed.
- Stakeholder involvement – This step recognizes the types of stakeholders (drinking water consumers, recreational users, governments, community groups, commercial interests, etc.), their interests in source protection and their ability to affect change (good and bad) in the watershed. It is critical to identify recreational users' potential role in spreading aquatic invasive species, and include them as a primary target for outreach. Through education, recreational users can become strong advocates for the water supply. The stakeholder group may also be expanded to include adjacent watershed managers in order to develop regional cooperation for preventing the spread of invasive species. Utilities can use the same public outreach toolbox developed for general source water protection efforts to engage with the community on both prevention and management actions. Options available provide for a range of outreach options that can be used singularly or in combination.
  - Passive outreach (flyers, signage, etc.)

- Public review/comment of management plan
- Public meetings to solicit comments
- Direct engagement of organizations/governments
- Steering committee with stakeholder participation

The goal of public engagement is to integrate the community into the planning process. While it takes effort, in the long term it will save time and help cultivate success, particularly with potentially contentious issues, such as herbicides in sources of drinking water. Appendix B includes a list of frequently asked questions on hydrilla management to help utilities develop communications resources for stakeholder engagement.

- Source water characterization - Unlike typical sources of contamination, because invasive species can travel between watersheds, it is useful to expand the range of watershed characterization to include nearby invasive species occurrences that are outside of the watershed. Understanding the modes of travel, vectors and waterbody access will help characterize the risks from nearby occurrences.
- Source water protection goals – Building off the source water characterization, utility managers may have different goals for different species. By ranking species based on important criteria, utilities can focus prevention and management efforts on high risk/high cost species (e.g., hydrilla and zebra mussels).
- Source water protection action plan, implementation, and periodic revision – These steps are consistent with the typical SWP process when applied to invasive species, and are critical for turning goals into defined action items that are re-evaluated based on the level of success over time.

## CONCLUSIONS

Hydrilla is a high priority risk for river and reservoir systems as it can impact water quality, aquatic habitat, and recreational uses. The dense mats formed by hydrilla are a hazard for boats and swimmers, as well as shading out native species. Decay of plant litter can increase natural organic matter in reservoirs, cause fish kills from low dissolved oxygen, impede flows through streams and channels and clog intake structures.

Herbicides have been effectively used to manage hydrilla in waterbodies across the US. However, the decision to apply herbicides in sources of drinking water, even to control a highly invasive plant such as hydrilla, is not taken lightly. Because the primary objective of the drinking water sector is protecting public health, utilities and the public require assurances that the decision to apply herbicides will not result in negative health effects to their customers. Further, drinking water supplies often serve multiple uses as a local or regional amenity for recreation, wildlife, and the preservation of natural resources. Similar to public health, the decision to apply herbicides to a water supply should not severely impact non-water supply functions of the waterbody.

Because of the recognition that negative impacts of pesticides have the potential to outweigh their benefits, in the US all pesticides and herbicides are subject to extensive, rigorous testing to determine 1) efficacy for specific use scenarios and target species and 2) the potential adverse impacts to human and ecologic health. The registration process for pesticides takes years to complete and requires substantial data prior to any environmental release. Initial registration is typically conditional and is only granted after an experimental use period that requires site-specific record-keeping and extensive field trial data collection that can last two to three years (McGaughey 2012). Registration of a pesticide comes with strict controls on the application and use of the product as detailed by the pesticide label, which is a legally enforceable requirement for their use (EPA 2018). The label restrictions are custom to each pesticide based on the data from the registration process that addresses toxicology, environmental hazards, residue chemistry, fate and transport and other factors. Even after registration at the federal level, many states conduct independent reviews prior to allowing pesticides and herbicides to be applied. Further, pesticide registration review is required approximately every 15 years to incorporate new science and evaluate data collected from pesticide use.

The two primary herbicides considered in this project for the control of hydrilla were fluridone and endothall. These two herbicides are effective against hydrilla, have been registered for aquatic plant management since 1986 and 1960, respectively, and are available in all states (CDMS 2018).<sup>18</sup> Therefore, both have been used extensively and have undergone multiple registration reviews and independent assessments. For this project, ten assessments and studies of the human health and ecological impacts associated with their use were reviewed (listed below). The independent assessments of the risks repeatedly came to similar conclusions that these two herbicides will result in no significant adverse effects when properly following the label directions.

- Generic Environmental Impact Statement on Aquatic Vegetation Management (endothall), 1981, prepared for the New York State Department of Environmental Conservation
- Fluridone Human Health Risk Assessment, 1992, prepared by the Washington Department of Ecology

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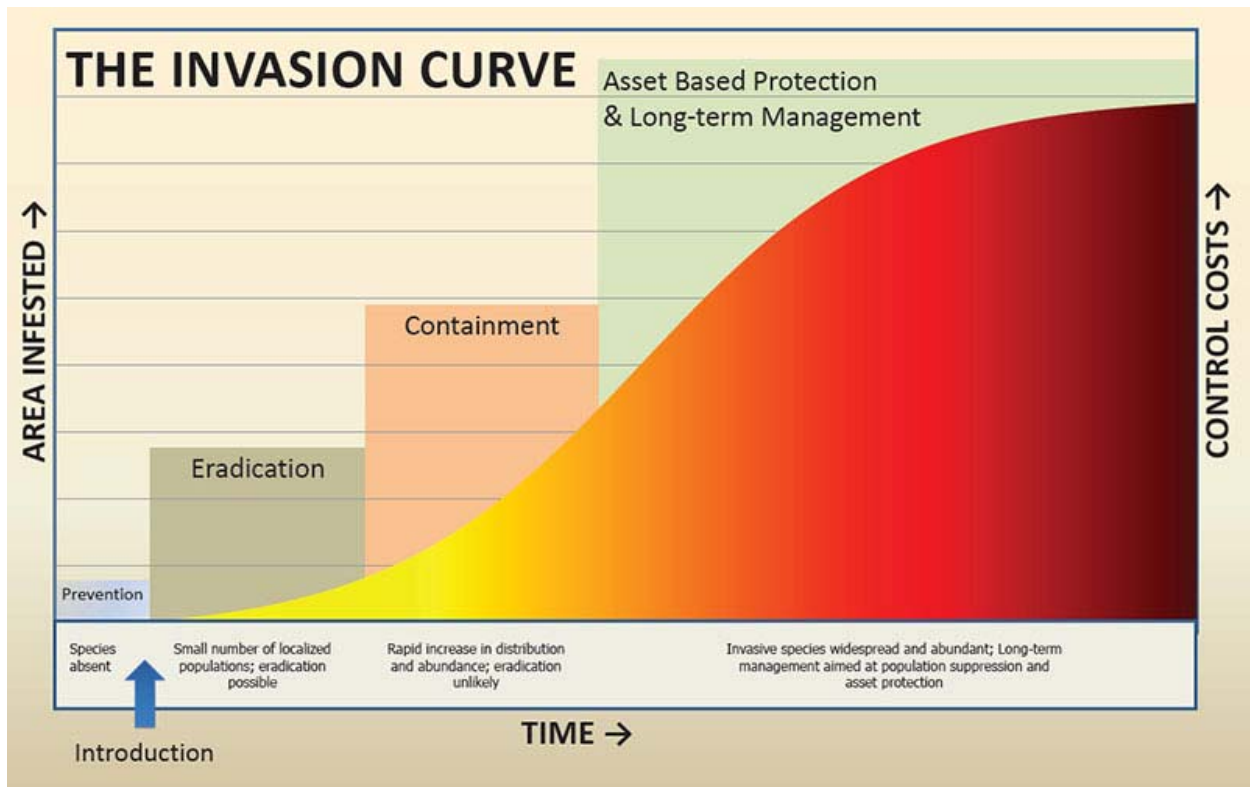
<sup>18</sup> State-specific restrictions may apply to their use.

- Supplemental Generic Environmental Impact Statement on Aquatic Vegetation Management (fluridone), 1995, prepared for the New York State Department of Environmental Conservation
- Human Health Effects of Endothall, 2001, prepared by the Washington Department of Ecology
- Fluridone Ecological Risk Assessment, 2005, prepared for the Bureau of Land Management
- Fluridone: Human Health and Ecological Risk Assessment Final Report, 2008, prepared for the US Department of Agriculture Forest Service
- Endothall: Human Health and Ecological Risk Assessment Final Report, 2009, prepared for the US Department of Agriculture Forest Service
- *Egeria densa* Biological Assessment, 2012, prepared by the California Department of Boating and Waterways
- Public Health Evaluations for Potential Exposures to Fluridone or Endothall Used for Treatment of *Hydrilla verticillata* in the Eno River, Orange and Durham Counties, NC, 2015, North Carolina Division of Public Health
- Impact of Low Dose Fluridone Treatments on Aquatic Plant Richness and Non-Target Species, 2017, prepared by Ken Wagner

Other aquatic herbicides that are effective against hydrilla (bispiribac-sodium, flumioxazin, imazamox, penoxsulam, topramezone, etc.) undergo the same rigorous EPA registration process. While these herbicides are newer than endothall and fluridone and there are fewer independent assessments of risks, available information indicates the label restrictions are sufficient to prevent adverse impacts (Washington Department of Ecology 2012).

Broadly speaking, no information was identified during the course of this project that would suggest that herbicides should categorically be excluded from use in sources of drinking water. However, public perception may remain an obstacle for utilities' considering the use of herbicides to manage hydrilla. The case studies reviewed during this project revealed that a focused effort to describe the risks and benefits to the public in advance of the herbicide application was valuable for obtaining stakeholder acceptance.

The decision to use herbicides to control hydrilla in sources of drinking water is an individual utility decision. Utilities and water resource managers must weigh the costs and risks from no action, chemical control, and non-chemical control options for their sources of drinking water to develop the optimum approach for addressing this aggressive aquatic invasive plant.



Source: US Army Corps of Engineers 2014.

**Figure 7 Invasive species management curve**

However, preventing invasive species from becoming established is both the most effective and least costly option for managing invasive species. As stated previously, engaging with recreational users and others that access drinking water sources to help prevent the spread of invasive species, or to facilitate early identification, will help reduce the occurrence of hydrilla and avoid more costly management actions. Figure 7 was developed by the US Department of Agriculture and the US Army Corps of Engineers based on decades of experience managing invasive species across the US. It illustrates that over time as invasive species become more established, the effort and costs associated with management escalate dramatically. If it is believed hydrilla could become introduced based on source protection planning, development of an invasive species management plan prior to their occurrence in sources of supply will help utilities respond quickly to aggressive invasive species such as hydrilla. A strong focus on prevention and on rapid response in the early stages following introduction will reduce long-term management costs and improve the potential for success.





## **APPENDIX A SELECT RESOURCES FOR DRINKING WATER UTILITIES**

### **GENERAL RESOURCES**

#### **Hydrilla Identification**

- Hydrilla Identification Fact Sheet prepared by the New Jersey Water Supply Authority. [http://www.njwsa.org/uploads/1/0/8/0/108064771/hydrilla\\_fact\\_sheet\\_elodacomparison.pdf](http://www.njwsa.org/uploads/1/0/8/0/108064771/hydrilla_fact_sheet_elodacomparison.pdf).

#### **General Aquatic Plant Management**

- Wagner, K. J. (2004). *The practical guide to lake management in Massachusetts: a companion to the final generic environmental impact report on eutrophication and aquatic plant management in Massachusetts*. Commonwealth of Massachusetts, Executive Office of Environmental Affairs. Available at <http://www.mass.gov/eea/docs/dcr/watersupply/lakepond/downloads/practical-guide-no-pics.pdf>.

#### **Herbicide Labels**

- Crop Data Management Systems, Inc. Herbicide Label Database. <http://www.cdms.net/Label-Database>.
- EPA Pesticide Product and Label System. <https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1>.

### **HYDRILLA MANAGEMENT CASE STUDY RESOURCES**

#### **Cayuga Inlet Managed by the Hydrilla Task Force of the Cayuga Lake Watershed**

- Cornell Cooperative Extension of Tompkins County. <http://ccetompkins.org/environment/invasive-nuisance-species/aquatic-invasives/hydrilla/fighting-hydrilla-in-the-cayuga-lake-watershed/cayuga-inlet-eradication-project-management-plan>.

#### **Croton River Managed by the New York State Department of Environmental Conservation**

- Croton River Hydrilla Control Project. <http://www.dec.ny.gov/animals/106386.html>.

#### **Delaware & Raritan Canal Managed by the New Jersey Water Supply Authority**

- Hydrilla: An Invasive Water Weed. <http://www.njwsa.org/hydrilla.html>.

## **Tonawanda Creek/Erie Canal Managed by the US Army Corps of Engineers**

- Great Lakes Hydrilla Collaborative.  
<http://hydrillacollaborative.com/Home/CaseStudies>.
- Cornell Cooperative Extension Western New York Hydrilla Project.  
<http://erie.cce.cornell.edu/invasive-species/wny-hydrilla-project>.

## **APPENDIX B**

### **HYDRILLA MANAGEMENT FREQUENTLY ASKED QUESTIONS AND ANSWERS FOR COMMUNICATIONS AND OUTREACH**

The following frequently asked questions and answers were developed for DEP to use in public outreach communications. Many of these can be used directly by utilities for answering questions from the public on hydrilla. Others that are specific to DEP and New Croton Reservoir can be used as examples for utilities to develop their own questions and answers for public outreach on chemical control of hydrilla.

