MANAGEMENT OF EURASIAN WATERMILFOIL IN HOUGHTON LAKE, MICHIGAN

Mark A. Heilman, SePRO Corporation, Carmel, IN
Kurt D. Getsinger, U.S. Army Engineer Research and Development Center, Vicksburg, MS
Anthony F. Groves, Progressive AE, Grand Rapids, MI

BACKGROUND

At 20,044 surface acres, Houghton Lake represents the largest inland lake in the state of Michigan. As a shallow lake (mean depth = 9 feet) with a large littoral area (~ 80% of lake surface area), Houghton Lake is a mesotrophic system with historically abundant populations of emergent and submersed aquatic vegetation. Stocked with walleye, smallmouth bass, northern pike, yellow perch, and bluegill, the lake is one of the best fishing resources in Michigan. The lake also is a major resource for waterfowl, including migratory ducks and coots. Good fishing, hunting, and other recreational opportunities make Houghton Lake a major tourist destination for state and regional residents, and tourism is a major resource for the local economy.

While the exact timeframe for the introduction of the invasive weed, Eurasian watermilfoil (*Myriophyllum spicatum*), hereafter called EWM, into Houghton Lake remains unknown, Bonnette (1996) noted that EWM was the second most abundant aquatic plant species. Surveys in 1999 and 2000 (Pullman 2000, Heilman and Pullman 2002) confirmed that EWM was by that time the most abundant plant species and found in over 10,000 acres of the system. Several thousand acres of the lake were covered with dense near-surface or topped-out EWM (Fig. 1A - October 2000 satellite image). These surface stands greatly interfered with navigation and were the source of massive quantities of plant fragments that washed ashore inundating shorelines. Although no formal studies have yet documented the impact of the EWM infestation on the local economy, the conclusion of the Houghton Lake Improvement Board (HLIB) and the lake community was that the infestation had reduced tourism and property values, and greatly increased costs of shoreline maintenance.

MANAGEMENT PLANNING

In 2001, the Houghton Lake Improvement Board (HLIB), seeking solutions to the EWM problem, began an intensive investigation of options for EWM control. On May 17, 2001, the US Army Engineer, Detroit District and the HLIB sponsored a technical workshop involving researchers from the US Army Corps of Engineers Aquatic Plant Control Research Program, Michigan Department of Natural Resources (MDNR), Michigan Department of Environmental Quality (MDEQ), and various aquatic plant management experts. The most current research information on EWM control options was presented, discussed, and documented (Getsinger et al. 2002a). Later in 2001, the HLIB hired a technical team to survey the lake and formally recommend management options. In its final report to the HLIB entitled the Houghton Lake Management Feasibility Study (Smith et al., 2002), the group presented survey results, a literature review of scientific information on Houghton Lake and EWM biology, and a summary of potential EWM management options, including review of benefits, drawbacks, and estimated cost of each option. An electronic Adobe Acrobat version of this report is available (Doug Henderson, ReMetrix LLC, 317-580-8135, doug@remetrix.com).

Figure 1. A) False color composite image of Houghton Lake, MI taken from IKONOS Satellite (Spacing Imaging LLC) on October 18, 2000. Contrast enhancement shows extensive beds of aquatic vegetation dominated by Eurasian watermilfoil. B) Natural color composite image of Houghton Lake, MI taken from IKONOS Satellite on September 30, 2002. No aquatic vegetation (Eurasian watermilfoil) was detected at or near the surface in this image. (Courtesy of ReMetrix LLC)

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After careful review of the scientific and economic merits of various management options, the HLIB selected a sequential integrated management plan that involved whole-lake treatment with the herbicide fluridone in the first year (2002) followed by possible introduction of *Euhrychiopsis lecontei*, a milfoil biocontrol agent, to control any new or recovering EWM populations detected by careful monitoring in subsequent years. The HLIB extended a detailed competitive bid for the fluridone treatment work that was awarded to a team of application specialists headed by SePRO Corporation, the manufacturer of the fluridone aquatic herbicide Sonar®.

