1.0 INTRODUCTION

The Waupaca Chain O' Lakes consists of 22 lakes in Waupaca County, Wisconsin. According to the 1965 recording sonar Wisconsin Department of Natural Resources (WDNR) lake survey map, the Chain is approximately 724 acres. The WDNR website lists the Chain lakes to be approximately 809 acres and according to the WDNR Geographic Information System (GIS) lake shapes, the chain is approximately 839 acres. At the time of this report, the most current orthophoto (aerial photograph) was from the National Agriculture Imagery Program (NAIP) collected in 2015. Based upon heads-up digitizing of the water level from that photo, the Chain was determined to be approximately 792 acres. Water quality sampling found the pH ranged from 8.3 to 8.7 in lakes sampled in 2016.

Eurasian water milfoil (*Myriophyllum spicatum*; EWM) was first documented in the Waupaca Chain O' Lakes in 2001. Due to distinct features of the EWM's morphology, Onterra field staff suspected that the EWM in the Waupaca Chain O' Lakes may be a hybrid, a cross between EWM and the indigenous northern water milfoil (*Myriophyllum sibiricum*). Investigations found that a single sample from Taylor Lake in 2013 had been sent by Golden Sands RC&D to the Annis Water Resources Institute at Grand Valley State University in Michigan for DNA analysis. The Institutes' results confirmed that the milfoil sent in from Taylor Lake was a hybrid between EWM and the native northern water milfoil. The WDNR collected additional suspect milfoil samples from Sunset, Round, George, Rainbow, and Otter Lakes in 2016 for genetic testing. All samples sent in were confirmed as being hybrid EWM (HWM).

The concept of heterosis, or hybrid vigor, is important in regards to hybrid water milfoil management in the Waupaca Chain O' Lakes. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. Hybrid water-milfoil typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2012). These conditions likely contribute to this plant being particularly less susceptible to biological (Enviroscience personal comm.) and chemical control strategies (Glomski and Netherland 2010, Poovey et al. 2007). Data gathered from whole-lake 2,4-D treatments in Wisconsin from 2009-2016 suggest that treatments in lakes with populations of HWM were not as successful when compared to lakes with pure-strain EWM. In other words, it appears that some strains of HWM, but not all, are more tolerant of 2,4-D treatments than pure-strain EWM.

The Waupaca Chain O' Lakes Protection and Rehabilitation District, known locally as the Waupaca Chain O'Lakes District (WCOLD), has sponsored past grant-funded projects to examine the ecosystem, including a series of 1991-1992 lake management planning projects, a 2003 aquatic plant management plan, a 2005 aquatic invasive species education, prevention and control project (AIS-EPC funded) and a five-year education, planning and treatment grant project in 2009.

2.0 HWM CONTROL AND MONITORING STRATEGY

With the assistance of Onterra in 2015, the WCOLD was awarded a WDNR AIS-Education, Planning and Prevention Grant to aid in funding studies aimed at documenting the current state of the Chain's native and non-native aquatic plant populations to guide the development of future management strategies. Surveys conducted in 2015 found that HWM can be found throughout much of the project waters.

A commonly used method for controlling non-native plant populations is through herbicide applications. Herbicides that target submersed plant species are directly applied to the water, either as a liquid or an encapsulated granular formulation. Factors such as water depth, water flow, treatment area size, and plant density work to dilute herbicide concentration within aquatic systems. Understanding Concentration-Exposure Times (often referred to as CETs) is an important consideration for the use of aquatic herbicides. Successful control of the target plant is achieved when it is exposed to a lethal concentration of the herbicide for a specific duration of time.

A Cooperative Research and Development Agreement between the Wisconsin Department of Natural Resources and U.S. Army Corps of Engineers Research and Development Center in conjunction with significant participation by private lake management consultants have coupled quantitative aquatic plant monitoring with in-lake herbicide concentration data to evaluate efficacy, selectivity, and longevity of chemical control strategies implemented on a subset of Wisconsin waterbodies. Although a continuum of these categories exists, the research indicates two main treatment strategies: 1) spot treatments and 2) large-scale (aka whole-lake) treatments.

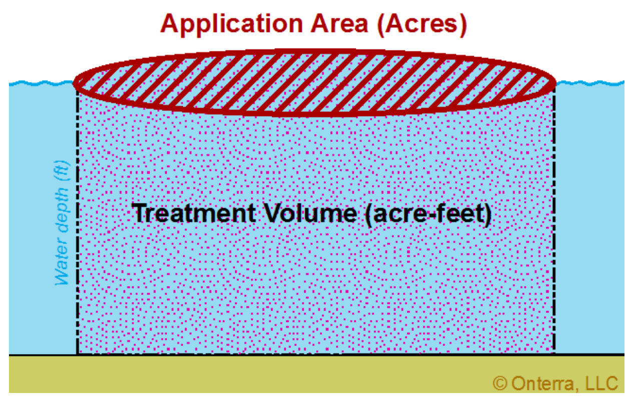


Figure 2.0-1. Herbicide Spot Treatment diagram.

Spot treatments are a type of control strategy where the herbicide is applied to a specific area such that when it dilutes from that area, its concentrations are insufficient to cause significant effects outside of that area. Herbicide application rates for spot treatment are formulated volumetrically, typically targeting EWM with 2,4-D at 3.0-4.0 ppm acid equivalent (ae). This means that sufficient 2,4-D is applied within the *Application Area* such that if it mixed evenly with the *Treatment Volume*, it would equal 3-4.0 ppm ae. This standard method for determining spot treatment use rates is not without flaw, as no physical barrier keeps the herbicide within the *Treatment Volume* and herbicide dissipates horizontally out of the area before reaching equilibrium (Figure 2.0-1). While lake managers may propose that a particular volumetric dose be used, such as 3.0-4.0 ppm ae, it is understood that actually achieving 3.0-4.0 ppm ae within the water column is not likely due to dissipation and other factors.

Ongoing research clearly indicates that the herbicide concentrations and exposure times of large (> 5 acres each) treatment sites are higher and longer than for small sites (Nault 2015). Research also indicates that higher herbicide concentrations and exposure times are observed in protected parts of a lake compared with open and exposed parts of the lake. Areas containing water exchange (i.e. flow) are often not able to meet herbicide concentration-exposure time (CET) requirements for control.

From an ecological perspective, large-scale (whole-lake) treatments are those where the herbicide is applied to specific sites, but when the herbicide reaches equilibrium within the entire volume of water (of the lake, lake basin, or within the epilimnion of the lake or lake basin); it is at a concentration that is sufficient to cause mortality to the target plant within that entire treated volume. WDNR administrative code defines large-scale treatments as those that exceed 10% of the littoral zone (NR 107.04[3]). The ecological basis of this standard is that if 10% of a lake were targeted with an herbicide at a standard spot treatment concentration, it may have the potential to produce lake-wide impacts. For example, if 10% of a lake is targeted with 2,4-D at 4.0 ppm ae, the whole-lake equilibrium concentration would be approximately 10% of that rate or 0.4 ppm ae. The target 2,4-D concentration for large-scale (aka whole lake) EWM treatments is typically between 0.250 and 0.400 ppm ae understanding that the exposure time would be dictated by herbicide degradation and be maintained for 7-14 days or longer. Therefore, spot treatments that approach 10% of a lake's area will become large-scale treatments.

Large-scale treatments have become more widely utilized by many lake managers (and public sector regulatory partners) as they impact the entire EWM population at once. This minimizes the repeated need for exposing the lake to herbicides as is required when engaged in an annual spot treatment program. In Wisconsin, most large-scale AIS treatments use liquid 2,4-D amine. Properly implemented large-scale 2,4-D herbicide treatments can be highly effective on pure-strain EWM populations, with minimal EWM being detected for a year or two following the treatment (Figure 2.0-2, left frame) on some systems. Some large-scale 2,4-D treatments have been effective at reducing EWM populations for 5-6 years following the application. Following the same herbicide use pattern, HWM populations were reduced the year following treatment to a lesser degree than similar pure EWM populations (Figure 2.0-2, right frame). In almost all HWM populations, rebound took less time and the rebounded populations were at much higher frequencies than EWM populations.

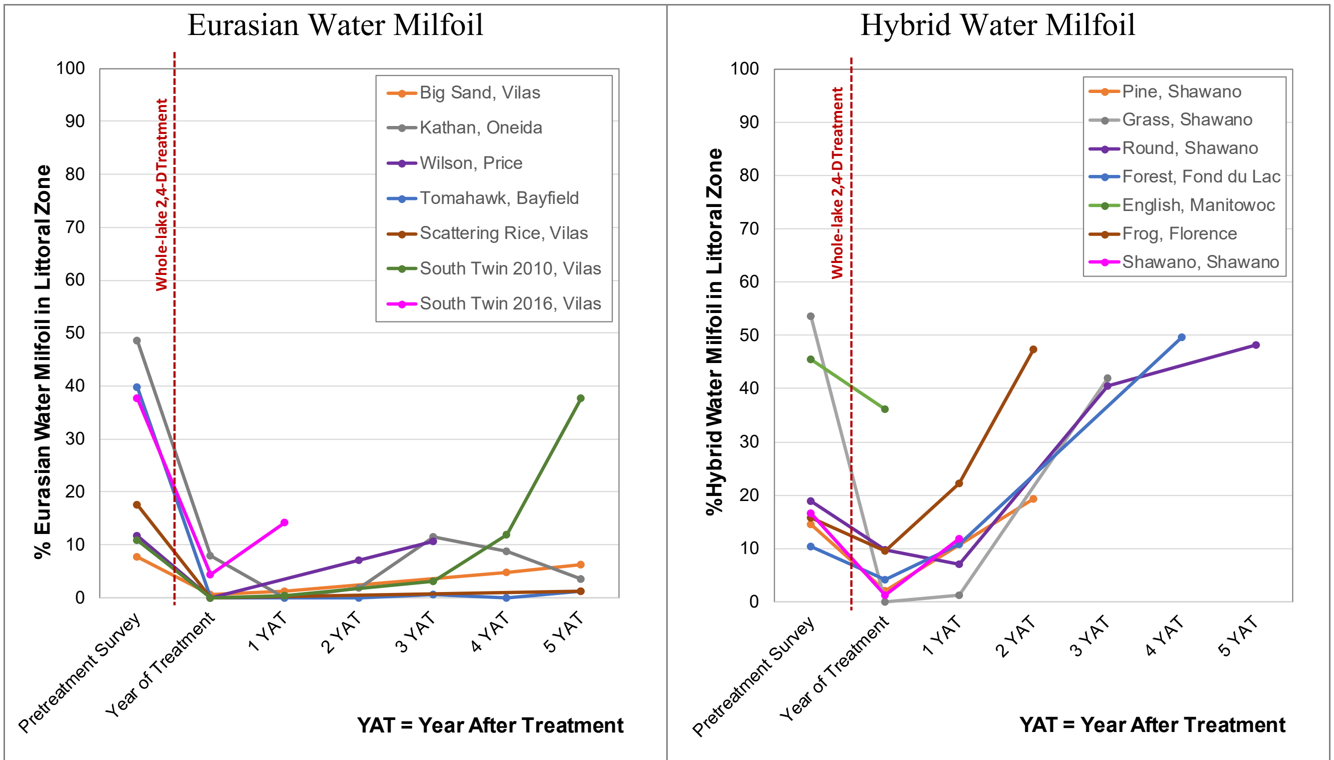


Figure 2.0-2. Littoral frequency of occurrence of invasive milfoil in lakes managed with large-scale 2,4-D amine treatments.

The concept of heterosis, or hybrid vigor, is important in regards to hybrid water milfoil management in the Waupaca Chain. The root of this concept is that hybrid individuals typically have improved function compared to their pure-strain parents. Hybrid water-milfoil typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2012). These conditions likely contribute to this plant being particularly less susceptible to biological (Enviroscience personal comm.) and chemical control strategies (Glomski and Netherland 2010, Poovey et al. 2007). In a recent study of 28 large-scale 2,4-D amine treatments in Wisconsin (Nault et al. 2017), HWM initial control was less and the longevity was shorter than pure-strain EWM control projects. Therefore, it appears that potentially most strains of HWM, but not all, are more tolerant of auxin-mimic herbicide treatments (e.g. 2,4-D, triclopyr) than pure-strain EWM. For clarity, that does not mean that they are resistant to the herbicide, as a higher dose would result in effective control; but the higher dose would result in increased native plant impacts and therefore is not a current best management practice.

Due to the implementation challenges of hybridity (hybrid vigor), water exchange, and connectivity of treatment waterbodies, a 3-year trial program was developed within a February 1, 2017 AIS-EPC Grant Application for the Waupaca Chain 'O Lakes (ACEI-195-17).

2.1 AIS Monitoring Strategy

During 2016, whole-lake point-intercept surveys and Late-Summer HWM Mapping Surveys were conducted on the entire Chain and would serve as a pretreatment dataset. These studies would be completed in 2017, 2018, and 2019 to track the efficacy of the treatments (i.e. HWM control) and selectivity of the native plant community (i.e. collateral native plant reductions).

During the *year of the treatment*, the project would include verification and refinement of the treatment plan immediately before control strategies are implemented. This potentially would include refinements of herbicide application areas, assessments of growth stage of aquatic plants, and documentation of thermal stratification parameters that influence the final dosing strategy.

Volunteer-based monitoring of temperature profiles would also be coordinated surrounding the treatment, as well as collection of post treatment herbicide concentration samples at multiple locations and sampling intervals. Waupaca County Land and Water Conservation Department (LWCD) has volunteered to assist within this project component.

The success criteria of a whole-lake treatment would be a 70% reduction in HWM littoral frequency of occurrence comparing point-intercept surveys from the *year prior to the treatment* to the *year of the treatment.* Regardless of treatment efficacy, a whole-lake treatment would not be conducted during the *year following the treatment*: Project success would be further demonstrated if significant HWM rebound does not occur during the *year following the treatment* and native plants during the *year following the treatment* are approximately at levels found *prior to the treatment.*

The WCOLD understands that HWM population rebound is inevitable following a whole-lake treatment. The rebound could be a result of survivorship, migration from other parts of the Chain, or sprouting/germinating from a seed or turion base. Depending on the results of the *year after treatment* surveys, the WCOLD would likely initiate volunteer or professional-based hand-harvesting activities, targeting the remnant HWM population. To properly coordinate hand-harvesting activities, an Early-Season AIS (ESAIS) Survey would be conducted in June 2019. With the spatial data from the ESAIS Survey and delineated harvest areas loaded onto a GPS unit, harvesters would remove HWM following a previously outlined strategy by Onterra and the WCOLD. Hand-harvesting would take place between the ESAIS (pre) and the late-summer HWM Peak-Biomass (post) surveys, allowing for evaluation of the management activity.

If the HWM population in some areas exceeds size or density levels that can be effectively controlled with hand-harvesting methods, the WCOLD would consider conducting herbicide spot treatments in those areas. Spot treatments of HWM populations would likely be conducted with herbicides that require short exposure times, such as diquat or herbicide combinations (diquat/endothall, 2,4-D/endothall, etc.).

Based on the data collected over the three-year project, the WCOLD would revisit its management plan as it applies to HWM control and monitoring. This may include targeting low-level HWM populations through coordinated volunteer and professional hand-harvesting efforts.

2.2 HWM Control Strategy

Year 1 - 2017

During the first year of the project, Dake Lake and Miner Lake were targeted for a large-scale 2,4-D treatment at 0.375 ppm ae. This is a slightly elevated herbicide concentration over pure-strain EWM large-scale 2,4-D treatments. Watershed modeling indicates these lakes have relatively long water residence times (1,211 days) and water exchange is not likely to impact the results of the treatment.

Also during 2017, Otter Lake was targeted with a large-scale treatment using a combination of 2,4-D (0.275 pm ae) and endothall (0.75 ppm ai). Otter Lake also has a long water residence time (480 days) where flow is not likely to significantly reduce herbicide concentrations faster than normal degradation. Having a comparative field trial with an elevated 2,4-D strategy (Dake/Miner) and a 2,4-D/endothall combination treatment (Otter) in the same year will prove valuable to determining future treatment strategies on the Chain.

One spot-treatment site totaling 4.4 acres in Columbia Lake was targeted with diquat in 2017. This high-traffic area and boat landing was targeted to alleviate navigation impairment as well as for containment purposes. Diquat is known to require a lower CET than 2,4-D, and this herbicide treatment will be evaluated within this report.

Year 2 - 2018

Youngs Lake, Bass Lake, Beasley Lake, and Long Lake are all in succession and contain some of the highest HWM populations within the Chain. While targeting these lakes is important to control HWM on a Chain-wide basis, there are a number of implementation challenges that make it more appropriate to target these lakes in year two.

Using traditional watershed modeling tools, the residence time of these lakes is quite short – approximately four days on Youngs-Bass Lakes, 14 days on Beasley Lake, and 48 days on Long Lake. However, this modeling may not be completely accurate and the whole topographic watershed may not be available for overland runoff. As is common for many lakes in the area, much of the watershed is sand, which allows water to percolate into the groundwater. If this is the case, the water residence times may be much longer than the modeling predicts.

With assistance from Waupaca County LWCD, a flow study was completed in 2017 that will provide more accurate data on flow between the waterbodies. Coinciding with these studies, acoustic-based bathymetric studies were conducted which allow for an understanding of water retention times. Based upon the results of the flow study and the initial outcomes of the 2017 herbicide treatment field trials, an herbicide treatment strategy would be developed for implementation during the spring of 2018. The results of this study are described within the Conclusions section of this report.

3.0 HERBICIDE TREATMENT PLANNING & IMPLEMENTATION

3.1 Pre-treatment Confirmation and Refinement Survey

On April 26, 2017, Onterra ecologists conducted the HWM Spring Pre-treatment Confirmation and Refinement Survey on Otter, Dake, Miner, and Columbia Lakes. During this survey, the presence of actively growing HWM was confirmed on each of the lakes or proposed treatment sites. Minimal native aquatic plant growth was observed except for muskgrasses. Temperature profiles were taken at two foot increments in each lake. Onterra staff provided training and delivered the herbicide monitoring supplies to Waupaca County LWCD staff during the pretreatment survey.

3.2 Finalized Dosing Strategy for Treatment

In order to finalize the dosing volume for the 2017 whole-lake treatments, it was necessary to understand the volume of water in which the herbicide is expected to mix. As the water warms, a thermal barrier develops in many lakes essentially separating the lake into an upper epilimnion with warmer water temperatures and a lower hypolimnion with cooler water temperatures. The transitional area separating the upper and lower portions of the water column is known as the metalimnion. In recent years, it has become common for lake managers to predict the mixing volume of a lake based on the middle/upper-middle of the metalimnion, understanding that some amount of herbicide will be lost to the metalimnion.

Staff from Waupaca County LWCD provided numerous temperature profiles leading up to the large-scale herbicide treatments on Otter, Dake, and Miner Lakes (Figures 3.2-1 – 3.2-3). During April and early-May, the lake was warming, but not developing separate strata. Towards the middle of May, stratification parameters finally became apparent in Otter and Miner Lakes; whereas the stratification was slow to develop in Dake Lake. Despite the weak stratification parameters observed in Dake Lake, it was recommended not to postpone the herbicide treatment any longer as warming water temperatures coupled with an increase in native plant growth became factors to consider. The final dosing depth for each lake is displayed on Figures 3.2-1 - 3.2-3.

Map 1 displays the final large-scale herbicide treatment design and dosing strategy for Otter Lake in 2017. The treatment included application of 25.2 gallons of 2,4-D amine (DMA IV®) and 60.3 gallons of endothall dipotassium salt (Aquathol® K) over 9.0 acres of the lake.

Map 2 displays the final large-scale herbicide treatment design and dosing strategy for Dake Lake in 2017. The treatment included the application of 73.2 gallons of 2,4-D amine (DMA IV®) over 11.4 acres of the lake.

Map 3 displays the final large-scale herbicide treatment design and dosing strategy for Miner Lake in 2017. The treatment included the application of 139.5 gallons of 2,4-D amine (DMA IV®) over 13.6 acres of the lake.

Map 4 displays the final herbicide spot-treatment strategy for Columbia Lake. The treatment included the application of 7.65 gallons of diquat dibromide (Tribune®) over 4.4 acres of the lake. Diquat is a contact herbicide that requires a shorter contact time compared to 2,4-D necessary to achieve control and is more commonly used in smaller spot-treatment scenarios in which shorter concentration exposure times are likely to occur. The treatment area was broken into two parts to account for the differing average depths between the two sections of the site.

The herbicide treatments were conducted by Wisconsin Lake and Pond Resource on May 23, 2017. The applicator reported a near-surface water temperature of approximately 60°F and northeast winds of 5 mph at the time of application.