#### **GENERAL INFORMATION ON HYDRILLA**

- 1) What is hydrilla?
  - a) Hydrilla is an aquatic invasive (non-native) plant that can grow quickly and prevent growth of native plant species. It can infest large portions of lakes and rivers, causing a variety of impacts to water quality, natural resources, and recreational use.
- 2) Why should I care?
  - a) Hydrilla grows in water up to 20 to 40 feet deep and forms dense mats that shade out other species.
  - b) The thick mats at the surface interfere with boating and swimming.
  - c) Hydrilla changes local ecology by killing off native plant species, changing the ecology.
  - d) Hydrilla causes changes to water quality, particularly in the fall when the mass of vegetation dies off and decays.
  - e) The dead vegetation can clog drinking water, irrigation and cooling intakes and screens.
  - f) It can reduce sportfish populations due to loss of open water and native vegetation.
  - g) It can harm the local economy by impacting tourism and waterfront property values.
- 3) How does hydrilla spread?
  - a) Hydrilla reproduces in multiple ways from seeds, tubers, turions (buds), and plant fragments.
  - b) Hydrilla fragments can remain viable out of water in moist conditions for up to four days.
  - c) Tubers and turions in sediment can remain dormant for several years and can withstand ice cover and drying.
- 4) What is hydrilla's habitat?
  - a) Hydrilla can grow in a wide variety of still and slow-moving waters, such as freshwater lakes, ponds, rivers, reservoirs and canals.
  - b) It tolerates a wide range of pH, nutrient, salinity and light levels.
  - c) The optimum temperature for growth is 68-81°F (20-27°C). In colder areas, it dies back and relies on buried tubers for next year's growth. In warmer areas, it does not fully die back during the winter.
- 5) How can we stop hydrilla?

- a) Typical ways of controlling aquatic plant growth include physical removal, biological controls, and herbicides.
  - b) Because hydrilla can easily regrow and spread from plant fragments, physical removal is not used due to the risk of making the infestation worse.
  - c) Effective biological controls are currently limited to adding sterile grass carp, which are restricted in New York, and many other states, to waters with no possibility of escape for the fish.
  - d) Herbicides are the predominant method for controlling hydrilla in New York and have been used in the Erie Canal, the Croton River, Cayuga Lake, and Cayuga Inlet.
    - i) The two primary herbicides used to control hydrilla in New York are fluridone and endothall.
    - ii) These two herbicides have been registered for aquatic plant management since 1986 and 1960, respectively, and are approved in all states.
    - iii) Both herbicides are approved in sources of drinking water when following the label restrictions.
    - iv) Other herbicides that can help control hydrilla include bispyribac-sodium, flumioxazin, imazamox, penoxsulam, and topramezone, but may not be approved in all states.
  - e) Controlling hydrilla requires continued treatment for years to truly eliminate the infestation.
- 6) What can I do to prevent the spread of hydrilla?
- a) Inspect and remove plant fragments and mud from boats, trailers, and equipment before and after each use.
  - b) Dispose of all debris in trash cans or above the waterline on dry land, because tubers and turions can be transported in clumps of sediment.
  - c) Clean and dry your equipment thoroughly before visiting other bodies of water and remove any plant fragments from boats, trailers and equipment.
  - d) Do not dispose of unwanted aquarium plants in water, ditches or canals.
  - e) Monitor recently acquired aquatic plants, because hydrilla tubers can be transported in the attached soil/growing material.

## **SPECIFIC INFORMATION FOR FLURIDONE TREATMENT IN NEW CROTON RESERVOIR**

- 1) When did DEP discover hydrilla in New Croton Reservoir?
  - a) Hydrilla was identified in the Reservoir in October 2014.
  - b) The largest infestation is in proximity to a boat launch that is not open to the public.
  - c) DEP installed small barriers around the boat launch in 2015 and 2016 to limit hydrilla's spread, while further study was ongoing.
  - d) Surveys of the reservoir in 2016 and 2017 identified additional locations of hydrilla that range from sparse to dense.
- 2) How could hydrilla impact DEP?
  - a) If left untreated, hydrilla is expected to infest all viable parts of the reservoir (19% to 55% of the surface area) including DEP's upstream reservoirs as well the Croton River and Hudson River downstream. Hydrilla in the Croton System risks its spread into Kensico Reservoir.

- b) The large biomass will change water quality and increase plant debris and decay (called natural organic matter) that can react with disinfectants to form undesired chemicals that are regulated in drinking water.
  - c) Hydrilla biomass can also cause clogging of intakes and treatment processes.
- 3) What herbicide is DEP considering for New Croton Reservoir?
- a) DEP is planning to use fluridone slow-release pellets at locations of hydrilla infestation.
  - b) DEP will apply the herbicide at low doses (approximately 2 to 4 parts per billion[ppb]) for 90 to 120 days during the spring and summer months.
  - c) DEP expects they'll need to treat for up to five years to effectively control hydrilla. Treatment could occur after the first five years, but at lower levels to ensure complete removal.
- 4) What are the risks to drinking water safety from fluridone?
- a) USEPA approves the use of fluridone for application near drinking water intakes at concentrations up to 20 ppb, well above DEP's planned dose of 2 to 4 ppb.
  - b) The New York State Department of Environmental Conservation also approves use of fluridone in New York.
  - c) Based on toxicology studies and a treatment dose of 4 ppb, an adult would have to drink more than 200,000 liters of water before it would cause negative effects, and a child would have to drink over 35,000 liters of water.
  - d) DEP's drinking water intake at New Croton Reservoir is deep and not expected to pull in the herbicide.
  - e) Significant thermal layering (a thermocline) typically develops in the reservoir in the spring and summer and prevents water in the upper 20 to 30 feet of the reservoir from mixing with deeper water. The water intakes are below 30 feet. Fluridone will only be applied in the shallower portions of the reservoir where hydrilla is growing, so it is not expected to reach the intakes.
- 5) What are the effects on fish in the reservoir from fluridone?
- a) While studies show that fish do absorb fluridone, it dissipates over time and does not bioaccumulate.
  - b) Potential impacts to fish from fluridone are not a concern until concentrations reach 500 ppb to over 8,000 ppb (depending on species), which is well above doses for hydrilla control.
- 6) What are the potential impacts to the Reservoir's ecology?
- a) Impacts to plants other than hydrilla are expected to be low, because hydrilla is more sensitive to fluridone treatment than other plant species.
  - b) It is expected that herbicide treatment will result in fewer ecological impacts than potential impacts from a large-scale hydrilla infestation.
- 7) How will fluridone application at New Croton Reservoir affect fluridone application in the Croton River downstream?
- a) DEP will coordinate with New York State Department of Environmental Conservation to ensure fluridone levels remain in the target range for the Croton River.
- 8) Where can I find more information on fluridone?
- a) <http://ccetompkins.org/environment/aquatic-invasives/hydrilla/management-options/herbicides/fluridone/fluridone-faq>



- 9) Where can I find more information on hydrilla in New Croton Reservoir?
  - a) DEP will have a website with information on the herbicide treatment program for New Croton Reservoir.

## **RECREATIONAL OUTREACH**

- 1) Where are the closest hydrilla infestations to New Croton Reservoir and the Croton River?
  - a) Hydrilla is in a small pond in Orange County, NY and the Silvermine River in Norwalk and New Canaan, Connecticut, both which are approximately 20 miles from New Croton Reservoir. Other nearby locations of hydrilla are the Connecticut River in Connecticut and the Delaware and Raritan Canal in New Jersey, both which are approximately 65 miles away.
  - b) Hydrilla is not currently widespread in the northeast, so managing hydrilla in New Croton Reservoir is regionally important to prevent further spread.
- 2) How long does DEP think fluridone treatment will be needed in New Croton Reservoir?
  - a) Intensive treatment is expected to be required for up to five years to provide effective hydrilla control. Decreasing amounts of treatment would be required for an additional five years as the infestation is reduced.
  - b) Control of hydrilla requires sustained management over a period of years to deplete the energy reserves within the tuber bank and ultimately eradicate the infestation.
- 3) What is DEP doing to prevent the spread of hydrilla?
  - a) DEP requires that boats be steam cleaned and stored onsite at the reservoir to prevent further spread of hydrilla.
  - b) DEP will work with contractors and agencies accessing the reservoir to ensure boats on official business do not spread or reintroduce hydrilla to the reservoir.
- 4) How will recreational users be notified during herbicide application?
  - a) DEP will use signs to ensure recreational users of the reservoir are aware of herbicide application.
  - b) DEP will use local newspapers to notify the public about the herbicide application.

**APPENDIX C  
WORKSHOP MATERIALS**



November 9, 2017

## CHEMICAL MANAGEMENT OF HYDRILLA FOR DRINKING WATER UTILITIES

### Workshop Background Materials

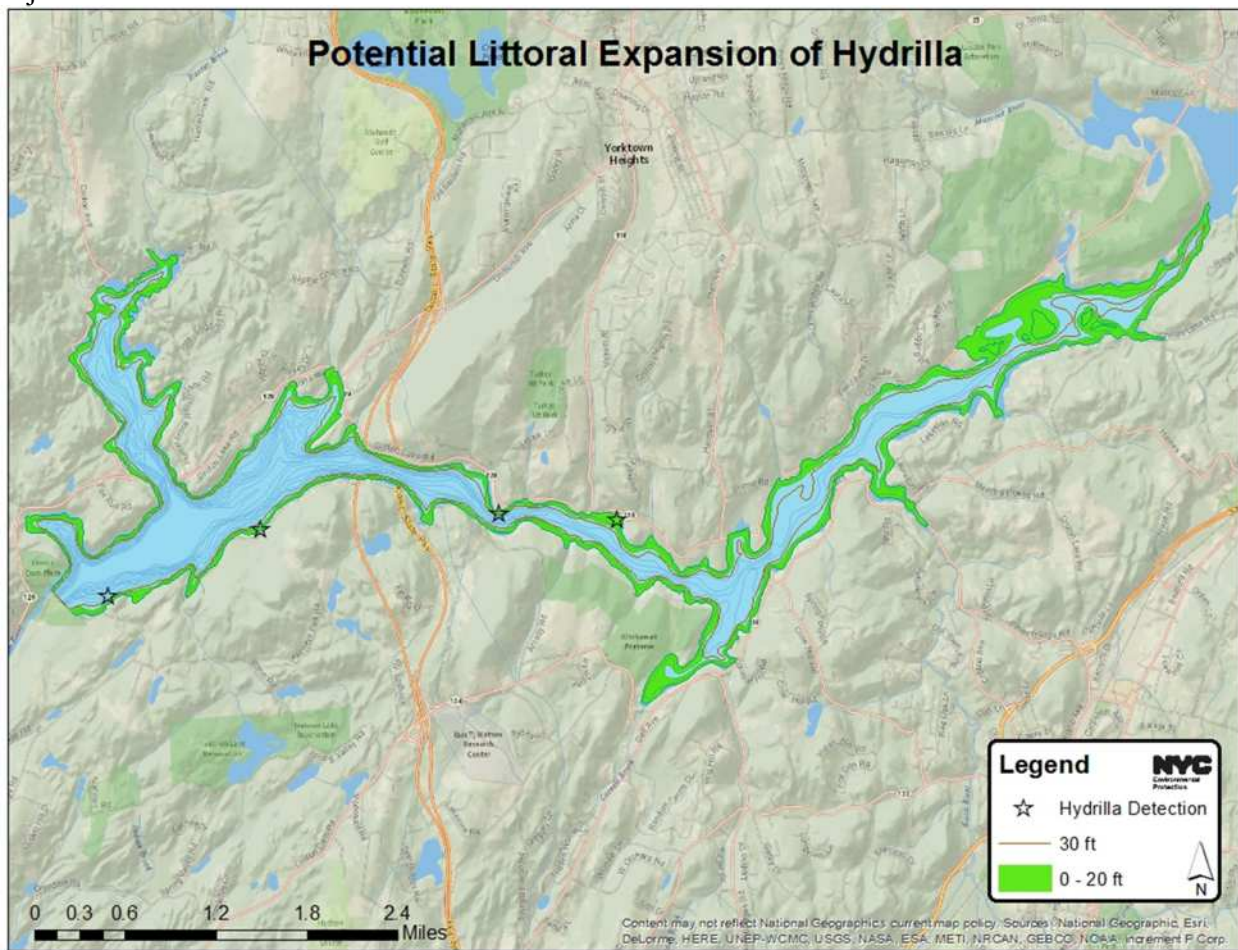
The primary objective of this project is to provide review of hydrilla control using fluridone in sources of drinking water. The review will be focused on the New York City Department of Environmental Protection's (DEP) upcoming plan for treatment of the New Croton Reservoir, but will also include input from case studies that have previously used fluridone for hydrilla control. This document provides background information on the New Croton Reservoir hydrilla infestation to support workshop discussions.

**New Croton Reservoir:** New Croton Reservoir, formed by impounding the Croton River, is the terminal reservoir of the Croton System and receives water from eleven other Croton System reservoirs. The Croton System typically supplies approximately 10 percent of NYC's drinking water demands. However, during drought conditions, the Croton System yield is sufficient to meet up to 30 percent of the City's demand. All water diverted from New Croton Reservoir by DEP flows to the Croton Water Filtration Plant (WFP) via the New Croton Aqueduct. Spills and releases from the reservoir continue down the Croton River to the Hudson River. In addition to supplying water for the City, there are a number of intakes for other utilities at New Croton Reservoir.

- **Location and size:** Located in Westchester County, approximately 22 miles north of New York City. Surface area is approximately 57 square miles and the reservoir has a capacity of 19 billion gallons.
- **Access:** DEP owns the property surrounding the reservoir and controls access to the adjacent watershed. A permit is required, which allows individuals to fish from shore or fish from non-motorized boats. Swimming is not allowed in the reservoir.
- **Fisheries:** The reservoir supports numerous fish species and is popular for recreational fishing. The reservoir supports a warm and cool water fishery with large and small mouth bass, chain pickerel, yellow and white perch, black crappie, bullfish and sunfish predominating. The reservoir itself is not stocked, but its upstream tributaries are stocked with trout.
- **Water quality:** The water quality classification for the reservoir is Class AA throughout its entire length, which indicates the highest and best use of the reservoir is for drinking water.
- **Drinking Water Intake:** The elevation of the reservoir at full pool is 196 feet. The reservoir is generally kept within two feet of full pool, except during drought conditions. The drinking water intakes are located at the upper release (166 ft. elevation) and lower release (116 ft. elevation).

