Evaluating Plant Response to Triclopyr Applied Alone and in Combination with Endothall in Noxon Rapids Reservoir for 2010: Phase 2

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Preface

This report presents data collected by the Geosystems Research Institute, Mississippi State University in 2010 on Noxon Rapids Reservoir. Funding was provided by a grant under the American Recovery and Re-Investment Act and the Montana Weed Trust as a subcontract from Sanders County, Montana to Mississippi State University. We thank Justin Nawrocki for conducting the rhodamine WT dye dissipation modeling and the creation of the dissipation maps; and Steve Esch, AVISTA Utilities, for providing Dam Operation data during the time of the study. We also thank Celestine Duncan, Brian Burke, Heidi Sedivy, and John Halpop for assistance with planning and on the ground logistics. Field assistance was provided by Dr. Wade Givens, Dr. Eric Dibble, Joshua Cheshier, Amanda Fernandez, Jonathan Fleming, and Cheryl McLaurin, all from Mississippi State University. Any errors in presentation or fact, however, are the responsibility of the authors.

Executive Summary

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Noxon Rapids Reservoir has established populations of both Eurasian watermilfoil and curlyleaf pondweed. It is estimated that there is > 300 acres of Eurasian watermilfoil and > 600 acres of curlyleaf pondweed currently present in the reservoir. In 2009, Phase I of a multi-year research and demonstration project began to link water-exchange processes with herbicide concentration exposure time relationships for control of both non-native plant species using a combination of triclopyr and endothall. In 2010, Phase II was initiated to further refine information collected during the previous year's study with respect to herbicide concentrations, herbicide selection, and bulk water-exchange processes in other areas of the reservoir. Results from Phase I and II will be a critical component of an Integrated Management Plan to address these invasive aquatic plants in Montana and throughout the region in other run of the river reservoirs.

The estimated herbicide half life of triclopyr applied alone under normal dam operations was 12.7 h. This contact and exposure time resulted in a 70% reduction in the presence of Eurasian watermilfoil by 7 WAT. The use of triclopyr alone was also much more selective with respect to non-target species than the combination of triclopyr + endothall. However, the use of triclopyr alone had little impact on curlyleaf pondweed. The estimated half lives of triclopyr and endothall in the combination plot were 21.9 and 19.3 h respectively, and resulted in an 86% reduction in the presence of Eurasian watermilfoil. The combination also resulted in greater control of curlyleaf pondweed; though the combination treatment was less selective with respect to non-target plant species. Plant control in Noxon could be improved if applications were to be made during early morning hours when water movement is minimal, or if dam operations could be slowed or stopped to increase the contact time of the herbicide with target plants. If contact time could be increased, reduced herbicide concentrations could possibly be used resulting in increased selectivity and decreased cost.

This study indicates that Eurasian watermilfoil and curlyleaf pondweed can be controlled in moving water situations if there is an understanding of water-exchange processes. Eurasian watermilfoil can be selectively removed and native species will rapidly re-colonize areas once inhabited by Eurasian watermilfoil. There is a tradeoff in selectivity between applications of triclopyr alone versus using the combination treatment. However, the use of triclopyr alone will not be conducive to all places in the reservoir, especially in areas of increased water-exchange; these areas will need the combination treatment to meet CET requirements.

Chapter 1

Phase 2 of Research and Demonstration Projects to Control Eurasian Watermilfoil and Curlyleaf Pondweed

Introduction

During summer 2007, the presence of Eurasian watermilfoil (*Myriophyllum spicatum*) and Curlyleaf pondweed (*Potamogeton crispus*) were confirmed in both Noxon Rapids Reservoir (Noxon) and Cabinet Gorge Reservoir in the lower Clark Fork River system (Madsen and Cheshier 2009). The reservoirs were created for hydro-power generation and are currently under management authority of Avista Utilities. The finding of Eurasian watermilfoil in these reservoirs is significant as it represents the first documented populations in the state of Montana. Therefore, management of this species is critical when population levels are minimal to reduce management costs and adverse impacts to non-target organisms. The state of Idaho has spent over $9 million to control Eurasian watermilfoil with concentrated efforts in Lake Pend Oreille and the Pend Oreille River (Woolf pers. comm.); where efforts focused on understanding concentration and exposure relationships between water-exchange characteristics, herbicide choice, and application techniques.

The scientific basis of knowing herbicide concentration and exposure time has been well developed through a series of small-scale studies by the U.S. Army Corps of Engineers Engineering Research and Development Center (Netherland et al. 1991, Netherland and Getsinger 1992, Getsinger and Netherland 1997). Though translating concentration and exposure time results to field situations has been more difficult; and to do so, requires a precise knowledge of water-exchange characteristics which are often difficult and expensive to collect (Getsinger et al. 1996).

As part of the initial planning and management implementation phase on Noxon, additional surveys were conducted in 2009 to further delineate Eurasian watermilfoil and curlyleaf pondweed populations (Wersal et al. 2009, Wersal et al. 2010a). During these surveys, it was estimated that Eurasian watermilfoil had and aerial coverage of approximately 370 acres and curlyleaf pondweed coverage was > 600 acres. Following these initial surveys and the delineation of plant beds, Sanders County, Montana and Avista Utilities initiated Phase 1 of a multi-year research and demonstration program. The research and demonstration program was designed in cooperation with the Montana Weed Trust, United States Army Corps. Engineers Chemical Control and Plant Physiological Processes Unit, and Mississippi State University's Geosystems Research Institute to address both ecological and aquatic plant management questions and concerns.

Phase 1 included bulk water-exchange studies with respect to dam operations to gain an understanding of water movement within small plant beds to aid in selecting appropriate management strategies for Eurasian watermilfoil and curlyleaf pondweed. Once water-exchange characteristics were known, combinations of triclopyr and endothall were applied at specific rates to meet contact and exposure time relationships (Netherland et al. 1991, Netherland and Getsinger 1992) for control of Eurasian watermilfoil and curlyleaf pondweed. After herbicide applications, the aquatic plant community was evaluated for both target and non-target herbicide effects, as well as water quality impacts.

Phase 2 of the research and demonstration program sought to further refine herbicide concentrations from those used in phase 1, address other areas of the reservoir that may have different water-exchange characteristics, and determine if it is feasible to use triclopyr alone. By refining herbicide concentrations and possibly utilizing one herbicide (in areas dominated by Eurasian watermilfoil), costs associated with purchasing herbicides and performing applications could potentially be reduced. These results will serve to refine selective herbicide techniques to control Eurasian watermilfoil and curlyleaf pondweed, information which will be a critical component of an Integrated Management Plan to address these invasive aquatic plants in Montana and the region.

Knowledge gained from research and demonstration will be used to develop an effective management plan for both Noxon and Cabinet Gorge Reservoirs and similar flowing water systems in the Pacific Northwest. Since Montana is a headwaters state, results from these studies benefit downstream water bodies in adjoining states; most notably slowing propagule spread to sites downstream such as Lake Pend Oreille, Pend Oreille River, and the greater Columbia River system. Herbicide treatments will be an important component of an aggressive Integrated Pest Management Plan that will include prevention, containment, mechanical, physical and potentially biological components.

Goals and Objectives

The goals of this project are to demonstrate, evaluate and refine strategies for using herbicides for selective control of Eurasian watermilfoil and curlyleaf pondweed in the lower Clark Fork River system. Phase 2 objectives are to:

(1) Further determine water-exchange processes in large contiguous aquatic plant stands in additional areas of Noxon Reservoir infested with Eurasian watermilfoil and curlyleaf pondweed;

(2) Utilize that information to refine species selective herbicides and herbicide concentrations; and

(3) Quantitatively assess herbicide efficacy on target plants as well as the response of the aquatic plant community in general.

Chapter 2

Bulk Water-exchange Processes and Herbicide Residues in Submersed Plant Stands in Noxon Rapids Reservoir

Introduction

Eurasian watermilfoil and curlyleaf pondweed are becoming increasingly problematic in the Pacific Northwest, with significant nuisance populations already formed in reservoirs of the Lower Clark Fork River (Madsen and Cheshier 2009). Run of the river reservoirs have presented consistent challenges in achieving effective and efficient control of invasive, submersed aquatic plants. Herbicide treatments in flowing water have often been inconsistent and unpredictable which has led to increased interest in developing cost-effective and efficacious operational recommendations for these systems. Run of the river reservoirs typically have variable water-exchange patterns that make it difficult to accurately and effectively place and hold herbicide near target plants. Water-exchange will impact aqueous distribution of herbicides, often resulting in reduced chemical exposure times against target plants and unacceptable control. Ultimately the success or failure of an herbicide treatment to submersed aquatic plants will depend upon the concentration of the herbicide used and the length of time that the target plant is exposed to the herbicide. The dose/response of a species has been described as a concentration and exposure time relationship (CET).

Herbicide concentration exposure time relationships have been designed to provide excellent plant control, are often species specific, and have been developed for endothall and triclopyr (Netherland et al. 1991; Netherland and Getsinger 1992). However, these previous studies and relationships were derived in small scale controlled settings; therefore, further research is needed to understand water-exchange characteristics that are site specific for a given waterbody. Previous field studies have utilized the inert fluorescent dye, rhodamine WT, to characterize and model bulk water-exchange within a waterbody and develop dissipation relationships with herbicides that are site specific (Fox et al. 1991, Fox et al. 1993, Turner et al. 1994). Results from these studies have indicated that a strong correlation exists between dispersal of the dye and herbicides. Though there will always be site specific phenomena such as natural flow, bottom structure that alters flow, dam operations, etc., that will ultimately affect herbicide concentration and exposure relationships.

Furthermore, water-exchange processes within submersed plant communities are often subtle and difficult to characterize. Plant architecture may alter water flow through beds and thus affect herbicide residence times. Pursuant to this, plant architecture will change from plant bed to plant bed depending on the specific site characteristics present for plant growth and the dominant plant species within the bed. Therefore, dye studies in these areas can offer insight and estimation of bulk water-exchange, thereby allowing for the prediction of herbicide half lives prior to putting herbicide in the water. Using these data in combination with CET relationships can result in a site specific treatment protocol utilizing appropriate herbicides, concentrations, formulations, and application techniques. This will allow for a more cost-effective application and provide selective control of the target plants.

Herbicide treatments in Noxon began in 2009 with 36 acres of Eurasian watermilfoil treated with a combination of triclopyr + endothall. The combination of triclopyr + endothall reduced exposure time requirements needed for Eurasian watermilfoil control in controlled studies as opposed to applying triclopyr alone (Madsen et al. 2010). This combination would be advantageous in run of the river systems such as Noxon, where long exposure times may not be met due to increased water flow. Based upon the results from these initial applications, it was determined that subsequent applications could possibly use reduced herbicide concentrations or utilize triclopyr alone. Lower herbicide concentrations or the use of one herbicide may increase treatment selectivity (depending upon exposure time) while reducing herbicide costs.

The objectives of this study were to:

1) determine the bulk water-exchange processes that occur in mixed stands of submersed plants during normal dam operations using rhodamine WT dye;

2) model herbicide residues and dissipation within stands of submersed aquatic plants.

Material and Methods

Four plots were selected for this study based on surveys conducted throughout the reservoir in 2008 and 2009 (Madsen and Cheshier 2009, Wersal et al. 2009) and are depicted in Figure 2.1. Plots 2 (23.8 acres) and 4 (28.5 acres) served as our untreated reference plots, meaning no herbicide or dye were placed in these plots. These are also the same untreated reference plots used in the Phase 1 study. Plots 7 (28.3 acres) and 8 (15.8 acres) were treated with a simultaneous application of dye and herbicides.

Water-exchange within plots 7 and 8 were measured using a 10AU field fluorometer (Turner Designs, Sunnyvale, CA) to measure rhodamine WT dye concentrations after application. Dye in plot 8 was also measured continuously by deploying 3 Hydrolab MS5 data sondes (Hydrolab, Loveland, CO). One data sonde was placed on each end of the plot and one sonde deployed in the center of the plot. Data from the sondes were used to compare data collected with the 10AU field fluorometer. The target concentration for dye applications in each plot was 10 parts per billion (ppb) or 0.05 liters of dye per acre foot (which is dependent upon water volume in each plot), which is typical for field evaluations such as this study. At this concentration the dye is harmless to humans, fish, and wildlife, and will quickly dissipate depending on local conditions. The fluorometer used for dye measurements has a detection capability of 0.01 ppb for rhodamine dye; therefore, if dye is present in a location the fluorometer will detect it.

The herbicides used in this study consisted of the liquid formulations of the contact herbicide endothall, applied as Aquathol® K (United Phosphorus Inc), and the systemic triclopyr, applied as (Renovate®3, SePRO Corporation). Herbicide concentrations were selected based upon results from the Phase 1 study and were slightly lower than in previous applications; though all concentrations were based upon previous CET relationships derived for Eurasian watermilfoil control (Netherland et al. 1991; Netherland and Getsinger 1992). Herbicide residues were collected by sampling the water within and directly outside of each plot. The samples were then frozen and sent to the Center for Invasive and Aquatic Plants, University of Florida (Gainesville, FL) for herbicide concentration determination.

Applications of the dye and herbicides were applied as a tank mix with water or water + herbicide using a variable-depth water injection system (LittLine®, CleanLakes Inc.). The LittLine® System applies herbicide using the relationship between the speed of the boat during application and the length of hose being deployed for the application. This allows the product to be placed near the bottom of the reservoir below the plant canopy where plants are growing. Herbicide delivered in this manner under the canopy of dense beds formed by non-native plants may allow for greater retention in the treatment area, thereby reducing herbicide drift and non-target injury. For this study, the application process simulated an operational liquid herbicide application, with the herbicide application system calibrated to deliver product to the appropriate depth-zone containing the targeted submersed plants.

Plot 7

Plot 7 was 28.2 acres in size with an average depth of 7.5 ft (Figure 2.1). Plot 7 was located on an outside bend in the reservoir just downstream from the railroad bridge. Due to its location and observed water flow, it was selected to have triclopyr applied alone in order to evaluate this systemic product without the interaction with endothall. We were assuming that water flow would follow the bend in the reservoir and keep the dye and herbicide near the shoreline, thereby preventing dye and herbicide from moving towards the main channel and being lost to dilution and dissipation.

Rhodamine dye was diluted with water and tank- mixed with triclopyr prior to injection in the water. The plot was treated with dye (9.8 ppb) and triclopyr (1.8 ppm) on July 21, 2010 beginning at 8:30 am and ending at 12:26 pm. Skies were clear, temperature was 59 F at the beginning of application, and there was a light wind 3.4 mph from the east. Dam operations were at maximum capacity during and after the herbicide application, where water was moving at 26,170 and 26,180 cfs at the beginning and end of the application respectively. Data collected from this plot would represent a worst- case scenario for applying triclopyr alone in a run of the river reservoir when dam operations are at maximum capacity.

Water sampling stations were established prior to the herbicide application with five permanent stations established within the plot. These stations were visited at 0 (immediately after the application), 1, 3, 6, 9, 18, 21, 24, and 30 hours after treatment (HAT) to collect dye measurements and water samples for herbicide residue determination (Figure 2.2). A total of 140 water samples were collected from plot 7 within and directly outside of the plot. Both dye and water samples were collected from stations 1 through 5 (permanent stations) at the water surface, middle depth, and just above the bottom sediment to determine chemical mixing within the water column. Dye measurements collected at stations outside the plot were generally taken at the water surface and between 3 and 10 feet as water depths directly outside of plot 7 fell sharply to > 40 ft.

Plot 8

Plot 8 was 15.8 acres in size with an average depth of 9 ft (Figure 2.1). Plot 8 was located just upstream from the North Shore boat ramp. The combination of triclopyr + endothall was chosen for this location as it is an exposed shoreline that is subject to increased water movement similar to plot 3 from the Phase 1 study. Similar to other locations in Noxon, plot 8 was directly adjacent to the main channel where water depth fell sharply to 130 ft. The potential for increased water flow and proximity to deep water may result in short half lives and reduced herbicide with target plants. Therefore, the combination of triclopyr + endothall should decrease the exposure time needed for effective control of Eurasian watermilfoil and curlyleaf pondweed.

Rhodamine dye was mixed with endothall in one tank and triclopyr in a second tank on the application boat. The plot was treated with dye (10 ppb), triclopyr (1 ppm), and endothall (2 ppm) on July 26, 2010 beginning at 7:22 am and ending at 10:25 am. Skies were clear, temperature was 55 F at the beginning of application, and there was a light wind < 2 mph. Dam operations were reduced (7,930 cfs) at the beginning of the application, though operations were at maximum (26,190 cfs) at the conclusion of the application.

Water sampling stations were established in a similar fashion to plot 7 prior to the herbicide application and were visited at 0 (immediately after the application), 1, 3, 6, 9, 21, 24, and 27 HAT to collect dye measurements and water samples for herbicide residue determination (Figure 2.3). A total of 120 water samples were collected from plot 8 within and directly outside of the plot. Both dye and water samples were collected from stations 1 through 5 (permanent stations) at the water surface, middle depth, and just above the bottom sediment to determine chemical mixing within the water column. Dye measurements collected at stations outside the plot were generally taken at the water surface and between 3 and 10 feet as water depths directly outside of plot 8 fell sharply to > 130 ft.

Data Analyses

Water-exchange (dye) half lives and herbicide residue half lives for all treated plots and sample depths were determined by regression analysis using an exponential decay function in Sigma Plot 11.0 (San Jose, CA). Half lives were not estimated for samples collected in the surface portion of the water column, as detection of both dye and herbicide were highly variable. Dye and herbicide dissipation patterns within, and outside of, treated plots were modeled with Golden Surfer 7.04 (Golden, CO) using the Kriging interpolation method. Kriging interpolation predicts unknown values from data collected from known locations.

Results and Discussion

Dam discharge patterns for July 21 and 26, 2010 are depicted in Figure 2.4. In general, there is a slack water period between the hours 11:00 pm and 5:00 am followed by a rapid increase in water discharge through the dam. The rapid discharge coincides with the increase in mid-morning power demand. Following this initial pull of water, discharge through the dam remains fairly constant between 26,000 and 27,000 cfs from approximately 8:00 am to 10:00 pm. Water discharge began much sooner and at a more rapid pace on July 21 than on July 26; where discharge was > 26,000 cfs by 6:30 am. That level of discharge was not reached until approximately 10:00 am on July 26 when the application was made to plot 8.

Plot 7

The whole-plot water-exchange half-life for rhodamine dye in plot 7 was 8.0 h (Figure 2.5). Half lives for the middle depth and bottom depths were 5.4 and 6.2 h respectively. The maximum dye concentration measured was at 6 HAT, in station 3, at the bottom where concentrations were 41.6 ppb. Station 3 was located in the center of the plot where the shoreline made a bend downstream. Water flow would have pushed dye from upstream locations along the shoreline causing it to concentrate at station 3. Pursuant to this, dye concentrations were always higher at station 3 with 1.2 ppb measured out to 24 h. With respect to depth profile, on average, 85% of the dye remained in the bottom third of the water column, with 50% of measured dye remaining at this depth out to 18 h. Dye measurements from the middle of the water column yielded approximately 13% of dye over time. At 30 HAT, the only dye measured in the plot was in stations 3, 4, and 5 in the bottom third of the water column, which would be expected as the dye moved with water flow. There was very little dye measured in stations outside of the plot; in fact, station 10 was the only place where dye was detected. Station 10 was the closest (80 ft (25 m)) from the plot 7 treatment boundary. All other stations were approximately 160-500 ft (50-150 m) from the treatment boundary. This indicates that dilution of the dye upon leaving the plot was rapid as it moved into the deeper water adjacent to the plot.

The predicted rhodamine dye dissipation from plot 7 is depicted in Figures 2.6 to 2.15. According to the dissipation model, dye concentrations were low in the top and middle portions of the water column. In general, dye at these depths followed water flow towards the downstream portion of the plot; or moved into the deeper water adjacent to the plot. Although, no dye was measured at the outer water sample stations with the exception of station 10, indicating whatever dye moved from plot 7 at the surface or mid-depth was at concentrations undetectable with the fluorometer. Dye at the bottom depth moved with water flow and concentrated on the shallow shelf near water sample station 3. The model indicates that dye was concentrated between stations 2 and 3 between 1 and 9 HAT, followed by the gradual dissipation of dye out to 24 HAT. Several factors will impact dye dissipation within a plot over time, and this model is based on only 5 water sample stations which limits its capabilities. Though, the model does give a general visual indication of water flow in an around the plot through time.

Triclopyr residues collected in the plot resulted in a whole plot half life of 12.7 h, much greater than what was estimated from dye measurements (Figure 2.16). Half lives in the middle and bottom portions of the plot were 12.5 and 13.5 h respectively. The average triclopyr concentration for the whole plot was 0.85 ± 0.09 ppm, with a maximum concentration of 2.2 ppm at 0 HAT. Residues declined steadily over time with 0.19 ± 0.08 ppm remaining 30 HAT. The depth distribution of triclopyr within the water column indicated that ≥ 50% of the herbicide remained in the bottom third of the water column to 18 HAT. Additionally, > 20% remained in the middle of the water column to 30 HAT. As the triclopyr mixed vertically in the water column, increased residues were detected near the surface of the water column; by 30 HAT, 40% of triclopyr was measured near the water surface.

Plot 8

The whole-plot water-exchange half life for rhodamine dye in plot 8 was 10.2 h (Figure 2.17). Half lives for the middle depth and bottom depths were 10.5 and 10.7 h respectively. The estimated whole plot half life as determined from data collected by the data sondes was 12.9 h (Figure 2.18). The discrepancy in half lives estimated from the field fluorometer and the data sondes is attributed to the data collection method. The field fluorometer offers a snap shot in time of dye concentrations at a specific site within the plot, whereas the data sondes were collecting and recording dye measurements every 10 minutes for a 24 h time period. The data sondes resulted in a more precise measurement of dye concentrations over time; however, there is a trade off in mobility. Once the data sondes are deployed, they cannot be moved to another plot until data are offloaded. In contrast, a field fluorometer can be easily moved from plot to plot, thereby allowing for the monitoring of several sites at once.