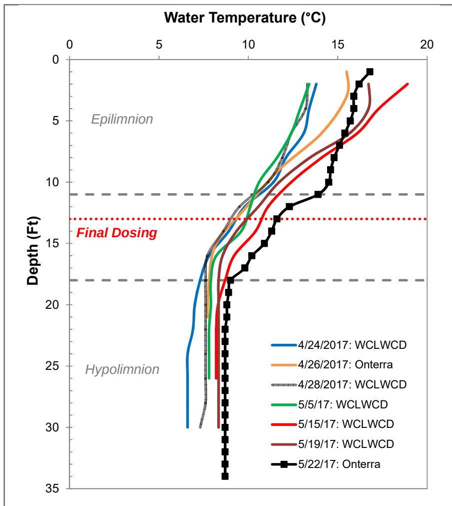


Figure 3.2-1 Pre-Treatment Temperature Profiles Collected on Otter Lake.

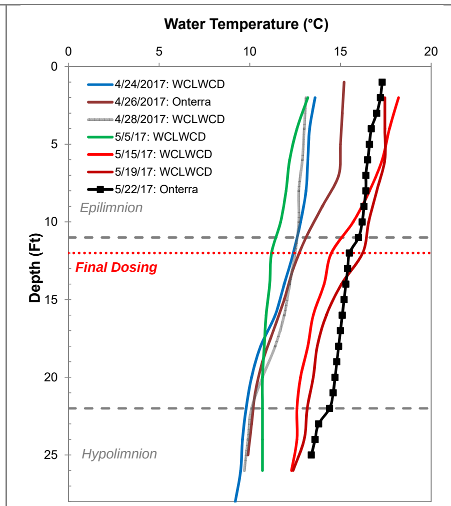


Figure 3.2-2 Pre-Treatment Temperature Profiles Collected on Dake Lake.

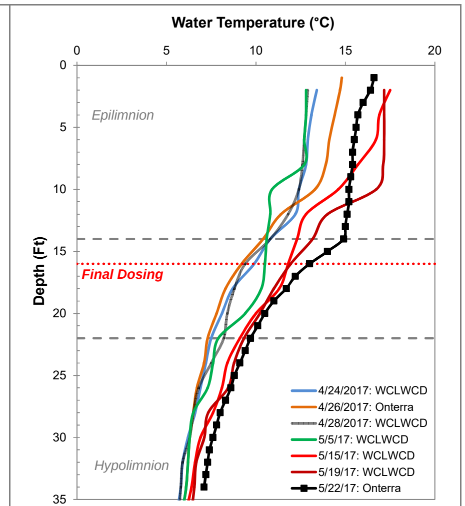


Figure 3.2-3 Pre-Treatment Temperature Profiles Collected on Miner Lake.

4.0 HERBICIDE MONITORING RESULTS

4.1 Herbicide Monitoring Results – Otter Lake

Map 1 displays the water sampling locations associated with the herbicide concentration monitoring for Otter Lake. Figure 4.1-1 shows the results of the 2,4-D monitoring for Otter Lake. The grey square symbol on Figure 4.1-1 represents water collected at 21 feet of water from the deep hole monitoring site (Site WO2). A negligible amount of herbicide was observed in the hypolimnion during the 2017 Otter Lake treatment in samples collected on 3 Days After Treatment (DAT) and 21 DAT which confirms that the herbicide was confined to its intended portion of the epilimnetic waters. Herbicide monitoring following the 2017 treatment found that the mean 1-7 DAT 2,4-D concentration was 0.310 ppm ae, slightly higher than the target concentration of 0.275 ppm ae. Monitoring showed 2,4-D levels were sustained at near the target concentration for a period of approximately 21 days. Samples collected on 28 DAT showed concentrations had decreased to 0.166 ppm ae and decreased to near detection limits by 35 DAT to 0.039 ppm ae.

Endothall concentrations were not tested at the lab and the 2,4-D values were used as a surrogate. It is theorized that endothall concentrations would approximately mimic the 2,4-D levels in the lake and an estimated endothall concentration is displayed on Figure 4.1-2. For example, mean 2,4-D concentrations were 127.3 % of the target concentration on 1 DAT (target = 0.275 ppm ae: actual = 0.350 ppm ae). Using this value, the estimated endothall concentration for 1 DAT was 127.3% of the target concentration (target = 0.532 ppm ae: estimated value = 0.677 ppm ae).

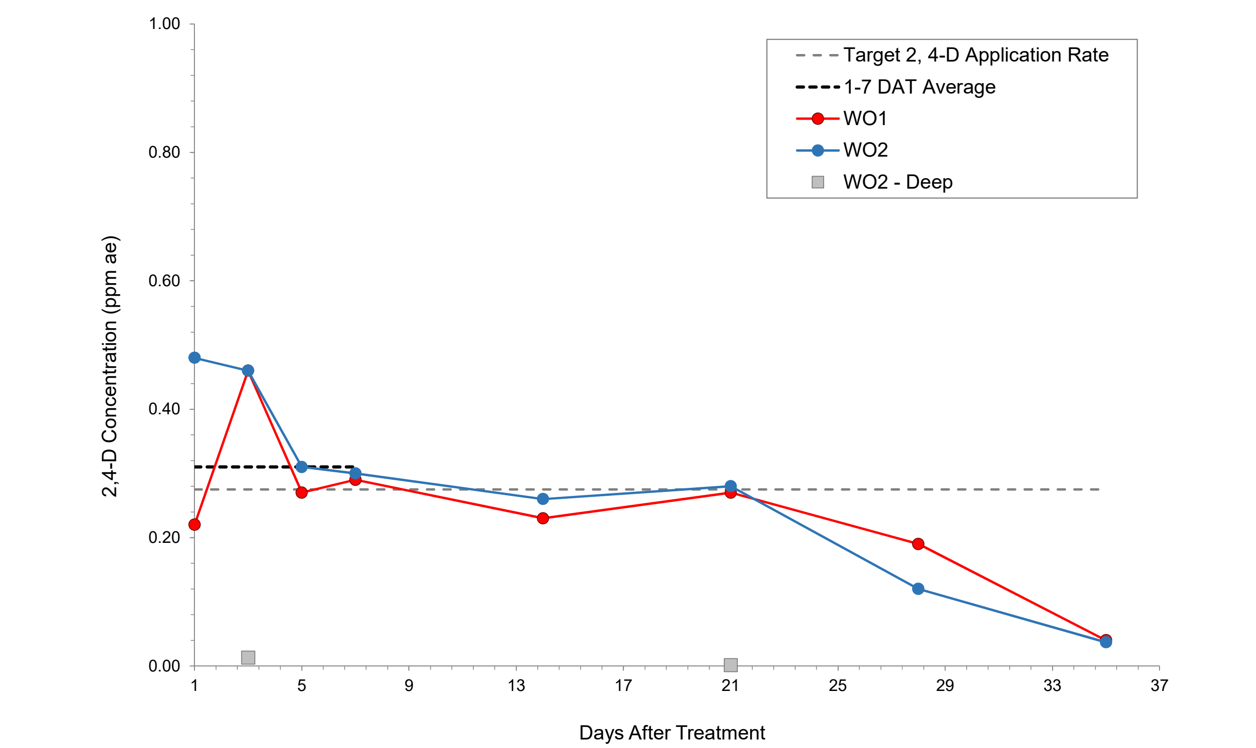


Figure 4.1-1. Otter Lake 2017 2,4-D Herbicide Concentration Monitoring Results from two monitoring locations.

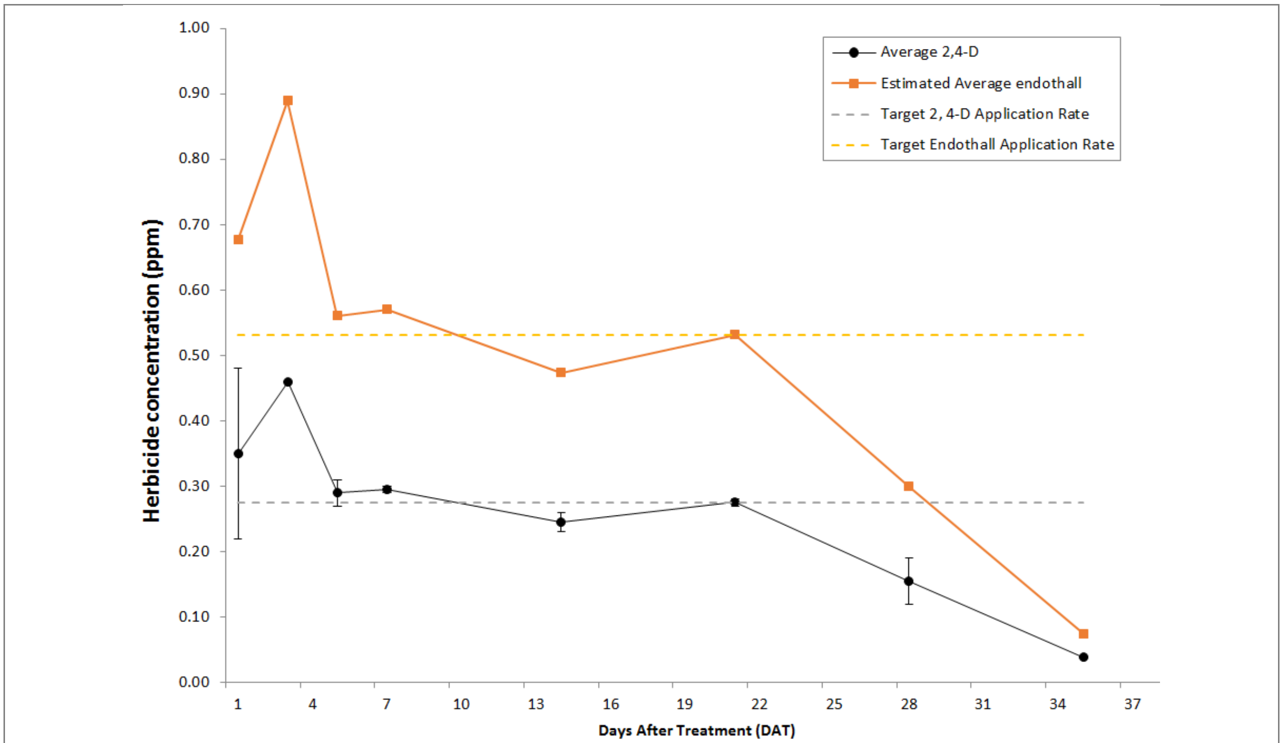


Figure 4.1-2. 2017 Otter Lake 2,4-D & estimated endothall concentration monitoring results. Black error bars represent the range of values between the two sampling sites.

Temperature profiles collected at each herbicide concentration sampling interval indicate that the lake remained thermally stratified throughout the duration of the monitoring timeframe. The closely spaced water temperature contours on the isotherm (Figure 4.1-3, left frame) indicate a thermal gradient separating the epilimnion and hypolimnion beginning at approximately 10 feet on the treatment date. As the water temperatures increased during the summer months, the thermal gradient appears to have remained at approximately 9-10 feet. This can also be observed on the temperature profiles (Figure 4.1-3, right frame), where uniform temperatures were observed down to about 10 feet before getting much colder in a short amount of depth.

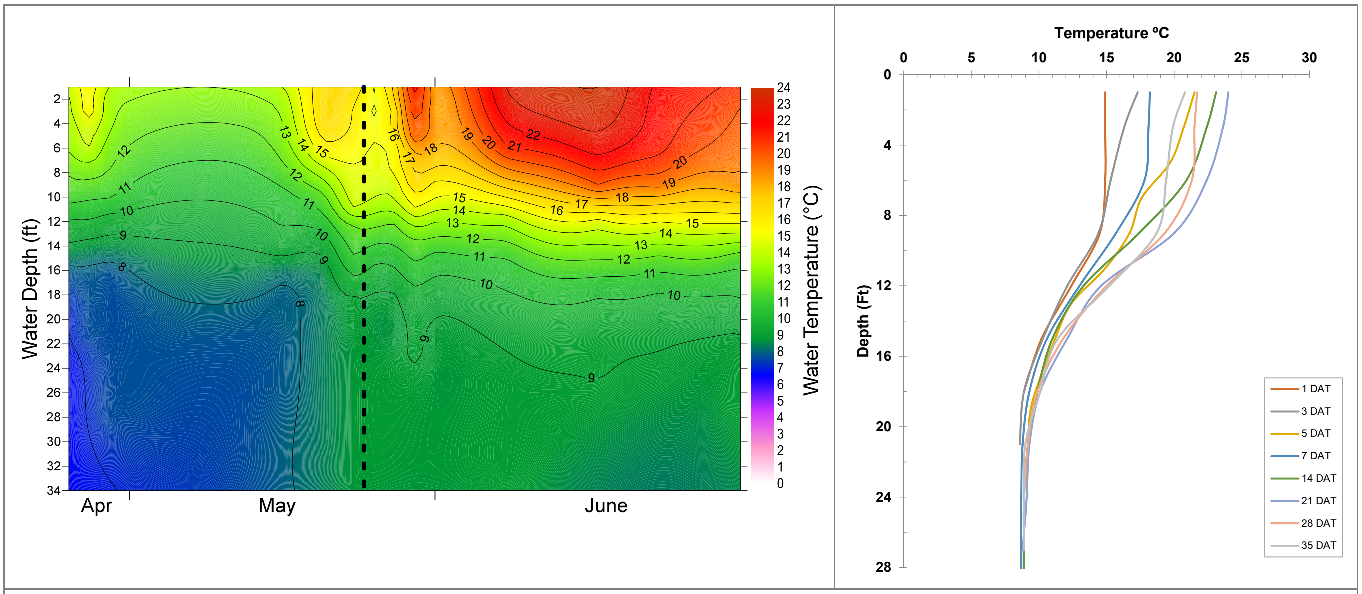


Figure 4.1-3. Temperature Isotherm (left) and Profiles (right) Collected from Otter Lake Following the 2017 Herbicide Treatment. Dashed line on isotherm represents treatment date.

4.2 Herbicide Monitoring Results – Dake Lake

Map 2 displays the water sampling locations associated with the herbicide concentration monitoring for Dake Lake. Figure 4.2-1 shows the results of the 2,4-D monitoring on Dake Lake. Concentrations showed little variation between the two sampling sites, including site WD1 where herbicide was not directly applied, confirming the herbicide had horizontally mixed within the lake. The grey square symbols on Figure 4.2-1 represent water collected at 23 feet of water from the deep hole monitoring site (Site WD1). A detectable amount of herbicide was observed in the hypolimnion during the 2017 Dake Lake treatment in samples collected on 3 DAT (0.220 ppm ae) and 21 DAT (0.210 ppm ae) which shows that some of the herbicide migrated into waters deeper than originally intended in the dosing strategy. Herbicide monitoring following the treatment found that the mean 1-7 DAT 2,4-D concentration was 0.491 ppm ae. The observed 2,4-D concentrations were significantly above the target concentration of .375 ppm ae. Monitoring showed 2,4-D levels were sustained at above the target concentration for a period of approximately 21 days. Samples collected on 28 DAT showed concentrations had decreased to 0.245 ppm ae and decreased further by 35 DAT to 0.185 ppm ae. After the initial concentration results from the lab showed detectable levels of herbicide remained at the last sampling interval on 35 DAT, another sample was collected on 80 DAT. The 80 DAT sample had a 2,4-D concentration of 0.024 which is approaching the minimum detection limit.

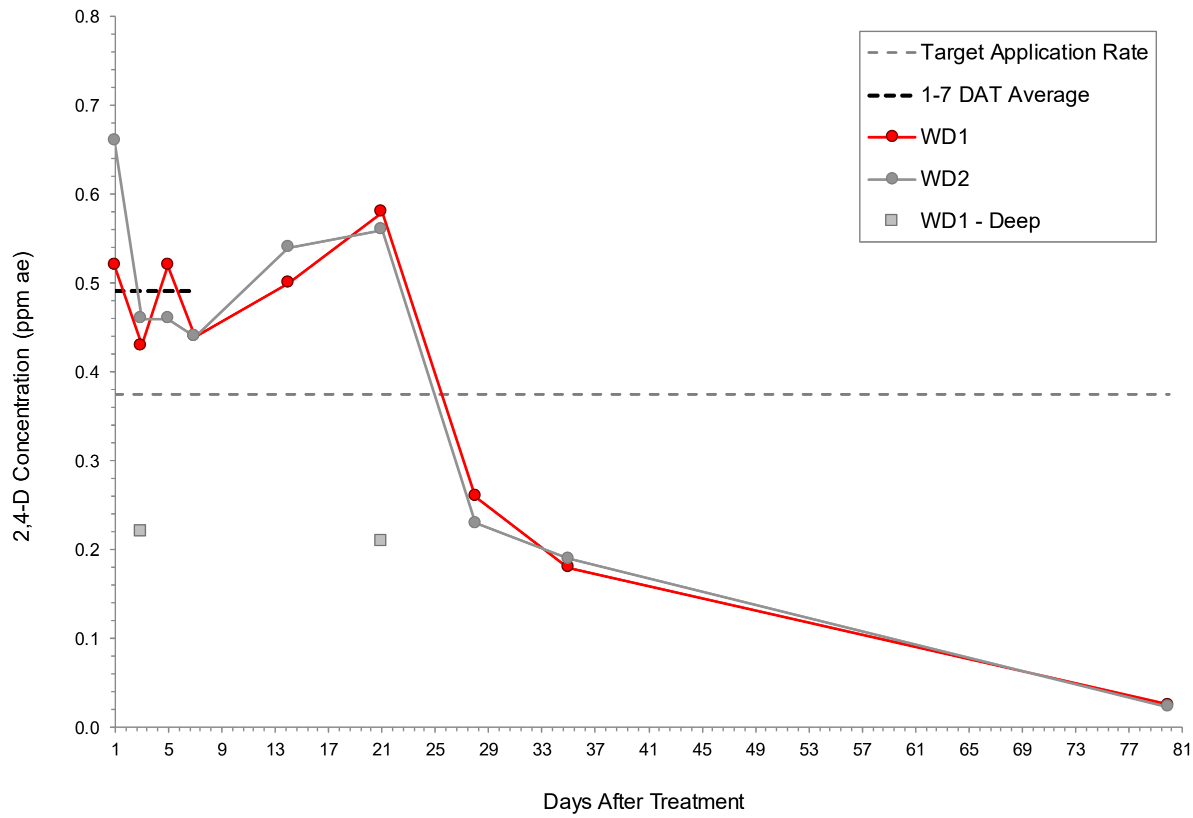


Figure 4.2-1. Dake Lake 2017 Herbicide Concentration Monitoring Results from two monitoring locations.

Temperature profiles collected before the treatment indicated that the lake did not show strong stratification during the time leading up to treatment. Temperature profiles collected after the treatment at each sampling interval showed inconsistent stratification characteristics in the weeks after the treatment (Figure 4.2-2, right frame). The profile collected on 1 DAT indicated the lake was mixed within most of the water column down to at least 21 feet. By 5 DAT and 7 DAT, the temperature profiles showed fairly strong stratification between 7 and 12 feet (Figure 4.2-2, right frame). Limnologists understand thermal stratification as occurring when there is a change of 1°C within 1 meter. The profile collected on 35 DAT showed water was mixed down to approximately 18 feet. The water temperature contours on the isotherm (Figure 4.2-2, left frame) indicate an event near the end of May corresponding with the 7 DAT sampling interval in which water temperatures cooled significantly followed by a time period in which there was a lack of a stable thermal gradient separating the epilimnion and hypolimnion. It is theorized that Dake Lake experienced multiple turnover events during the time frame surrounding the treatment monitoring in 2017. Inputs of cold water, cool ambient air temperatures, and wind events may contribute to the mixing of the water column in Dake Lake. It is unclear why the measured herbicide concentrations were higher than anticipated during the first 21 days of sampling. With herbicide being detected in the deeper water samples during the sampling period, it would be expected to result in concentrations lower than the target concentrations within the epilimnion. It may be possible that a WDNR 1965 sonar reading on Dake Lake lacked accuracy and thus, volume calculations derived from this data source resulted in a higher dose of herbicide than expected.

