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Herbicide Application Technique Development for Flowing Water: Summary of Research Accomplishments

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Prepared for Headquarters, U.S. Army Corps of Engineers

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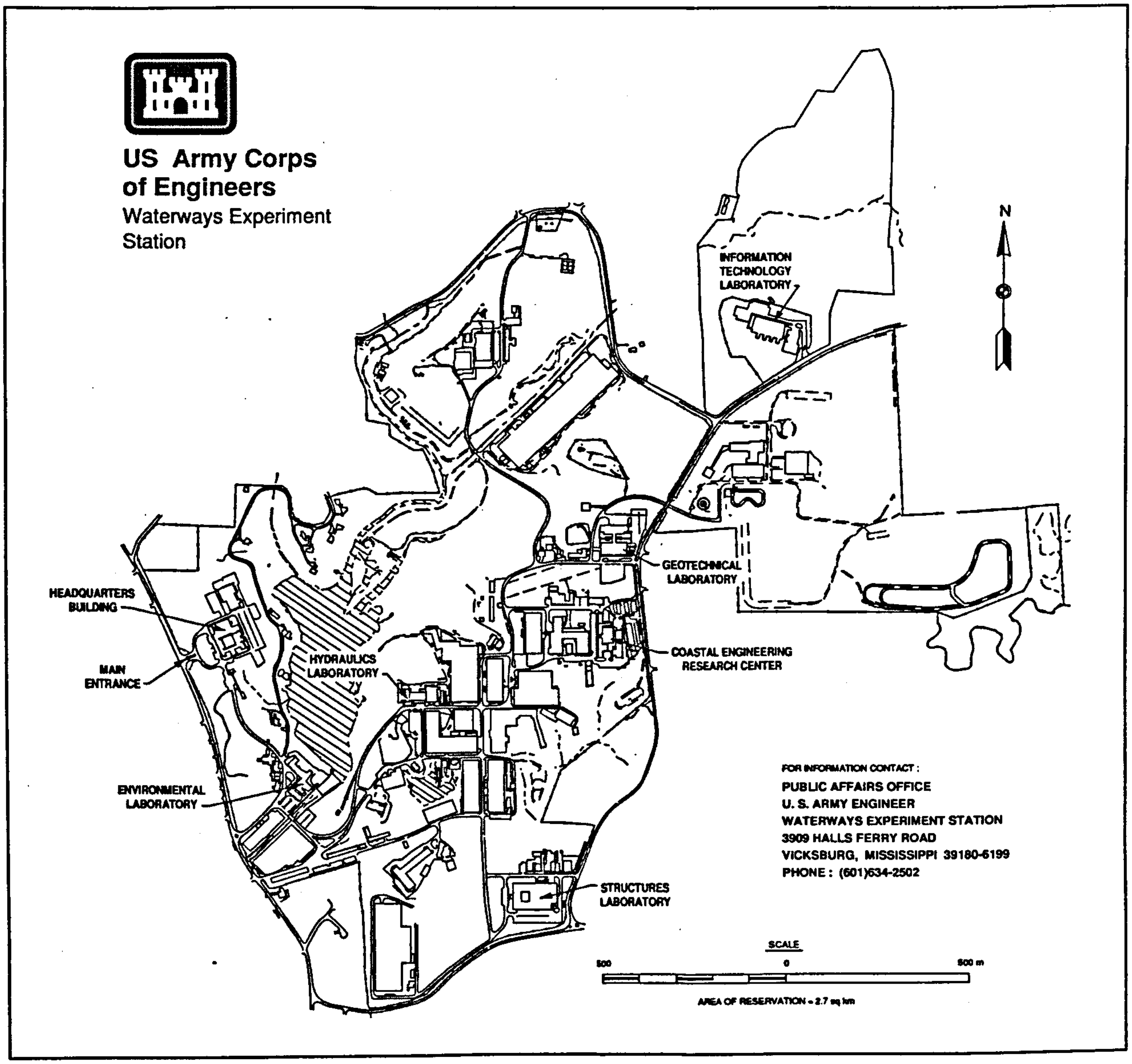

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Contents

Preface

The work reported herein was sponsored by the U.S. Army Engineer Districts, Jacksonville and Seattle, and by the Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32354. The APCRP is assigned to the U.S. Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, Construction General. The APCRP is managed under the Center for Aquatic Plant Research and Technology (CAPRT), Dr. John W. Barko, Director. Mr. Robert C. Gunkel was Assistant Director for the CAPRT. Program Monitor during this study was Ms. Denise White, HQUSACE.

