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2,4-D CONCENTRATION AND EXPOSURE TIME RELATIONSHIPS FOR THE CONTROL OF EURASIAN WATERMILFOIL

by

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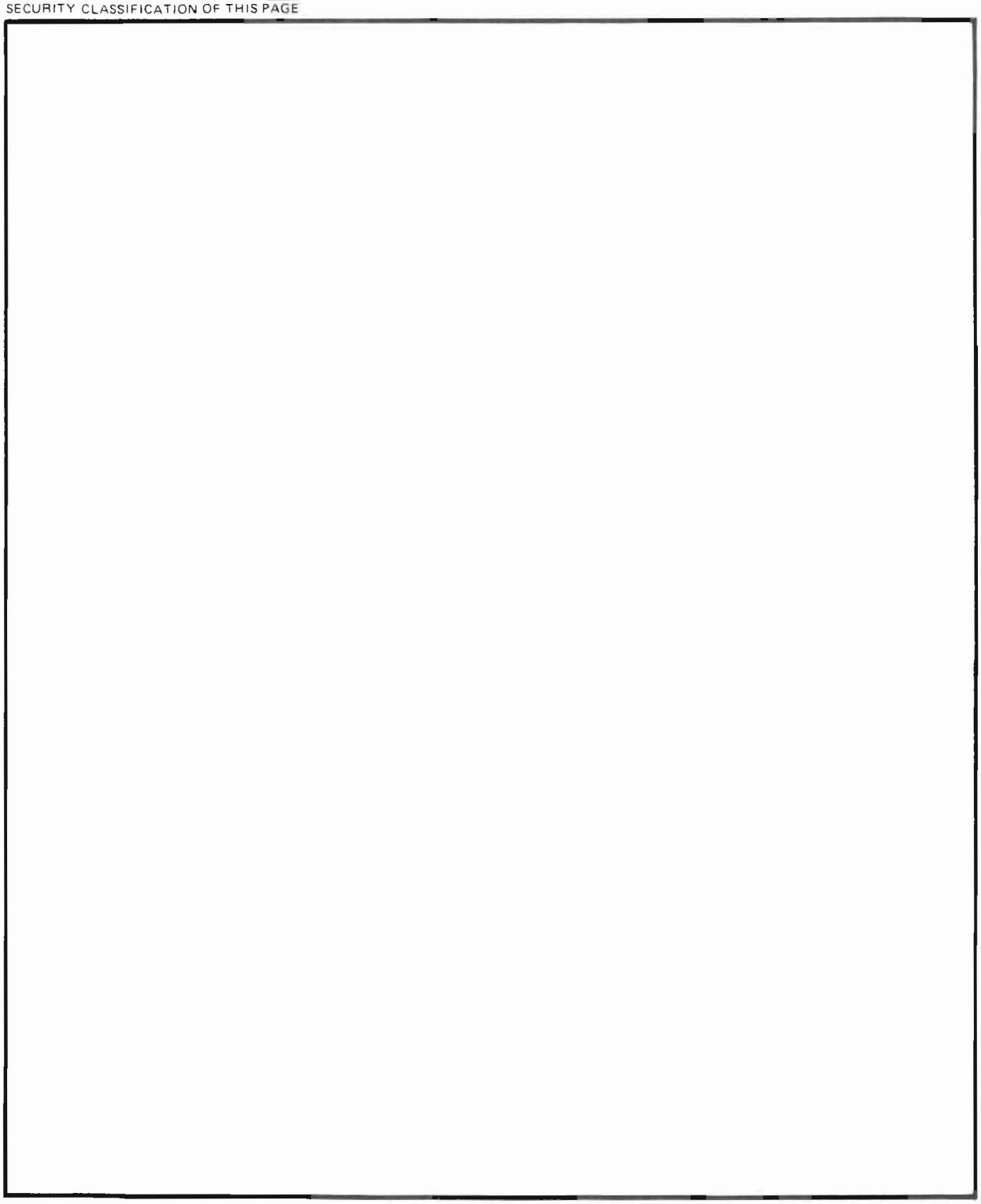

PREFACE

This study was conducted by personnel of the US Army Engineer Waterways Experiment Station (WES) as a part of the US Army Corps of Engineers (USACE) Aquatic Plant Control Research Program (APCRP). Funds for the effort were provided by USACE, under Department of the Army Appropriation No. 96X3122, Construction General, 902740. Mr. E. Carl Brown (USACE) was Technical Monitor.