- Drinking Water Treatment: Treatment involves stacked dissolved air floatation and filtration with anthracite/sand dual media filter. The filtered water is then disinfected by treatment with UV and chlorine. After treatment, the water is chemically adjusted as required and subsequently dosed with orthophosphate for corrosion control and hydrofluorosilicic acid to add fluoride.
  - UV System Type: Low pressure high output – narrow spectrum
  - UV Transmittance: > 95%
  - UV Reduction Equivalent Dose (RED): 40 mJ/cm<sup>2</sup>
  - Wavelength: 253.7 nanometers

**Hydrilla Detection:** Results from aquatic vegetation surveys of New Croton Reservoir from 2014/2015 identified a number of locations of hydrilla. The total area of hydrilla infestation in the reservoir is estimated at approximately 50 acres. However, additional surveys were conducted in 2017, which may adjust the current estimate.



**DEP's Objective:** The objective of DEP's plan for fluridone treatment of New Croton Reservoir is to achieve complete eradication of the infestation.

**Constraints on Hydrilla Management in New Croton Reservoir:**

- Hydrilla infestations located within ¼ mile of intake limits herbicide options
- New York State Department of Environmental Conservation (NYSDEC) indicated they would not permit the introduction of sterile grass carp to the reservoir

**Other Considerations:** The NYSDEC is treating the Croton River downstream of New Croton Reservoir with fluridone for hydrilla control. The first treatment occurred between July and October 2017. Per the Croton River 5-year Management Plan, the treatment target for the Croton River is 2 ppb of fluridone. Coordination considerations include:

- Migration of fluridone from the reservoir treatment areas to the river could affect the concentrations for the river treatment.
- Water releases from the reservoir need to be high enough to submerge hydrilla on the river banks and allow for herbicide contact.

**Additional Resources:**

- NYSDEC website has details of both the Croton River and New Croton Reservoir hydrilla infestations <http://www.dec.ny.gov/animals/106386.html>
- DEP Watershed Water Quality Annual Reports: These reports provide an annual overview of watershed water quality throughout the NYC water supply system, and therefore provide a summary of relevant ambient water quality conditions.
  - [http://www.nyc.gov/html/dep/pdf/reports/fad\\_5.1\\_watershed\\_monitoring\\_program\\_-\\_2015\\_watershed\\_water\\_quality\\_annual\\_report\\_07-16.pdf](http://www.nyc.gov/html/dep/pdf/reports/fad_5.1_watershed_monitoring_program_-_2015_watershed_water_quality_annual_report_07-16.pdf)
  - [http://www.nyc.gov/html/dep/pdf/reports/fad\\_5.1\\_watershed\\_monitoring\\_program\\_-\\_2016\\_watershed\\_water\\_quality\\_annual\\_report\\_07-17.pdf](http://www.nyc.gov/html/dep/pdf/reports/fad_5.1_watershed_monitoring_program_-_2016_watershed_water_quality_annual_report_07-17.pdf)



**CHEMICAL MANAGEMENT OF HYDRILLA FOR DRINKING WATER UTILITIES**

**Workshop Agenda  
November 17, 2016  
NYCDEP Offices  
2nd Floor Conference Room  
465 Columbus Avenue  
Valhalla, NY 10595**

<b>TIME</b>	<b>TOPIC</b>	<b>DETAILS</b>
8:00 AM	Coffee / Refreshments	
8:30 AM	Opening	· WRF introduce goals/purpose of the workshop
		· DEP Welcome
		· Facilitators review agenda, ground rules, logistics
		· Participants introduce themselves, identify their name and organization.
9:00 AM	Topic #1: Selection of hydrilla control strategies	· Meredith Taylor, DEP, overview of New Croton Reservoir hydrilla and DEP's rationale for selecting fluridone treatment
		· Review of selection criteria from case studies
		· Input from outside experts
		· Questions and Discussion
10:30 AM	Break	
10:45 AM	Topic #2: Fluridone: Environmental fate and safe practices	· Rob Richardson, NC State University, overview of fluridone fate and transport
		· Review safe practices implemented by case studies
		· Input from outside experts
		· Questions and Discussion
12:15 PM	Lunch	
1:00 PM	Topic #3: Contingency planning for herbicide use in sources of drinking water	· Ben Wright, Hazen and Sawyer, assessing risks from fluridone treatment
		· Brainstorming of potential risks and contingencies
		· Review of contingencies from case studies
		· Input from outside experts
2:30 PM	Wrap-up discussion	· Questions and Discussion
		· Summarize main discussion points
		· Review recommendations
		· Closing remarks and adjourn



## Workshop Discussion Questions

1. **Topic #1: Selection of hydrilla control strategies**
  - a. Pros and cons of eradication vs long-term management vs “No Action” options
  - b. Factors that would preclude the use of herbicide treatment
  - c. Other herbicide options for drinking water sources
  - d. Strategies for preventing future infestation
  - e. Likelihood of herbicide resistance and methods to prevent it
  - f. Effectiveness and impacts of non-chemical alternatives (e.g. lower reservoir and dredge tuber bank)
  
2. **Topic #2: Chemical treatment: Environmental fate and safe practices**
  - a. Need and/or effectiveness of booms to contain the treated area
  - b. Potential for toxic degradation byproducts n-methyl formamide and 3-trifluoromethyl benzoic acid
  - c. Communicating public health protections (pesticide registration toxicology results, multiple barrier approach, etc.)
  - d. Monitoring options to ensure water supply is safe (continuous, frequency of grab samples, locations, etc.)
  - e. Specific Operational Considerations for DEP
  - f. Coordination with Croton River treatment
  - g. Maintaining reservoir levels during treatment (is it important?)
  - h. Public outreach examples/practices (sharing data, project updates, etc.)
  
3. **Topic #3: Contingency planning for herbicide use in sources of drinking water**
  - a. Technologies for alerting utilities of problems
  - b. Mitigation actions in the event of a spill or other issue
  - c. Communication strategies for contingencies (both internal and to the public)





## Chemical Management Of Hydrilla For Drinking Water Utilities

Date: November 17, 2017, 8:30am – 3:00pm

Location: Valhalla Training Room

Project ID: Water Research Foundation 4747

Name	Bureau, Office
Ben Wright	Hazen
Orrin Schneider	American Water
Josh Weiss	Hazen
Jennifer Wainner	WaterRF
Dale Barbant	DEB/BUS
Heather Desko	NY Water Supply Authn
Chris Doyle	Solid de Lile M.n.
David Mitchell	Sturbridge MA
Rob Richardson	NCSU
Mark Heilman	SePRO
Linda DeBolt	Hazen
Cathy McGlynn	NYSDEC
Mike Greer	USACE, Buffalo
MATT VALAPE	HAZEN
Paul Herz	BWS
Alice Fulmer	WRF
WILLOW EYRES	NYSDEC
Heather Landis	Hazen
Anthony Lamunno	NYSDEC

**APPENDIX D**  
**WORKSHOP PRESENTATIONS**



# Hydrilla in New Croton Reservoir

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Meredith Taylor, NYC DEP

## Overview



- Hydrilla in the Croton System
- New Croton Management Objectives and Constraints
- New Croton Reservoir Physical Conditions

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## Hydrilla in the Croton System



- **Fall 2013**- David Werier discovers hydrilla in mouth of Croton River during RTE survey, confirmed by DEC

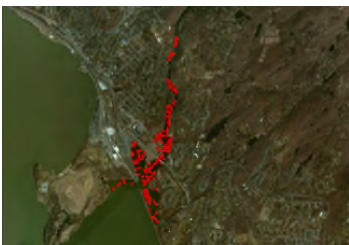
- **Summer 2014**- Allied Biological survey documents extensive but sporadic hydrilla, base of New Croton Reservoir to Croton Bay



- **Summer 2014**- Hydrilla discovered New Croton Reservoir in several patches at dam and near boat launch; not found upstream

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## Hydrilla in the Croton System



- **Fall 2014**- NYSDEC/DEP meet and begin to put together a response plan

- **Summer 2015**- Allied Biological hydrilla survey of Hudson River and Croton Bay & 46 locations in the Hudson River, DEP surveys reservoir and finds 4 distinct infestations



- **Fall 2015**- DEP installs Aquascreen benthic barriers at boat launch and continues to strategize on a treatment/eradication program

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## Hydrilla in the Croton System



- **Summer 2016-** DEP continues to use benthic barriers at the boat launch
  - NYSDEC plans to treat the Croton River with endothall but the treatment is postponed due to high flows out of New Croton Reservoir (resulting from high rainfall and an HAB)



- **Winter 2017-** DEP presents control plan to DEP Commissioner. Deputy Mayor directs DEP to engage objective experts to review strategy and options.

- **Summer 2017-** NYSDEC treats the Croton River with fluridone

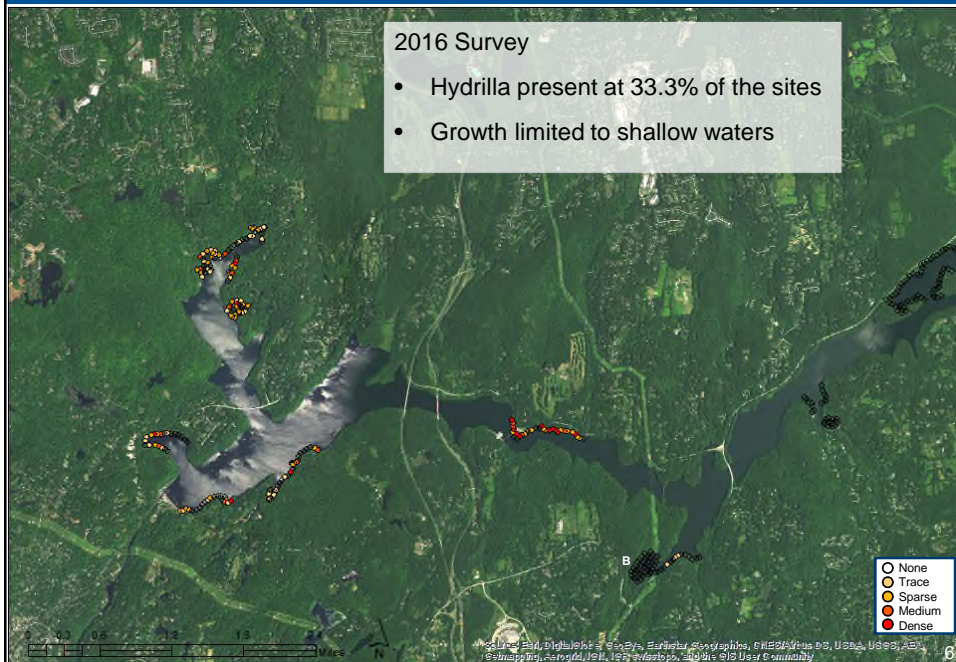
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## Hydrilla in New Croton Reservoir



### 2016 Survey

- Hydrilla present at 33.3% of the sites
- Growth limited to shallow waters



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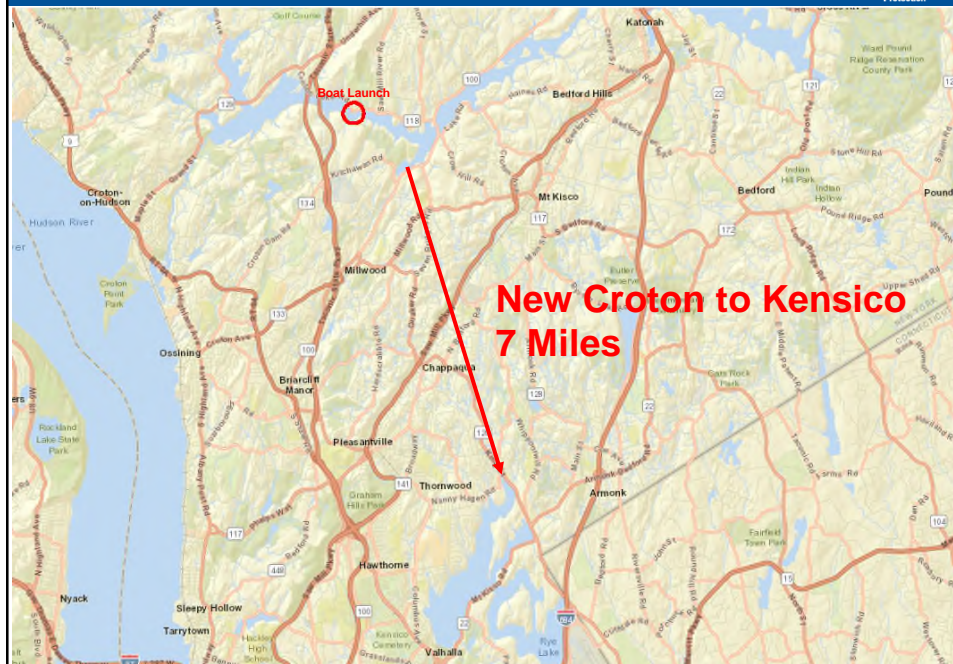
## Hydrilla Management Objectives