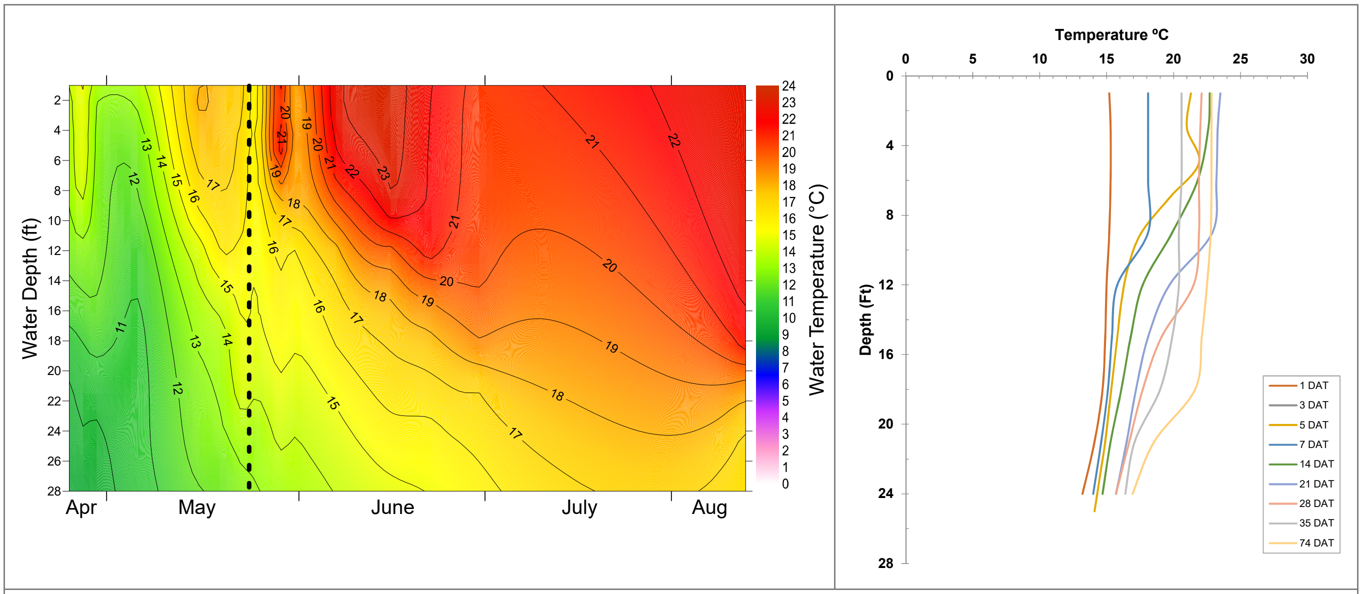


Figure 4.2-2. Temperature Isotherm (left) and Profiles (right) Collected from Dake Lake Following the 2017 Herbicide Treatment. Dashed line on isotherm represents treatment date.

4.3 Herbicide Monitoring Results – Miner Lake

Map 3 displays the water sampling locations associated with the herbicide concentration monitoring for Miner Lake. Figure 4.3-1 shows the results of the 2,4-D monitoring on Miner Lake. For the most part, concentrations showed little variation between the two sampling sites, including site WM2 where herbicide was not directly applied, confirming the herbicide had horizontally mixed within the lake. The grey square symbols on Figure 4.3-1 represent water collected at 27 feet of water from the deep hole monitoring site (Site WM2). A negligible amount of herbicide was observed in the hypolimnion in samples collected on 3 DAT and 21 DAT which confirms that the herbicide was confined to its intended portion of the epilimnetic waters. Herbicide monitoring following the treatment found that the mean 1-7 DAT 2,4-D concentration was 0.429 ppm ae. The observed 2,4-D concentrations were above the target concentration of .375 ppm ae. Monitoring showed 2,4-D levels were sustained at near the target concentration for a period of approximately 28 days. Samples collected on 35 DAT showed concentrations had decreased to 0.235ppm ae. After the initial concentration results from the lab showed detectable levels of herbicide remained at the last sampling interval on 35 DAT, another sample was collected on 80 DAT. The 80 DAT sample had a 2,4-D concentration of 0.040 which is approaching the minimum detection limit.

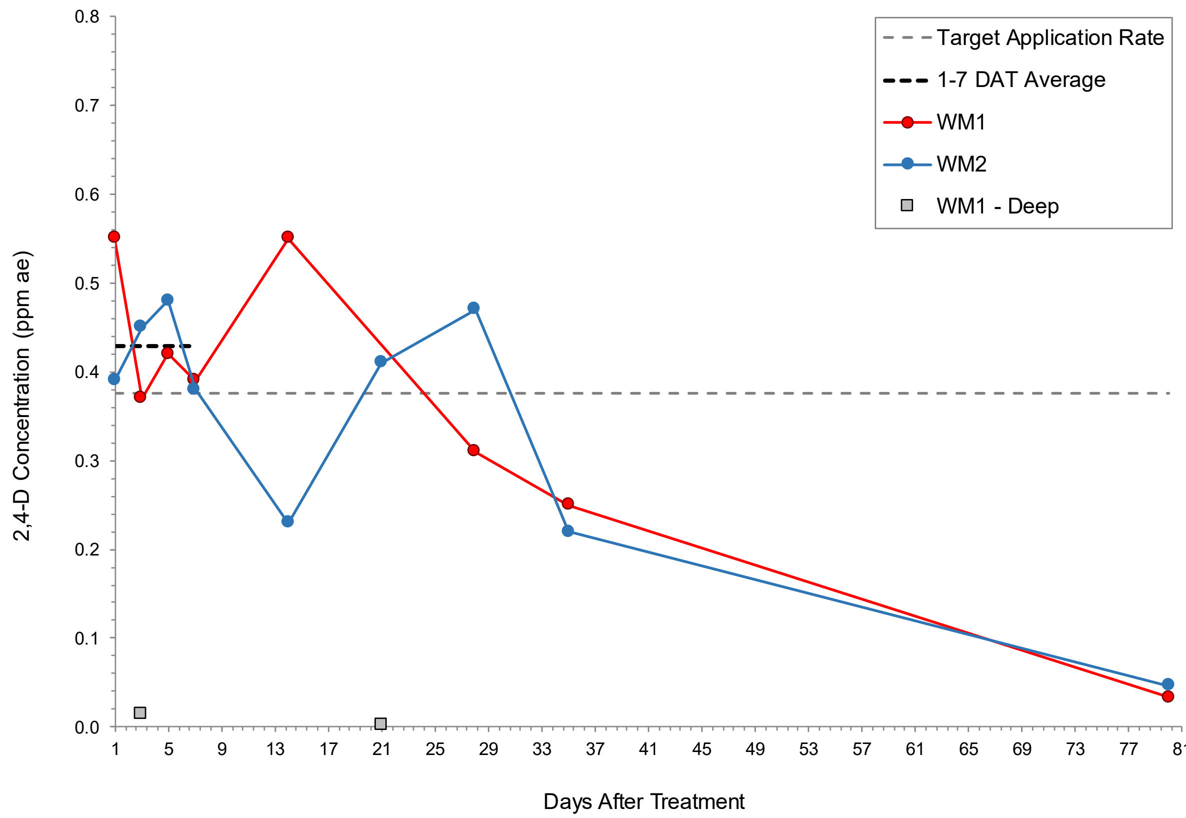


Figure 4.3-1. Miner Lake 2017 Herbicide Concentration Monitoring Results from two monitoring locations.

Temperature profiles collected before the treatment and at each herbicide concentration sampling interval indicate that the lake remained thermally stratified throughout the duration of the treatment. The closely spaced water temperature contours on the isotherm (Figure 4.3-2, left frame) indicate a thermal gradient separating the epilimnion and hypolimnion beginning at approximately 15 feet on the treatment date. As the water temperatures increased during the summer months, the thermal gradient appears to have moved closer to around 12 feet. This can also be observed on the temperature profiles (Figure 4.3-2, right frame), where uniform temperatures were observed down to about 12 feet before getting much colder in a short amount of depth.

A dosing depth of 17 feet was used for the treatment planning which corresponded to the upper metalimnion at the time just prior to treatment. As the thermal barrier set up slightly shallower than the dosing depth, a smaller water volume would have contained the herbicide and thus lead to somewhat higher than anticipated epilimnetic concentrations. Degradation rates of 2,4-D in Miner Lake were relatively slow with little change in concentrations through the 28 DAT sampling interval. 2,4-D is broken down largely by microbial activity and lakes with low productivity may see a lower herbicide degradation rate than lakes with higher productivity.

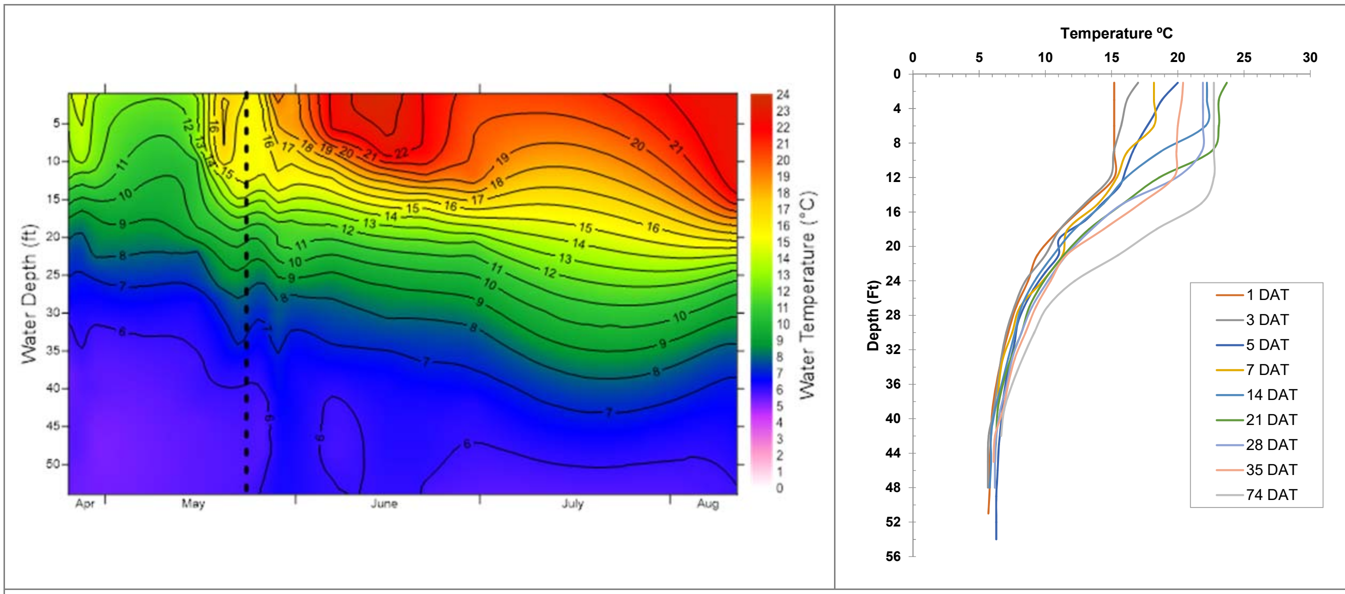


Figure 4.3-2. Temperature Isotherm (left) and Profiles (right) Collected from Miner Lake Following the 2017 Herbicide Treatment. Dashed line on isotherm represents treatment date.

5.0 AQUATIC PLANT MONITORING RESULTS

5.1 June 2017 Early-Season AIS Survey (ESAIS)

On June 15-16, 2017, Onterra staff completed the Early Season AIS Survey on the Waupaca Chain 'O Lakes. During this meander-based survey, the entire littoral areas of the lakes were surveyed for exotic plants. Lakes included in the spring 2017 whole-lake treatment program as well as Ottman Lake were not visited during the ESAIS survey.

While HWM is usually not at its peak growth at this time of year, the water is typically clearer during the early summer allowing for more effective viewing of submersed plants, and HWM is often growing higher in the water column than many of the native aquatic plants at that time of year. The HWM mapped during the Early-Season AIS Survey is refined during the Late-Summer Peak-Biomass survey. Curly-leaf pondweed (*Potamogeton crispus*; CLP) is at or near its peak growth in early summer before naturally senescing (dying back) in mid-summer, making early summer the most probable time to locate this exotic species.

Curly-leaf pondweed was located in several lakes within the Chain during the ESAIS survey. The CLP mapping results are displayed on Map 5.

Based on the June ESAIS Survey, a preliminary hand-harvesting strategy was also devised. Volunteers from the WCOLD and paid divers from the Red Granite Fire Department would target HWM occurrences in three high-use locations in Waupaca Chain (Figure 5.1-1). Approximately 2.5 hours of hand-harvesting efforts occurred in late-June 2017 near piers at Becker Marine in Lime Kiln Lake. The harvest yield from these efforts was reported to be approximately 3/4's of a 20" by 40" bag.

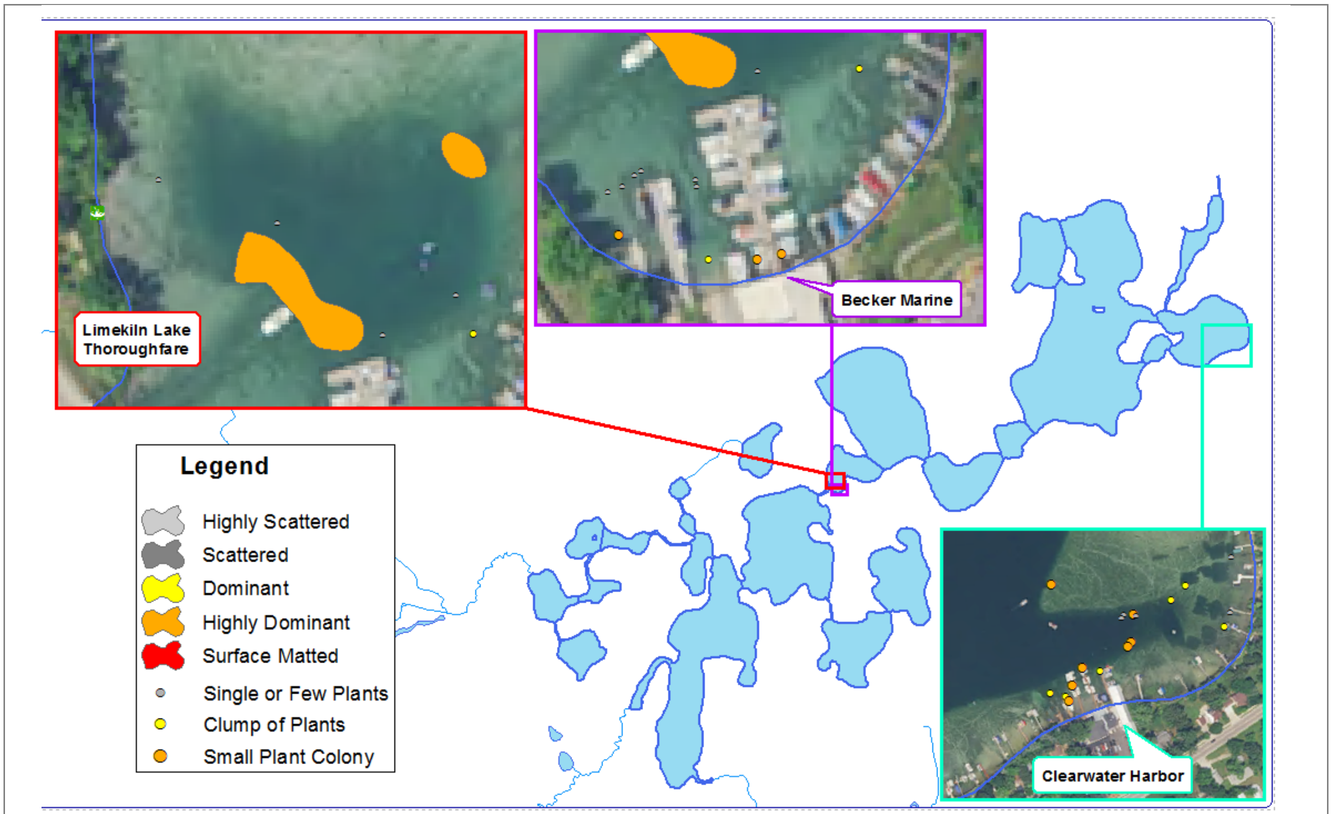


Figure 5.1-1. Waupaca Chain 2017 HWM Hand-Harvesting Control Sites.

5.2 Late-Summer HWM Peak-biomass Survey

The HWM population was mapped on September 27-28, 2017. During the survey, Onterra field crews meandered the littoral zone of the lakes and mapped HWM populations using sub-meter GPS technology. This meander-based survey, which mimics the methodology used in the ESAIS survey, was completed late in the growing season (August/September) when HWM had reached its peak growth stage. Because HWM should be at or near its maximum density, the results of this survey provide an understanding of where HWM is in the lake and what its full impact on the ecology of the lake may be. As a result, these data are useful in determining the efficacy of control actions used during the summer months as well as assisting in the next year's control planning.

Within the 4.4 acre site in Columbia Lake that was targeted for herbicide control in 2017, slightly less HWM was present than during the pre-treatment survey in 2016; however, large colonized beds of HWM remain present and the herbicide treatment fell short of control expectations for the site (Figure 5.2-1). Some level of seasonal HWM control was achieved from the 2017 diquat treatment as no HWM was visible at the time of the June ESAIS survey; however the plants that were impacted from the treatment were able to recover later in the growing season.

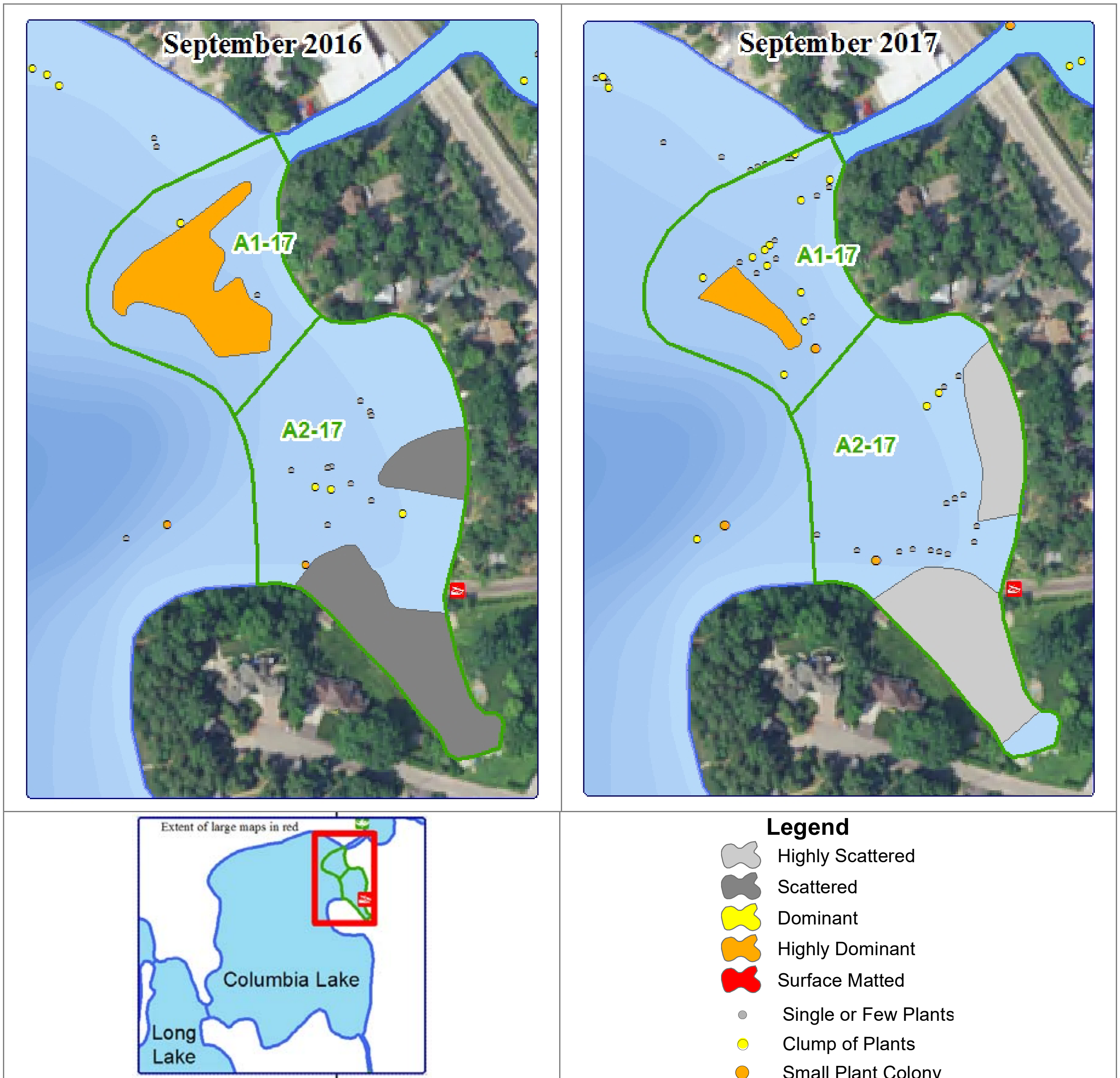


Figure 5.2-1. HWM Populations in Columbia Lake

When conducting large-scale whole lake treatments such as was done in Otter, Dake, and Miner Lakes in 2017, understanding the HWM population in the *year-of-treatment* (2017) is important; however, an insufficient amount of time has passed to understand if the control actions resulted in successful control or if the HWM plants were simply injured and will rebound the following year. No HWM was observed in Miner or Dake Lakes during the late-summer peak biomass survey and only a few single or few plant occurrences were located in Otter Lake (Map 6).