SELECTIVE EWM CONTROL WITH SONAR HERBICIDE

Since the mid 1990's, laboratory and field research studies have documented the selective properties of low-dose (<10 parts per billion _ ppb or μg L^{-1}) applications of fluridone for the control of EWM (Netherland et al. 1997; Getsinger et al. 2002b; Getsinger et al. 2002c; Madsen et al. 2002). As the active ingredient in Sonar® aquatic herbicide, fluridone acts systemically and kills the entire plant (shoot and roots). Fluridone prevents photosynthesis, and thus plants cannot produce food for continued growth. Affected plants show pale or bleached new growth and slowly die over the course of 45-90 days provided a phytotoxic dose of fluridone is maintained over this period. The slow mode-of-action of fluridone allows it to be used for EWM control in entire lake systems with minimal risks of oxygen depletion and other water quality issues. EWM is more sensitive to fluridone exposure than most native aquatic plant species. Therefore, with low-dose protocols plus detailed residue monitoring and management, Sonar® has been used operationally to selectively control EWM throughout many areas of the northern United States. With a focus on selective control, MDEQ permits for spring treatments require a 6 ppb fluridone treatment to the top 10 feet of the water column (assumed littoral zone) followed by second 'booster' or 'bump' treatment at 14-21 days after the initial application. The second bump application brings the dose back up to 6 ppb and increases exposure period out to the 60-90 days needed for control in most cases.

MANAGEMENT FUNDING

Funding of the Houghton Lake Management Plan is being obtained via special assessment of benefiting properties and local units of government abutting Houghton Lake. Under provisions of Part 309 (Inland Lake Improvements) of the Michigan Natural Resources and Environmental Protection Act, PA 451 of 1994, formal public hearings were held in the fall of 2001 and a special assessment district was established to finance the project. Assessments are being collected on an annual basis over a five-year period (2002 to 2006). The project is being coordinated under the direction of the HLIB. In accordance with Part 309, the HLIB is composed of a riparian representative, a representative of each township bordering Houghton Lake, the county drain commissioner, a county commissioner, and a representative of the MDEQ.

PERMITTING, IMPLEMENTATION, AND MONITORING

In order to meet MDEQ permit requirements for the 2002 Sonar® treatment of Houghton Lake, detailed vegetation and bathymetric data from 2000 & 2001 surveys of the lake were used to produce a comprehensive management and application plan that was submitted to the MDEQ in February 2002. EWM distribution maps from 2000 and 2001 were submitted showing presence and estimated density of EWM based on results of the point-intercept survey of 912 sites in the lake on a 300-meter (984-foot) grid (Fig. 2 - 2001 EWM map). Using MDEQ recommended methods, littoral coverage of 22 different submersed plant species was documented. Using Geographic Information Systems (GIS), EWM was selectively removed from 2001 survey results to develop the required post-treatment vegetation goal map. The 2001 bathymetric survey results were modeled to produce an updated bathymetric map of the lake and detailed 1-foot resolution volumetric data to determine proper dose to the top 10 feet of the lake's water column.

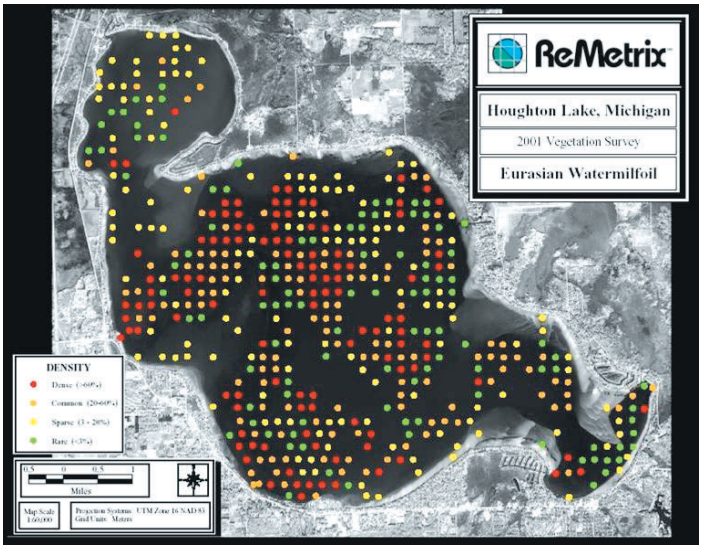

Figure 2. Eurasian watermilfoil distribution and estimated cover at 912 sites from July 24-August 1, 2001 point-intercept aquatic vegetation survey of Houghton Lake, MI. Red and orange sites indicate 80% and 40% mean cover of milfoil respectively. (Courtesy of ReMetrix LLC)