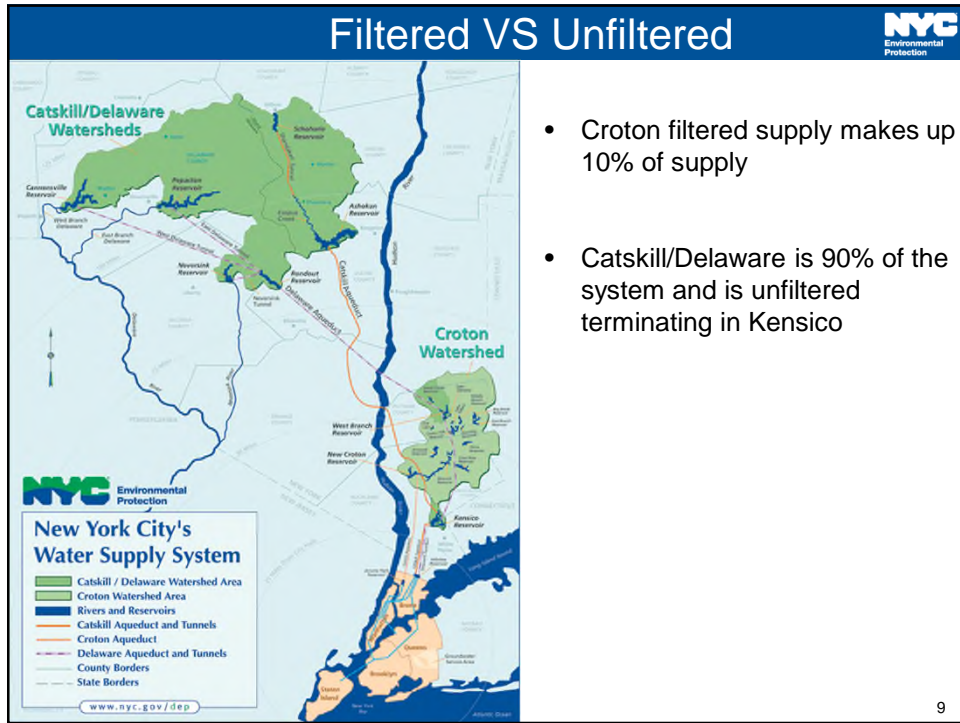
- The New York City Department of Environmental Protection (DEP) protects public health and the environment by supplying clean drinking water, collecting and treating wastewater, and reducing air, noise, and hazardous materials pollution.
- DEP is primarily concerned with the drinking water supply vs NYSDEC's broader ecological concerns
- New Croton Reservoir is treated with sodium hypochlorite, phosphoric acid, alum and by UV and filtered through sand and anthracite as part of the Croton System
- #1 Concern is to prevent spread to the unfiltered Catskill/Delaware system
- Eradication would most likely need to be the goal in order to justify the use of chemical treatment

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## New Croton to Kensico







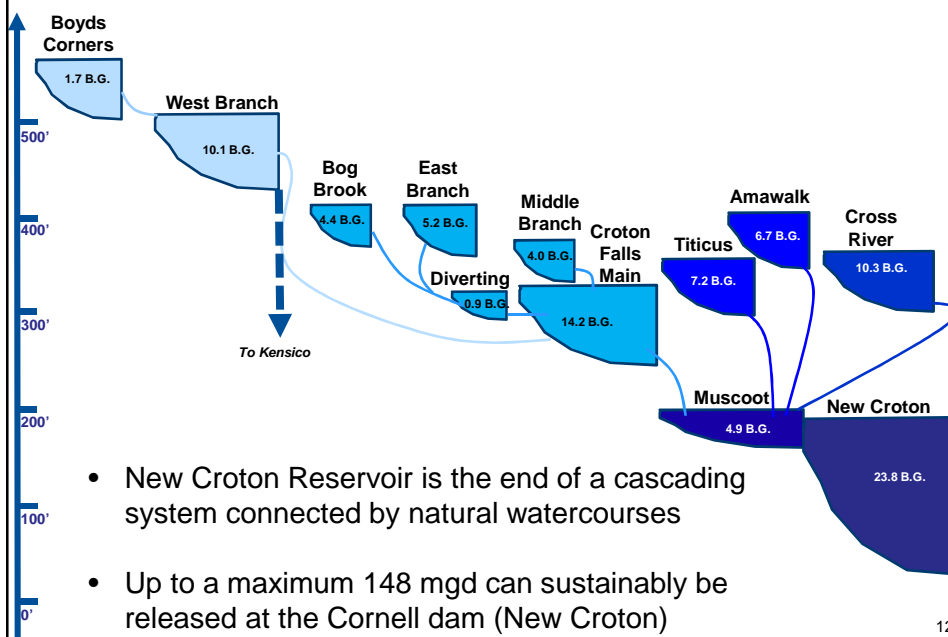
## Pilot Project Description

- **Chemical Treatment at site A and B**
  - Sonar H4C (2.7% fluridone) – A pellet applied at low concentrations 5 times, July 1 – September 30.
  - Applied at 2 ppb (NY MCL drinking water = 50 ppb)
  - Can be applied around active intakes – not during pilot
  - Used in drinking water supply in California for many years
  - Boom & curtain for pilot will prevent any spread
  - Weekly WQ samples to be collected throughout the reservoir to monitor for spread outside treatment area
- **Diver Assisted Suction Harvesting at site C**
  - Physically remove plants around the boat launch
  - Short-term solution to prevent spread



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## Constraints on Control



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## Other Constraints



- New Croton supply will need to be at full capacity (Minimal/No Releases):
  - October of 2018, 2019, 2020 while the Catskill Aqueduct is being cleaned
  - October – May of 2022, and 2023 for the Rondout bypass tunnel construction
- NYSDEC won't permit the use of grass carp due to risk of downstream spread and there are concerns with native SAV in reservoir
- The New Croton boat launch will be moving to the east in 2018
- Required Min. Flow according to Title 6 DEC Part 672-3:
  - April 1 – June 30                      75 mgd unless below normal then 16.5 mgd
  - July 1 – March 31                      5.5 mgd

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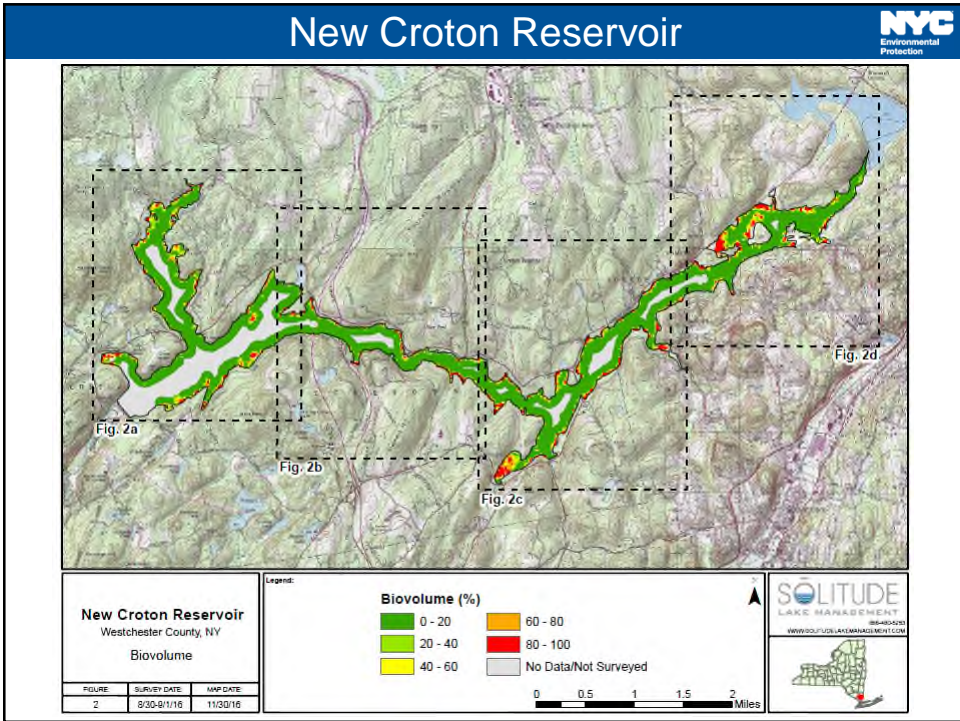
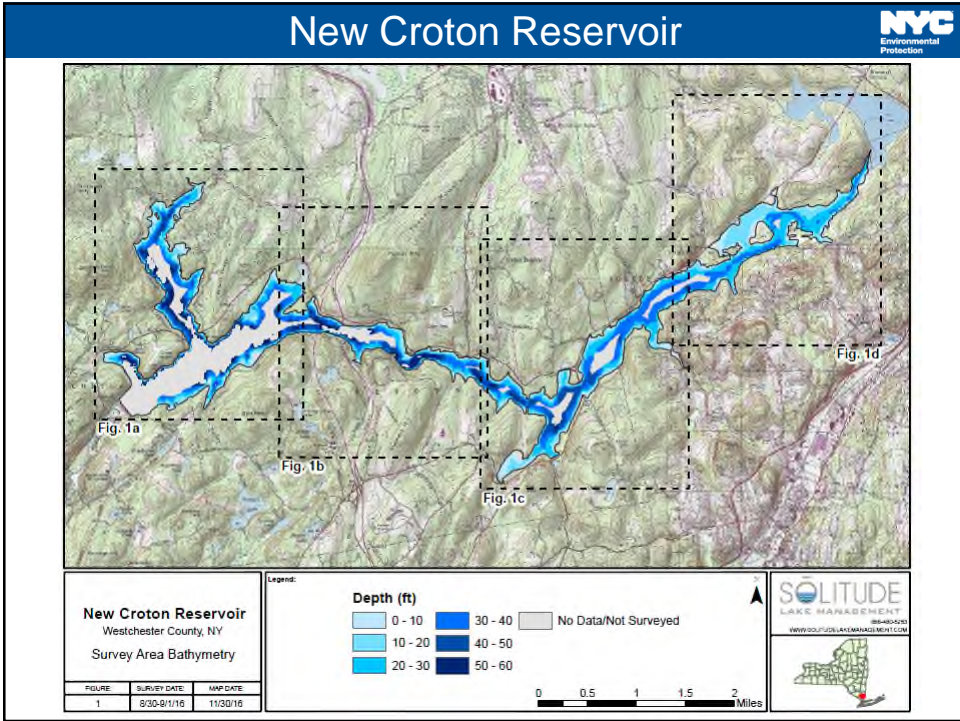
## Other Considerations



- Stakeholder perception of treatment with herbicides – regulators, consumers, environmental groups
- Permitting/ Very few control options
- Persistence of tubers- need to stay at “eradication” for > 5-10 years
- Limited surveillance information
- Multiple transport vectors and few impediments to transport
- Probability of having necessary conditions to treat consistently

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## Other SAV Present



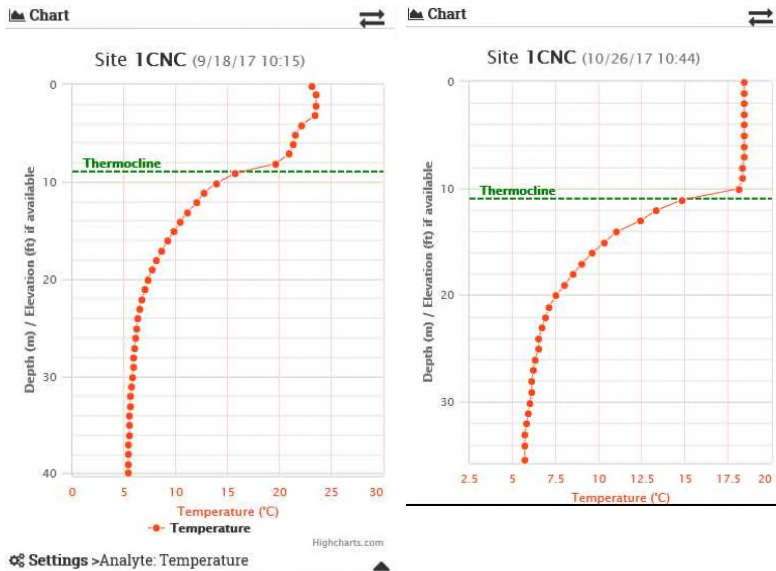
Common Name	Scientific Name	# Occurrences	% Occurrence
<b>Overall SAV</b>		<b>339</b>	<b>99.1%</b>
Coontail	<i>Ceratophyllum demersum</i>	310	90.6%
<b>Eurasian Water Milfoil</b>	<b><i>Myriophyllum spicatum</i></b>	<b>306</b>	<b>89.5%</b>
<b>Hydrilla</b>	<b><i>Hydrilla verticillata</i></b>	<b>114</b>	<b>33.3%</b>
Benthic Filamentous Algae		111	32.5%
Water Smartweed	<i>Polygonum amphibium</i>	44	12.9%
Small Duckweed	<i>Lemna minor</i>	20	5.8%
Great Duckweed	<i>Polyrhiza spirodela</i>	14	4.1%
Common Watermeal	<i>Wolffia columbiana</i>	13	3.8%
<b>Brittle Naiad</b>	<b><i>Najas minor</i></b>	<b>10</b>	<b>2.9%</b>
White Water Lily	<i>Nymphaea odorata</i>	3	0.9%
Leafy Pondweed	<i>Potamogeton foliosus</i>	3	0.9%
Long-leaf Pondweed	<i>Potamogeton nodosus</i>	3	0.9%
Clasping-leaf Pondweed	<i>Potamogeton richardsonii</i>	1	0.3%
Bassweed	<i>Potamogeton amplifolius</i>	1	0.3%
Spikerush	<i>Eleocharis</i> sp.	1	0.3%

Submersed Aquatic Vegetation Abundance Summary 2016 – Solitude Lake Management

## New Croton Reservoir Physical Conditions



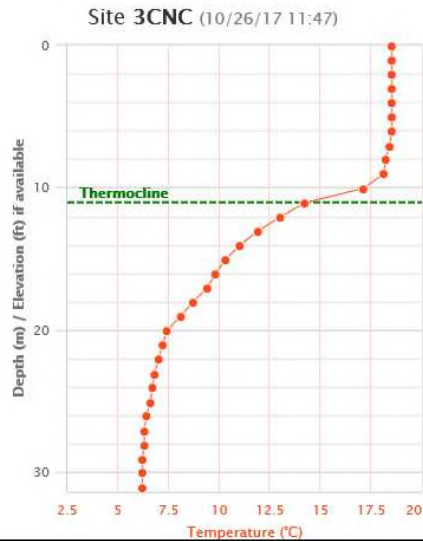
•Summer stratification occurs between April and November



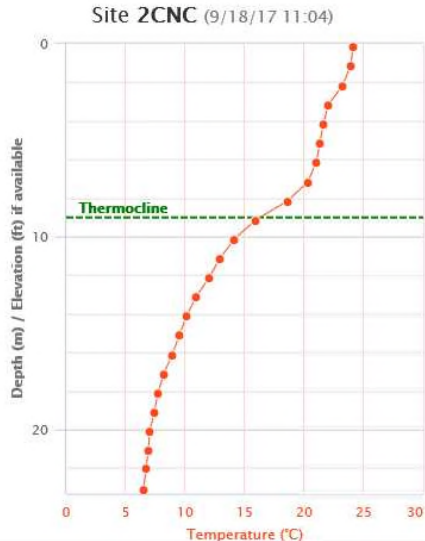
## New Croton Reservoir Physical Conditions



Chart



Chart



## New Croton Reservoir Physical Conditions



- pH is typically circumneutral
  - 2016: 11% of samples exceeded 8.5 which may reflect algal blooms in surface samples during July, August, and September
- Mean alkalinity for 2016 was 68 mg Calcium Carbonate/L
- Phosphorus is on average ~19 ppm
- Nitrogen – 3% of samples in 2016 exceeded 0.5 ppm
- Dissolved oxygen varies by depth and conditions but can be found in the range of 0.2 mg/L – 12.5 mg/L

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# Overview of Fluridone Fate and Transport

Rob Richardson  
Professor and Extension Specialist  
Crop and Soil Science Department  
North Carolina State University

NC STATE EXTENSION

## Fluridone

- Inhibits phytoene desaturase in plants
- Strongly adsorbed to sediments
- Transformation:
  - Half life of 22-55 h in deionized water
  - Half life of ~20 d in aerobic pond water
  - Half life of ~90 d in hydrosol
  - Degraded primarily by photolysis by UV light
  - Some microbial degradation
  - N methylformamide (NMF) identified in lab, but never under field conditions

WSSA. 2014. Herbicide Handbook.

