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Aquatic Plant Control Research Program

Development of an Automated Digital System for Delivery of Aquatic Herbicides

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Environmental Laboratory

Development of an Automated Digital System for Delivery of Aquatic Herbicides

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Abstract

The National Pollutant Discharge Elimination System (NPDES) requires that aquatic herbicide applicators revise treatment strategies to achieve high precision delivery of products and detailed reporting of treatments. A unique three-dimensional (3-D) technology was developed to meet these requirements using a new system that accounts for depth variation within a treatment area. Adaptations to a 3-D aquatic environment must account for variable depth, boat speed, difficult to see treatment plot boundaries, prevention of overtreatment by unintended crossing of treatment lines, and effects of horizontal and vertical dilution of the applied chemical. A test was conducted in Lake Underhill, FL, during which dye was delivered by the new system using the existing techniques and using the new 3-D technique. Results showed that a computer could automate a liquid herbicide treatment process and account for depth variations within a plot. Testing of the delivery system was a successful phase in developing and refining precision application techniques for submersed aquatic herbicide applications.

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Preface

This study was conducted for the Aquatic Plant Control Research Program (APCRP) under project number 96X3122. The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE). The technical monitor was Dr. Linda Nelson.

The work was performed by the Aquatic Ecology and Invasive Species Branch (EEA), Ecosystem Evaluation and Engineering Division (EE), U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Dr. Tim E. Lewis was Chief, CEERD-EEA; Mr. Mark D. Farr was Chief, CEERD-EE; and Dr. Alfred Cofrancesco, CEERD-EZT was the Technical Director. The Deputy Director of ERDC-EL was Dr. Jack E. Davis and the Director was Dr. Ilker R. Adiguzel.

The authors acknowledge the contributions of Mr. Dean Jones, University of Florida Center for Aquatic and Invasive Plants for field assistance. Dye applications were conducted by the Florida Fish and Wildlife Conservation Commission. Technical reviews of this report were provided by Dr. Christopher Mudge, EEA, and Dr. Bradley Sartain, Louisiana State University. This report is dedicated to our colleague, Dr. Mike Netherland.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
acre-feet	1,233.5	cubic meters
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
hectares	1.0 E+04	square meters
inches	0.0254	meters
miles per hour	0.44704	meters per second
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

Acronyms and Abbreviations

Acronym	Meaning
ac	acre
APCRP	Aquatic Plant Control Research Program
AR	Application Rate
DoD	Department of Defense
EE	Ecosystem Evaluation and Engineering Division
EEA	Aquatic Ecology and Invasive Species Branch
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
ft	feet
g	gallon
GIS	Geographic Information System
GPS	Global Positioning System
ha	hectares
HQUSACE	Headquarters, U.S. Army Corps of Engineers
kph	kilometers per hour
L	Liter
m	meters
MT	MicroTrak
mph	miles per hour
NOAA	National Oceanic and Atmospheric Administration
NPEDS	National Pollutant Discharge Elimination System
ppb	parts per billion
PC	Personal Computer
RWT	rhodamine WT
USACE	U.S. Army Corps of Engineers
USEPA	U.S Environmental Protection Agency
2-D	two-dimensional
3-D	three-dimensional

1 Introduction

1.1 Background

The practice of chemically treating nuisance aquatic vegetation has been altered by the U.S Environmental Protection Agency's (USEPA) National Pollutant Discharge Elimination System (NPDES) which requires that applicators achieve a much more precise manner of herbicide delivery than in the past. Further, detailed reporting of all applications is mandated to preserve public records of treatment events. In addition, developing precise delivery techniques for area-specific applications, with the goal of using less herbicides, reducing toxicity to non-target organisms, and refining species-selective control of target plants, has been recognized as an important factor to improve herbicide use for management of submersed plants (Getsinger et al. 2008). To accommodate these new requirements and challenges, advanced practitioners in the field of aquatic herbicide application have adapted chemical application technologies developed for agricultural field settings. Crop protection chemicals are applied to agricultural lands on a two-dimensional (2-D) area basis in units of volume (or mass) of active ingredient per unit area (i.e., liters or kilograms per hectare (gallons or pounds per acre)). This controller system automatically adjusts area application rate based on tractor speed, measured by global positioning system (GPS) data, and swath width of treatment (set by operator). Further, spatial databases, generated externally and GPS positioning data are used by the controller system to apply the exact amount of chemical required to a precise location (aka precision application). This precision application process reduces the amount of chemical product used, consequently reducing application costs and environmental impacts.

1.2 Objectives

The overall objectives of this effort was to develop, test, and demonstrate an enhanced automated digital control system for precise application of herbicides to control submersed vegetation. Three phases of work were identified and included the following objectives:

- Phase 1: develop and verify testing of a prototype control system,

- Phase 2: conduct a field validation study involving the simulation of a liquid herbicide application using an inert water-tracing dye,
- Phase 3: field test a fully operational herbicide treatment with aqueous residue monitoring and evaluation of efficacy against target vegetation.

Phase 1 of the work has been completed and is documented in Appendix A. This report documents Phase 2 of the overall effort and includes a description of the equipment tested, the field test site and conditions, the design of the herbicide simulation (dye release) test, and analyses of results.

1.3 Approach

The 2-D agricultural-based precision application method is a good starting point for improving the precision of submersed aquatic applications, but it does not account for the unique challenges of a 3 dimensional (3-D) submersed aquatic environment. These challenges include the following: (a) Target application rates are specified as aqueous concentrations (mass or volume ingredient per unit volume), therefore, local depth and surface area must be taken into account, (b) treatment plot boundaries may not be as obvious as they would for terrestrial field applications, (c) effects of a fluid medium (water), causing dilution, must be considered, (d) to ensure products are applied evenly and efficiently on treatment areas, the operator must completely cover the designated area minimizing gaps or double treatment, and (e) the operator must alter the application rate to account for depth, and cycle the product dispenser on and off based on plot boundary crossings (application tracks). Overcoming these challenges is a substantial task load for even an experienced operator and opportunities for errors are plentiful, especially when striving for precision application. Therefore, enhancement of an automated control system for 3-D precision applications into water was identified as an area needing further technology development.

1.4 Scope

Active acoustic signals collected from a boat-based echosounder can be digitally processed to characterize the canopy geometry and general density of submersed vegetation. This was first demonstrated using a calibrated scientific-grade echosounder (Sabol et al. 2002, 2009), and more recently, using a low-cost uncalibrated echosounder (Sabol 2014). In both cases, data is stored on a digital media and processed later on a personal computer (PC) in the lab or office in a non-real-time processing mode. A recent review of this technology indicates that it would be possible to develop a real-time processor. It has further been demonstrated that processed maps of submersed vegetation data can be used to control the dispersal rates within the water column of a liquid-based herbicide dispensing system (Getsinger et al. 2013). These breakthroughs represent a significant advancement in the efficiency of performing both submersed vegetation detection/mapping and herbicide application functions. This study determined that it is feasible to link these technologies to develop a system capable of metering spatially explicit herbicide dosing based on submersed vegetation attributes determined either in real-time, or by accessing historical geographic information system (GIS) based maps. Real-time precision application will improve control over more traditional techniques. Benefits provided to operational control practices would include the following: (a) reduce operator error due to automation, (b) improve application of herbicides based on lake morphometry, (c) maximize herbicide application to target plant stands, (d) minimize non-target herbicide application outside of defined treatment area, (e) use less herbicide at a cost savings, and (f) enhance digital documentation of actual herbicide applications that can be used for NPDES reporting requirements.

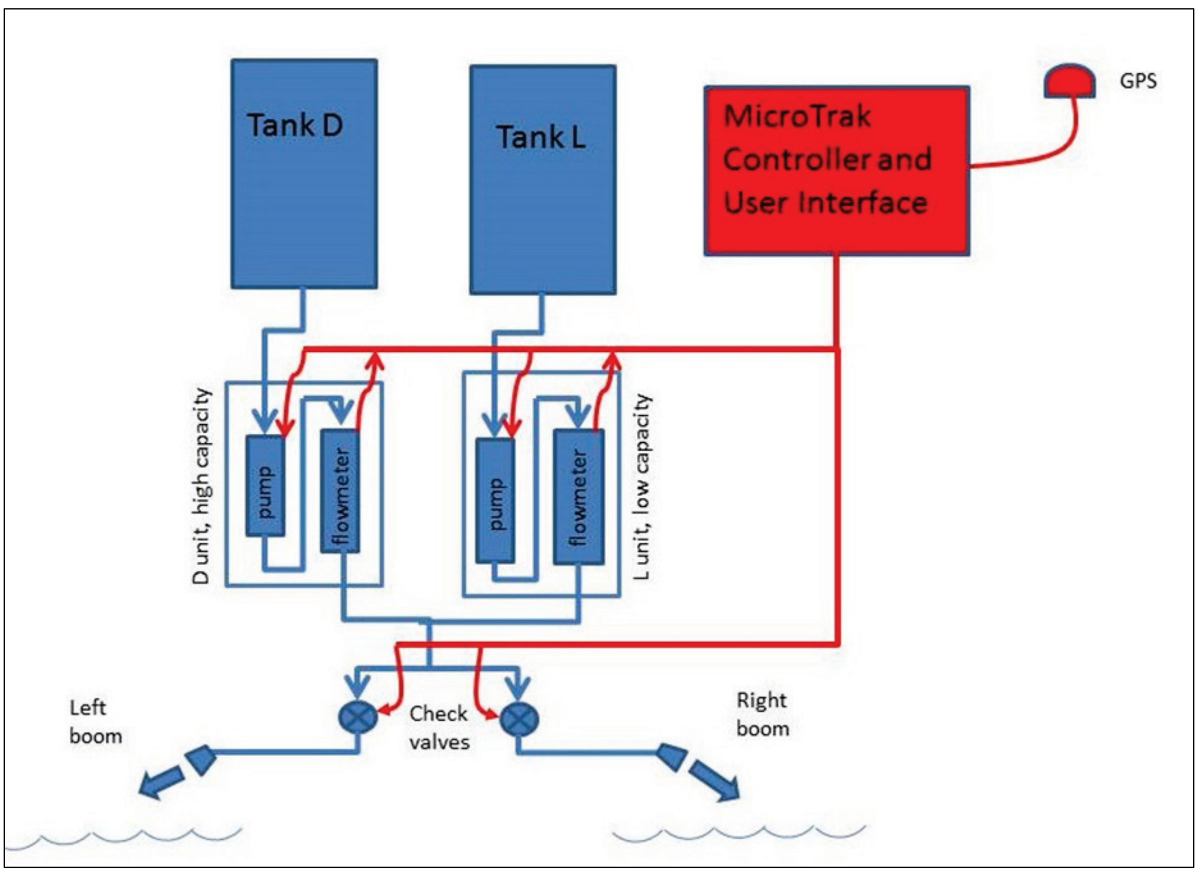
2 Materials and Methods

2.1 System description and functions

The overall application system was integrated into a chemical delivery boat (Figure 1). Basic components and control of the MicroTrak (MT) system (MT-3405D Dual Control Automatic Controller, MicroTrak Systems, Inc., Eagle Lake, MN) are illustrated in Figure 2. Two separate units (referred to as loops) are controlled by the MT computer (controller), this enables different chemicals to be simultaneously used in each loop if needed and each pump can operate at an independent rate. Each tank feeds a separate sealed box containing a dosing pump and an ionizing flowmeter. Discharge of each box enters a single conduit and then the flow is directed to two check (on/off) valves, one for each of the two delivery nozzles, allowing each nozzle to be turned on and off independently. The user interfaces with the MT control panel to set target application rate (AR) in liters/hectares (ha) (gallons/acre), and select appropriate boom width (defined as the width, perpendicular to the boat path, that is treated). The MT computer uses a GPS to determine boat speed. Boat speed, boom width, and AR are used to compute target pump flow rate (volume/time), which is sent, using system command code, to each loop-specific pump. The flowmeter within each unit box reports the resulting flow rate back to the controller which then computes the actual AR. The computer also drives the check valves which can be instantly turned on or off. System time and status data are written to a file to document the application.

Figure 1. Dye application boat outfitted with digital delivery system, Lake Underhill, FL, February 2016.

Figure 2. Mechanical and electronic control of existing MT system. Blue indicates mechanical components and red indicates electronic components and control.



The added hardware for the 3-D enhancement of the system consists of a quad-core automotive fanless Engineer Research and Development Center (ERDC)-PC (also referred to as ERDC computer or PC) connected to the system GPS and the MT computer. This added PC sends enhanced data to the MT computer to execute delivery of the herbicide. The user (herbicide applicator and/or boat operator) enters needed data files and control parameters for the operation. A simplified version of the enhanced control and data management structure is illustrated in Figure 3. The user must specify target concentration and boom width. The PC queries the GPS for position which is then used to determine depth (using gridded data input from an earlier survey, Appendix B) and whether the boat is inside or outside of the treatment area (also from input gridded data). Target concentration is then multiplied by depth to get target AR liters/ha (gallons/acre) and checked to verify that computed AR is within prescribed set limits. The target AR is then sent to the MT computer which then runs in its normal 2-D mode. The MT computer queries the GPS and computes boat speed. Target flow rate is then computed (target AR x speed x boom width) and sent, via system command code to the pump and check valve. The flowmeter reports back to the MT computer which then computes actual AR. The data packet of status variables is collected from the MT computer by the PC which then writes an output file. All system functions are listed in Table 1. An output file is written to the hard drive and the calculated or “painted” treatment area map is only in random access memory (RAM) storage and is not archived (see Appendix D).

Figure 3. Electronic control, computations, and data management of entire 3-D system with PC enhancements.

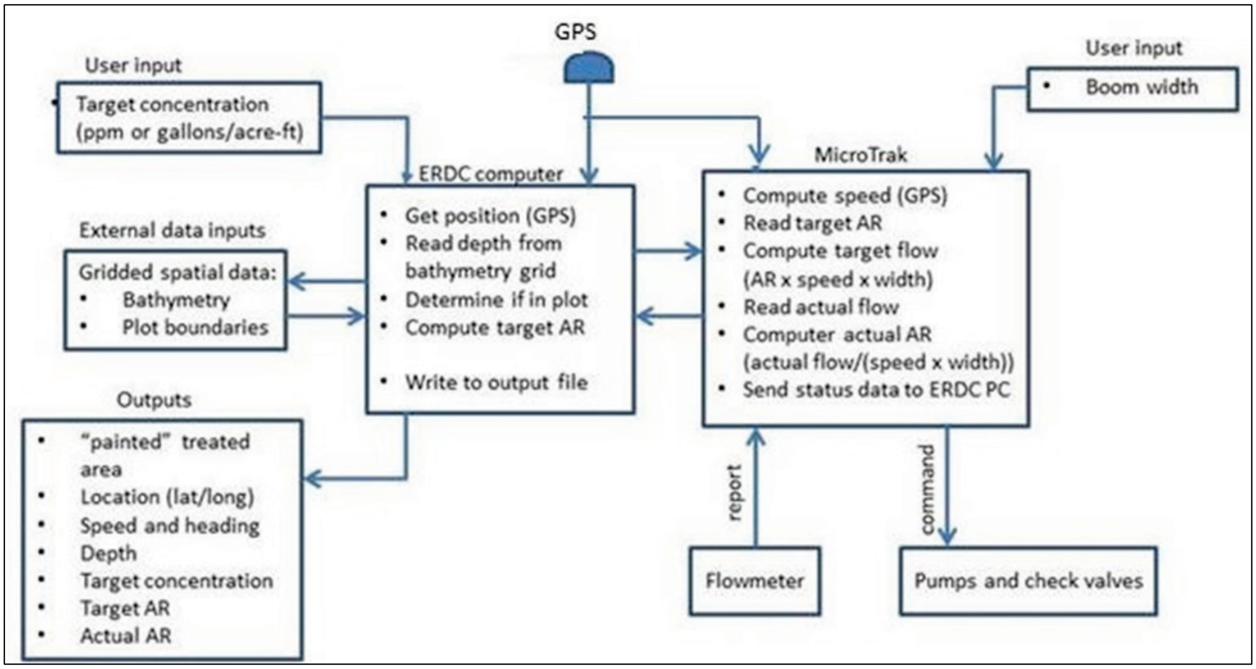


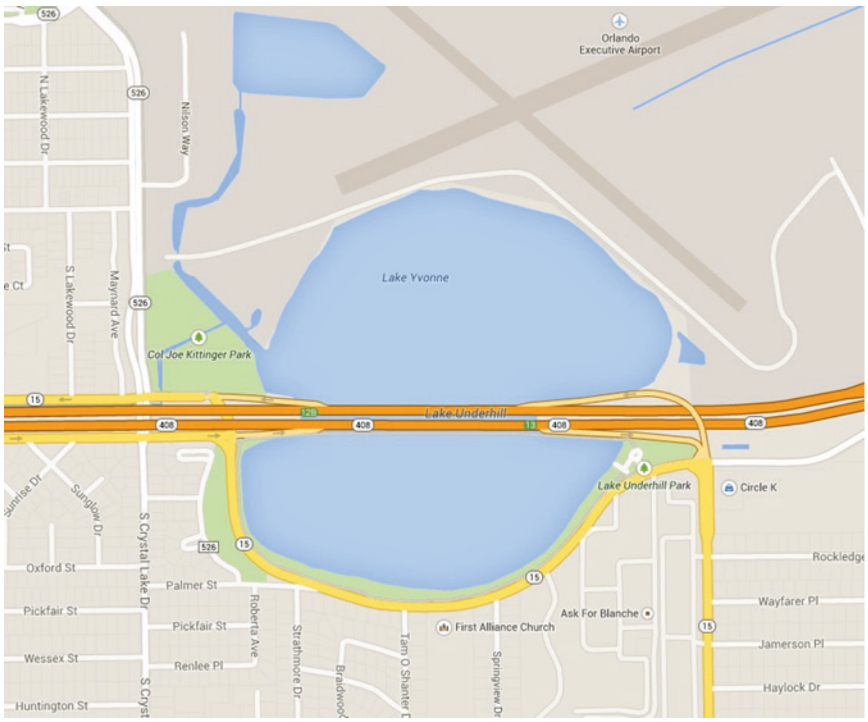
Table 1. Functionality list of 3-D automated treatment system.

Function #	Function description	MT controller	ERDC PC
1	Compute speed (MT GPS)	X	
2	User input boom width		X
3	Compute current AR for use by MT		X
4	Compute current required flow rate (=AR x boom width x speed)	X	
5	Read actual flow rate and compute actual AR (report to PC)	X	
6	Read GPS string (Lowrance or GPS)		X
7	Determine current depth (from external gridded data)		X
8	Determine whether current location is in plot from external gridded plot boundary file		X
9	Compute current target AR (=target concentration x depth x in-plot factor)		X
10	Request current status from MicroTrak, store data		X
11	Paint area treated graphic		X

2.2 Site description and test conditions

Lake Underhill was selected as the site for the aquatic herbicide simulation test using the liquid fluorescent tracer dye, rhodamine WT (RWT). This inert dye has been correlated with dissipation of many commonly used aquatic herbicides (Fox et al. 1992, 1993, 2002; Turner et al. 1994). The lake is a 59 ha (147 acre) circular urban water body (Figure 4) east of Orlando, FL. The lake is bisected east and west by two separate low-span bridges for State Highway 408, and is bounded on the north by the Orlando Executive Airport. The southern half of the lake is surrounded by Lake Underhill Park, with a boat launch and dock on the east side.

Figure 4. The dye test site was located on 59-ha (147-acre) Lake Underhill near Orlando, FL.