Dye concentrations generally increased as measurements were taken downstream and the dye was moving with bulk water- flow. There was never any dye measured at station 1 throughout the study. Station 1 was on the upstream end of plot where water depths were greater (dropping to 120 ft within 150 ft from the plot boundary) and bulk water- flow was the greatest. The maximum dye concentration measured was at 3 HAT, in station 3, at the bottom where concentrations were 20.0 ppb. Dye concentrated in stations 3-5 over the course of the study in large part due to the shallow shelf in the center portion of plot 8, the dense plant beds which held dye in place, and the number of docks and manmade structures that interrupted water-flow and retained dye in the plot. On average, > 70% of the dye in plot 8 was measured in the bottom third of the water column with concentrations > 1 ppb in stations 3 and 4 at 24 HAT. However, by 27 HAT there was no measurable dye left in the plot. Similar to plot 7, there was no dye measured at any of the water sampling stations outside of the plot. Plot 8 was a long narrow shelf that was directly adjacent (100-175 ft) to the main river channel where water depths dropped to ≥ 120 ft. Dye that moved off- target was rapidly diluted to non-detectable concentrations and washed downstream.

The predicted rhodamine dye dissipation from plot 8 is depicted in Figures 2.19 to 2.27. Similar to plot 7, dye concentrations were low in the top and middle portions of the water column. The dye that was present at these depths moved downstream towards the North Shore boat ramp or into the deeper water of the main channel. Dye was much more concentrated in the bottom third of the water column, especially at 0 to 9 HAT. According to the dissipation model, dye at the bottom depth concentrated between sample stations 3 and 5; this is most likely due to the presence of a shallow shelf and an increase in the number of docks and boat lifts in this part of the plot. The shallow shelf and structures held the dye in place for a longer period of time. Based on the concentric zones produced by the model for plot 8, it appears that dye was lost much more rapidly from all water depths to the main channel instead of following water flow along the shoreline and out of plot. The main channel ran closer to plot 8 than plot 7, and water depth dropped much more sharply outside of plot 8 than in plot 7; therefore, the pull of water away from plot 8 to the main channel was likely much greater.

Half-lives for triclopyr in plot 8 are depicted in Figure 2.28. The whole plot half- life was estimated to be 21.9 h which again is higher than what was determined using dye data. At, 1 HAT the whole plot maximum triclopyr concentration was 1.1 ± 0.2 ppm, which was very near the target concentration. On average, 60% of triclopyr measured remained in the bottom third of the water column to 27 HAT. Additionally, approximately 30% of measured triclopyr was found in the middle of the water column. At 27 HAT, 0.07 ppm of triclopyr remained in plot 8. There were no triclopyr residues measured outside of the plot at the stations established 150 to 325 ft. from the plot boundary.

The whole plot half- life for endothall in plot 8 was 19.3 h (Figure 2.29). However, the estimated half- lives of endothall in the middle and bottom portions of the water column were much less at 12.0 and 10.3 h respectively. The greatest endothall concentration (1.8 ppm) was measured in the bottom of the water column at 0 HAT. By 27 HAT, residues at the bottom were measured at 0.2 ppm. Greater than 50% of endothall remained in the bottom third of the water column when compared to the other sample depths. Endothall concentrations decreased steadily over time through vertical mixing and dissipation, and at 27 HAT the average whole plot endothall concentration was 0.1 ppm. Similar to triclopyr, there were no endothall residues measured outside of the plot at the same sample stations.

Dye and Herbicide Residue Implications

Results from this study show that herbicide half- lives of > 12 h can be attained for both triclopyr and endothall under normal dam operation procedures. Though, the use of triclopyr alone is likely site specific and will not work in all parts of the reservoir. Based on dissipation data, plots closer to the main channel are likely to have lower half-lives and reduced contact times due to water flow and the more abrupt drop in water depth. These areas would require the use of the herbicide combination. Considering previously CET relationships for triclopyr and Eurasian watermilfoil control (Netherland and Getsinger 1992), it can be expected to observe approximately 70% control within plot 7. Expected control in plot 8, when using the half- lives of triclopyr and endothall separately, would be approximately 70 to 85% (Netherland et al. 1991, Netherland and Getsinger 1992. However, there is an additive effect when triclopyr and endothall are applied in combination, thereby reducing the CET required for effective control (Madsen et al. 2010). In a small scale study of the efficacy of triclopyr and endothall combinations on Eurasian watermilfoil, it was reported that when triclopyr + endothall was applied at 0.5 + 1.0 ppm with a 12 h exposure, the combination resulted in 100% at 2-4 weeks after treatment. In the current field study, half- lives of both triclopyr and endothall were above 12 h, therefore Eurasian watermilfoil control in this plot should be above 80%. In operational control programs in run of the river reservoirs this would be considered good control. In Lake Pend Oreille, Idaho, 70% control of Eurasian watermilfoil was achieved throughout the reservoir using triclopyr alone (Madsen and Wersal 2008). Control can be increased if applications can be made during early morning hours during the slack water period, or if dam operations can be slowed or stopped, even for just a few hours, to increase the contact time of the herbicide with target plants.

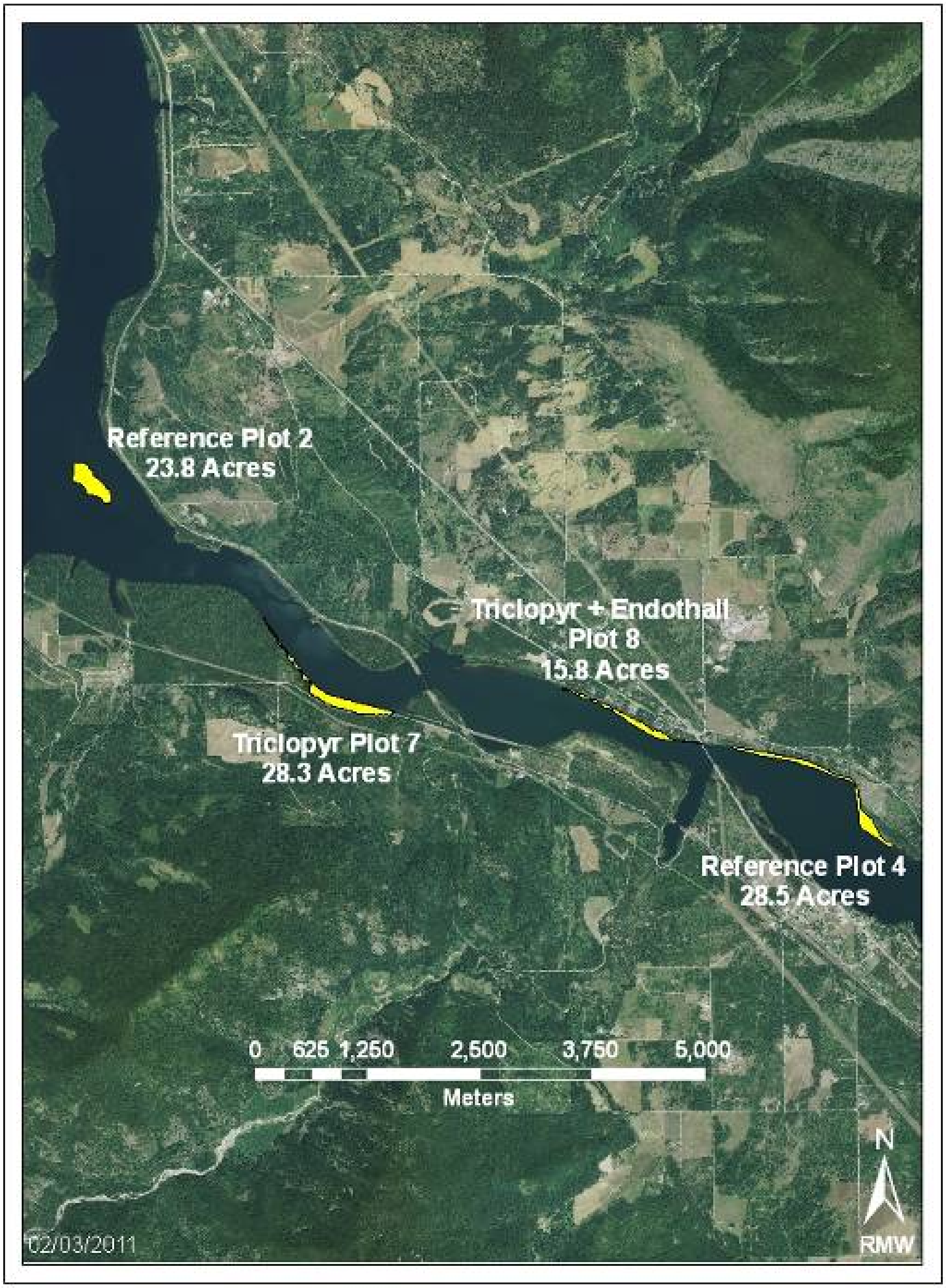

Figure 2.1. Locations of herbicide and untreated reference plots in Noxon Rapids Reservoir, July 2010.

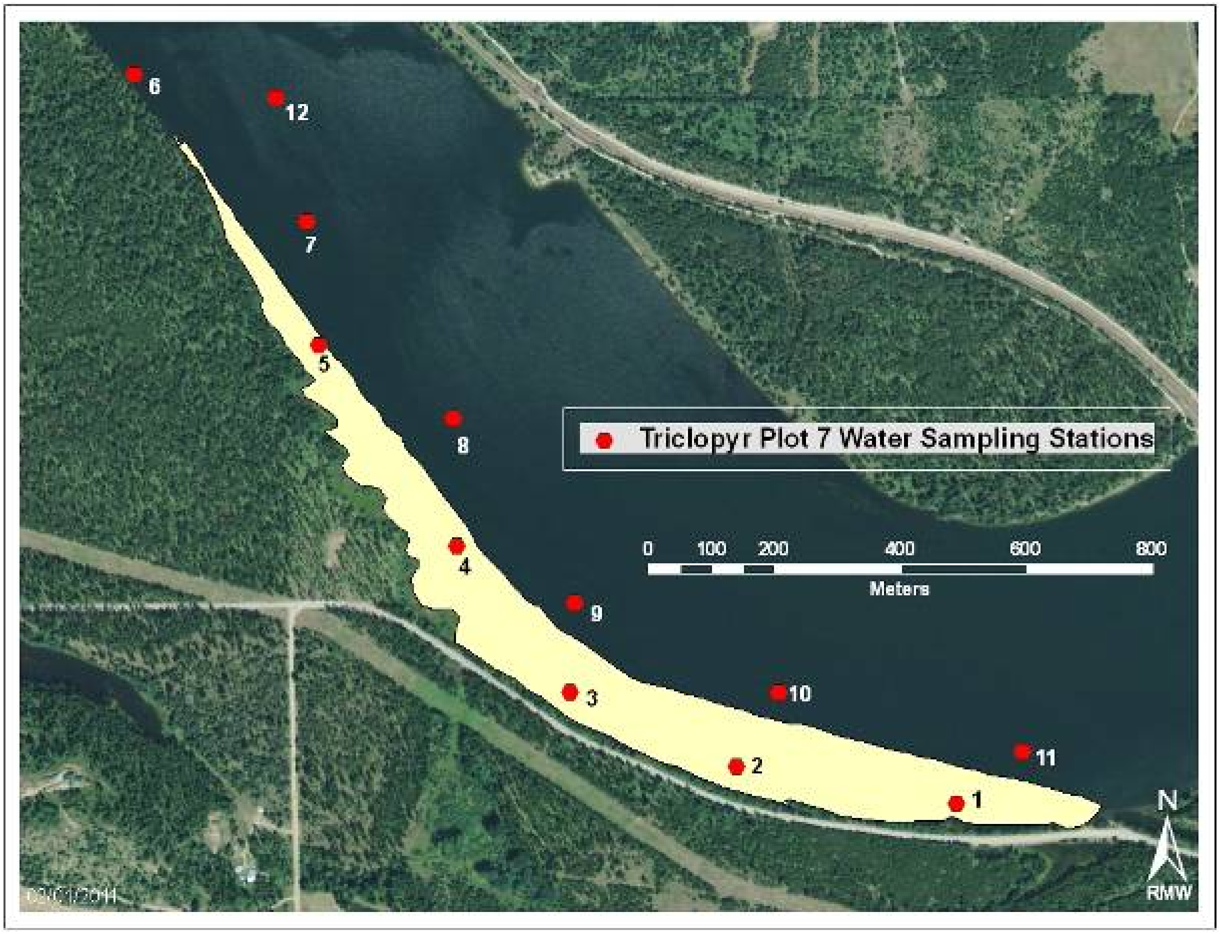

Figure 2.2. Rhodamine WT dye and water sample station locations within triclopyr treated plot 7 in Noxon Rapids Reservoir, July 2010.

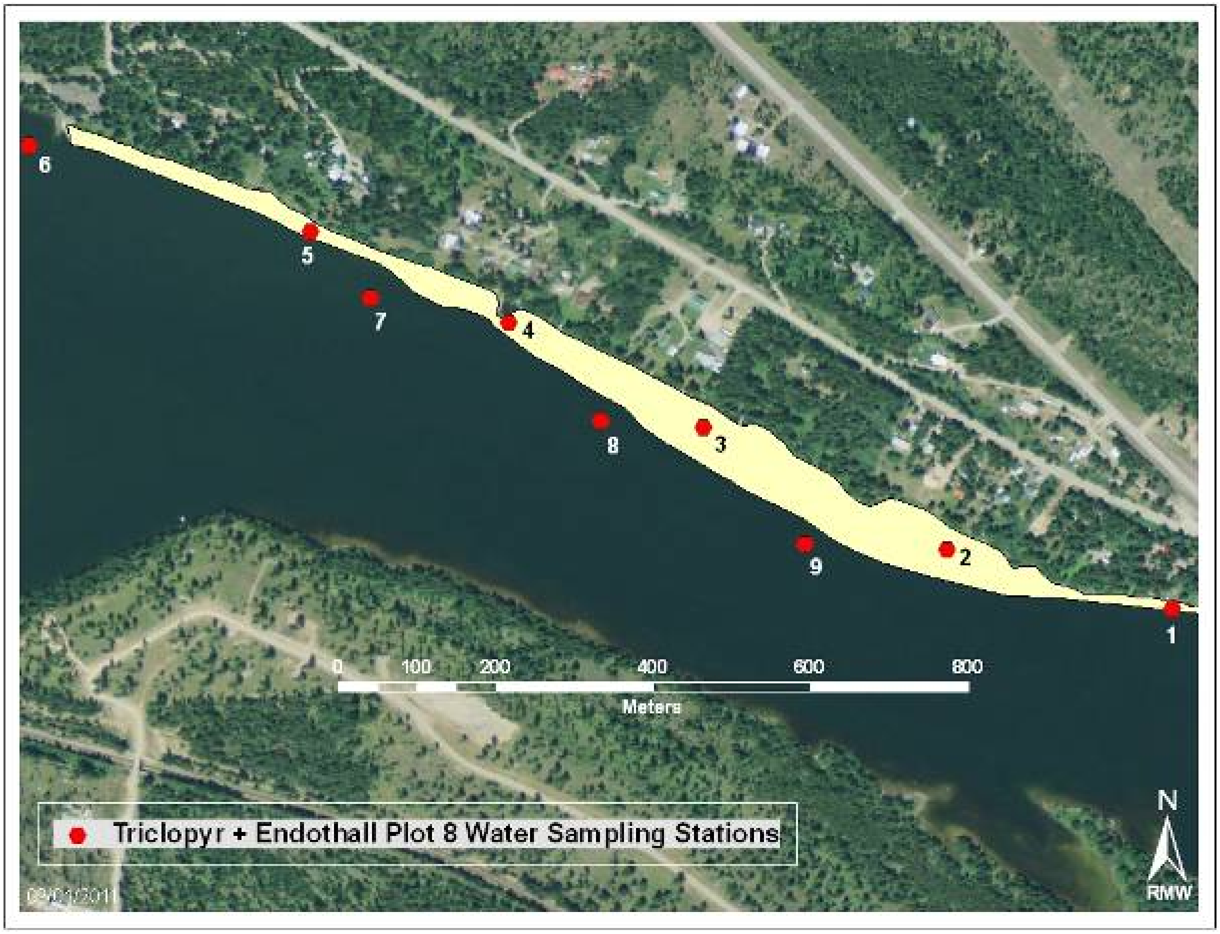

Figure 2.3. Rhodamine WT dye and water sample station locations within triclopyr + endothall treated plot 8 in Noxon Rapids Reservoir, July 2010.

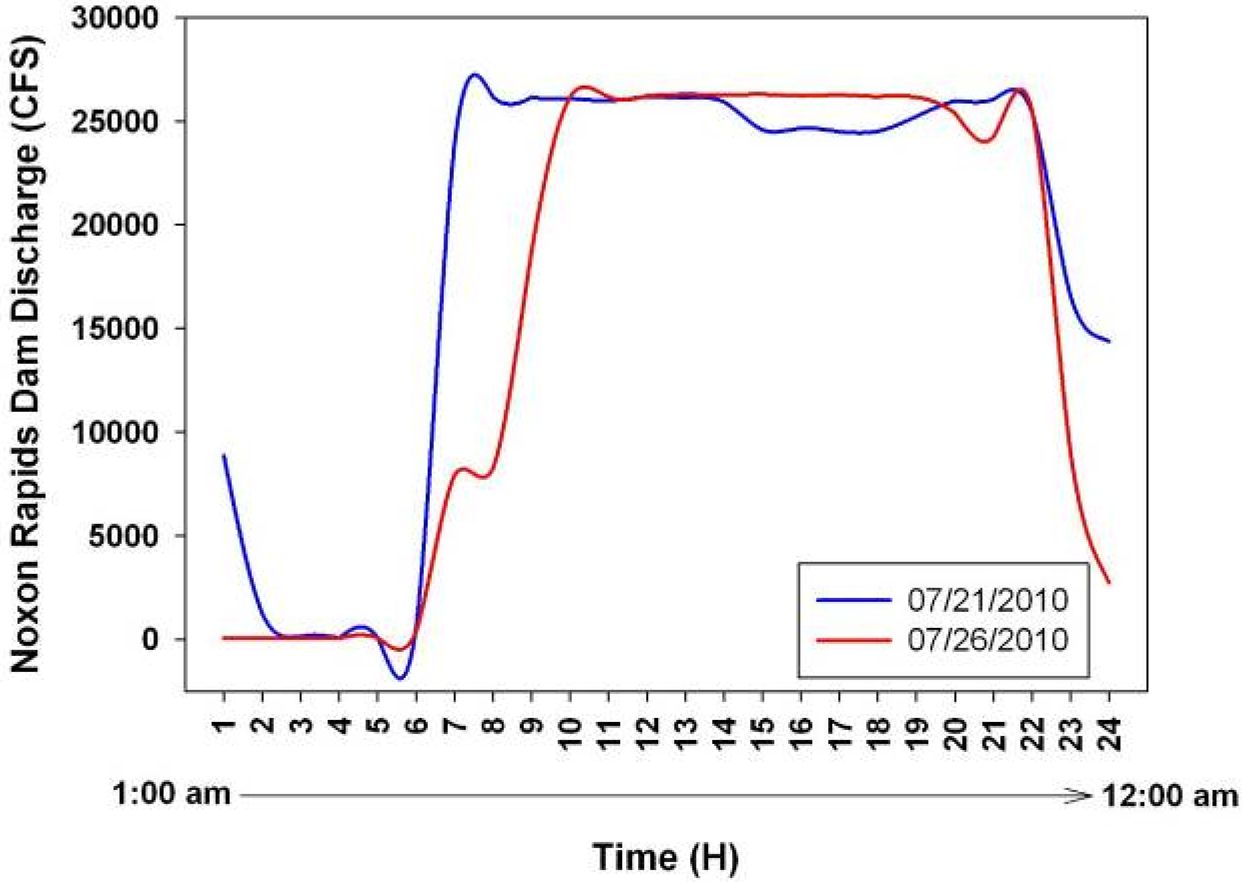

Figure 2.4. Noxon Rapids dam discharge for July 21 (Plot 7 was treated) and July 26 (Plot 8 was treated), 2010.