NC STATE EXTENSION



## Fluridone Degradation

- Fluridone degradation occurs in the water column via photolysis by UV light
- UV light can only penetrate most natural waters to a depth of a few inches
- Water depth will have a significant influence on the speed of degradation (while the rate of degradation remains the same in the top few inches, increased water depth = more fluridone to degrade)
- Microbial degradation occurs, but is much slower than photolysis

NC STATE EXTENSION

**Submersed biomass does not correlate with a significant removal (uptake) of herbicide**

**Plant Uptake = 1 to 4% of the Herbicide Applied**



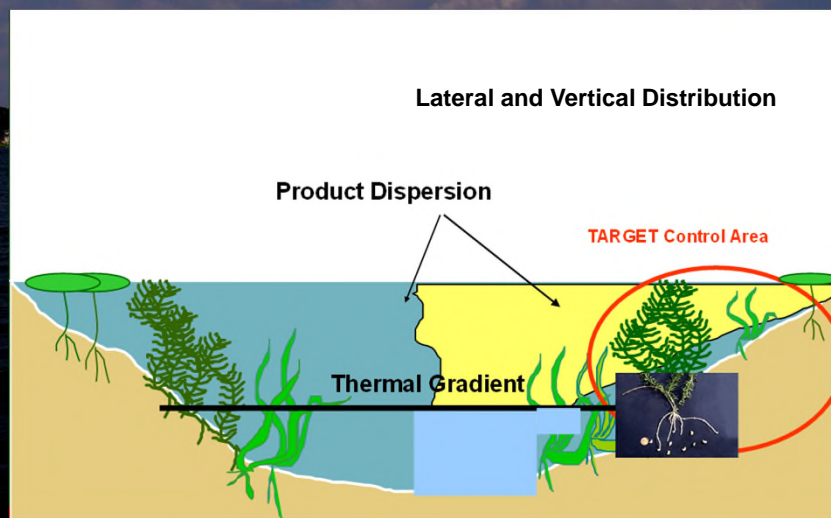
NC STATE EXTENSION

# Herbicide Dispersion

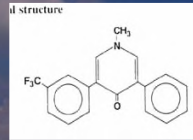
- Aquatic herbicides disperse in water
  - Movement from the application site
    - Flow, winds, current – drive dispersion
    - Scale of treatment is a major factor
- Concentrations can be rapidly diluted
  - Can be advantageous or disadvantageous
- Dispersion and degradation are distinct processes
  - Together or individually, both processes can lead to non-detectable herbicide concentrations

NC STATE EXTENSION

# Rate of Dispersion – Major Influence on Efficacy



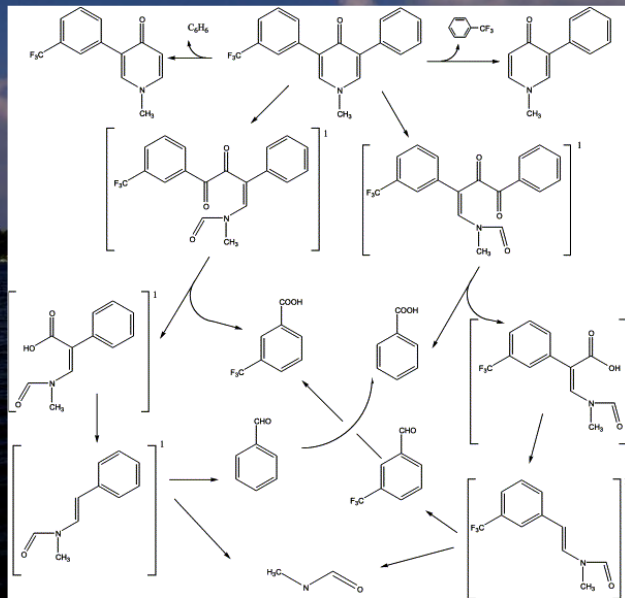
# Photolysis



- Photolysis occurs in the top inches of lake water
  - UV light penetration
- How does water depth impact degradation?
  - Degradation is much slower in deep water
  - You simply have more product to degrade in deeper water
- Can photolysis occur below a thermocline?
  - No
- Can photolysis occur below a dense plant mat?
  - Very limited

NC STATE EXTENSION

## Photolytic Degradation of Fluridone



Molecules split by photolysis into smaller parts

- Photolysis
- Microbial
- Hydrolysis

NC STATE EXTENSION



## Use of Herbicides for Hydrilla

- Treat Water to Achieve a Desired Aqueous Concentration
  - You are Targeting the Plants!
- Each Herbicide - Unique Concentration/ Exposure Profile
  - Concentrations can range from 10 to 4000 ppb
    - 400x difference in target rates
  - Exposure requirements from hrs to 3+ months
    - Up to 400X difference in exposure requirements
  - Longer exposures allow use of lower concentrations

NC STATE EXTENSION

## Monoecious Hydrilla Use Pattern

- Granular fluridone applied soon after tuber/turion sprouting (small hydrilla plants)
- Herbicide release from pellets provides low rate of fluridone over an extended period of time near sediment / water interface
- Proper application kills hydrilla shoots slowly; prevents establishment and new turion formation
- Repeated application over several years depletes the turion bank and provides long term control

NC STATE EXTENSION

# Application of Granular Fluridone

- Good fit for monoecious hydrilla
- Low fluridone concentrations in the water column
  - Higher concentrations near the sediment/ water interface (kills sprouting tubers)
- Fluridone releases slowly from formulation matrix as well as gets adsorbed and desorbed by sediments and OM.



NC STATE EXTENSION

## Examples of vertical gradient in Sonar concentration during pellet treatment: Lake Gaston NC – monoecious hydrilla

Site	6/18/ S	6/18/ M	6/18/ B	6/23/ S	6/23/ M	6/23/ B	7/6/ S	7/6/ M	7/6/ B	7/28/ S	7/28/ M	7/28/ B	8/26/ S	8/26/ M	8/26/ B
Lyons-1	ND	ND	1.3	0.5	1.6	1.2	ND	ND	1.3	1	1.2	2.6	ND	ND	1.5
Lyons-2	ND	ND	1.9	1.1	1	2.1	ND	ND	1.2	ND	1	1.4	ND	ND	1.3
Lyons-3	ND	ND	1.7	1.4	2.5	3.9	ND	ND	1.9	ND	1.3	1.6	ND	ND	1.5
Lyons-4	ND	ND	1.3	0.5	1	1.2	ND	ND	1.5	ND	ND	1.2	ND	1.1	-
Lyons-5	ND	ND	ND	1	1.1	2.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVG	ND	ND	1.29	0.9	1.44	2.12	ND	ND	1.2	ND	0.8	1.41	ND	0.42	1.14

Site	6/18/ S	6/18/ M	6/18/ B	6/23/ S	6/23/ M	6/23/ B	7/6/ S	7/6/ M	7/6/ B	7/28/ S	7/28/ M	7/28/ B	8/26/ S	8/26/ M	8/26/ B
Lyons-1	-	ND	1.2	1.2	1.8	2.6	1	ND	1.2	ND	ND	1.3	ND	ND	ND
Lyons-2	ND	1.7	3.4	0.5	1.7	1.9	ND	ND	1.2	ND	ND	ND	ND	ND	2.6
Lyons-3	1	1.7	3.9	1	1.9	2.6	1	2.2	2	ND	ND	1.2	ND	ND	ND
Lyons-4	ND	1.5	2.5	1.6	2.1	1.8	ND	ND	ND	1	ND	ND	ND	ND	1
Lyons-5	ND	ND	ND	0.5	1.2	1.8	ND	ND	ND	ND	ND	ND	ND	1	ND
AVG	ND	1.08	2.25	0.96	1.74	2.14	ND	0.3	1	ND	ND	0.65	ND	ND	0.87

NC STATE EXTENSION

Under ongoing emergency declaration, California Department of Food and Agriculture (CDFA) has used Sonar pellets in 43,000-acre **Clear Lake** for decades without any adverse effects.

Typical localized treatment

- 5 acre blocks
- 120 ppb (38 lbs 5% pellets per acre in 6 feet of water)
- split across 4 – 5 applications

CDFA sediment porewater monitoring using 'peepers'

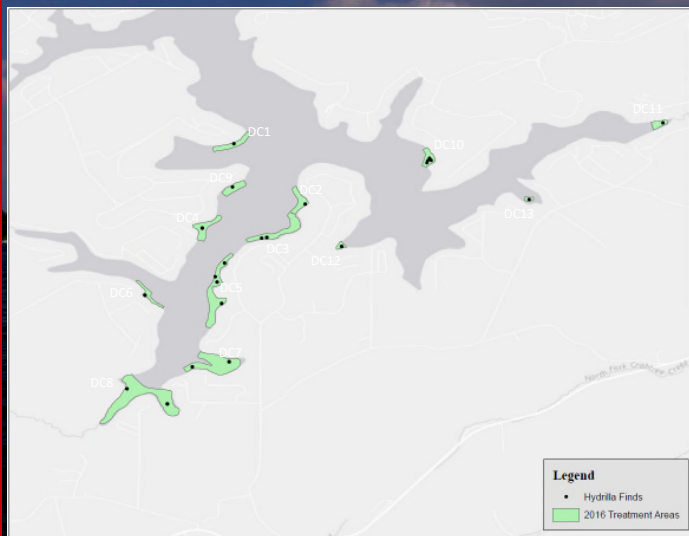
- avg = 6.1 ppb
- maximum 43 ppb

**TABLE 1: CDFA - Clear Lake - FasTEST/Peepers/Soil OM**  
Collection Date: August 4, 2009 (12 days post install)

Sample Site	FasTest		Peeper - Upper Cell (above sediment)		Peeper - Lower Cell (below sediment)		% OM
	1 ft. from surface	1 m from bottom	Peeper 1	Peeper 2	Peeper 1	Peeper 2	
	26-1	<1.0	<1.0	1.4	<1.0	19.6	
26-2	<1.0	<1.0	4.1	<1.0	3.7	11.5	3.06
26-3	<1.0	<1.0	5.6	6.6	9.7	7.8	1.21
38-1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.82
38-2	<1.0	<1.0	<1.0	<1.0	3.8	2.7	0.69
38-3	<1.0	<1.0	<1.0	<1.0	11.4	3.8	0.71
56-1	<1.0	<1.0	3.5	<1.0	5.2	2.9	13.10
56-2	<1.0	<1.0	1.6	1.2	1.2	<1.0	14.20
56-3	<1.0	<1.0	2.0	1.9	<1.0	1.6	16.20
69-1	<1.0	<1.0	<1.0	<1.0	4.0	NA	0.87
69-2	<1.0	<1.0	<1.0	1.1	2.3	2.0	1.43
69-3	<1.0	<1.0	1.0	<1.0	<1.0	42.7	0.83
77-1	<1.0	<1.0	4.4	NA	23.2	NA	1.32
77-2	<1.0	<1.0	3.3	2.0	3.7	3.6	1.24
77-3	<1.0	<1.0	2.7	1.8	10.0	11.2	0.70
Soda 1	2.3	2.8	10.2	NA	22.0	NA	6.94
Soda 2	<1.0	3.8	3.8	3.8	1.5	4.8	11.60
Soda 3	2.7	1.3	11.6	1.9	2.1	1.3	10.50
Mean*	0.72	0.86	3.21	1.52	6.94	6.79	4.87

\* Assumes concentration values <1.0 are 0.5 ppb.  
NA = No sample, peeper lost or insufficient soil

**NC STATE EXTENSION**



**Deep Creek Lake**  
**3,900 acres**  
**Western Maryland**

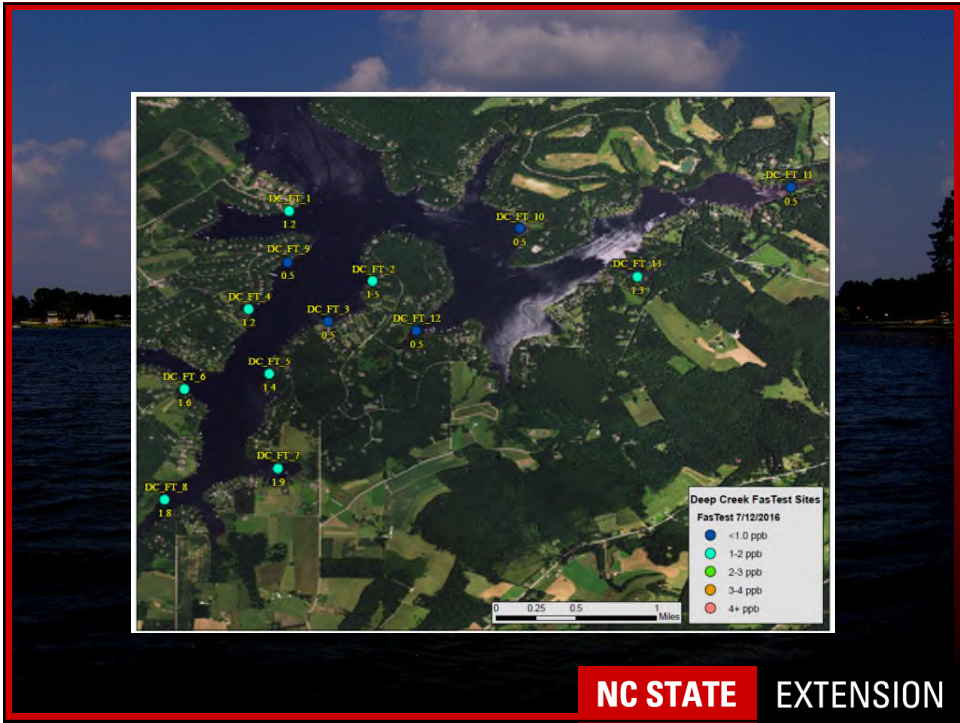
Hydrilla eradication effort since 2014.