During the Chain-wide peak-biomass mapping survey, all lakes with the exception of Ottman Lake were surveyed. Ottman Lake requires access through a private property and no HWM was located in this lake during surveys completed in 2015. The population of HWM was found to be widespread throughout the Chain with some of the largest and most dense colonies being found in Long Lake, Beasley Lake and Bass Lake.

5.3 2017 Point-Intercept Survey Results – Otter Lake

Point-intercept surveys were completed by Onterra staff on the Waupaca Chain lakes on August 1-3, 2017. Zero occurrences of HWM were recorded on the 2017 point-intercept survey in Otter Lake. The littoral frequency of occurrence of HWM exhibited a 100% decrease since the 2016 survey (Figure 5.3-1). Along with understanding the level of HWM control achieved from the control action, the point-intercept data will also allow an understanding of non-target native plant impacts from the treatment. White water lily, spatterdock, muskgrasses, and stoneworts exhibited an increase in occurrence from 2016-2017 although the populations were not statistically different between the two surveys (Figure 5.3-1). Five native species that were sampled during the 2016 survey were not found during the 2017 survey and included coontail, sago pondweed, flat-stem pondweed, stiff pondweed and variable-leaf pondweed (Figure 5.3.-1). Each of these species was found on just one sampling location during the 2016 survey (LFOO = 3.8%). The decreases in occurrence for these species were not statistically valid due to a small sample size.

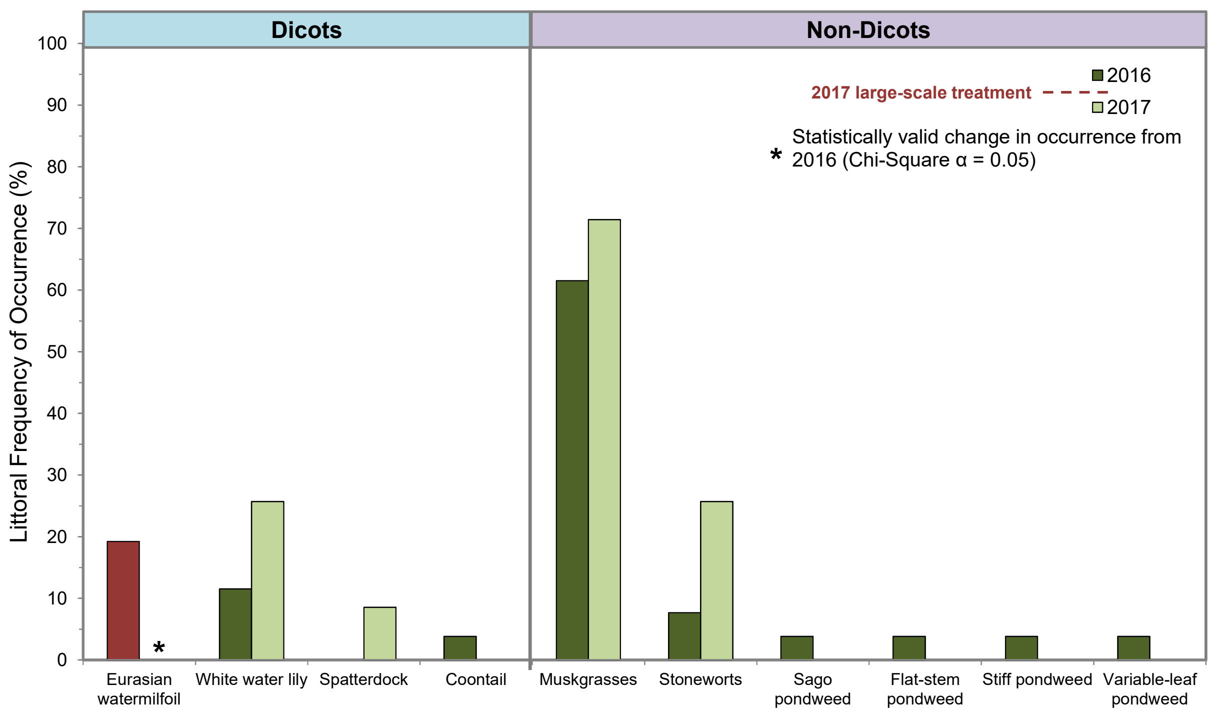


Figure 5.3-1. Littoral frequency of occurrence of aquatic plant species from 2016-2017 in Otter Lake. Whole-lake 2,4-D & endothall herbicide treatment occurred in spring 2017.

Figure 5.3-2 shows a semi-quantitative analysis of the abundance of natives through looking at total rake fullness ratings (i.e. how full of plants is the sampling rake at each location). In 2016, 73% of the point-intercept sampling locations within the littoral zone contained vegetation compared to 83% in 2017. It is important to note that the aquatic plant fullness in 2017 is completely comprised of native plant species, whereas HWM was a contributor to the aquatic plant biomass in 2016.

Emergent and floating-leaf aquatic plant communities are also an important component of a lake's aquatic plant community. These communities provide valuable structural habitat and stabilize bottom and shoreland sediments. A community mapping survey was completed in 2016 in Otter Lake as a part of the management planning project. The community mapping survey was replicated in 2017 in order to document any changes to this important component of the plant community following the large scale herbicide treatment. Map 7 displays the results of the 2016 and 2017 community mapping surveys. Overall, the differences between the two surveys were minimal and the floating-leaf and emergent communities appeared healthy in 2017.

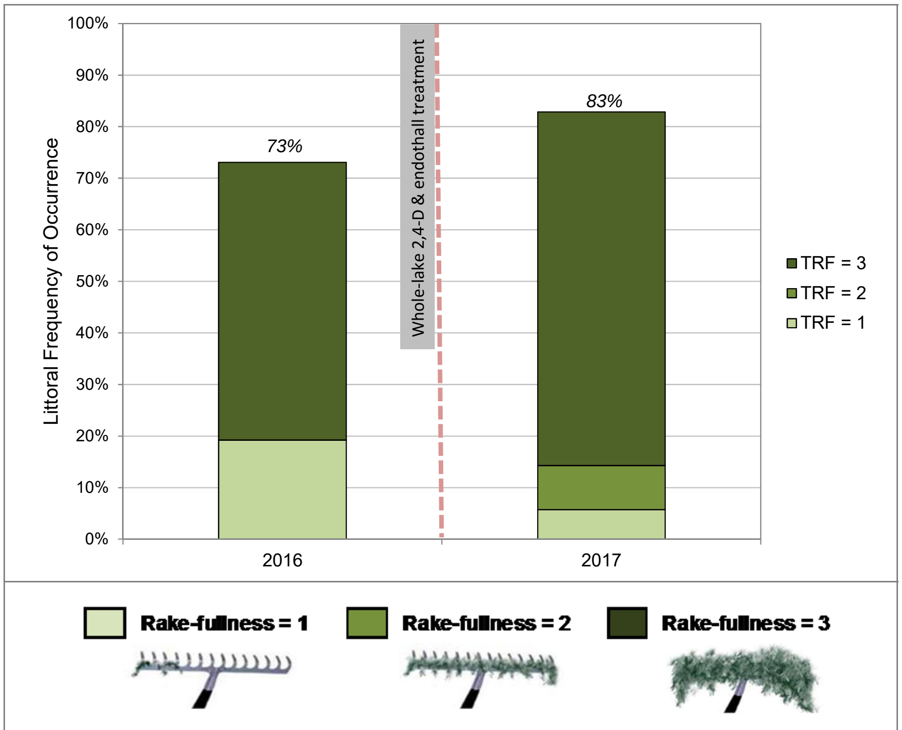


Figure 5.3-2. Otter Lake total rake fullness ratings from 2016–2017. The red-dashed line indicates the 2017 whole-lake herbicide treatment.

5.4 2017 Point-Intercept Survey Results – Dake Lake

Point-intercept surveys were completed by Onterra staff on the Waupaca Chain lakes on August 1-3, 2017. Zero occurrences of HWM were recorded on the 2017 point-intercept survey in Dake Lake. The littoral frequency of occurrence of HWM exhibited a 100% decrease since the 2016 survey (Figure 5.4-1). Along with understanding the level of HWM control achieved from the control action, the point-intercept data will also allow an understanding of non-target native plant impacts from the treatment. Two native species, sago pondweed (*Stuckenia pectinata*) and slender naiad (*Najas flexilis*), exhibited a statistically valid decrease in occurrence between the two surveys. Slender naiad is an annual that relies on seed production and has been shown to be particularly susceptible to auxin herbicides (e.g. 2,4-D, triclopyr). Additional species located on the point-intercept surveys that did not have a statistically different occurrence are displayed on Figure 5.4-1.

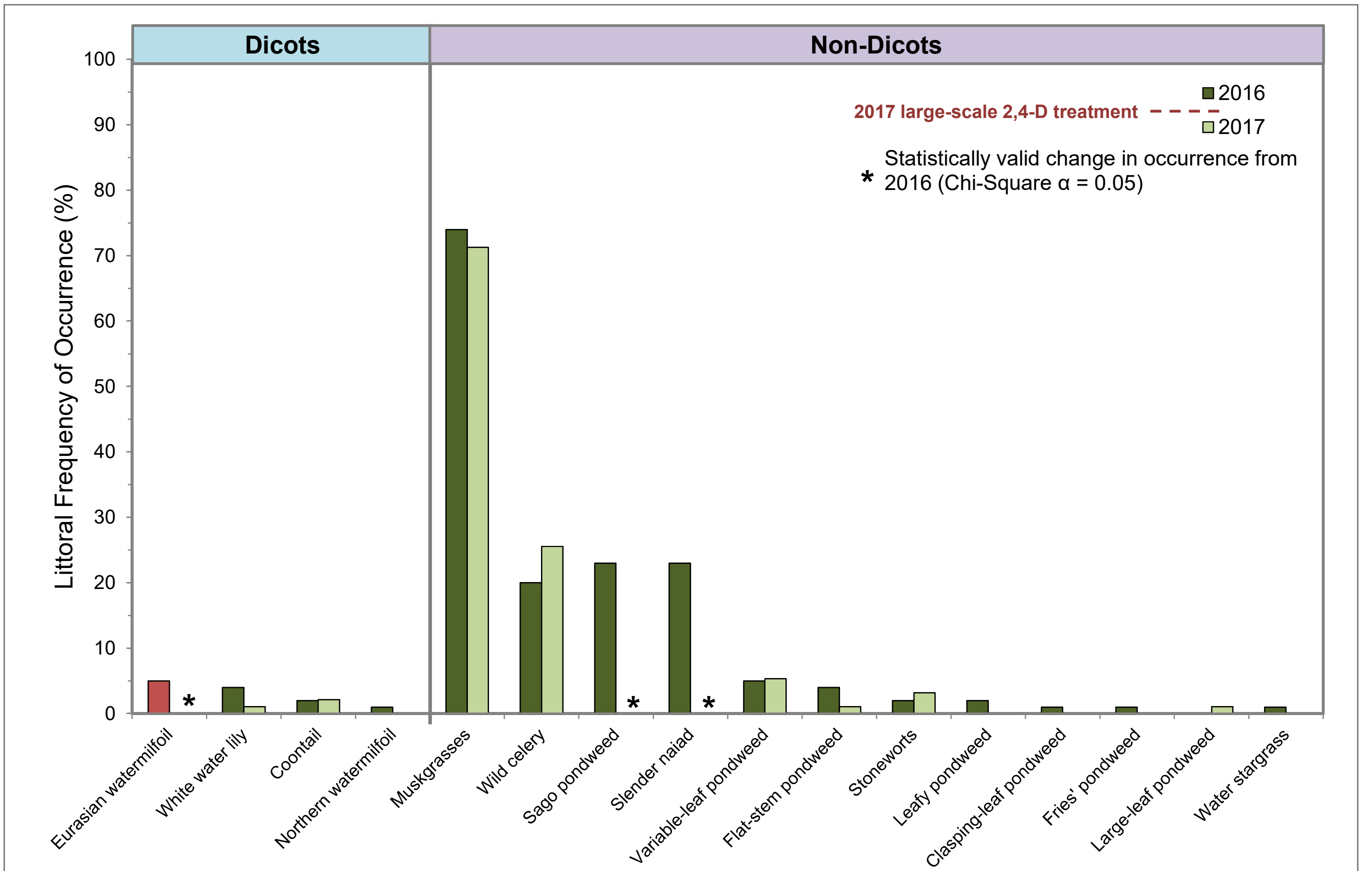


Figure 5.4-1. Littoral frequency of occurrence of aquatic plant species from 2016-2017 in Dake Lake. Data from Onterra 2016 & 2017 Point-Intercept Surveys. Whole-lake 2,4-D herbicide treatment occurred in spring 2017.

Figure 5.4-2 shows a semi-quantitative analysis of the abundance of natives through looking at total rake fullness ratings (i.e. how full of plants is the sampling rake at each location). In both the 2016 and 2017 surveys, 84% of the point-intercept sampling locations within the littoral zone contained vegetation. It is important to note that the aquatic plant fullness in 2017 was completely comprised of native plant species, whereas HWM was a contributor to the aquatic plant biomass in 2016.

Emergent and floating-leaf aquatic plant communities are also an important component of a lake's aquatic plant community. These communities provide valuable structural habitat and stabilize bottom and shoreland sediments. A community mapping survey was completed in 2016 in Dake Lake as a part of the management planning project. The community mapping survey was replicated in 2017 in order to document any changes to this important component of the plant community following the large scale herbicide treatment. Map 8 displays the results of the 2016 and 2017 community mapping surveys. A reduction of floating leaf communities, largely white water lily, was evident within bays in the northwest and west ends of Dake Lake. Onterra's experience indicates white-water lily is typically resilient to standard large-scale 2,4-D use-patterns. It is theorized that the higher concentrations and longer exposure times observed during the 2017 large-scale 2,4-D treatment of Dake Lake resulted in the impacts to white water lilies. Continuing monitoring will take place to allow an understanding of recovery from these impacts.

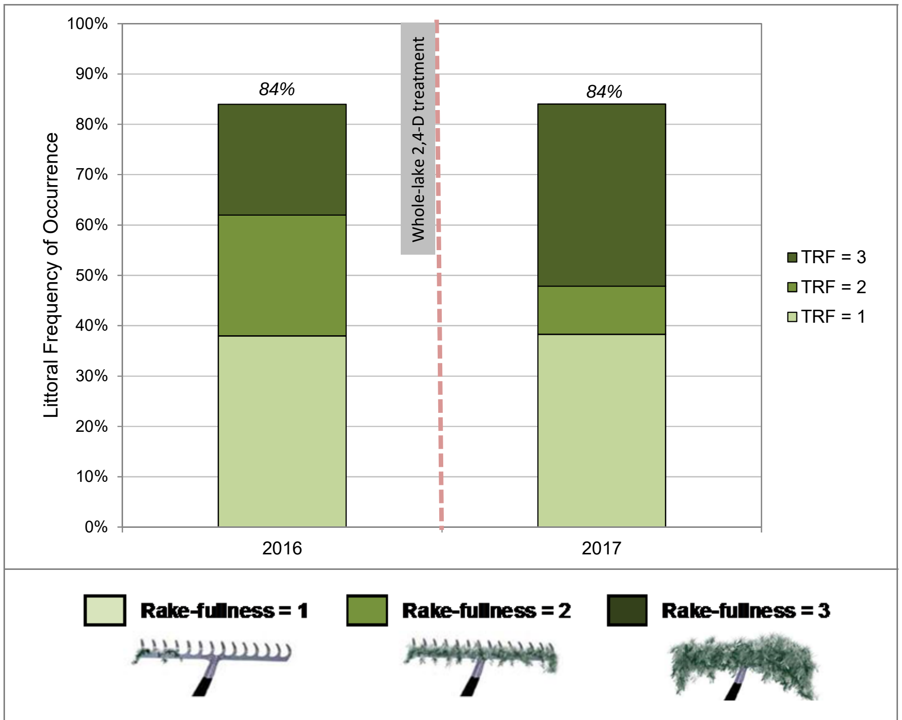


Figure 5.4-2. Dake Lake total rake fullness ratings from 2016–2017. The red-dashed line indicates the 2017 whole-lake herbicide treatment.

5.5 2017 Point-Intercept Survey Results – Miner Lake

Point-intercept surveys were completed by Onterra staff on the Waupaca Chain lakes on August 1-3, 2017. Two occurrences of HWM were recorded on the 2017 point-intercept survey in Miner Lake. The littoral frequency of occurrence of HWM exhibited a statistically valid 78.6% decrease since the 2016 survey (Figure 5.5-1). Along with understanding the level of HWM control achieved from the control action, the point-intercept data will also allow an understanding of non-target native plant impacts from the treatment. Three native species, sago pondweed (*Stuckenia pectinata*), slender naiad (*Najas flexilis*), and muskgrasses (*Chara* spp.) exhibited a statistically valid decrease in occurrence between the two surveys, while one species, stoneworts (*Nitella* spp.) showed a statistically valid increase. Additional species located on the point-intercept surveys are displayed on Figure 5.5-1.

Muskgrasses and stoneworts are actually macroalgae and due to their lack of vascular tissue are unable to translocate herbicides; therefore, they are typically unaffected by herbicide use. While field identification of muskgrasses and stoneworts is possible, some errors may have been made in one of the surveys. If these two macrophyte groups were lumped together, the populations would not be statistically different between the two surveys.

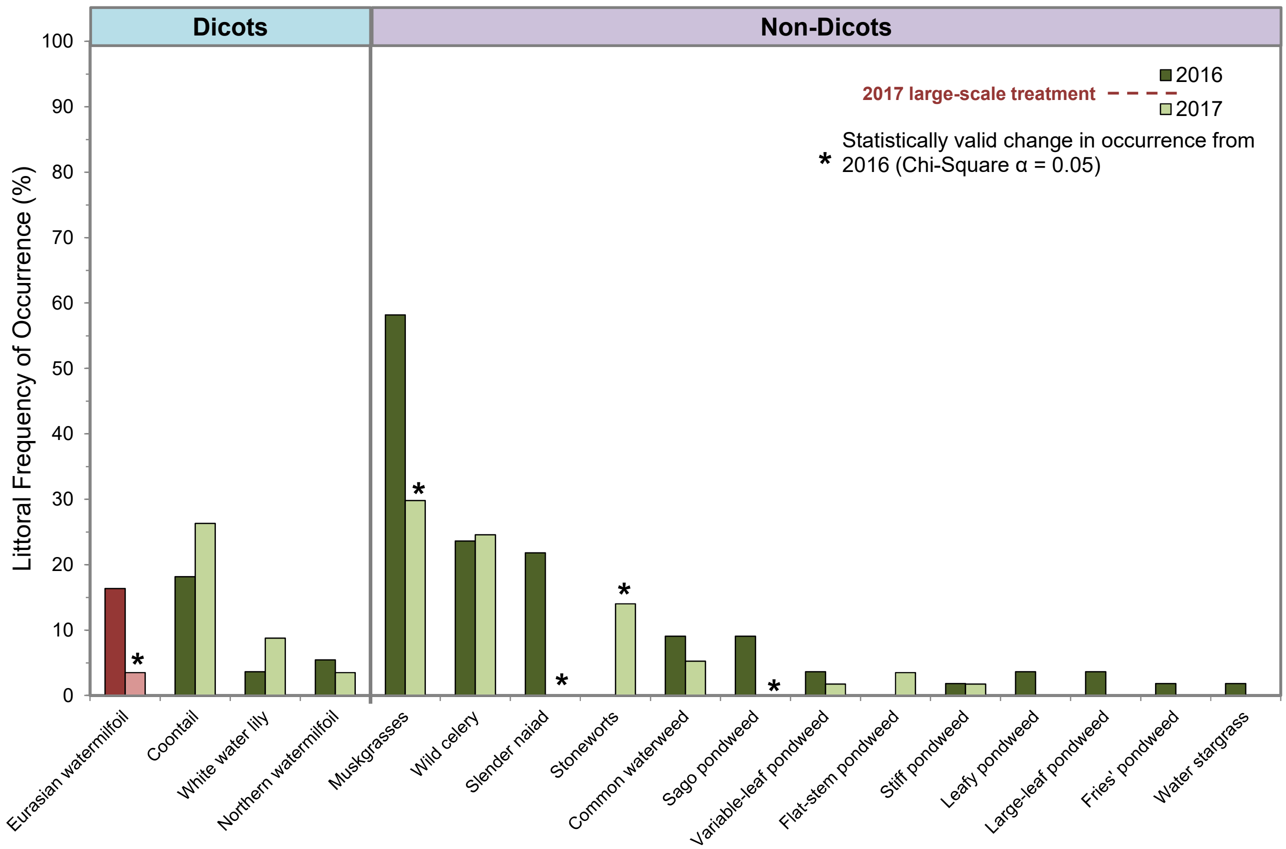


Figure 5.5-1. Littoral frequency of occurrence of aquatic plant species from 2016-2017 in Miner Lake. Data from Onterra 2016 & 2017 Point-Intercept Surveys. Whole-lake 2,4-D herbicide treatment occurred in spring 2017.