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The Principal Investigator for this report was Dr. Kurt D. Getsinger, Ecosystem Processes and Effects Branch (EPEB), Environmental Processes and Effects Division (EPED), EL, WES. The report was prepared by Dr. Getsinger, and Drs. Alison M. Fox and William T. Haller, University of Florida Center of Aquatic Plants (UF-CAP).

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1 Introduction

Background

The focus of the Aquatic Plant Control Research Program's (APCRP) Chemical Control Technology Area is to develop environmentally compatible techniques for herbicides and plant growth regulators (PGRs) that provide improved tools for managing nuisance aquatic vegetation (Getsinger and Decell 1992). In recent years, several lines of research have been pursued within this technology area, including the following: (a) Herbicide Concentration and Exposure Time Studies; (b) Herbicide Application Technique Development for Flowing Water; (c) Field Evaluation of Selected Herbicides for New Aquatic Uses; (d) PGRs for Aquatic Plant Management; (e) Herbicide Delivery Systems; (f) Species-Selective Use of Aquatic Herbicides and PGRs; and (g) Coordination of Control Tactics with the Phenology of Aquatic Plants. Studies in these work units are conducted at the U.S. Army Engineer Waterways Experiment Station (WES) in Vicksburg, MS, WES's Lewisville Aquatic Ecosystem Research Facility in Lewisville, TX, and at selected field locations throughout the country.

Although the chemical control work units function as individual research efforts, they have been carefully designed and scheduled to act as integral components for successful development of improved application techniques. As structured, these integrated work units collectively support development and evaluation of safe and effective chemical formulations and application techniques for the aquatic environment. Consequently, aquatic plant managers are provided with effective operational techniques that minimize chemical dose, while maximizing the control of target plants, reducing the amount of chemicals placed in the environment, and decreasing the effort and costs associated with aquatic applications.

An important outcome of the chemical control research activities has been the close working relationship that WES scientists have developed with the chemical industry and the U.S. Environmental Protection Agency (EPA). This cooperation enables chemical control researchers to stay informed of the latest developments in aquatic pesticides and regulation requirements. In addition, interaction with U.S. Army Corps of Engineers Districts and other Federal agencies responsible for aquatic plant management activities, such as the Tennessee Valley Authority, the U.S. Bureau of Reclamation, and the U.S. Department of Agriculture, is necessary to coordinate and focus resources on regional and national problems. Finally, cooperation with State and local aquatic plant management programs and institutional research facilities is maintained to augment WES's laboratory and field research capabilities.

In response to recent major reductions in APCRP funding levels, four of the Chemical Control Technology Area work units will be terminated prematurely in Fiscal Year 1996: (a) Herbicide Concentration and Exposure Time Studies; (b) Herbicide Application Technique Development for Flowing Water; (c) Field Evaluation of Selected Herbicides for New Aquatic Uses; and (d) PGRs for Aquatic Plant Management. As work in these areas is completed, a series of reports will be published to summarize and document the final accomplishments in each terminated work unit. This report is a product in that series.

Chemical Control in Flowing Water

Using herbicides to control submersed plants in static water conditions has proven to be a predictable and effective method for managing nuisance vegetation. However, chemical applications in flowing water situations or in sites requiring spot treatment or partial treatment of large water bodies can result in inconsistent control of target plants. This inconsistency is related to the concentration/exposure time (CET) relationship of a particular herbicide and target plant species (Netherland and Getsinger 1991). To achieve desired efficacy, target plants must remain in contact with herbicides at specific concentrations for specific time periods. Since the major avenue for herbicide uptake in submersed plants is via the shoot from the surrounding water column, water exchange can dramatically influence the efficacy of a treatment by altering the exposure period and thereby impacting CET relationships. Many unsuccessful chemical treatments can undoubtedly be attributed to off-target movement of treated water caused by gravity flow, wind mixing, thermal stratification, tidal action, and other hydrodynamic processes. Clearly, a better understanding of water movement in and around target submersed vegetation is essential for obtaining desired levels of nuisance plant control in flowing-water situations.