Multiple Sonar pellet formulations used including H4C in 2016

Areas between 1 and 29 acres treated with 4 split applications totaling 50 – 135 ppb.

**NC STATE EXTENSION**





**NC STATE** EXTENSION

Representative FastTEST Analytical Summary for Deep Creek Lake  
 Sonar Pellet Treatment (2016)

ZONE FT ID	ACRES	6/14/2016	7/6/2016	7/12/2016	8/1/2016	8/16/2016	8/29/2016	9/12/2016	AVG
DC_FT_1	5.1	0.5	1.9	1.2	1.1	0.5	0.5	0.5	0.9
DC_FT_2	5.1	1.1	1.4	1.5	1.2	1.3	0.5	0.5	1.1
DC_FT_3	9.2	0.5	1.7	0.5	2	1.2	0.5	1.1	1.1
DC_FT_4	6.2	0.5	1.3	1.2	1.6	0.5	0.5	1.2	1.0
DC_FT_5	15	1.5	0.5	1.4	1.8	1.1	0.5	1.1	1.1
DC_FT_6	3.1	1	1.5	1.6	1.7	0.5	1	0.5	1.1
DC_FT_7	18.2	1.7	2.3	1.9	2.7	0.5	2.6	1.4	1.9
DC_FT_8	29.2	0.5	2	1.8	3.5	1.1	2.6	1.3	1.8
DC_FT_9	4.3	0.5	0.5	0.5	1.5	0.5	0.5	0.5	0.6
DC_FT_10	3.9	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DC_FT_11	2.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
DC_FT_12	1.2	0.5	0.5	0.5	0.5	0.5	1.2	0.5	0.6
DC_FT_13	1.1	0.5	0.5	1.3	0.5	1	1.3	0.5	0.8

**NC STATE** EXTENSION

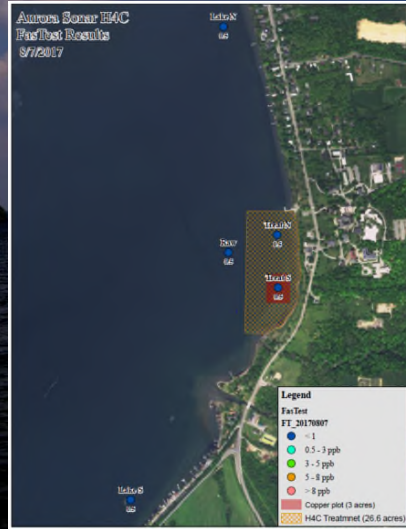


**Aurora NY Sonar H4C  
2017 FastEST Summary**

- 7 split applications of 20 ppb H4C to 27-acre area of hydrilla infestation

SITE	ppb fluridone (7 events)	
	AVG*	MAX
TreatN	0.8	1.6
LakeN	0.9	1.8
LakeS	0.9	1.6
TreatS	0.8	1.6

\*Mean calculation assumes 0.5 ppb for <1 results (one LakeN result not included due to likely sediment contamination)



**NC STATE EXTENSION**

# Questions/Discussion?



**NC STATE EXTENSION**

## Primary Mode of Degradation

All aquatic herbicides are subject to microbial degradation (one exception)

- Photolysis (5/13)
- Inactivation followed by microbial (2/13)
- Microbial Degradation (3/13)
- Hydrolysis (2/13)
- Copper (1/13) – elemental
  - Biologically inactive but never broken down

NC STATE EXTENSION

## Photolysis (5 of 13 Products)

- Energy from sun breaks chemical bonds
  - Ultraviolet (uv) light - THINK SUNBURN !!
  - Different wavelengths of uv for different molecules
- Fluridone and Penoxsulam –
  - half-lives 15 to 45+ days
  - Influenced by water depth and water clarity
- Triclopyr, Imazapyr, and Imazamox
  - half-lives average 5 to 14 days

NC STATE EXTENSION



## Understanding Fluridone Risks for Drinking Water

CHEMICAL MANAGEMENT OF HYDRILLA FOR DRINKING WATER UTILITIES  
November 17, 2017



### Risk Considerations

Human Exposure (drinking water, fish consumption)

- What is the potential for exposure?
- What is the potential for exposure to result in negative health impacts?

Exposure to Non-target Organisms

- What is the potential for exposure to result in impacts as opposed to impacts from other alternatives?

Hazen

## Methodology

Approach to looking at herbicide exposure in this presentation is based on the typical multiple barrier approach used for assessing risk to drinking water

1. Minimize presence in the reservoir (i.e. keep herbicide doses as low as possible)
2. Natural attenuation
  - Dilution of partial lake treatment within the larger reservoir
  - Natural degradation during residence time in the reservoir
3. Reduction through engineered water treatment
4. Risk of resulting level of exposure by consumers (acute and chronic)

Hazen

## Fluridone Application

Label restricts fluridone in proximity to drinking water intakes to 20 ppb

4 ppb and below has been used at a number of other waterbodies  
Croton River, D&R Canal, California Bay Delta

Spot treatment vs whole lake treatment will provide some dilution depending on flow dynamics and location of treatment and intake locations

Hazen

## Natural Attenuation

Photolysis is a major mechanism for degradation of fluridone

Wavelengths ~297 nm are particularly effective (approx 15 to 60 hours per Mossler, Shilling, and Haller, 1989)

Microbial degradation is the second major mechanism for degradation of fluridone

Wide variation between lakes, lab studies have shown up to 35% removal over 100 to 150 days

Hazen

## Fluridone Treatment Efficacy

Potential for fluridone removal with typical drinking water treatment processes

Sedimentation, Flocculation, Filtration

Some adsorption to soil particles is expected (NCBI, 2017)

$K_{oc}$  is per 260 to 740 cm<sup>3</sup>/gm, low to moderate soil adsorption (USEPA 2004)

Aeration

Volatilization from water surfaces is not expected to be an important fate process based upon fluridone estimated Henry's Law constant (NCBI, 2017)

UV Treatment

Designed for pathogen inactivation, wavelengths not optimized for fluridone

Residence time is generally too short based on fluridone photolysis studies

Hazen

## Fluridone Treatment Efficacy, cont'd

Potential for fluridone removal with typical drinking water treatment processes

### Biologically Active Filtration (ozone with carbon filters)

No information on the ability of ozone to oxidize fluridone

Adsorption is expected to occur to the carbon filter, though not optimized for synthetic organics removal

Residence time most likely too short to achieve substantial removal

### Activated Carbon

Activated carbon has been found to remove fluridone

Jar tests are needed to confirm dose, contact time and effectiveness of specific carbon products

Hazen

## USEPA Human Health Risk Assessment for Fluridone (2004)

### Hazard Characterization of Fluridone

- The acute toxicity of fluridone is moderate to low.
- Fluridone was negative for inducing mutations in all guideline studies of the standard battery of mutagenicity tests.
- No neurotoxicity was reported in any of the studies.
- Fluridone did not significantly affect any of the reproductive parameters.
- In the available toxicity studies there were no estrogen, androgen and/or thyroid mediated toxicity, but may be subjected to additional screening and/or testing to better characterize effects related to endocrine disruption.

Hazen



## USEPA Human Health Risk Assessment for Fluridone (2004)

Table 10 - Drinking Water Exposure Fluridone MOEs					
Exposed Person - Body Weight	Water Concentration (ug/l)	Water Consumption (liter/day)	Dose (mg/kg/day)	NOAEL (mg/kg/day)	MOE
<b>Acute Exposure</b>					
Adult - 60 kg	20	2	0.00067	125	187500
<b>Short/Intermediate Term and Chronic Exposures</b>					
Adult - 60 kg	20	2	0.00067	15	22500
Adult - 70 kg	20	2	0.00057	15	26250
Infant/Child - 10 kg	20	1	0.00200	15	7500

Margin of Exposure (MOE) of a substance is the ratio of its no-observed-adverse-effect level (NOAEL) to its estimated dose of human intake

Hazen

## USEPA Human Health Risk Assessment for Fluridone (2004)

Table 11 - Drinking Water Exposure NMF MOEs					
Exposed Person - Body Weight	Water Concentration (ug/l)	Water Consumption (liter/day)	Dose (mg/kg/day)	NOAEL (mg/kg/day)	MOE
<b>Acute Exposure</b>					
Adult - 60 kg	2.64	2	0.000088	10	113636
<b>Short/Intermediate Term Exposure</b>					
Adult - 70 kg	2.64	2	0.000075	10	132576
Infant/Child - 10 kg	2.64	1	0.000264	10	37879

Hazen

## USEPA Fluridone Registration Review

Risk Assessment expected to be published in the next month or two

Record of decision expect in the May to July timeframe

*“The Agency does not expect to conduct a drinking water assessment (DWA) as part of registration review for fluridone because maximum application rates to waters near drinking water inputs have not increased since the 2004 TRED.”*

Re-registration decision unlikely to affect current label restrictions on uses in sources of drinking water

Hazen

## Ecotoxicology of Fluridone

### California Boating and Waterways

Application and toxicity studies on ESA aquatic resources in Bay Delta region have shown no adverse effects in ~15 years of studies and treatments

### Bureau of Land Management Fluridone Ecological Risk Assessment

The LC<sub>50</sub> (1.3 mg/L) was selected as the invertebrate acute TRV, and the NOAEL of 0.6 mg/L was selected as the chronic TRV.

The lower of the cold- and warmwater fish endpoints were selected as the TRVs for fish. Therefore the coldwater 96-hour LC<sub>50</sub> of 4.2 mg/L was selected as the acute TRV, and the warmwater fish NOAEL of 0.48 mg /L was used as the TRV for chronic effects.

### Wagner et al, 2017 Impacts to species richness and non-target plants

Some observable impacts during first year, but recovery in year 2 and 3

Hazen



**APPENDIX E**  
**WORKSHOP DISCUSSION SUMMARY**

November 17, 2017

## CHEMICAL MANAGEMENT OF HYDRILLA FOR DRINKING WATER UTILITIES

### Workshop Summary

#### Mechanical Treatment

##### 1. Benthic Barriers

Consensus seems to be that using benthic mats/barriers are effective in the short term and as spot treatment. They cannot be left in place from season to season due to sediment settlement on top and likely vegetation growth making it extremely difficult to remove at a later date.

In the southern portion of Cayuga Lake, the mats were to support the SONAR treatment in the first year. The fluridone treatment was ineffective due to the water turnover in Fall Creek. In the Delaware and Raritan Canal (D&R Canal), the barriers are on the wish list of treatment methods as this is considered an ongoing management plan for the hydrilla removal. Henrietta Pond, in upstate New York, uses benthic barriers and it is effective, however this works due to the smaller size of the water body.

Limitations: Benthic barriers are not considered economically feasible as a standalone treatment method due to the size of the reservoir. Using the mats as more of a spot treatment would also prove to be too expensive. The NYC DEP estimated that for a small portion of treatment area the cost would be approximately two million dollars.

##### 2. Hand-pulling/Hand-tool removal

Cayuga Lake/Inlet uses this method for new emergence of plants, if it is not dense growth, discovery in new areas, and for any remaining plants after fluridone treatment. This requires an intensive amount of monitoring. D&R Canal considers hand-pulling as part of the future management of hydrilla removal, in combination with spot treatments and potential use of benthic mats.

Limitations: Hand removal of the plant is problematic. Fragmentation of monocious hydrilla, the type found in New York, increases dispersion of viable plants capable of reproduction. Combining suction harvesting with hand-pulling can limit the amount of plant fragments.

##### 3. Silt Curtains

Silt curtains are suspended vertically from the surface of the water to the sediment. The curtains can prolong contact time of the herbicide, capture fragments of the plant, or they can be used in areas with increased water flow to deflect the current and reduce the dilution of the herbicide in the treatment area.

Limitations: Economically and logistically not feasible due to the size and depth of the Reservoir. Could potentially use curtains for pilot areas, however this will depend on desired outcome of testing. It will

prove difficult to curtain the pilot area (20 miles). The curtain would need to be up for 60-90 days. Could be damaged in that time. Fishermen could damage with boat.

## Biocontrol

### 1. Carp

Grass carp stocking is used in other states which permit the introduction of the fish. Grass carp are commonly used in aquatic weed control due to their plant-based diet. Most states require the use of sterile triploid carp if introduced into the water ways.

Limitations: Though grass carp have been used in other states to assist with the removal of hydrilla infestations, the New York State Department of Environmental Conservation (NYSDEC) will not permit the introduction into the Reservoir.

### 2. Arthropods

Scientists are currently conducting research on the use of arthropods as biological control. Larvae of insects typically associated with hydrilla and other macrophytes feed on the plant tissue. There is a researcher in China and Korea currently working with chironimdae which are very effective on hydrilla. There is possible quarantine testing soon.

Limitations: Research is ongoing, still in testing phase.

## Herbicides / Chemical Treatment

The size of the infestation usually dictates the use of herbicides as the primary treatment method. If herbicides are chosen as the treatment method, a management plan including other types of treatment will likely be more successful.

Multiple year management plans are necessary for eradication. None of the herbicides will translocate to the tuber bank. By removing the shoots each season, the tuber bank will slowly be depleted. Most eradication programs using fluridone have a policy of treating 1-3 seasons beyond the absence of hydrilla to assure success.

