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Aquatic Plant Control Research Program

Demonstration and Evaluation of Eurasian Watermilfoil Control using Aquatic Herbicides in Fort Peck Lake, MT

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Environmental Laboratory

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Final Report

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Abstract

Eurasian watermilfoil (EWM) was first observed in Fort Peck Lake, MT in 2010 and has spread to over 100 locations in the lake. In 2012, field trials were conducted to evaluate aquatic herbicides for controlling EWM and provide management guidance. This work follows those initial 2012 demonstrations.

Five sites were identified for herbicide treatments and bulk water exchange processes were determined using inert tracer dye, rhodamine WT (RWT). Field trials conducted in 2014 spanned two growing seasons, summer (July) and fall (September). Treatments were with a variable-depth application technique, or for one plot, a hand gun from the surface. Vegetative communities were assessed at pretreatment, and at 8 and 52 weeks.

Non-target native vegetation was sparse pretreatment in all plots, but generally survived treatments. Treatments had no impacts on water quality measured in the field, including dissolved oxygen levels. Control of EWM was limited (< 50%) in small, open-water plots treated with diquat and endothall, where no barrier curtains were deployed. Control of EWM was near 100% through one year after treatment in plots where barrier curtains mitigated bulk water exchange processes and extended herbicide contact times were maintained.

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Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APRCP). The APCRP is sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), and is assigned to the U.S. Army Engineer Research and Development Center (ERDC) under the purview of the Environmental Laboratory (EL), Vicksburg, MS. Funding was provided under 96X3122. The APCRP is managed under the Civil Works Environmental Engineering and Sciences Office.

This work was partially funded by the Fort Peck Project Office, U.S. Army Corps of Engineers (USACE) Omaha District. Cooperative efforts were provided by the Fort Peck Project Office, Tetra Tech, Inc. (Portland, OR), Environmental Science Associates (Bend, OR) and Cold Water Environmental LLC (Lake Elmo, MN). Work was coordinated with the Charles M. Russell National Wildlife Refuge, a major stakeholder on Fort Peck Lake and the Montana Fish, Wildlife and Parks.

The work was performed by the Aquatic Ecology and Invasive Species Branch (EEA), Ecosystem Evaluation and Engineering Division (EE), ERDC-EL. At the time of publication, Dr. Tim E. Lewis was Chief, CEERD-EEA; Mr. Mark D. Farr was Chief, CEERD-EE; Dr. Alfred Cofrancesco, EL, Technical Director. Dr. Linda Nelson, EL, was Assistant Technical Director and Program Manager for the APCRP. The Deputy Director of EL was Dr. Jack E. Davis and the Director was Dr. Ilker R. Adiguzel.

At the time of publication of this report, Dr. David W. Pittman was Director of ERDC. COL Teresa A. Schlosser was ERDC Commander.

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 (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
Mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
ounces (U.S. fluid)	2.957353 E-05	cubic meters
pints (U.S. liquid)	4.73176 E-04	cubic meters
pints (U.S. liquid)	0.473176	liters
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
pounds (mass) per square yard	0.542492	kilograms per square meter
quarts (U.S. liquid)	9.463529 E-04	cubic meters
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

ac	acres
APCRP	Aquatic Plant Control Research Program
CET	Concentration and Exposure Time
cfs	cubic feet/second
cms	cubic meters/second
DAT	Day(s) After Treatment
DENA	diethylnitrosamine
DO	Dissolved Oxygen
DoD	Department of Defense
EL	Environmental Laboratory
EE	Ecosystem Evaluation and Engineering Division
EEA	Aquatic Ecology and Invasive Species Branch
EPA	Environmental Protection Agency
EWM	Eurasian watermilfoil
ERDC	Engineer Research Development Center
ft	feet
GPS	Global Positioning System
ha	hectare
HQUSACE	Headquarters, U.S. Army Corps of Engineers
m	meters
MCL	Maximum Contamination Level
MSDS	Material Safety Data Sheet
PAC	Percentage Area Covered
ppm	parts per million
PVI	Percent Vegetation Inhabited
RWT	rhodamine WT
TR	Technical Report
USACE	U.S. Army Corps of Engineers
WAT	Week(s) After Treatment
YAT	Year(s) After Treatment

1 Introduction

1.1 Background

The invasive Eurasian watermilfoil (EWM) (*Myriophyllum spicatum*) is a widespread nuisance submersed plant in lakes, rivers, ponds, and reservoirs in the United States (Figure 1). Its distribution throughout Montana, while comparatively less than most states, has spread rapidly since first reported in Noxon Rapids and Cabinet Gorge Reservoirs in the Columbia River drainage in 2007. It is known to occur in Broadwater, Flathead, Gallatin, Jefferson, Madison, Richland, Roosevelt, Lake, Sanders, Garfield, McCone, Petroleum, Phillips and Valley counties, which include the Missouri River drainage. First observed in Fort Peck Lake in 2010, EWM is now known to occur in over 100 locations scattered around the reservoir, including within the dredge cut areas and the Missouri River. If left unmanaged, these riverine systems will be impacted by this species, and these sites will be continuous sources of plant fragments to downstream waters.

Figure 1. Eurasian watermilfoil at Fort Peck Lake, MT.

1.2 Approach

Chemical management of submersed aquatic plants in areas of high water exchange is challenging due to the reduced herbicide concentration and exposure time (CET). Chemicals are diluted by the surrounding untreated water, and therefore, herbicide efficacy to target plants is reduced (Netherland et al. 1991; Netherland and Getsinger 1992; Netherland et al. 1993). The use of herbicide combinations (i.e., tank mixes) may provide a synergistic effect to improve efficacy in areas where water exchange dilutes aqueous herbicide concentrations (Getsinger et al. 1996a). Concurrent applications of herbicide and an inert tracer dye are routinely used to determine bulk water exchange patterns and predict herbicide dissipation under field conditions (Turner et al. 1994; Fox et al. 2002; Wersal and Madsen 2011). Measuring these factors can elucidate treatment efficacy (Netherland et al. 1991; Netherland and Getsinger 1992; Getsinger et al. 1996b; Getsinger and Netherland 1997).

1.3 Scope

In submersed plant stands, water exchange processes are complex, subtle, and difficult to characterize. In these situations, inert fluorescent dyes can provide an estimate of bulk water exchange and be used to predict real-time, post-treatment dispersion/dissipation of aquatic herbicides. When coupled with known herbicide CET relationships, results from this tracer dye technique can be used to develop prescription treatment strategies where the appropriate herbicide, formulation (liquid or granular), application technique, and dose are used to overcome impacts of water exchange and to provide desired and selected control of target plants (Getsinger et al. 2013; Pennington et al. 2015).

1.4 Environmental setting

1.4.1 Hydrology

The Missouri River is the primary hydrological source to the Fort Peck Lake, to include the Dredge Cuts and downstream in the emergency spillway. Water management activities on the Fort Peck Lake has direct influence on the hydrological conditions of the Dredge Cuts and the Missouri River downstream of the spillway. Fort Peck Lake is the first in a series of six U.S. Army Corps of Engineers (USACE) dams and reservoirs on the Missouri River, which is collectively referred to as the Mainstream Reservoir System (System). The System is operated under guidelines in the Missouri River Mainstream System Master Water Control Manual (USACE 2006).

While, hydrological conditions in Fort Peck Lake are actively managed to maintain the following four regulation zones: (1) Exclusive Flood Control, (2) Annual Flood Control, (3) Carryover Multiple Use and (4) Permanent Pool, conditions in the Dredge Cuts are not. While the hydrological setting of the Dredge Cuts are consequent of the management of Fort Peck Lake, they are fairly static throughout the seasons. During the July 2014 plant assessment surveys, average water releases from the Fort Peck Dam were 207 cubic meters/second (cms) or 7,300 cubic feet/second (cfs). During the September 2014 surveys, average water releases from the Fort Peck Dam were 142 cms (5,000 cfs).

1.4.2 Climatic conditions

Particular climate conditions in the Fort Peck Lake system are marked by distinct seasonal changes. Mountains to the west block cool, moist Pacific Ocean air masses from moving eastward, however; there are no barriers to the north or south. Consequently, cold, dry continental air masses move through the area in the winter, and warm, humid masses, originating in the tropical regions, flow through the area in the summer. It is these movements and their associated fronts that cause nearly continuous wind throughout the region (USACE 2008). Prevailing winds during both the summer and fall field trials predominantly originated from the east.

1.5 Objectives

In an effort to continue to evaluate potential herbicide options for controlling EWM in hydraulically complex systems, a series of field trials were conducted in selected areas of the Fort Peck Lake system in Montana. These trials were based on results of previous field trials in 2012.

Objectives of the study were to

- evaluate site-specific treatment approaches to demonstrate how EWM can be controlled using herbicides under a variety of environmental conditions common to the Fort Peck Lake system,
- evaluate the use of barrier curtains to limit bulk water exchange and maximize aqueous herbicide contact time within the targeted treatment areas, and
- provide improved guidance to the Fort Peck Project Office for controlling EWM in the lake.

2 Materials and Methods

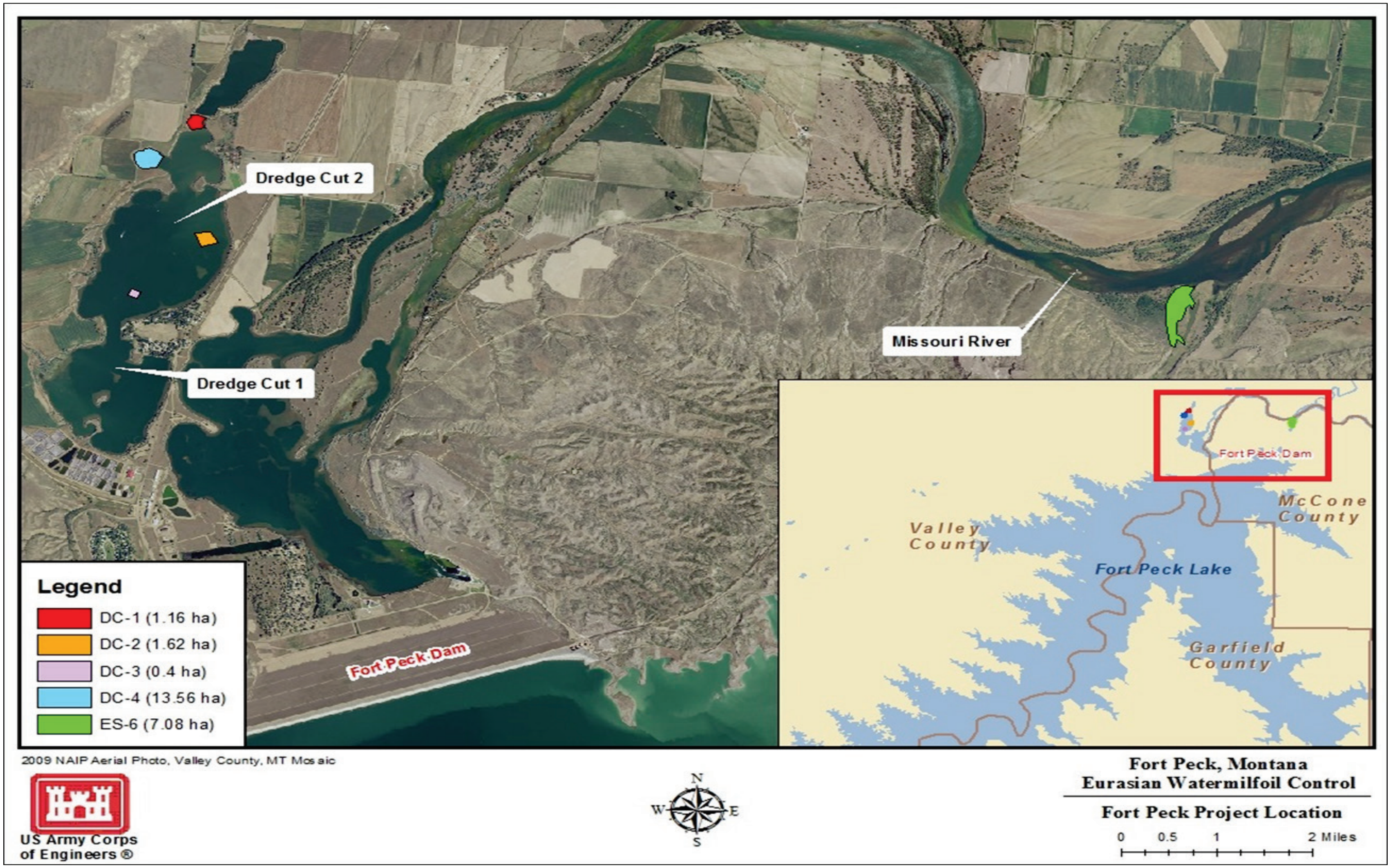
2.1 Description of treatment plots

Two locations within the Fort Peck Lake system, the northern dredge cut area, (known as Dredge Cut 2), located north of the main body of the lake, and the emergency spillway of the Fort Peck Dam on the Missouri River were selected for this field study to demonstrate the application of aquatic herbicides to control EWM (Figure 2). Within these two locations, the following five treatment plots were established: four in Dredge Cut 2 (DC-1, DC-2, DC-3, and DC-4) and one in the emergency spillway (ES-6) using Global Positioning System (GPS) technology. All plots combined comprised a total of 23.82 hectare (ha) or 58.86 acres (ac).

Plot selection was based on the following parameters: (1) known infestation of EWM, (2) reasonable access to the site, (3) proximity to federally listed species habitat, and (4) relative ease of installing a barrier curtain to prevent bulk water exchange processes in selected plots.

Plots were situated in areas where moderately dense stands of EWM occurred, representative of EWM infestations in the Fort Peck Lake system. Plots also contained populations of desirable native submersed plants. Average depth of plots located in the littoral zone of Dredge Cut 2 ranged from 1.86 to 3.93 meters (m) or 6.10 to 12.89 feet (ft) and in the littoral zone of the emergency spillway average depths ranged from 1.52 to 1.95 m (4.98 to 6.40 ft).

Figure 2. July and September 2014 treatment plot locations at Fort Peck Lake, MT.