A detailed application plan was submitted that proposed the use of herbicide application systems linked to Global Positioning Systems (GPS) and a field computer for variable-rate precision injection of Sonar®. Using digital versions of updated lake bathymetric maps, these variable rate systems are designed to automatically adjust herbicide application rate based on boat speed and water depth at the precise location of the application vessel. Real-time application rate is also digitally recorded at one-second intervals for use in the development of as-applied maps for treatment documentation. Through GIS, over 130 application transects at 330-foot intervals were mapped and modeled to calculate exact volume of Sonar® that would be applied along each

transect to achieve target level of 6 ppb fluridone in the water. This GPS-GIS application approach is designed to provide even application of herbicides throughout the lake or treatment site. Since the canals of the lake were also heavily infested with EWM, their treatment was also part of the submitted plan, and digital aerial photography of the lake was used to map and calculate exact treatment area for combination of fluridone and diquat treatments.

The 2001 survey results were also used to select 36 different sites for plant and water sampling around the lake. Laboratory susceptibility testing (PlanTEST™) of EWM from these sites would be used to confirm phytotoxic response of Houghton's EWM population to the 6 ppb – bump 6 ppb fluridone protocol. Herbicide residues would be monitored throughout the 90-day Sonar® treatment using an enzyme-linked immunoassay (ELISA) test (FasTEST™). Along with water residues, biochemical response of sampled EWM to fluridone would be quantified throughout the treatment using laboratory testing (EffecTEST™)
(™ trademarks of SePRO Corporation).

The 2002 Sonar® treatment of Houghton Lake was permitted by MDEQ on April 23, 2002. Using fresh field samples from 25 of 36 sites, late April PlanTEST™ pretreatment plant analysis confirmed an acceptable phytotoxic response by EWM to 6 ppb bump 6 ppb protocol. After proper notification of lake residents through mailings and posting, SePRO made the first application of 660 gallons of Sonar® A.S. formulation (4 lbs fluridone per gallon) on May 15, 2002 to the top 10 feet of the lake (52,571 million gallons of water). FasTEST™ residue data (Fig. 3) show at 48 hours, lake-wide fluridone concentration was 7.0 ppb and fell to 5.2 ppb 5 days later as the lake fully mixed and residue dissipation began. By 14 days after initial treatment, residues had dropped to 3.2 ppb indicating the need for a second application of 2.8 ppb (308 gallons Sonar® A.S.). At 48 hours after the second application, lake-wide concentration was 6.15 ppb. Residue monitoring documented a 120-day exposure to greater than 2 ppb fluridone for the lake's EWM and non-target plant communities. Throughout the treatment period, EffecTEST™ biochemical response testing showed changes in EWM concentration of photosynthetic pigments indicative of exposure to phytotoxic dose of fluridone (Fig. 4 - Houghton EWM ß-carotene levels).

In order to re-confirm assay results and as part of a comprehensive study of the Houghton Lake treatment, the Environmental Laboratory of the U.S. Army Engineer Research and Development Center (ERDC) also conducted fluridone residue measurements using high performance liquid chromatography (HPLC) and additional biochemical plant response testing. These results showed similar fluridone residue levels and plant response as indicated by SePRO testing. The complete report from the ERDC summarizing results from the pre- and post-treatment studies of Houghton Lake should be available to the public in 2004.

Treatment impacts on EWM, non-target plant species, and lake water quality were quantified through 1) annual August point-intercept surveys (2002 - year of treatment, 2003 - one-year post-treatment), 2) annual late July hydroacoustic surveys of plant bottom coverage and biovolume using ERDC-developed hydroacoustic technology (SAVEWS – Submersed Aquatic Vegetation Early Warning System), 3) high-resolution satellite image analysis, and 4) fortnightly water quality monitoring coordinated with the Michigan Water Research Center at Central Michigan University. Results of point-intercept surveys, satellite image analysis, and water quality monitoring are discussed briefly here.