However, there are other important aspects and potential constraints in using herbicides where water exchange is a factor besides the direct influence on efficacy against target plants. Of primary concern is the potential off-target movement of herbicide active ingredients out of treated areas. In addition to diminishing effectiveness in the treatment area, this off-target movement of herbicides has the potential to injure vegetation outside or downstream of the defined application zone. Moreover, accurate predictions of off-target herbicide concentration/dissipation profiles can be crucial with respect to water-use restrictions (such as potable water intakes, irrigation, swimming, fishing, etc.) that may be imposed by some formulation labels.

In 1986, a research work unit was initiated to examine the problems, inconsistencies, and data gaps associated with using aquatic herbicides in flowing water systems. The primary objectives of this effort were to (a) characterize flow velocities and water-exchange patterns in submersed plant stands under a variety of simulated and field conditions, (b) evaluate application techniques that maximize herbicide contact time in flowing-water environments, and (c) provide guidance to operational personnel for improving the control of nuisance submersed vegetation in high water-exchange environments.

While meeting the primary objectives of the work unit, additional information was generated which led to development of techniques for (a) monitoring and/or predicting dispersion/dissipation of herbicides from treated areas as related to potable water intakes and potential impacts to nontarget vegetation, and (b) reducing effort and costs associated with water residue sampling in herbicide field dissipation studies required for EPA aquatic use registration.

These primary and secondary work unit objectives were accomplished through a series of large-scale water-exchange studies using flowmeters and tracer dye and via field application technique evaluations using dye and herbicides. Utilizing the previously described integrated work unit approach, critical information from the Herbicide Concentration and Exposure Time Studies work unit (Getsinger and Netherland, in preparation) was matched with results from many of these water-exchange studies to design improved application techniques for specific flowing water situations. The methodologies spawned during this 10-year research effort have substantially improved the management of Eurasian watermilfoil (*Myriophyllum spicatum* L.) and hydrilla (*Hydrilla verticillata* Royle) in rivers, lakes, and reservoirs throughout the U.S. In addition, these innovative treatment techniques are being used to manage other target species in a variety of field situations.

This report charts the chronological progress of this "flowing water" work unit while summarizing major research findings and accomplishments. These summaries are presented as three sections: Flowmeter Studies 1986-1987; Tracer Dye Studies 1987-1990; and Operational Herbicide Evaluations 1989-1995. Details of individual studies conducted under this work unit can be found in specific publications cited throughout this report and listed in the Reference section.

2 Flowmeter Studies: 1986-1987

In an effort to characterize water exchange in dense stands of submersed vegetation and to relate these patterns to potential herbicide treatments, flow velocities were measured in and around submersed plant stands using electromagnetic-sensor portable velocity meters in a variety of hydraulic flume and field situations (Getsinger and Westerdahl 1986; Getsinger 1987; Getsinger 1988; Getsinger, Green, and Westerdahl 1990). Initially, vegetated flowing-water conditions were simulated in large-scale hydraulic flumes at WES using Eurasian watermilfoil and hydrilla and at the Tennessee Valley Authority Aquatic Research Laboratory, Browns Ferry, AL, using Eurasian watermilfoil. Eventually, field sites were selected for evaluations in the Holston River, Tennessee, that supported dense stands of wild celery (*Vallisneria americana* Michaux.), sago pondweed (*Potamogeton pectinatus* L.), and water stargrass (*Heteranthera dubia* (Jacq)MacM.) and in irrigation/drainage canals near Sacramento, CA, that were infested with stands of Eurasian watermilfoil, coontail (*Ceratophyllum demersum* L.) and elodea (*Elodea canadensis* Rich.).

Results from these studies verified that dense stands of submersed macrophytes substantially alter water movement in lotic systems. Moreover, the physical structure and height of plants, as well as the areal extent of the stand, can influence water velocities. While velocities above and around submersed stands can be relatively high (15 to 35 cm/sec), concurrent intrastand velocities are usually quite low (< 1 cm/sec). Although low, these intrastand velocities can still drive water-exchange patterns that reduce herbicide contact time and target plant efficacy. Intrastand water-exchange characteristics become increasingly important as size of treatment area decreases and product-specific CET relationships favor long herbicide exposure periods. These studies also demonstrated that conventional electromagnetic-sensor portable flowmeters can be used to characterize linear flow patterns in and around submersed plant stands when velocities exceed 1 cm/sec; however, the use of these instruments for measuring intrastand velocities below 1 cm/sec is limited.