### 1. Chelated copper:

A contact herbicide effective in removal of hydrilla. Chelated copper-containing pesticides disrupt cell walls and alter proteins in the plant tissue. Effective as a backup control method used in conjunction with long-acting, systemic herbicides. The damage to the plant tissue from a chelated copper treatment could increase the efficacy of other herbicides.

Used at the Aurora site in Cayuga Lake (Figure 5) as a backup to the fluridone treatment. This treatment reduced the presence of hydrilla from 60% to 2% in the first year. This is an ongoing treatment.

California Department of Food and Agriculture (CDFA) uses copper in conjunction with fluridone treatment in their hydrilla eradication program in Clear Lake (Figure 6). As part of the treatment plan, copper is applied mid-season if plants are found.



Limitations: Historical use of copper within New York, however something occurred (Meredith can find backstory) years ago which caused the use of copper-containing herbicides to be restricted/banned. Broad-spectrum herbicide which will damage non-target plants if dispersed in water column and not applied directly to the hydrilla plant.

## 2. Endothall:

A systemic aquatic herbicide which inhibits photosynthesis and protein synthesis in targeted plants. Valuable herbicide in treatments which require short application times due to operational constraints.

Due to a high water exchange environment from the Niagara River, water movement impedes management plans. Operational constraints allow short blocks of time to apply herbicides. At the Erie Canal a treatment window of only 48 hours was possible. The application of endothall occurred over four years and reduced the presence of hydrilla from 40% down to 1%.

One of the two best options out of 26 management options the D & R Canal management team considered. Endothall was included as a backup in the plan along with hydro-raking, to support the fluridone treatments.

Limitations: More toxic than copper or fluridone. Drinking water MCL 0.1 mg/L.

## 3. Fluridone:

A systemic aquatic herbicide which damages carotenoid and chlorophyll pigments crucial to photosynthesis. Effective herbicide in low dose – long term applications.

Fluridone is used as the primary treatment method in the D & R Canal, which has five drinking water intakes and two intakes for irrigation. Because of the density of the infestation, fluridone was the best option. The Aurora site at Cayuga Lake is the water supply for a small municipality. Fluridone was chosen due to the need for a longer acting systemic chemical treatment.

There has been no recorded bioaccumulation in plants, no direct impact on fish or other non-target species. Because it is a long acting treatment (90 days), the nutrient release from the dying plants is lower impact than that of fast acting herbicides.

Limitations: Raw water intakes off of the New Croton Reservoir (if any) might be problematic for non-drinking water purposes. Water mixing lowers effectiveness of the treatment.

## New Croton Reservoir Constraints

- New Croton Reservoir is at the bottom of system. There is very little control over elevation of water in the reservoir. Because the levels fluctuate, the tubers can be in deeper water and difficult to access for periods of time.
- 2.7% fluridone, pellet, 5x 7/1-9/30, 2ppb. NY MCL = 50ppb. Can be applied around intakes, **but not during pilots**.
- Goal of eradication 5-10 years, however the Reservoir needs to be at full capacity for the duration of the 2018, 2019, and 2020 Catskill Aqueduct cleaning and the 2022-2023 RWBT shutdown. The reservoir cannot be drawn down.

- Potential impact on Croton River NYSDEC hydrilla management plan. NYSDEC Article 15 permit applied for annually. Upstream source of the herbicide might complicate matters in the application process each year.
- Reintroduction: Excursions of the plant through the entire system of reservoirs and water ways, waterfowl, boating.
- Limitations in the pesticide permitting process: native vegetation, drinking water, irrigation crops, livestock watering, low concentration material over long period time. Complications in the ongoing monitoring of the permit.
- Size of reservoir and budget limitations for survey limited the survey to one week instead of three weeks that it would likely take to survey the 36 miles of shoreline.

## Monitoring

- Water quality monitoring to inform the utility and end users
- Water quality monitoring to inform decisions moving forward, i.e. how long to retain certain concentration throughout the project area
- Plant and tuber monitoring to determine the timeline of the plants' responses to the treatments

There are several constraints when regarding water quality monitoring. Details of the logistics in sampling, analysis, turnaround time impact the efficacy of program. These constraints should be considered in determining the frequency of monitoring necessary. There are no guidelines for monitoring.

- Croton River monitoring was determined by threshold level.
- Aurora site at Cayuga Lake: daily monitoring
- D & R Canal: weekly monitoring of plant. Now it is less frequent.

Water quality monitoring for drinking water samples are constrained by laboratory turnaround times. These tests will provide a lower detection limit. The average turnaround is 3-4 days, but it has been delayed up to 5-10 days. Problematic considering that people will already be drinking the water. Fast tests are available but with higher detection limits. The lower limit of a fast test is 1ppb, while the lower limit of the laboratory test is 0.29ppb. There is currently one chemist at an accredited laboratory in Connecticut which is used regionally. D&R Canal submitted samples and the variability in testing was observed up to 40% with duplicate testing using differing methodologies.

## Outreach

1. D & R Canal: Prior to the treatment, two meetings were held with stakeholders. Contacted the NJDEP and reached out to all mayors, elected officials of the towns the Canal runs through. A FAQ sheet was prepared and educational signage was posted at over 100 locations. In addition, a website was created for the treatment. Surface water sample results were posted 24-48hrs after received.

They provided a script to all people potentially getting phone calls about the treatment program. Information on sampling efforts and results was sent daily for first month and half to all users. Two newspaper articles published (New Brunswick) both with a positive spin. They

received no negative feedback from the season and a lot of positive feedback received on local and national scale.

Feedback from the public included a request for a fluridone emergence response plan. The plan was effective in assuaging concerns.

2. Cayuga Lake: Put emphasis on public outreach. Hydrilla happy hours open to anyone interested were held at a local establishment impacted by the management plan. Some negative feedback from a Cornell professor writing editorials against the project. To address his concerns, he was invited to the public meetings. He attended and that issue was resolved.
3. Croton River: Very little pushback received from the public because of the amount of transparency given to public. The 5th public stakeholder meeting will be hosted in January providing as much info as possible on what has happened and what modifications are coming. A letter distribution goes out to all of the riparian owners before the application begins. DEC is willing to provide public outreach assistance for DEP.

DEP will likely have to work more closely with Ossining because the DEC wasn't impacting their drinking water directly and the town wasn't interested in involvement.

DEC didn't provide any more information than what was presented today on toxicological concerns, and it was acceptable. Diving into the EPA toxicology numbers started to go over people's heads.

4. Learning from emerging contaminant projects: best way to communicate this information is to flip the information. Ex: state how many glasses of water you would have to drink before it impacted human health.

## No Action Alternative

The implications of a no action alternative range could mean increased risk to human health, higher water utility rates, and ecological degradation. After the discovery of hydrilla in the Eno River in North Carolina, there was a five-year delay from first meeting held until action was taken to manage the infestation. During this time, it spread a mile per year for each year in that time. The amount of hydrilla nearly double in those five years. Surveys in the Croton River showed an increase of 60% growth between 2015 and 2016.

Unmanaged hydrilla poses a risk to our public drinking water supply. Dense mats of hydrilla can cause a reservoir to lose capacity to hold its maximum volume. In addition, the plants can block drinking water intakes and clog the UV used to treat the water. If left unmanaged in the Croton system, the plant can migrate to some of the smaller reservoirs in the system impacting more of the water supply. If the plant reaches the Catskill / Delaware system, it can deeply impact the main drinking water source. All of aforementioned risks can lead to higher water rates for the consumer, and potentially decrease access to potable water.



The rapid growth of the plant can out compete native plant species, lead to eutrophication of the water system, and alter the water quality. Hydrilla is now in the New Croton Reservoir and the Croton River. The Croton River leads to the Hudson River and there are concerns of an infestation establishing in hospitable locations, and ultimately spreading to tributaries along the river.



## REFERENCES

- Arias, R. S., Netherland, M. D., Scheffler, B. E., Puri, A., and Dayan, F. E. 2005. "Molecular Evolution of Herbicide Resistance to Phytoene Desaturase Inhibitors in *Hydrilla verticillata* and Its Potential Use to Generate Herbicide-Resistant Crops." *Pest Management Science*, 61(3): 258-268.
- BASF Corporation. 2010. *Clearcast Pesticide Label*. Florham Park, NJ: BASF.
- BASF Corporation. 2014. *OASIS Pesticide Label*. Florham Park, NJ: BASF.
- Blackburn, R. D., and Weldon, L. W. 1970. "Control of *Hydrilla verticillata*." *Hyacinth Control Journal*, 8(4).
- CADBW (California Department of Boating and Waterways). 2012. *Egeria densa Control Program Biological Assessment: A Program for Selective Control of Egeria densa in the Sacramento-San Joaquin Delta and Its Tributaries*. Accessed December 4, 2017. [http://www.dbw.ca.gov/pages/28702/files/EDCP-Biological\\_Assessment-131231.pdf](http://www.dbw.ca.gov/pages/28702/files/EDCP-Biological_Assessment-131231.pdf).
- CDMS (Crop Data Management Systems, Inc.). 2018. Pesticide Label Database. Accessed February 12, 2018. <http://www.cdms.net/Label-Database>.
- Chamberlain, E., Shi, H., Wang, T., Ma, Y., Fulmer, A., and Adams, C. 2011. "Comprehensive Screening Study of Pesticide Degradation via Oxidation and Hydrolysis." *Journal of Agricultural and Food Chemistry*, 60(1): 354-363.
- Cornell Cooperative Extension. 2016a. "Fighting Hydrilla in the Cayuga Lake Watershed." Accessed December 3, 2017. <http://csetompkins.org/environment/invasive-nuisance-species/aquatic-invasives/hydrilla/fighting-hydrilla-in-the-cayuga-lake-watershed>.
- Cornell Cooperative Extension. 2016b. "Hydrilla Frequently Asked Questions." Accessed February 21, 2018. <http://csetompkins.org/environment/aquatic-invasives/hydrilla/about-hydrilla/hydrilla-faq>.
- Croton-on-Hudson. 2017. "Village Water Department." Accessed December 12, 2017. [http://www.crotononhudson-ny.gov/Public\\_Documents/CrotonHudsonNY\\_WebDocs/Water/index](http://www.crotononhudson-ny.gov/Public_Documents/CrotonHudsonNY_WebDocs/Water/index).
- Dodd, S. R., Haynie, R. S., Williams, S. M., and Wilde, S. B. 2016. "Alternate Food-Chain Transfer of the Toxin Linked to Avian Vacuolar Myelinopathy and Implications for the Endangered Florida Snail Kite (*Rostrhamus sociabilis*)." *Journal of Wildlife Diseases*, 52(2): 335-344.
- Durkin, P. R. 2008. *Fluridone: Human Health and Ecological Risk Assessment Final Report*. Washington, DC: USDA Forest Service.
- Ellis, K. 2014. "There's Something Fishy in North Carolina's Freshwater...and It's Not the Fish." Accessed December 2, 2017. <http://jomc565.web.unc.edu/2014/12/09/theres-something-fishy-in-north-carolinas-freshwater-and-its-not-the-fish/>.
- ENSR International. 2005. *Fluridone Ecological Risk Assessment*. Reno, NV: Bureau of Land Management.
- EPA (US Environmental Protection Agency). n.d. "Models for Pesticide Risk Assessment." Accessed December 4, 2017. <https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#health>.
- EPA (US Environmental Protection Agency) 2004. *Human Health Risk Assessment for Fluridone*. Washington, DC: EPA Office of Prevention, Pesticides, and Toxic Substances.



- EPA (US Environmental Protection Agency). 2009. *Water Treatment Technology Feasibility Support Document for Chemical Contaminants for the Second Six-Year Review of National Primary Drinking Water Regulations*. Accessed December 6, 2017. <https://nepis.epa.gov/Exe/ZyPDF.cgi/P1007BBH.PDF?Dockey=P1007BBH.PDF>.
- EPA (US Environmental Protection Agency) 2015. *Endothall: Human Health Risk Assessment in Support of Registration Review*. Washington, DC: EPA Office of Chemical Safety and Pollution Prevention.
- EPA (US Environmental Protection Agency). 2018. "Introduction to Pesticide Labels." Accessed January 21, 2018. <https://www.epa.gov/pesticide-labels/introduction-pesticide-labels>.
- FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act). 1996. 7 U.S.C. §136 et seq.
- Getsinger, K. D., Poovey, A. G., Glomski, L., Slade, J. G., and Richardson, R. J. 2011. *Utilization of Herbicide Concentration/Exposure Time Relationships for Controlling Submersed Invasive Plants on Lake Gaston, Virginia/North Carolina*. Vicksburg, MS: Engineer Research and Development Center Environmental Lab.
- Giannotti, A. L., Egan T. J., Netherland, M. D., Williams, M. L., and Knecht, A. K. 2014. *Hydrilla Shows Increased Tolerance to Fluridone And Endothall In the Winter Park Chain of Lakes: Considerations for Resistance Management and Treatment Options*. Accessed February 23, 2018. <https://conference.ifas.ufl.edu/aw14/Presentations/Grand/Thursday/Session%209A/0850%20Giannotti.pdf>.
- Great Lakes Hydrilla Collaborative. 2018. "Tonawanda Creek/Erie Canal Hydrilla Eradication Project, New York." Accessed February 21, 2018. <http://hydrillacollaborative.com/Home/CaseStudies>.
- Harms, N. E., Purcell, M., Zhang, J., Grodowitz, M. J., and Ding, J. 2017. *Surveys for Biological Control Agents of Hydrilla verticillata in the Peoples Republic of China in 2013*. Vicksburg, MS: US Army Engineer Research and Development Center, Environmental Laboratory.
- Haughey, M. A., Anderson, M. A., Whitney, R. D., Taylor, W. D., and Losee, R. F. 2000. "Forms and Fate of Cu in a Source Drinking Water Reservoir following CuSO<sub>4</sub> Treatment." *Water Research*, 34(13): 3440-3452.
- Hoyer, M. V., and Canfield, D. E. (Eds.). 1997. *Aquatic Plant Management in Lakes and Reservoirs*. Gainesville, FL: University of Florida, Center for Aquatic Plants.
- IFAS (University of Florida, Institute of Food and Agricultural Sciences). 2017a. "2,4-D Considerations." Accessed December 15, 2017. <https://plants.ifas.ufl.edu/manage/developing-management-plans/chemical-control-considerations/24-d-considerations/>.
- IFAS (University of Florida, Institute of Food and Agricultural Sciences). 2017b. "Biological Control." Accessed December 15, 2017. <https://plants.ifas.ufl.edu/manage/control-methods/biological-control/>.
- IFAS (University of Florida, Institute of Food and Agricultural Sciences). 2017c. "Details about the Aquatic Herbicides Used in Florida." Accessed November 13, 2017. <https://plants.ifas.ufl.edu/manage/control-methods/chemical-control/details-about-the-aquatic-herbicides-used-in-florida/>.
- Kornacki, A., Greer, L., Ruby, R., Netherland, M., and Greer, M. 2014. "Combating Hydrilla." Accessed January 18, 2018. <http://www.lrb.usace.army.mil/Media/News-Stories/Article/494240/combating-hydrilla/>.