Point-intercept data from vegetation surveys shows that in 2001, the year prior to treatment, EWM was present at 490 (54%) of the 912 surveyed sites. In 2002, the year of treatment (3 months following initial application), EWM was found at only 45 sites (<5%), indicating 91% control of EWM by 90 days after initial treatment. In August 2003 (15 months after initial treatment), EWM was not found at any of the 912 survey sites, indicating complete control of that target invasive species in the main body of the lake. The initial 2001 survey documented the presence of 22 aquatic plant species, including EWM. By August 2002, number of species found decreased to 21, and by August 2003, the number decreased to 19. Of the non-target species not present in the 2003 survey, all were known to have moderate to high susceptibility to fluridone, and significant impacts on these species were not unexpected. In 2001, the year prior to treatment, some level of vegetation was found at 705 (77%) of 912 survey sites. In 2002, the year of treatment (3 months following initial application), sites with vegetation decreased to 680 (74.6%). In 2003, sites with vegetation decreased to 496, still above half (54%) of all sites surveyed. Of those 496 sites, 226 (24.8% of 912 total) had only *Chara* spp. (muskgrass), while the remaining 270 (30% of 912 total) had additional macrophyte species present.

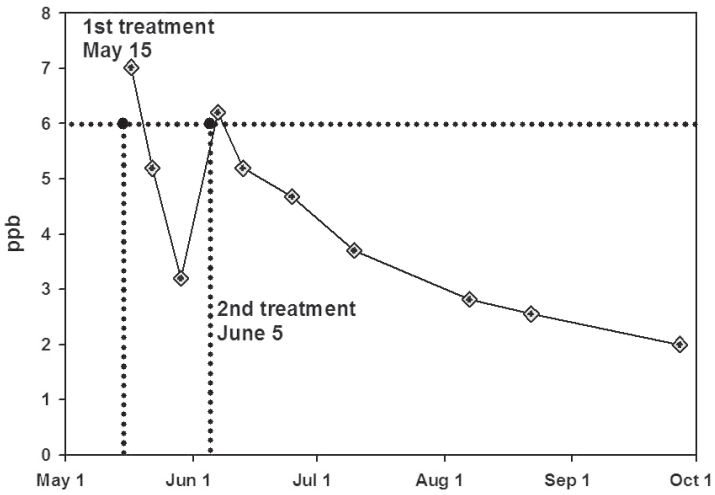

Figure 3. Enzyme-linked immunoassay (ELISA) measurements (FasTEST™) of fluridone residues in Houghton Lake during 2002 Sonar® treatment. Results are the mean of samples from 36 sites around the lake.

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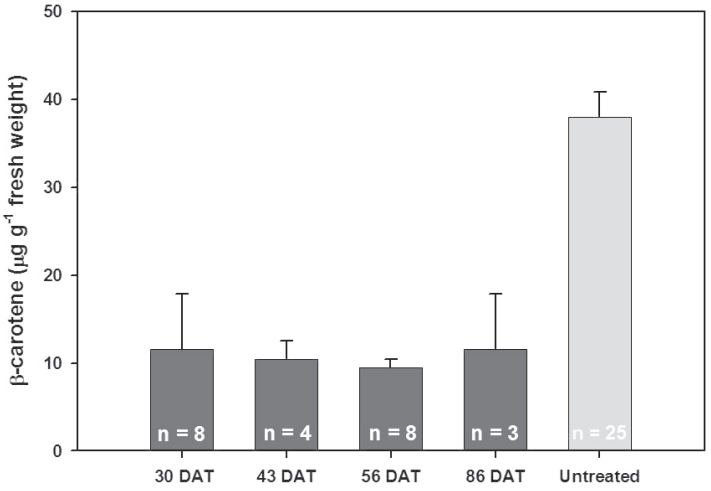

Figure 4. ß-carotene content of Eurasian watermilfoil (EWM) sampled at various sites in Houghton Lake, MI during the 2002 Sonar® treatment. Number of sample sites noted within each graph bar. This data shows that the herbicide is affecting the EWM, compared to untreated plants.

Starting in October 2000, high resolution IKONOS satellite imagery (©Space Imaging LLC) has been annually acquired and analyzed using digital analysis software to calculate the acreage of detectable near-surface and topped-out submersed vegetation on Houghton Lake. On October 18, 2000, after a banner-year for EWM growth, over 7,600 acres of submersed vegetation was detected via satellite (Fig. 1A). Field surveys that fall confirmed that almost all detected vegetation was EWM. On September 30, 2001, only 3,176 acres could be detected. However, as 2001 point-intercept survey data show, EWM continued to dominate the lake despite annual variability in total biomass. Analysis of a third IKONOS image taken on September 30, 2002, 138 days after the initial Sonar® treatment, did not detect any topped out or near-surface growth of submersed vegetation Fig. 1B), indicating the excellent control of EWM achieved by the treatment program.