As part of data support for testing, an acoustic-based bathymetric survey was conducted on 24 and 25 September 2014 and is documented in Appendix B. Results of this survey (Figure 5) show a lake morphometry that is characteristic of a bowl-shaped depression with a broad flat bottom reaching a depth of around 6 meters (m) (20 feet (ft)). The shoreline depths fall off rapidly typically reaching levels of 1.5–1.8 m (5-6 ft) a short distance from shore. Numerous deep holes were found near the shoreline, particularly along the northern shore. These holes are borrow areas used to build up the lake shore near the airport. Lake levels were recorded from a staff gage installed along the northern shore adjoining the airport. Lake level during the 2014 bathymetric survey was 0.64 m (2.09 ft). Lake level during the February 2016 dye application study was 0.82 m (2.70 ft), 0.18 m (0.59 ft) higher than during the earlier bathymetric survey. This difference was not automatically accounted for in the processing software, but all depth and volume calculations reported in this document do take this difference into account. Three 0.4 ha (~1 ac) plots, spatially separated by a distance of 500–700 m (1600–2300 ft), were selected for the dye study (Figure 5). Characteristics of these plots are summarized in Table 2.

Figure 5. Depth (m) contour map in latitude and longitude coordinates in NAD 83, based on 24 and 25 September 2014 survey, and lake level for Lake Underhill, FL. Three dye treatment plot boundaries and designations are indicated as rectangles with a surface area of 0.4 ha (1 ac) each. Plot separation distances are approximately 500–700 m (1600–2300 ft).

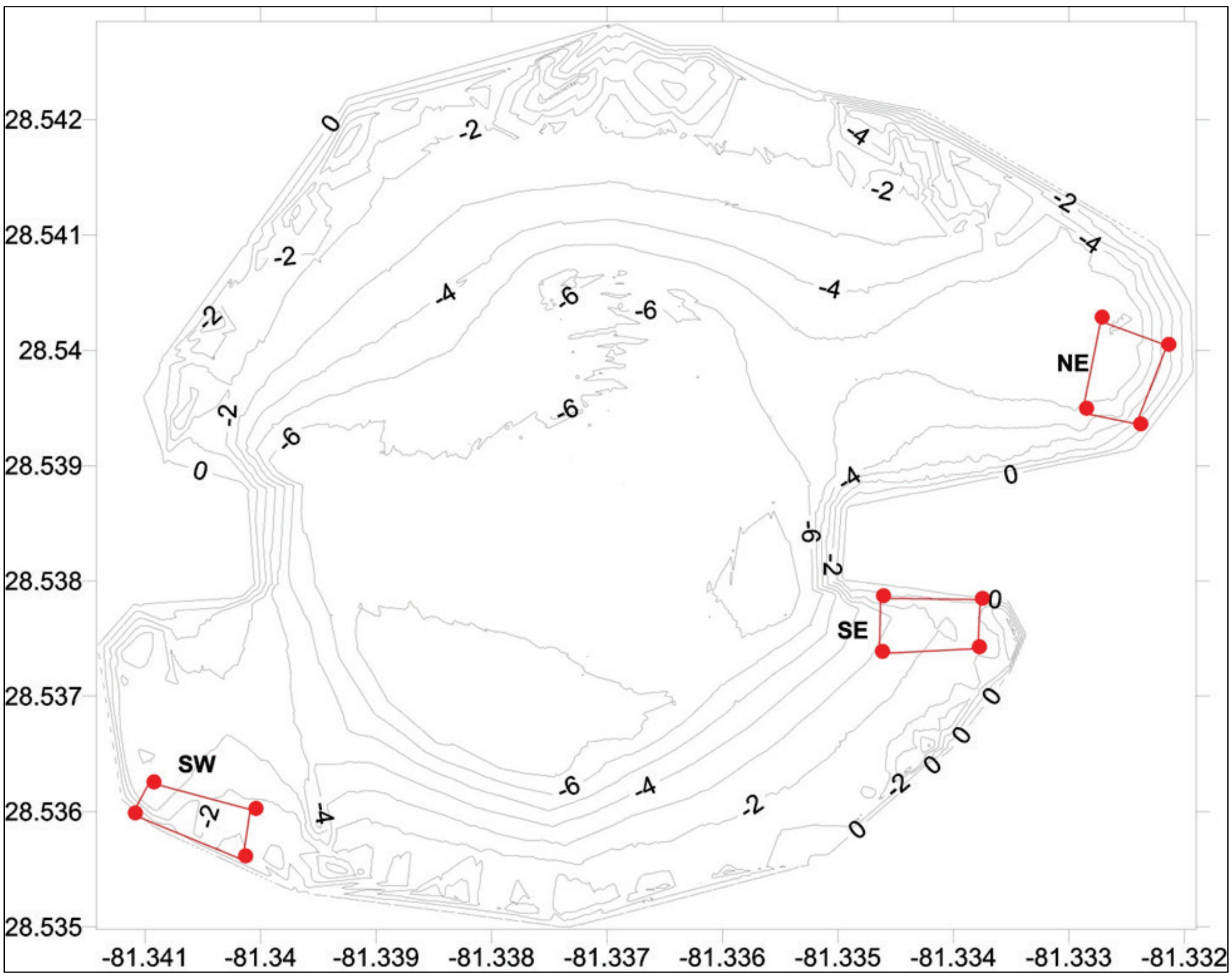


Table 2. Characteristics of treatment plots – volumes and depths are corrected to 9 February 2016 lake level.

Plot	Area ha (ac)	Volume m^3 (acre-ft)	Depth m (ft)		
			Mean	Minimum	Maximum
NE	0.43 (1.06)	21,709 (17.6)	5.1 (16.6)	2.4 (7.8)	6.2 (20.4)
SE	0.46 (1.10)	9,374 (7.6)	2.1 (6.9)	0.5 (1.5)	3.4 (11.2)
SW	0.42 (1.04)	9,251 (7.5)	2.2 (7.2)	1.4 (4.7)	3.9 (12.8)

A National Oceanic and Atmospheric Administration (NOAA) station at nearby Orlando Executive Airport collected hourly weather data (wind and temperature) during the test period (Appendix C). Skies were clear during the entire test period. During 9 and 10 February, winds were brisk at 24–32 kilometers per hour (kph) (15–20 miles per hour (mph)), gusting to 56 kph (35 mph), and generally from the west. However, on 11 February the wind was calm.

Immediately prior to the first dye application on 10 February, a thermal depth profile was taken near the center of the lake (Figure 7) at 1 m (3 ft) depth increments. All measurements from surface to the bottom at 6 m (20 ft) were within 0.2 ° of 12 °C, indicating isothermal conditions throughout the water column (i.e., no layers of thermal stratification that would prevent mixing of dye from surface to bottom).

2.3 Experimental design

Dye release tests were conducted in the selected plots on three consecutive days (9–11 February 2016). On 9 February, whole-plot treatments were applied with metered release of lake water only to verify proper functioning of the digital system before commencing the dye release study. After verification that the system was working correctly, based on the 9 February water release test, the three plots were subjected to two different dye delivery treatments over the next two days, one on each day (Table 3).

The dye treatments represented a comparison of a traditional 2-D submersed delivery technique and a computer enhanced 3-D submersed delivery technique. The 2-D delivery applies product (dye or herbicide) at an equal rate over the entire area of the plot, regardless of differing depths within the plot, using the mean plot depth to calculate the volume component required for a submersed application. For example, a 0.4 ha (1 acre) plot with a mean depth of 3.04 m (10 ft) might receive a very uniform application of 25 liters (L) (6.6 gallon (g)) of product to provide the desired nominal application rate. While the whole plot would receive the desired amount of product, this delivery could result in slightly overdosing areas that were shallower than the mean depth and slightly under dosing areas deeper than the mean depth. However, the computer enhanced 3-D delivery in the same plot would be dispensed at a rate proportional to the actual depth at each location, a more precise application.

Table 3. Assignment of dye treatment techniques to plots on Lake Underhill, FL, 2016.

Treatment	Day	
	10 February (windy)	11 February (calm)
2-D	NE	SE, SW
3-D	SE, SW	NE

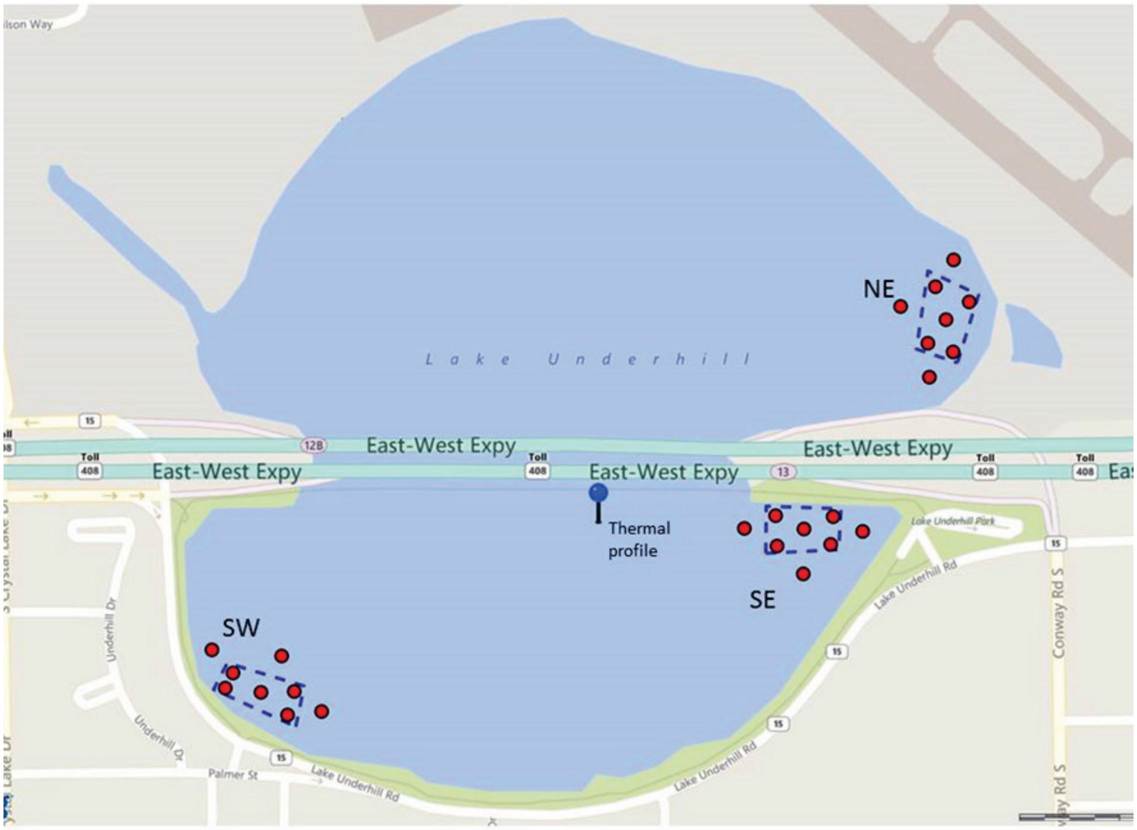
The planned delivery of dye in these tests would result in nominal aqueous concentrations of 7.7, 7.3 and 7.3 µg/L (parts per billion (ppb)) for plots NE, SE, and SW, respectively. In graphics and analysis to follow, it was assumed a nominal target concentration of 7.5 µg/L (ppb).

Dye delivery was performed from a boat (Figure 1) using two delivery hoses. Each hose was lowered into the water column on opposite sides of the stern with one slightly below the surface 0.15 m (0.5 ft) and the other at a depth of 1.5–3 m (5–10 ft). During application, boat speed was maintained at 3.2–6.4 kph (2–4 mph) with an application swath width of 7.6 m (25 ft). Delivery transects were spaced 7.6 m (25 ft) apart with the assumption that dye would uniformly mix between the application swaths, a distance of 3.8 m (12.5 ft), on either side of the boat, as shown in Figure 6.

Figure 6. Dye delivery operation in SE plot on Lake Underhill, FL, 10 February 2016. Note wind-generated waves in the plot.

An automated sampling system (Hydrolab data sondes, Ott Hydromet, Kempten, Germany), configured to measure aqueous dye concentration and water temperature, was installed in the center of each plot at mid-depth four hours before the first dye application. Measurements were taken hourly on the half hour. In addition, eight stations were established by GPS positions in each plot, five within the plot and three outside the plot (Figure 7). Each of these points was sampled hourly after treatment at depths corresponding to the midpoint of the upper half and the lower half of the water column. Measurements were made using a manually operated Turner Designs Cyclops-7 submersible fluorometer (Turner Designs, Sunnyvale, CA). Collecting the entire set of measurements within a plot took around 15 minutes, and each measurement set was taken an integer number of hours after treatment in that plot. Measurements were taken at 1, 2, 3, 5, 6, 15, and 22 hours after treatment.

Figure 7. Sampling locations for dye measurements on Lake Underhill, FL, consisting of a combination of sites sampled by hand-held instrumentation and automated instrumentation fixed at the center of each plot.



Each individual dye release treatment was designed to provide an output file of one second status records (Appendix D). All files were examined to verify that key functions of the system operated as intended. These included plot boundary cutoff, preventing retreatment, and delivery rate control. Just prior to moving the equipment to the test site, a system calibration was performed in accordance with MT procedures (MicroTrak 2012). The procedure was performed with a standard 189 L (50 g) barrel and repeated until the system delivered to within 1 percent of the target rate set.

3 Results and Discussion

3.1 System function verification

Examination of the system output files verified that design requirements were correctly implemented during the dye treatments. These findings included the following: (a) Boundary cutoff function. All treatment files showed that this function was working properly. In all cases no dye flow occurred more than approximately one meter outside of plot boundaries. (b) Delivery cutoff in treated areas exhibited the performance desired, and (c) Delivery rate control function. The 2-D mode target delivery rate L/ha (gal/ac) is set by the operator and the system should deliver that amount of agent uniformly over the plot area. The 3-D mode target delivery rate is computed by the system software based on local depth queried from the digital bathymetric database. The input (2-D) or computed (3-D) target rate directs the mechanical system to deliver that rate and the system reports that actual value. It was not expected that actual rate would always match the target rate due to inherent delays in mechanical systems. This function worked as intended. Details of the delivery process are presented below.

Table 4 shows a performance summary extracted from operational files reported from the dye tests. In all six cases, the computed actual dye concentration was within 10% of the nominal target concentration.

Table 4. Performance summary of treatment techniques extracted from output files.

	Treatment event					
	10 February 2016			11 February 2016		
	SE	SW	NE	SE	SW	NE
Treatment	3D	3D	2D	2D	2D	3D
Time to treat (min)	15.0	21.9	23.5	14.3	16.1	16.0
Measured plot area in hectare (ac)	0.44 (1.10)	0.42 (1.04)	0.43 (1.06)	0.44 (1.10)	0.42 (1.04)	0.43 (1.06)
Reported area treated in hectare (ac)	0.40 (1.0)	0.44 (1.1)	0.49 (1.2)	0.44 (1.1)	0.44 (1.1)	0.4 (1.0)
Measured plot volume m^3 (ac-ft)*	9374 (7.6)	9351 (7.5)	21709 (17.6)	9374 (7.6)	9351 (7.5)	21709 (17.6)
Planned volume dye discharge in liters (g)	26.2 (6.9)	25.7 (6.8)	64.3 (17.0)	26.2 (6.9)	25.7 (6.8)	64.3 (17.0)
Reported volume dye discharge in liters (g)	25.4 (6.7)	28.4 (7.5)	68.5 (18.1)	26.2 (6.9)	25.4 (6.7)	64.7 (7.1)
Target [dye] µg/L (ppb)	7.3	7.3	7.7	7.3	7.3	7.7
Computed actual [dye]** µg/L (ppb)	6.6	7.5	7.7	6.8	6.7	7.3

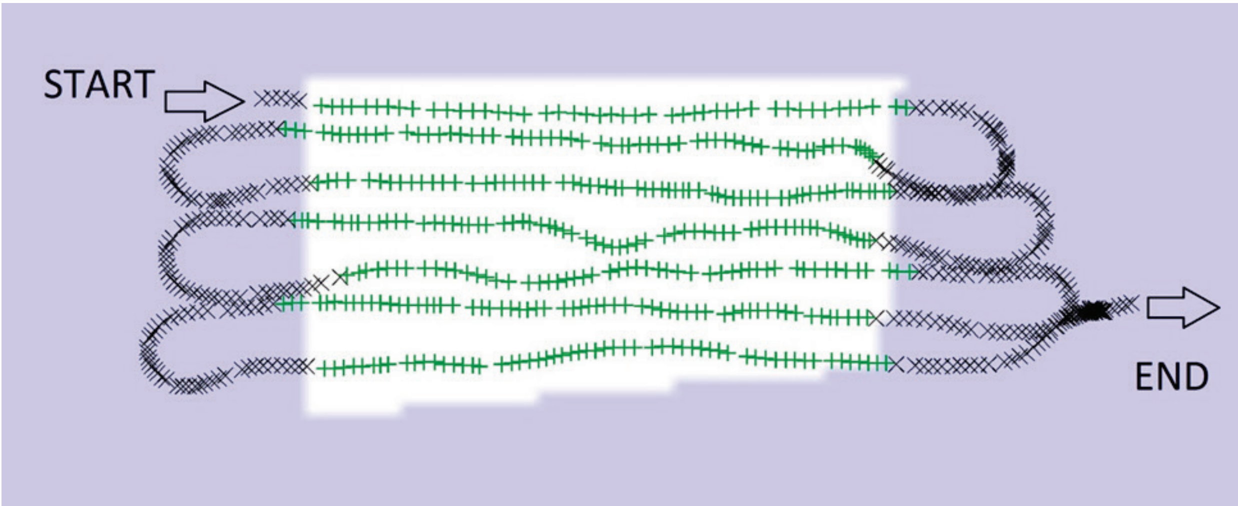
*Based on 9 February 2016 lake level 0.82 m (2.7 ft)

**Actual volume dye mixture discharged X computed [dye mixture] {2.44 ppt = target [dye] x plot volume/planned delivery volume} divided by plot volume X conversion factors.

3.2 Treatment plot boundary cutoff

The delivery system is designed to discharge (flow) product only within the boundary of a plot. This is examined graphically by plotting output positions and flow status (on/off) for all outputs in each treatment event (plot x day). In all application cases, no dye flow occurred more than a few feet outside of plot boundaries and discharge of dye always began within a few feet of entering a plot. A several-second delay in switching dye flow on or off when crossing a plot boundary is most likely the cause of a slight shift in dye flow when crossing those boundaries (Figure 8).

Figure 8. Position and dye flow (discharge) status for SE plot, Lake Underhill, FL, 11 February 2016, superimposed over treatment mask (white is within plot, purple is outside plot). Green crosses indicate dye flow, while black X's indicate no dye flow.



3.3 Delivery cutoff in treated areas

In order to conduct a precision application, the delivery system is designed to prevent retreating areas previously treated. This is implemented by cutting off dye flow after three consecutive samples within half the boom width of any previously treated location (recorded in computer random access memory). Examination of the graphic output (position vs. dye flow status) for all treatments identified cases of overlap in the treatment paths navigated. However, in all cases, the dye flow cutoff function worked as intended and overlapping treatments were avoided. Three examples are illustrated below (Figures 9–11) with circled areas indicating boat treatment path overlap.

Figure 9. Position and dye flow (discharge) status for SE plot in Lake Underhill, FL, 10 February 2016, superimposed on treatment mask (white is within plot, purple is outside plot). Green crosses indicate dye flow, while black X's indicate no dye flow. Red circled areas indicate treatment boat path overlap.