- Langeland, K. A. 1996. “*Hydrilla verticillata* (LF) Royle (Hydrocharitaceae), The Perfect Aquatic Weed.” *Castanea*, 293-304.
- Masterson, J. 2007. “Indian River Lagoon Species Inventory.” Accessed February 15, 2018. [http://www.sms.si.edu/irlspec/Hydrilla\\_verticillata.htm](http://www.sms.si.edu/irlspec/Hydrilla_verticillata.htm).
- McGaughey, B. D. 2012. *Presentation for The Interface between Aquatic Herbicide Use and Salmonids: A Focus on Critical Habitat in the Pacific Northwest Region*. Accessed January 18, 2018. <http://www.complianceservices.com/wp-content/uploads/2014/06/Aquatic-Herbicide-Toxicology-CoE-Presentation.pdf>.
- McGlynn, C., and Eyres, W. 2017. *Croton River Hydrilla Control Project Five Year Management Plan*. Albany, NY: New York State Department of Environmental Conservation, Bureau of Invasive Species and Ecosystem Health.
- Mossler, M. A., Shilling, D. G., and Haller, W. T. 1989. “Photolytic Degradation of Fluridone.” *Ecology*, 55: 188-194.
- Mulholland-Olson, C. 2004. “Introduced Species Summary Project Hydrilla (*Hydrilla verticillata*).” Accessed February 2, 2018. [http://www.columbia.edu/itc/cerc/danoff-burg/invasion\\_bio/inv\\_spp\\_summ/Hydrilla\\_verticillata.html](http://www.columbia.edu/itc/cerc/danoff-burg/invasion_bio/inv_spp_summ/Hydrilla_verticillata.html).
- NCAES (North Carolina Agricultural Extension Service). 1992. *Hydrilla*. Accessed November 2, 2017. <http://www.weedscience.ncsu.edu/aquaticweeds/hydrilla.PDF>.
- NCBI (National Center for Biotechnology Information). 2017. “Fluridone Compound Information.” Accessed November 8, 2017. <https://pubchem.ncbi.nlm.nih.gov/compound/fluridone#section=Top>.
- NEANS (Northeastern Aquatic Nuisance Species Panel). 2017. “Ecological and Economic Costs Associated with Hydrilla (*Hydrilla verticillata*).” Accessed November 8, 2017. <https://www.northeastans.org/hydrilla/ecoconhydrilla.htm>.
- Netherland, M. 2011. *Environmental Fate of Aquatic Herbicides*. Accessed October 30, 2017. <https://conference.ifas.ufl.edu/sehac/Onsite%20pdfs/Wednesday-pdf/Aquatic%20III/0825%20Netherland.pdf>.
- Netherland, M. D., Jones, K. D., Ruby, R., and Greer, M. n.d. “A Synopsis of the 2014 Hydrilla Treatments on the Erie Canal.” Accessed November 28, 2017. <http://erie.cce.cornell.edu/resources/a-synopsis-of-the-herbicide-treatments-for-control-of-hydrilla-on-the-erie-canal>.
- Nufarm Americas. 2017. *Clipper Pesticide Label*. Alsip, IL: Nufarm Americas.
- NYCDEP (New York City Department of Environmental Protection). 2010. *Rules for the Recreational Use of Water Supply Lands and Waters*. Accessed July 21, 2017. <http://www.nyc.gov/html/dep/pdf/recrules/recrules.pdf>.
- NYCDEP (New York City Department of Environmental Protection). 2018. “Muscoot Reservoir.” Accessed November 21, 2017. [http://www.nyc.gov/html/dep/html/watershed\\_protection/muscoot.shtml](http://www.nyc.gov/html/dep/html/watershed_protection/muscoot.shtml).
- NYSDEC (New York State Department of Environmental Conservation). 2017a. “Hydrilla in New York.” Accessed July 17, 2017. <http://www.dec.ny.gov/animals/104790.html>.
- NYSDEC (New York State Department of Environmental Conservation). 2017b. “Triploid Grass Carp in New York Ponds.” Accessed December 22, 2017. <http://www.dec.ny.gov/outdoor/7973.html>.
- NYSDEC (New York State Department of Environmental Conservation). 2017c. “Water Sample Analysis Results - Croton River Hydrilla Project.” Accessed November 1, 2017. <http://www.dec.ny.gov/animals/110624.html>.

- NYCRR (Codes, Rules and Regulations of The State of New York). n.d. “Water Quality Standards for Taste-, Color- and Odor-Producing, Toxic and Other Deleterious Substances. Title 6. Chapter X. Subchapter A. Article 2. Part 703. Section 5.” [https://govt.westlaw.com/nycrr/Document/I4ed90418cd1711dda432a117e6e0f345?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=\(sc.Default\)&bhcp=1](https://govt.westlaw.com/nycrr/Document/I4ed90418cd1711dda432a117e6e0f345?viewType=FullText&originationContext=documenttoc&transitionType=CategoryPageItem&contextData=(sc.Default)&bhcp=1).
- Ortiz, M., Nissen, S. J., and Gray, C. J. 2017. *Endothall Behavior in Eurasian Watermilfoil (Myriophyllum Spicatum) and Hydrilla (Hydrilla Verticillata)*. Accessed December 15, 2017. [https://www.icaiss.org/pdf/2017presentations/Tuesday/PM/1F/500\\_Ortiz.pdf](https://www.icaiss.org/pdf/2017presentations/Tuesday/PM/1F/500_Ortiz.pdf).
- Owens, C. S., Smart, R. M., and Dick, G. O. 2012. “Tuber and Turion Dynamics in Monoecious and Dioecious Hydrilla (*Hydrilla verticillata*).” *Journal of Aquatic Plant Management*, 50: 58-62.
- Petta, J., Riffle, M., and Chamberlin, J. 2012. *New Tradewind and Clipper Aquatic Herbicides*. Accessed December 4, 2017. <https://conference.ifas.ufl.edu/aw12/PDFs%20of%20Onsite%20PPTs/Thursday/B/10b%201000%20Valent%202012.pdf>.
- Rybicki, N. B., and Landwehr, J. M. 2007. “Long-Term Changes in Abundance and Diversity of Macrophyte and Waterfowl Populations in an Estuary with Exotic Macrophytes and Improving Water Quality.” *Limnology and Oceanography*, 52(3): 1195-1207.
- SePRO. 2017. *Sonar Pesticide Label*. Rocky Mount, NC: SePRO.
- SePRO. 2012. *Galleon Pesticide Label*. Rocky Mount, NC: SePRO.
- SOLitude Lake Management. 2017. *D&R Canal Submersed Aquatic Vegetation Management Plan*. Accessed November 15, 2017. <http://www.njwsa.org/uploads/1/0/8/0/108064771/2017finaldrCANALSavmanplanslms.pdf>.
- Stubbs, D. 2014. *EPA and Aquatic Pesticide Registration - No Unreasonable Adverse Effects on Man or the Environment*. Accessed October 27, 2017. [http://michiganlakes.msue.msu.edu/uploads/files/Convention\\_Presentations\\_Thursday/D\\_on\\_Stubbs\\_AERF\\_EPA\\_and\\_Aquatic\\_Pesticide\\_Registration.pdf](http://michiganlakes.msue.msu.edu/uploads/files/Convention_Presentations_Thursday/D_on_Stubbs_AERF_EPA_and_Aquatic_Pesticide_Registration.pdf).
- Sun, K., Keiluweit, M., Kleber, M., Pan, Z., and Xing, B. 2011. “Sorption of Fluorinated Herbicides to Plant Biomass-Derived Biochars as a Function of Molecular Structure.” *Bioresource Technology*, 102(21): 9897-9903.
- Sutton, D. L., and Vandiver, V. V. 1986. *Grass carp: A Fish for Biological Management of Hydrilla and Other Aquatic Weeds in Florida*. Gainesville, FL: Agricultural Experiment Stations, Institute of Food and Agricultural Sciences, University of Florida.
- Syngenta Crop Protection. 2009. *Diquat Pesticide Label*. Greensboro, NC: Syngenta Crop Protection.
- TAMU (Texas A&M University) AgriLife Extension. 2017. “Aquaplant A Pond Manager Diagnostic Tool: Hydrilla”. Accessed December 13, 2017. <https://aquaplant.tamu.edu/management-options/hydrilla/>.
- True-Meadows, S., Haug, E. J., and Richardson, R. J. 2016. “Monoecious Hydrilla—A Review of The Literature.” *J. of Aquat. Plant Manage.*, 54: 1-11.
- United Phosphorous, Inc. 2016. *Aquathol K Pesticide Label*. King of Prussia, PA: United Phosphorous.
- United States Army Corps of Engineers. 1986. *Hydrilla in the Potomac River and Tributaries (MD, VA, DC): Environmental Impact Statement*. Washington, DC: United States Army Corps of Engineers.

- United States Army Corps of Engineers. 2014. "The Invasion Curve." Accessed January 25, 2018. <https://media.defense.gov/2014/Jul/30/2000809105/-1/-1/0/140501-A-UK000-001.JPG>.
- USFWS (US Fish and Wildlife Service). 2015. "Triploid Grass Carp." Accessed December 3, 2017. <https://www.fws.gov/warmsprings/FishHealth/fishbusters.html>.
- USGS (US Geological Survey). 2016. "*Hydrilla verticillata* Distribution by Drainage and Biotype (October 2016)." Accessed January 18, 2018. <https://nas.er.usgs.gov/XIMAGESERVERX/2016/20161027161554.jpg>.
- USGS (US Geological Survey). 2017. "Nonindigenous Aquatic Species *Hydrilla verticillata*." Accessed December 12, 2017. <https://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=6>.
- Valent. 2012. *Tradewind Pesticide Label*. Washington, DC: Valent.
- Wagner, K. J. 2004. *The Practical Guide to Lake Management in Massachusetts: A Companion to The Final Generic Environmental Impact Report on Eutrophication and Aquatic Plant Management in Massachusetts*. Boston: Commonwealth of Massachusetts, Executive Office of Environmental Affairs.
- Wagner, K. J., Verteramo, M., Stewart, T., Burke, K., Sawicki, E., Carron, A., and Tying, P. 2017. Impact of Low Dose Fluridone Treatments on Aquatic Plant Richness and Non-Target Species. Presented at North American Lake Management Society, November 6-9, 2017, Denver, Colorado.
- Washington Department of Ecology. 2002. "Aquatic Plant Management Description of Method - Triploid Grass Carp." Accessed November 16, 2017. <http://www.ecy.wa.gov/programs/wq/plants/management/aqua024.html>.
- Washington Department of Ecology. 2012. *Environmental Impact Statement for Penoxsulam, Imazamox, Bispyribac-Sodium, Flumioxazin, & Carfentrazoneethyl*. Accessed February 18, 2018. <https://fortress.wa.gov/ecy/publications/documents/0010040addendum1.pdf>.
- Wilde, S. B., Murphy, T. M., Hope, C. P., Habrun, S. K., Kempton, J., Birrenkott, A., Wiley, F., Bowerman, W. W., and Lewitus, A. J. 2005. "Avian Vacuolar Myelinopathy Linked to Exotic Aquatic Plants and a Novel Cyanobacterial Species." *Environmental Toxicology*, 20(3): 348-353.
- Wisconsin DNR (Department of Natural Resources). 2012. *Endothall Chemical Fact Sheet*. Accessed December 2, 2017. <http://dnr.wi.gov/lakes/plants/factsheets/EndothallFactsheet.pdf>.
- WSSA (Weed Science Society of America). 2014. *Herbicide Handbook*. Westminster, CO: Weed Science Society of America.



## ABBREVIATIONS

ALS	Acetolactate synthase
AOP	Advanced Oxidation Processes
AWWA	American Water Works Association
BAF	Biologically active filtration
CADBW	California Division of Boating and Waterways
CDMS	Crop Data Management Systems
cfs	cubic feet per second
D&R	Delaware and Raritan
DASH	Diver-assisted suction harvesting
DBP	Disinfection byproducts
DEP	New York City Department of Environmental Protection
EIS	Environmental Impact Statement
EPA	US Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
ft	Feet
FWC	Florida Fish and Wildlife Conservation Commission
GEIS	Generic Environmental Impact Statement
IFAS	University of Florida, Institute of Food and Agricultural Sciences
LPHO	Low-pressure high-output
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goal
mg/L	Milligrams per liter
NCBI	National Center for Biotechnology Information
NEANS	Northeastern Aquatic Nuisance Species Panel
NOM	Natural organic matter
NYS	New York State



NYSDEC	New York State Department of Environmental Conservation
O3	Ozone
ppb	Parts per billion
ppm	Parts per million
SAV	Submerged Aquatic Vegetation
SEIS	Supplemental Environmental Impact Statements
SEQRA	State Environmental Quality Review Act
SWP	Source water protection
TAMU	Texas A&M University
USACE	US Army Corps of Engineers
USFWS	US Fish and Wildlife Service
USGS	US Geological Survey
UV	Ultraviolet Light
WFP	Water Filtration Plant
WTP	Water Treatment Plant