Potential negative impact on water quality was a prominent concern of Houghton Lake stakeholders during management plan development. It was feared that dramatic reductions in the coverage of EWM after a Sonar® treatment might significantly decrease water clarity through either increased nutrient availability and enhanced algal growth, or through destabilization of sediments producing re-suspension and greater water turbidity (cloudy or muddy water). Another concern in year of treatment was the potential for reduced dissolved oxygen in the lake due to plant die-back, which can consume oxygen during organic matter decomposition.

In September 2001(pretreatment), total phosphorus measurements for various sites within the lake were nearly all less than 10 ppb, values typically indicative of an oligotrophic system. Chlorophyll *a*, a general indicator of algal abundance, ranged from 2-10 ppb at most sites, and Secchi disk transparencies ranged from 5.9 – 9.8 feet around the lake. These Chl *a* and Secchi values would indicate that Houghton Lake is a mesotrophic lake system. Dissolved oxygen values at almost all sites and depths were well above 5 parts per million (ppm).

In 2002, a variety of water quality studies including measurements of temperature, light, turbidity, dissolved oxygen, chlorophyll, and total phosphorus and total nitrogen were conducted on a biweekly basis from May through September to monitor treatment impacts. Results indicate that water quality remained similar to the 2001 pretreatment conditions. The lake remained well-mixed throughout the treatment period except for temporary slight stratification in late June. Light penetration was good with Secchi transparencies between 3.3 and 8.2 feet, which in shallow areas, was often equal to the water depth. Turbidity levels were very low, indicating minimal resuspension of sediments during the treatment. Except for a few isolated lower readings, dissolved O_2 remained above 5 ppm at both the surface and bottom throughout the study period. Chlorophyll values were low to moderate, with only an occasional peak above 30 ppb. Highest values occurred in May and July, periods that also showed peaks in total P, which remained very low for most of the treatment. Comparison of total P and N (nitrogen) ratios indicated that the lake was generally P-limited in terms of algal growth. A comprehensive review of Houghton 2002 water quality data will be available in the final ERDC report.

LONG-TERM MANAGEMENT STRATEGY AND CONCLUSIONS

In discussions of management designs for Houghton Lake, the HLIB, regulators, researchers, and consultants identified 4 major goals for the lake's long-term restoration: 1) reduce impacts of EWM on the lake ecosystem and its users, 2) encourage adequate levels of native plant diversity and abundance, 3) protect lake water quality, and 4) protect the lake's fishery. A sequential, integrated plant management/ restoration program was selected by the HLIB to meet these goals. Whole-lake treatment with Sonar® herbicide was the first step in this program, and has clearly met goal #1 by providing effective control of EWM through two growing seasons. While there have been impacts on native plant populations in the 15 months since the treatment was initiated, some level of impact was expected based on the presence of several fluridone-sensitive non-target species in the lake. Nineteen different species are still present in the lake and recovering. The lake's management plan also calls for potential work to re-vegetate the lake with certain species impacted by the treatment, such as *Elodea canadensis*, as early as 2004. Surveys have also documented the reappearance of *Zizania aquatica* (wild rice) in isolated locations within the lake, and efforts to restore this valuable native species in areas with suitable habitat could be assisted by EWM removal. Limnological studies have documented no significant changes in water quality within the lake as a result of the 2002 Sonar® treatment. Sufficient native plant growth remained to stabilize sediments and allow for proper nutrient cycling

within the system. Finally, while there is no scientific documentation of direct effects of Sonar® treatment on the lake's fishery, anecdotal information from property owners and regular users of the lake suggests that fishing is as good or better than in the years prior to treatment.

Overall, a comprehensive management plan to control EWM and provide a long-term strategy to maintain a healthy and diverse aquatic plant community has been implemented on Houghton Lake. The first stage of this plan—whole-lake control of Eurasian watermilfoil—has been successfully completed. Homeowners and lake users have been provided relief from the problems and issues associated with a widespread EWM infestation. Vigilance against re-infestation by EWM is critical, and an intensive monitoring program is in place to provide for rapid response to further problems with the invasive species. Efforts to reintroduce or expand the current populations of certain desirable native plants will be investigated to promote increased aquatic plant diversity. The focus of all efforts is the long-term health and economic value of the Houghton Lake ecosystem, a priceless freshwater resource for the state of Michigan and the Great Lakes region.

Acknowledgements

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