Figure 5.5-2 shows a semi-quantitative analysis of the abundance of natives through looking at total rake fullness ratings (i.e. how full of plants is the sampling rake at each location). In 2016, 80% of the point-intercept sampling locations within the littoral zone contained vegetation compared to 72% in 2017. It is important to note that the aquatic plant fullness in 2017 was almost completely comprised of native plant species, whereas HWM was a contributor to the aquatic plant biomass in 2016.

Emergent and floating-leaf aquatic plant communities are also an important component of a lake's aquatic plant community. These communities provide valuable structural habitat and stabilize bottom and shoreland sediments. A community mapping survey was completed in 2016 in Miner Lake as a part of the management planning project. The community mapping survey was replicated in 2017 in order to document any changes to this important component of the plant community following the large scale herbicide treatment. Map 9 displays the results of the 2016 and 2017 community mapping surveys. A reduction of floating leaf communities, largely white water lily, was evident within parts of Miner Lake. Onterra's experience indicates white-water lily is typically resilient to standard large-scale 2,4-D use-patterns. It is theorized that the higher concentrations and longer exposure times observed during the 2017 large-scale 2,4-D treatment of Miner Lake resulted in the impacts to white water lilies. Continuing monitoring will take place to allow an understanding of recovery from these impacts.

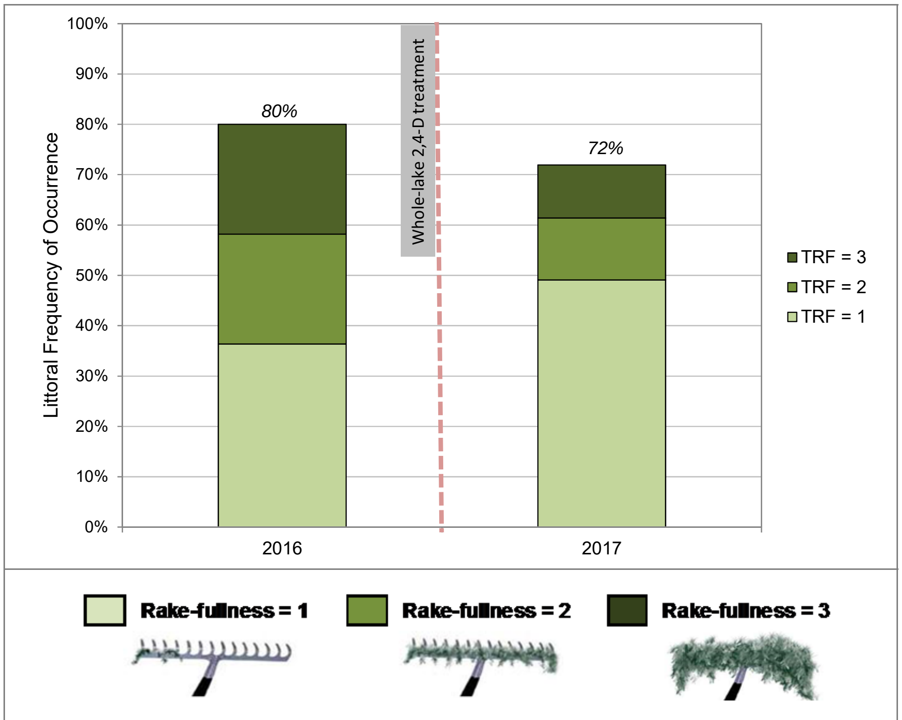


Figure 5.5-2. Miner Lake total rake fullness ratings from 2016–2017. The red-dashed line indicates the 2017 whole-lake herbicide treatment.

6.0 2017 TREATMENT STRATEGY CONCLUSIONS

Surveys conducted in 2017 on Otter, Dake and Miner Lakes show that the large-scale treatments conducted in the spring were successful in meeting the HWM control objectives. No HWM was located during the late-summer mapping surveys in Dake Lake or Miner Lake following the treatment although two HWM occurrences were found on the point-intercept survey in Miner Lake. Minimal HWM consisting of single plants was found in Otter Lake during surveys conducted in 2017. The reduction of the HWM population in 2017 exceeded the qualitative and quantitative success criteria for the whole-lake treatments and met lake managers control expectations. The diquat spot treatment in Columbia Lake provided seasonal control; however HWM in this treatment area had begun to rebound by the end of the growing season. Some reductions in native plant communities were observed in the lakes that underwent whole-lake treatments, notably slender naiad, white water lily, and sago pondweed. It will be important to continue monitoring these populations to understand long-term implications from the 2017 control strategy. Ongoing research is investigating the relationship of the pH of lakes and how it relates to the degradation pattern in treatments utilizing 2,4-D. Water quality testing completed in 2016 on select lakes in the Chain found relatively hard water with pH ranging between 8.3 and 8.7.

The results of the late-summer peak biomass survey found the lake-wide HWM population consisted of approximately 20.3 acres of colonized HWM or about 8.3 acres less than the 2016 survey (Figure 6.0-1, Map 6). Much of the reduction in acreage observed in 2017 is from lakes that were included in the herbicide treatment control efforts. The acreage estimates only take into account the HWM polygons, not HWM mapped within point-based methodologies (*Single or Few Plants, Clumps of Plants*, or *Small Plant Colonies*). Taken out of context, this figure can be misleading as it relates to the HWM population changes. For instance, large areas of the lake may be mapped using point-based methods in one year and if these areas increased in density slightly, they would likely be mapped using polygon-based methods in the following year and result in a large increase in acreage. Similarly, an increase in point-based EWM occurrences within a lake would not be represented on this figure. Of the HWM acreage mapped in 2017, approximately 8.0 acres or 39% was within Long Lake, 2.7 acres or 13% in Bass Lake, and 2.5 acres or 12% in Beasley Lake (Figure 6.0-2).

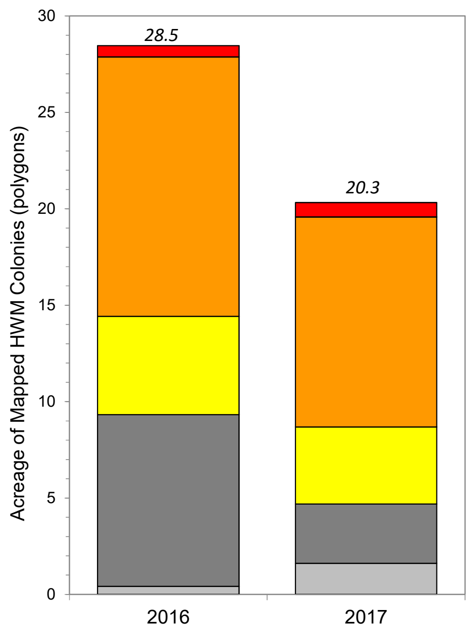


Figure 6.0-1. Waupaca Chain O' Lakes 2016-2017 HWM Colony Density Ratings. Created using data from 2016 & 2017 Late-Summer EWM Peak-Biomass Surveys.

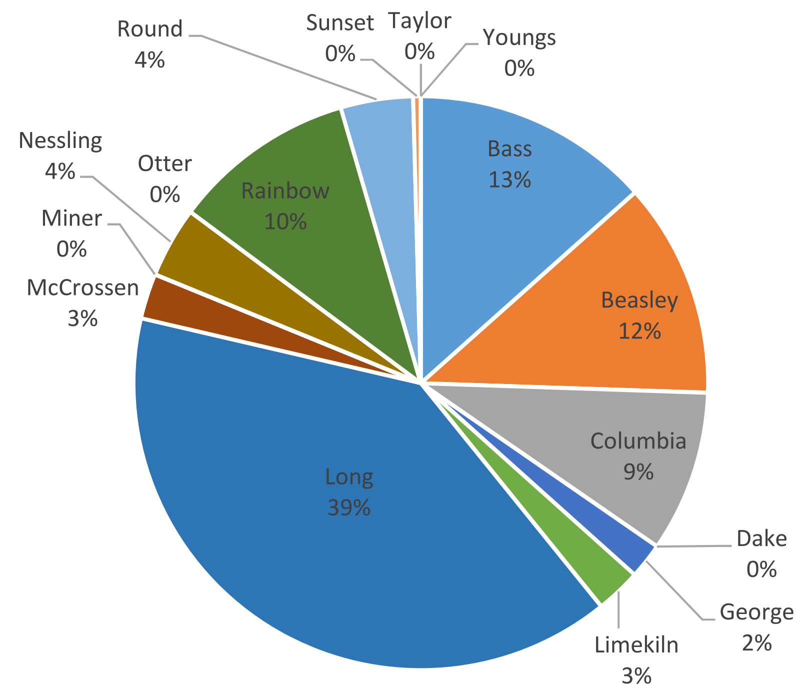


Figure 6.0-2. Waupaca Chain O' Lakes 2017 Colonized HWM Acreage Distribution by Lake. Created using data from 2017 Late-Summer EWM Peak-Biomass Survey.

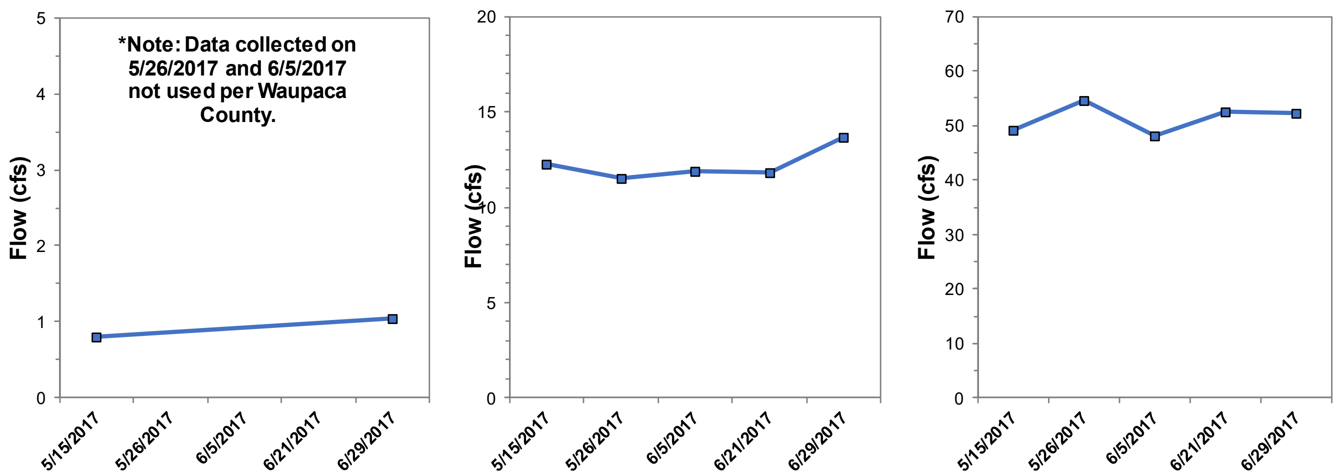
Curly leaf pondweed monitoring in 2017 found that the population was localized in some areas of the Chain. Continued monitoring of this species will be valuable if active management is to occur in the future.

7.0 2017 FLOW MONITORING RESULTS

Flow data was collected on the Waupaca Chain O' Lakes at three locations in May and June of 2017; 1) at the outlet from Youngs Lake to Beasley Lake, 2) at the outlet of the Upper Chain to the Lower Chain (outlet from Knight Lake to Beasley Lake), and 3) at the mouth of the Crystal River at Long Lake's outlet (Figure 7.0-1 and Figure 7.0-2).

Figure 7.0-1 2017 Flow Monitoring Locations and Waupaca Chain Morphometry Diagram

Site 1- Youngs Lake Outlet	Site 2 – Upper Chain Outlet	Site 3- Crystal River Outlet



May 2017 Discharge: 43 acre-ft June 2017 Discharge: 42 acre-ft	May 2017 Discharge: 730 acre-ft June 2017 Discharge: 742 acre-ft	May 2017 Discharge: 3,192 acre-ft June 2017 Discharge: 3,033 acre-ft

Figure 7.0-2. 2017 Flow Monitoring Results. Data collected and provided by Waupaca County LWCD.

Precipitation data is available from the Midwest Regional Climate Center (MRCC) from Waupaca. In the past 20 years, the average precipitation during the growing season (April through October) in Waupaca was approximately 24 inches. In 2017, Waupaca saw approximately 26 inches during the growing season, over 2 inches more than the average. While more precipitation was seen on average during the growing season in 2017, flow in Emmons Creek and Hartman Creek, for which data is available from 2011 through 2017, was not significantly higher in Emmons Creek or Hartman Creek in 2017. No significant correlation was observed between flow and precipitation in either stream (Figures 7.0-3 and 7.0-4). The Waupaca Chain O' Lakes is located within the central sands region and discharge is likely dominated by baseflow, meaning groundwater dominates the flow. The discharge modeled using the 2017 data collected on the Waupaca Chain O' Lakes is believed to be representative of an average flow in the lakes.

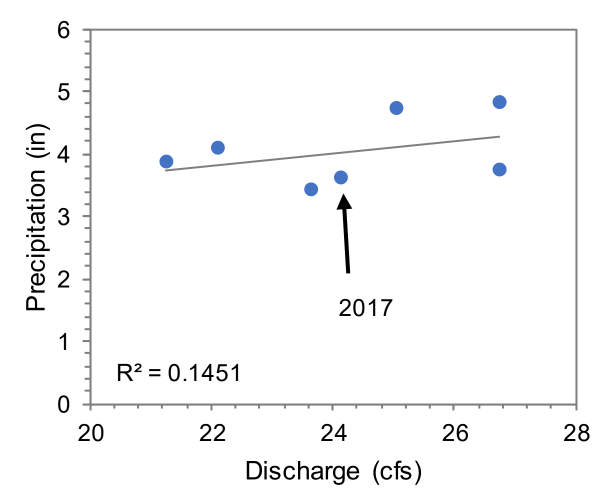


Figure 7.0-3. Spring precipitation and flow in Emmons Creek. Flow data is from May through June from 2011 to 2017 and precipitation data is from April through May from 2011-2017.

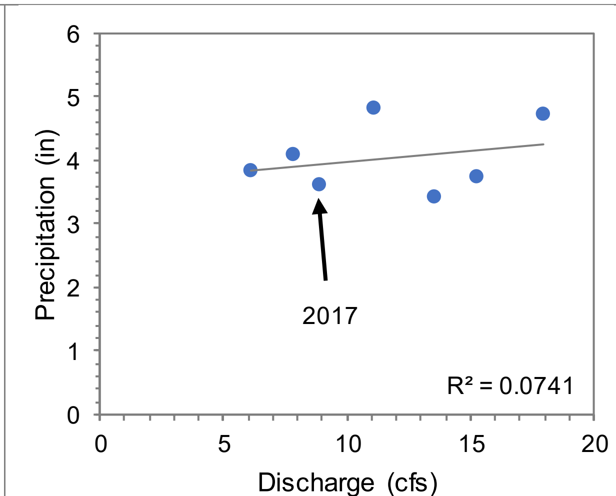


Figure 7.0-4. Spring precipitation and flow in Hartman Creek. Flow data is from May through June from 2011 to 2017 and precipitation data is from April through May from 2011-2017.

Using the available data, flushing rates for Bass, Beasley, and Long Lakes were calculated and displayed in Table 7.0-1. The modeling indicates that water residence time is about 9 days in Bass Lake, 6-7 days within the epilimnion of Beasley Lake, and 12-14 days in the epilimnion of Long Lake.

Table 7.0-1. Modeled Water Residence from Flow Study Data. May and June

	Bass Lake	Beasley Lake	Long Lake
Lake Volume (acre-feet):	12	306	3,182
Whole-Lake Residence Time (Days):	9	12	31
Epilimnetic (18 ft) Residence Time (Days):	-	7	14
Epilimnetic (15 ft) Residence Time (Days):	-	6	12

8.0 2018 PROPOSED HWM CONTROL STRATEGY DEVELOPMENT

8.1 2018 Proposed Large-Scale HWM Control Strategy

In 2018, the WCOLD will continue to implement an integrated approach to managing the HWM population in the system. As discussed above, the largest and densest HWM colonies exist in Bass, Beasley, and Long Lakes. Based on the results of the 2017 field trials and 2017 flow monitoring studies, standard large-scale use patterns with 2,4-D alone are not anticipated to provide more than limited seasonal reductions in HWM populations. Dr. Scott Nissen (Colorado State University) is currently investigating herbicide uptake and translocation of various aquatic herbicides. Within a recent newsletter, Dr. Nissen is quoted, "Based on our endothall studies in flowing water, we thought that endothall must have some systemic activity, and now we have data that confirms that endothall does translocate from shoots to root tissue. In fact, the ratio of endothall in the root vs. shoot tissue after 192 hours of exposure was greater for endothall than for other systemic herbicides that we have evaluated." These data do not indicate that a combination 2,4-D and endothall treatment requires a shorter exposure time, but they do provide perspective on the justification of adding endothall for HWM control.

The watershed-based water residence time of Otter Lake is 480 days. While the 2017 combination 2,4-D/endothall treatment in this waterbody was successful, at least in the short term, the transferability of this trial treatment to lakes with much shorter exposure times is unknown. At this time, Onterra does not feel sufficient evidence exists to know if there is a high likelihood of successful control on Bass, Beasley, and Long Lakes with a combination 2,4-D/endothall large-scale treatment. Because of the relatively small size of Bass and Beasley Lakes, a field trial with this herbicide use pattern is recommended in 2018 (Map10). Being ten times larger, a treatment of Long Lake would be postponed until after the results of the 2018 field trial are understood, potentially for 2019. Rough cost estimates to treat Bass and Beasley Lake would be $9,000, whereas Long Lake would be an additional $55,000.

This large-scale herbicide use pattern is similar to those conducted in 2017 and requires a certain level of planning, coordinating, and monitoring. Herbicide concentration monitoring will again evaluate the herbicide degradation rates in the days and weeks following the treatment and a formal document detailing the monitoring will be developed in the coming weeks leading up to the proposed treatment.

On October 25, 2017, Onterra staff systematically collected continuous, advanced sonar data across Bass, Beasley and Long Lakes. One result of this survey produced an updated bathymetric map of the system. The success of properly planning and implementing large-scale treatments rely on accurate bathymetric information with which advanced water volume calculations are conducted. This ensures meeting target concentrations outlined within the dosing strategy, which is devised to provide HWM control while balancing native plant selectivity.

Post treatment assessments would be conducted including Chain-wide point-intercept surveys, Chain-wide late-season HWM mapping surveys, and floating-leaf/emergent plant community surveys on large-scale treatment lakes.

8.2 2018 Proposed Small-Scale HWM Control Strategy

Other more isolated populations of dense HWM exist in the Chain that are not applicable for consideration in a whole-lake treatment herbicide use pattern, but may be appropriate for consideration for control through herbicide spot treatments or coordinated hand-harvesting. As discussed within the lake management planning project, control of EWM/HWM with small spot treatments (working definition is less than 5 acres) with systemic herbicides is rarely effective due to rapid herbicide dissipation. For 2017, an herbicide with a shorter exposure time requirement was recommended: diquat. Unfortunately, the 2017 spot treatment in Columbia Lake resulted in seasonal control and may completely rebound by the summer of 2018 if no additional management actions are conducted.

The long-term control of EWM/HWM targeted with diquat continues to be evaluated on many lakes across Wisconsin. On some lakes, the preliminary results appear promising. As a contact herbicide, diquat does not move (translocate) through plant tissue. Therefore, only the exposed plant material is impacted by the herbicide. Concern exists whether this herbicide has the capacity to kill the entire plant or simply removes all the above ground biomass and the plant rebounds from unaffected root crowns. Diquat also has a high affinity for binding with organic particles. In shallow waters where the application equipment creates disturbance of the lake bottom, the diquat being applied will quickly bind to the suspended particles and be instantly unavailable to cause impacts to the target plants. In lakes with high organic material encrusted on the plant, this may also reduce the efficacy of the treatment.