2.2 Site preparation

2.2.1 Treatment plots DC-1, DC-4 and ES-6

Barrier curtains (DOT Medium Duty/moving Water Turbidity Curtain, Enviro-USA, Cocoa, Florida) were installed at DC-1, DC-4 and ES-6 prior to herbicide application to reduce bulk water exchange in these plots during treatment periods, thereby, extending herbicide CET relationships around the target plants. The curtain at DC-1 consisted of ten, 6.1 m deep by 15.24 m long sections (20 x 50 ft). When sections of the curtain were connected, a total length of 152.4 m (500 feet) was achieved. The barrier curtain installed at DC-4 consisted of ten, 6.1 m deep by 15.24 m long sections (20 x 50 ft) and one, 3.05 m deep by 6.1 m wide (10 x 20 ft) section. When sections of the curtain were connected, a total length of 158.5 m (520 ft) was achieved. The barrier curtain installed at ES-6 consisted of two, 1.52 x 6.1 m (5 x 20 ft), four, 3.05 x 6.1 m (10 x 20 ft) and five, 6.1 x 15.24 m (20 x 50 ft) sections. When sections were connected, a total length of 112.78 m (370 ft) was achieved. The tops of the curtains were buoyed with micro-foam floatation devices while the bottoms were weighted with galvanized chain column from surface to bottom. Curtains were towed into position with a boat and anchored at both ballast to ensure that curtains would be secured in the water ends along the shoreline. To stabilize these curtains, a Danforth-style anchor system was deployed at the approximate center of the barrier (Figure 3). Four people laboring approximately eight hours were required to install the curtains in each treatment plot.

Figure 3. DC-1 after installation of the barrier curtain in July 2014 in Dredge Cut 2 at Fort Peck Lake, MT.

2.2.2 Treatment Plots DC-2 and DC-3

DC-2 and DC-3 were established as open water sites. Since no barrier curtains were installed to limit water movement, these plots could be impacted by water-exchange processes along all boundaries.

2.3 Vegetation assessments

An assessment of plant density and diversity was conducted in all plots pretreatment using the point-intercept method developed for quantitatively assessing submersed plant communities (Madsen 1999). A 25 m grid was established within each plot prior to treatment. At each grid-point, a double-sided thatch rake attached to a pole (Figure 4) was slowly lowered and twisted one full turn. Upon retrieval to the surface, each plant species attached to the rake was recorded and ranked on a scale of 0 to 5 (0=no plants to 5=surface canopy of vegetation at the grid-point).

Figure 4. Example of typical EWM density in the selected treatment plots of Fort Peck Lake system, MT.

Pretreatment plant density data for plots DC-1, DC-2, DC-3 and DC-4 was collected on 17 July 2014. Plot size determined the number of sample collection points. The following plots were divided into multiple collection points as follows: DC-1 (28), DC-2 (27), DC-3 (5) and DC-4 (55). Plant data collection for ES-6 occurred on 20 July 2014 and was divided into 141 sample collection sites; 52 of which were inaccessible by boat due to low water conditions, or in some cases dewatered; therefore, data was collected at only a total of 89 points. During these sampling events, average water releases from the Fort Peck Dam were approximately 207 cms (7,300 cfs).

Plant density was again assessed in these plots at eight weeks after treatment (WAT) (15–18 September 2014) and one year after treatment (YAT) (31 August and 1 September 2015) using previously described methods (Table 1). During plant assessment surveys conducted in September 2014, average water releases from the Fort Peck Dam were approximately 139 cms (4,900 cfs).

The eight WAT plant assessments were conducted on 18 September 2014 for treatment plots DC-1 and DC-2, which were divided into 19 and 49 collection points, respectively. Vegetation assessments conducted at DC-2 and DC-3 on this date also functioned as pretreatment data collection as DC-2 and DC-3 were retreated 23 September 2014 (Table 1). The eight

WAT plant assessments for treatment plots DC-3 and DC-4 occurred on 15 September 2014. DC-3 and DC-4 were divided into 5 and 73 collection points, respectively. Treatment plot ES-6 was assessed on 16 September 2014; 48 of the established 141 sample collection sites were inaccessible by boat, or in some cases, completely dewatered due to low water levels, therefore, plant data were not recorded at those sites.

During one YAT plant assessment surveys conducted in September 2015, average water releases from Fort Peck Dam were approximately 226 cms (8,000 cfs). DC-1 was divided into 27 sample collection sites, DC-2 was divided into 27 sample collection sites and five sample collection sites for DC-3 and 74 sample collection sites for DC-4 were all assessed on 1 September 2015. At one YAT, ES-6 plant assessment was conducted on 31 August 2015, with 84 of the 141 established sample collection sites accessible. The remaining sample collection sites at ES-6 were dewatered due to low water levels, therefore, plant data were not recorded at those sample sites.

Chi-square analysis was performed on data collected for vegetation assessments to determine deviations in observed frequency of aquatic vegetation and to determine if those changes were significantly different from pretreatment conditions.

Table 1. Vegetation assessment schedule of treatment plots for field trials at Fort Peck, MT.

Vegetation Assessments				
Treatment Plot	Pretreatment	8 WAT	Pretreatment and 8 WAT	1YAT
DC-1	7/7/2014	9/18/2014	-	9/1/2015
DC-2*	7/7/2014	-	9/18/2014	9/1/2015
DC-3*	7/7/2014	-	9/15/2014	9/1/2015
DC-4**	9/15/2014	-	-	9/1/2015
ES-6**	9/16/2014	-	-	8/31/2015

*DC-2 and DC-3 were treated both in July 2014 and September 2014; therefore, the vegetation assessment conducted in September 2014 at these plots represented both eight WAT and “pretreatment” data.
**Vegetation assessments were conducted in DC-4 and ES-6 on July 7 and 20, 2014, respectively. However, these plots were not treated with herbicide until September due to irrigation restrictions and low-water conditions. No eight WAT data was collected at DC-4 and ES-6 due to major storm events.

Immediately prior to herbicide application during the treatment periods, a Lowrance® HDS Digitial Ecosounder System with a Structure Scan Module was used to record data of the submerged aquatic vegetation profile (biovolume) in all plots with the exception of DC-3 and ES-6 during the September treatment. Due to a system error, submerged aquatic vegetation was not measured at DC-3 in July. Submerged aquatic vegetation was not measured with the Digital Echosounder System in treatment plot ES-6 in September due to the shallow water, as the shallow-draft boat utilized to access the treatment plot was not equipped with this system.

2.4 Herbicide products

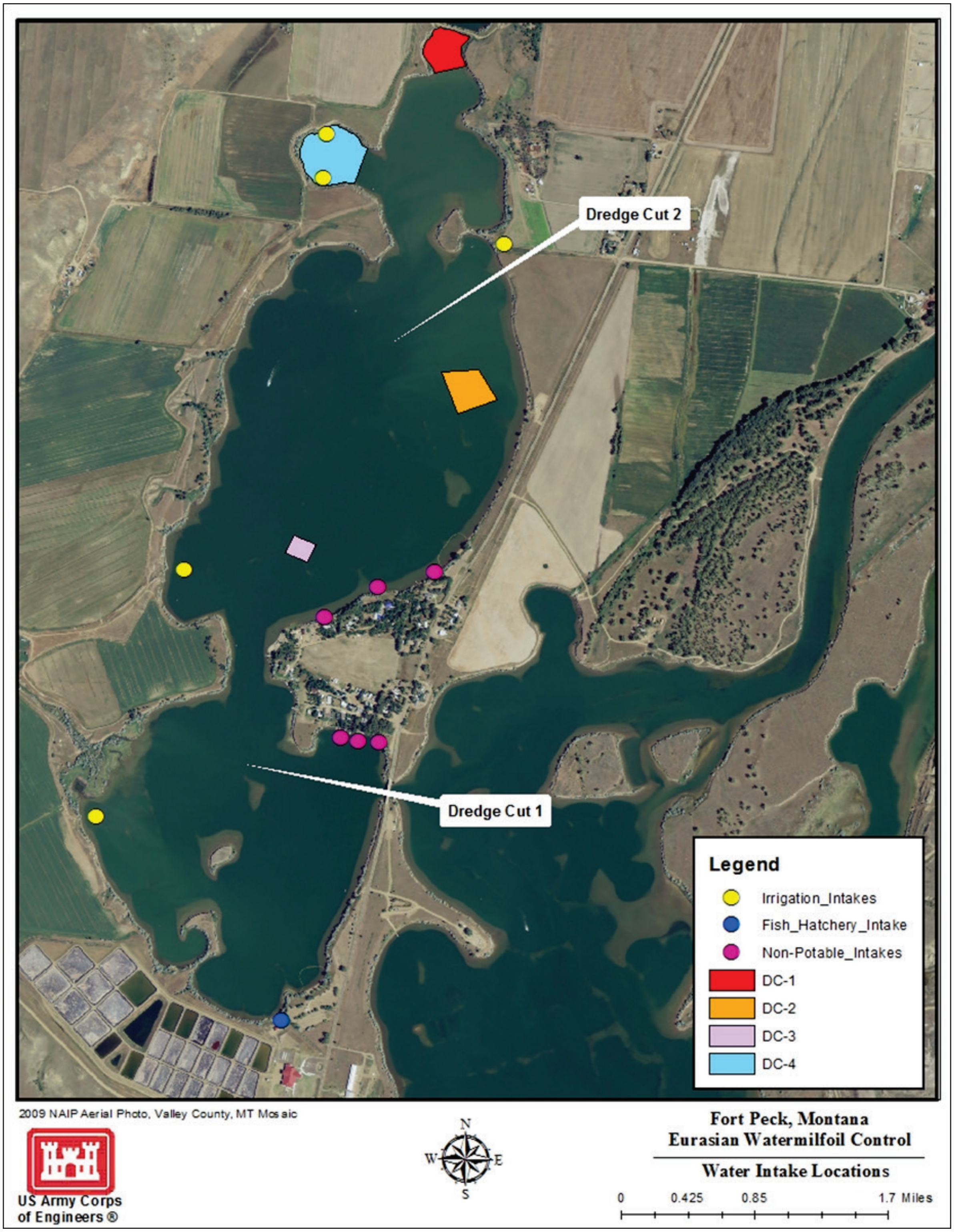
Liquid formulations of the post-emergent aquatic herbicides, endothall (dipotassium salt- 7-oxabicyclo [2.2.1] heptanes-2-3-dicarboxylic acid) as Aquathol® K, triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) as Kraken®, and diquat dibromide (6,7-dihydrodipyrido [1,2-a:2',1'-c] pyrazinediium) as Reward®, were used for this study, either alone or in combination. Endothall is a contact herbicide that that works by interfering with plant respiration and disrupting plant cell membranes (EPA 2005). Endothall has shown some level of species selectivity when used in aquatic sites (Skogerboe and Getsinger 2001). Triclopyr is a selective systemic herbicide that works as an auxin-mimic by moving through plant tissue and interrupting cell growth and division (EPA 1998). Triclopyr is primarily selective for dicot (broadleaved) species rather than monocots (grasses). Diquat dibromide is a non-selective contact herbicide that works by interfering with photosynthesis and disrupting cell membranes (EPA 1995). Each of these herbicides have been utilized for managing EWM for many years.

All products are approved for aquatic site use by the U.S. Environmental Protection Agency (EPA) and by the Montana Department of Agriculture for use in Montana and were evaluated in the *Environmental Assessment and Findings of No Significant Impact: Control of Eurasian Watermilfoil, Fork Peck Project Area, Various Counties, MT* (USACE, 2011) against listed species found in Montana. Concurrent applications of the inert fluorescent dye, rhodamine WT (RWT), were applied with the herbicides to determine bulk water exchange patterns and potential aqueous herbicide exposure times under field conditions.

All use restrictions (Federal and state) on the herbicide labels were met, which included potable water and irrigation set-back distances per label specific requirements. There are no swimming or fishing restrictions on the herbicides used in these evaluations. There were no potable water intakes within 183 m (600 feet) of any plots treated with endothall or within 488 m (1,600 feet) of any plots treated with triclopyr, per label setback restrictions. No setback requirements exist for diquat. All required permits for the herbicide applications were obtained by the Fort Peck Project Office. Herbicide-specific use restrictions are provided in Appendix 1.

Twelve water intakes were located in the vicinity of the treatment plots within Dredge Cut 1 and Dredge Cut 2 (Figure 5). Five are used for crop irrigation (two of which are located inside DC-4). One intake provides water for the Montana Fish, Wildlife and Parks fish hatchery and is located on the southern edge of Dredge Cut 1. The remaining six intakes are non-potable. The Fort Peck Project Office coordinated with all intake operators prior to application to ensure intakes were not in use according to label restrictions.

Figure 5. Location of water intakes within Dredge Cut 1 and Dredge Cut 2 in relation to the treatment plots on Fort Peck Lake, MT in 2014.



2.5 Treatment schedule, herbicide rates, and application techniques

Herbicide application rates for this study were selected based on results from previous growth chamber evaluations (Netherland et al. 1991; Netherland and Getsinger 1992) and successful field verification trials in eastern Washington State, western Montana (Getsinger et al. 1997; Wersal and Madsen. 2011; Getsinger et al. 2013; Getsinger et al. 2014), and in Fort Peck Lake in 2012 (Pennington et al. 2015). Treatment dates and nominal herbicide and dye application rates are shown in Table 2. The liquid RWT dye was applied as a tank mix with water combined with herbicides using a variable-depth injection system ([LittLine®], Clean Lakes, Inc., Coeur d'Alene, ID) to achieve an aqueous concentration of 10 µg /L (10 ppb) in each plot. This dye treatment process simulated an operational liquid aquatic herbicide application. In cases where products were not compatible within one tank, two separate tanks were used to apply herbicides at the nominal rates required.

Herbicide and dye was applied by a licensed applicator using either a LittLine® system from a semi-v hulled boat, or in shallower waters by a 113.5-liter (30 gallon) polyurethane tank mounted to a shallow-draft flat-bottom boat. The LittLine® system was mounted on a boat propelled by outboard motors, delivering the products to the mid and lower portions of the water column using two drop hoses. In shallow areas, dye and herbicides were applied using a hand gun with a pressurized spray being delivered to the water surface (Figure 6). Herbicide/dye treatment swaths across the plots were approximately 15 m (50 ft) wide as the application boat traveled 5–6.5 km/h (3–4 mph) across the plots.