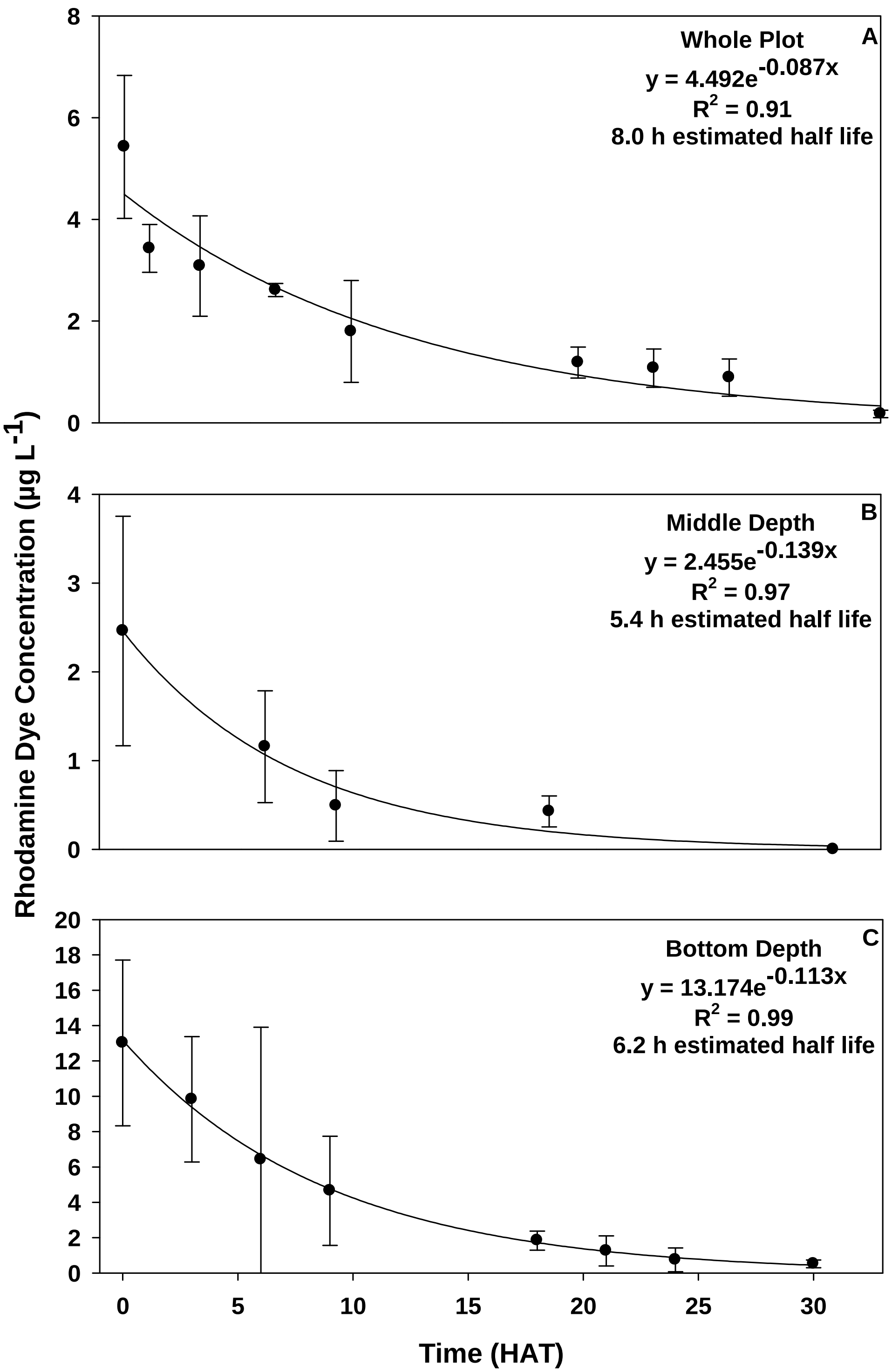

Figure 2.5. Rhodamine dye concentrations and respective half lives for the whole plot (A), middle depth (B), and bottom depth (C) for plot 7 (triclopyr alone) in Noxon Rapids Reservoir, July 2010.

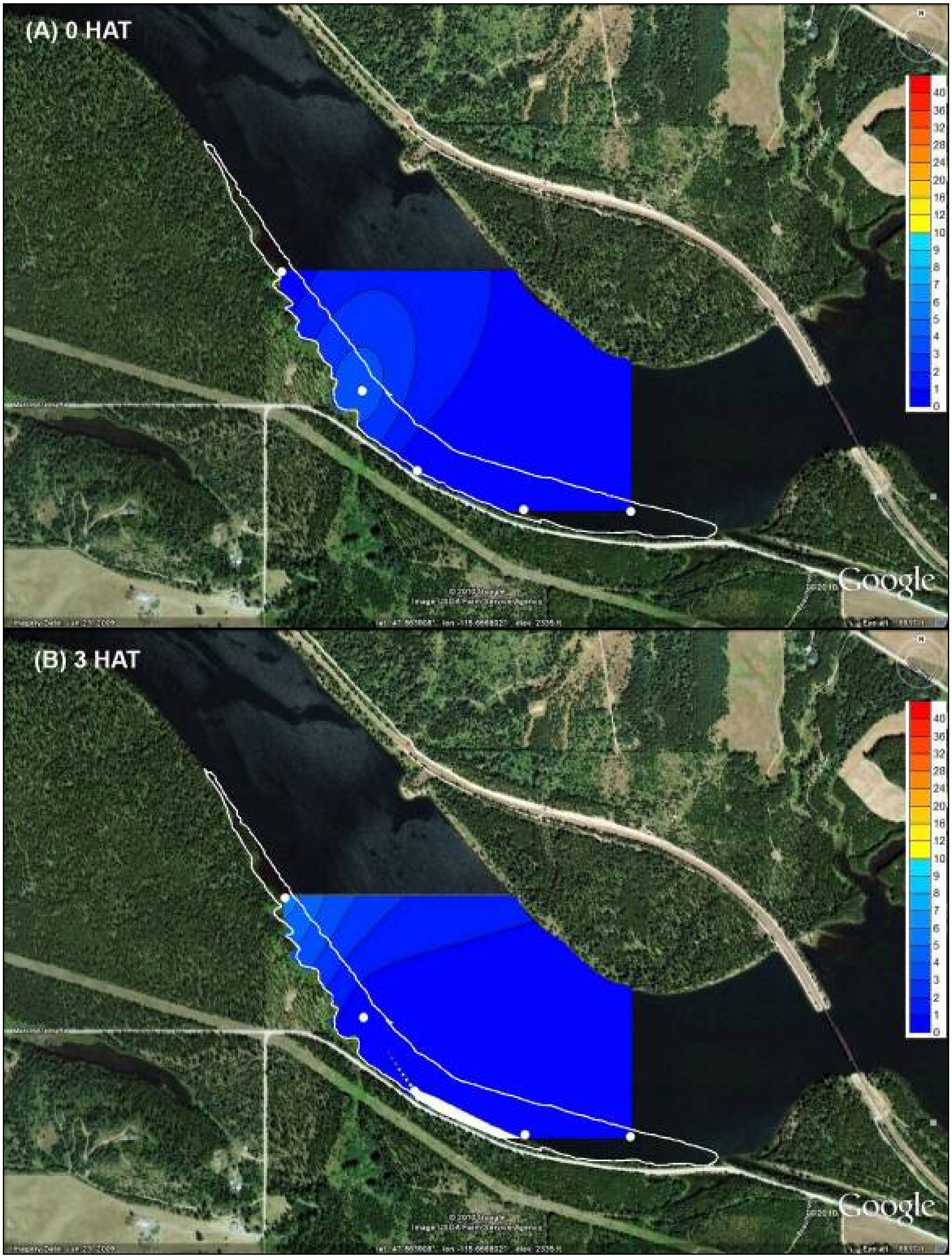

Figure 2.6. Predicted rhodamine dye dissipation from the top of the water column from plot 7 at 0 HAT (A) and 3 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

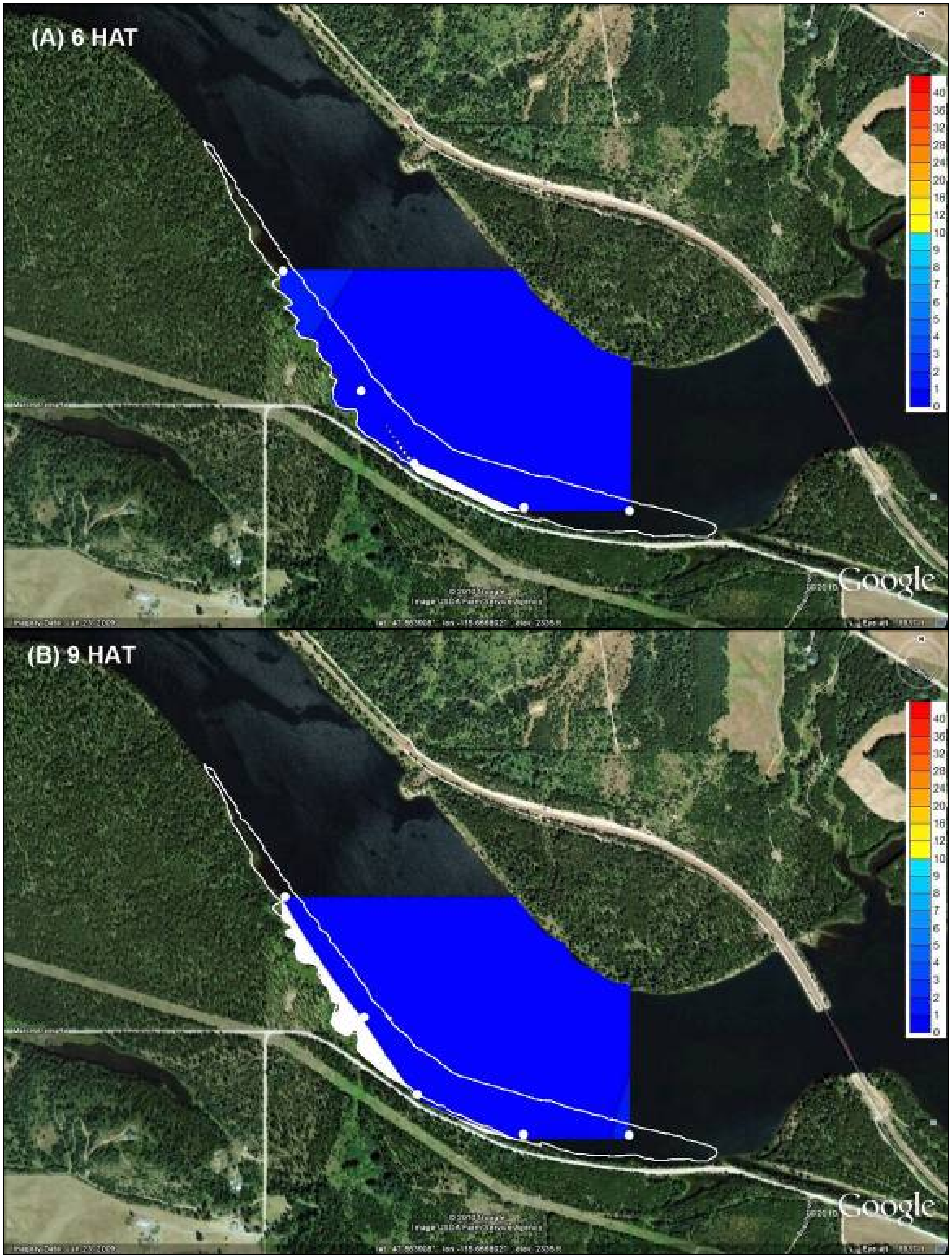

Figure 2.7. Predicted rhodamine dye dissipation from the top of the water column from plot 7 at 6 HAT (A) and 9 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

Figure 2.8. Predicted rhodamine dye dissipation from the top of the water column from plot 7 at 21 HAT (A) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

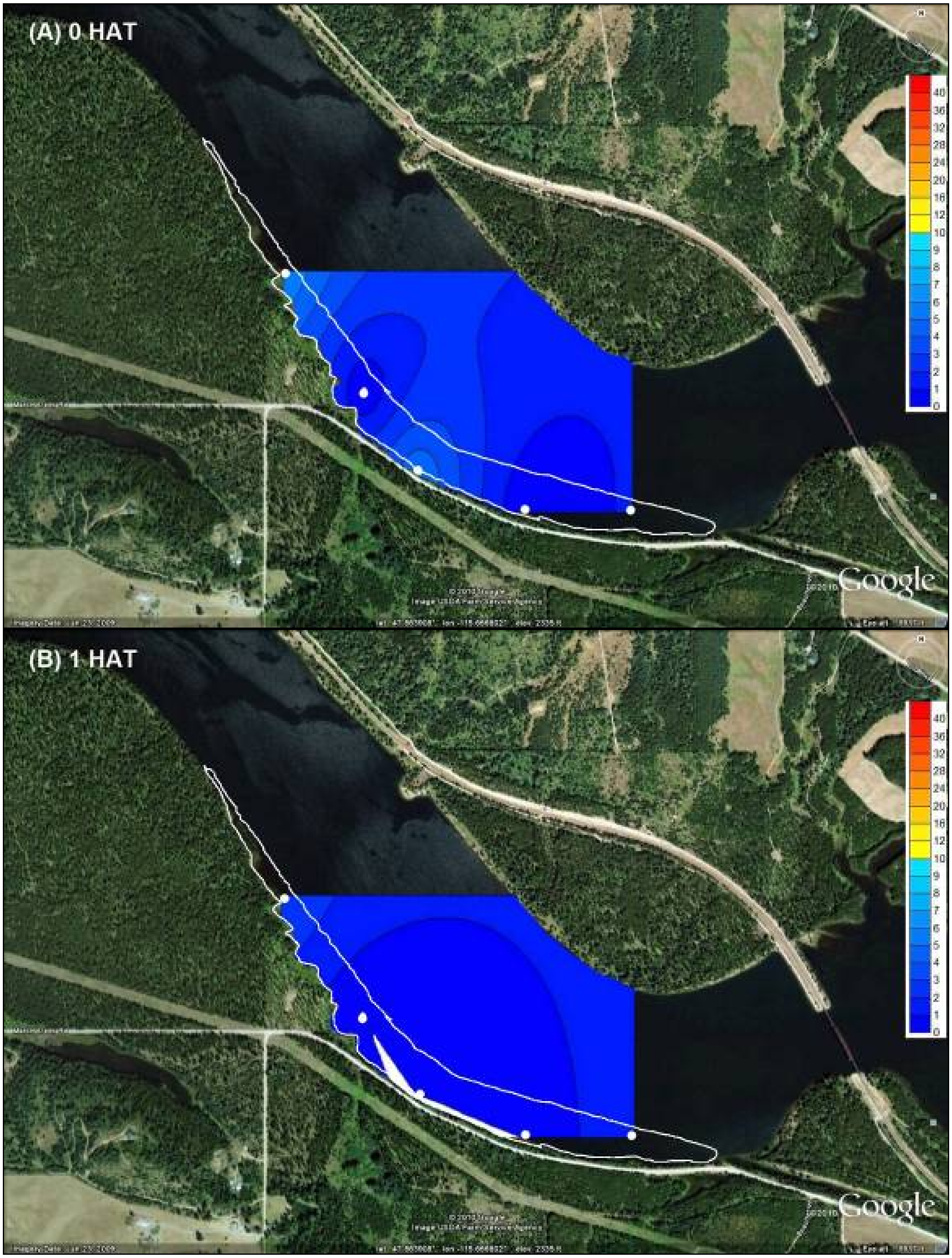

Figure 2.9. Predicted rhodamine dye dissipation from the middle of the water column from plot 7 at 0 HAT (A) and 1 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

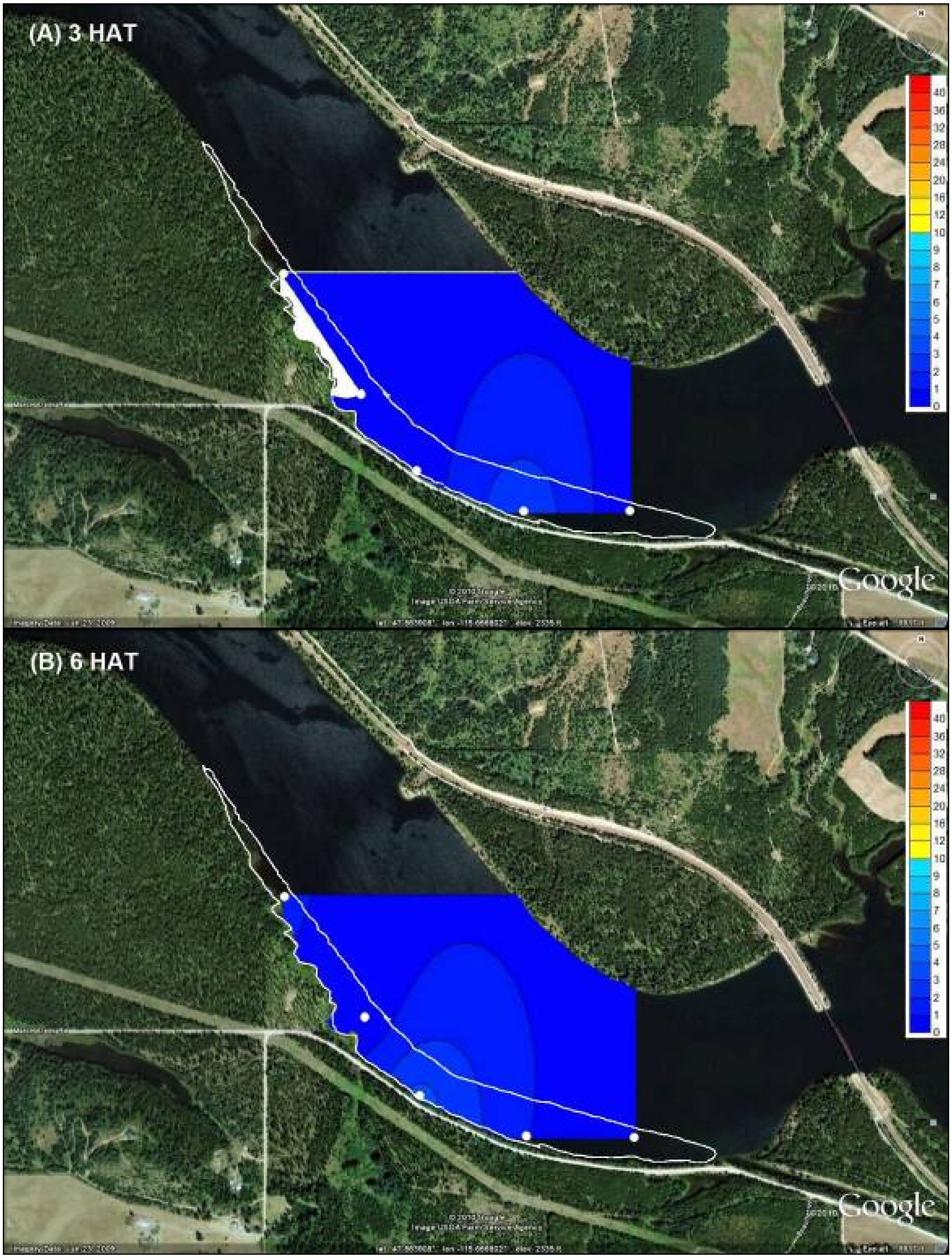

Figure 2.10. Predicted rhodamine dye dissipation from the middle of the water column from plot 7 at 3 HAT (A) and 6 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

Figure 2.11. Predicted rhodamine dye dissipation from the middle of the water column from plot 7 at 9 HAT according to the Kriging interpolation method from 5 water sampling stations, July 2010.

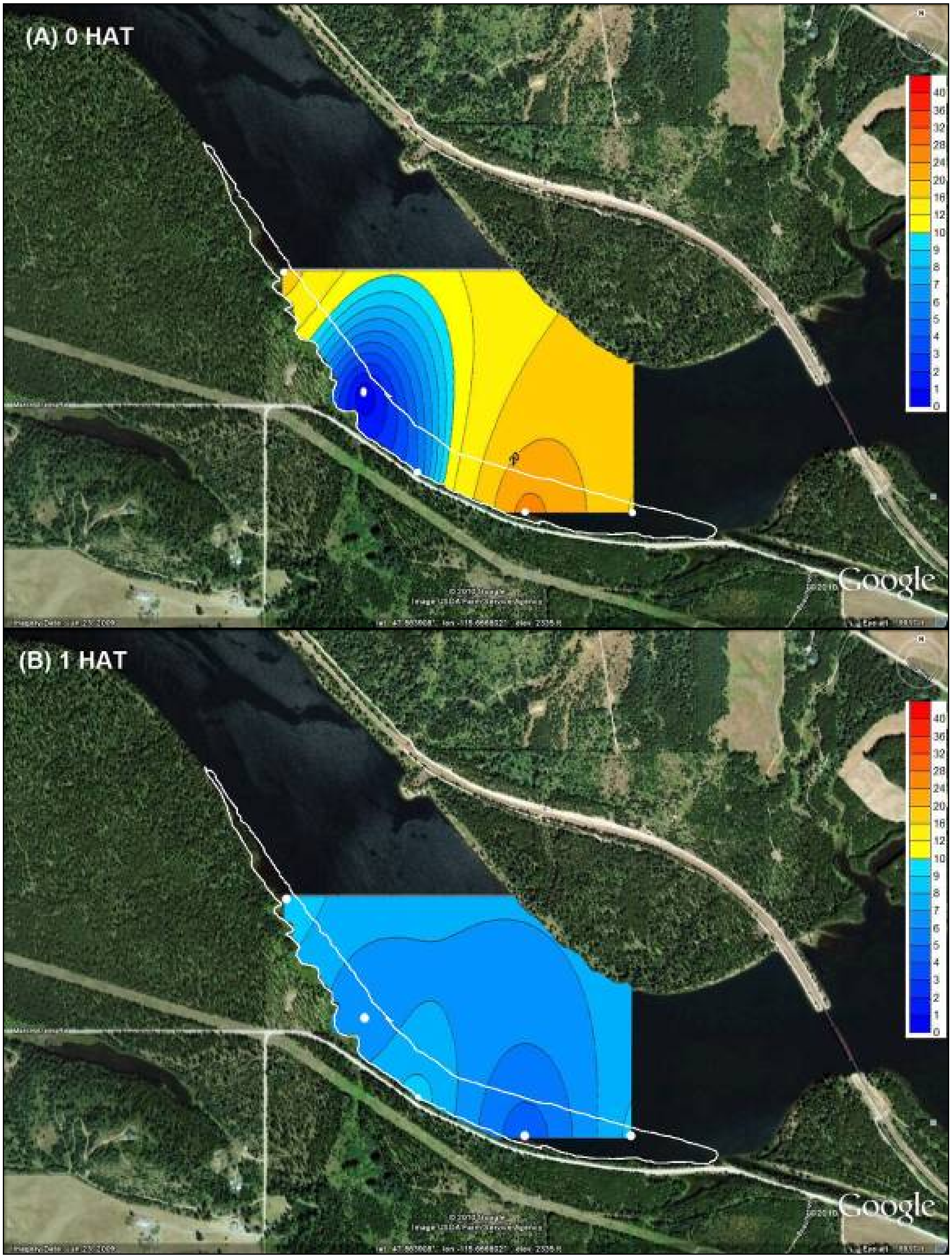

Figure 2.12. Predicted rhodamine dye dissipation from the bottom of the water column from plot 7 at 0 HAT (A) and 1 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