When diquat is mixed with endothall, as is commercially available under the Aquastrike® brand, it is theorized to have even shorter exposure time requirements than diquat alone. While diquat does not have systemic activity, endothall has proven to have a high level of systemic activity (i.e. moves throughout the plant, including into the root crown) at cold water temperatures. Within a recent United Phosphorus, Inc. (UPI) newsletter-style report, Dr. Scott Nissen (Colorado State University) is quoted, "We have data that confirms that endothall does translocate from shoots to root tissue. In fact, the ratio of endothall in the root vs. shoot tissue after 192 hours of exposure was greater for endothall than for other systemic herbicides that we have evaluated." The manufacturers of endothall (UPI), have shown that increased systemic activity of endothall occur when water temperatures are colder (<60°F).

This herbicide use-pattern has shown promise controlling EWM in a few Wisconsin treatments. Map 11 displays nine sites throughout the Chain that are preliminarily recommended for spot treatments utilizing Aquastrike®. These sites were chosen based on the presence of colonized HWM consisting largely of *dominant* densities or greater and in which at least a one-acre treatment site could be constructed with a reasonable sized buffer. Comparing HWM mapping surveys from the summer before the treatment to the summer following the treatment will allow an understanding of the level of control achieved.

As a part of an integrated HWM control strategy, the WCOLD is piloting a hand-harvesting program for select locations in the Chain in order to determine what role this management technique may have in future HWM management actions. Sites that are not of sufficient size to result in a successful herbicide treatment will be considered for professional hand-harvesting control actions. Specific sites to be prioritized for hand-harvesting may include areas that are not being targeted through herbicide treatments, but are of higher use, high visibility to lake users, near public access locations, or otherwise prioritized by WCOLD members.

There is great advantage of hiring an experienced firm that offers paid hand-harvesting services over a volunteer effort, including reliability of effort, documentation of work completed, and transferability of effort spent towards future planning. Professional hand-harvesting firms can be contracted for these efforts and can either use basic snorkeling or scuba divers, whereas others might employ the use of a Diver Assisted Suction Harvest (DASH) which involves divers removing plants and feeding them into a suctioned hose for delivery to the deck of the harvesting vessel. The DASH methodology is considered a form of mechanical harvesting and thus requires a WDNR approved permit. DASH is thought to be more efficient in removing target plants than divers alone and is believed to limit fragmentation during the harvesting process. DASH may be beneficial for use on the Waupaca Chain for areas that contain dense HWM and/or are in deeper water.

Based upon Onterra's HWM surveys during the summers of 2016 and 2017, two areas within the Chain have been preliminarily prioritized for DASH during 2018. Map 12 shows the two preliminary areas, one in Lime Kiln Lake (Site Y-18) and the second in George Lake (Site Z-18). Due to the area's high use, site Y-18 is set as the highest priority. The WCOLD has contracted with a professional hand-harvesting firm (DASH, LLC) to provide DASH HWM harvesting services in 2018. Map 12 may be used by DASH, LLC and the WCOLD to begin the permitting process with the WDNR to obtain a conditional permit.

In early summer 2018, Onterra will conduct an Early Season AIS Survey (ESAIS Survey). Based on the results of the ESAIS Survey, the hand-harvesting control strategy will be revised if necessary and finalized (Figure 8.2-1). The final WDNR approved mechanical harvesting permit will be based on the strategy developed following Onterra's 2018 ESAIS survey which could be different from the preliminary strategy outlined on Map 12. Onterra will provide the finalized hand-harvesting strategy and the spatial data from the ESAIS survey to the professional hand-harvesting firm for use in obtaining the final mechanical harvesting permit from the WDNR. Hand-harvesting would take place between the ESAIS (pre) and the late-summer HWM Peak-Biomass (post) surveys, allowing for evaluation of the management activity.

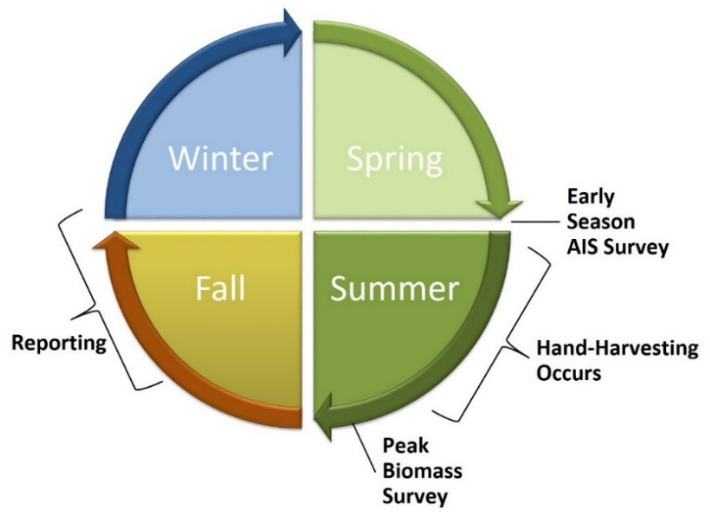
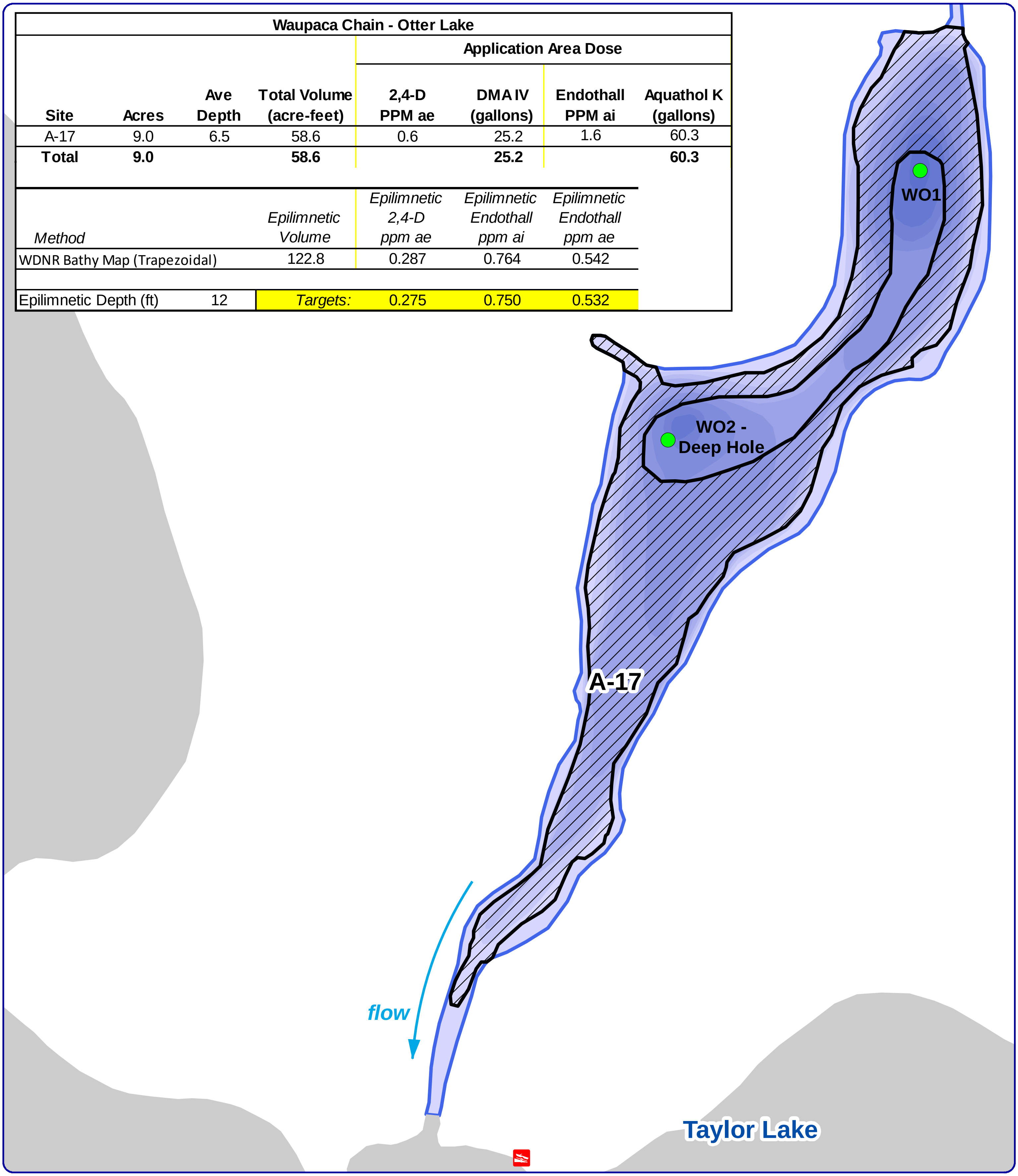


Figure 8.2-1. Hand-Harvesting Control & Monitoring Timeline. Includes potential hand-harvesting efforts which may or may not take place.

Waupaca Chain - Otter Lake

Site	Acres	Ave Depth	Total Volume (acre-feet)	Application Area Dose: 2,4-D PPM ae	Application Area Dose: DMA IV (gallons)	Application Area Dose: Endothall PPM ai	Application Area Dose: Aquathol K (gallons)
A-17	9.0	6.5	58.6	0.6	25.2	1.6	60.3
Total	**9.0**		**58.6**		**25.2**		**60.3**

Method		*Epilimnetic Volume*	*Epilimnetic 2,4-D ppm ae*	*Epilimnetic Endothall ppm ai*	*Epilimnetic Endothall ppm ae*
WDNR Bathy Map (Trapezoidal)		122.8	0.287	0.764	0.542
Epilimnetic Depth (ft)	12	*Targets:*	0.275	0.750	0.532



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Onterra LLC
Lake Management Planning
815 Prosper Road
De Pere, WI 54115
920.338.8860
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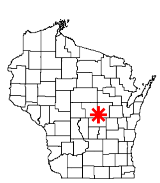
Sources:
Roads and Hydro: WDNR
Aquatic Plants: Onterra, 2016
Map Date: May 22, 2017
Filename: Otter_HWM_T2017_Perm1.mxd



Project Location in Wisconsin

Legend

2017 Final Herbicide Application Area

2017 Herbicide Concentration Monitoring Locations

Map 1
Otter Lake
Waupaca County, Wisconsin

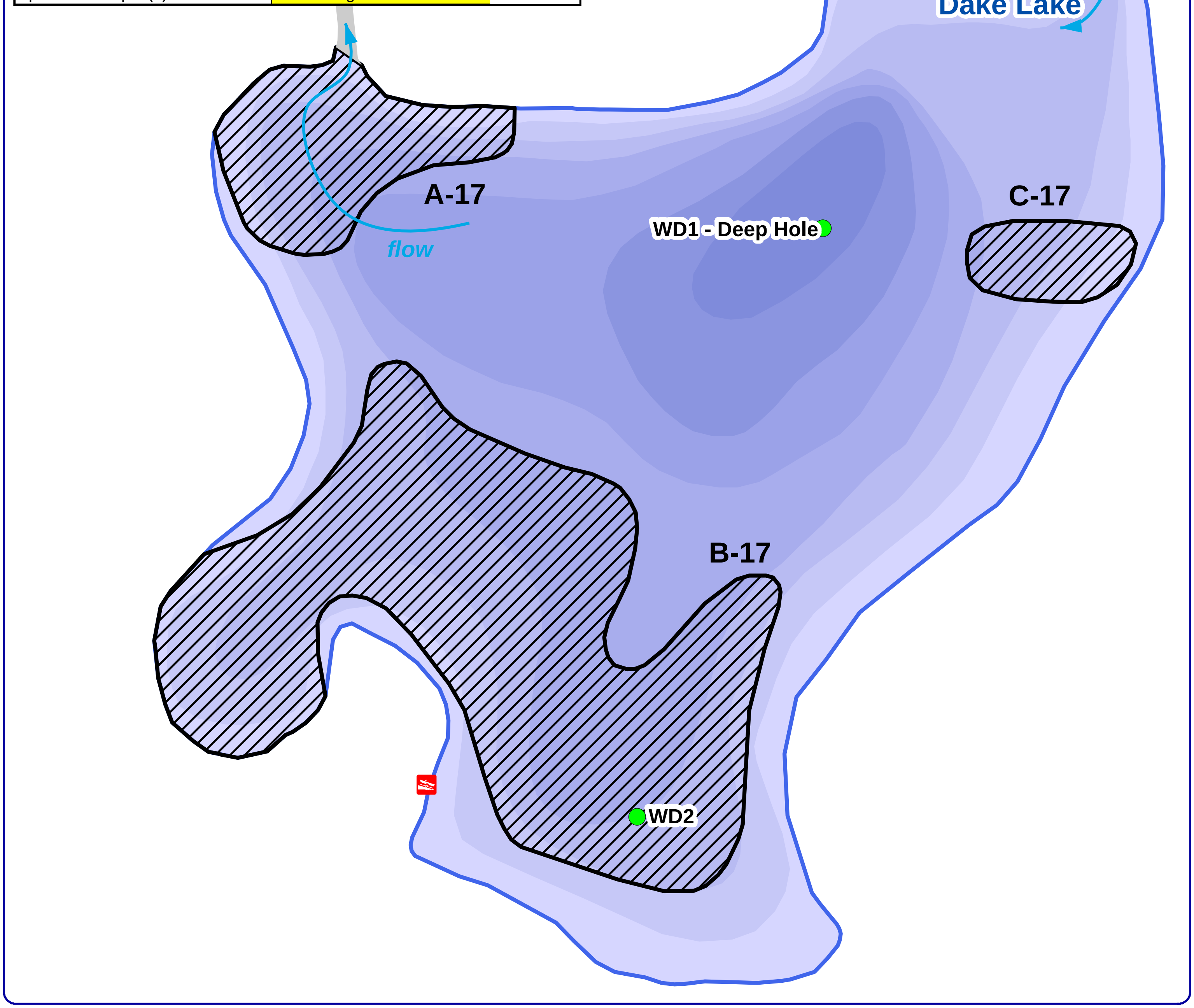
2017 Final HWM Herbicide Control Strategy

Waupaca Chain - Dake Lake

Site	Acres	Ave Depth	Total Volume (acre-feet)	Application Area Dose: 2,4-D PPM ae	Application Area Dose: DMA IV (gallons)
A-17	1.9	5.0	9.4	1.30	8.8
B-17	8.9	7.0	62.0	1.35	59.9
C-17	0.6	7.5	4.9	1.30	4.5
Total	**11.4**		**76.3**		**73.2**

Method	*Epilimnetic Volume*	*Epilimnetic 2,4-D ppm ae*
WDNR Bathy Map (Trapezoidal)	271.5	0.377

Epilimnetic Depth (ft)	12	*Target:*	0.375



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230
Feet

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Sources:
Roads and Hydro: WDNR
Aquatic Plants: Onterra, 2016
Map Date: May 22, 2017
Filename: Dake_HWM_T2017_Perm1.mxd

Project Location in Wisconsin

Legend

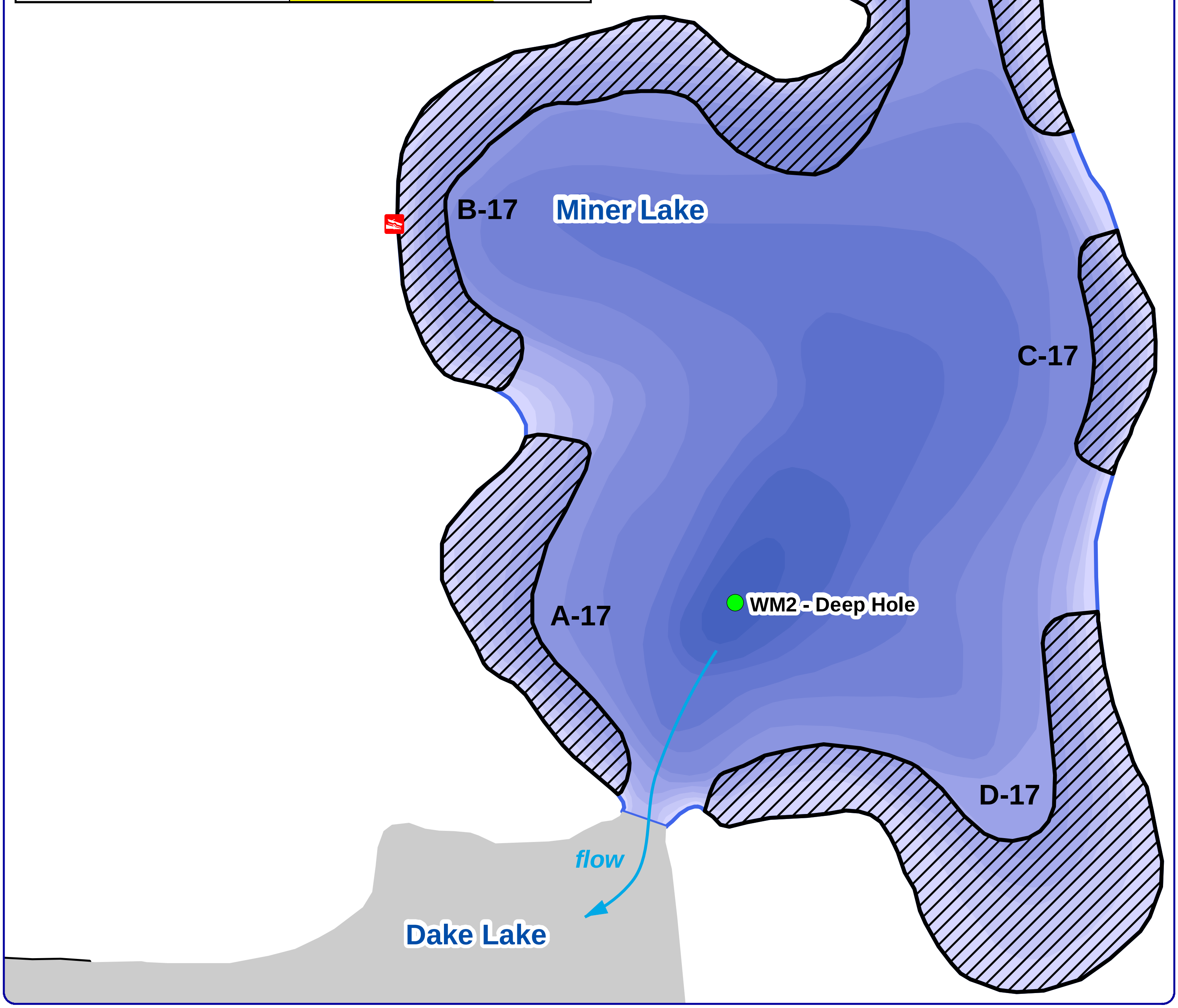
2017 Final Herbicide Application Area

2017 Herbicide Concentration Monitoring Locations

Map 2
Dake Lake
Waupaca County, Wisconsin
2017 Final HWM Herbicide Control Strategy

Waupaca Chain - Miner Lake					
				Application Area Dose	
Site	Acres	Ave Depth	Total Volume (acre-feet)	2,4-D PPM ae	DMA IV (gallons)
A-17	1.8	6.5	11.6	2.35	19.4
B-17	6.7	6.5	43.3	2.35	72.8
C-17	0.8	5.5	4.6	2.35	7.8
D-17	4.3	5.5	23.5	2.35	39.5
Total	**13.6**		**83.0**		**139.5**

Method		*Epilimnetic Volume*	*Epilimnetic 2,4-D ppm ae*
WDNR Bathy Map (Trapezoidal)		519.6	0.375
Epilimnetic Depth (ft)	16	*Target:*	0.375



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Feet

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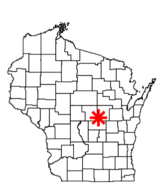
Sources:
Roads and Hydro: WDNR
Aquatic Plants: Onterra, 2016
Map Date: May 22, 2017
Filename: Miner_HWM_T2017_Perm1.mxd