Table 2. Herbicide and dye application rates and schedules of treatment plots for summer (July 2014) and fall (September 2014) field trials at Fort Peck, MT.

July 2014											
Treatment Plot	*Hectares*	*Mean Depth (m)*	*Barrier Curtain*	*Triclopyr*		*Endothall*		*Diquat*		*Rhodamine WT*	
				mg/L	Site Total (L)	mg/L	Site Total (L)	mg/L	Site Total (L)	µg/L	Site Total (L)
DC-1	1.16	3	Yes	0.25	6.39	0.75	13.56	-	-	10	0.63
DC-1 II*	1.16	3	Yes	-	-	-	-	-	-	10	2.1
DC-2	1.62	3.93	No	-	-	1	33.02	0.12	8	10	2.39
DC-3	0.4	1.86	No	-	-	-	-	0.24	2	10	0.31
DC-4	13.56	-	Yes	No Herbicide or Dye Treatment							
ES-6	7.08	1.52	Yes	-	-	-	-	-	-	10	4.38
September 2014											
Treatment Plot	*Hectares*	*Mean Depth (m)*	*Barrier Curtain*	*Triclopyr*		*Endothall*		*Diquat*		*Rhodamine WT*	
				mg/L	Site Total (L)	mg/L	Site Total (L)	mg/L	Site Total (L)	µg/L	Site Total (L)
DC-1	1.16	3.26	Yes	No Herbicide or Dye Treatment							
DC-2	1.62	3.66	No	-	-	-	-	0.12	8.4	10	2.5
DC-3	0.4	3.17	No	-	-	-	-	0.24	2.6	10	0.4
DC-4	13.56	3.81	Yes	0.25	23.19	0.75	49.2	-	-	10	5.1
ES-6	7.08	1.95	Yes	0.35	25.18	1	50.88	-	-	10	4

*Note DC-1 II: On the afternoon of 24 July 2014, a storm event produced wind speeds as high as 120 km/h (75 mph); this inclement weather resulted in the barrier curtain becoming entirely detached from its anchor system in the treatment area. The barrier curtain was reset on 29 July 2014, and a dye study was conducted. No herbicide was applied to the site as two days had lapsed since initial treatment, and it was hypothesized that control could have been achieved from the exposure time from completion of application on 22 July and across the 52-hour period prior to the wind storm.

Herbicide applications conducted in 2014 spanned two phases of the growing season, summer (July) and fall (September). Treatment plots DC-1, DC-2, and DC-3 were treated on 22 July 2014, water temperature averaged 20.3ºC (68.5°F) with winds from the northeast up to 3.9 km/h (2.4 mph). Treatment plot ES-6 was utilized as a dye study site and treated only with RWT on 24 July 2014, water temperature averaged 19.1ºC (66.4°F) with winds from the southeast up to 14 km/h (8.7 mph). Treatment plot DC-4 received no herbicide or dye treatments in July due to adherence to irrigation restrictions within the plot. During herbicide application in July, winds were calm and skies were clear; however, on the afternoon of 24 July 2014, wind speeds as high as 120 km/h (75 mph) were reported. This wind storm event resulted in the barrier curtain becoming entirely detached from the treatment area at DC-1. The barrier curtain was reset on July 29, 2014 and a dye study was conducted (refer to footnote of Table 2). At the emergency spillway, skies were overcast but winds were calm during treatment. The high winds on 24 July did not impact the barrier curtains at DC-4 or ES-6.

Treatment plots DC-2, DC-3, and DC-4 were treated on 23 September 2014, water temperature averaged 15.3°C (59.5°F), and winds were from the west up to 7.2 km/h (4.5 mph). Plot ES-6 was treated on 24 September 2014, and no average water temperature was recorded as the treatment was applied by a boat not equipped with the required instrumentation, nor were datasondes available for use during the fall treatment period. Treatment plot DC-1 was left as an untreated site (Table 2) due to lack of EWM from the summer treatment period. Plots DC-2 and DC-3 were re-treated in September since control of EWM was not achieved following herbicide treatments applied in July.

Figure 6. Variable depth LittLine® application of herbicide and rhodamine WT dye on 23 September 2014.

Bulk water-exchange processes within the treated plots were determined by measuring RWT dye in situ using a handheld Turner Designs Cyclops-7 submersible fluorometer (Sunnyvale, CA) at predetermined "permanent" locations within the treatment plots. Measurements were recorded at 30.5 cm (1 ft) below the surface, mid-depth, and 30.5 cm (1 ft) above the bottom of the lakebed. Measurements were recorded immediately after treatment and every hour until detectable levels were one quarter below the target concentration of 10 µg /L, or ≤ 2.5 µg /L.

2.6 Water quality

Three hydrolab datasondes were deployed in the treatment plots prior to each treatment. During July 2014, the datasondes were suspended at mid-depth in the water column at DC-1, DC-2, DC-3, and ES-6. Due to high wind speeds (as high as 120 km/h (75 mph)) on the afternoon of 24 July, recorded data from the datasondes were expunged in DC-1. Following the subsequent dislodged barrier curtain at DC-1 from the inclement weather, the barrier curtain was reset, and two datasondes were deployed within the DC-1 plot on 28 July. The data presented in Table 2 depicts the dye application that was conducted on 29 July (identified as DC-1II). One datasonde was suspended just below the surface at 30.5 cm (1 ft), and the other was suspended approximately 30.5 cm (1 ft) above the sediment surface. These depths were selected to determine if the thermocline would have an impact on dye and herbicide dissipation rates. Each datasonde logged dissolved oxygen (DO), pH, and RWT dye concentration every 10 minutes during the deployment periods, results ranging from 32–273 HAT (Table 3). No water quality data were collected during September field trials as no hydrolab datasondes were available for use at that time.

3 Results and Discussion

3.1 Environmental conditions

During the July 2014 treatment, the average water temperature in DC-2 was 21.4°C (70.52°F) and 20°C (68°F) in the emergency spillway. Mean DO concentration was 8.6 in DC- 2, but only 0.2 mg/L in the emergency spillway. Average DO in the emergency spillway was likely decreased due to the shallow depths and across all plots, pH ranged from 8.03–9.13 (Table 3). As previously mentioned in Section 2, winds were calm and skies were clear during treatments; however, on the afternoon of 24 July 2014, wind speeds as high as 120 km/h (75 mph) were reported. This wind storm event resulted in the barrier curtain becoming entirely detached from the treatment area at DC-1. The barrier curtain was reset on 29 July 2014 and a dye study was conducted (refer to Section 2). At the emergency spillway, skies were overcast but winds were calm during treatment. The high winds on 24 July did not impact the barrier curtains at DC-4 or ES-6.

Table 3. Range of temperature, dissolved oxygen and pH of treatment plots at Fort Peck Lake, MT for July 2014.

July 2014					
Plot	Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Collection Period	Total HAT
DC-1*	16.97 to 47.82	6.93 to 10.12	8.16 to 8.73	7/28/2014 (12:00) to 8/2/2014 (18:00)	273
DC-1**	16.85 to 44.95	4.95 to 8.27	8.04 to 8.82	7/28/2014 (12:00) to 8/2/2014 (18:00)	273
DC-2	17.26 to 31.29	8.18 to 11.35	8.03 to 8.86	7/22/2014(05:00) to 7/23/2014(15:40)	32
DC-3	16.7 to 30.5	6.91 to 8.79	8.13 to 8.91	7/22/2014 (05:00) to 7/23/2014 (15:50)	32
DC-4	No Data	No Data	No Data	No Data	No Data
ES-6	16.11 to 33.19	0.07 to 0.50	8.09 to 9.13	7/29/2014 (12:00) to 7/31/2014 (14:30)	167

*Shallow- 30.5 cm (1 ft) below surface of water.
**Deep- 30.5 cm (1 ft) above bottom.

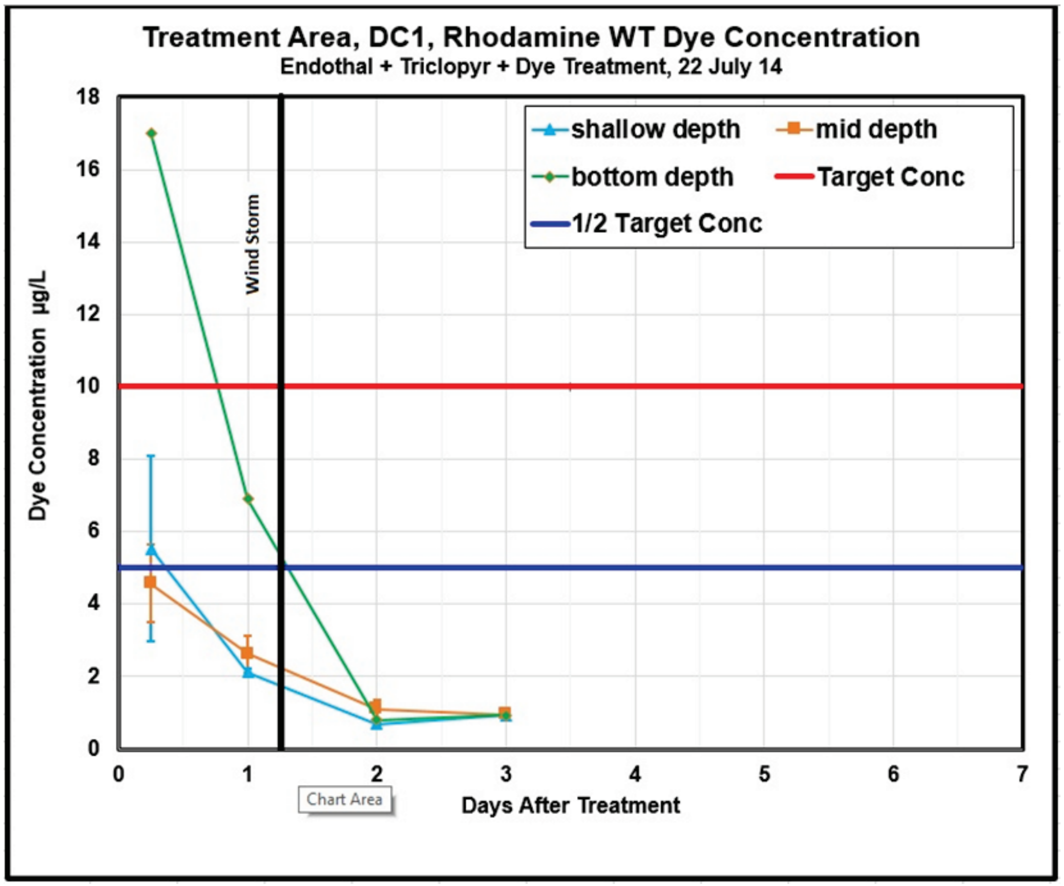
3.2 Water Exchange Processes

3.2.1 July 2014

3.2.1.1 Treatment Plots Utilizing Barrier Curtains (DC-1 and ES-6)

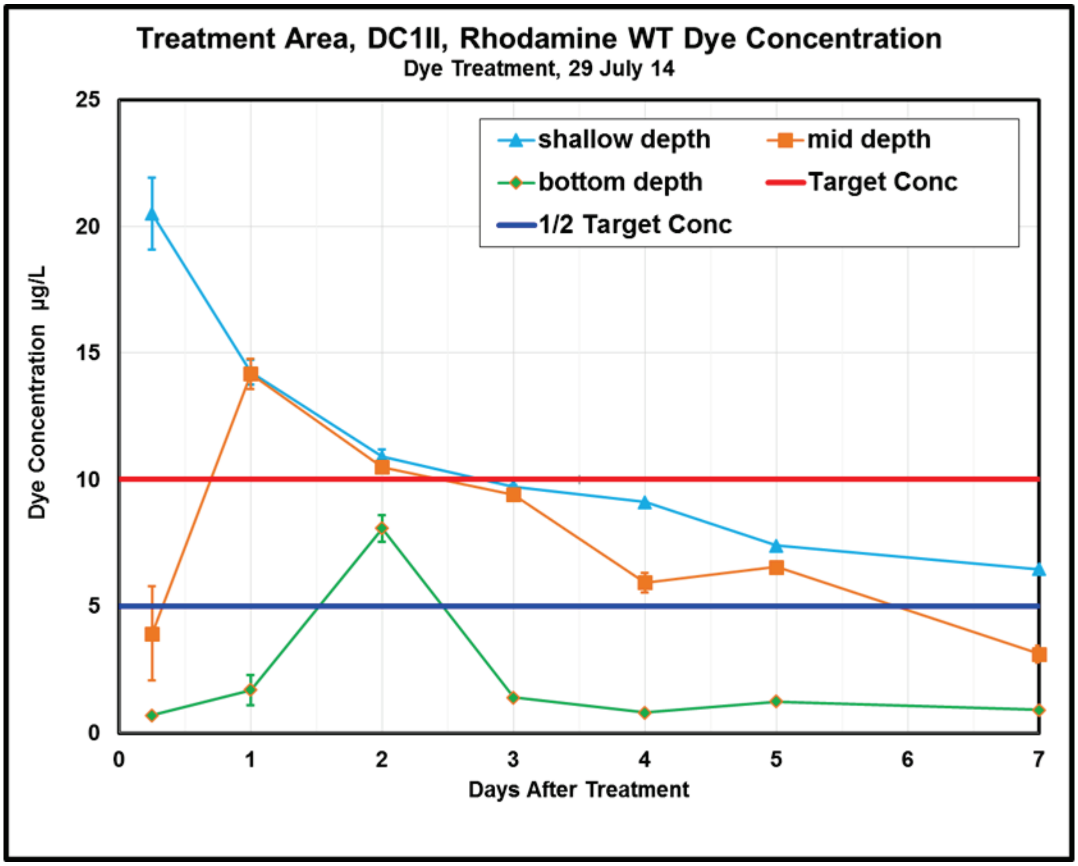
In July, surface depth dye concentrations at DC-1 did not achieve the desired target concentration of 10 µg/L and were nearly undetectable by two days after treatment (DAT). Bottom concentration achieved the desired target concentration at four DAT and precipitously declined (Figure 7). This rapid decline in dye concentration was caused by the extreme wind storm event that completely disrupted the barrier curtain and exposed the treated plot to major water exchange processes. As with the dye, these processes would have quickly moved and greatly diluted the herbicide into surrounding waters outside of the plot.