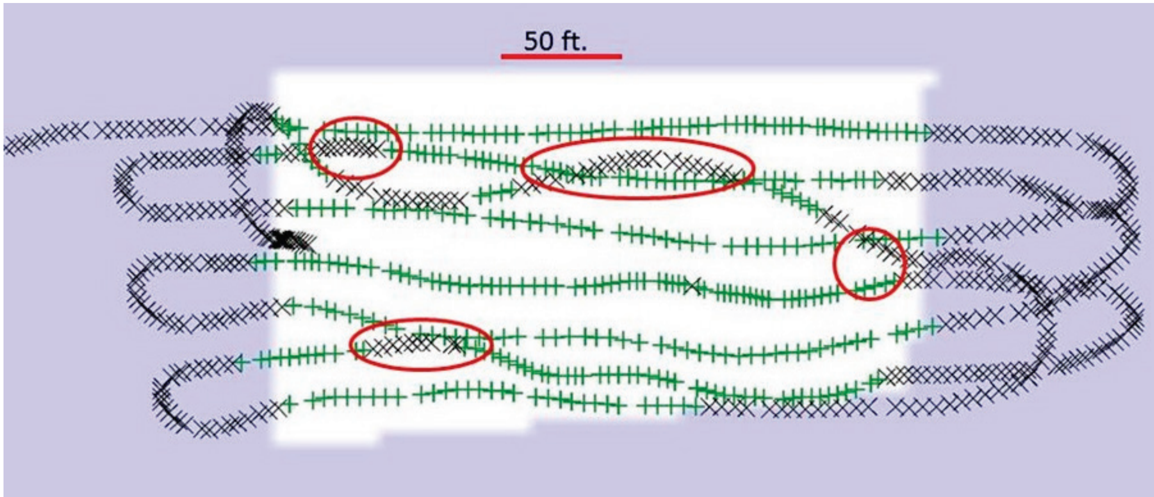


Figure 10. Position and dye flow (discharge) status for SW plot in Lake Underhill, FL, 10 February 2016, superimposed on treatment mask (white is within plot, purple is outside plot). Green crosses indicate dye flow, while black X's indicate no dye flow. Red circled areas indicate treatment boat path overlap.

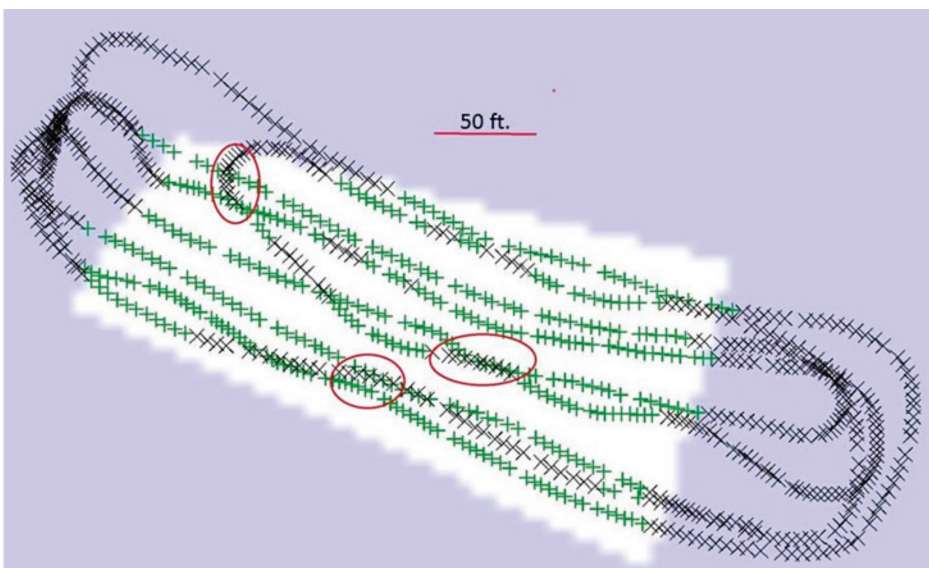
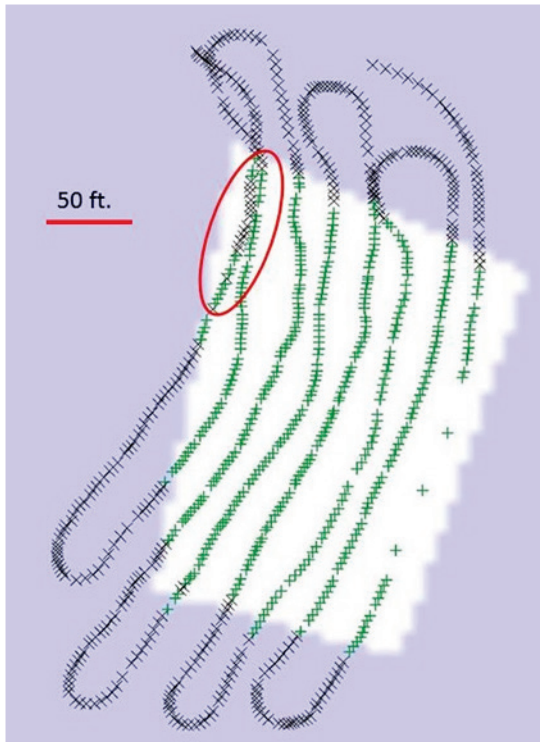


Figure 11. Position and flow (discharge) status for NE plot in Lake Underhill, FL, 11 February 2016, superimposed on treatment mask (white is within plot, purple is outside plot). Green crosses indicate dye flow, while black X's indicate no dye flow. Red circled areas indicate treatment boat path overlap.



3.4 Delivery rate control

In 2-D mode, delivery rate is constant per unit of area treated (boat speed x time increment x boom width, when flow is on), thus, dye flow rate (volume/time) changes only with boat speed. In 3-D mode, delivery rate is constant per unit of volume treated (boat speed x time increment x boom width x depth, when flow is on), thus dye flow rate (volume/time) changes with boat speed and depth. To achieve the target dye concentration (around 7.5 µg/L) within a plot, the 2-D delivery rate (liters/ha) must account for the mean depth of the plot. For the 3-D mode, delivery rate is automatically changed with depth, so mean depth is only needed to determine the amount of chemical (dye) added to the tank. To verify that these requirements were met, depth vs. delivery rate graphics are presented for 2-D and 3-D delivery modes (Figures 12 and 13). Target delivery rate is a user-specified value for 2-D mode, while it is computed for 3-D mode based on conditions at the moment. Actual delivery rate is the amount delivered by the pumps in response to the target rate command.

The 2-D target delivery rate graphic (Figure 12a) shows the expected constant delivery rate liters/ha (g/ac) across varied depths. The SE and SW plots have roughly the same mean depth so target delivery rate lines are almost superimposed. The NE plot is considerably deeper so its delivery rate line lies above the other two plots. The only anomalous feature in this graphic is the unexpectedly low target rate ~ 19 L/ha (~2 g/ac) in the shallowest part of the SE plot. The cause of this four second anomaly has not been identified. For the 3.8 L/1233 m^3 (1 g/ac ft) intended rate, the target rate should not fall below that value times the mean depth (Table 2). The 2-D actual delivery rate graphics (Figure 12b) is similar to the target rate graphic with considerable scatter above and below the line. There are a considerable number of low or zero actual values. A spot check of some of these values showed that

- There is a short period (around one minute) at the beginning of operations when the mechanical system (actual rate) does not respond as directed to the target rate (ex: SW/11Feb/11:23:12).
- After the above period has passed, every time the pump must start from zero, such as upon entering a plot, it takes a few seconds for the pump (actual rate) to reach and stabilize on the target rate (ex: SW/11Feb/11:26:42). Some refinements in the software could alleviate the delay and stabilization period, even if not refined, this situation should not significantly impact application accuracy on a field scale treatment.
- Most of the actual rates that exceeded the target rate occurred immediately after the pump was turned on, such as when entering the plot. The pump (actual rate) overshot the directed target rate and several seconds were needed for it to stabilize at the target rate (ex: NE/10Feb/3:09:16).

Target rates in the 3-D mode (Figure 13a) responded in the linear manner desired (i.e., a 50% increase in depth results in a 50% increase in target rate). The actual delivery rate (Figure 13b) generally follows the target delivery rate, with slightly more scatter. Actual values below the line were spot checked and found to be due to causes similar to those listed above.

Figure 12. Target (a) and actual (b) delivery rate versus depth for 2-D delivery mode of dye for all 2-D treatments in Lake Underhill, FL, February 2016.

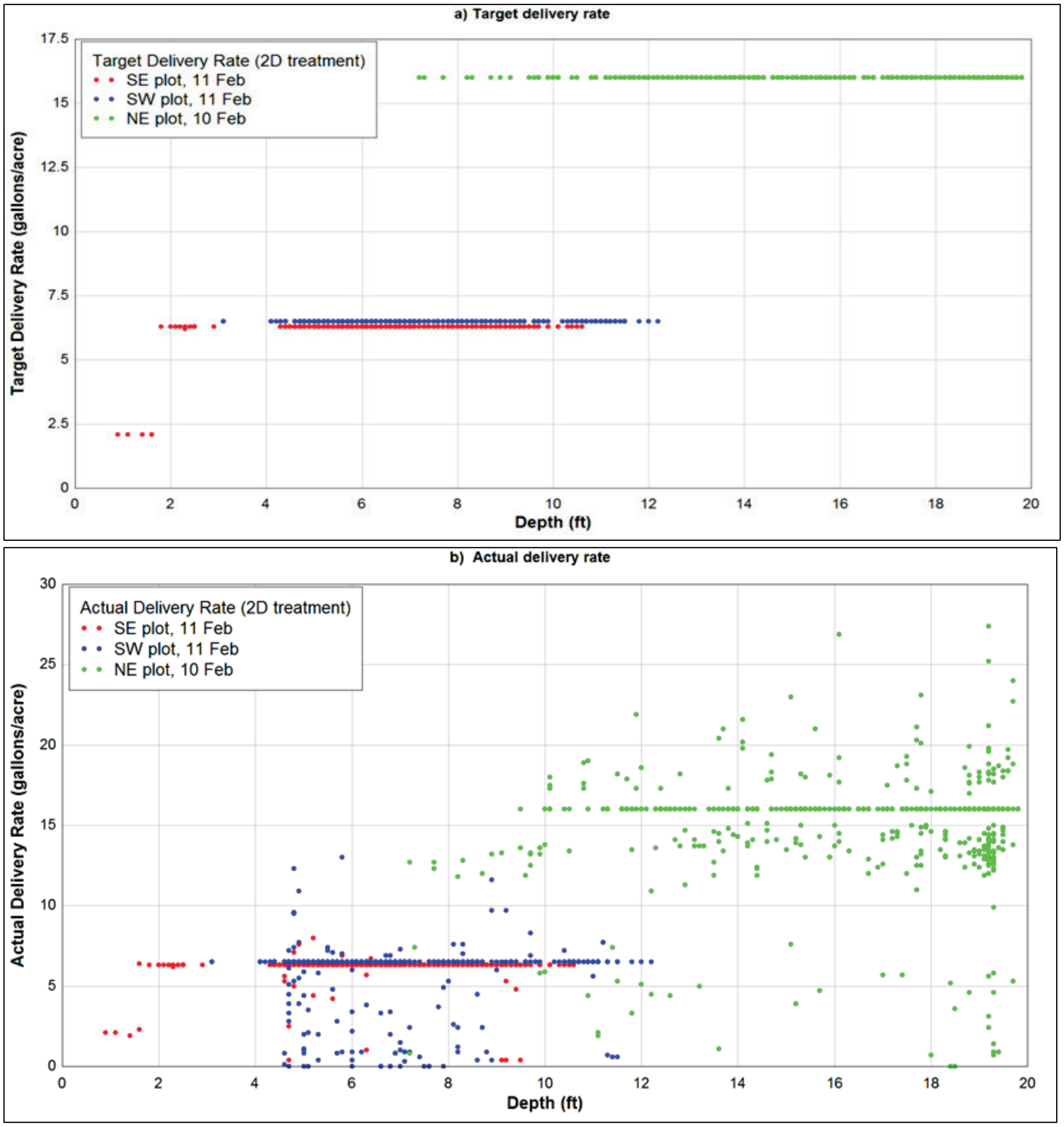
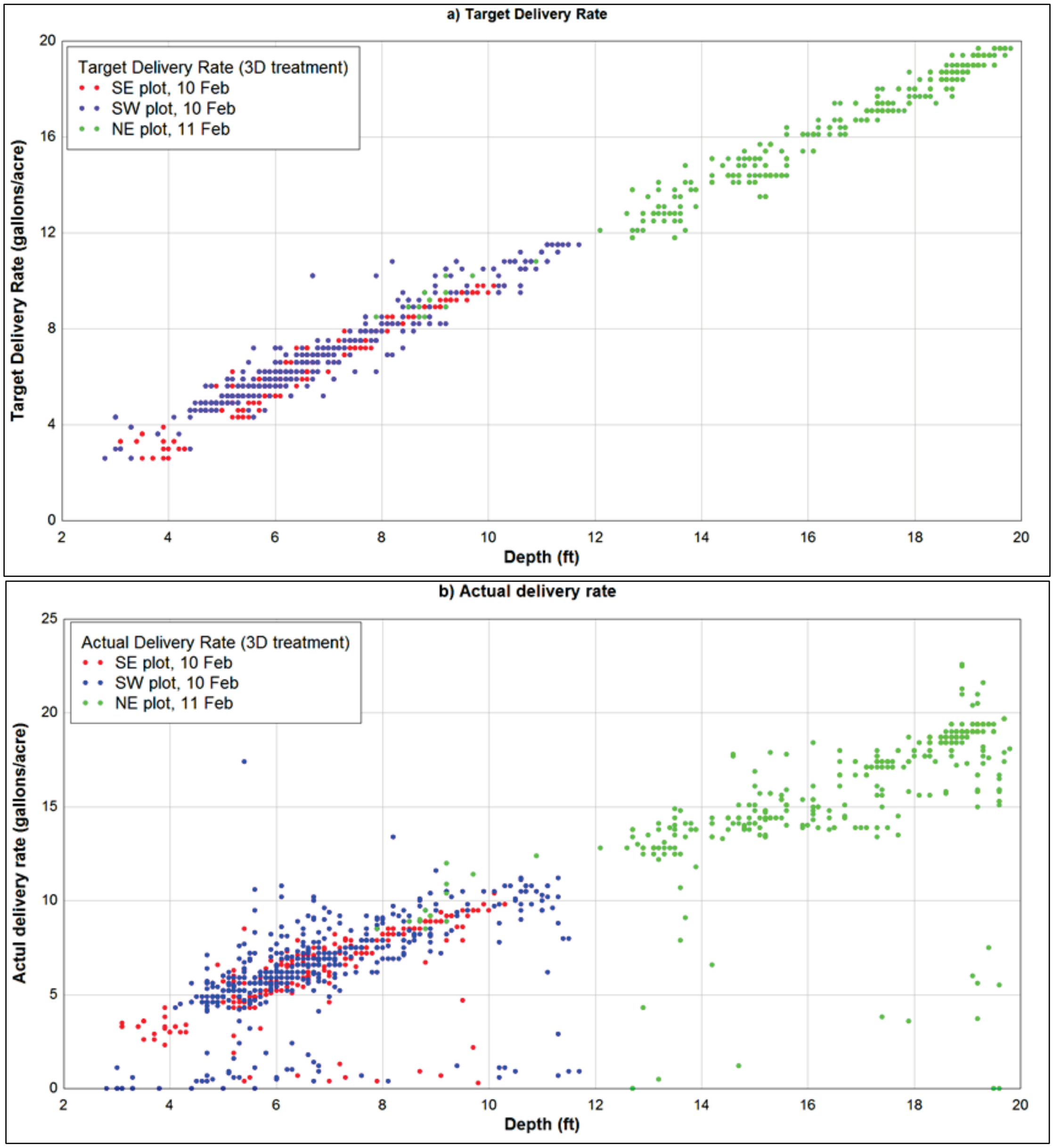


Figure 13. Target (a) and actual (b) delivery rate versus depth for 3-D delivery mode of dye for all 3-D treatments in Lake Underhill, FL, February 2016.



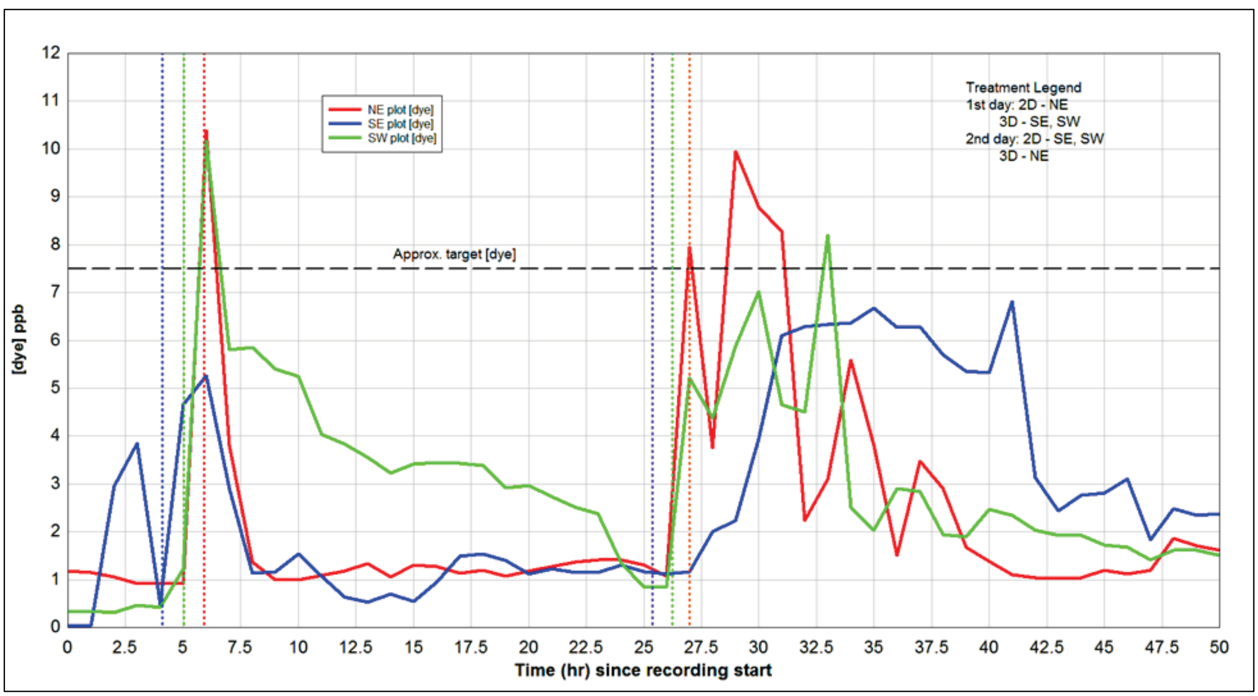
3.5 Analysis and comparison of 2-D and 3-D dye treatments

Analysis of dye concentration data was inconclusive in being able to differentiate between the 2-D and 3-D treatment types. High dye concentrations were found shortly after treatment but rapidly dispersed, apparently more as a result of wind conditions and plot locations than treatment type. Spatially-sampled dye concentrations were extremely varied within plot and time after treatment. Thus, it was not possible to statistically demonstrate that the 3-D mode resulted in more uniform dye concentrations horizontally and vertically within a plot than that yielded by the 2-D mode. Details of the dye test analyses are provided below.

The Hydrolab data (Figure 14) consists of a single mid-depth data point in the center of each plot, sampled hourly. Although much reliability cannot be placed on a single observation per plot*time, there are a few observations to note.

- On very windy 10 February, dye was quickly flushed from windward plots (NE and SE), but lingered in the leeward plot (SW).
- Also on 10 February, only a single hourly observation showed dye concentrations above the target concentration for plots NE and SW. No above-target dye concentration measurements occurred in the SE plot.
- On 10 February, two hourly dye concentration measurements in the SE plot rose well above background levels an hour or more before treatments of SE plot (or any other plots) were initiated.
- On calm 11 February, dye concentrations in all plots, particularly SE, lingered well above background levels for many hours.

Figure 14. Hydrolab dye concentration measurements in treated plots in Lake Underhill, FL. Vertical dotted lines indicate time treatment was completed by plot.