Recommendations from these flowmeter studies for areas where water movement might prevent a herbicide application from providing an exposure period that satisfies the CET requirements were as follows: (a) water-exchange patterns should be determined prior to treatment, and (b) the inert water-tracing dye rhodamine WT (RWT) should be investigated for characterizing those water-movement patterns. In addition, it was recommended that studies using RWT be conducted to determine the effects of thermal stratification, stage of plant growth, and various application techniques on the potential distribution of herbicides in the water column.

3 Tracer Dye Studies: 1987-1990

Building on results of the flowmeter work, a series of field studies were conducted using the inert fluorescent tracer dye RWT. Dye studies were used to characterize bulk water exchange in submersed plant stands, evaluate conventional and innovative submersed application techniques, and simulate off-target movement of herbicides. The research focused on major problems faced by field personnel when controlling submersed vegetation in flowing-water situations. Herbicide retention times in tidal systems were determined in hydrilla stands in the Crystal River in Florida and the Potomac River near Washington, DC (Fox, Haller, and Getsinger 1991; Fox et al. 1991; Getsinger et al. 1991). Riverine and large water bodies were studied in the hydrilla- and Eurasian watermilfoil-infested waters of the St. Johns and Withlacoochee rivers, Lakes Lochloosa, Orange, Washington, and Kissimee in Florida (Fox, Haller, and Getsinger 1990; Getsinger, Green, and Westerdahl 1990; Getsinger, Haller, and Fox 1990), and the Pend Oreille and Columbia rivers in Washington (Getsinger, Green, and Westerdahl 1990; Getsinger, Sisneros, and Turner 1993). Thermal stratification was addressed in many of these studies by examination of the water column and its role in potential herbicide distribution. Supportive laboratory studies were used to show that submersed plants were not a factor in the loss of RWT from aqueous solutions (Turner, Netherland, and Getsinger 1991).

These investigations confirmed that RWT applications are a reliable and relatively easy technique for determining water-exchange characteristics, relative to potential herbicide contact time, in submersed plant stands under most field situations, including tidal systems. The capability of real-time data collection after RWT applications enable repeated treatments to be conducted under a wide range of environmental conditions. Dye half-lives can be easily calculated for proposed treatment plots and matched with selected herbicide CET relationships to predict efficacy on target or nontarget plants. Based on current herbicide CET information, dye studies can also verify conditions in which herbicide applications would be of little or no use for controlling target vegetation.

Tracer dyes were also shown to be useful in simulating the effects of thermal stratification, plant height, and application techniques (e.g., variable depth drop-hoses, shallow-depth subsurface injection, surface broadcast, granules, adjuvants) on water column uniformity of aqueous levels of herbicides surrounding submersed plants. Dye studies clearly showed that thermally stratified water conditions (e.g., warm surface and cool depths) can inhibit vertical mixing of water layers and thus prevent the even distribution of posttreatment herbicide concentrations. This phenomenon may be particularly critical when using surface broadcast or shallow-depth injection techniques with liquid formulations, in which case the thermal inhibition of mixing may interfere with herbicide delivery. In contrast, isothermal water temperature conditions can promote water column mixing and thereby improve herbicide distribution through the water column in submersed plant stands. Even distribution may also be enhanced by using clay granular formulations, or other inert carriers and/or adjuvants, that aid in delivering the active ingredient below the thermocline.

In addition, dye profiles measured in downstream waters indicated that stationary RWT-impregnated carriers (e.g., gypsum matrices) can be used to simulate controlled release of herbicides in flowing water. When correlated with appropriate herbicide CET information and site-specific water-exchange characteristics, these types of carrier systems could be designed to provide customized herbicidal release profiles that satisfy the particular CET requirements for effective control of target species. This type of application technique would help achieve desired level of control, with minimal herbicide delivery.

Recommendations based on the results of these studies included the continued use of the tracer dye RWT to characterize water-exchange patterns in submersed plant stands, determine potential off-target movement herbicides, and evaluate potential submersed herbicide application techniques. It was suggested that relationships between the dissipation of RWT and aquatic herbicides in the field be examined and that herbicide application techniques be developed and evaluated for submersed plant stands in flowing water, taking into consideration the hydrodynamic processes that occur in and around those stands. Preferably, these techniques would encompass the use of RWT and various formulations and methods of application, including controlled- or slow-release devices.