Figure 7. Rhodamine WT concentration following treatment behind the barrier curtain at DC-1 within the Fort Peck Lake system, MT on 22 July 2014 prior to the barrier curtain becoming dislodged from high winds (solid black line indicates approximate time windstorm occurred and dislodged barrier curtain).



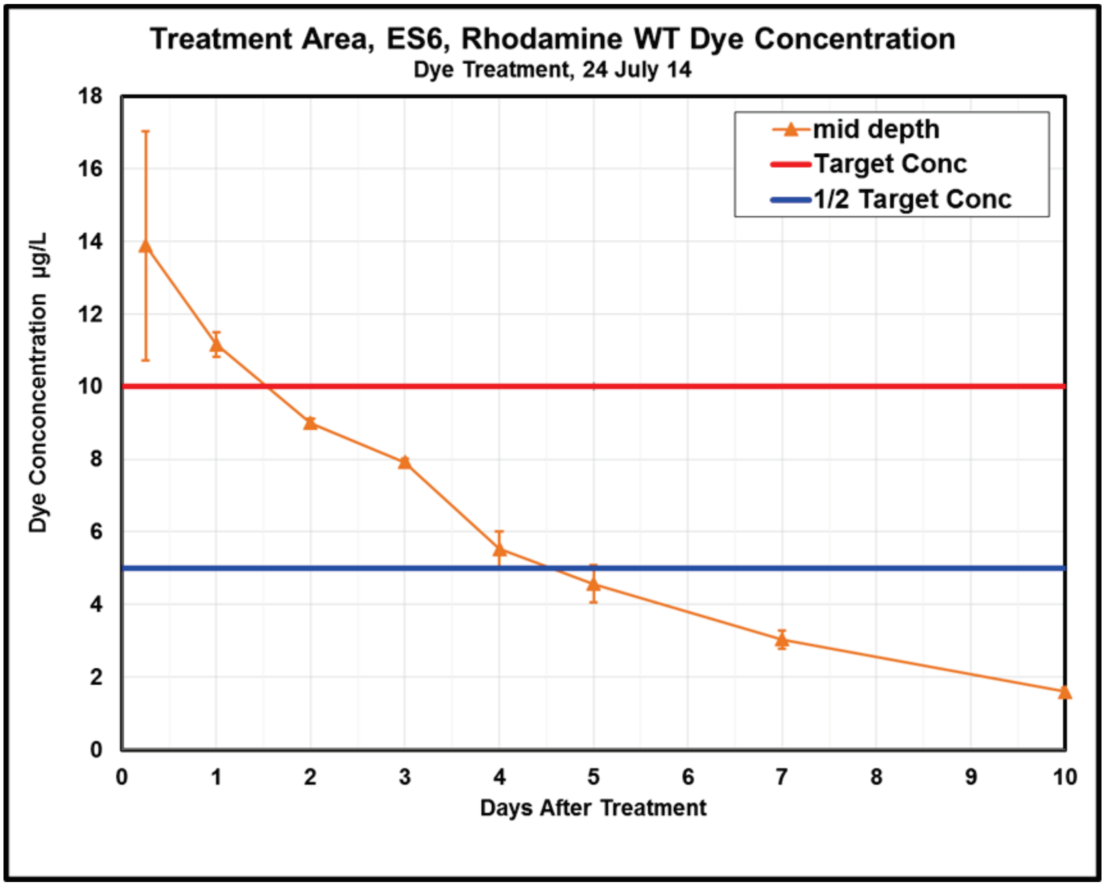
The 29 July dye-only treatment showed that the target concentration was achieved at the surface and mid-depth in DC-1II, and concentrations in those water strata were still measured at 4–6 µg/L (40-60% of target concentration) by seven DAT (Figure 8). Dye concentration at the bottom peaked at 8 µg/L at two DAT, but declined and remained around 2 µg/L through seven DAT. These data indicated that water exchange within this plot could be minimized when the barrier curtain remained in place.

Figure 8. Rhodamine WT concentration following a dye-only application behind the barrier curtain at DC-1II in Dredge Cut 2 of the Fort Peck Lake system, MT following the re-installation of the barrier curtain on 29 July 2014.



The target dye concentration at mid-depth was achieved in ES-6 and dye concentrations remained greater than 5µg/L through four DAT (Figure 9). These extended dye concentrations were achieved by the use of the barrier curtain.

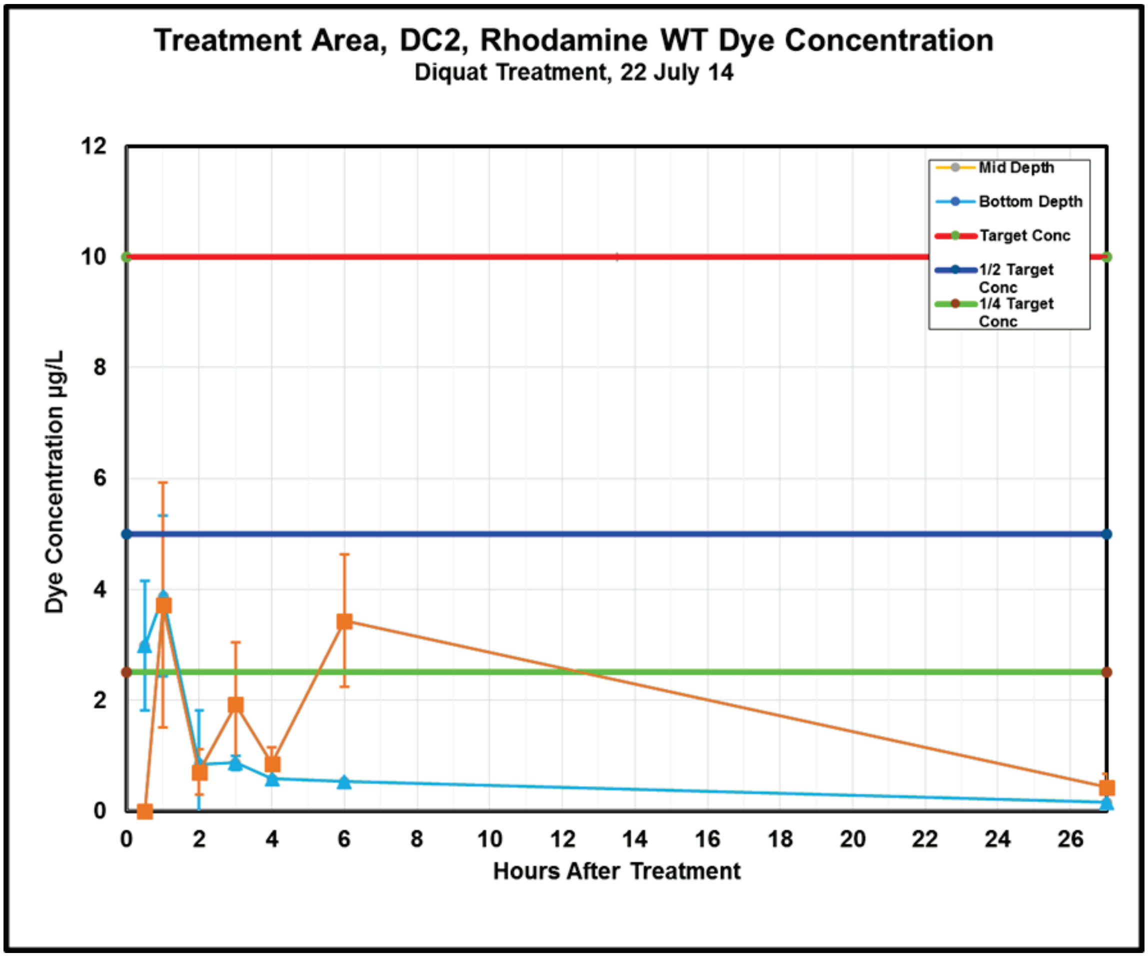
Figure 9. Rhodamine WT concentration following a dye-only application behind the barrier curtain at ES-6 in the Missouri River spillway downstream of the Fort Peck Lake system, MT on 24 July 2014.



3.2.1.2 *Open Water Treatment Plots (DC-2 and DC-3)*

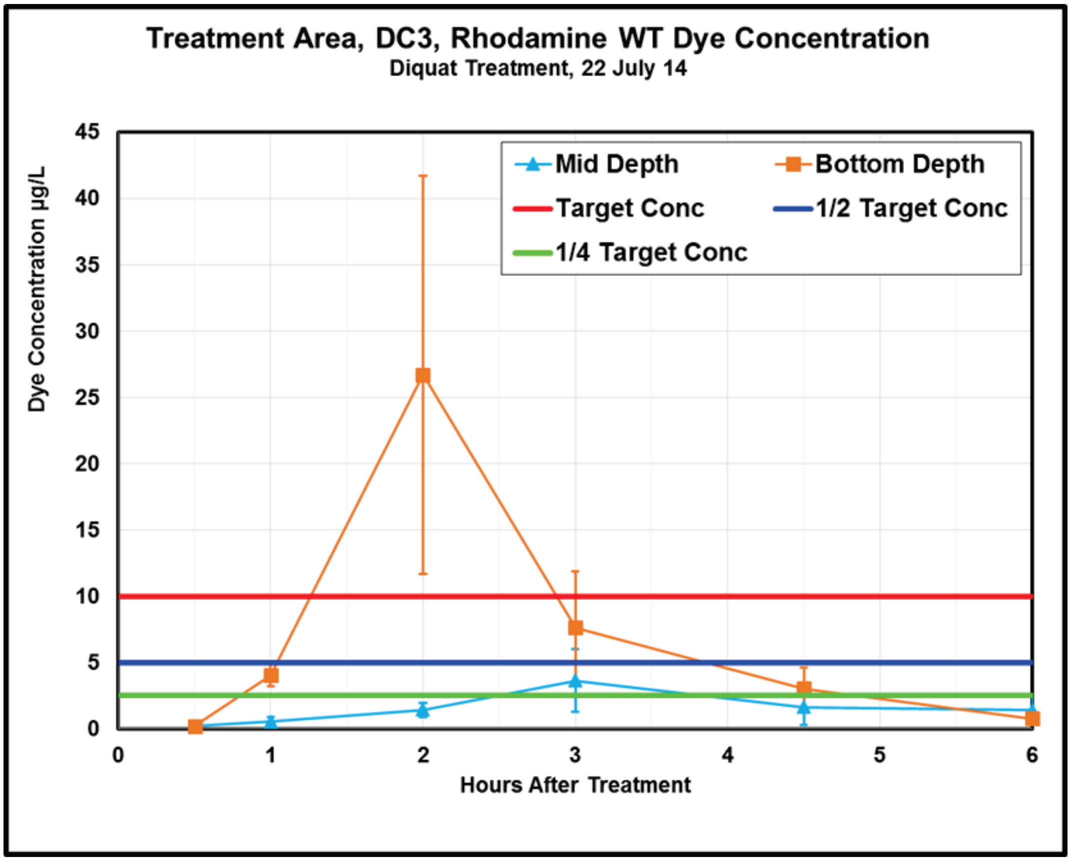
Treatments in the open water plots DC-2 and DC-3 were conducted without the use of a barrier curtain. Dye concentration for both of these sites were highly variable, indicating that the water-exchange processes diluted the aqueous dye (Figures 10 and 11). Concentrations at DC-2 never achieved target levels at any measured depth, and dissipated to less than 1 µg/L by 4 HAT (Figure 10). At mid-depth, concentrations never achieved even half the target level, and were near 1 µg/L at 6 HAT (Figure 10).

Figure 10. Rhodamine WT concentration following open water treatment at DC-2 within Dredge Cut 2 of the Fort Peck Lake system, MT on 22 July 2014.



In DC-3, dye concentrations exceeded the target level at bottom depths, but were 50% below the target level at mid-depth (Figure 11). This indicated that mixing to a greater depth occurred in this plot.

Figure 11. Rhodamine WT concentration following open water treatment at DC-3 within Dredge Cut 2 of the Fort Peck Lake system, MT on 22 July 2014.

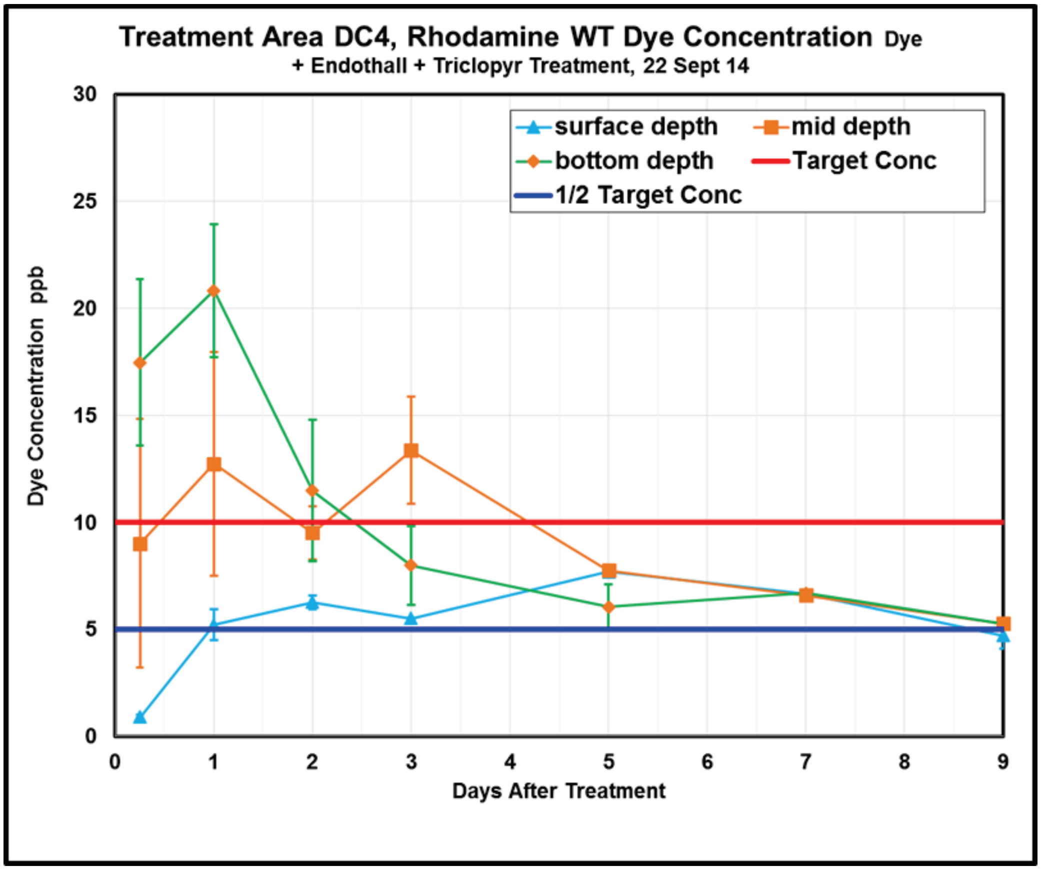


3.2.2 September 2014

3.2.2.1 Treatment Plots Utilizing Barrier Curtains (DC-4 and ES-6)

Surface data at DC-4 indicated only 5µg/L was achieved following a dye-only treatment in September, and remained at that level at nine DAT (Figure 12). Mid-depth and bottom concentrations achieved the target of ≥10 µg/L and gradually decreased to 5µg/L by nine DAT.