This work was initiated in November 1986 under the general supervision of Dr. John Harrison, Chief, Environmental Laboratory (EL), Mr. Donald L. Robey, Chief, Ecosystem Research and Simulation Division (ERSD), EL, and under the direct supervision of Dr. Thomas L. Hart, Chief, Aquatic Processes and Effects Group (APEG), ERSD. Mr. J. Lewis Decell was the Program Manager for the APCRP. Dr. Howard E. Westerdahl (APEG) was the principal investigator for the work unit, and Mr. W. Reed Green performed the research with assistance from Mmes. Yvonne Vallette, Cindy Waddle, and Cindy Teeter, and Messrs. Dave Stuart and Arthur Miller (APEG). Reviewers of this report were Drs. Kurt Getsinger and Kien Luu of APEG. This report was edited by Mr. Bobby Odom, assigned to the WES Information Products Division under the Intergovernmental Personnel Act.

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CONTENTS

2,4-D CONCENTRATION AND EXPOSURE TIME RELATIONSHIPS FOR THE CONTROL OF EURASIAN WATERMILFOIL

PART I: INTRODUCTION

Background

1. Rivers and reservoirs with relatively short hydraulic retention times or significant wind-induced or tidally influenced circulation patterns offer unique conditions affecting chemical control of nuisance submersed aquatic plants. Herbicide efficacy in these environments is influenced primarily by three conditions: (a) herbicide concentration in the water or sediment (depending on primary mode of action); (b) length of time the targeted plant species remains exposed to a herbicide concentration; and (c) the growth stage of the target plant at the time of treatment. Young actively growing submersed plants are generally considered to be more susceptible to herbicides than are mature plants; however, plant efficacy interaction between herbicide concentration and exposure time is not fully understood.

2. Previous studies using the herbicide endothall to control hydrilla (*Hydrilla verticillata* L.f. Royle) and 2,4-D to control Eurasian watermilfoil (*Myriophyllum spicatum* L.) in dynamic aquatic environments have illustrated the variability in plant control and the potential for futile operational control efforts. Getsinger, Fox, and Haller (in preparation) suggested that proper timing of endothall applications (in a spring and tidally influenced area of the Crystal River, Florida) to maximize herbicide concentration and exposure time may improve chances for control of hydrilla. Until initiation of this ongoing study, control efforts in Crystal River, Florida, have been frequent, costly, and less than satisfactory. Lim and Lozoway (1976), British Columbia Water Investigative Branch (1980), Killgore (1983), Westerdahl et al. (1983), and Getsinger and Westerdahl (1984) observed variability in Eurasian watermilfoil control following applications of liquid and granular 2,4-D to areas of large lakes, reservoirs, and riverine systems. Many of these 2,4-D applications resulted in low herbicide concentrations within the water and short periods of plant exposure.

3. The observed variability in herbicide efficacy from these efforts exhibits the need for the determination of the relationships between concentration and exposure time, and plant efficacy. When these relationships are established, the results should be useful to both herbicide developers and applicators in the design of herbicide formulations and the improvement of application techniques to achieve submersed plant control in dynamic aquatic environments.

Objectives

4. The objectives of this study were to define the relationships between 2,4-D concentration and exposure time for the control of Eurasian watermilfoil under laboratory conditions using concentrations, exposure times, and plant biomass similar to field conditions and to compare these findings with previous 2,4-D concentration and exposure time studies conducted under both laboratory and field conditions.