4 Operational Herbicide Evaluations: 1989-1995

The main objective of the final phase of the flowing-water work unit involved coupling field water-exchange information from RWT dye additions with laboratory-derived CET relationships to develop application techniques for improving control of target plants in high water-exchange environments. An ancillary objective of this effort was to establish correlations between the behavior of RWT and selected herbicides when applied to submersed plant stands. Once established, these dye/herbicide relationships can be used to reliably predict posttreatment water concentration and water-column distribution, off-target movement, and contact time of herbicide active ingredients.

Field studies in which RWT was added concurrently to chemical applications on hydrilla were conducted for the herbicides diquat (Reward), endothall (Aquathol K), fluridone (Sonar), and bensulfuron methyl (Mariner). These studies were conducted in Lakes Orange, Washington, Hell 'n' Blazes, and Seminole and in the Crystal River, all in Florida (Fox, Haller, and Shilling 1991; Fox, Haller, and Getsinger 1992, 1993; Fox and Haller 1994; Langeland et al. 1994). Additional dye/herbicide studies were conducted in Eurasian watermilfoil stands in the Pend Oreille River, Washington, Guntersville Reservoir, Alabama, and Lake Minnetonka, Minnesota (Getsinger, Turner, and Madsen 1992a,b; Getsinger, Turner, and Madsen 1993, 1994; Turner, Getsinger, and Netherland 1994; Getsinger 1995; Fox and Haller 1995; Getsinger et al. 1996; Turner, Getsinger, and Burns, in preparation).

These dye/herbicide evaluations verified laboratory- and mesocosm-derived herbicide CET relationships for hydrilla and Eurasian watermilfoil, demonstrating that CET relationships are valid for predicting herbicide efficacy in the field. Data collected from these studies established correlations between the behavior of RWT and a majority of the most commonly used aquatic herbicides. These correlations allow RWT to be used to simulate and predict herbicide dissipation and dispersion in water, useful factors when designing or implementing submersed applications with respect to potable and irrigation water intake structures and other potential water-use restrictions. This herbicide/dye association also aids in selecting appropriate water residue sampling locations for aquatic herbicide dissipation studies, thereby reducing the volume of samples required for expensive analytical procedures.

Finally, these dye/herbicide evaluations contributed to the development of the prescription herbicide treatment strategy. This strategy utilizes site-specific water-exchange data and herbicide- and plant-specific CET relationships to determine the appropriate herbicide and minimum dose required for obtaining desired control of the target plant. Prescription treatment strategies also utilize innovative application techniques developed in this work unit, such as sequential and/or block treatments, controlled-release carriers, and low-dose deliveries. Just as importantly, this information can be used to determine when herbicide applications will not provide an effective management option, i.e., when site-specific water-exchange characteristics will not allow sufficient herbicide contact time for adequate control.

An important contribution of the flowing water work unit has been the documented operational improvement in managing Eurasian watermilfoil and hydrilla in rivers, canals, lakes, and reservoirs. These "success stories" involve improvements in the level, duration, and selectivity of target plant control. In some cases, using this innovative technology allowed for success in treatments that would not otherwise have been attempted using older, conventional technology. Furthermore, the repeated achievements of these field applications have encouraged States such as California, Nevada, New York, Vermont, and Washington to consider incorporating selective, low-dose, flowing-water herbicide techniques into their aquatic plant management plans.

Specific examples of these successful operational-scale treatments include the eradication of Eurasian watermilfoil in Long Lake, Washington, and excellent selective control of that plant in Sacheen Lake and in several locations along the Columbia and Pend Oreille rivers, Washington (Farone and McNabb 1993; Getsinger 1993; McNabb 1993; Madsen, Getsinger, and Turner 1994; McNabb 1995; Getsinger et al. 1996). Other operational applications have been documented in milfoil-dominated sites of Lake Minnetonka, Minnesota (Madsen and Getsinger 1995) and Guntersville Reservoir, Alabama (Turner, Getsinger, and Burns, in preparation).