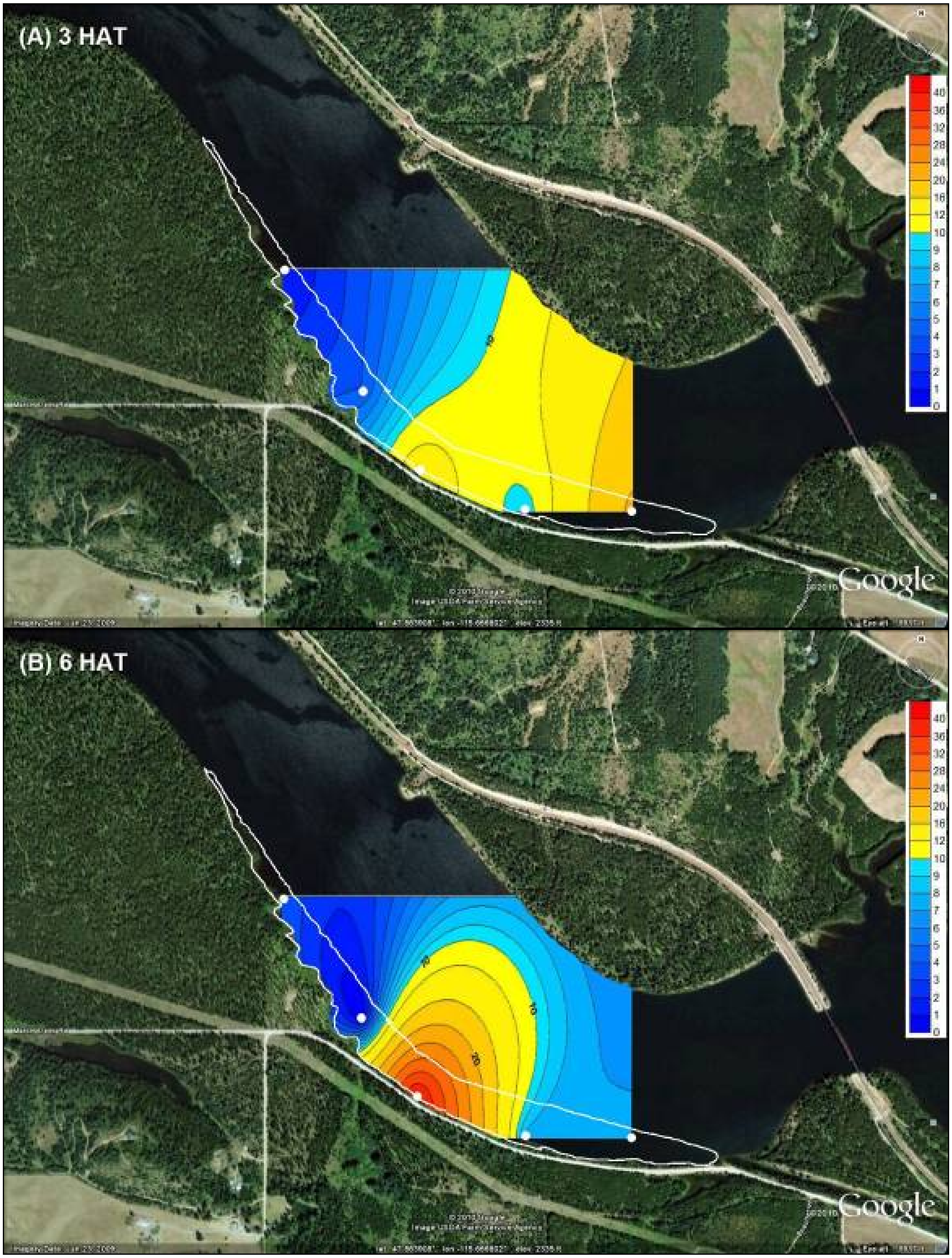

Figure 2.13. Predicted rhodamine dye dissipation from the bottom of the water column from plot 7 at 3 HAT (A) and 6 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

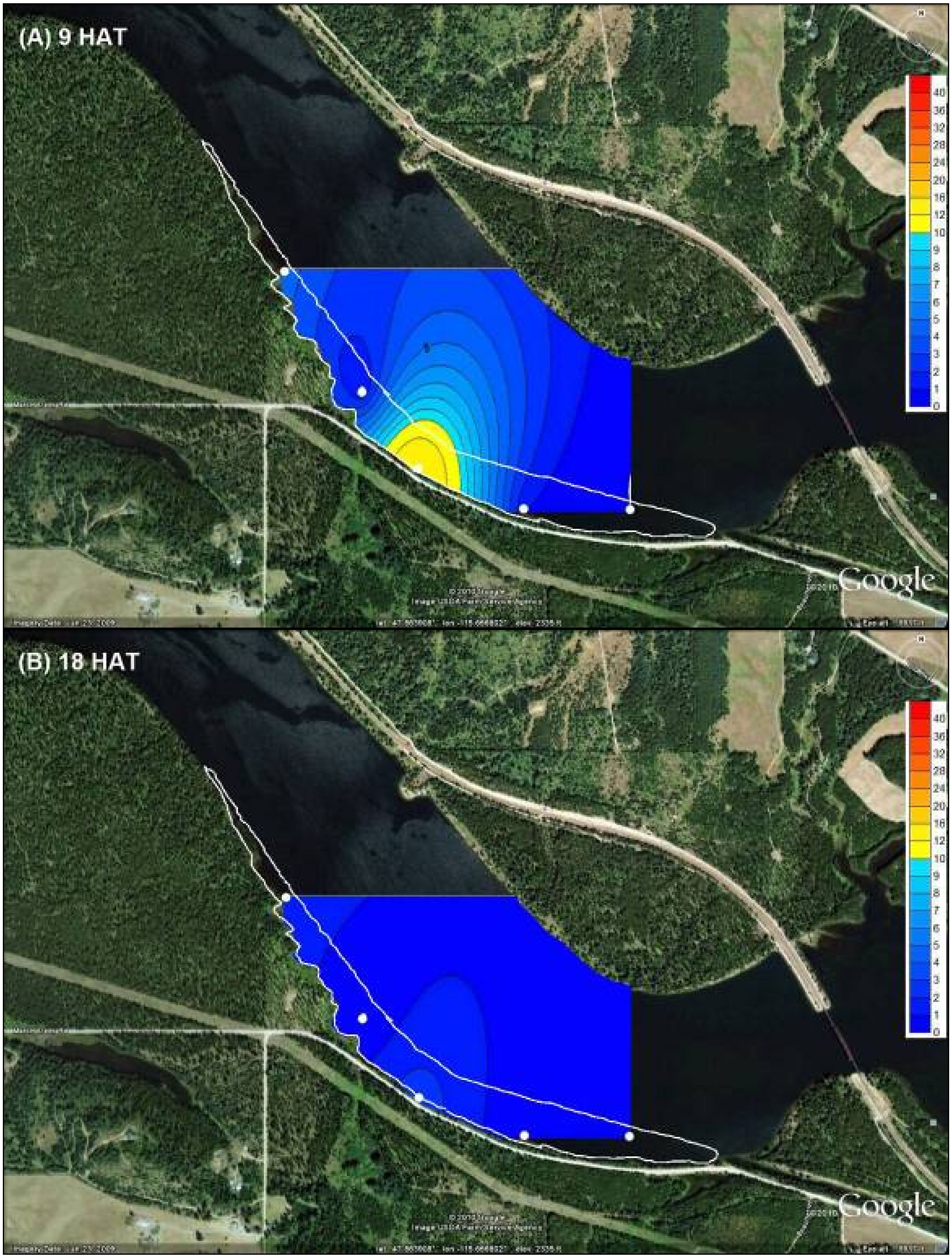

Figure 2.14. Predicted rhodamine dye dissipation from the bottom of the water column from plot 7 at 9 HAT (A) and 18 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

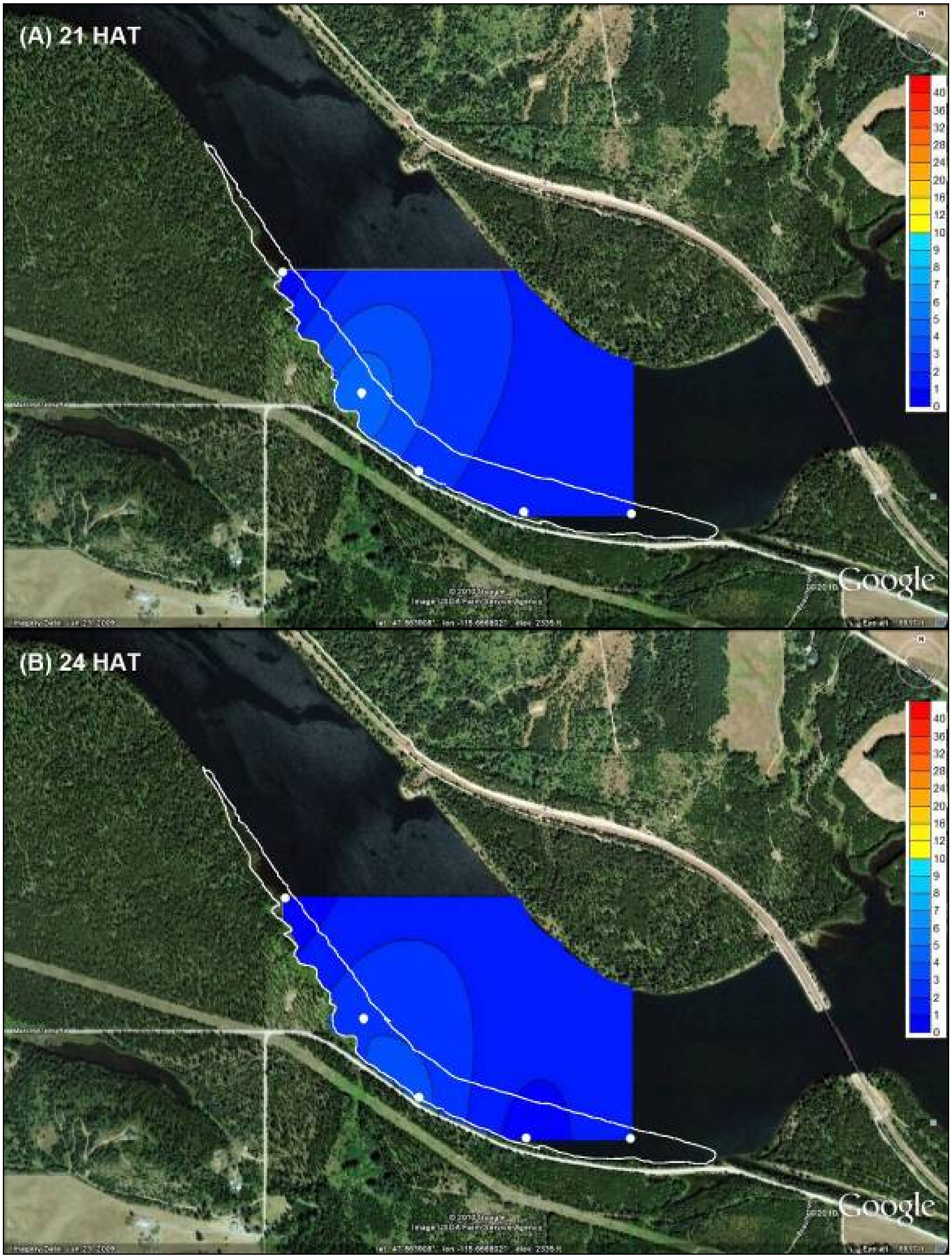

Figure 2.15. Predicted rhodamine dye dissipation from the bottom of the water column from plot 7 at 21 HAT (A) and 24 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

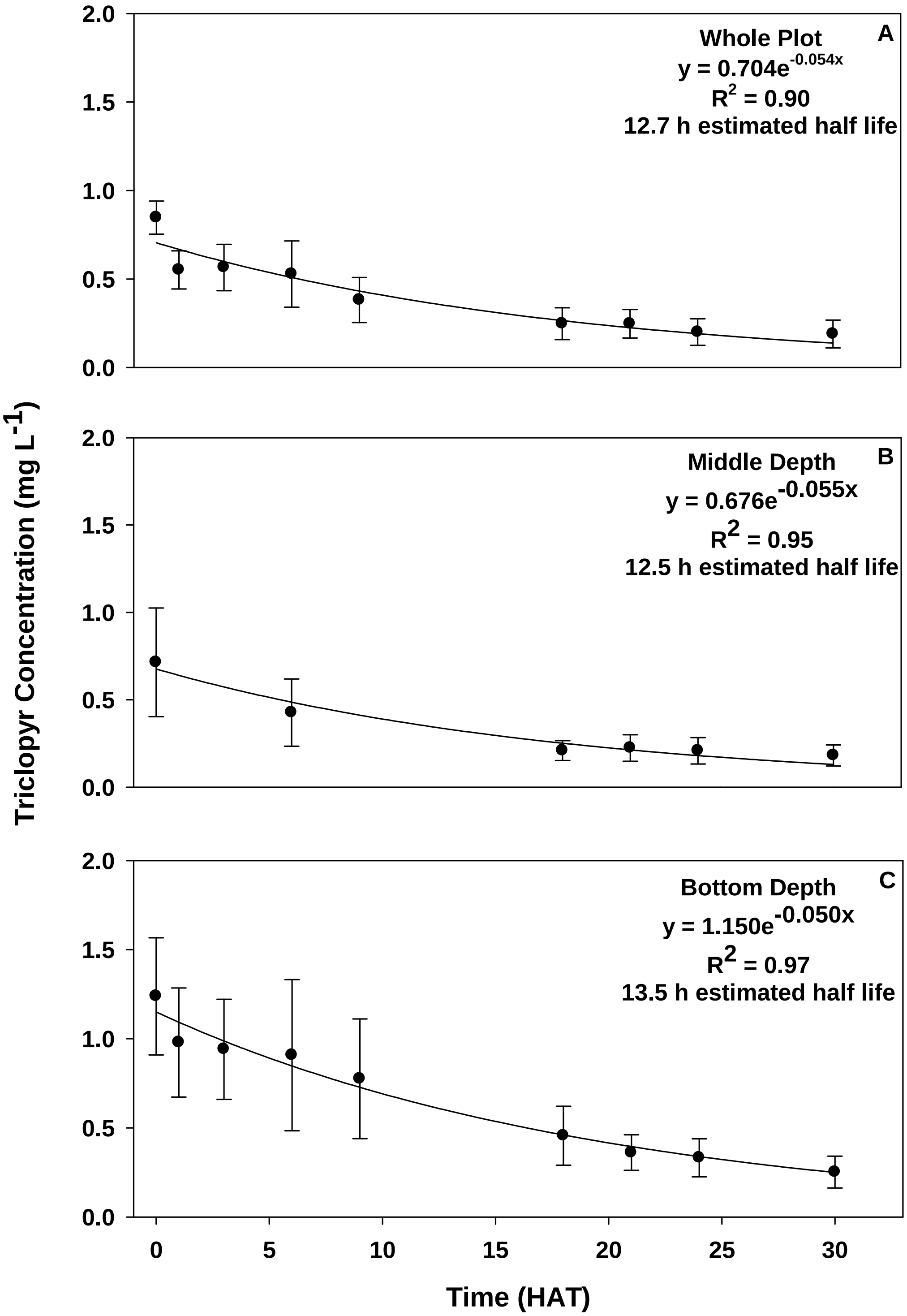

Figure 2.16. Triclopyr concentrations and respective half lives for the whole plot (A), middle depth (B), and bottom depth (C) for plot 7 (triclopyr alone) in Noxon Rapids Reservoir, July 2010.

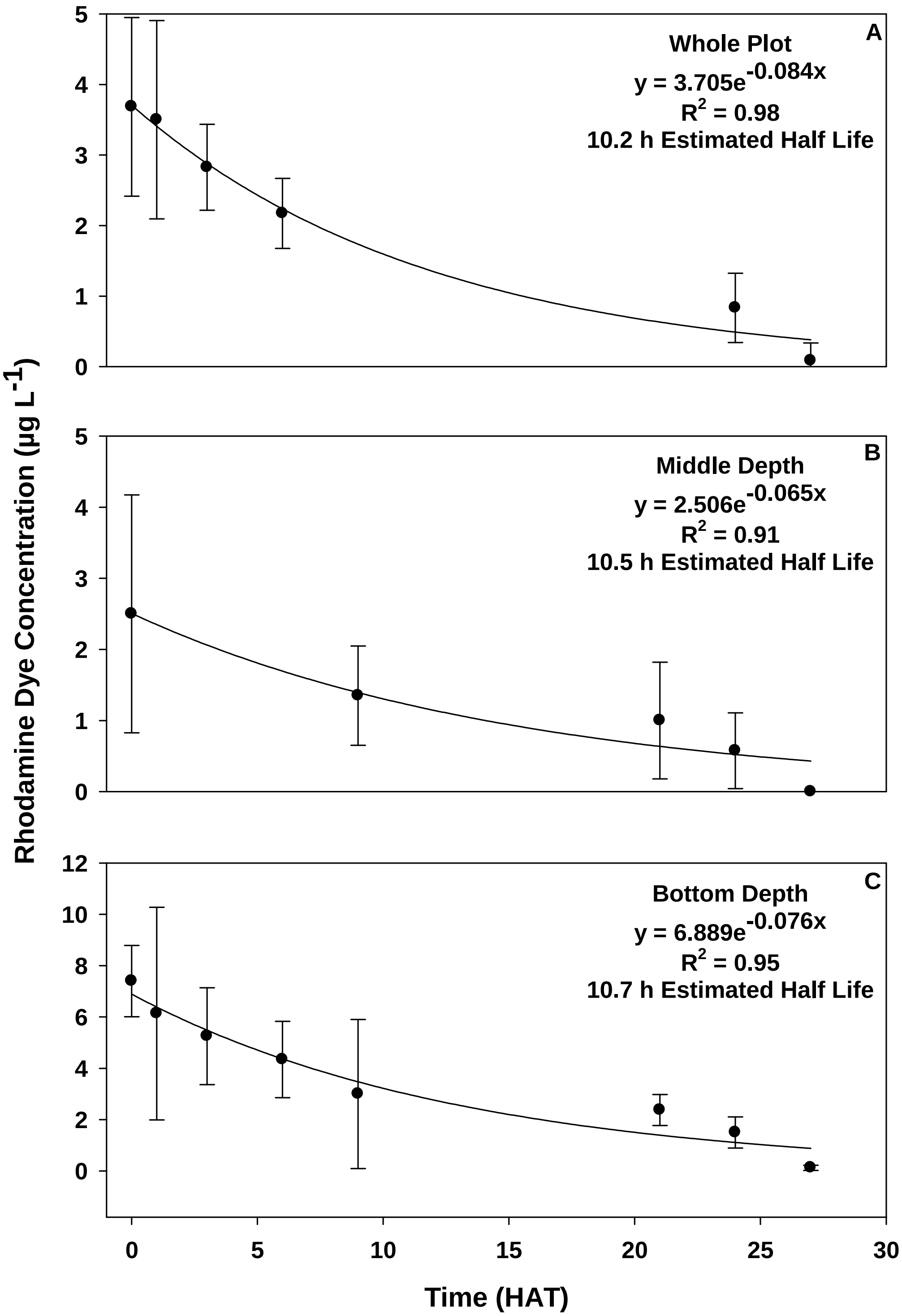

Figure 2.17. Rhodamine dye concentrations and respective half lives for the whole plot (A), middle depth (B), and bottom depth (C) for plot 8 (triclopyr + endothall) in Noxon Rapids Reservoir, July 2010.

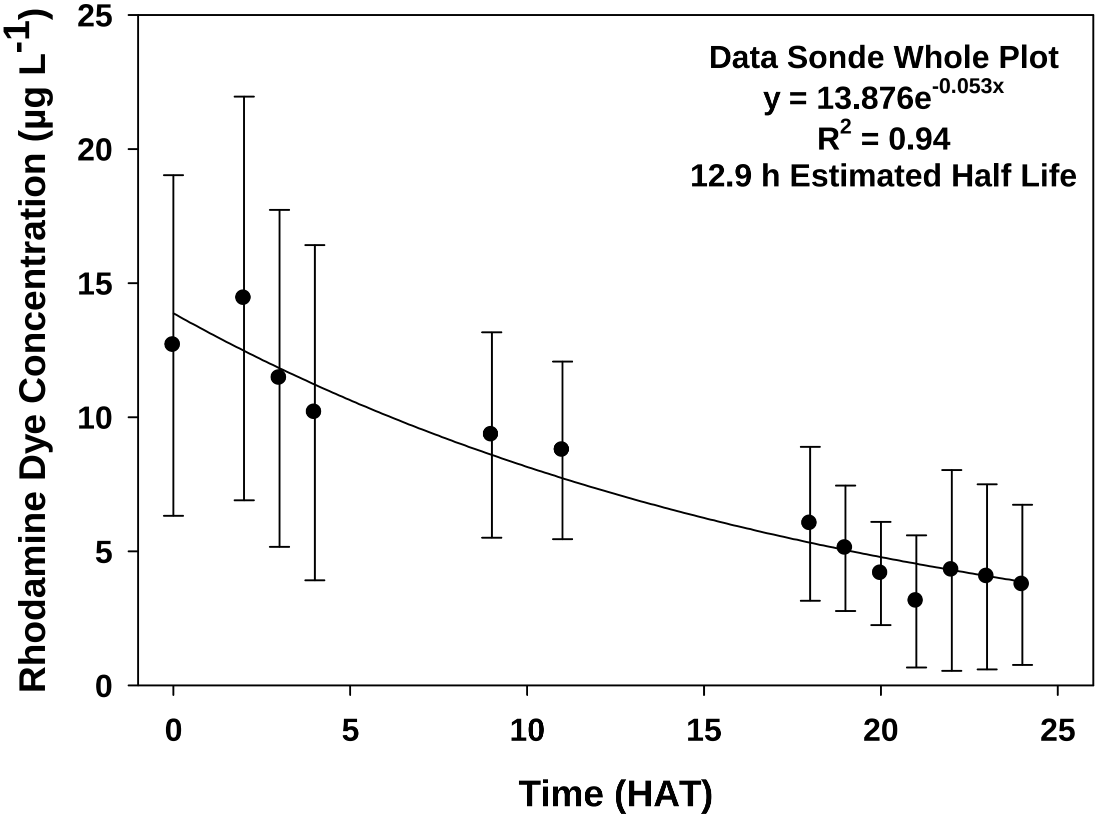

Figure 2.18. Rhodamine dye concentration and respective half life for all of plot 8 (triclopyr + endothall) in Noxon Rapids Reservoir, July 2010 as measured by HACH data sondes.