Project Location in Wisconsin

Legend

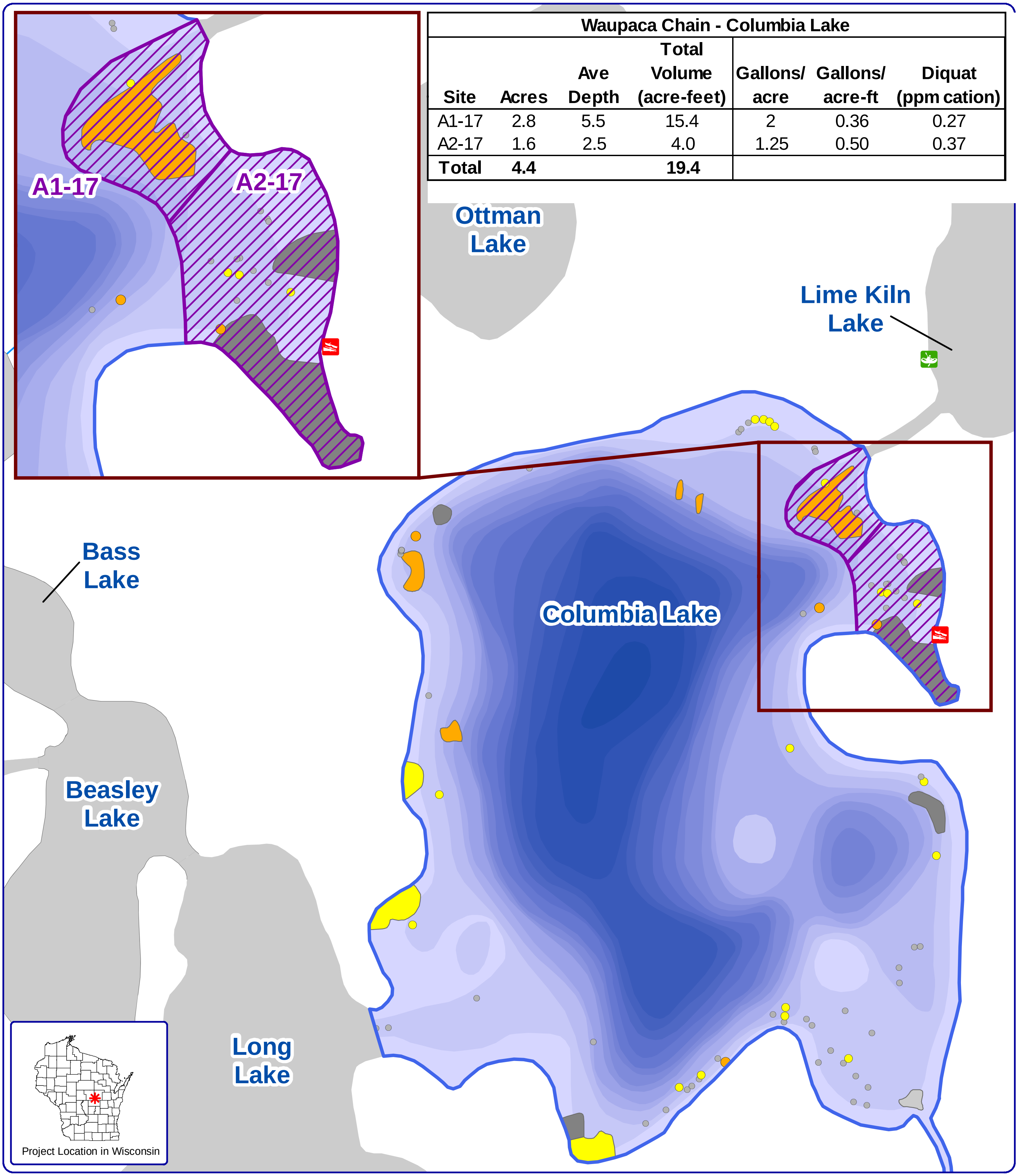
2017 Final Herbicide Application Area

2017 Herbicide Concentration Monitoring Locations

Map 3
Miner Lake
Waupaca County, Wisconsin

2017 Final HWM Herbicide Control Strategy

Waupaca Chain - Columbia Lake						
Site	Acres	Ave Depth	Total Volume (acre-feet)	Gallons/ acre	Gallons/ acre-ft	Diquat (ppm cation)
A1-17	2.8	5.5	15.4	2	0.36	0.27
A2-17	1.6	2.5	4.0	1.25	0.50	0.37
Total	**4.4**		**19.4**			



410
Feet

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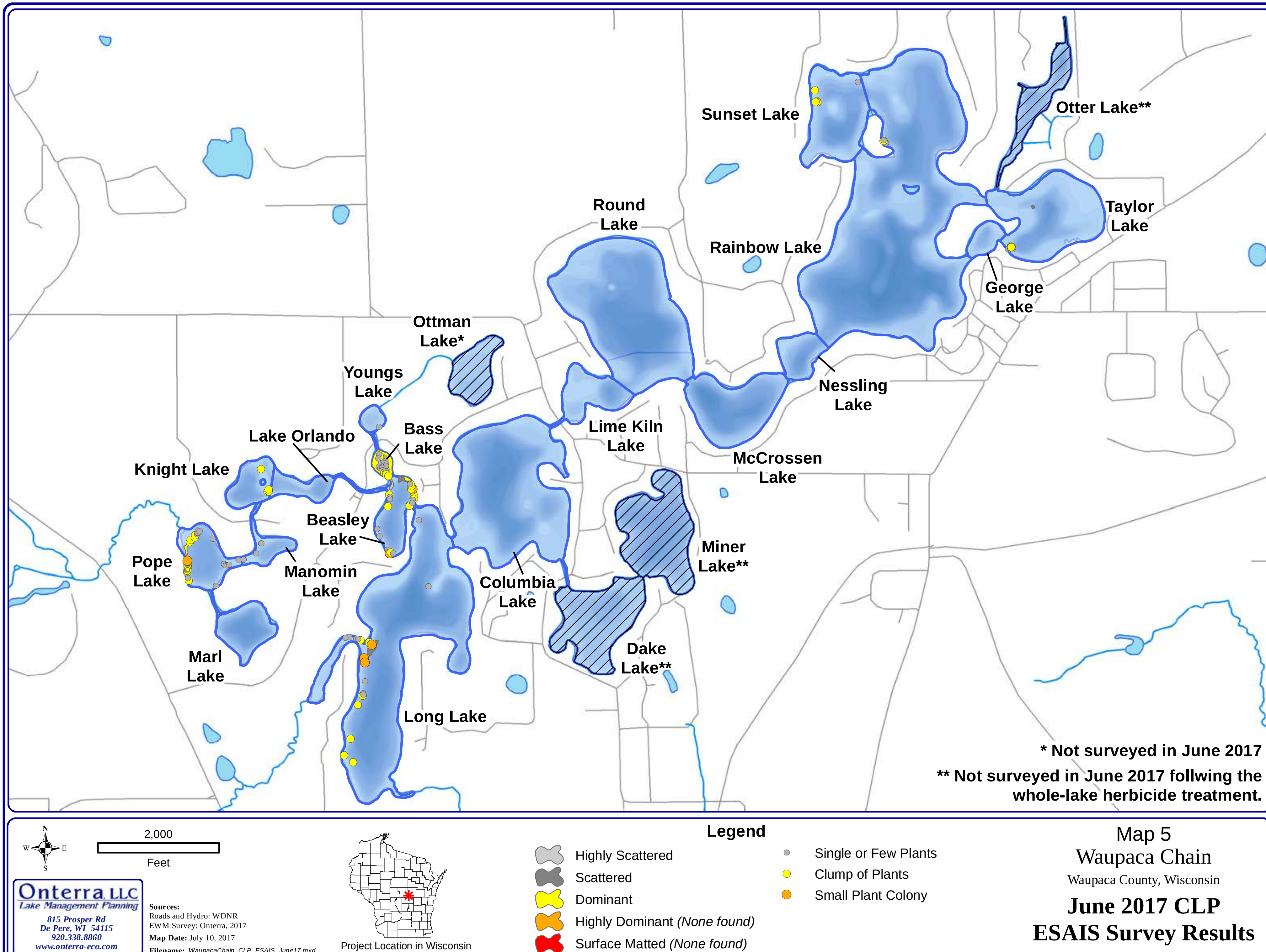
Sources:
Roads and Hydro: WDNR
Aquatic Plants: Onterra, 2016
Map Date: May 3, 2017
Filename: Columbia_HWM_T2017_Perm1.mxd

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- 2017 Final Diquat Application Area

Map 4
Columbia Lake
Waupaca County, Wisconsin
2017 Final HWM Treatment Strategy



Map 5
Waupaca Chain
Waupaca County, Wisconsin

June 2017 CLP ESAIS Survey Results

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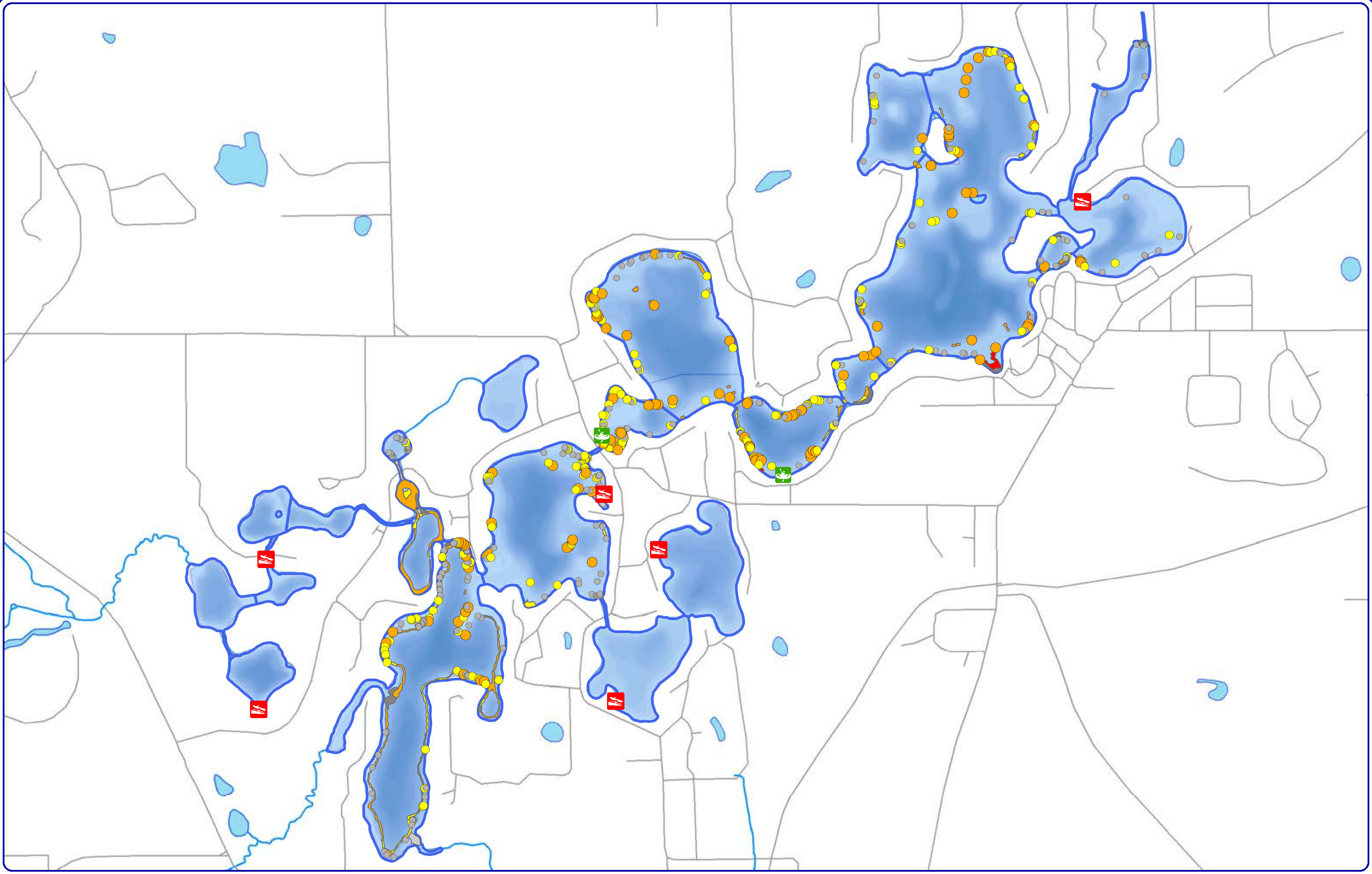
Sources:
Roads and Hydro: WDNR
EWM Survey: Onterra, 2017

Map Date: July 10, 2017

Filename: *WaupacaChain_CLP_ESAIS_June17.mxd*



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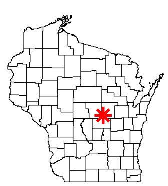
Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
EWM Survey: Onterra, 2017
Map Date: October 10, 2017
Filename: *WaupacaChain_EWM_PB_Sept17.mxd*



Project Location in Wisconsin

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matted
- Single or Few Plants
- Clump of Plants
- Small Plant Colony

Map 6

Waupaca Chain

Waupaca County, Wisconsin

September 2017 EWM
Peak-Biomass Survey Results

N
W E
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350
Feet

Legend

Exotic Plant Communities
- Purple loosestrife
- Pale yellow iris

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

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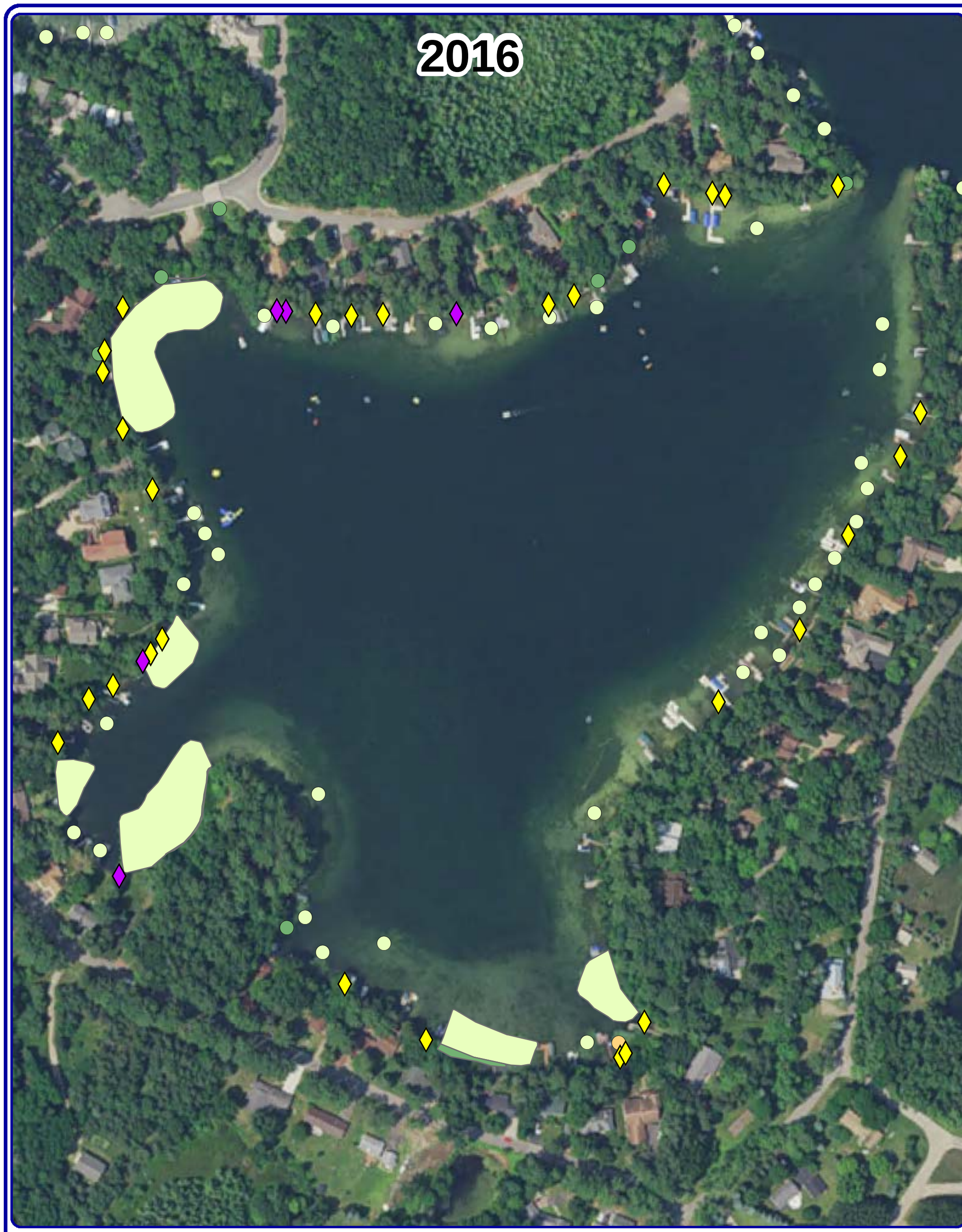
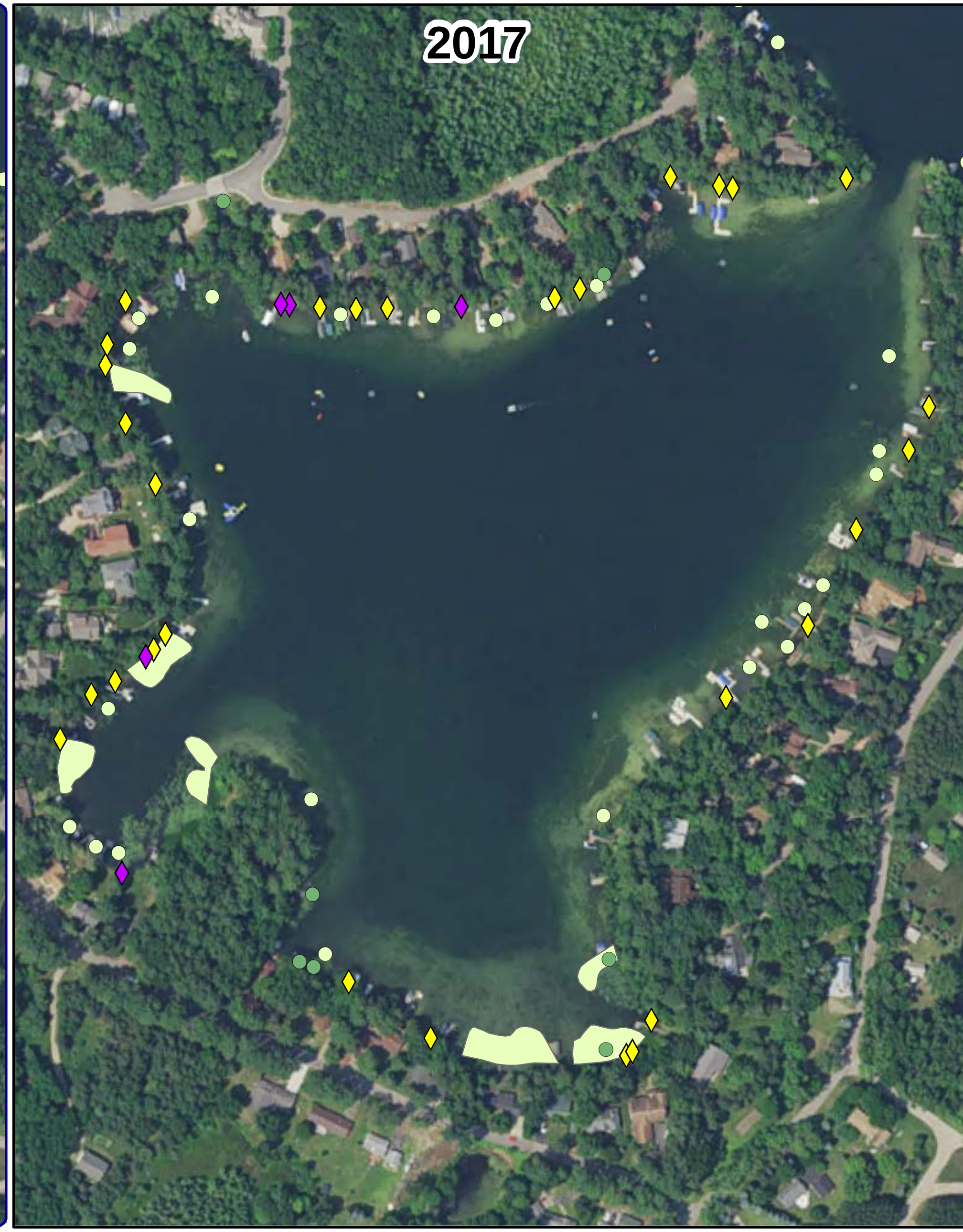
<Bol>Sources:</Bol>
Roads and Hyrdo: WDNR
Aquatic Plants: Onterra, 2016&2017
Map Date: August 2011, 2017
Filename: Otter_Comm_2016vs2017.mxd

Map 7
Otter Lake
Waupaca County, Wisconsin
2016 vs 2017 Plant Survey: Community Mapping





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350

Feet

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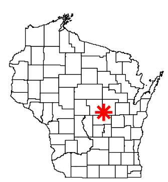
Sources:
Aquatic Plants: Onterra, 2016 & 2017
Orthophotography: NAIP, 2015
Map date: August 11, 2017
Filename:Dake_Comm_2016&2017.mxd