Improved hydrilla control has been obtained in the Crystal River, Florida, and particularly in the St. Johns and Withlacoochee rivers, Florida (Haller, Fox, and Shilling 1990; Fox and Haller 1992; Fox, Haller, and Shilling 1994). Large stretches (10-20 km) of the St. Johns and Withlacoochee have consistently been cleared of hydrilla for the first time since the plant infested those systems over 15 years ago. A successful flowing water treatment of hydrilla was also achieved in Foster Creek, South Carolina (De Kozłowski 1994). Finally, a hydrilla-eradication program using the improved flowing-water herbicide technology is currently being implemented in Pipe and Lucerne lakes, Washington (McNabb and Marquez 1996).

5 Conclusions and Recommendations

Conclusions

Hydrodynamic processes driven by gravity flow, tides, and wind- and thermal-induced circulation can impact the effectiveness of submersed herbicide application techniques. When viewed in the context of well-defined herbicide- and plant-specific CET relationships, water-exchange patterns in submersed plant stands can play a major role in determining success or failure of a treatment.

In flowing-water situations that harbor dense stands of submersed plants, and also in small stands surrounded by larger areas of static water, exchange processes may be complex, subtle, and difficult to characterize using conventional flowmeters. In such situations, the inert fluorescent dye rhodamine WT can provide a better estimate of bulk water exchange and can be used to predict posttreatment dispersion/dissipation patterns of many aquatic herbicides. This dye technique can also reduce time and costs associated with dissipation studies required for aquatic registration and/or re-registration. When coupled with herbicide CET relationships, this information can be used to develop prescription treatment strategies where the appropriate herbicide formulation and minimum dose are used to provide desired control of the target plant.

Numerous operational treatments around the country have repeatedly verified that the use of water-exchange information, herbicide CET relationships, and innovative application techniques significantly improve management of Eurasian watermilfoil and hydrilla in flowing-water situations. Accomplishments in this flowing-water work area have established new standards for the environmentally sound management of nuisance vegetation using herbicides in many areas previously proclaimed "unmanageable."

Recommendations

Based on the results of this work, the following actions are recommended:

a. Continue to refine herbicide CET relationships for target plants, and initiate similar studies for nontarget vegetation.

b. Utilize CET relationships and site-specific water-exchange information to develop prescription treatment strategies for selectively managing nuisance plants and restoring native vegetation.

c. Develop more user-friendly and economical methods to measure site-specific water exchange reliably for use in operational prescription treatment herbicide programs.

d. Develop environmentally compatible controlled-release carriers/ formulations to assist in providing prescription herbicide treatments.

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Using herbicides to control submersed plants in static water conditions is a predictable and effective method for managing nuisance vegetation; however, chemical applications in areas of high water exchange can often result in inconsistent control of target plants. Poor plant control can be related to concentration/exposure time (CET) relationships of particular herbicides and target plant species. Many unsuccessful treatments can be attributed to off-target movement of treated water due to hydrodynamic processes.

A long-term work unit was initiated to examine the problems and inconsistencies associated with using herbicides in flowing-water systems. The objectives of this effort were to (a) characterize flow velocities and water-exchange patterns in submersed plant stands under a variety of simulated and field conditions, (b) evaluate application techniques that maximize herbicide contact time in flowing-water environments, and (c) provide guidance to operational personnel for improving the control of nuisance submersed vegetation in high water-exchange environments.

Field studies using electronic flowmeters and tracer dyes showed that dense stands of submersed macrophytes substantially alter water movement in lotic environments, potentially reducing herbicide contact time. Intrastand flow velocities can be quite low compared with velocities along the outside edges of the plant stand. Results from

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more sensitive tracer dye studies indicated that subtle water-exchange patterns (both within and outside stands), driven by temperature, wind, and other factors, can also reduce herbicide contact time.

Additional field studies coupled water-exchange information with laboratory-derived CET relationships and verified the predicted efficacy against Eurasian watermilfoil and hydrilla. Correlations were established between the behavior of the inert dye rhodamine WT (RWT) with selected herbicides in a variety of flowing-water systems, demonstrating that RWT can be used to simulate herbicide dissipation.

These dye/herbicide evaluations contributed to the development of prescription treatment strategies to improve the control of Eurasian watermilfoil and hydrilla. Field verification of these strategies occurred in 10 lake, reservoir, and river systems around the country.

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