Figure 12. Rhodamine WT concentration following dye-only application behind the barrier curtain at DC-4 within Dredge Cut 2 of the Fort Peck Lake system, MT on 22 September 2014.



In September, only surface and mid-depth concentrations at ES-6 were collected up to seven DAT, as the plot was too shallow for data collection at predetermined bottom depths (Figure 13). Only concentrations recorded at mid-depth levels reached target concentration of 10 µg/L. However, at twenty-three DAT, concentrations were still measured at 2.5 µg/L (Figure 14).

Figure 13. Rhodamine WT concentration at surface and mid-depth up to seven days after treatment following dye-only application behind the barrier curtain at ES-6 in the Missouri River spillway downstream of the Fort Peck Lake system, MT on 24 September 2014.

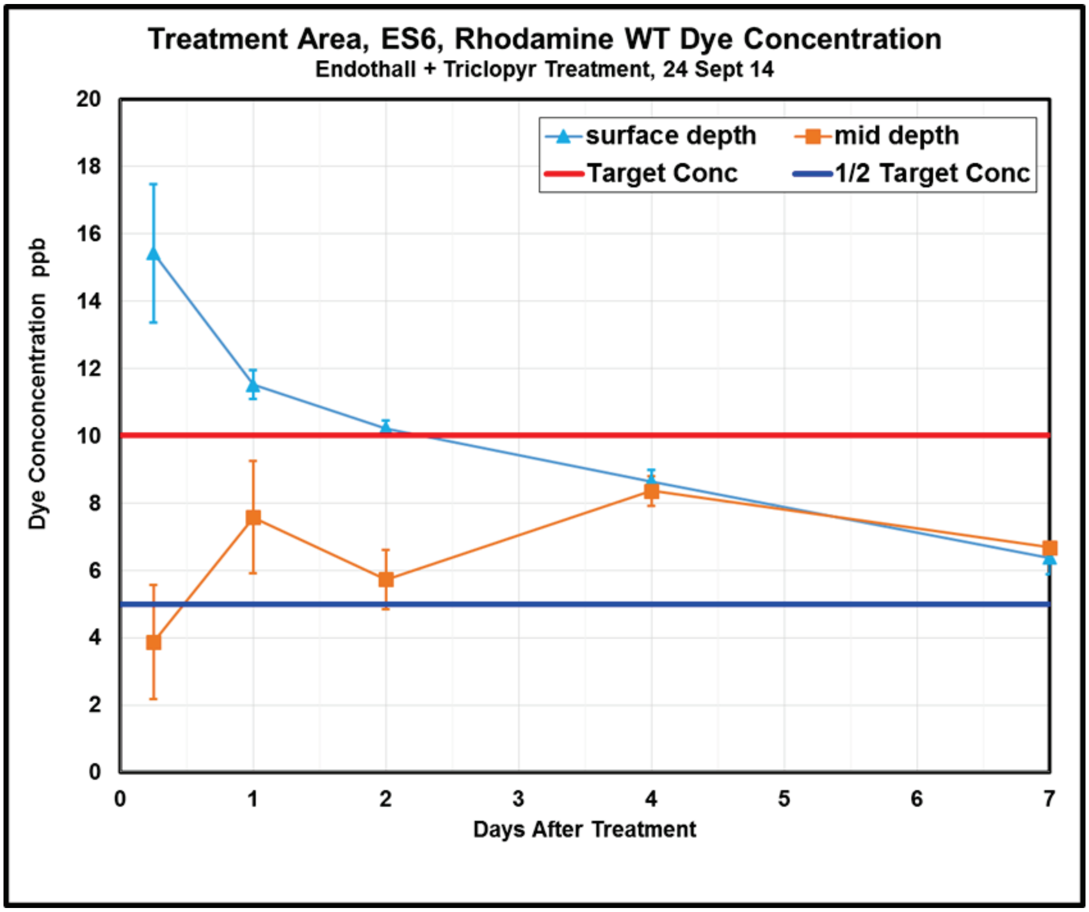
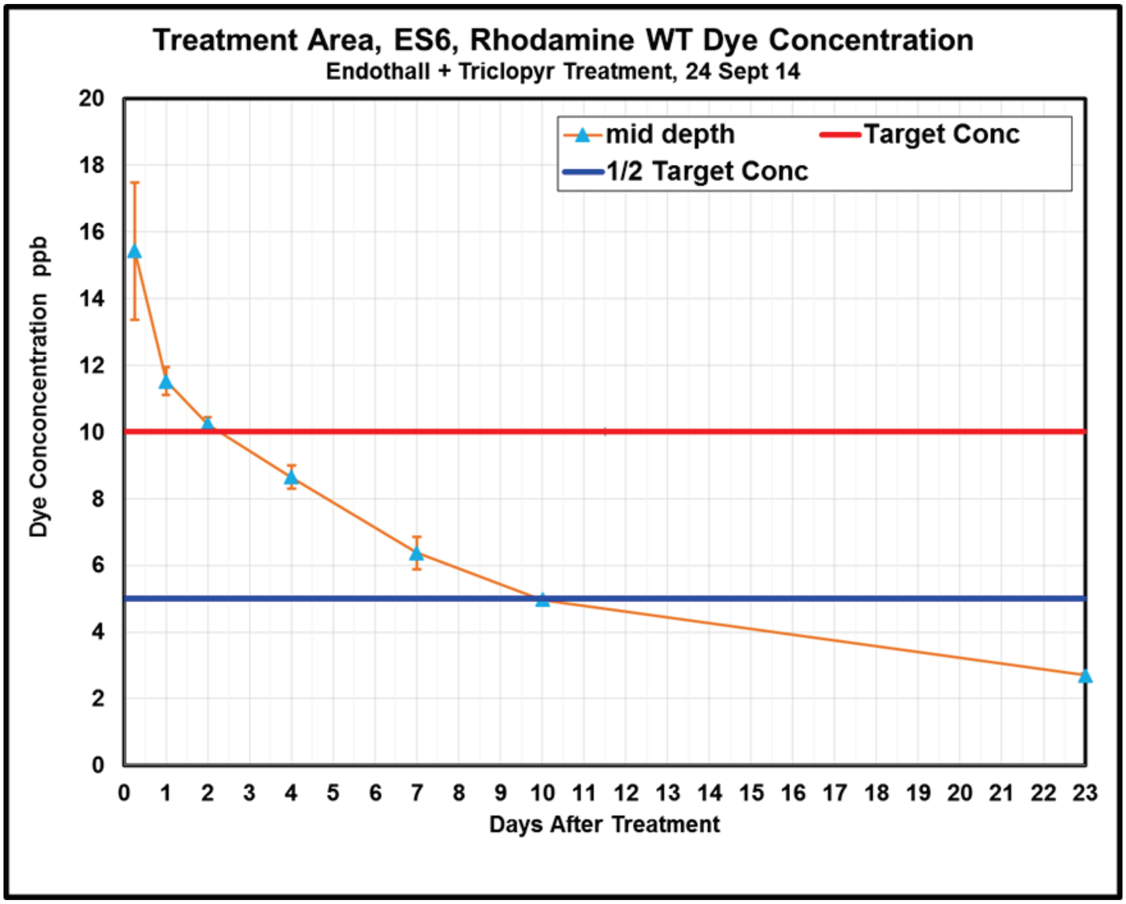


Figure 14. Rhodamine WT concentration at mid-depth levels following dye-only application behind the barrier curtain at ES-6 up to 23 days after treatment in the Missouri River spillway downstream of the Fort Peck Lake system, MT on 24 September 2014.



3.2.2.2 *Open Water Treatment Plots (DC-2 and DC-3)*

Following unsuccessful results from treatments in July, it was determined to treat DC-2 and DC-3 again. Target concentration levels of 10 µg/L were never attained at either treatment plot (Figures 15 and 16). Concentration levels dissipated to 1 µg/L by 4 HAT for DC-2 (Figure 15), and 5 HAT for DC-3 (Figure 16).

Figure 15. Rhodamine WT concentration following open water treatment at DC-2 within Dredge Cut 2 of the Fort Peck Lake system, MT on 23 September 2014.

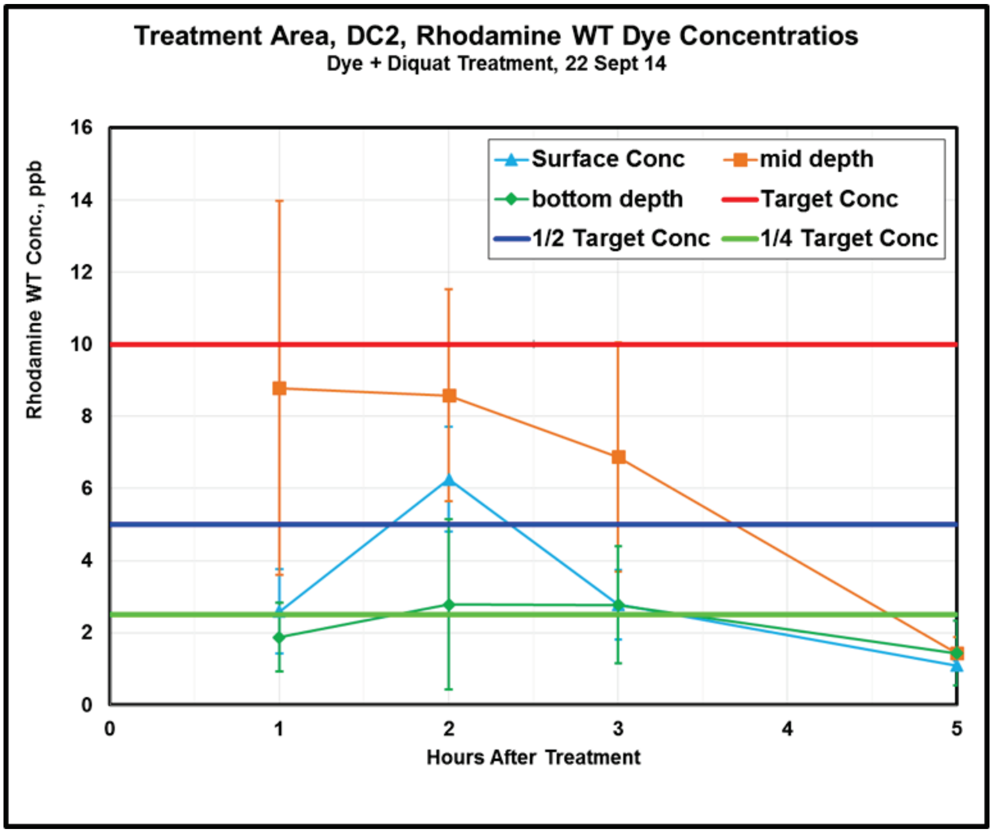


Figure 16. Rhodamine WT concentration following open water treatment at DC-3 within Dredge Cut 2 of the Fort Peck Lake system, MT on 23 September 2014.

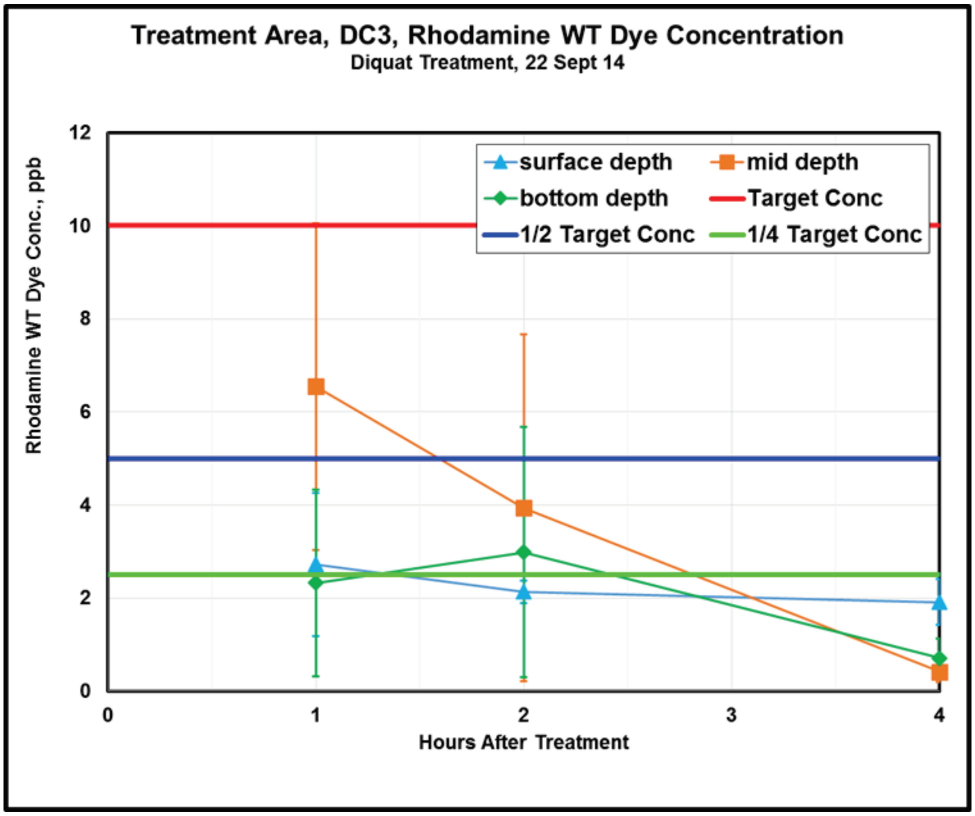


Table 4 shows the estimated water-exchange half-lives in all treated plots as determined by aqueous dye measurements. Estimated half-lives were calculated at < 0.5 HAT in plots which were not protected by barrier curtains. In contrast, plots which were protected by barrier curtains provided calculated water-exchange half-lives ranging from 30–108 HAT, a 60 to >200 fold increase. Since dye simulates liquid herbicide dissipation characteristics in treated plots, much more favorable herbicide contact time scenarios would be expected in plots protected by barrier curtains. Without the use of barrier curtains in these settings, herbicide is likely to dissipate quickly into surrounding untreated waters, thus, reducing exposure time. Consequently, herbicide efficacy against target plants would be reduced.