Manually sampled Turner Cyclops 7 measurements within each plot (excluded outside samples) were averaged by time after treatment for each treatment administered (Figures 15 and 16). The 10 samples per group (five stations x two depths) allowed a confidence interval to be computed. The following observations were noted:

- On windy 10 February, the pattern is somewhat similar to that observed with the Hydrolab data. Dye concentrations in windward plots (NE and SE) rapidly declined but lingered in the leeward plot (SW).
- Also on 10 February, a single hourly plot-mean concentration was above target concentration for each of plots SE and SW shortly after treatment. No plot-mean dye concentrations were above target level for the NE plot; further, the target level was at no time within the 90% confidence interval for that plot. This is in contrast to a single above target concentration observation in the Hydrolab data.
- On calm 11 February, means for plots SW and SE exhibited similar behavior, both lingered near, but not above, target concentration for the first five hours after treatment. The target concentration was within the 90% confidence interval for these plots for the first 5–6 hours after treatment. Mean concentrations in the NE plot started low and declined with time. At no time was the target concentration within the 90% confidence interval for the NE plot on that day. These data are also at odds with Hydrolab observations on the NE plot, that day showed several above target concentration measurements.

Figure 15. Mean of dye concentration measurements (Turner Cyclops 7) in treated plots in Lake Underhill, FL, 10 February 2016.

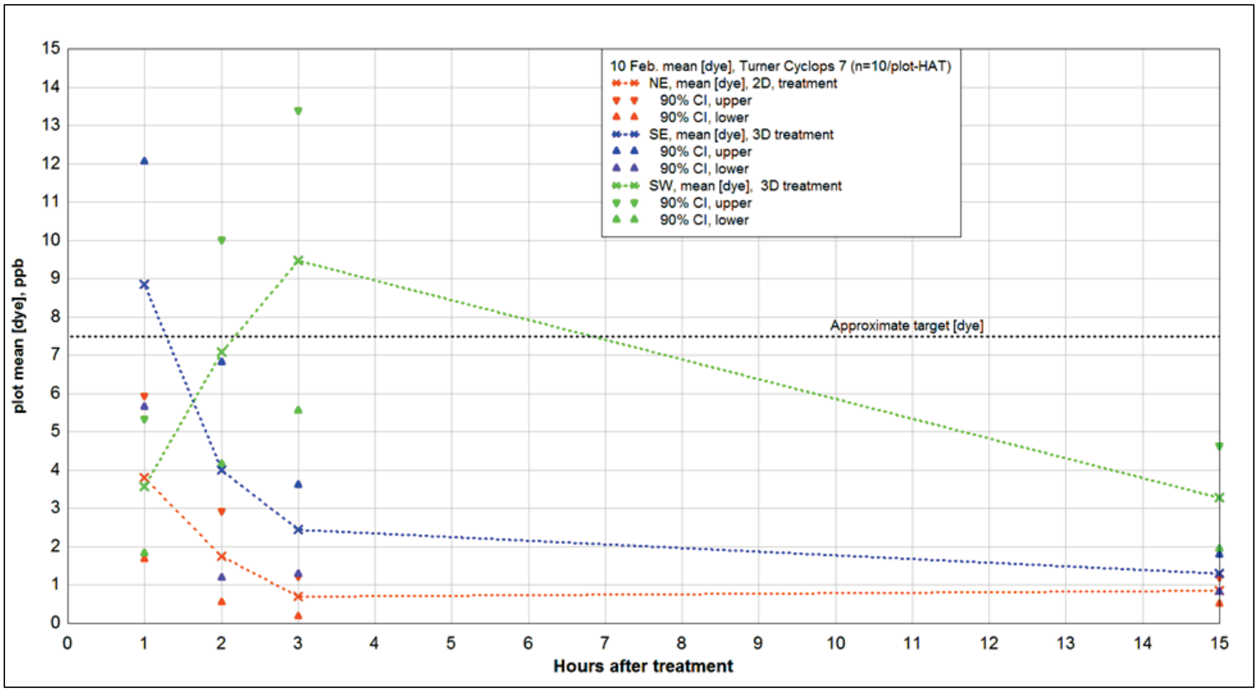
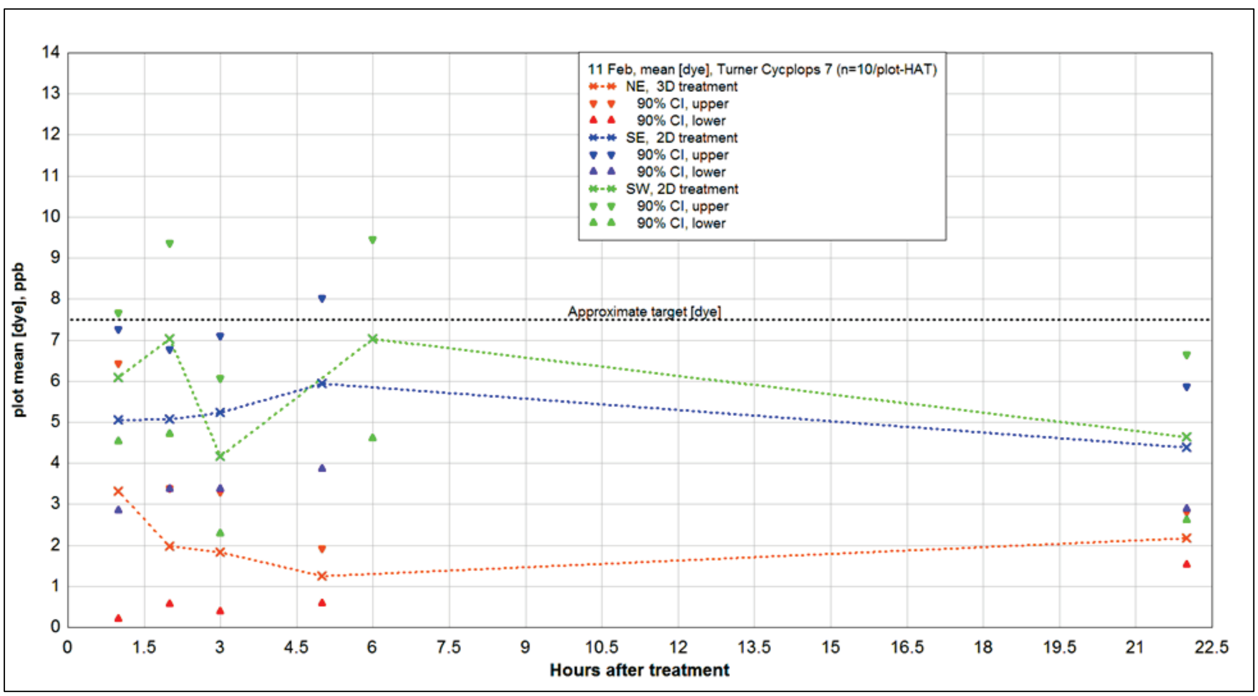


Figure 16. Mean of dye concentration measurements (Turner Cyclops 7) in treated plots in Lake Underhill, FL, 11 February 2016.



These observations on within-plot dye concentrations suggest differences between plot characteristics, locations, and daily wind conditions, but not necessarily differences between treatments. Differences measured are likely the result of wind-driven water movement and perhaps plot depth. Both treatment types placed enough dye into each plot to achieve concentrations near the intended target concentration (Table 4). Difference between treatments should be evident by examining mean water column dye concentration as a function of sample station depth. Average water column dye concentration was computed by averaging the upper and lower Turner Cyclops 7 measurements for each station and sampling period. The depth at each within-plot sampling station is normalized to the percentage of mean depth for that plot. Likewise, dye concentration was normalized to percent of the target dye concentration. Data from plots NE and SE on 10 February were discarded due to the fast flushing of dye under windy conditions as described above. Remaining data for the first three hours after treatment were grouped by treatment and plotted by time after treatment (Figures 17–19). A linear regression to predict normalized dye concentration as a function of normalized depth was computed for each treatment type within time after treatment. A t-test was performed to determine whether there was a significant difference between estimated treatment slopes within time period (Table 5).

Figure 17. Plot of normalized depth vs. normalized dye concentration for treatments in Lake Underhill, FL, one hour after releasing dye.

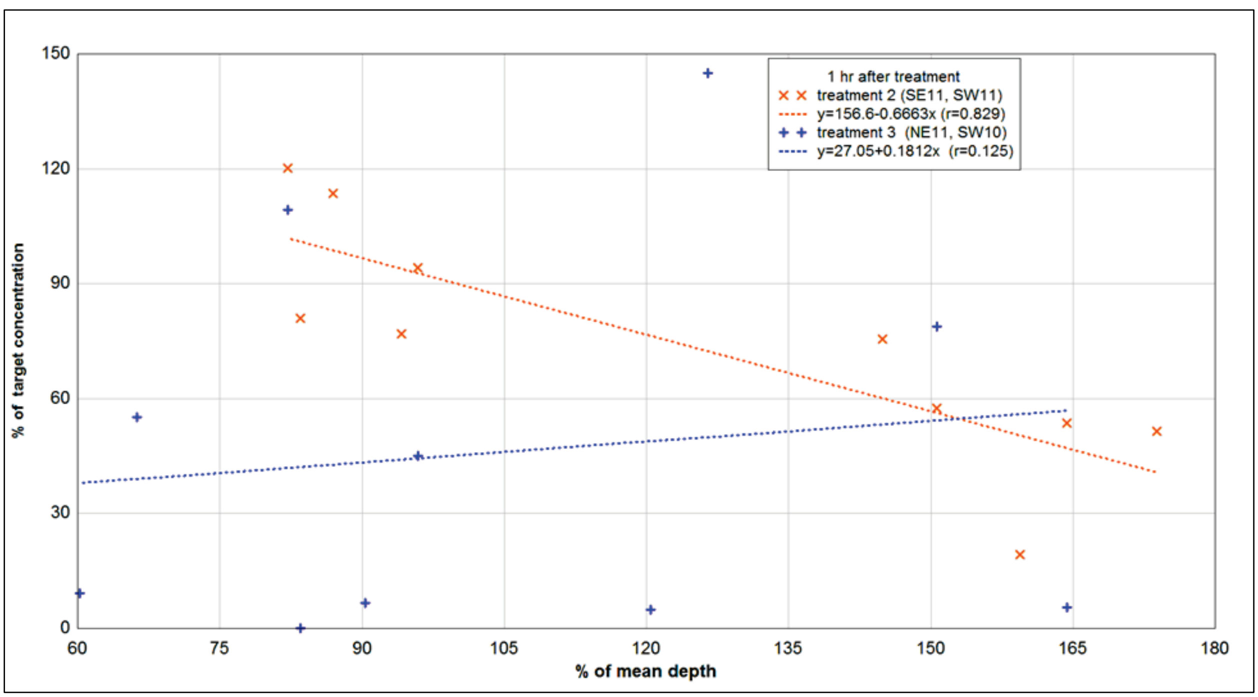


Figure 18. Plot of normalized depth vs. normalized dye concentration for treatments in Lake Underhill, FL, two hours after releasing dye.

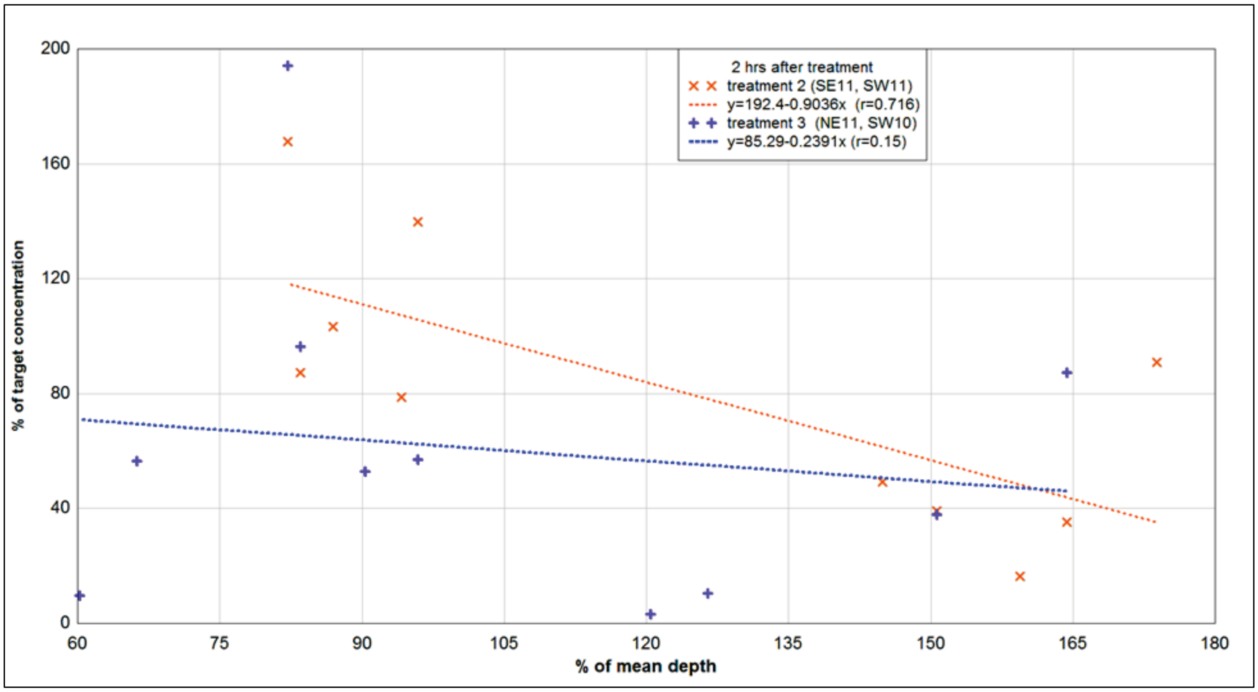


Figure 19. Plot of normalized depth vs. normalized dye concentration for treatments in Lake Underhill, FL, three hours after releasing dye.

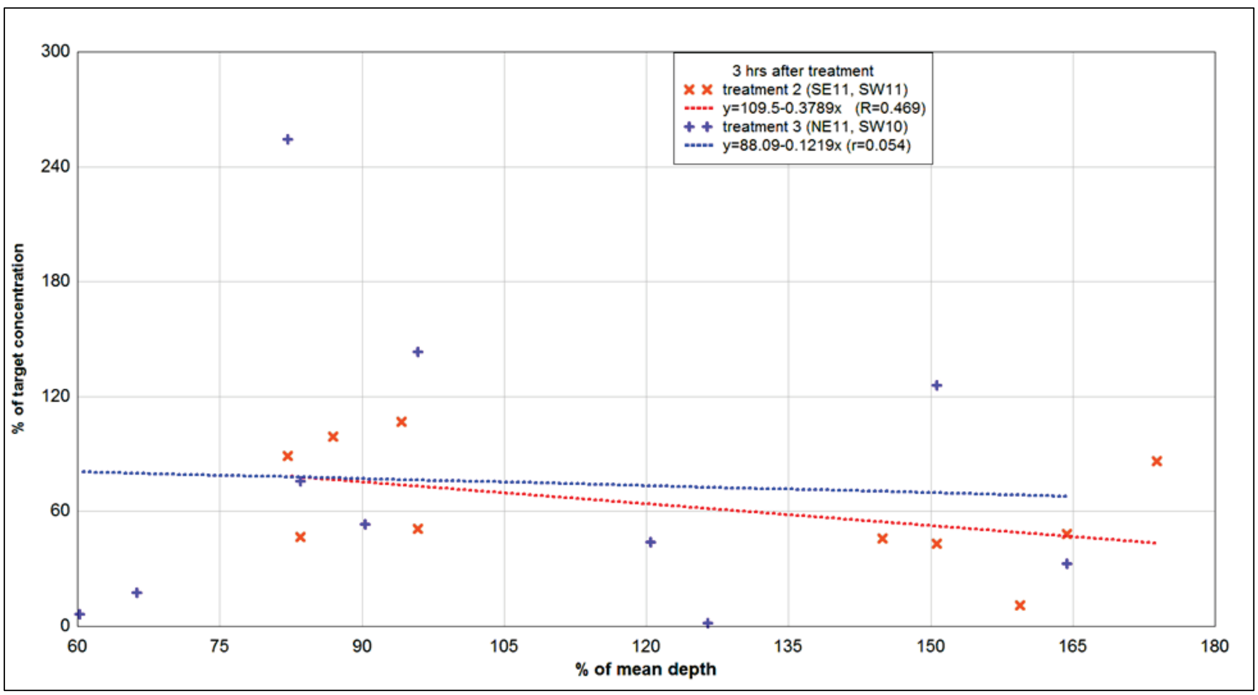


Table 5. T-test of equality of estimated slopes (B) between treatments in Lake Underhill, FL, by time after treatment.

Hours after treatment	H_0: (B_{2D} – B_{3D}) = 0		
	B_{2D} – B_{3D}	t	Pr > abs(t)
1	-0.8475	-1.64	0.1207
2	-0.6644	-1.05	0.3095
3	-0.2569	-0.32	0.7545

The linear regressions exhibit the expected slopes, near zero, for 3-D treatment, and negative for 2-D treatment, increasing to near zero as time proceeds. However, high point scatter across the models results in the inability to reject the null hypothesis of equal slopes, even at the 0.10 level.

4 Conclusions and Recommendations

4.1 Conclusions

1. The dye tests conducted on Lake Underhill, FL, demonstrated that a computer could automate a liquid herbicide treatment process and account for depth variations within a plot. This has implications for complying with, and even exceeding, requirements for NPDES or any other regulatory reporting. The level of transparency built into a system that is largely run by a computer allows this information to be shared with any stakeholder and regulator that would request treatment information. Furthermore, this system could allow for real-time tracking in the field during a treatment, providing regulators, and the public, a higher level of transparency.
2. Testing of the delivery system was a successful phase in developing and refining precision application techniques for submersed aquatic herbicide applications. The key treatment system components, boundary cutoff, delivery cutoff, and delivery rate control, functioned as designed to deliver a precise application of dye in treatment plots, over surface area and water depth.
3. Due to unexpected environmental conditions experienced during the dye treatments (high winds), analysis of dye concentration data was inconclusive in being able to differentiate between the 2-D and 3-D treatment types. Although this study could not statistically confirm any dye residue differences between the 2-D and 3-D applications, further research could determine the difference in these methods. A uniformly applied surface treatment does pose the risk of over treating in shallow areas, or under treating in deeper areas, where this situation could be avoided using a 3-D application system.

4.2 Recommendations

Recommendations to modifications in future study designs which may help resolve the expected difference between the 2-D and 3-D application techniques include:

1. Conduct studies during continuously calm periods, or under light wind conditions, so dye dispersion within plots is not subjected to high winds that impact bulk water exchange processes.
2. Establishing treatment plots of 4 ha (10 ac) or more will maximize perimeter-to-area relationships that can mitigate rapid dispersion of dye

from within plots, and determine the dye residue dynamics found within slightly larger plots than those tested here.

3. More robust dye sampling protocols (locations and events) will aid in statistical resolution of differences between treatment techniques.
4. Extend data collection period to enable a more stable dye dispersion profile within the plot to reduce spatial variance to aid in resolving differences between treatment techniques.
5. Dye application methods should be reexamined to determine the impact of hose placement on aqueous residue profiles. This reexamination should include application methods, such as applying only at the surface, only at the bottom, and staggered treatments.
6. Further refinements to the software of this system to account for application swaths that leave small untreated areas, in-plot shut downs of dye flow, a "tank cleanout" process following plot treatments, fix the observed one minute delay in fluid release at system start up, and an enhanced user interface to make the system more user friendly.

Once the above recommendations are addressed, implementation of Phase 3 of the overall project goals through field testing a fully operational herbicide treatment - with aqueous residue monitoring and evaluation of efficacy against target vegetation is recommended.