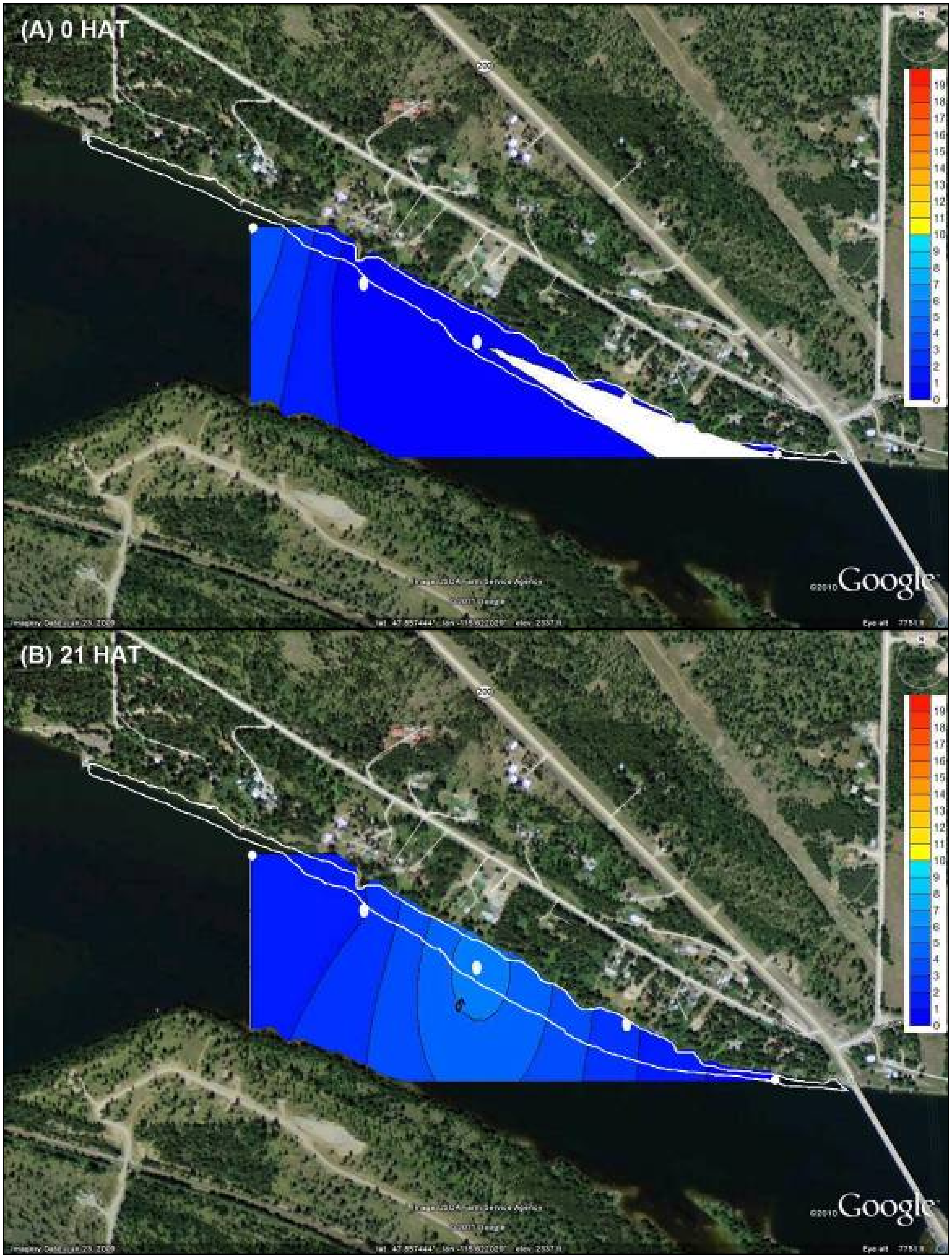

Figure 2.19. Predicted rhodamine dye dissipation from the top of the water column from plot 8 at 0 HAT (A) and 21 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

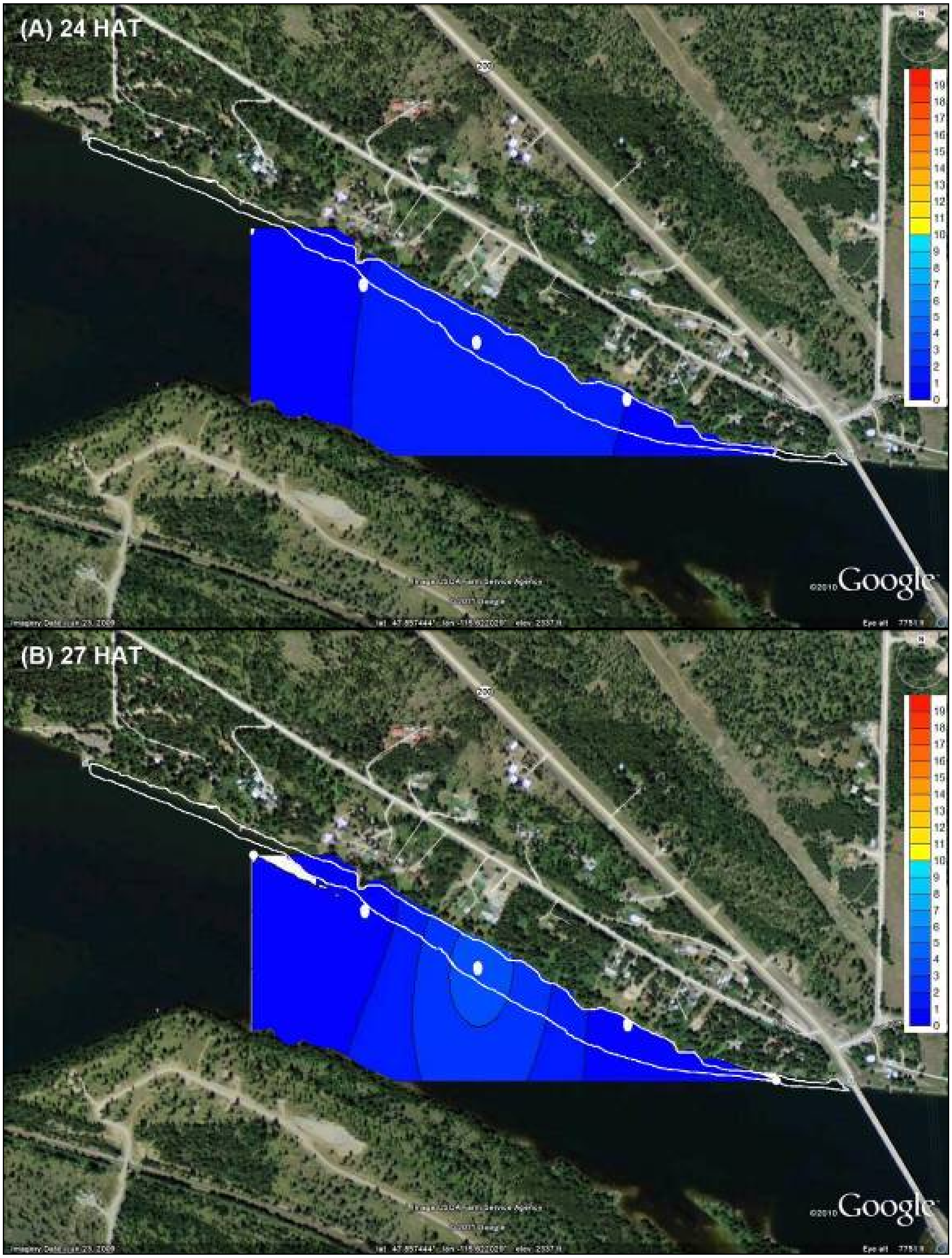

Figure 2.20. Predicted rhodamine dye dissipation from the top of the water column from plot 8 at 24 HAT (A) and 27 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

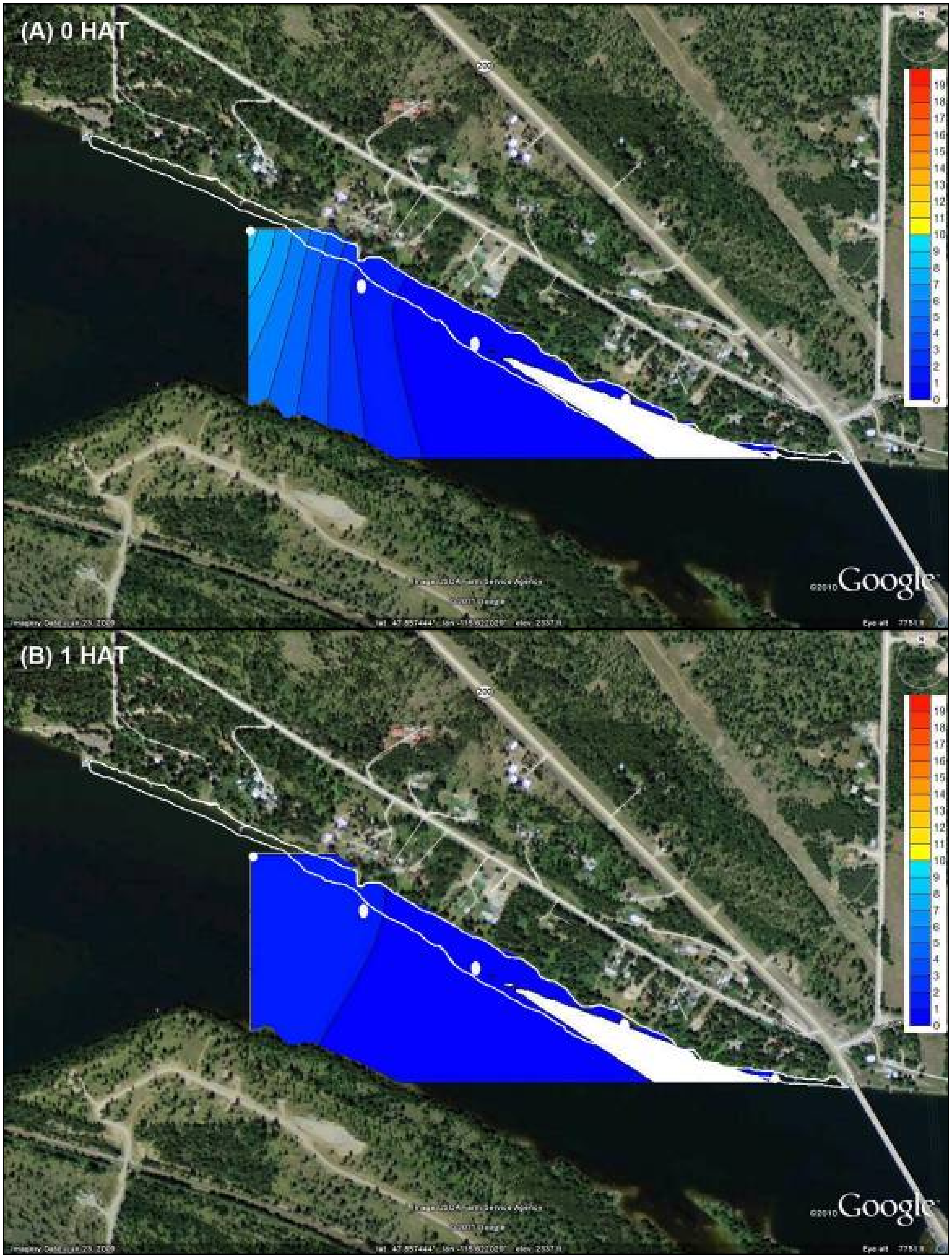

Figure 2.21. Predicted rhodamine dye dissipation from the middle of the water column from plot 8 at 0 HAT (A) and 1 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

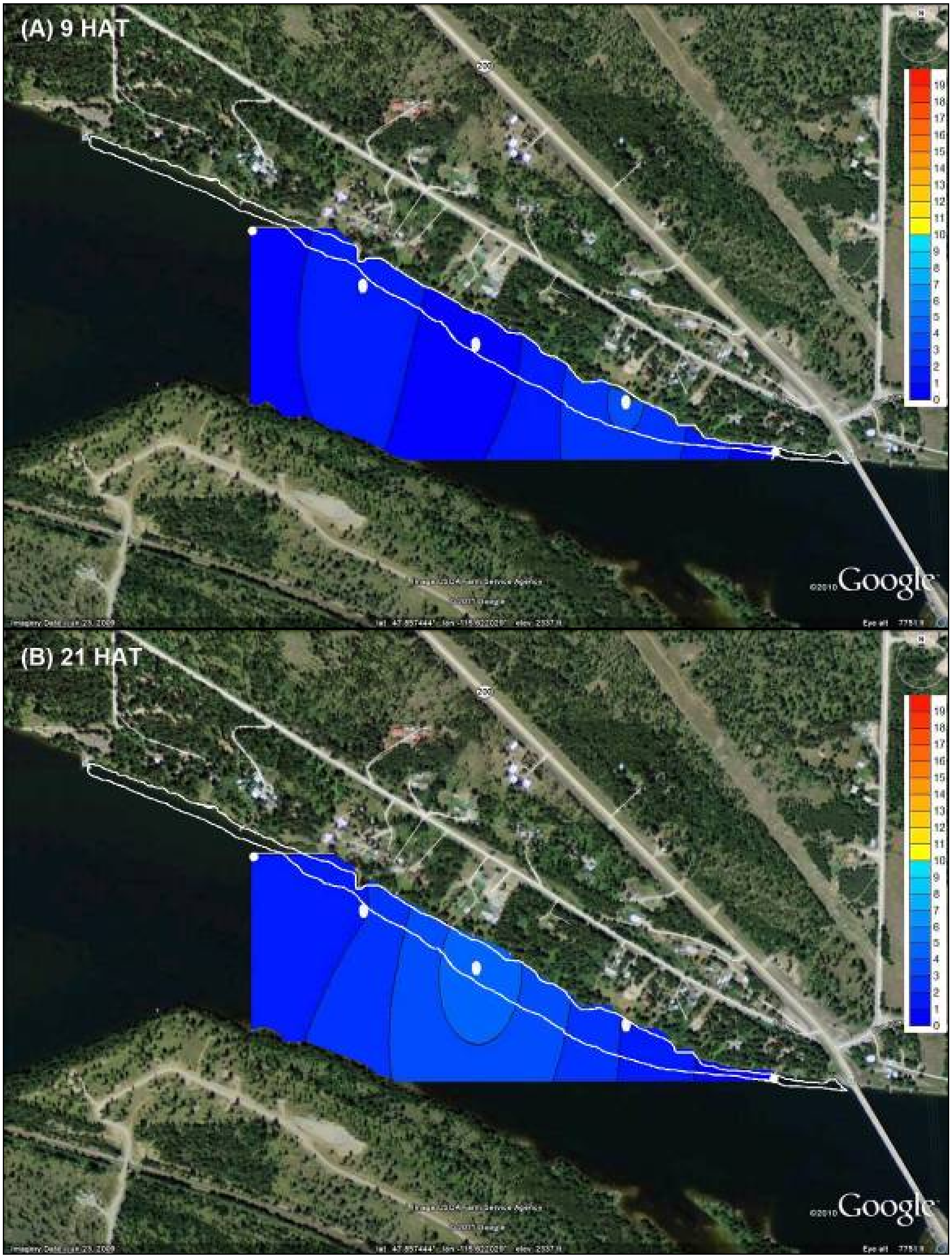

Figure 2.22. Predicted rhodamine dye dissipation from the middle of the water column from plot 8 at 9 HAT (A) and 21 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

Figure 2.23. Predicted rhodamine dye dissipation from the middle of the water column from plot 8 at 24 HAT (A) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

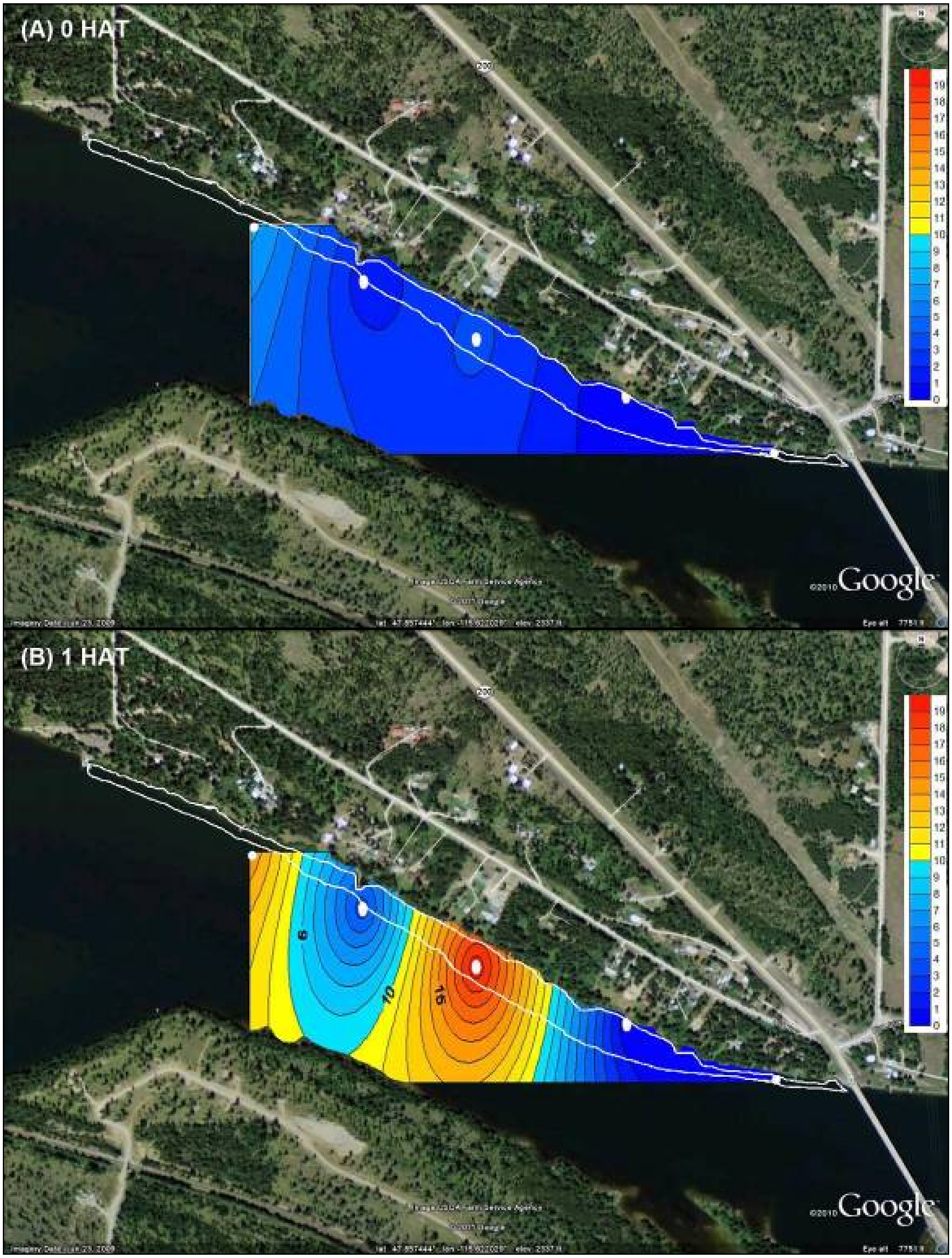

Figure 2.24. Predicted rhodamine dye dissipation from the bottom of the water column from plot 8 at 0 HAT (A) and 1 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