Table 4. Calculated half-life (ʎ) of rhodamine WT dye across all treatment plots in the Fort Peck Lake system, MT in July and September 2014. Note treatment plots with barrier curtains (DC-1, DC-4, and ES-6) have a significantly longer half-life than those treatment plots without barrier curtains.

Treatment Plot	Hectares	Barrier	July 2014 ʎ	September 2014 ʎ
DC-1	1.16	Yes	30 HAT	-
DC-1 II	1.16	Yes	108 HAT	-
DC-2	1.62	No	<0.5 HAT	3.8 HAT
DC-3	0.4	No	<0.5 HAT	1.5 HAT
DC-4	13.56	Yes	-	216 HAT
ES-6	7.08	Yes	108 HAT	226 HAT

3.3 Plant Assessments and CET

The frequency of occurrence of EWM and native aquatic species present in DC-1, DC-2, and DC-3 prior to treatment in July 2014, and present in DC-4 and ES-6 prior to treatment in September 2014, are presented in Table 5.

Table 5. Eurasian watermilfoil and native aquatic plant occurrence prior to July treatment at DC-1, DC-2, and DC-3, and prior to September treatment in DC-4, and ES-6, in the Fort Peck Lake system, MT in 2014.

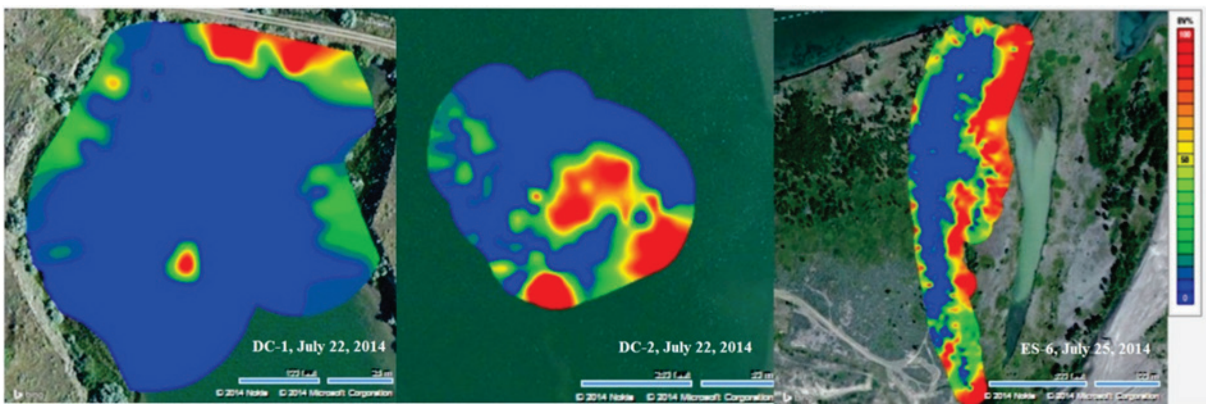
Species	Treatment Plot (July 2014)			Treatment Plot (September 2014)	
	DC-1	DC-2	DC-3	DC-4	ES-6
	Percent (%) Frequency of Occurrence				
Myriophyllum spicatum (Eurasian Watermilfoil)	21.4	59.3	60.0	9.6	46.2
Ceratophyllum demersum (Coontail)	14.3	0.0	0.0	0.0	0.0
Ranunculus longirostris (White Water-buttercup)	3.6	0.0	0.0	4.1	22.6
Chara sp. (Muskgrass)	0.0	0.0	0.0	5.5	0.0
Elodea canadensis (Common Elodea)	0.0	0.0	0.0	0.0	22.6
Potamogeton foliosus (Leafy Pondweed)	0.0	0.0	0.0	0.0	0.0
Eleocharis acicularis (Needle Spikerush)	25.0	0.0	0.0	1.4	0.0
Sagittaria sp. (Arrowhead)	14.3	0.0	0.0	0.0	0.0
Stuckenia pectinata (Sago Pondweed)	0.0	0.0	0.0	0.0	7.5

	Species	Treatment Plot (July 2014)			Treatment Plot (September 2014)	
		DC-1	DC-2	DC-3	DC-4	ES-6
		Percent (%) Frequency of Occurrence				
Dicot	*Microphyllum spicatum* (Eurasian Watermilfoil)	21.4	59.3	60.0	9.6	46.2
	Ceratophyllum demersum (Coontail)	14.3	0.0	0.0	0.0	0.0
	Ranunculus longirostris (White Water-buttercup)	3.6	0.0	0.0	4.1	22.6
Non-dicot	*Chara sp.* (Muskgrass)	0.0	0.0	0.0	5.5	0.0
	Elodea canadensis (Common Elodea)	0.0	0.0	0.0	0.0	22.6
	Potamogeton foliosus (Leafy Pondweed)	0.0	0.0	0.0	0.0	0.0
	Eleocharis acicularis (Needle Spikerush)	25.0	0.0	0.0	1.4	0.0
	Sagittaria sp. (Arrowhead)	14.3	0.0	0.0	0.0	0.0
	Stuckenia pectinata (Sago Pondweed)	0.0	0.0	0.0	0.0	7.5

Shoots of EWM growing in all treatment plots were green and healthy, and had formed a canopy on the water surface. Dense stands were observed along the shorelines of DC-1 in July 2014, and DC-4 and ES-6 in September 2014.

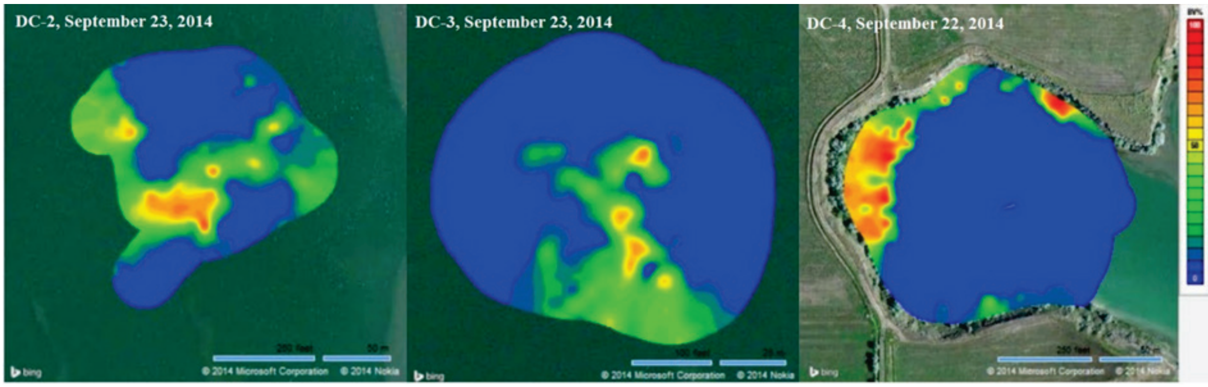
Profile data collected from Ecosounder System with a Structure Scan Module is presented in Figures 17 and 18. No profile data was collected for DC-3 due to an equipment malfunction, or DC-4 as it was not treated with herbicide in July. An offset of 0.46 m (1.5 ft) was added to the depth of survey data in the BioBase© software to generate heat mats of aquatic vegetation. These figures depict the location and density of vegetation stands within the treatment plot.

Figure 17. Vegetation biovolume heat map, from left to right, for DC-1 and DC-2 in the Fort Peck Lake Dredge Cut on 22 July 2014, and for ES-6 in the Missouri River on 25 July 2014. Red indicates dense stands of biomass, while blue indicates no detected biomass.



Pretreatment conditions in July 2014 for DC-1 showed a 21.5% coverage of submersed vegetation, or Percentage Area Covered (PAC), and a 25.1% biovolume of the water column, or Percent Vegetation Inhabited (PVI) (Figure 17). Pretreatment conditions in July 2014 for DC-2 showed a 50.7% PAC and 45.9% PVI, and in July 2014, ES-6 showed a 64.6% PAC and 53.4% PVI (Figure 17).

Figure 18. Vegetation biovolume heat map, from left to right, for DC-2 and DC-3 on 23 September 2014, and for DC-4 on 22 September 2014 in the Fort Peck Lake Dredge Cut, MT. Red indicates dense stands of biomass while blue indicated no detected biomass.



Prior to the re-treatment in September 2014, DC-2 showed a 55.6% PAC and 28.8% PVI, DC-3 showed a 34.5% PAC and 24.1% PVI, and DC-4 showed a 20.8% PAC and 41.7% PVI (Figure 18). No profile data was collected for DC-1 as it was not treated in September. No profile data was collected for ES-6 as low water conditions prevented boat access to the treatment plot.

Aquatic plant frequency of occurrence for DC-1 (barrier curtain plot) during each plant assessment period is depicted in Table 6. As indicated from the eight WAT post-treatment vegetation assessment, 100 % control of EWM was achieved at DC-1. In spite of the failure of the barrier curtain at ~ 48 HAT (due to an extreme wind storm event), the estimated water-exchange half-life of 30 hr (Table 4) in this plot allowed for the excellent control of EWM using the triclopyr + endothall treatment combination. However, by one YAT, EWM populations had recovered at the site yielding ~ 31% control of the plant compared to pretreatment levels. This level of EWM control compares favorably with a triclopyr + endothall treatment conducted in Noxon Rapids Reservoir in western Montana in 2009, where the water exchange half-life was 33 hr and control was measured at 88% eight WAT, and 80% at one YAT (Getsinger et al. 2103).

Table 6. Eurasian watermilfoil and aquatic plant occurrence prior to July treatment (triclopyr + endothall), eight weeks after treatment (eight WAT) and one year after treatment (one YAT) following associated herbicide treatments behind a barrier curtain at DC-1 within Dredge Cut 2 in the Fort Peck Lake system, MT. Reference Table 2 to review treatment rates and schedule.

		Frequency of Occurrence (%)			Pre-treatment - 8 WAT		8 WAT - 1 YAT		Pre-treatment - 1 YAT	
		Pre-treatment	8 WAT	1 YAT	% Change	Significance	% Change	Significance	% Change	Significance
DC-1										
Myriophyllum spicatum	Eurasian Watermilfoil	21.4	0	14.8	-100.0%	*	100.0%	n.s.	-30.9%	n.s.
Ceratophyllum demersum	Coontail	14.3	0	0	-100.0%	n.s.	0.0%	-	-100.0%	*
Ranunculus longirostris	White Water-buttercup	3.6	0	7.4	-100.0%	n.s.	100.0%	n.s.	105.6%	n.s.
Chara sp.	Muskgrass	0	15.8	11.1	100.0%	*	-29.8%	n.s.	100.0%	n.s.
Elodea canadensis	Common Elodea	0	0	7.4	0.0%	-	100.0%	n.s.	100.0%	n.s.
Potamogeton foliosus	Leafy Pondweed	0	0	0	0.0%	-	0.0%	-	0.0%	-
Eleocharis acicularis	Needle Spikerush	25	5.3	3.7	-78.8%	n.s.	-30.2%	n.s.	-85.2%	n.s.
Sagittaria sp.	Arrowhead	14.3	0	0	-100.0%	n.s.	0.0%	-	-100.0%	n.s.
Stuckenia pectinata	Sago Pondweed	0	0	0	0.0%	-	0.0%	-	0.0%	-

n.s.= No Significance
* = p < 0.05
**=p < 0.01
***=p<0.001

Eight weeks after the initial treatment, the assessment before the retreatment showed that plot DC-2 still had a dense infestation within the treatment plot and the density of EWM at DC-3 had increased following treatment (diquat) in July (Table 7). Vegetation assessments at one YAT indicated no success following the second treatment in both DC 2 and DC3, as no significant differences were measured in EWM levels in either of these open water plots (Table 7). Even though these plots were treated with relatively quick-acting products (endothall and diquat), plant control < 50% – most likely related to the rapid water-exchange half-lives measured in these plots ranging from 0.5 – 3.8 hr (Table 4). Rapid herbicide dissipation in small, open-water plots on large water bodies is quite typical. Applications of endothall and diquat to small, open-water plots on Noxon Rapids Reservoir provided moderate levels of EWM control (50–65%) through one YAT (Getsinger et al. 2014). However, efficacious herbicide residues within the Noxon plots ranged from 3 – 9 HAT, considerably longer than the predicted herbicide contact times in the Ft. Peck plots.

Table 7. Eurasian watermilfoil and aquatic plant occurrence prior to treatment in July 2014 (pretreatment), prior to re-treatment in September 2014 (fall treatment) and one year after treatment (one YAT) following associated open water herbicide treatments at DC-2 and DC-3 within Dredge Cut 2 in the Fort Peck Lake system, MT. Reference Table 2 to review treatment rates and schedule.