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Appendix A: Developmental Testing of a 3-D Digitally-integrated Aquatic Herbicide Dispensing System: First-Phase Test

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17 November 2014

A.1 Introduction

The U.S. Army Engineer Research and Development Center (ERDC), and Clarke Aquatic Systems entered into a Cooperative Research and Development Agreement to develop, test, and demonstrate an enhanced digital control system for precise application of herbicide to control submersed aquatic vegetation.

There are three phases of the work under this agreement

- Phase 1 consists of development and verification testing of a prototype control system.
- Phase 2 consists of a field validation study involving dye release
- Phase 3 consists of a fully operational herbicide treatment with residue testing and follow-on plant monitoring.

Lake Underhill in Orlando, FL, was selected for the first two phases of this work effort. An acoustic survey of the lake was conducted on 24–25 September 2014 to develop bathymetric and plant density data. Initial equipment testing and field verification were performed during 21–24 October 2014.

This report documents the results of this first-phase test. The objective is to examine and verify all functional requirements of the prototype system, identify functional shortcomings, and determine whether the system is ready for the Phase 2 dye test.

A.2 System description

Basic components and control of the existing MicroTrak (MT) system are illustrated (Figure 2, main body of report, above). Two separately controllable units (referred to as loops) are controlled by the MT controller. Pump capacity differs between loops, D loop uses a high capacity pump, while L loop uses a low capacity pump. This enables different chemicals to be simultaneously used in each loop. Each tank feeds a separate sealed box containing a dosing pump and an ionizing flowmeter. Discharge of each box enters a single conduit and then the flow is split to two check (on/off) valves, one for each of the two delivery nozzles. This further allows each nozzle to be turned on and off independently. The user interfaces with the MT control panel to set target Application Rate (AR, in gallons/acre) and boom width (defined as the width, perpendicular to the boat path, that is treated). The MT uses its dedicated GPS to determine boat speed. Boat speed, boom width, and AR are used to compute target pump flow rate, which is sent, using system command code, to each loop-specific pump. The flowmeter within each unit box reports the resulting flow rate back to the controller which then computes the actual AR. The controller also drives the check valves which can be instantly turned on or off. System time and status data are written to a file to document the application.

The added hardware for the ERDC enhancement consists of a personal computer (PC) connected to a separate GPS. In future tests, this GPS will be the same on the boat used by the operator for navigation (Lowrance external GPS linked to a Lowrance HDS sounder which provides depth and navigational displays). In the initial test, a stand-alone Trimble GPS was used. The user interacts with the MT computer through a PC. Electronic control and data management of the overall system are illustrated (Figure 3, main body of report, above)

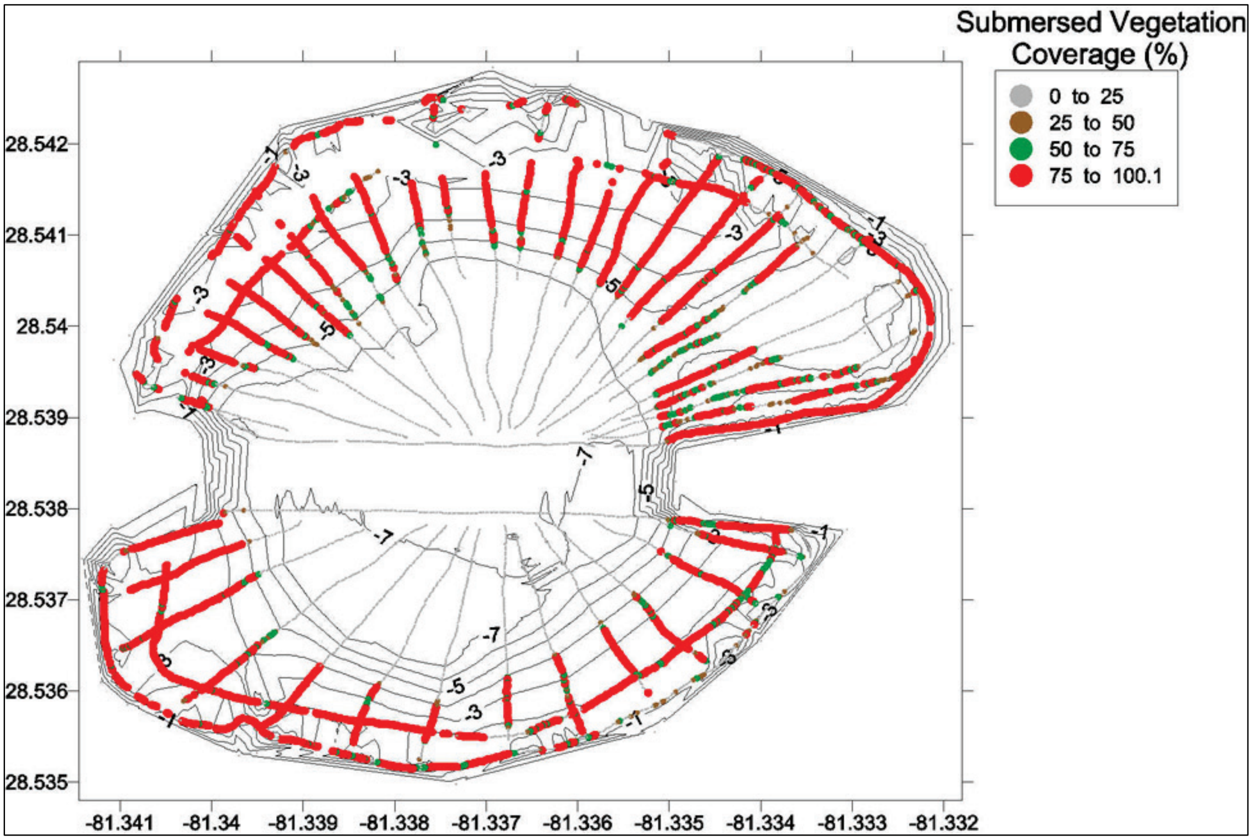
A simplified version of the control and data management structure is illustrated (Figure 3, main body of report, above). The user must specify target concentration to the ERDC computer, and boom width to the MT controller. ERDC controller queries the GPS for position which is then used to determine depth and in/out of plot status from the gridded databases input separately. Target concentration is then multiplied by depth to get target AR (gallons/acre) and checked to verify that computed AR is within set limits. Target AR is then sent to the MT which then runs in its normal areal mode. The MT queries its own GPS and determines boat speed. Target flow rate is then computed (target AR x speed x boom width) and sent, via system command code, to the pump and check valve. Flowmeter reports back to MT which then computes actual AR. The data packet of status variables is sent to the ERDC computer which then outputs these data to a file. All functions of the entire system are listed in Table 1 (main body of report, above). Two text files are written to the hard drive, a flow log file of MT status data, and a position log file from ERDC PC calculations. The “painted” treatment area map is presently only in RAM storage and not archived. A sample of each file type and associated variable definitions are contained in this Appendix.

A.3 Test site and plan

Lake Underhill, a 147-acre circular urban lake (Figure 4, main body of report, above) just east of downtown Orlando, FL, was selected as the test site. It is bisected in the east-west direction by two separate low-span bridges for highway 408. It is bounded on the north by Orlando Executive Airport. The southern half is surrounded by an urban park with walkways, a boat launch, and dock on the east side (Lake Underhill Park). An acoustic survey of the lake (Sabol 2014) was conducted on 24 and 25 September to obtain bathymetric and submersed plant information needed for this test.

The lake bathymetric (Figure A1) exhibited gradual depth changes - deep in the center (~26 ft) getting progressively shallower near shore. Along the northern shoreline numerous deep holes were found. Presumably, these are sediment borrow pits used to build the steep shoreline around much of the lake. Submersed vegetation (primarily hydrilla, Illinois pondweed, *Vallisneria*, and naiad) was abundant along the entire shoreline but decreased at depths greater than 15 ft towards the center of the lake (depths 21–26 ft). Density within the northern half of the lake was considerably greater than the southern half, which appears to have been chemically treated recently. Plant density in the northern half of the lake was greater along the northern and western edge of the lake; the eastern third of the north half contained relatively little vegetation due to depths over 15 ft almost to the shoreline. During the September survey, there was no surface-topped vegetation, although it was visibly dense half a foot below the surface in the northern nearshore area. By late October most of the northern nearshore area exhibited topped vegetation (except for the eastern third). Water level change contributed to this as the lake level dropped 0.4 ft between late September and late October (from 2.09 to 1.70 ft on a permanent staff gage located along the northern shoreline).

Figure A1. Depth contours (m) and vegetation coverage (%) classes generated from September acoustic survey; horizontal coordinates in degrees longitude and latitude.



Two test plots were selected (Figure A2) in the northern half of the lake. Test plot #1, located along the eastern shore of the northern half of the lake, has an area of 8.7 acres. It is deep throughout most of that area (mean depth 15.7 ft) and, correspondingly contains relatively little vegetation except directly on the shoreline. The plot's volume is approximately 140 acre ft (based on September bathymetric survey, uncorrected for lake level drop by test time). Test plot #2 is nearshore along the northern edge of the lake. This 8 ac plot had a mean depth of 10 ft, with a volume of ~ 80 ac ft. Almost the entire area contains topped vegetation with the exception of a few deep holes near shore. The two plots represent very different operational conditions. Plot #1 is characterized by deep open water and sparse vegetation. Plot #2 is shallow with dense topped vegetation that would likely impede navigation of a boat with an outboard motor.

Figure A2. Test plots selected for equipment test.

Basic equipment and software checks were performed on 21–23 October. After all issues were resolved, a series of tests were conducted on the lake on 24 October. Data were collected to verify workings of each of the functional areas identified (Table 1 main body of report, above). Additionally, a simulated whole-plot treatment was performed in plot #1 while recording the discharge of water and lapse of time. Finally, several passes were made through dense areas in plot #2. Operational data were collected during several pauses to clear the boat propeller, which was frequently necessary. Analyses were performed to verify each intended functionality. Additional analyses were performed to (1) measure response time of the delivery system to rapid changes in target AR, (2) compare actual and estimated total "chemical" delivery in the simulated operational treatment of plot #1, and (3) closely examine how the system operated during a delay to clear the propeller.

A.4 Test results

Functions 1–5 (Table 1, main body of report, above) are existing functions performed by the MTcontroller. Remaining functions are new functions performed by the ERDC computer. Each function, however seemingly minor, was examined to verify proper functioning.

1. Compute speed function. Speed is computed within the MT controller, using data from the Garman GPS, and is output to the FlowLog file. MT documentation does not specify units although the output is multiplied by 10. To determine units and verify computation, two data segments were selected that were run in a near-straight line at near constant speed for between 10 and 20 seconds in duration (13:12:25–13:12:44, and 13:22:39–13:22:52). Starting and ending positions were determined by matching system times within the associated PosLog file that contains position data from a separate GPS. Approximate distance traveled between starting and ending times was computed using meters per degree conversions for latitude (111,794 m/deg) and longitude (98,703 m/deg at 28 deg latitude). This distance was then divided by the duration and converted to candidate units of speed (m/sec, ft/sec, km/hr, knots, and miles/hr. For both cases, the computed speed was within a percentage point agreement of the MT-computed speed for units of miles/hr x 10. This concludes that the speed is being correctly computed in units of miles/hr x 10.
2. Read boom width. Boom width values (6th variable after the D or L loop flag in flow log) were examined and found to be set to 600 when a loop was discharging and zero otherwise. According to the MT documentation units are in inches, thus, width was set to 50 ft, this was confirmed by the equipment operator. This value should then be used to calculate required flow rate of the pumps.
3. Read target application rate (AR g/ac) from ERDC computer. ERDC-generated position files (PosLog) were compared with corresponding MT-generated flow files (FlowLog). In all cases the “Current Target Rate” value in the flow files matched the target application rate computed within the ERDC computer.
4. Compute current actual flow rate and actual AR. The required flow rate is calculated as speed x boom width times target AR times unit conversions. While the MT controller does calculate and control the flow rate, neither the target nor actual flow rates are reported out. Therefore, this cannot be explicitly verified. We only know the target AR and the actual AR, computed by the MT controller from flow measurements generated by the flowmeter.
5. Read actual flow rate and compute actual AR. As described above, this function cannot be verified for lack of flow data. The function is performed

internally by the MT controller and not reported out. All we can confirm is that the actual AR quickly follows the commanded target AR.

6. Read GPS string. Because a connector cable was not available for this test, the ERDC computer used a separate GPS and not the applicator boat's resident GPS (external Lowrance GPS). In future tests, GPS needed by the ERDC computer will be obtained from the boat's external Lowrance GPS. GGA strings output in the PosLog files conformed to the NMEA sentence structure for the GGA string and output positions appeared to match position on the lake. Further, position conversion performed by the ERDC program (converts position in degrees and decimal minutes into decimal degrees) was verified as correct. Therefore, we conclude this function is working correctly and that it may not be necessary to continue recording the GGA strings.
7. Determine local depth from external gridded bathymetric data. Based on the GPS data accessed by the ERDC computer, the bathymetric array location is computed from the gridded bathymetric map previously generated. The grid position is computed (lat/long to grid array position), the depth is read from the digital gridded bathymetric map, and depth units are converted from meters (grid file) to feet (used by MT). Eight random points were selected from the PosLog files collected on 24 October at locations in or near the two treatment plots. Depths within this file (units of feet) were compared with meter-depths in the gridded bathymetry file (Surfer gridded data file output_edited_w_boundary2 [used in 24 Oct test] generated on 23 October with a 2 m grid spacing; queried in Surfer grid display) at the grid cell intersection closest to the latitude/longitude position read from the PosLog file.

Table A1. Summary of this comparison; meter depths in the bathymetric grid were converted to feet (3.281 ft/m).

Depth (ft) in PosLog file	Bathymetric grid depth converted to feet	Difference (B-A) and relative difference (((B-A)/B)x100%)
-3.608	-3.996	-0.338 (9.7%)
-5.577	-6.201	-0.624 (10.1%)
-7.217	-7.317	-0.100 (1.4%)
-9.840	-10.123	-0.283 (2.8%)
-12.800	-12.960	-0.160 (1.2%)
-11.801	-11.484	0.317 (-2.8%)
-17.400	-17.389	0.011 (-0.1%)
-17.060	-16.900	0.160 (-0.9%)

While the paired numbers were close they were not in exact agreement as expected. The fact that both the difference and the relative difference were not constant suggests that the disagreement cannot be attributed to an arithmetic bias (either additive or multiplicative), (i.e., unit conversion error) alone. Also, the fact that the magnitude of the difference seems to decrease with depth suggests disagreement may be in converting geographic position data to grid cell location (spatial variability in depth is greater in the shallow areas). A final note, lake level changes, such as occurred over the month period between the original bathymetric survey (24 September) and system test (24 October), are not currently accounted for in the software.

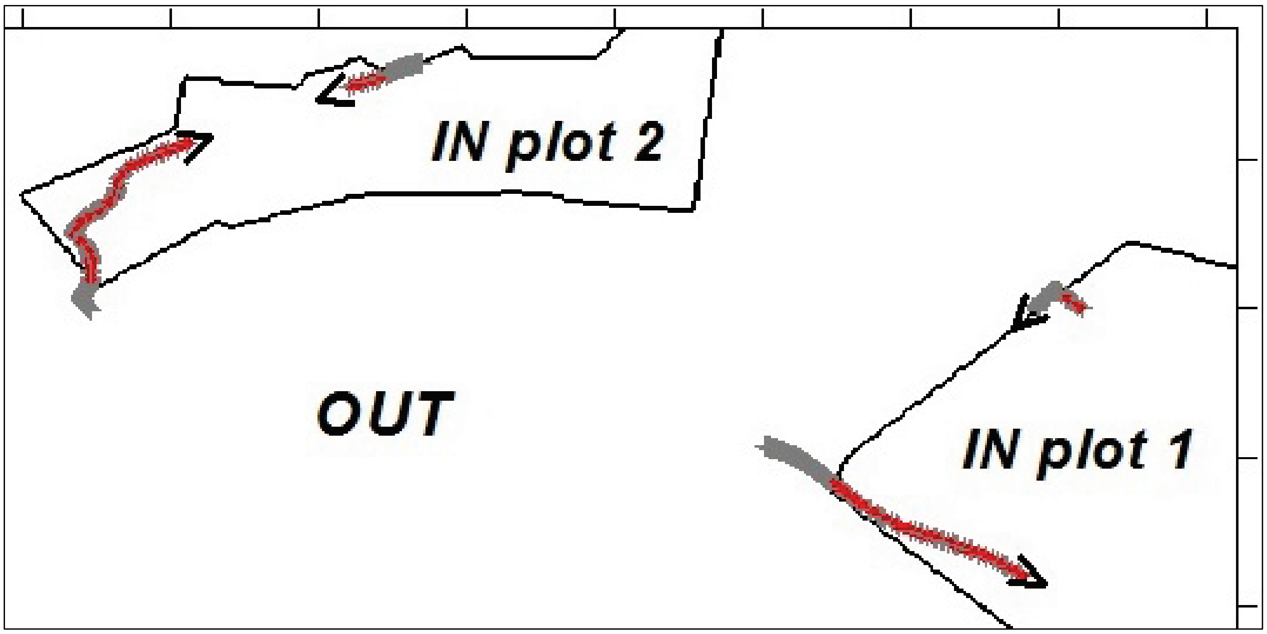
8. Determining when within treatment plot. This determination is performed in a similar fashion to the depth grid query described above. To verify correct functioning, four segments from the 24 October PosLog files were selected and plotted. One segment was selected for entering (turning on applicator) and one for leaving (turning off applicator) each plot. Selected segments are listed below in Table A2.

Table A2. Selected segments.

Plot	Boundary cross type	Begin segment	End segment
1	Enter plot	12:44:00	12:47:00
	Leave plot	12:51:00	12:51:40
2	Enter plot	14:06:00	14:08:00
	Leave plot	14:10:00	14:10:52

The in/out factor (0 for out, 1 for in) from the even numbered lines of the segments in PosLog files were plotted by position overlaying a map of the treatment boundaries (Figure A3). Upon initial entry into a treatment area, all points within the plot should display ***in,*** and all points out should display as ***out.*** As evident in Figure A3, when outside a plot, either before entering or after leaving, the in-out factor correctly reads 0. However, when within either plot the in/out variable appears to flicker between in and out. This is not the intended function. The gridded boundary file (Surfer grid file Area1+2_2) was examined and found to be correct (i.e., only 1 within either plot and 0 otherwise). The density of off settings (zeros) within a treatment plot appears to vary with boat speed. For example, in the left most segment within plot #2 there is a high density of zeros near the sharp right turn (speed ~1.1 mph) but a decreasing density of zeros near the end of the segment (speed ~ 3.0 mph). This suggests that the algorithm for repainting the treated plot is the cause and needs reexamination and modification.

Figure A3. Verification of plot boundary determination. Gray crosses indicate outside (applicator off) and red circles indicate inside (applicator on); arrows indicate direction of travel.



9. Compute target application rate (AR). This is calculated by the ERDC computer and is simply target concentration (gallons/acre-ft) x depth (ft) x in-plot factor (0 or 1). There are physical limits to the range of flows that can be delivered using the existing dual pump system, both at the minimum and maximum ends*. Additionally, there are bounds on depths of application based on prudent application practices. For example, at depths beyond 10 ft only the equivalent application rate for 10 ft is used, and at depths less than 2 ft no application is made. Both pump limits and application limits are handled by bounding the target application rate between 2 and 10 gallons/acre. Using a target concentration of 1 gallon/acre ft this bounds the depth application rates between 2 and 10 ft. While the required functionality should make it

* While specifications on flow bounds of the pump in each loop (D and L) were not obtained, maximum flow rate for the D loop pump (sole pump used in this testing) was computed as 2.56 gallons/minute based on actual AR at high speeds (>3.0 mph) in deep water (>10 ft) during system time 12:51:53 to 12:52:07. In this segment, the pump was unable to reach the target AR until the boat slowed (i.e., pump was at it maximum flow rate).

impossible to deliver more than a target AR of 10 gallons/acre or less than 2 gallons/acre (including no application at depths shallower than 2 ft), it is currently possible to under-deliver the target AR if speed in deep areas (>10 ft) is too fast. The operator gets a message on the MicroTrak screen that speed to too fast but there is no recording of the delivery deficiency. The entire position logs for both plots were visually examined to verify the intentional functionality described above. In no case was a target AR of greater than 10 gallons/acre prescribed. At depths between 2 and 10 ft the target AR was correctly computed as the target concentration (1 gallon/acre-ft) times depth in feet. At depths less than 2 ft (plot #2) the target AR was not set to zero, but continued to be the target concentration x depth. The ERDC software was not shutting down application below 2 ft and will need correcting.