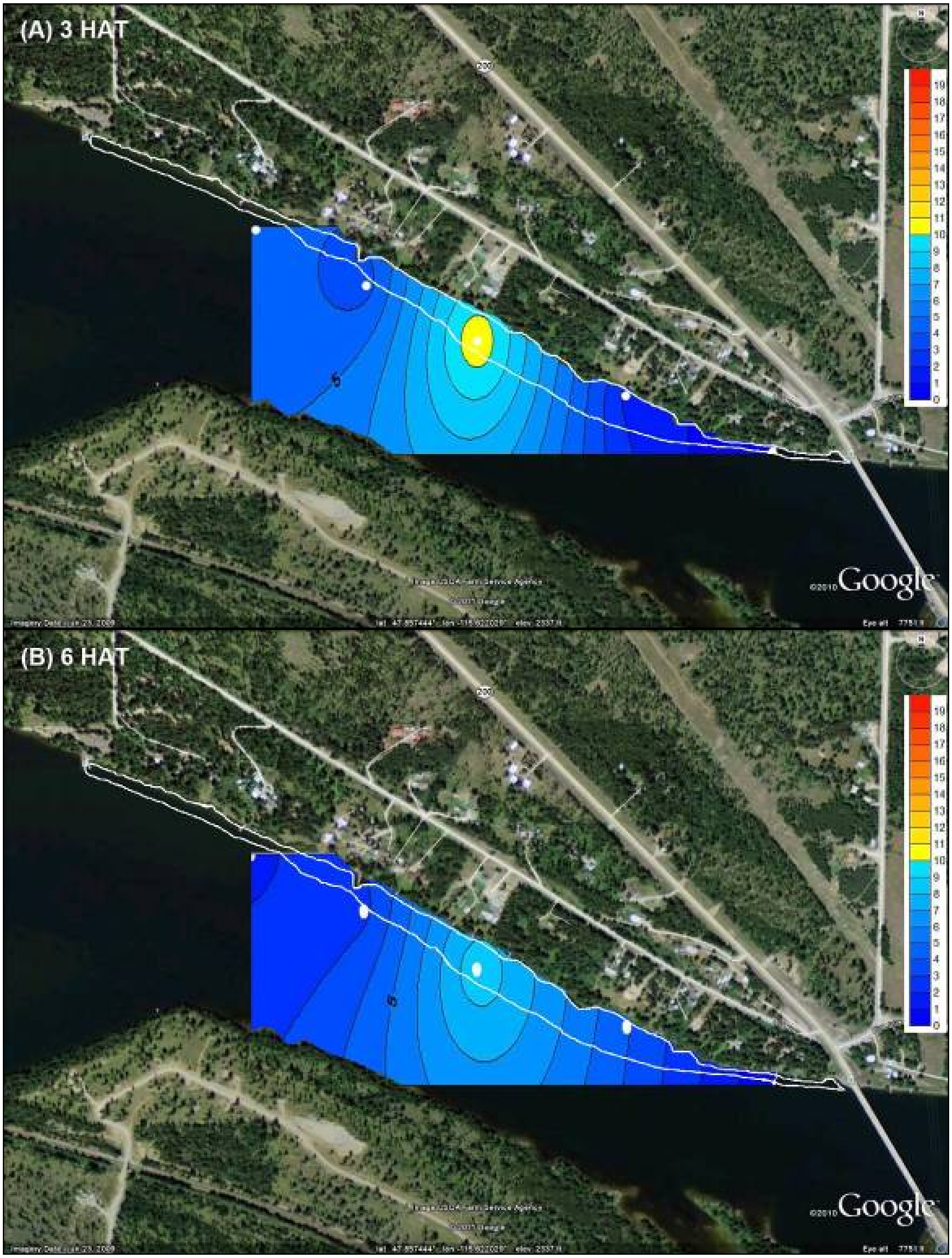

Figure 2.25. Predicted rhodamine dye dissipation from the bottom of the water column from plot 8 at 3 HAT (A) and 6 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

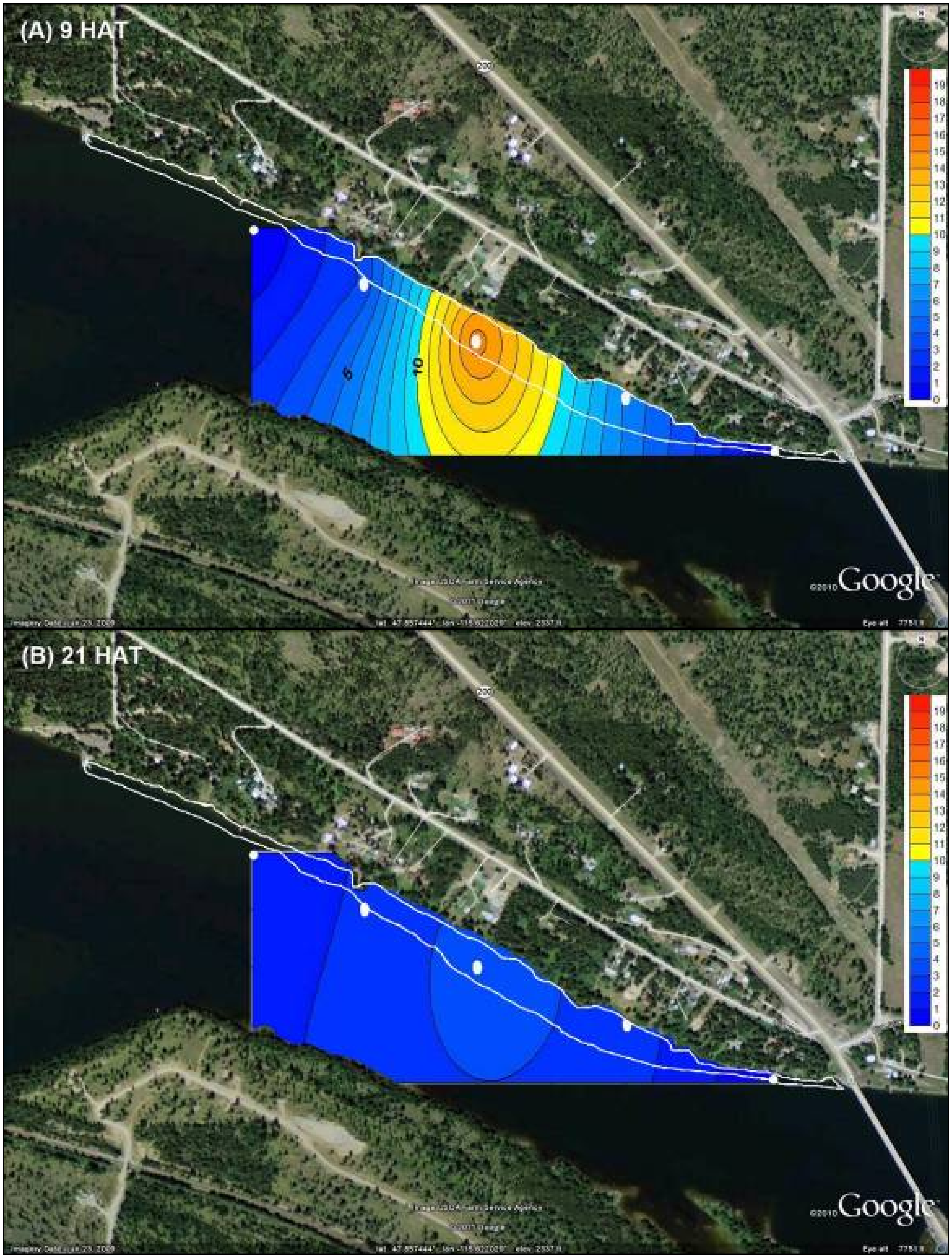

Figure 2.26. Predicted rhodamine dye dissipation from the bottom of the water column from plot 8 at 9 HAT (A) and 21 HAT (B) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

Figure 2.27. Predicted rhodamine dye dissipation from the bottom of the water column from plot 8 at 24 HAT (A) according to the Kriging interpolation method from 5 water sampling stations, July 2010.

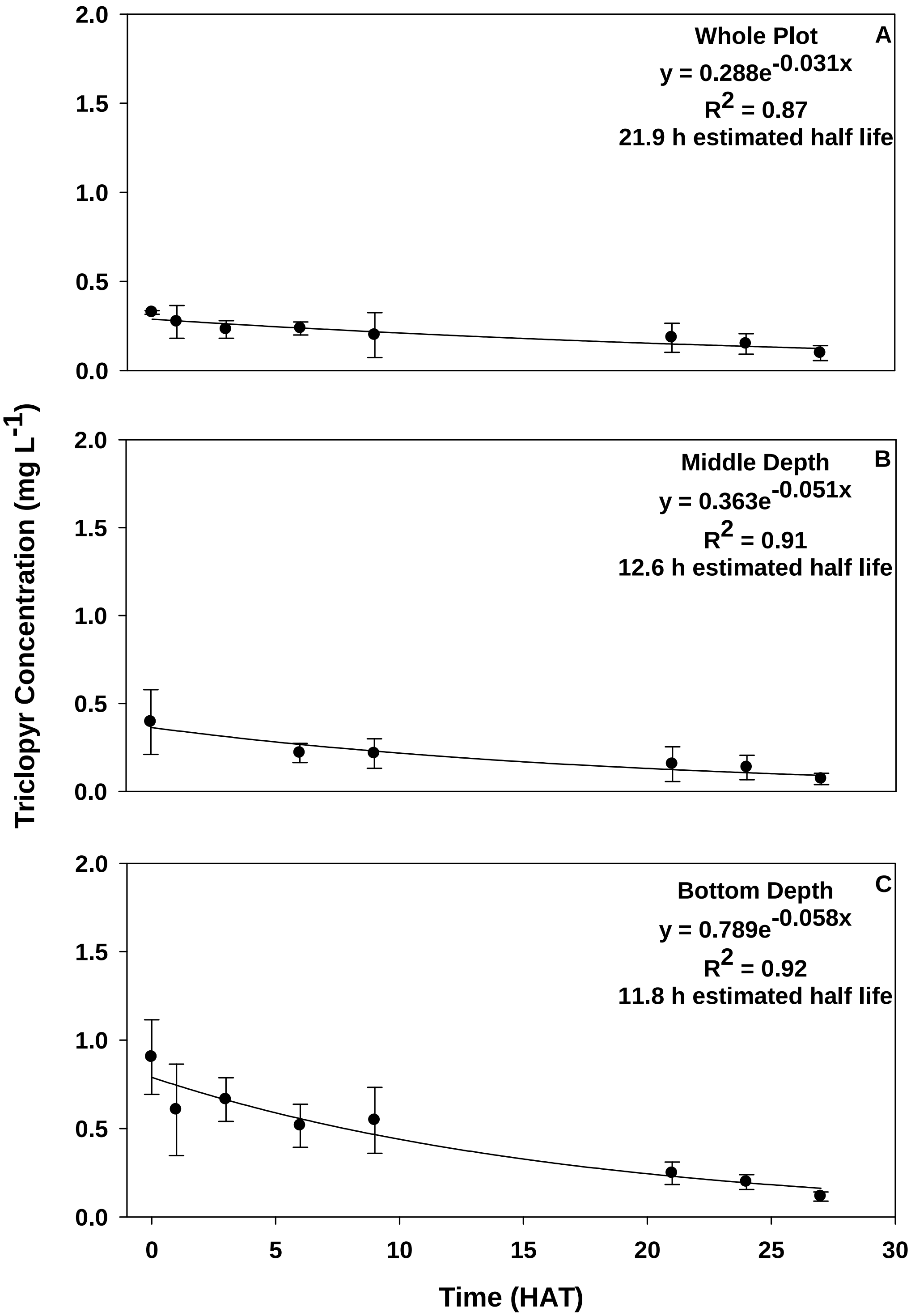

Figure 2.28. Triclopyr concentrations and respective half lives for the whole plot (A), middle depth (B), and bottom depth (C) for plot 8 (triclopyr + endothall) in Noxon Rapids Reservoir, July 2010.

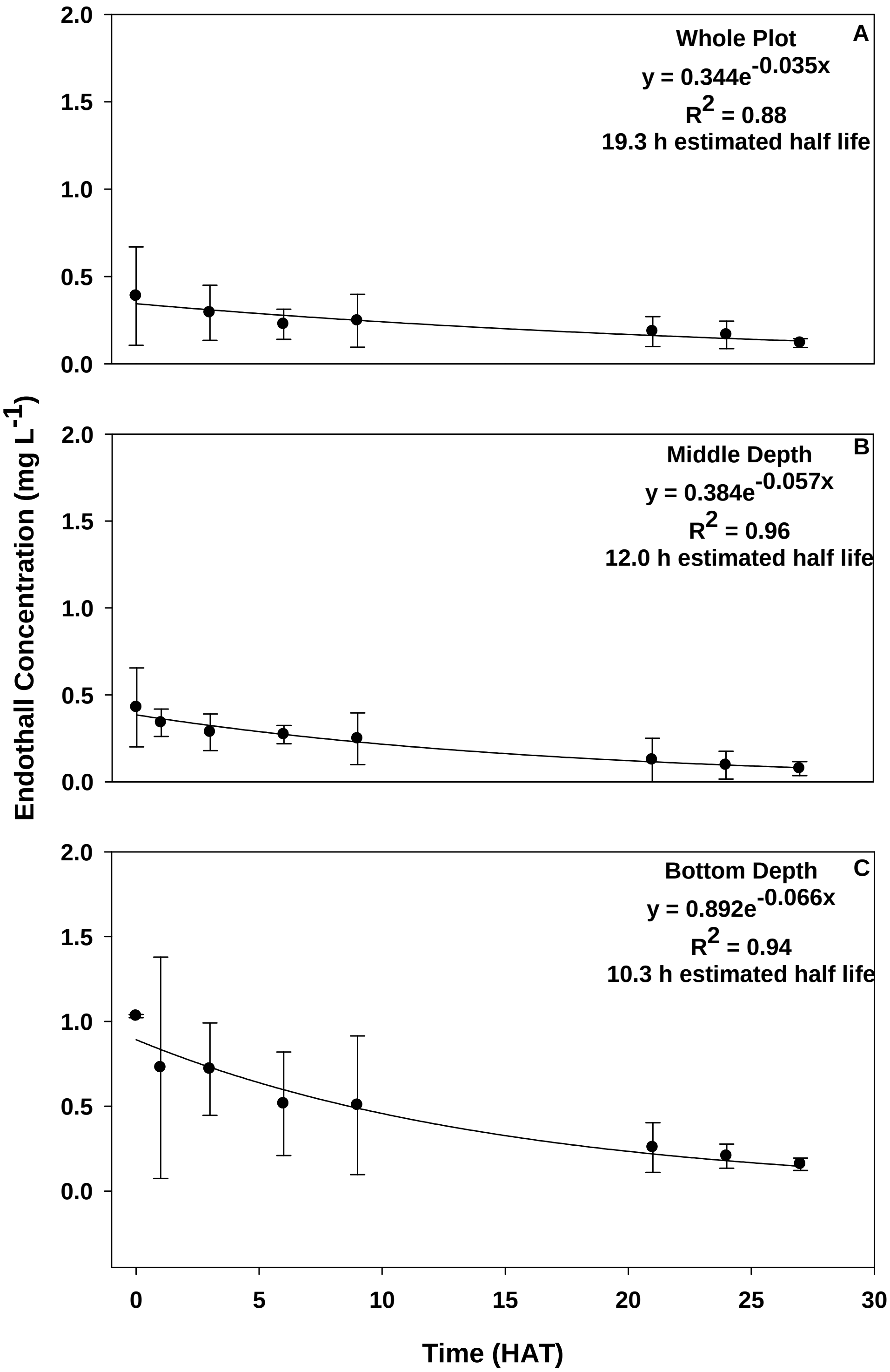

Figure 2.29. Endothall concentrations and respective half lives for the whole plot (A), middle depth (B), and bottom depth (C) for plot 8 (triclopyr + endothall) in Noxon Rapids Reservoir, July 2010.

Chapter 3

Aquatic Plant Response to Herbicide Applications in Small Plots in Noxon Rapids Reservoir, Montana

Introduction

The introduction of non-native plants into littoral zone habitats often alters the complex interactions occurring in these areas (Madsen 1998). Dense stands of non-native plants are often responsible for reduction in oxygen exchange, depletion of dissolved oxygen, increases in water temperatures, and internal nutrient loading (Madsen 1998). Eurasian watermilfoil (*Myriophyllum spicatum* L.) is a non-native invasive species that, when present, has been associated with declines in native plant species richness and diversity (Madsen et al. 1991, Madsen et al. 2008). Monotypic stands of Eurasian watermilfoil directly reduce native plant species richness and diversity, and also indirectly reduce habitat complexity resulting in reduced macroinvertebrate abundance (Krull 1970, Keast 1984) and reduction in fish growth (Lillie and Budd 1992). Eurasian watermilfoil also poses nuisance problems to humans in the form of increasing flood frequency and intensity, impeding navigation, and limiting recreation opportunities (Madsen et al. 1991).

Although the impacts form Eurasian watermilfoil are numerous, controlling this species is often difficult and unpredictable. Flowing water, such as the Lower Clark Fork River, further complicates the use of herbicides as water flow will increase the dilution and dissipation of the herbicides. Herbicide applications in run of the river reservoirs are often subject to more extreme perturbations than those of natural lakes. Run of the river reservoirs have variable water-exchange patterns, typically tied to dam operations, that will impact aqueous distribution of herbicides resulting in reduced chemical exposure times against target plants and unacceptable effectiveness (Getsinger et al. 1997). Herbicide concentration exposure time (CET) relationships designed to provide excellent plant control have been developed specifically for Eurasian watermilfoil using triclopyr and endothall alone (Netherland et al. 1991, Netherland and Getsinger 1992). Small plot and whole lake studies have verified CET relationships and documented the efficacy range for triclopyr rates, as well as selectivity removing Eurasian watermilfoil populations with little to no harm to native plant communities (Getsinger et al. 1997, Getsinger et al. 2000, Poovey et al. 2004, Wersal et al. 2010a). Noxon Rapids Reservoir experiences routine high flow rates as this reservoir is used for hydro-power generation, and these high flow rates would, in turn, reduce the efficacy triclopyr applied alone.

Therefore, small scale research has been conducted to investigate the interactions associating with combining a contact herbicide with a systemic herbicide for aquatic use. The combination would also have the added benefit of targeting the invasive monocot, curlyleaf pondweed (*Potamogeton crispus*), which is not typically affected by label rates of triclopyr applied alone (Netherland et al. 2000, Poovey et al. 2002). Early small scale trials of the combination resulted in reduced contact time needed for effective Eurasian watermilfoil control, while maintaining the benefits of the longer term control afforded by the systemic herbicide (Madsen et al. 2010). Though small scale trials have been conducted, there has been limited field assessment of this herbicide combination. Pursuant to this, effective herbicide concentrations used in field situations still need to be determined; and the selectivity spectrum of non-target plants to this combination is still unknown. Therefore, our objectives of this study were to:

1) demonstrate at the field scale the effectiveness of combining triclopyr with endothall for control of Eurasian watermilfoil and curlyleaf pondweed in flowing systems;

2) further refine herbicide concentrations from the Phase 1 study with respect to plant response;

3) evaluate the use of triclopyr alone in Noxon Rapids Reservoir;

4) evaluate the plant community response to herbicide applications.

Materials and Methods

Point Intercept Assessments. Pretreatment (0 weeks after treatment (WAT)) point intercept surveys were conducted on July 20, 2010 using a 50 m grid to assess the plant community in four plots on Noxon Rapids Reservoir prior to herbicide application (see chapter 2 for a plot description). Similar surveys were conducted from September 7-10, 2010 to assess plant community response at 7 WAT. Plots 2 and 4 were chosen as untreated reference plots, and plots 7 and 8 were chosen as herbicide plots.

Survey methods were similar to those utilized during recent projects in the Pacific Northwest (Madsen and Wersal 2008, Madsen and Wersal 2009, Wersal et al. 2010ab). A total of 36, 38, 35, and 37 points were surveyed in Plots 2, 4, 7, and 8 respectively. Plots 2 and 4 are the same reference plots that were utilized in the Phase 1 study from 2009. Surveys were conducted by boat using Global Positioning System (GPS) technology. A Dell Latitude E 6400 XFR (Round Rock, TX) ruggedized computer outfitted with a Trimble AgGPS106™ (Sunnyvale, CA) GPS receiver was used to navigate to each point. Survey accuracy was 1-3 m (3-10 ft) depending on satellite reception. At each survey point, a weighted thatch rake was deployed twice to determine the presence of plant species. Spatial data were recorded electronically using FarmWorks Site Mate® software (Hamilton, IN). The software allowed for in-field geographic and attribute data collection. Data were recorded in database templates using specific pick lists constructed exclusively for this project. Site Mate® provided an environment for displaying geographic and attribute data, and enabled navigation to specific locations on the lake.

Statistical Analyses. Plant species presence was averaged over all points sampled and multiplied by 100 to calculate percent frequency. Changes in the occurrence of plant species between the pre treatment and 7 WAT surveys were determined using the McNemar's test to assess the differences in the correlated proportions within a given data set between variables that are not independent, i.e. sampling the same points pre and post treatment (Stokes et al. 2000, Wersal et al. 2006, Wersal et al. 2010b). Mean species richness, native species richness, and non-native species richness was calculated for each plot and subjected to a Wilcoxin Signed Rank test. All analyses were conducted using SAS® analytical software (Cary, NC), at a $p < 0.05$ significance level.

Results and Discussion

Plot 7

The presence of Eurasian watermilfoil in Plot 7 significantly declined from 50% before herbicide treatment to 16% 7 WAT, which represents a 70% reduction in its occurrence in the plot (Table 3.1). The 70% reduction in Eurasian watermilfoil presence corroborates the estimated half-life for this plot and the CET relationships that were established in earlier studies (Netherland and Getsinger 1992). The locations of remaining Eurasian watermilfoil after treatment were primarily along the boundary of the plot towards the main channel and one location near the downstream end of the plot (3.1). These areas had the lowest concentrations of dye and herbicide and the shortest half-lives with respect to points surveyed along the shoreline. The reduced concentrations and contact time would result in reductions in herbicide efficacy in these locations. The only other species in plot 7 that exhibited a significant decline was curlyleaf pondweed.

Curlyleaf pondweed was observed at 81% and 50% of survey points during the pre and post treatment surveys respectively. The decline in plot 7 is most likely due to natural senescence (Woolf and Madsen 2003), although the increased triclopyr concentrations in this plot may have been high enough to impact weaker plants. However, the locations of curlyleaf pondweed within the plot during the post treatment survey would suggest that senescence is a more plausible explanation (Figure 3.2).

There was no significant impact from the herbicide application on native plant species at 7 WAT (Table 3.1). Furthermore, species richness and native species richness were not different between the pre and post treatment surveys. The only significant differences in plot 7 were reductions in Eurasian watermilfoil, curlyleaf pondweed, and the subsequent non-native species richness. Similar results were observed in Hayden Lake, ID when applications of 2,4-D and triclopyr were made for Eurasian watermilfoil control (Wersal et al. 2010b). Based on results from plot 7, the use of triclopyr alone resulted in selective control of Eurasian watermilfoil; a result due to the CET achieved after treatment. A longer exposure time would have likely resulted in non-target plant injury, especially to northern watermilfoil (*Myriophyllum sibiricum*) and white water-buttercup (*Ranunculus aquatilis*).