Project Location in Wisconsin

Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

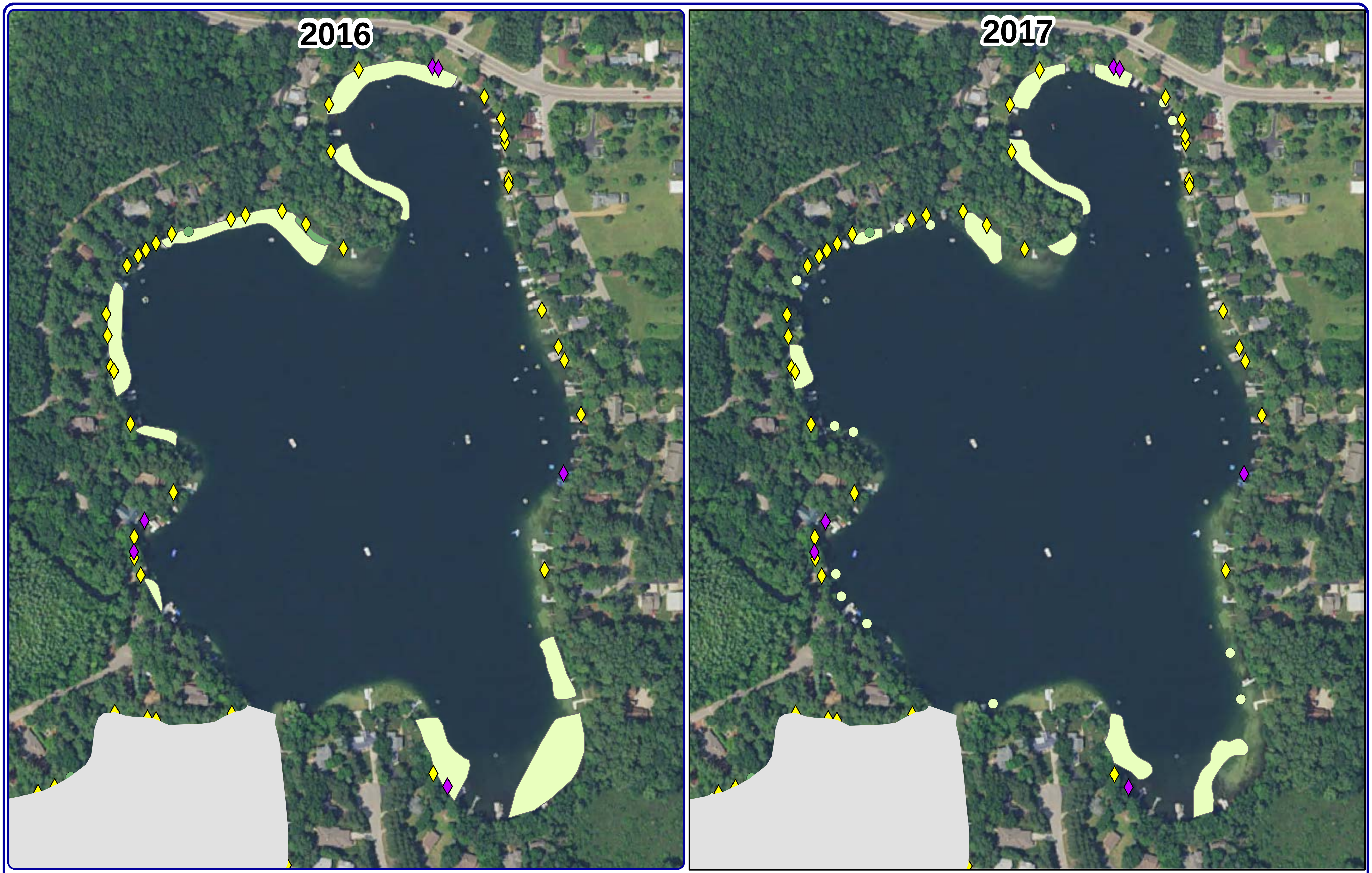
Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 8

Dake Lake

Waupaca County, Wisconsin

2016 & 2017 Aquatic Plant Communities



350
Feet

Sources:
Aquatic Plants: Onterra, 2016 & 2017
Orthophotography: NAIP, 2015
Map date: August 11, 2017
Filename:Miner_Comm_2016&2017.mxd

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Project Location in Wisconsin

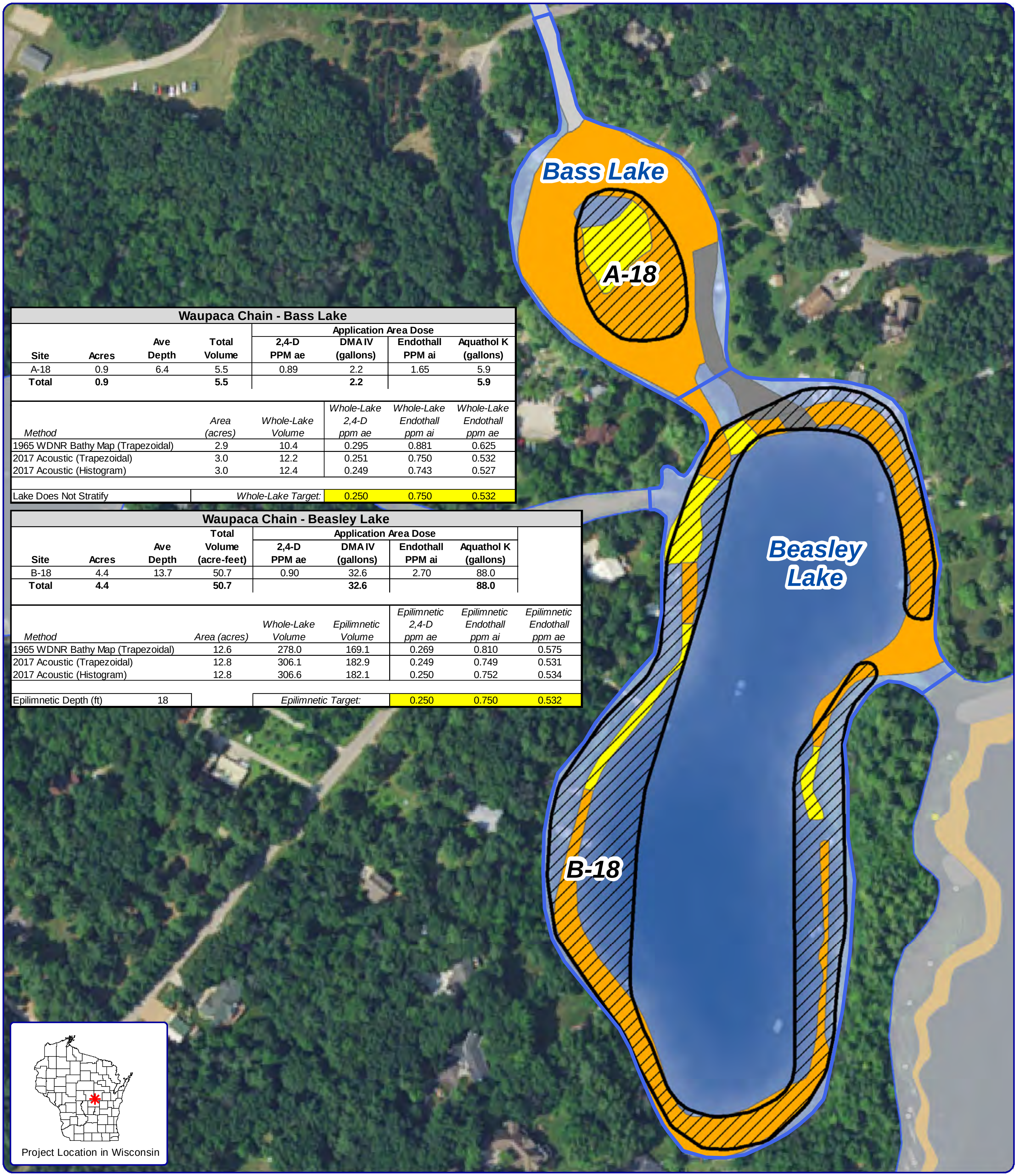
Legend

Small Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Large Plant Communities
- Emergent
- Floating-leaf
- Mixed Floating-leaf & Emergent

Map 9
Miner Lake
Waupaca County, Wisconsin

2016 & 2017 Aquatic Plant Communities



Waupaca Chain - Bass Lake

Site	Acres	Ave Depth	Total Volume	Application Area Dose: 2,4-D PPM ae	DMA IV (gallons)	Endothall PPM ai	Aquathol K (gallons)
A-18	0.9	6.4	5.5	0.89	2.2	1.65	5.9
Total	**0.9**		**5.5**		**2.2**		**5.9**

Method	*Area (acres)*	*Whole-Lake Volume*	*Whole-Lake 2,4-D ppm ae*	*Whole-Lake Endothall ppm ai*	*Whole-Lake Endothall ppm ae*
1965 WDNR Bathy Map (Trapezoidal)	2.9	10.4	0.295	0.881	0.625
2017 Acoustic (Trapezoidal)	3.0	12.2	0.251	0.750	0.532
2017 Acoustic (Histogram)	3.0	12.4	0.249	0.743	0.527
Lake Does Not Stratify		*Whole-Lake Target:*	0.250	0.750	0.532

Waupaca Chain - Beasley Lake

Site	Acres	Ave Depth	Total Volume (acre-feet)	Application Area Dose: 2,4-D PPM ae	DMA IV (gallons)	Endothall PPM ai	Aquathol K (gallons)
B-18	4.4	13.7	50.7	0.90	32.6	2.70	88.0
Total	**4.4**		**50.7**		**32.6**		**88.0**

Method	*Area (acres)*	*Whole-Lake Volume*	*Epilimnetic Volume*	*Epilimnetic 2,4-D ppm ae*	*Epilimnetic Endothall ppm ai*	*Epilimnetic Endothall ppm ae*
1965 WDNR Bathy Map (Trapezoidal)	12.6	278.0	169.1	0.269	0.810	0.575
2017 Acoustic (Trapezoidal)	12.8	306.1	182.9	0.249	0.749	0.531
2017 Acoustic (Histogram)	12.8	306.6	182.1	0.250	0.752	0.534
Epilimnetic Depth (ft)	18		*Epilimnetic Target:*	0.250	0.750	0.532

N
W E
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210
Feet

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Sources:
Roads & Hydro: WDNR
Aquatic Plants: Onterra, 2017
Bathymetry: Onterra, 2017; processed by C-Map USA
Map Date: January 22, 2018
Filename: BasBeasley_HWM_T2018_Prelim3.mxd

Legend

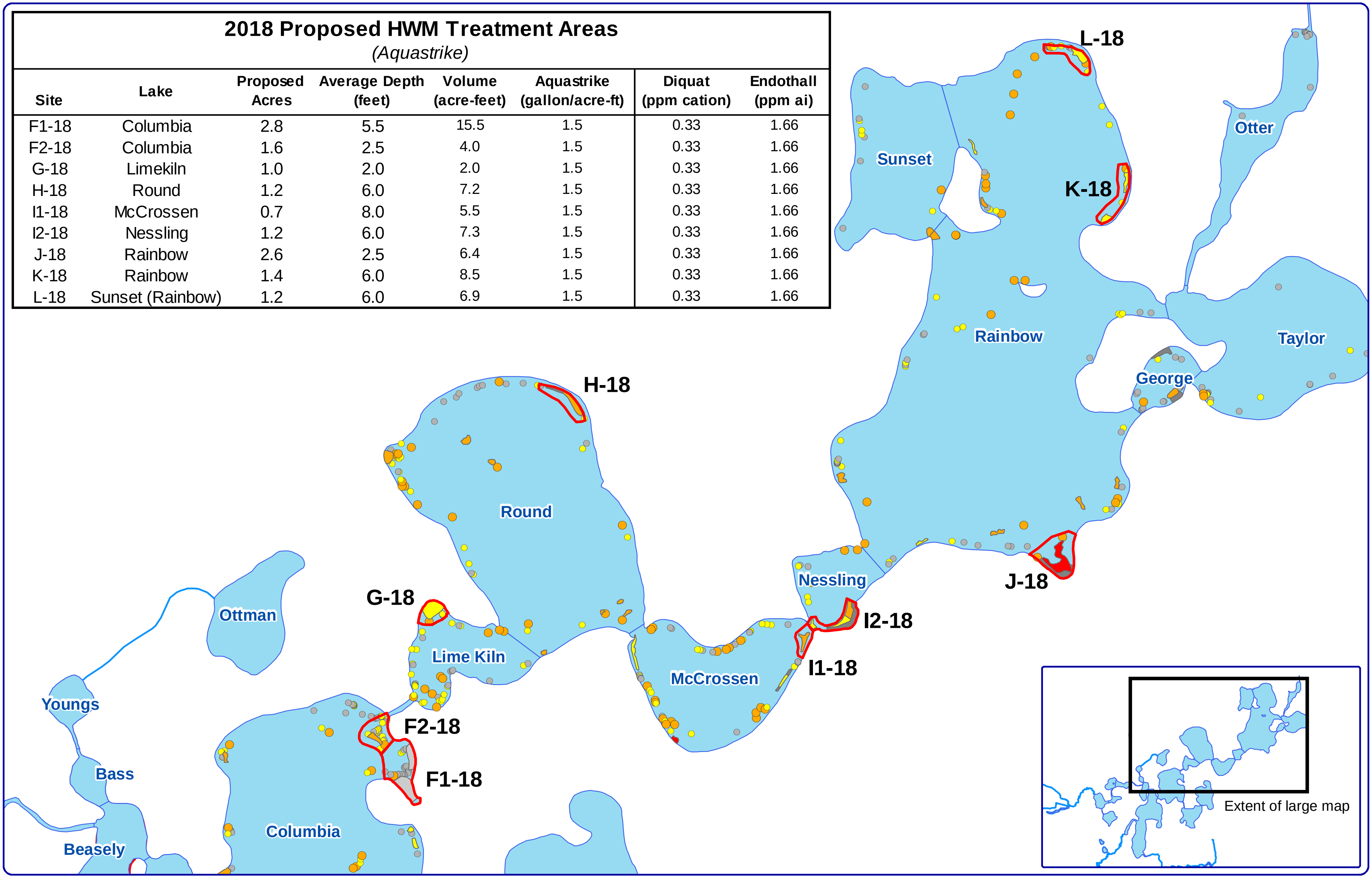
- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matting
- Single or Few Plants
- Clumps of Plants
- Small Plant Colony
- 2018 Preliminary Herbicide Application Area

Map 10
Bass & Beasley Lake
Waupaca County, Wisconsin

2018 Preliminary HWM Treatment Strategy

2018 Proposed HWM Treatment Areas
(Aquastrike)

Site	Lake	Proposed Acres	Average Depth (feet)	Volume (acre-feet)	Aquastrike (gallon/acre-ft)	Diquat (ppm cation)	Endothall (ppm ai)
F1-18	Columbia	2.8	5.5	15.5	1.5	0.33	1.66
F2-18	Columbia	1.6	2.5	4.0	1.5	0.33	1.66
G-18	Limekiln	1.0	2.0	2.0	1.5	0.33	1.66
H-18	Round	1.2	6.0	7.2	1.5	0.33	1.66
I1-18	McCrossen	0.7	8.0	5.5	1.5	0.33	1.66
I2-18	Nessling	1.2	6.0	7.3	1.5	0.33	1.66
J-18	Rainbow	2.6	2.5	6.4	1.5	0.33	1.66
K-18	Rainbow	1.4	6.0	8.5	1.5	0.33	1.66
L-18	Sunset (Rainbow)	1.2	6.0	6.9	1.5	0.33	1.66



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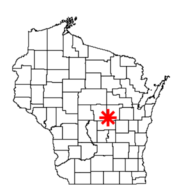

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matted
- Single or Few Plants
- Clump of Plants
- Small Plant Colony
- Proposed Herbicide Spot-Treatment Site

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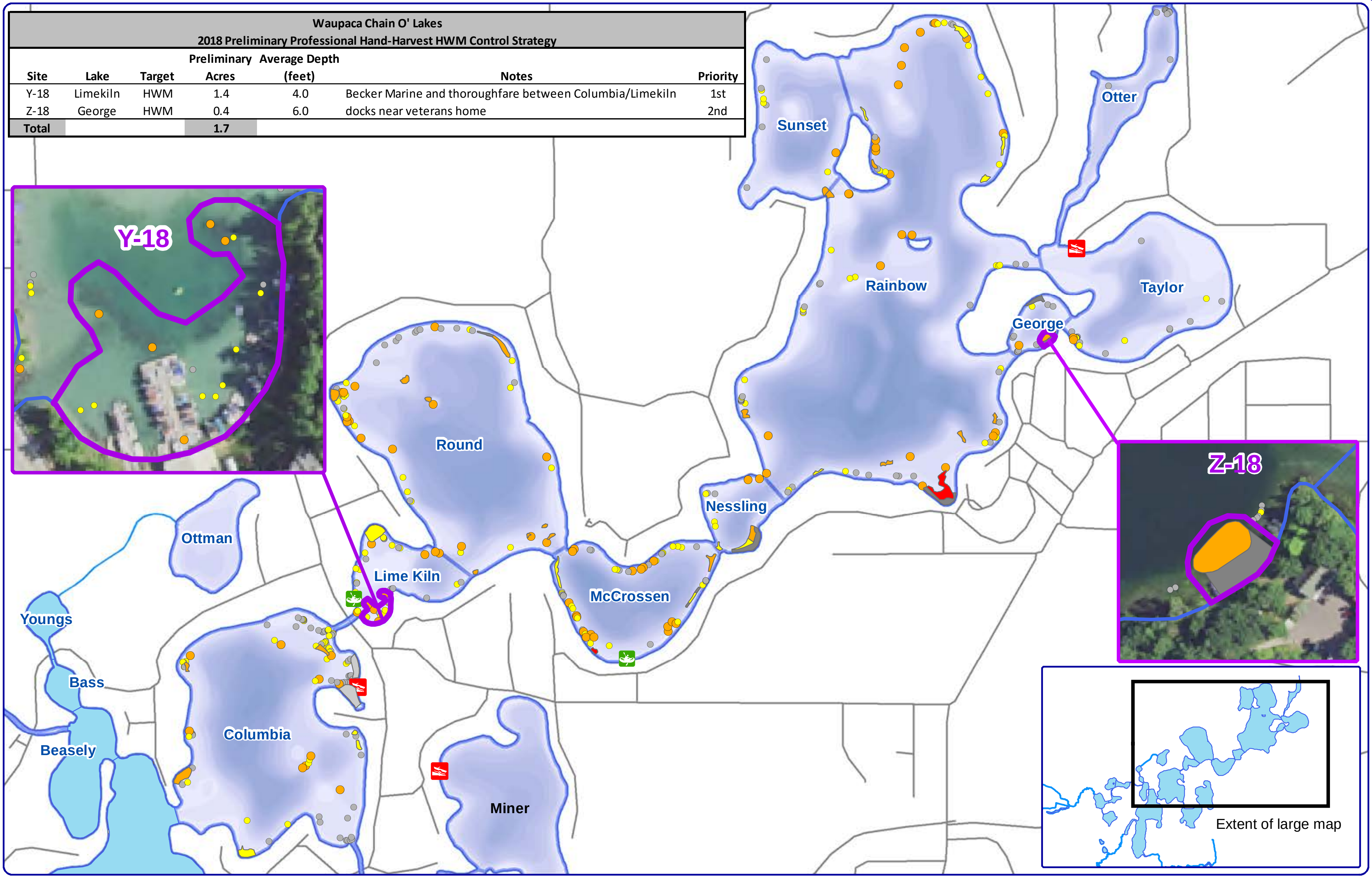
Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
EWM Survey: Onterra, 2017
Map Date: January 15, 2018
Filename: *WaupacaChain_HWM_T2018_SpotTreat_Prelim_v1.mxd*

Map 11
Waupaca Chain
Waupaca County, Wisconsin

Preliminary 2018 Herbicide Spot-Treatment HWM Control Strategy v1

Waupaca Chain O' Lakes 2018 Preliminary Professional Hand-Harvest HWM Control Strategy						
Site	Lake	Target	Preliminary Acres	Average Depth (feet)	Notes	Priority
Y-18	Limekiln	HWM	1.4	4.0	Becker Marine and thoroughfare between Columbia/Limekiln	1st
Z-18	George	HWM	0.4	6.0	docks near veterans home	2nd
Total			1.7			



N W E S
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Feet

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Sources:
Roads and Hydro: WDNR
Bathymetry: WDNR, digitized by Onterra
EWM Survey: Onterra, 2017
Map Date: April 26, 2018 - TWH
Filename: *WaupacaChain_HWM_HH_2018_Prelim.mxd*

Project Location in Wisconsin

Legend

- Highly Scattered
- Scattered
- Dominant
- Highly Dominant
- Surface Matted
- Single or Few Plants
- Clump of Plants
- Small Plant Colony
- Proposed Professional Hand-Harvesting Site

Map 12
Waupaca Chain
Waupaca County, Wisconsin

Preliminary 2018 HWM Hand-Harvesting Control Strategy v1