10. Output GPS string and status variables in position file (PosLog file). GPS string output was confirmed in step 6 above. Status variables output correctly match intended output (Appendix) with the exception that speed has yet to be computed and reported (or copies from the MT-generated flow log file.
11. Output MT report file. Contents of flow log file match those of the intended output (Appendix).
12. Paint area treated. The current function loads the gridded boundary map into RAM and paints 0's over 1's as an area is treated and this repainted file is not saved at the end of operations. There is no permanent record of this file, which would be useful for treatment documentation. Additionally, the on/off flicker described in function #8 above, may be the result of repainting procedure. Cannot currently verify this function.

Beyond the functionality verified above, there are several other useful information items that can be gleaned from these tests. First is determination of the system response time when the target AR is changed. How long does it take for the actual AR to match the command? This could be useful to determine the command rate frequency – it is pointless to issue commands at a faster rate than they can be complied with. Next, we examine the simulated application operation conducted in plot #1 on 24 October. Was the “chemical” delivered at the rate expected? Lastly, a close look was taken at operational data during the passage through dense vegetation in which it was necessary to pause to clear the propeller. This is expected to be a common occurrence when using application boats with outboard motors.

System response time. The flow log file was examined for cases of sudden change in target AR, such as entering the boundary of a plot. The magnitude of each change was recorded along with the time required for the actual AR to reach the target AR. Sudden shutoffs from a maximum AR (10 gallons/acre) were accomplished by the next 1-Hz output report (i.e. <1 second). Time required to achieve a startup to the maximum AR was dependent on boat speed. At moderate boat speeds (≤2.6 mph) response time was typically no more than 2 seconds. At faster speeds time to achieve target AR took longer. Above 3 mph full target AR (10 gallon/acre) could not be achieved, but this cannot be considered a system response time issue – the combination of speed and maximum AR exceeded pump capacity. Response time to achieve lower target ARs were typically accomplished in a single report cycle. The 1 Hz command frequency is probably adequate.

Simulated treatment. The entirety of plot #1 was "treated" with water on 24 October in a manner as close as possible to a real operation. Only the D-loop tank was used during this test. A total of 84.8 gallons were discharged. As described in function #12 above, we have no digital record of the treated area, however the operator's impression, based on Lowrance navigation guidance, was that the entire plot was covered with minimal over- and under-lap. Test plot #1 (Figure 5) contains 8.74 acres. I visually approximated that 90% of this area is deeper than 10 ft depth. With the application rate ceiling of 10 ft (10 gallons/acre), this 90% would account for 78.6 acre-ft (8.74 ac x 0.90 x 10 ft). The remaining 10% is between 0 and 10 ft (average ~ 5 ft). For treatment quantity calculations the 0-2 ft region would be excluded, but as noted in function description #9 this region was treated in our simulated treatment so will not be excluded here. The remaining shallow 10% contributes 4.4 acre-ft (8.74 ac x 0.10 x 5 ft). Therefore, the treatable volume of plot #1 sums to 83.0 acre-ft. At the target concentration of 1.0 gallon/acre-ft the predicted quantity is 83.0 gallons – approximately 2% less than the quantity actually delivered in the simulated treatment. The treatment took almost exactly 1 hour which included two refills of the tank.

System response to treatment delays. The particular delay here was caused by the need to clear vegetation from the lower unit of the outboard motor, however any number of things could result in a delay. Two propeller-clearing events were identified while entirely within plot #2. These segments were isolated from within the flow log and position log files along with 5–10 seconds of data before and after the pause (14:08:20-14:08:45, and 14:08:55-14:09:15). Key state variables including depth, in/out factor, ERDC target AR, MTtarget AR, actual AR, and speed are extracted from the files (Table 1, page 16, main body of report). The following observations were made:

1. The ERDC-computed target AR is transmitted to the MTand this value then become the current MT target AR that same time step or the next (1 sec. later). The MicroTrak does not respond to intermittent zeros from the ERDC target AR.
2. When speed rapidly declines as the boat motor is throttled back (from >2 mph to <1 mpg) the actual AR overshoots the MT target AR for several seconds.
3. Discharge is ended (presumably the check valve shuts off and actual AR goes immediately to zero) several seconds after speed slows. The control mechanism responsible for this shut down is not evident from the data.
4. While actual AR is shut off, the MT target AR still keeps the same value it had before actual AR went to zero.
5. Several seconds after speed resumes the discharge ramps up, over several additional seconds, to ultimately match the MT target AR.

This functioning is as intended although it is possible to cause a brief overdose of chemical when the boat slows rapidly.

Figure A4.

		ERDC			MICROTRAK		
segment	time	depth	in_out	ERDC_targAR	MTtargetAR	MTactAR	speed(mph)
1	2:08:21 PM	-7.21776	1	7.2	6.9	6.9	2.4
1	2:08:22 PM	-7.21776	0	0	7.2	7.2	2.3
1	2:08:23 PM	-5.90544	0	0	7.2	7.2	2.3
1	2:08:24 PM	-5.90544	1	5.9	7.2	7.2	2.2
1	2:08:25 PM	-6.23352	0	0	5.9	8.8	1.8
1	2:08:26 PM	-6.23352	1	6.2	5.9	7.9	1.7
1	2:08:27 PM	-6.23352	0	0	5.9	8.8	1
1	2:08:28 PM	-6.23352	0	0			
1	2:08:29 PM	-6.23352	0	0	5.9	0	0.7
1	2:08:30 PM	-6.23352	0	0	5.9	0	0.3
1	2:08:31 PM	-6.23352	0	0	5.9	0	0.1
1	2:08:32 PM	-6.23352	0	0	5.9	0	0.7
1	2:08:33 PM	-6.23352	0	0	5.9	0	0.6
1	2:08:34 PM	-6.23352	0	0	5.9	0	0.4
1	2:08:35 PM	-6.23352	0	0	5.9	0	0.2
1	2:08:36 PM	-6.23352	0	0	5.9	0	0.3
1	2:08:37 PM	-6.23352	0	0	5.9	0	1.1
1	2:08:38 PM	-4.9212	0	0			
1	2:08:39 PM	-5.24928	0	0	5.9	0	1.4
1	2:08:40 PM	-5.24928	1	5.2	5.9	0	1.6
1	2:08:41 PM	-5.24928	0	0	5.2	2	2
1	2:08:42 PM	-5.57736	1	5.6	5.2	2.2	2.2
1	2:08:43 PM	-5.57736	0	0	5.6	5.6	2.3
2	2:08:55 PM	-7.21776	0	0	7.2	9.6	1.7
2	2:08:56 PM	-7.54584	0	0	7.2	10.6	1.3
2	2:08:57 PM	-7.54584	1	7.5	7.5	9.8	0.9
2	2:08:58 PM	-7.54584	0	0			
2	2:08:59 PM	-7.54584	0	0	7.5	12.1	0.5
2	2:09:00 PM	-7.54584	0	0	7.5	13	0.3
2	2:09:01 PM	-7.54584	0	0	7.5	0	0.5
2	2:09:02 PM	-7.87392	0	0	7.5	0	0.8
2	2:09:03 PM	-7.87392	0	0	7.5	0	1.5
2	2:09:04 PM	-7.87392	0	0	7.5	0	1.9
2	2:09:05 PM	-7.54584	0	0	7.5	0	2
2	2:09:06 PM	-7.54584	0	0	7.5	0	2.2
2	2:09:07 PM	-7.21776	0	0	7.5	0	2.5
2	2:09:08 PM	-7.21776	1	7.2			
2	2:09:09 PM	-7.54584	1	7.5	7.5	1.1	2.8
2	2:09:10 PM	-7.21776	0	0	7.5	1.6	3
2	2:09:11 PM	-7.21776	1	7.2	7.5	4.8	3.1
2	2:09:12 PM	-6.5616	1	6.6	7.2	6.2	3.1
2	2:09:13 PM	-6.88968	1	6.9	6.6	6.6	3.2
2	2:09:14 PM	-6.88968	1	6.9	6.9	6.9	3.2
2	2:09:15 PM	-6.5616	1	6.6	6.9	6.9	3.2

A.5 Summary and conclusions

1. An initial development field test of a 3-D aquatic herbicide dispensing controller system was conducted in an urban Orlando, FL, lake during 21–24 October 2014.
2. Individual functional components of the system were tested and evaluated under operational type conditions and a simulated operational test was conducted in a ~9 acre plot.
3. The simulated operational treatment of the ~9-acre plot using water took one hour and automatically dispensed almost the identical amount of “chemical” as was calculated in advance.
4. Specific deficiencies were identified and recommendations for specific software modifications are made.
5. Overall the system worked well and after recommended modifications are implemented it will be ready for the Phase 2 dye test.

A.6 Recommendations

1. ON/OFF flicker. This rapid switching between in and out of plot designation when within a treatment plot is thought to be caused by the specific algorithm that "paints" the treated area (designates which grid cells within a plot have been treated). This algorithm needs to be modified. It is recommended that the software be revised to only "paint" a grid cell as treated after the applicator boat has left that grid cell location.
2. Lower limit of AR. The software function to cease application when computed target AR is below the lower limit set by the operator (currently 2 gallons/acre) is not working. Recommend fixing code to prevent application at rates below the set lower limit of AR.
3. Water level adjustment. There is currently no means of accounting for changes in water level between application date and when the bathymetric survey was conducted. In the present case, Lake Underhill water level dropped 0.4 ft between the 24 September bathymetric survey and the 24 October equipment test. Recommend adding software capability to adjust for water level changes.
4. Reading gridded depths. A discrepancy was found between the depths recorded in the position log file and corresponding grid cell depths for the grid location nearest the recorded GPS position. This is suspected to be related to mapping of GPS position to grid cell location. Recommend re-examining this algorithm. Agreement between GPS position and grid cell depth (using Surfer grid reading function) should be exact.
5. Applicator boat speed and deficient application. The operational test identified the problem of excess boat speed exceeding pump capacity at the maximum AR which led to deficient application. Efficiency dictates that a plot be treated in the minimum time possible so staying near the maximum allowable speed is necessary. The operator needs a real-time display to provide guidance on what this speed should be. Also, over- or under-application can be quantified as the ratio of Actual Application Rate to Current Target Rate (both in Flow Log file). This metric could be recorded in the output file (without having to compute it later) or better yet, change the treated or untreated flag (presently 0 or 1) in the permanent treatment map to a percentage based on this ratio.
6. Permanent record of treated area. Currently, the painted treatment plot is not permanently archived, as would be useful to document a treatment. Recommend writing out the final application treatment

grid after the end of a treatment to serve as part of the permanent record.

7. Navigational aid to operator. The operational test in plot #1 revealed the difficulty the operator faces in maintaining proper speed (recommendation #5) and picking a course that covers all areas once without leaving gaps or double treatment. A real-time graphic of treated area (including account of boom width) displayed to the operator as the operation proceeds may facilitate finding an efficient path. As an alternative, the path could be pre-planned and loaded into the navigation GPS for the operator to follow, however, this eliminates flexibility in dealing with unforeseen events.
8. System response and command frequency. No change is recommended to the 1-Hz command frequency of the ERDC controller.
9. Output data format changes. The output data format used for this test (shown below) was expedient for the purpose of this test, however that may not be the case for future testing, much less for operations. The following specific format changes are recommended, primarily for the benefit of the analyst:
    a. Discontinue reporting GPS string. The GGA GPS string was output to confirm proper reading of the data and to verify position data was correctly converted. This has been verified and it should not be necessary to repeat. If desired a measure of GPS quality (such as HDOP) could be added to the second line. Additionally, the alternating data types by line makes the position log file awkward to handle.
    b. Speed measure. A measure of speed is planned for the position log file. However, this is already computed by the MT and verified. It may be expedient to just copy it from the flow log file rather than independently compute it from a separate GPS, which would likely yield slightly different estimates.
    c. Add heading data. It would be useful to compute and output heading (direction of travel) within the position log file.
    d. Awkward dual file format. Each of the two files output contains critical data items but neither alone has everything needed for analysis, thus requiring merging data streams. A single file containing all necessary data would be preferred. If not, suggest adding latitude and longitude to the flow log file.

10. <u>Phase 2 - dye test</u>. After implementation and verification (office or preferably mini-field-based test immediately before dye test) of the above recommended software changes, we recommend proceeding with the phase II dye test.

Figure A5. Flow Log file (CSV format). Generated by MT system sample

```
10/24/2014,12:45:09 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23034,6634,6478,1562,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:10 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23034,6634,6478,1562,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:11 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23035,6634,6478,1562,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:12 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23035,6635,6478,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:13 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23036,6635,6478,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:14 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23036,6636,6478,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:15 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23037,6636,6478,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:17 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23037,6637,6478,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:18 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23037,6637,6479,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:19 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23038,6638,6479,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:20 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23038,6638,6479,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:21 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23039,6639,6479,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:22 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23039,6639,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:23 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23040,6640,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:24 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23040,6640,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:25 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23041,6640,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:27 PM,AUTO,100,100,D,100,100,26,0,0,600,3,8,0,23041,6641,6479,1563,L,100,0,26,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:28 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23042,6641,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:29 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23042,6642,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:30 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23043,6642,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
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10/24/2014,12:45:32 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23044,6643,6479,1563,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:33 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23044,6644,6479,1563,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:34 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23045,6644,6479,1563,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
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10/24/2014,12:45:44 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23049,6648,6480,1564,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:45 PM,AUTO,100,100,D,100,100,23,0,0,600,3,8,0,23049,6649,6480,1564,L,100,0,23,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:47 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23050,6649,6480,1564,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:48 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23050,6650,6480,1564,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
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10/24/2014,12:45:50 PM,AUTO,100,100,D,100,100,24,0,0,600,3,8,0,23051,6651,6480,1564,L,100,0,24,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:51 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23051,6651,6480,1564,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
10/24/2014,12:45:52 PM,AUTO,100,100,D,100,100,25,0,0,600,3,8,0,23052,6652,6480,1564,L,100,0,25,0,0,0,0,0,0,79,9965,25,1323
```

A.7 Variable definitions

1. System date (mm:dd:yyyy)
2. System time (local, based on computer)
3. Mode of operation (manual or auto [controlled by PC]
4. PC-computed target AR for D-loop
5. PC-computed target AR for L-loop
6. D loop (next 13 variable specifically refer to D loop)
7. Target AR (gallons/acre)
8. Actual AR (gallons/acre)
9. Speed (mph x 10)
10. 0, inactive column
11. 0, inactive column
12. Total boom width (inches)
13. System mode variable (not used in interpretation)
14. System status variable (not used in interpretation)
15. Volume measure 1 (not used in interpretation)
16. Volume measure 2 (not used in interpretation)

17. Area measure 1 (not used in interpretation)
18. Area Measure 2 (not used in interpretation)
19. L loop (next 13 variables specifically refer to L loop)
20. Target AR (gallons/acre)
21. Actual AR (gallons/acre)
22. Speed (mph x 10)
23. 0, inactive column
24. 0, inactive column
25. Total boom width (inches)
26. System mode variable (not used in interpretation)
27. System status variable (not used in interpretation)
28. Volume measure 1 (not used in interpretation)
29. Volume measure 2 (not used in interpretation)
30. Area measure 1 (not used in interpretation)
31. Area Measure 2 (not used in interpretation)