		Frequency of Occurrence (%)			Pre-treatment to Fall		Fall Treatment-1 YAT		Pre-treatment to 1	
		Pre-treatment	Fall Treatment	1 YAT	% Change	Significance	% Change	Significance	% Change	Significance
DC-2										
Myriophyllum spicatum	Eurasian Watermilfoil	59.3	36.7	48.2	-38.1%	n.s.	31.3%	n.s.	-18.7%	n.s.
Ceratophyllum demersum	Coontail	0	0	0	0.0%	-	0.0%	-	0.0%	-
Ranunculus longirostris	White Water-buttercup	0	2	0	-100.0%	n.s.	100.0%	n.s.	0.0%	-
Chara sp.	Muskgrass	0	20.4	0	100.0%	*	-100.0%	*	0.0%	-
Elodea canadensis	Common Elodea	0	10.2	0	100.0%	n.s.	-100.0%	n.s.	0.0%	-
Potamogeton foliosus	Leafy Pondweed	0	4.08	0	100.0%	n.s.	-100.0%	n.s.	0.0%	-
Eleocharis acicularis	Needle Spikerush	0	0	0	0.0%	-	0.0%	-	0.0%	-
Sagittaria sp.	Arrowhead	0	0	0	0.0%	-	0.0%	-	0.0%	-
Stuckenia pectinata	Sago Pondweed	0	51	0	100.0%	***	-100.0%	***	0.0%	-
DC-3										
Myriophyllum spicatum	Eurasian Watermilfoil	60	80	60	33.3%	n.s.	-25.0%	n.s.	0.0%	n.s.
Ceratophyllum demersum	Coontail	0	0	0	0.0%	-	0.0%	-	0.0%	-
Ranunculus longirostris	White Water-buttercup	0	0	0	0.0%	-	0.0%	-	0.0%	-
Chara sp.	Muskgrass	0	20	0	100.0%	n.s.	-100.0%	n.s.	0.0%	-
Elodea canadensis	Common Elodea	0	0	0	0.0%	-	0.0%	-	0.0%	-
Potamogeton foliosus	Leafy Pondweed	0	0	0	0.0%	-	0.0%	-	0.0%	-
Eleocharis acicularis	Needle Spikerush	0	0	0	0.0%	-	0.0%	-	0.0%	-
Sagittaria sp.	Arrowhead	0	0	0	0.0%	-	0.0%	-	0.0%	-
Stuckenia pectinata	Sago Pondweed	0	0	0	0.0%	-	0.0%	-	0.0%	-

n.s.= No Significance
* = $p < 0.05$
**=$p < 0.01$
***=$p<0.001$

The one YAT vegetation assessments in plots DC 4 and ES 6 indicated successful results behind barrier curtains in plot DC-4 (triclopyr + endothall), 100% EWM control, and in plot ES-6 (triclopyr + endothall), ~ 95% EWM control (Table 8). The excellent efficacy results measured in these plots was not unexpected, since water-exchange half-lives were measured at > 200 hr (Table 4).

Table 8. Eurasian watermilfoil and aquatic plant occurrence prior to September treatment and one year after treatment (one YAT) following associated herbicide treatments behind a barrier curtain at DC-4 within Dredge Cut 2 in the Fort Peck Lake system, and ES-6 in the Emergency Spillway of the Missouri River, MT. Reference Table 2 to review treatment rates and schedule.

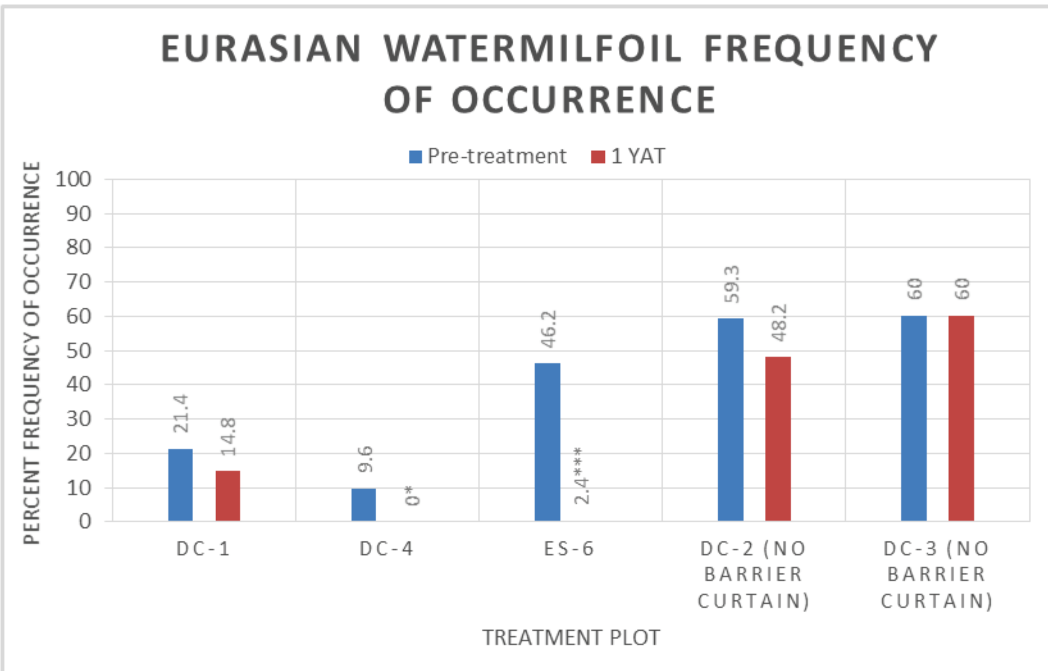
		Frequency of Occurrence (%)		Pre-treatment - 1 YAT	
		Pre-treatment	1 YAT	% Change	Significance
DC-4					
Myriophyllum spicatum	Eurasian Watermilfoil	9.6	0	-100.0%	**
Ceratophyllum demersum	Coontail	0	0	0.0%	-
Ranunculus longirostris	White Water-buttercup	4.1	1.4	-65.9%	n.s.
Chara sp.	Muskgrass	5.5	10.8	96.4%	n.s.
Elodea canadensis	Common Elodea	0	5.4	100.0%	*
Potamogeton foliosus	Leafy Pondweed	0	0	0.0%	-
Eleocharis acicularis	Needle Spikerush	1.4	4.1	192.9%	n.s.
Sagittaria sp.	Arrowhead	0	0	0.0%	-
Stuckenia pectinata	Sago Pondweed	0	0	0.0%	-
ES-6					
Myriophyllum spicatum	Eurasian Watermilfoil	46.2	2.4	-94.8%	***
Ceratophyllum demersum	Coontail	0	0	0.0%	-
Ranunculus longirostris	White Water-buttercup	22.6	6	-73.5%	*
Chara sp.	Muskgrass	0	6	100.0%	*
Elodea canadensis	Common Elodea	22.6	27.4	21.2%	***
Potamogeton foliosus	Leafy Pondweed	0	0	0.0%	-
Eleocharis acicularis	Needle Spikerush	0	0	0.0%	-
Sagittaria sp.	Arrowhead	0	0	0.0%	-
Stuckenia pectinata	Sago Pondweed	7.5	17.9	138.7%	***

n.s.= No Significance
* = $p < 0.05$
**= $p < 0.01$
***= $p < 0.001$

A comparison of EWM control across treatments is presented in Figure 18. Although 100% EWM control was initially seen in DC1 (triclopyr + endothall; 30 hr water-exchange half-life) at eight WAT, EWM recovery was well underway one YAT. Since the barrier curtain was disrupted by the wind-storm event 48 HAT, the water-exchange half-life and herbicide contact time were greatly reduced, suppressing EWM control by one YAT. However, excellent control of EWM was achieved in the triclopyr + endothall plots DC-4 and ES-6 by one YAT, undoubtedly due to the greatly extended water-exchange half-lives (leading to extended herbicide contact times) in these plots (≥ 200 hr).

In contrast, EWM populations in plots DC-2 and DC-3 were poorly controlled. The quick-acting properties of endothall and diquat could not be overcome by the rapid water-exchange half-lives in these open water plots.

Figure 19. Percent frequency of occurrence of EWM at treatment plots prior to, and one year after herbicide application in the Fort Peck lake system, MT. Treatment plots DC-1 (triclopyr + endothall), DC-4 (triclopyr + endothall), and ES-6 (triclopyr + endothall) utilized barrier curtains, while DC-2 (diquat) and DC-3 (diquat) were open water treatment plots. Eurasian watermilfoil was significantly reduced at DC-4 and ES-6. No statistical significance of frequency of occurrence was noted at DC-1, DC-2, and DC-3.



Note: * = $p < 0.05$; ** = $p < 0.01$; and *** = $p < 0.001$.

There was some native vegetation observed in the treatment plots (Tables 5–8), with the most abundant species comprising coontail, muskgrass, spikerush, arrowhead, whitewater buttercup, and sago pondweed. Generally, herbicide injury to these non-target plants was greatest in the endothall and diquat plots, and least in the triclopyr + endothall treated plots. These non-target plant impacts were similar to results measured in plots treated with the same products in Noxon Rapids Reservoir in western Montana (Getsinger et al. 2103). Muskgrass, seemed to be the exception and generally increased post-treatment in most plots.

4 Conclusions and Recommendations

Fort Peck Lake is a large and hydraulically complex reservoir with substantial day-to-day water level fluctuations. The lake contains extended fetches of open water that, while in association with strong prevailing winds, can compromise aquatic herbicide CET relationships. The Dredge Cuts (used in this study) have a much more stable surface water elevation and are less susceptible to impacts from prevailing winds. The Missouri River downstream of the Fort Peck Dam also experiences atypical water level fluctuations as a result of operating the Fort Peck Dam. These various conditions suggest that different management strategies may be utilized to obtain an effective CET to achieve control of aquatic invasive species within the Missouri River, the Fort Peck Lake, and within the Dredge Cuts. The field trials conducted in 2012, and in this supplemental study, confirm that water-exchange patterns are variable in the waters associated with Fort Peck Lake. This variability can reduce herbicide contact time requirements in treated areas and suppress the level of control in the year of treatment. This reduced efficacy can lead to recovery and regrowth of EWM the following growing season (one YAT), resulting in short-term control.

4.1 Conclusions

The following conclusions can be reached based on this study:

- Relatively small treatment plots of < 4 ha (10 acres) can be impacted by water-exchange processes in open fetch areas of the lake (primarily wind-induced), thus decreasing herbicide contact time around target plants, and greatly reducing efficacy of EWM.
- The short-term use of barrier curtains can greatly limit water exchange within treated plots and provide adequate herbicide contact time for appropriate products (e.g., diquat, endothall and triclopyr), yielding acceptable EWM control.
- Eurasian watermilfoil can be adequately controlled (> 85%) for periods of up to one YAT, in areas of the lake where water-exchange processes are reduced and product-specific herbicide CET relationships can be maintained.
- When used in conjunction with barrier curtains to maximize herbicide contact time, the combination of triclopyr + endothall can be very effective in controlling EWM through one YAT.

- While moderate injury occurred to some native plants located in the herbicide-treated plots (especially with the more broad-spectrum diquat and endothall), these populations will recover following treatments.
- The lake is subject to strong wind events and these conditions can disrupt barrier curtain placement and function if curtains are not securely anchored. If early in the post-treatment period, the disruption can diminish herbicide CET relationships required for adequate control of EWM.

4.2 Recommendations

Based on information documented in this study, the following recommendations are presented to improve the efficacy of herbicides to control EWM in Fort Peck Lake:

- Evaluate efficacy at six to eight WAT, and one and two YAT to determine duration of control time of EWM beyond the season of application. This approach can be useful in planning and scheduling additional herbicide applications, or other control methods, if required.
- Continue to refine and evaluate deployment of barrier curtains to hydraulically separate sections of the lake to increase herbicide contact time around target plant stands. The use of barrier curtains can reduce bulk water exchange between the enclosed treatment site and surrounding untreated waters. This approach is recommended for bays and other areas with high water exchange characteristics (e.g., in the Dredge Cut area), and will allow for the specified herbicide CET requirements against target plants. As a general precaution, anchor systems for curtains deployed in areas subjected to high wind events should be adequately strengthened to mitigate curtain disruptions during wind-storm events.
- Evaluate other quick-acting contact aquatic herbicides, such as flumioxazin, and newly developed diquat/endothall products, and granular formulations of systemic aquatic herbicides, such as triclopyr and 2,4-D for use in Fort Peck Lake to control EWM.
- The ability to conduct a whole-area treatment should be investigated for Dredge Cut 2. Barrier curtains should be used to sequester water intakes and greatly reduced contamination from aqueous herbicide residues. Herbicide is likely to be widely and evenly dispersed across the entire Dredge Cut area. However, in order to obtain adequate EWM control, higher application rates should be considered to mitigate

herbicide dissipation/dilution driven by water exchange processes in the Dredge Cut area.

- Fall applications should be considered as part of an overall EWM treatment strategy for the lake, using herbicides that have proven effectiveness in cooler water. Such treatments would avoid crop irrigation summertime water recreation issues.
- Evaluate the newly registered aquatic herbicide, ProcellaCOR (florpyrauxifen-benzyl), for EWM control in the lake. This recently registered product has been deemed a reduced-risk pesticide by the EPA, and has proven effective in small-scale trials against EWM and invasive hybrid watermilfoils.
- Other technologies to extend herbicide contact time should be evaluated, such as pressurized bubble curtain barriers.

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Appendix A: Product Label Use Restrictions

Triclopyr: For waters treated with triclopyr (Kraken®), there are no restrictions on swimming, fishing, livestock consumption, or grazing (except lactating dairy animals). The setback for potable water intake structures during applications of triclopyr are determined by the treatment area (acres) and the concentration of triclopyr (Table A1). Based on the concentration of triclopyr used for this project, the potable water setback was 1,600 ft; however, there were no functioning potable water intakes within 1,600 ft of any plots treated with triclopyr in this study.

Table A1. Minimum setback distances for the application of Kraken® from functioning potable water intakes.