Plot 8

Eurasian watermilfoil in plot 8 significantly declined by 7 WAT with the combination of triclopyr + endothall (Table 3.2). Eurasian watermilfoil was observed at 63% of sample points during the pretreatment survey and 9% of survey points during the post treatment survey; an 86% reduction in occurrence. The locations of Eurasian watermilfoil 7 WAT were primarily on upstream end of the plot, one point in the center of the plot, and one point at the downstream end of the plot (Figure 3.3). This is not surprising, as the upstream end of the plot was subject to the greatest bulk water flow (there was no dye measured at the water sample stations), and a large portion of dye and herbicide had moved into the main channel prior to moving downstream in the plot. The level of efficacy in plot 8 (86%) corroborates previous CET relationships established for each herbicide applied alone (Netherland et al. 1991, Netherland and Getsinger 1992). However, in small scale research the combination of triclopyr + endothall resulted in enhanced activity and increased control of Eurasian watermilfoil at exposure times similar to the half- lives estimated for this plot (Madsen et al. 2010).

The presence of curlyleaf pondweed also significantly declined from 74% pretreatment to 3% 7 WAT (Table 3.2 and Figure 3.4). The decline is likely an effect of both the endothall applied and natural senescence of the plants in the plot. Endothall, being a contact herbicide, would have had an immediate effect on plant processes and would have killed the curlyleaf pondweed that had not already begun to senesce.

The combination of triclopyr + endothall was much less selective in plot 8, as several native species were impacted (Table 3.2). Pursuant to this, species richness, native species richness, and non-native species richness also declined 7 WAT. Although non-target injury occurred in this plot, the native macro-algae chara quickly re-colonized after the herbicide application. This initial re-establishment of native vegetation will likely resist Eurasian watermilfoil fragments from re-infesting the area. Getsinger et al. (1997) reported similar results with respect to native plant community response after herbicide application; however by 1 year after treatment, the native plant community had significantly improved when compared to pre-treatment levels.

There will be a trade-off in selectivity when using triclopyr alone versus the combination of triclopyr + endothall. Triclopyr would have likely been much less effective if applied alone in plot 8 given the estimated half- life for dye and triclopyr residues. Endothall applied alone would have likely had short term efficacy, but Eurasian watermilfoil would have started to re-grow by 4 WAT. Therefore, in areas such as plot 8, the combination of triclopyr + endothall would be the best choice for maximum control. Once the Eurasian watermilfoil has been removed, native plants can re-establish from the propagule bank.

Plot 2

The presence of plants in Plot 2 changed little from pre treatment to 7 WAT (Table 3.3). Eurasian watermilfoil was found at survey points during the post treatment survey where it was not observed during previous surveys (Figure 3.5). Therefore, the reductions observed in Eurasian watermilfoil in plots 7 and 8 can be attributed to the herbicide applications. Curlyleaf pondweed did not change between surveys (Figure 3.6). Nevertheless, a significant reduction in northern watermilfoil was observed.

Plot 4

Plot 4 was much more variable with respect to the plant community where declines were observed with flowering rush, chara, curlyleaf pondweed, and non-native species richness (Table 3.4). The variability is likely due to its location in the riverine portion of Noxon which is subject to more extreme environmental factors, most notably water flow. Still, the presence of Eurasian watermilfoil did not change from the pretreatment survey to 7 WAT (Figure 3.7), further supporting the efficacy of the herbicide applications in plots 7 and 8. The decline in curlyleaf pondweed in this plot is evidence of natural senescence and supports this explanation in the treatment plots as well (Figure 3.8).

Conclusions. Herbicide applications were effective at reducing the presence of Eurasian watermilfoil in the treated plots, 70% and 86% for plots 7 and 8 respectively. This study is further evidence that Eurasian watermilfoil control can be achieved in run of the river reservoirs when there is an understanding of water-exchange processes. Our data indicate that Eurasian watermilfoil can be selectively removed and native species will rapidly re-colonize areas once inhabited by Eurasian watermilfoil. There will likely be a trade-off in selectivity between applications of triclopyr alone versus the combination treatment. The use of triclopyr alone will not be conducive to all places in the reservoir, especially in areas of increased water-exchange; these areas will need the combination treatment to meet CET requirements. Pursuant to this, the potential short term impacts of herbicide applications on the native plant community should not overshadow the long-term effects that Eurasian watermilfoil will have if left unmanaged.

Table 3.1. Aquatic plant occurrence in plot 7 herbicide (triclopyr alone) treatment area in Noxon Rapids Reservoir, MT for pretreatment and 7 weeks after treatment in 2010. Differences between sampling events were determined at a $p < 0.05$ significance level using the McNemars test. Differences in mean species richness (± 1 SE) data were determined using a Wilcoxin Signed Rank test at $p < 0.05$ significance level.

Plant Species	Common Name	0 WAT % Occurrence	7 WAT % Occurrence	p-value
Ceratophyllum demersum	Coontail	38	44	0.63
***Chara* sp.**	Muskgrass	16	19	0.73
Elodea canadensis	Elodea	47	47	0.99
Heteranthera dubia	Water stargrass	9	6	0.65
Myriophyllum sibiricum	Northern watermilfoil	38	22	0.19
Myriophyllum spicatum	Eurasian watermilfoil	50	16	0.01
Potamogeton crispus	Curlyleaf pondweed	81	50	0.01
Potamogeton foliosus	Leafy pondweed	31	16	0.19
Potamogeton illinoensis	Illinois pondweed	0	3	0.79
Potamogeton richardsonii	Clasping-leaved pondweed	13	22	0.31
Ranunculus aquatilis	White water-buttercup	22	19	0.70
Stuckenia pectinata	Sago pondweed	59	50	0.46
Species Richness		3.8 ± 0.3	3.0 ± 0.3	0.06
Native Richness		2.6 ± 0.2	2.4 ± 0.2	0.53
Non-native Richness		1.2 ± 0.1	0.6 ± 0.1	<0.01

Table 3.2. Aquatic plant occurrence in plot 8 herbicide (triclopyr + endothall) treatment area in Noxon Rapids Reservoir, MT for pretreatment and 7 weeks after treatment in 2010. Differences between sampling events were determined at a $p < 0.05$ significance level using the McNemars test. Differences in mean species richness (± 1 SE) data were determined using a Wilcoxin Signed Rank test at $p < 0.05$ significance level.

Plant Species	**Common Name**	**0 WAT % Occurrence**	**7 WAT % Occurrence**	**p-value**
Ceratophyllum demersum	Coontail	57	37	0.14
***Chara* sp.**	Muskgrass	9	37	0.01
Elodea canadensis	Elodea	31	51	0.08
Heteranthera dubia	Water stargrass	3	3	0.99
Myriophyllum sibiricum	Northern watermilfoil	40	3	<0.01
Myriophyllum spicatum	Eurasian watermilfoil	63	9	<0.01
Potamogeton crispus	Curlyleaf pondweed	74	3	<0.01
Potamogeton foliosus	Leafy pondweed	11	0	0.04
Potamogeton illinoensis	Illinois pondweed	3	0	0.79
Potamogeton richardsonii	Clasping-leaved pondweed	31	3	<0.01
Ranunculus aquatilis	White water-buttercup	46	20	0.03
Stuckenia pectinata	Sago pondweed	40	3	<0.01
Vallisneria americana	Wildcelery	0	6	0.06
Species Richness		3.9 ± 0.3	1.7 ± 0.2	<0.01
Native Richness		2.5 ± 0.3	1.6 ± 0.2	0.02
Non-native Richness		1.3 ± 0.1	0.1 ± 0.1	<0.01

Table 3.3. Aquatic plant occurrence in plot 2 reference area in Noxon Rapids Reservoir, MT for pretreatment and 7 weeks after treatment in 2010. Differences between sampling events were determined at a $p < 0.05$ significance level using the McNemars test. Differences in mean species richness (± 1 SE) data were determined using a Wilcoxin Signed Rank test at $p < 0.05$ significance level.

Plant Species	**Common Name**	**0 WAT % Occurrence**	**7 WAT % Occurrence**	**p-value**
Ceratophyllum demersum	Coontail	61	53	0.40
***Chara* sp.**	Muskgrass	6	14	0.17
Elodea canadensis	Elodea	50	75	0.02
Heteranthera dubia	Water stargrass	11	8	0.71
Myriophyllum sibiricum	Northern watermilfoil	11	0	<0.01
Myriophyllum spicatum	Eurasian watermilfoil	67	80	0.20
Potamogeton crispus	Curlyleaf pondweed	75	61	0.22
Potamogeton foliosus	Leafy pondweed	31	22	0.36
Potamogeton illinoensis	Illinois pondweed	17	14	0.71
Potamogeton praelongus	Whitestem pondweed	3	3	0.99
Potamogeton richardsonii	Clasping-leaved pondweed	31	17	0.17
Ranunculus aquatilis	White water-buttercup	6	6	0.99
Stuckenia pectinata	Sago pondweed	31	58	0.01
Species Richness		3.9 ± 0.3	4.1 ± 0.3	0.80
Native Richness		2.6 ± 0.2	2.7 ± 0.2	0.65
Non-native Richness		1.4 ± 0.1	1.4 ± 0.1	0.98

Table 3.4. Aquatic plant occurrence in plot 4 reference area in Noxon Rapids Reservoir, MT for pretreatment and 7 weeks after treatment in 2010. Differences between sampling events were determined at a $p < 0.05$ significance level using the McNemars test. Differences in mean species richness (± 1 SE) data were determined using a Wilcoxin Signed Rank test at $p < 0.05$ significance level.

Plant Species	**Common Name**	**0 WAT % Occurrence**	**7 WAT % Occurrence**	**p-value**
Butomus umbellatus	Flowering rush	7	0	<0.01
Ceratophyllum demersum	Coontail	50	67	0.16
***Chara* sp.**	Muskgrass	7	0	<0.01
Elodea canadensis	Elodea	30	40	0.36
Heteranthera dubia	Water stargrass	3	10	0.31
Myriophyllum sibiricum	Northern watermilfoil	33	40	0.63
Myriophyllum spicatum	Eurasian watermilfoil	30	27	0.76
Nitella sp.	Nitella	0	13	<0.01
Potamogeton crispus	Curlyleaf pondweed	46	3	<0.01
Potamogeton foliosus	Leafy pondweed	13	30	0.09
Potamogeton illinoensis	Illinois pondweed	3	0	0.81
Potamogeton richardsonii	Clasping-leaved pondweed	20	10	0.31
Ranunculus aquatilis	White water-buttercup	20	10	0.17
Stuckenia pectinata	Sago pondweed	23	17	0.52
Species Richness		2.7 ± 0.4	2.7 ± 0.3	0.84
Native Richness		2.0 ± 0.3	2.3 ± 0.3	0.49
Non-native Richness		0.8 ± 0.1	0.3 ± 0.1	<0.01

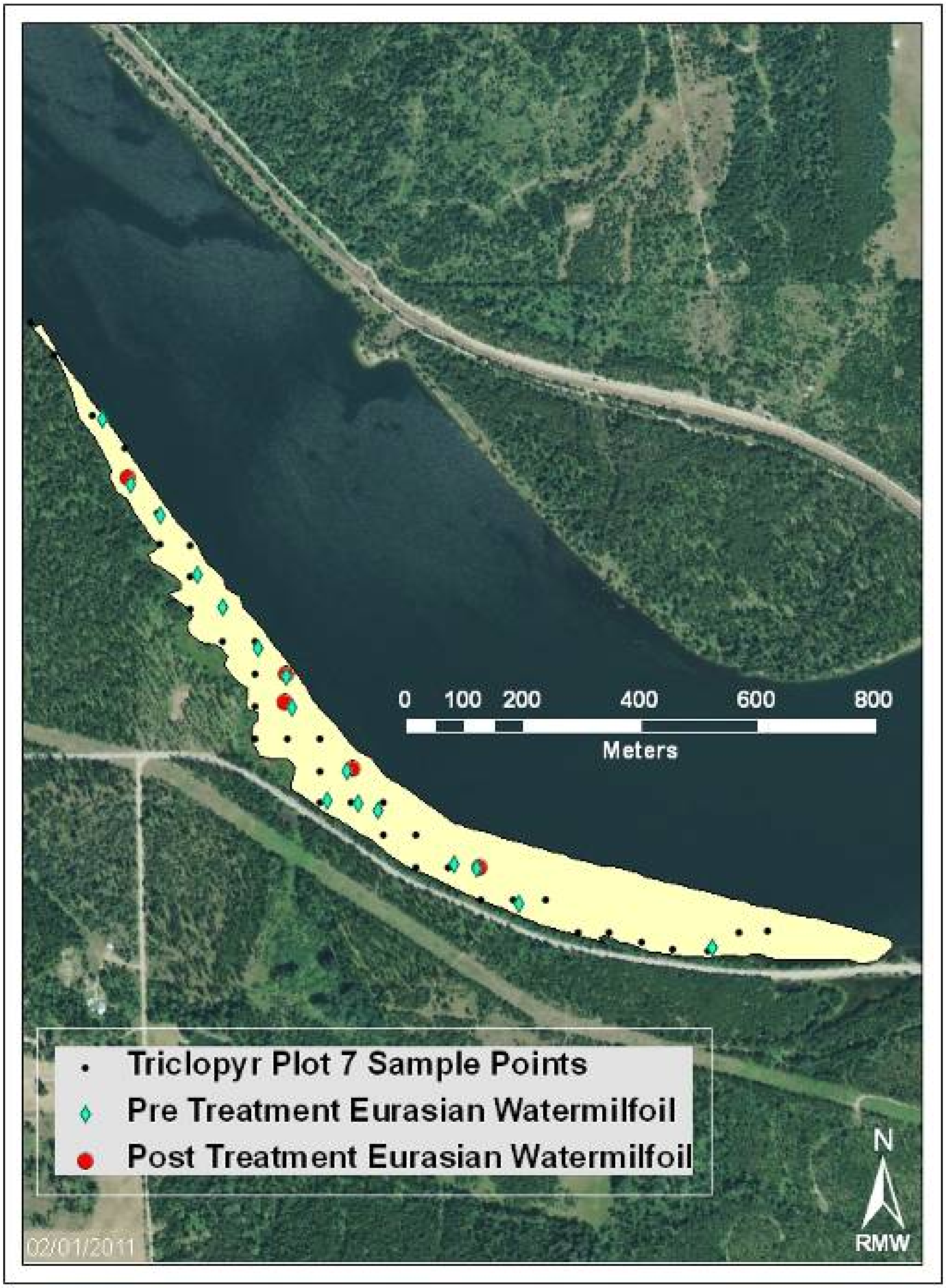

Figure 3.1. Pre and post treatment locations of Eurasian watermilfoil in plot 7 which received an application of triclopyr alone.

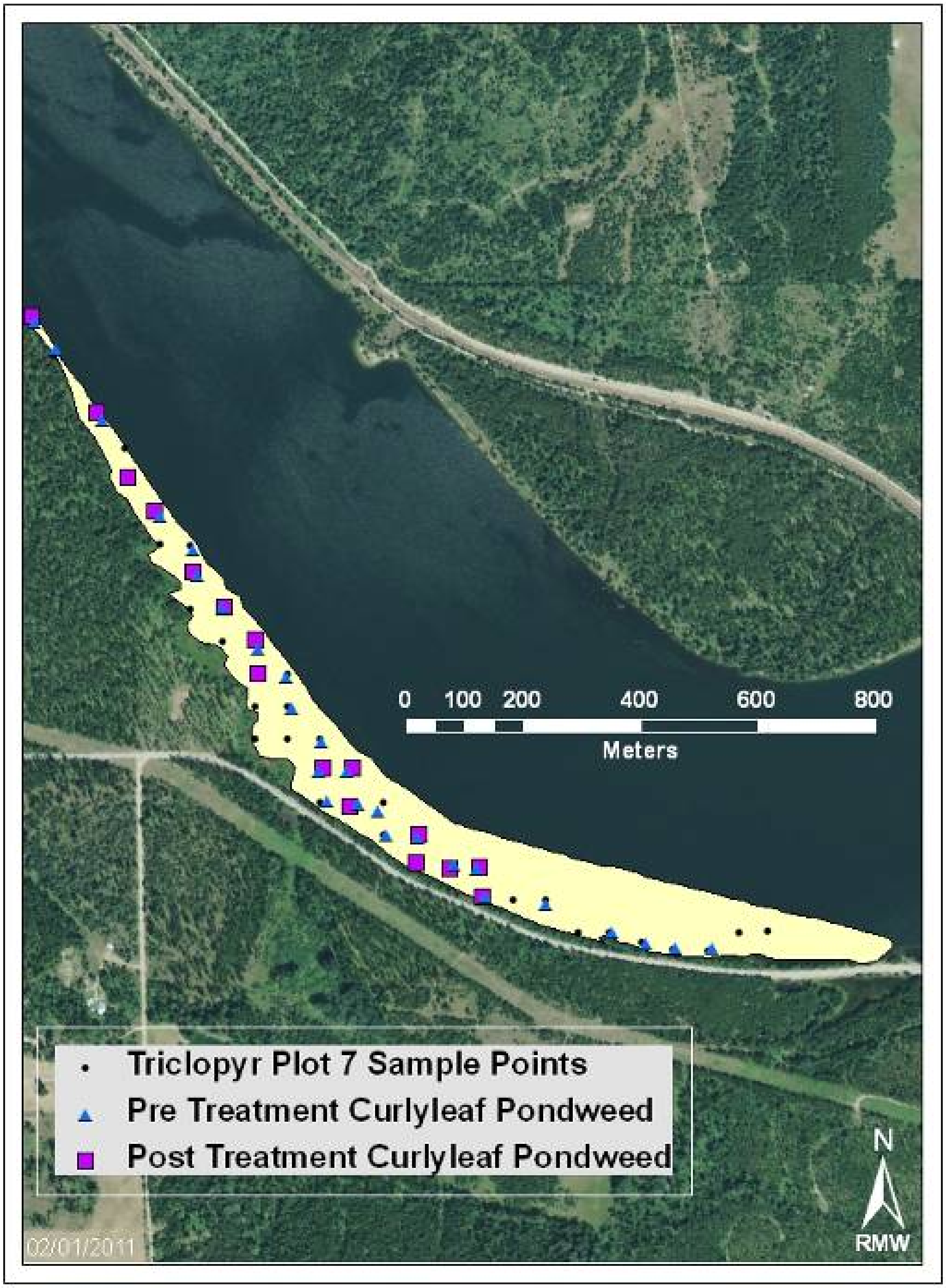

Figure 3.2. Pre and post treatment locations of curlyleaf pondweed in plot 7 which received an application of triclopyr alone.

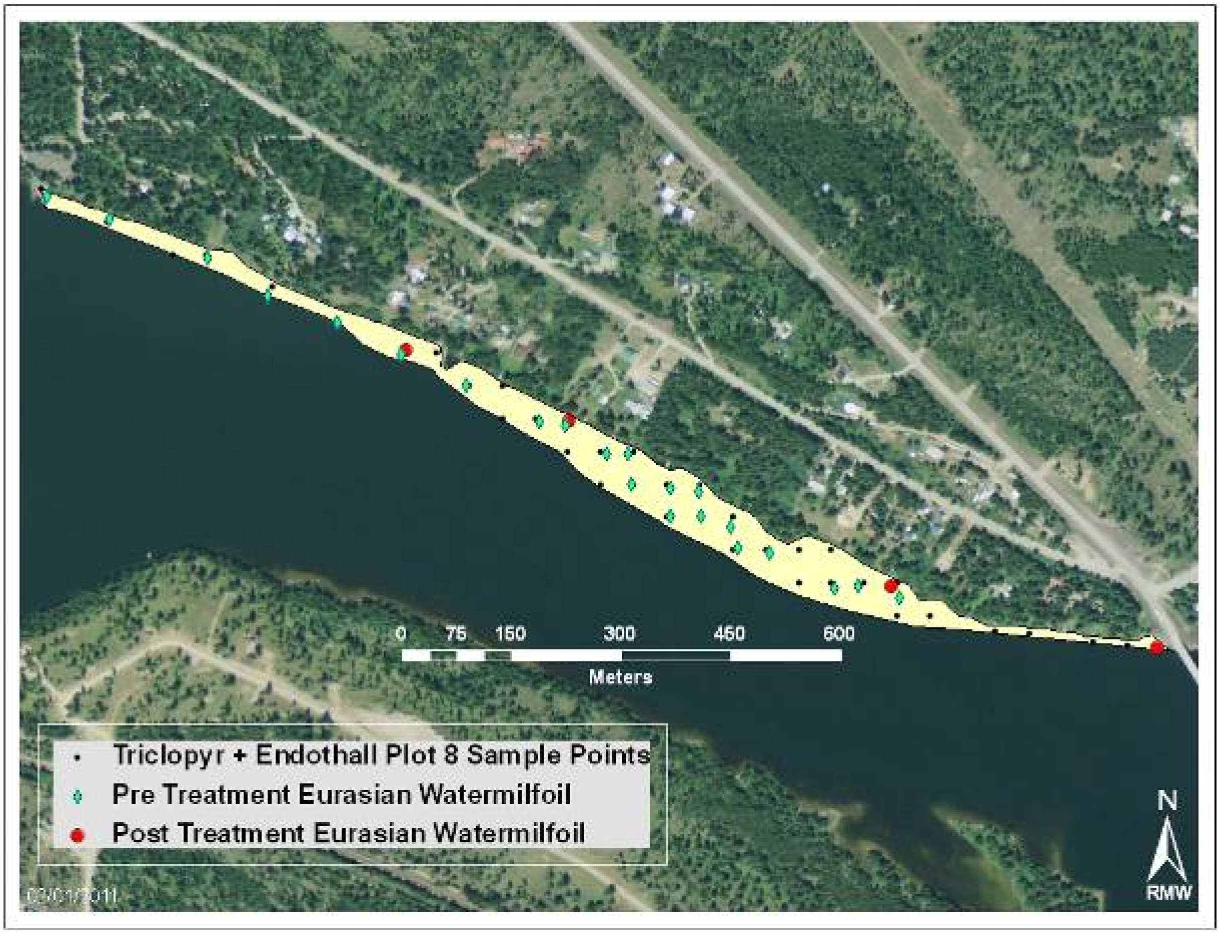

Figure 3.3. Pre and post treatment locations of Eurasian watermilfoil in plot 8 which received an application of triclopyr + endothall.