Figure A6. Position Log file (CSV format). Generated by ERDC PC controller. Sample

```
$GPGGA,164508.00,2832.38371145,N,08120.06417984,W,2,08,1.2,30.781,M,-31.004,M,7.0,0138*42
10/24/2014,12:45:09 PM,16.7522222222222,-81.3344029973333,28.5397285241667,2,1.2,0,-16.404,100,1,10
$GPGGA,164509.00,2832.38330351,N,08120.06363153,W,2,08,1.2,30.771,M,-31.004,M,3.0,0138*4C
10/24/2014,12:45:10 PM,16.7525,-81.3343938588333,28.5397217251667,2,1.2,0,-16.404,100,0,0
$GPGGA,164510.00,2832.38289459,N,08120.06307944,W,2,08,1.2,30.773,M,-31.004,M,4.0,0138*41
10/24/2014,12:45:11 PM,16.7527777777778,-81.3343846573333,28.5397149098333,2,1.2,0,-16.404,100,1,10
$GPGGA,164511.00,2832.38248617,N,08120.06253022,W,2,08,1.2,30.777,M,-31.004,M,5.0,0138*49
10/24/2014,12:45:12 PM,16.7530555555556,-81.3343755036667,28.5397081028333,2,1.2,0,-16.404,100,0,0
$GPGGA,164512.00,2832.38208112,N,08120.06198196,W,2,08,1.2,30.775,M,-31.004,M,6.0,0138*47
10/24/2014,12:45:13 PM,16.7533333333333,-81.334366366,28.539701352,2,1.2,0,-16.07592,100,1,10
$GPGGA,164513.00,2832.38168297,N,08120.06142748,W,2,08,1.2,30.774,M,-31.004,M,7.0,0138*4F
10/24/2014,12:45:14 PM,16.7536111111111,-81.3343571246667,28.5396947161667,2,1.2,0,-16.07592,100,1,10
$GPGGA,164514.00,2832.38129580,N,08120.06087135,W,2,08,1.2,30.760,M,-31.004,M,7.0,0138*4D
10/24/2014,12:45:15 PM,16.7538888888889,-81.3343478558333,28.5396882633333,2,1.2,0,-16.07592,100,1,10
$GPGGA,164515.00,2832.38090995,N,08120.06030965,W,2,08,1.2,30.751,M,-31.004,M,3.0,0138*40
10/24/2014,12:45:16 PM,16.7541666666667,-81.3343384941667,28.5396818325,2,1.2,0,-16.07592,100,0,0
$GPGGA,164516.00,2832.38052776,N,08120.05974388,W,2,08,1.2,30.736,M,-31.004,M,4.0,0138*4B
10/24/2014,12:45:17 PM,16.7544444444444,-81.3343290646667,28.5396754626667,2,1.2,0,-16.07592,100,1,10
$GPGGA,164517.00,2832.38014812,N,08120.05917729,W,2,08,1.2,30.730,M,-31.004,M,5.0,0138*48
10/24/2014,12:45:18 PM,16.7547222222222,-81.3343196215,28.5396691353333,2,1.2,0,-16.07592,100,1,10
$GPGGA,164518.00,2832.37976621,N,08120.05860595,W,2,08,1.2,30.720,M,-31.004,M,6.0,0138*4D
10/24/2014,12:45:19 PM,16.755,-81.3343100991667,28.5396627701667,2,1.2,0,-16.07592,100,1,10
$GPGGA,164519.00,2832.37938563,N,08120.05802940,W,2,08,1.2,30.713,M,-31.004,M,7.0,0138*42
10/24/2014,12:45:20 PM,16.7552777777778,-81.33430049,28.5396564271667,2,1.2,0,-16.07592,100,1,10
$GPGGA,164520.00,2832.37900443,N,08120.05745334,W,2,08,1.2,30.717,M,-31.004,M,7.0,0138*41
10/24/2014,12:45:21 PM,16.7555555555556,-81.334290889,28.5396500738333,2,1.2,0,-15.74784,100,0,0
$GPGGA,164521.00,2832.37862845,N,08120.05687806,W,2,08,1.2,30.713,M,-31.004,M,3.0,0138*4A
10/24/2014,12:45:22 PM,16.7558333333333,-81.334281301,28.5396438075,2,1.2,0,-15.74784,100,1,10
$GPGGA,164522.00,2832.37825531,N,08120.05630478,W,2,08,1.2,30.710,M,-31.004,M,4.0,0138*49
10/24/2014,12:45:23 PM,16.7561111111111,-81.3342717463333,28.5396375885,2,1.2,0,-16.07592,100,0,0
$GPGGA,164523.00,2832.37788783,N,08120.05572839,W,2,08,1.2,30.699,M,-31.004,M,5.0,0138*46
10/24/2014,12:45:24 PM,16.7563888888889,-81.3342621398333,28.5396314638333,2,1.2,0,-15.74784,100,1,10
$GPGGA,164524.00,2832.37752785,N,08120.05514512,W,2,08,1.2,30.702,M,-31.004,M,6.0,0138*44
10/24/2014,12:45:25 PM,16.7566666666667,-81.3342524186667,28.5396254641667,2,1.2,0,-15.74784,100,1,10
$GPGGA,164525.00,2832.37717656,N,08120.05455983,W,2,08,1.2,30.687,M,-31.004,M,7.0,0138*46
10/24/2014,12:45:26 PM,16.7569444444444,-81.3342426638333,28.5396196093333,2,1.2,0,-15.74784,100,1,10
$GPGGA,164526.00,2832.37683132,N,08120.05397538,W,2,08,1.2,30.686,M,-31.004,M,7.0,0138*48
10/24/2014,12:45:27 PM,16.7572222222222,-81.334232923,28.5396138553333,2,1.2,0,-15.74784,100,0,0
$GPGGA,164527.00,2832.37649216,N,08120.05338879,W,2,08,1.2,30.688,M,-31.004,M,3.0,0138*4D
10/24/2014,12:45:28 PM,16.7575,-81.3342231465,28.5396082026667,2,1.2,0,-15.74784,100,1,10
$GPGGA,164528.00,2832.37615229,N,08120.05280153,W,2,08,1.2,30.693,M,-31.004,M,4.0,0138*49
10/24/2014,12:45:29 PM,16.7577777777778,-81.3342133588333,28.5396025381667,2,1.2,0,-15.74784,100,0,0
$GPGGA,164529.00,2832.37581571,N,08120.05221100,W,2,08,1.2,30.692,M,-31.004,M,5.0,0138*41
10/24/2014,12:45:30 PM,16.7580555555556,-81.3342035166667,28.5395969285,2,1.2,0,-15.41976,100,1,10
$GPGGA,164530.00,2832.37548290,N,08120.05162090,W,2,08,1.2,30.699,M,-31.004,M,6.0,0138*40
10/24/2014,12:45:31 PM,16.7583333333333,-81.3341936816667,28.5395913816667,2,1.2,0,-15.41976,100,0,0
$GPGGA,164531.00,2832.37514809,N,08120.05102507,W,2,08,1.2,30.700,M,-31.004,M,7.0,0138*4F
10/24/2014,12:45:32 PM,16.7586111111111,-81.3341837511667,28.5395858015,2,1.2,0,-15.41976,100,1,10
$GPGGA,164532.00,2832.37481759,N,08120.05043046,W,2,08,1.2,30.710,M,-31.004,M,7.0,0138*4E
10/24/2014,12:45:33 PM,16.7588888888889,-81.334173841,28.5395802931667,2,1.2,0,-15.74784,100,0,0
$GPGGA,164533.00,2832.37448448,N,08120.04984044,W,2,08,1.2,30.713,M,-31.004,M,3.0,0138*4F
10/24/2014,12:45:34 PM,16.7591666666667,-81.3341640073333,28.5395747413333,2,1.2,0,-15.41976,100,1,10
$GPGGA,164534.00,2832.37415538,N,08120.04924733,W,2,08,1.2,30.700,M,-31.004,M,4.0,0138*4E
10/24/2014,12:45:35 PM,16.7594444444444,-81.3341541221667,28.5395692563333,2,1.2,0,-15.41976,100,1,10
$GPGGA,164535.00,2832.37383006,N,08120.04865214,W,2,08,1.2,30.692,M,-31.004,M,5.0,0138*40
10/24/2014,12:45:36 PM,16.7597222222222,-81.3341442023333,28.5395638343333,2,1.2,0,-15.41976,100,1,10
```

Odd numbered rows are standard NMEA-format GGA sentence from the GPS. The GGA sentence is used to extract position data. It was verified to be read correctly and is not used in this analysis. It will likely not be included as an output in further testing. Interested readers can readily find the full description online.

Even numbered rows are status variables generated by the ERDC controller. Variables are defined below:

1. System date (mm:dd:yyyy)
2. System time (local, based on computer)
3. Time (decimal hours, GMT)
4. Longitude (decimal degrees)
5. Latitude (decimal degrees)
6. GPS quality (0..2, invalid, GPS fix, DGPS fix)
7. Horizontal dilution of position (HDOP)
8. 0 (variable to be added later)
9. Depth (ft)
10. Target concentration (gallons/acre-ft x 10)
11. In/out of treatment plot (0 or 1)
12. Target AR (gallons/acre)

Appendix B: Acoustic Survey of Lake Underhill, 24–25 September 2014

Prepared by: Bruce Sabol, Sabol Consulting LLC, 1 October 2014

Lake Underhill was selected as the test site for a new digital herbicide dispensing system planned for fall of 2014. It is a 147-acre circular urban lake (Figure 2, page 14, main body of report, above) just east of downtown Orlando, FL. It is bisected in the east-west direction by two separate low-span bridges for highway 408. It is bounded on the north by Orlando Executive Airport. The southern half is surrounded by an urban park with walkways, and a boat launch and dock on the east side (Lake Underhill Park). As part of support for this planned test, an acoustic survey was conducted on 24 and 25 September 2014. The survey was conducted by Bruce Sabol with boat and navigation support provided by Mr. Dean Jones, University of Florida.

B.1 Methods

Acoustic instrumentation used consisted of the SAVEWS Jr (Submersed Aquatic Vegetation Early Warning System) equipment set (Sabol et al. 2012) which included

1. Lowrance HDS-10 digital sounder with 200 kHz skimmer transducer
2. Lowrance StructureScan using 800 kHz downlooking channel
3. Lowrance optional external GPS system.

Transducer was mounted off the side of the survey boat and GPS antenna and transducers were co-located. General procedures used followed the SAVEWS Jr user's manual (Sabol et al. 2012).

The first day's effort used a survey pattern described below for both northern and southern halves of the lake.

1. Inner perimeter transects 30-50 ft offshore.
2. Outer perimeter transect 200-300 ft offshore.
3. Twelve evenly spaced "spoke" transects running perpendicular to local shore from nearshore and ending near the center of the lake.

No transects were run under the bridge since GPS signal would have been lost. After a preliminary look at the first day's data it was decided to run 12 additional half-spoke transects in the northern half. Emphasis was placed on the northern half because it is the likely location of the test plot. These half-spoke transects were placed between the spoke transects done on the first day and run from near the lake center inward toward shore as far as possible.

Data were processed with the SAVEWS Jr software in accordance with the user's manual. All processed data were checked for quality. The extremely dense submersed vegetation (primarily Hydrilla) near the north shore resulted in loss of bottom tracking in many areas making it necessary to discard false bottom detections in a significant portion of this area. The southern half of the lake had apparently been chemically treated recently and vegetation was not so dense, resulting in no data loss.

No digitized lake boundary could be found, therefore, the boundary was digitized using Google Earth Pro. Thirty-seven points were picked to define the lake boundary. This was not intended to produce a survey-quality boundary map, but rather to capture the interpolation required to generate a grid, as described below.

Surfer 7.0 was used to generate maps and gridded data. Post and post-classed maps were generated for output survey points, depth, and vegetation coverage. Bathymetric data were gridded using triangulated irregular network (TIN) interpolation, which is the standard for hydrographic mapping. A 20 ft x 20 ft grid was generate in depth units of meters using state plane coordinates (zone Florida East and NAD 83).

B.2 Results

No online data could be located on the lake's current water elevation, however, a staff gage along the northern shore was located (accessible from airport) that read 2.09 ft. It needs to be determined what reference plane or elevation is used for this gage.

Maps for edited survey data for position, plant coverage, and depth are illustrated below (Figures B1–B3).

Figure B1. Map of edited survey points (gray dots) with lake boundary (red dashed line) and boundary points (red dots). Coordinates in degrees latitude and longitude (NAD 83).

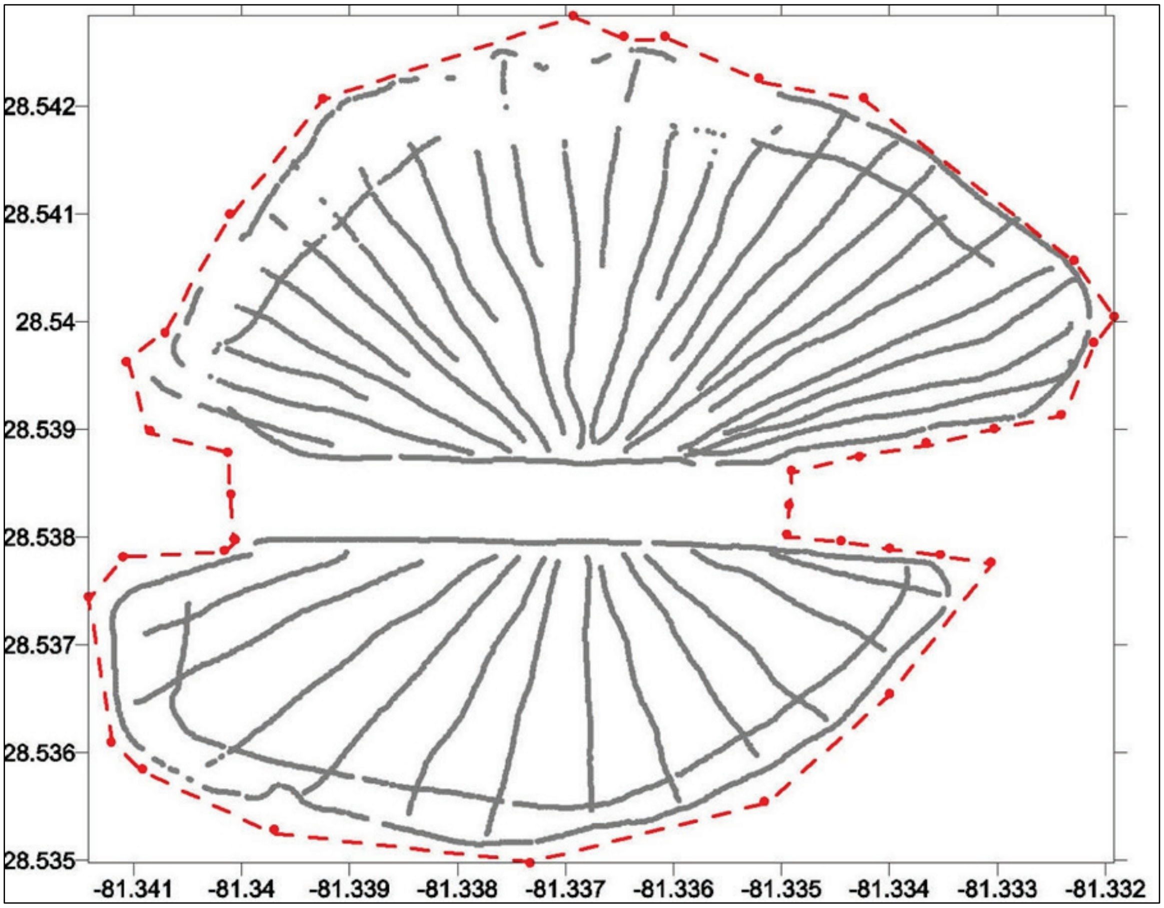


Figure B2. Post classed map of acoustically detected plant coverage. Coordinates in degrees latitude and longitude (NAD 83). Lake boundary in black dashed line.

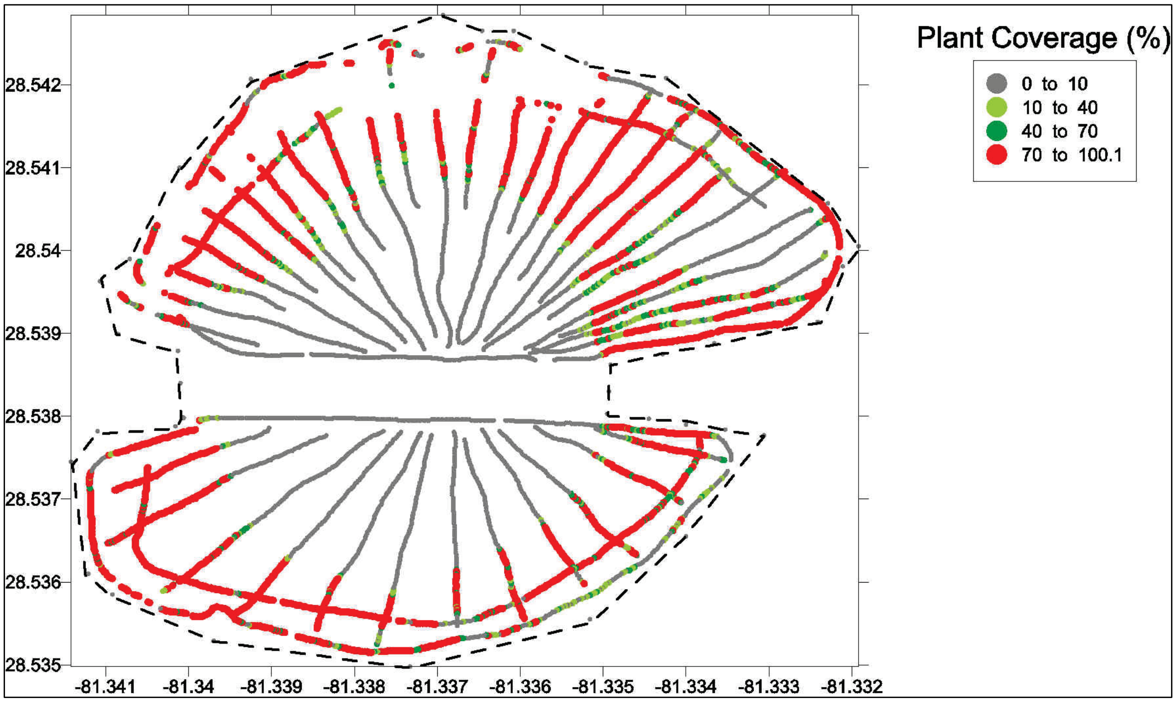
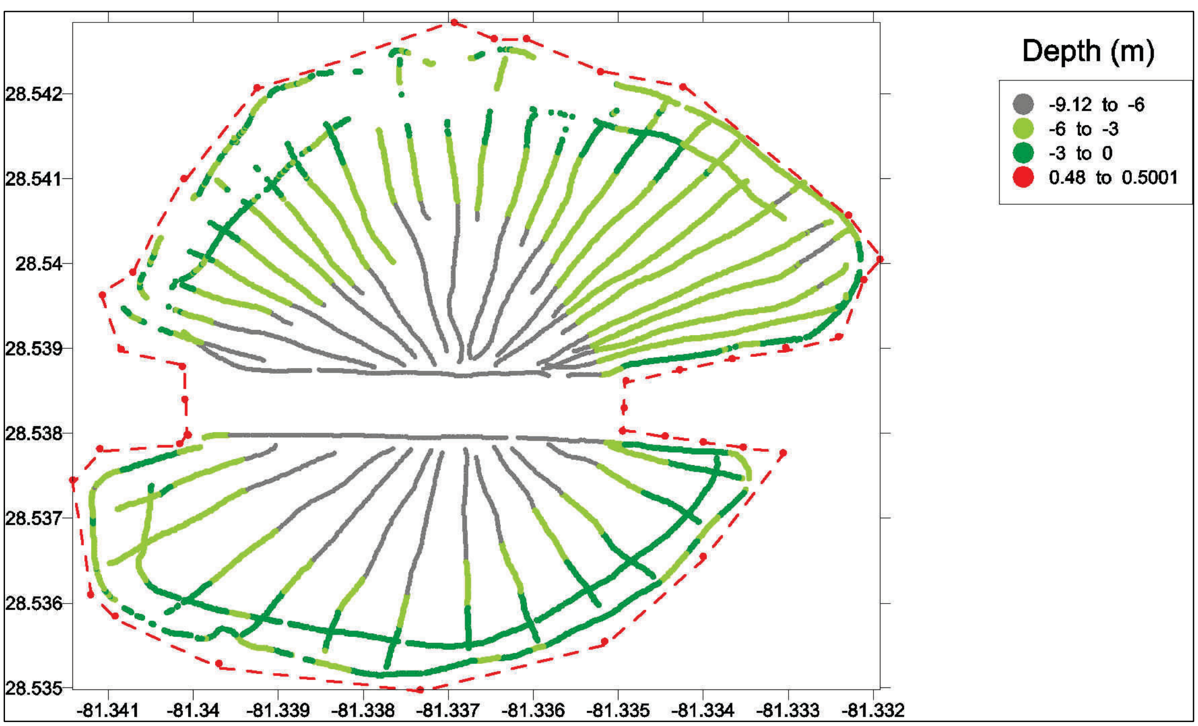


Figure B3. Post classed map of bathymetry. Coordinates in degrees latitude and longitude (NAD 83). Lake boundary in red-dashed line.



Data generated by the gridding procedure are displayed below (Figures B4 and B5).

Figure B4. 20-ft x 20-ft gridded output (Florida state plane, East zone, NAD 83) overlain on contour map (m).