Area Treated (acres)	Concentration of Triclopyr Acid in Water (ppm ae)				
	0.75	1.0	1.5	2.0	2.5
	Required Setback Distance (ft) from Potable Water Intake				
<4	300	400	600	800	1,000
>4–8	420	560	840	1,120	1,400
>8–16	600	800	1,200	1,600	2,000
>16–32	780	1,040	1,560	2,080	2,600
>32 acres, calculate a setback using the formula for the appropriate rate at right	Setback (ft) = (800*ln (acres) – 160)/3.33	Setback (ft) = (800*ln (acres) – 160)/2.5	Setback (ft) = (800*ln (acres) – 160)/1.67	Setback (ft) = (800*ln (acres) – 160)/1.25	Setback (ft) = (800*ln (acres) – 160)

Endothall: Quiescent or slow moving waters treated with Aquathol K have no restrictions for swimming, fishing, or irrigation[*]. Waters treated with Aquathol K should not be used for animal consumption for up to 25 days, depending on the application rate[†]. The drinking water setback from functioning potable water intakes in the treated water body must be greater than or equal to 600 feet. The concentration of endothall acid in

[*] Treated water can be used for irrigating turf, ornamental plants and crops immediately after treatment with the following exceptions: Do not use treated water to irrigate the following for 7 days after the treatment: annual nursery or greenhouse crops including hydroponics and newly seeded or transplanted annual crops, newly seeded or transplanted ornamentals, and newly sodded or seeded turf.

[†] Animal consumption restrictions based on application rate where, 0.5 ppm dipotassium salt – 7 days; 4.25 ppm – 14 days; and 5.0 ppm – 25 days.

drinking (potable) water should not exceed the maximum contamination level (MCL) of 0.1 ppm. There were no potable water intakes within 600 feet of any plots treated with endothall in this study.

Diquat: For waters treated with diquat (reward®), there are no restrictions on swimming and fishing. Other restrictions including drinking, livestock/domestic animal consumption, and irrigation to turf/ornamentals and food crops are rate dependent as shown in table below. Rate-dependent setbacks of 350–1600 feet from functioning potable water intake. There were no water intakes within these setback distances of any plots treated with diquat in this study.

Figure A2. Water use restrictions following applications with reward (diquat) landscape and aquatic herbicide (days).

Application Rate	Drinking	Fishing and Swimming	Livestock/ Domestic Animals Consumption	Spray Tank Applications** and Irrigation to Turf and Landscape Ornamentals	Spray Tank Applications** and Irrigation to Food Crops and Production Ornamentals
2 gal/surface acre	3 days	0	1 day	3 days	5 days
1 gal/surface acre	2 days	0	1 day	2 days	5 days
0.75 gal/surface acre	2 days	0	1 day	2 days	5 days
0.50 gal/surface acre	1 day	0	1 day	1 day	5 days
Spot Spray* (<0.5 gal/surface acre)	1 day	0	1 day	1 day	5 days

*Add a nonionic surfactant (with at least 75% of the constituents active as a spray adjuvant) at the rate recommended by the manufacturer.
**For preparing agricultural sprays for food crops, turf or ornamentals (to prevent phytotoxicity), do not use water treated with Reward Landscape and Aquatic Herbicide before the specified time period.

Appendix B: Raw Plant Data Frequency of Occurrence

Table B1. Raw plant data frequency of occurrence.

July 2014				Numer of Times Species Occurred at a Sample Site									
Treatment Plot	Date Sampled	Total No Sites Sampled		EWM	No Plant	Spikerush (ELAC)	Coontail (CEDE)	Arrowhead (SAGR)	White Buttercup (RALO)	Elodea (ELCA)	Muskgrass (CHARA)	Leafy Pondweed (POFO)	Sago Pondweed (STPE)
DC-1	7/17/2014	28	PRESENCE	6	19	7	4	4	1	0	0	0	0
	% Frequencey of Occurrence			21.43%	67.86%	25.00%	14.29%	14.29%	3.57%	0.00%	0.00%	0.00%	0.00%
DC-2	7/17/2014	27		16	11	0	0	0	0	0	0	0	0
	% Frequencey of Occurrence			59.26%	40.74%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC-3	7/17/2014	5		3	2	0	0	0	0	0	0	0	0
	% Frequencey of Occurrence			60.00%	40.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC-4	7/17/2014	55		11	41	0	0	3	4	2	1	0	0
	% Frequencey of Occurrence			20.00%	74.55%	0.00%	0.00%	5.45%	7.27%	3.64%	1.82%	0.00%	0.00%
ES-6	7/20/2014	89		25	64	0	0	0	0	0	0	0	0
	% Frequencey of Occurrence			28.09%	71.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
September 2014				Numer of Times Species Occurred at a Sample Site									
Treatment Plot	Date Sampled	Total No Sites Sampled		EWM	No Plant	Spikerush (ELAC)	Coontail (CEDE)	Arrowhead (SAGR)	White Buttercup (RALO)	Elodea (ELCA)	Muskgrass (CHARA)	Leafy Pondweed (POFO)	Sago Pondweed (STPE)
DC-1	9/18/2014	19	Presence	0	16	1	0	0	0	0	3	0	0
	% Frequencey of Occurrence			0.00%	84.21%	5.26%	0.00%	0.00%	0.00%	0.00%	15.79%	0.00%	0.00%
DC-2	9/18/2014	49		18	17	0	0	0	1	5	10	2	25
	% Frequencey of Occurrence			36.73%	34.69%	0.00%	0.00%	0.00%	2.04%	10.20%	20.41%	4.08%	51.02%
DC-3	9/15/2014	5		4	1	0	0	0	0	0	1	0	0
	% Frequencey of Occurrence			80.00%	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	20.00%	0.00%	0.00%
DC-4	9/15/2014	73		7	64	1	0	0	3	0	4	0	0
	% Frequencey of Occurrence			9.59%	87.67%	1.37%	0.00%	0.00%	4.11%	0.00%	5.48%	0.00%	0.00%
ES-6	9/16/2014	93		43	47	0	0	0	21	21	0	0	7
	% Frequencey of Occurrence			46.24%	50.54%	0.00%	0.00%	0.00%	22.58%	22.58%	0.00%	0.00%	7.53%
September 2015				Numer of Times Species Occurred at a Sample Site									
Treatment Plot	Date Sampled	Total No Sites Sampled		EWM	No Plant	Spikerush (ELAC)	Coontail (CEDE)	Arrowhead (SAGR)	White Buttercup (RALO)	Elodea (ELCA)	Muskgrass (CHARA)	Leafy Pondweed (POFO)	Sago Pondweed (STPE)
DC-1	9/1/2015	27	Presence	4	18	1	0	0	2	2	3	0	0
	% Frequencey of Occurrence			14.81%	66.67%	3.70%	0.00%	0.00%	7.41%	7.41%	11.11%	0.00%	0.00%
DC-2	9/1/2015	27		13	14	0	0	0	0	0	0	0	0
	% Frequencey of Occurrence			48.15%	51.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC-3	9/1/2015	5		3	2	0	0	0	0	0	0	0	0
	% Frequencey of Occurrence			60.00%	40.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DC-4	9/1/2015	74		0	64	3	0	0	1	4	8	0	0
	% Frequencey of Occurrence			0.00%	86.49%	4.05%	0.00%	0.00%	1.35%	5.41%	10.81%	0.00%	0.00%
ES-6	8/31/2015	84		2	56	0	0	0	5	23	5	0	15
	% Frequencey of Occurrence			2.38%	66.67%	0.00%	0.00%	0.00%	5.95%	27.38%	5.95%	0.00%	17.86%

1 Treated water can be used for irrigating turf, ornamental plants and crops immediately after treatment with the following exceptions: Do not use treated water to irrigate the following for 7 days after the treatment: annual nursery or greenhouse crops including hydroponics and newly seeded or transplanted annual crops, newly seeded or transplanted ornamentals, and newly sodded or seeded turf.

* Animal consumption restrictions based on application rate where, 0.5 ppm dipotassium salt – 7 days; 4.25 ppm – 14 days; and 5.0 ppm – 25 days.

Appendix C: Rhodamine WT Fluorescent Dye for Use in Determining Bulk Water Exchange Processes, as Related to Aquatic Herbicide Applications

The inert tracer fluorescent dye, RWT will be utilized for our aquatic herbicide study on Fort Peck Lake, MT. The RWT will be applied in conjunction with the herbicides (endothall and triclopyr) used to control Eurasian watermilfoil. The RWT dye is not an adjuvant, and since we will be conducting in-water, submersed treatments, we will not be using any adjuvants in our study. While adjuvants (stickers/spreaders, etc) are routinely used for emergent plant and/or terrestrial applications, they are sparingly used to treat submersed plants.

Rhodamine WT dye has been used to measure water exchange and flows in the U.S. for over 40 years. Our research group pioneered the use of RWT to mimic aquatic herbicide dispersion in the late 1980s, and we have been using the dye since then, including many water exchange studies in USACE reservoirs (references below). Many of these studies have been in cooperation and/or consultation with the EPA, the U.S. Fish and Wildlife Service, the Tennessee Valley Authority, and other Federal agencies.

This dye has been approved by the EPA for use over potable water intakes at an aqueous concentration of 0.01 mg/L (10µg/L). We targeted 0.01 mg/L (10µg/L) or less for our water exchange studies. As shown on the Material Safety Data Sheet (MSDS), the reported LC 50 levels for RWT versus rainbow trout are 330 mg/L (320,000 µg/L), and for daphnia are 170 mg/L (170,000 µg/L), well above our nominal concentration of 0.01 mg/L.

In order to detect the very low levels of RWT applied in our studies, we use an instrument called a fluorometer, which can measure dye as low as 0.1µg/L (0.0001 mg/L). Aqueous dye concentrations of 10µg/L are essentially undetectable to the human eye, so measurements with a fluorometer are required. The dye usually degrades in the water column within a few days.

A number of fluorescent dyes are commercially available, but relatively few are suitable for water tracer studies (Wilson et al. 1986). Dyes that have been used in tracer studies include fluorescein, lissamine FF, rhodamine B, and RWT. The properties of RWT are well-suited to most studies and this is the dye most commonly used as a water tracer (Martin and McCutcheon 1999). Wilson et al. (1986) outlined the following desirable properties of RWT for tracer studies: (1) high solubility in water, (2) high fluorescence, easily detectable, (3) fluorescent in a part of the visible spectrum not common to materials generally found in water, thereby, reducing the problem of background fluorescence, (4) harmless in low concentrations, (5) inexpensive, and (6) reasonably stable in a normal water environment.

Health and safety are primary considerations in the aquatic application of tracer dyes, including potential toxic effects on lake biota and effects on human health. Concentrations of dye known to affect biota are generally much higher than those required for tracer studies (Martin and McCutcheon 1999). In the presence of high nitrite concentrations (more than 1 mg/L), RWT has been found to form the carcinogen diethylnitrosamine (DENA). The potential for DENA formation is very low in surface water bodies because of relatively low nitrite concentrations in these waters. The EPA and the U.S. Geological Survey have adopted a policy that prohibits the injection of fluorescent dyes in quantities that would result in dye concentrations greater than 10 µg/L at drinking water intakes.

Hazardous Materials Identification System ratings are presented in the MSDS for health (moderate hazard), flammability (slight hazard), and reactivity (slight hazard) for RWT. According to Environmental and Water Quality Operational Studies by the USACE, "Rhodamine WT has been chosen as the dye most suitable for use in inflow studies ..." and "poses no known environmental or health hazards when used in unpolluted waters." Therefore, RWT has been selected for use in our study based on the characteristics noted and experience using this dye in many similar tracer studies.

The RWT formulation was developed specifically for water tracing and can be monitored and quantified in-situ using a portable fluorometer (or analyzer with an appropriate sensor). Several studies have shown significant correlations between dissipation patterns of this dye and those of aquatic herbicides fluridone, endothall and triclopyr (Fox et al. 1991;

Fox et al. 1992, 1993; Getsinger et al. 1996). Results from these studies indicated that aquatic herbicide dissipation can be predicted by monitoring dye movement and concentration. Correlations in dispersal patterns must first be established for any given herbicide.

The regulatory standards that apply to the use of RWT are as follows:

- The standards established by the EPA in the Federal Register (Vol. 63, No. 40) state the maximum RWT concentrations to be 10 µg/L for water entering a drinking water plant (prior to treatment and distribution) and 0.1µg/L in finished drinking water.

The chemical formula of RWT dye is $C_{29}H_{29}ClN_2Na_2O_5$. The elemental composition is presented in Table C1. This compound is reportedly chemically inert and characterized by the presence of the xanthene nucleus ($C_{13}H_{10}O$).

Rhodamine WT has the most numerous qualities preferred by many state and federal agencies for open-channel studies. Also, fluorescent dye tracers do not usually require formal permits for use in a study (ASTM D5613 - 94(2008) Standard Test Method for Open-Channel Measurement of Time of Travel Using Dye Tracers). The drinking water standard established by the National Sanitation Foundation (NSF) in the NSF Standard 60 state the maximum concentration of RWT to be 0.1 mg/L (100 µg/L).

Table C1. Elemental composition of RWT

Element	Symbol	Atomic Mass	# of Atoms	Mass %
Carbon	C	12.0107	29	61.43%
Hydrogen	H	1.0079	29	5.16%
Chlorine	Cl	35.4532	1	6.25%
Nitrogen	N	14.0067	2	4.94%
Sodium	Na	22.9897	2	8.11%
Oxygen	O	15.9994	5	14.11%

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14. ABSTRACT

Eurasian watermilfoil (EWM) was first observed in Fort Peck Lake, MT in 2010 and has spread to over 100 locations in the lake. In 2012, field trials were conducted to evaluate aquatic herbicides for controlling EWM and provide management guidance. This work follows those initial 2012 demonstrations.
Five sites were identified for herbicide treatments and bulk water exchange processes were determined using inert tracer dye, rhodamine WT (RWT). Field trials conducted in 2014 spanned two growing seasons, summer (July) and fall (September). Treatments were with a variable-depth application technique, or for one plot, a hand gun from the surface. Vegetative communities were assessed at pretreatment, and at 8 and 52 weeks.

Non-target native vegetation was sparse pretreatment in all plots, but generally survived treatments. Treatments had no impacts on water quality measured in the field, including dissolved oxygen levels. Control of EWM was limited (< 50%) in small, open-water plots treated with diquat and endothall, where no barrier curtains were deployed. Control of EWM was near 100% through one year after treatment in plots where barrier curtains mitigated bulk water exchange processes and extended herbicide contact times were maintained.

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