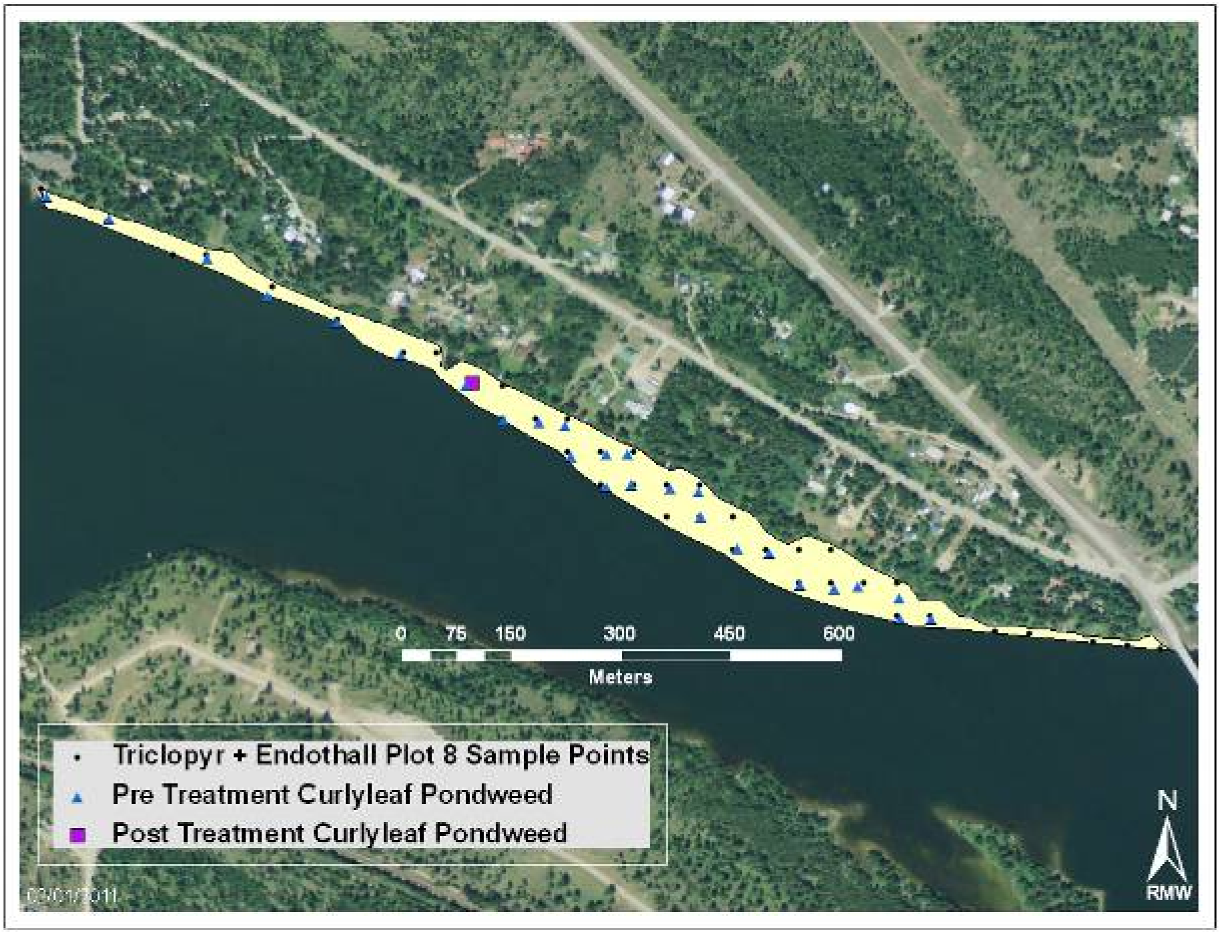

Figure 3.4. Pre and post treatment locations of curlyleaf pondweed in plot 8 which received an application of triclopyr + endothall.

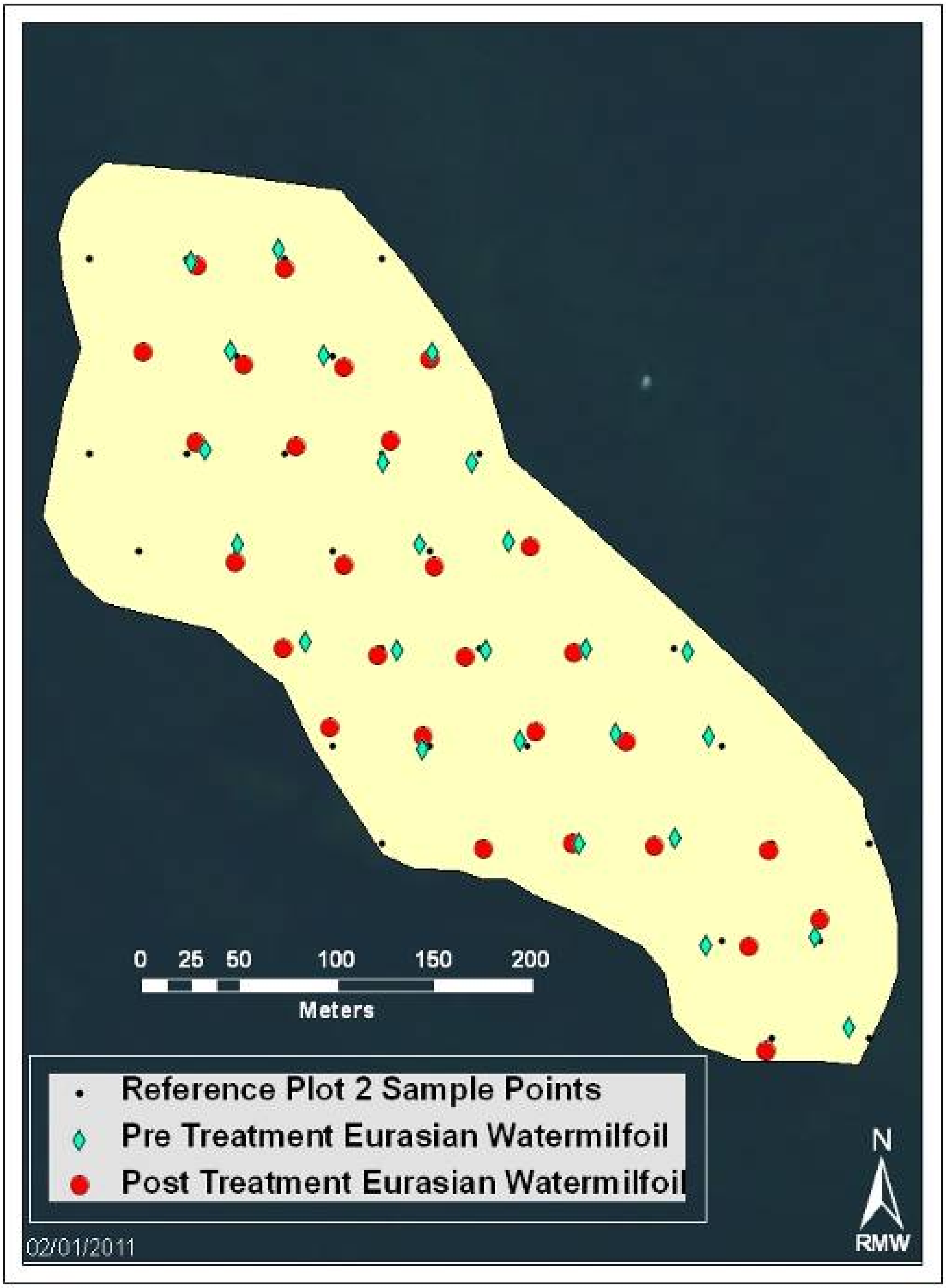

Figure 3.5. Pre and post treatment locations of Eurasian watermilfoil in plot 2 an untreated reference plot.

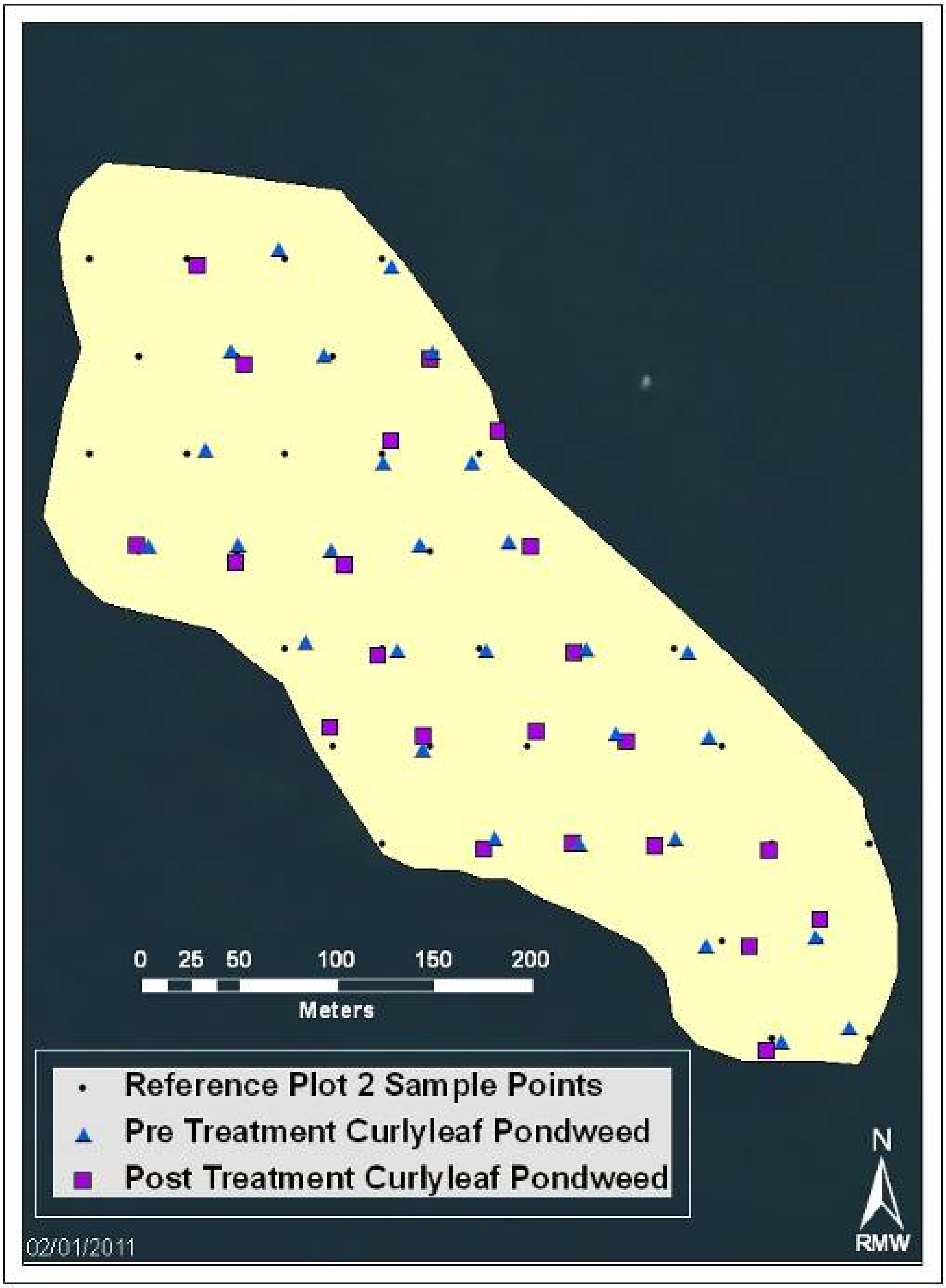

Figure 3.6. Pre and post treatment locations of curlyleaf pondweed in plot 2 an untreated reference plot.

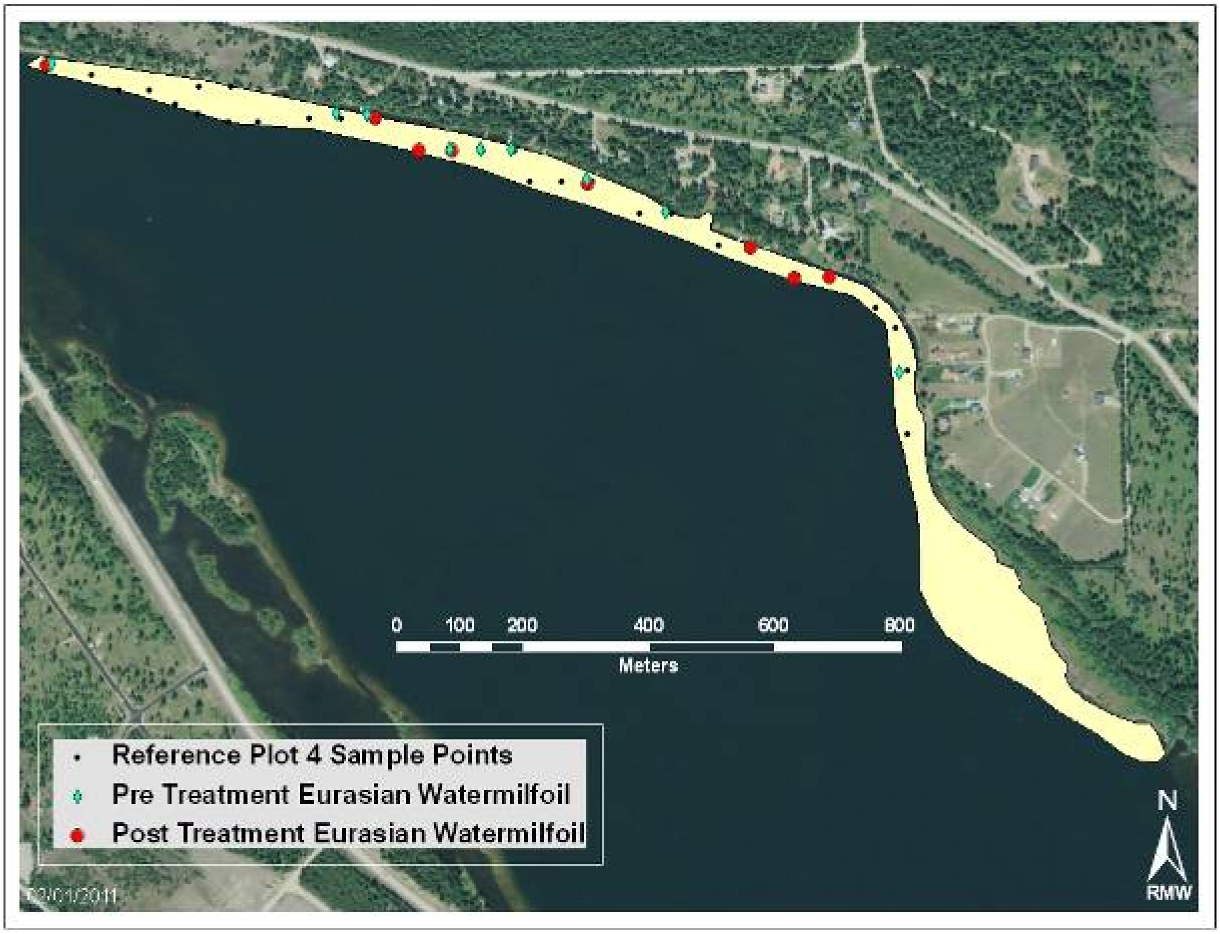

Figure 3.7. Pre and post treatment locations of Eurasian watermilfoil in plot 4 an untreated reference plot.

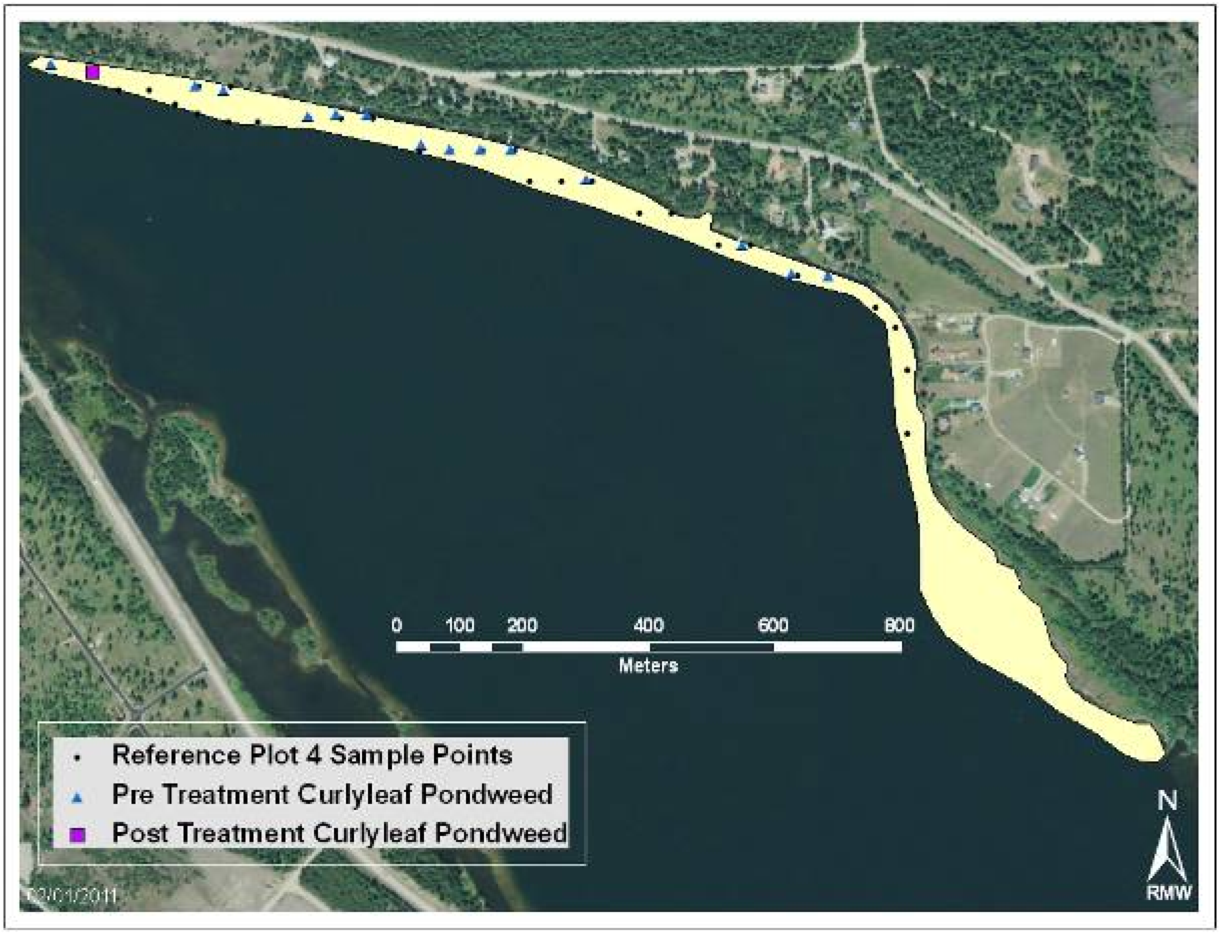

Figure 3.8. Pre and post treatment locations of curlyleaf pondweed in plot 4 an untreated reference plot.

Chapter 4

Conclusions and Recommendations

- Daily reservoir discharge patterns will impact bulk water-exchange half-lives and/or water movement within submersed plant stands.

- 70-86% control of Eurasian watermilfoil can be achieved under normal reservoir discharge patterns using triclopyr alone or triclopyr + endothall given half- lives of 12 to 22 hours.

- Injection of herbicides using the variable-depth application technique resulted in placement of product in the lower levels of the water column. This type of precision application could provide better contact of herbicides with target plants. Increased contact could potentially provide acceptable control while allowing for reduced levels of herbicides to be used, because the plant stands are treated rather than treating the entire water column.

- In this study, effective concentrations for the combination treatment were reduced (1 ppm triclopyr + 2 ppm endothall) from applications made in 2009 (1.8 ppm triclopyr + 2.5 ppm endothall in plot 1), while still maintaining similar Eurasian watermilfoil control.

- Although the use of triclopyr alone was effective, higher concentrations were needed to meet CET requirements.

- The use of triclopyr alone resulted in greater selectivity with respect to the combination treatment.

- Applying triclopyr alone will be site specific and only effective in areas with reduced water-exchange. Therefore, this treatment may have limited utility in Noxon.

- The combination of triclopyr + endothall resulted in greater control of Eurasian watermilfoil, though this treatment is less selective than triclopyr alone.

- In areas of high water-exchange, it will be necessary to use the combination treatment to meet CET requirements and maintain acceptable Eurasian watermilfoil control.

- The potential short term impacts of herbicide applications on the native plant community should not overshadow the long-term effects that Eurasian watermilfoil and curlyleaf pondweed will have if left unmanaged. There is a native propagule bank that will re-establish vegetation after management strategies have been implemented and the non-native plants removed.

- Although there was some limited herbicide effects on curlyleaf pondweed in plot 8, much of the declines observed were due to natural senescence. To effectively address the growing curlyleaf pondweed population in Noxon, research needs to be conducted to establish its life history characteristics; particularly when senescence begins in the summer and when turion sprouting begins in the fall.

- Once the life history has been documented, management can target the times of turion sprouting, most likely in the fall, which corresponds to times of reduced water flow.

- Other optimal times to manage curlyleaf pondweed would be earlier in the season prior to turion formation; however in Noxon, this usually corresponds to increased water flow in the spring of the year.

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