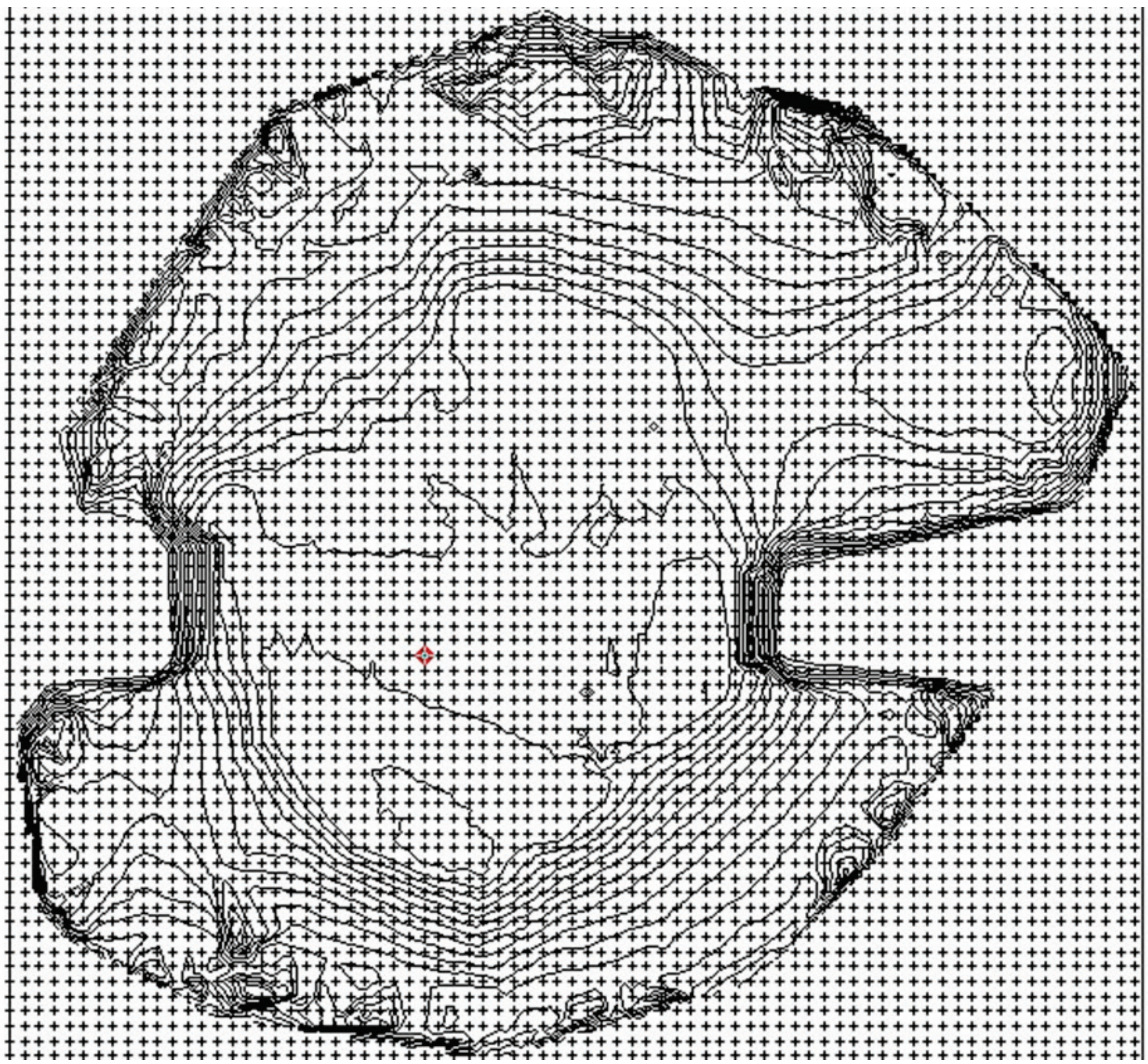
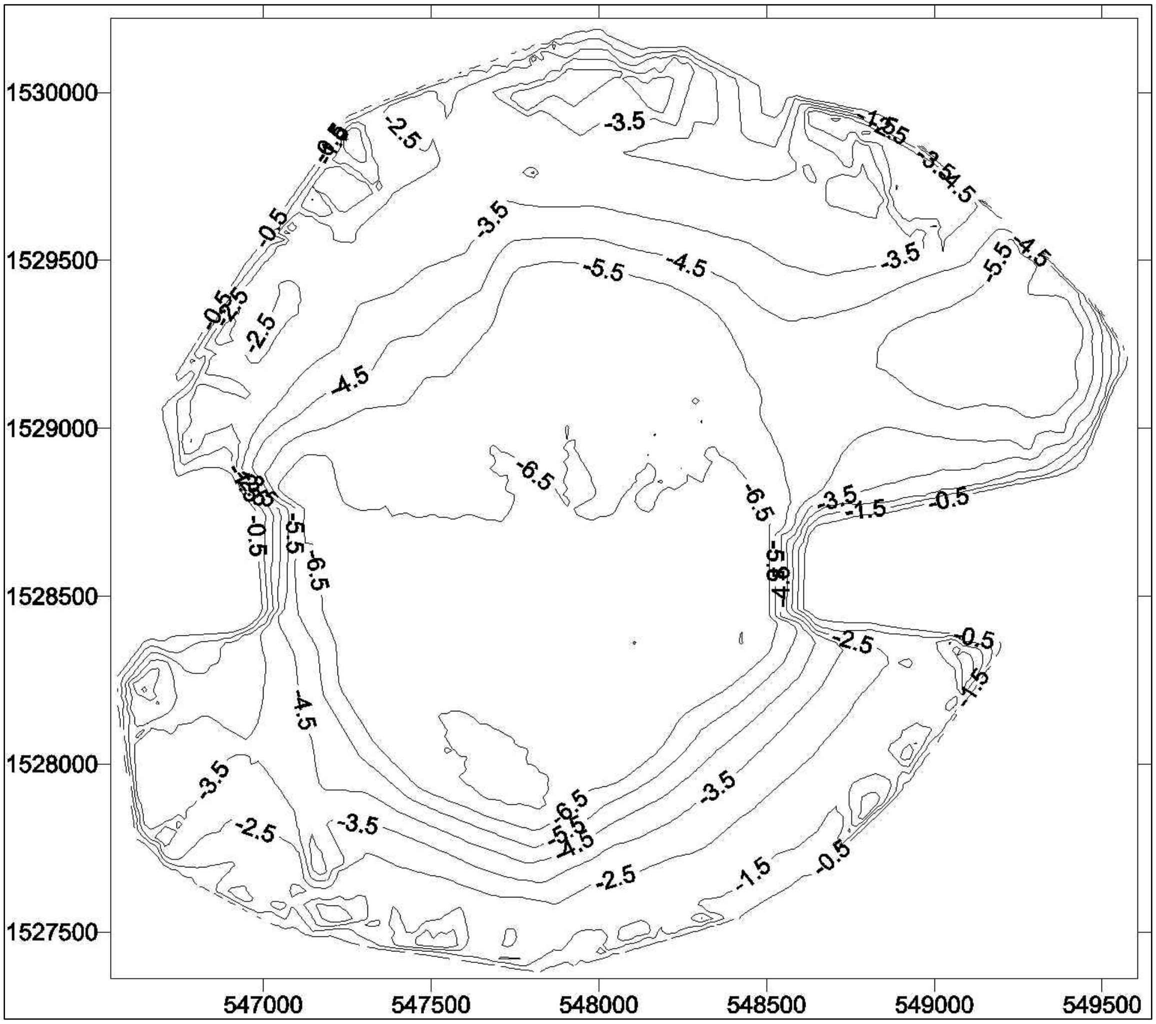


Figure B5. Depth (m) contour map in Florida State Plane (East) coor-dinates (ft) in NAD 83.

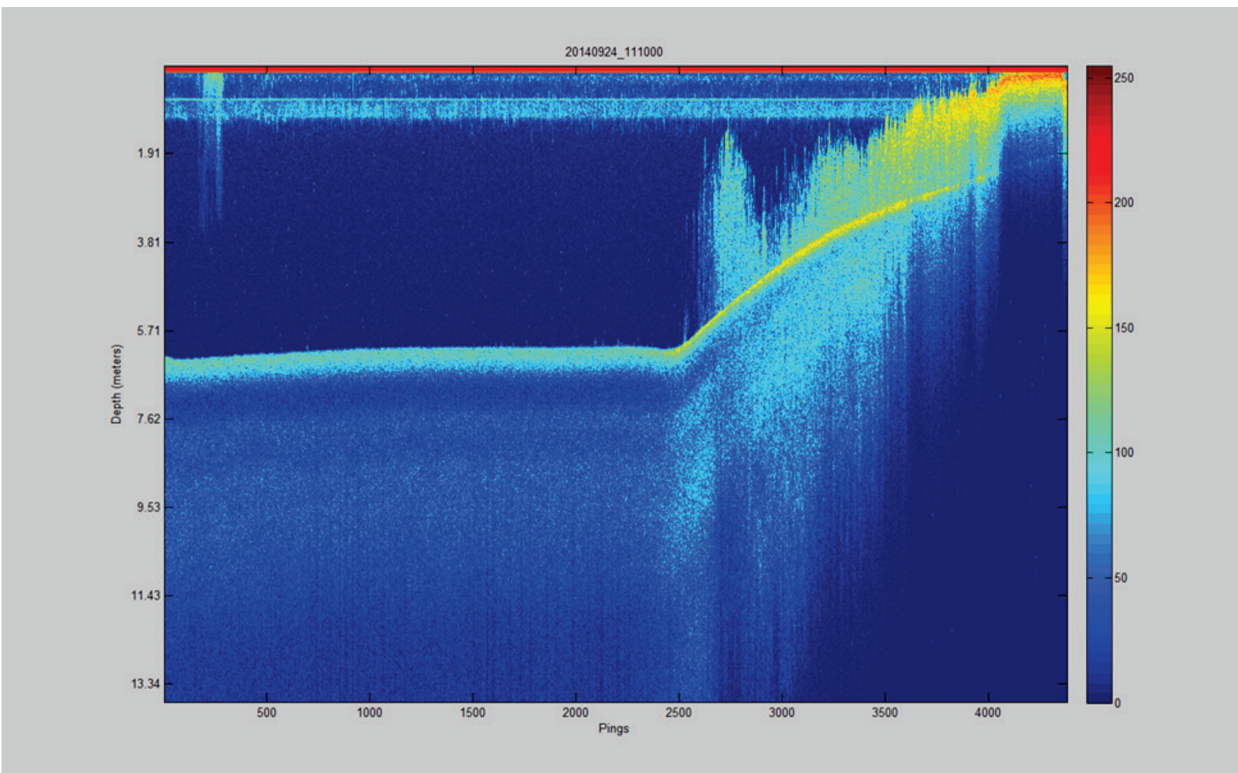


B.3 Observations and suggestions

Generally, the lake exhibited gradual depth changes, deep in the center (~26 ft) getting progressively shallower near shore. What was unexpected is that very near shore, particularly in the northern half, there are numerous large deep holes. Presumably these are sediment borrow pits used to build the steep shoreline around much of the lake, particularly along the northern shore by the airport. This location has the highest density of vegetation, therefore, much survey data in these areas were removed due to quality issues, so these areas are not defined in as high a resolution as desired.

An echogram of a spoke transect through dense vegetation in the northern half of the lake is presented (Figure B6). Depth is on the vertical axis and horizontal distance (actually time) is along the horizontal axis. Echo intensity is represented by the coloration, with high echo intensity in hot colors (red, orange, yellow) and low echo intensity in cool colors (blue, green, violet). The transect runs from near the center of the lake toward the northern shoreline. The flat lake center is around 6 m deep with a low reflectivity (soft) bottom. Towards shore, the bottom rises rapidly and exhibits more reflective (harder) characteristics. At a depth of roughly 5.5 m, very tall (3.8 m), very sparse hydrilla appears. At approximately 4 m depth, the density of plants increase markedly and continues to increase all the way to shore. At approximately 2.4 m depth, the canopy density becomes so great that the bottom cannot be acoustically detected. For this transect, this corresponds to the data section removed, because correct bottom tracking is the prerequisite for all other derived estimates. This transect is fairly typical of conditions along the northern and northwestern portions of the north half of the lake.

Figure B6. Example echogram of spoke transect in northern half of lake.



The specific requirements for selection of test plots are not known, however, depth accuracy is known to be important. For this reason it is recommended that any plots in the north or northwest parts of the northern half of the lake not be closer than 300 ft from the shoreline to assure adequate depth data. At other locations sites can be considerably closer to shore.

B.4 Data availability

Digital copies of all data presented and source data may be obtained by contacting the authors. Also, if additional graphics or data products not presented here are required, contact the authors and they will generate them.

Appendix C: Weather Conditions Reported by National Oceanic and Atmospheric Administration (NOAA) Station at Orlando International Airport Near Lake Underhill, FL

Table C1.

date	time (EST)	wind speed (mph)(G = gusts to)	wind direction (from)	temperature (deg – F)	note: plot treatment
2/10/16	10:53	15	W	53	
	11:53	20 (24 G)	NW	57	
	12:53	13 (24 G)	W	58	SE plot @ 13:22
	13:53	25 (35 G)	W	60	SW plot @ 14:08
	14:53	26 (32 G)	NW	61	NE plot @ 14:58
	15:53	16 (26 G)	W	59	
	16:53	22 (30 G)	W	56	
	17:53	16 (24 G)	W	53	
	18:53	17 (23 G)	W	50	
	19:53	13	W	49	
	20:53	10	W	47	
	21:53	8	W	46	
	22:53	7	W	45	
	23:53	7	W	44	
2/11/16	00:53	5	W	43	
	01:53	-0-	--	43	
	02:53	5	SW	40	
	03:53	-0-	--	42	
	04:53	-0-	--	43	
	05:53	3	N	42	
	06:53	3	NW	42	
	07:53	7	N	45	
	08:53	6	variable	50	
	09:53	6	N	54	SE plot @ 10:35
	10:53	6	N	58	SW plot @ 11:23

date	time (EST)	wind speed (mph)(G = gusts to)	wind direction (from)	temperature (deg – F)	note: plot treatment
	11:53	6	NW	61	NE plot @ 12:11
	12:53	-0-	--	63	
	13:53	5	NW	65	
	14:53	5	S	65	
	15:53	9	SW	66	
	16:53	9	W	66	
	17:53	6	S	65	
	18:53	6	S	61	
	19:53	7	S	59	
	20:53	9	W	56	
	21:53	-0-	--	54	
	22:53	-0-	--	56	
	23:53	3	S	52	
2/12/16	00:53	6	SW	50	
	01:53	6	SW	50	
	02:53	7	SW	49	
	03:53	5	S	50	
	04:53	6	SW	49	
	05:53	5	S	49	
	06:53	5	SE	47	
	07:53	5	S	50	
	08:53	3	SW	57	
	09:53	10	SW	64	
	10:53	9	SW	68	
	11:53	15 (21 G)	SW	72	
	12:53	12	W	74	
	13:53	13 (21 G)	W	75	

Appendix D: Example of 3-D Treatment System Output File and Data Definition for Dye Applications in Lake Underhill, FL, February 2016

Table D1.

GPS Date	GPS Time	GMT	Lon	Lat	Flow1	Prefix	Target	Actual	Speed			Width	Boom Flag	Mode Flag	Status	Volume1	Area1
2/10/2016	3:01:27 PM	20.025	-81.3325	28.53927	0	D	160	0	19	0	0	0	0	8	0	1	0
2/10/2016	3:01:28 PM	20.02528	-81.3325	28.53928	0	D	160	0	23	0	0	0	0	8	0	1	0
2/10/2016	3:01:29 PM	20.02556	-81.3325	28.53929	0	D	160	0	27	0	0	0	0	8	0	1	0
2/10/2016	3:01:30 PM	20.02583	-81.3325	28.53931	0	D	160	0	29	0	0	0	0	8	0	1	0
2/10/2016	3:01:31 PM	20.02611	-81.3325	28.53932	0	D	160	0	30	0	0	0	0	8	0	1	0
2/10/2016	3:01:32 PM	20.02639	-81.3325	28.53933	0	D	160	0	30	0	0	0	0	8	0	1	0
2/10/2016	3:01:33 PM	20.02667	-81.3325	28.53935	0	D	160	0	33	0	0	0	0	8	0	1	0
2/10/2016	3:01:35 PM	20.02722	-81.3325	28.53937	0	D	160	0	33	0	0	0	0	8	0	1	0
2/10/2016	3:01:36 PM	20.0275	-81.3324	28.53938	0	D	160	0	41	0	0	0	0	8	0	1	0
2/10/2016	3:01:37 PM	20.02778	-81.3324	28.53939	160	D	160	8	35	0	0	300	3	8	1	1	0
2/10/2016	3:01:38 PM	20.02806	-81.3324	28.5394	160	D	160	127	33	0	0	300	3	8	1	1	0
2/10/2016	3:01:39 PM	20.02833	-81.3324	28.53942	160	D	160	74	36	0	0	300	3	8	1	1	0
2/10/2016	3:01:40 PM	20.02861	-81.3324	28.53943	160	D	160	127	33	0	0	300	3	8	1	2	0
2/10/2016	3:01:41 PM	20.02889	-81.3324	28.53945	160	D	160	123	36	0	0	300	3	8	1	2	0
2/10/2016	3:01:42 PM	20.02917	-81.3324	28.53946	160	D	160	118	38	0	0	300	3	8	1	2	0
2/10/2016	3:01:43 PM	20.02944	-81.3324	28.53948	160	D	160	128	35	0	0	300	3	8	1	3	0
2/10/2016	3:01:45 PM	20.03	-81.3324	28.53951	160	D	160	120	37	0	0	300	3	8	1	3	0
2/10/2016	3:01:46 PM	20.03028	-81.3324	28.53952	160	D	160	133	33	0	0	300	3	8	1	4	0
2/10/2016	3:01:47 PM	20.03056	-81.3324	28.53953	160	D	160	119	37	0	0	300	3	8	1	4	0
2/10/2016	3:01:48 PM	20.03083	-81.3324	28.53955	160	D	160	138	32	0	0	300	3	8	1	4	0
2/10/2016	3:01:49 PM	20.03111	-81.3324	28.53956	0	D	160	0	32	0	0	0	0	8	0	5	0
2/10/2016	3:01:50 PM	20.03139	-81.3324	28.53957	0	D	160	0	31	0	0	0	0	8	0	5	0
2/10/2016	3:01:51 PM	20.03167	-81.3324	28.53959	0	D	160	0	29	0	0	0	0	8	0	5	0
2/10/2016	3:01:52 PM	20.03194	-81.3324	28.5396	0	D	160	0	31	0	0	0	0	8	0	5	0
2/10/2016	3:01:53 PM	20.03222	-81.3324	28.53961	0	D	160	0	27	0	0	0	0	8	0	5	0
2/10/2016	3:01:55 PM	20.03278	-81.3324	28.53963	0	D	160	0	30	0	0	0	0	8	0	5	0
2/10/2016	3:01:56 PM	20.03306	-81.3323	28.53964	0	D	160	0	28	0	0	0	0	8	0	5	0
2/10/2016	3:01:57 PM	20.03333	-81.3323	28.53965	0	D	160	0	28	0	0	0	0	8	0	5	0
2/10/2016	3:01:58 PM	20.03361	-81.3323	28.53966	160	D	160	53	29	0	0	300	3	8	1	5	0

D.1 Definition of relevant variables.

GMT – Greenwich mean time (decimal hours)

Lon – longitude, decimal degrees (negative indicates west of prime meridian), NAD83

Lat - latitude, decimal degrees, north, NAD83

Flow1 – computer -directed flow rate (gallons/acre x 10)

Prefix – active loop (D or L)

Target – target application rate (gallons/acre x 10)

Actual – actual measured discharge rate (gallons/acre x 10)

Speed – GPS measured boat speed (MPH x 10)

Width – boom width (inches), zero when not discharging

Volume1 – cumulative volume discharged (gallons x 10)

Area1 – cumulative area treated (acres x 10).

REPORT DOCUMENTATION PAGE					*Form Approved OMB No. 0704-0188*
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1. REPORT DATE *(DD-MM-YYYY)* September 2019	**2. REPORT TYPE** Final report				**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Development of an Automated Digital System for Delivery of Aquatic Herbicides					**5a. CONTRACT NUMBER**
					5b. GRANT NUMBER
					5c. PROGRAM ELEMENT NUMBER
Bruce M. Sabol, Brett Bultemeier, R. Eddie Melton Jr., Kurt D. Getsinger, and Michael D. Netherland					**5d. PROJECT NUMBER** 96X3122
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					11. SPONSOR/MONITOR'S REPORT NUMBER(S)
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14. ABSTRACT The National Pollutant Discharge Elimination System (NPDES) requires that aquatic herbicide applicators revise treatment strategies to achieve high precision delivery of products and detailed reporting of treatments. A unique three-dimensional (3-D) technology was developed to meet these requirements using a new system that accounts for depth variation within a treatment area. Adaptations to a 3-D aquatic environment must account for variable depth, boat speed, difficult to see treatment plot boundaries, prevention of overtreatment by unintended crossing of treatment lines, and effects of horizontal and vertical dilution of the applied chemical. A test was conducted in Lake Underhill, FL, during which dye was delivered by the new system using the existing techniques and using the new 3-D technique. Results showed that a computer could automate a liquid herbicide treatment process and account for depth variations within a plot. Testing of the delivery system was a successful phase in developing and refining precision application techniques for submersed aquatic herbicide applications.					
15. SUBJECT TERMS	Invasive plants Aquatic plants Introduced organisms		Aquatic herbicides Automation		
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