Materials and Methods

5. The laboratory system used for this study was a modification of the aquaria system used by Hall et al. (1982) and Westerdahl et al. (1983). The system consisted of 24, 55-ℓ, vertical aquaria (0.75 m × 0.3 m^2) located in a controlled environment greenhouse. Twelve Sunbrella light fixtures were suspended approximately 2-m above the aquaria platform, set at a light:dark cycle of 13:11 hr. The mean photosynthetically active radiation measured at the water surface was 1600 $\mu E/m^2$ (Hall et al. 1982).

6. Eurasian watermilfoil, collected from the field, was supplied by Suwannee Laboratories, Inc., Lake City, FL. Four apical shoots (15 cm long) were planted 5 cm deep in 250-ml glass beakers containing nitrogen-enriched sediment collected from Brown's Lake, Waterways Experiment Station, Vicksburg, MS. Eleven beakers were placed in each aquarium. Each aquarium was independently supplied with a continuous flow of reconstituted hard water (Hall et al. 1982; US Environmental Protection Agency 1975). The water volume (50 ℓ) of each aquarium was displaced with fresh, reconstituted hard water every 24 hr. Air was bubbled through each aquaria to provide a source of carbon

dioxide and to circulate the water. Water temperature was maintained between 19 and 23° C.

7. The study consisted of 16 treatments including fourteen 2,4-D concentration exposure time combinations and two untreated references (Table 1). All tests were arranged in a completely randomized design with three replications. The tests were separated into two independent test runs using 24 aquaria.

8. Each aquarium containing Eurasian watermilfoil was treated when the shoot apices reached to within 5 to 10 cm of the water surface (2 weeks). One randomly selected beaker of Eurasian watermilfoil was removed from each aquarium, just prior to 2,4-D application, to provide an estimate of the pretreatment plant biomass. The 24 beakers of plant material were harvested and combined into one biomass sample, dried to constant weight at 55° C, and weighed. The biomass equivalent of 10 beakers was then calculated from this combined sample.

9. The pretreatment biomass of Eurasian watermilfoil was similar to biomass produced in the field. Seasonal maximum biomass measured in the littoral zone of different systems can range from 32 to 360 g/m^2 dry weight (Grace and Wetzel 1978). The mean Eurasian watermilfoil biomass (dry weight) collected from the three 2,4-D test plots of Lim and Lozoway (1976) in British Columbia, Canada, early in the growing season was 129, 463, and 273 g/m^2. The average dry weight biomass treated within this study was 11.16 and 11.11 g/aquarium for each of the two runs, which was equivalent to 124 g/m^2 dry weight at a water depth of 0.5 m.

10. The 2,4-D stock solutions used to treat the Eurasian watermilfoil were prepared from analytical grade 2,4-D acid (>97 percent acid). The 2,4-D acid was dissolved in ethyl alcohol and diluted with distilled water to make 1-ℓ stock solutions. Calculated volumes of the 2,4-D stock solution were added to the aquaria to provide the treatment concentrations. The 2,4-D solution remained in each aquarium for the required exposure time, after which, each aquarium was emptied and refilled with fresh water at least three times to remove 2,4-D residues.

11. Three water samples were taken for 2,4-D residue analysis from each aquarium: (a) immediately after treatment to verify treatment concentrations; (b) just prior to the first rinse to determine residue level decline over the exposure time; and (c) after the final rinse to verify the removal of the

2,4-D residues. Residue samples were analyzed by the Analytical Laboratory Branch, Tennessee Valley Authority, Chattanooga, TN. Actual residue concentrations in the aquaria immediately after treatment were consistent with the expected 2,4-D treatments. The mean 2,4-D residue concentrations at the time of treatment were: (a) 0.51 mg acid equivalent (ae)/ℓ (± 0.01 standard error (SE)), (b) 1.02 mg ae/ℓ (±0.06 SE), and (c) 2.03 mg ae/ℓ (± 0.06 SE). Residue decline over the exposure time was negligible. The largest decline (-0.3 mg ae/ℓ) occurred in the 1.0 mg ae/ℓ for 48-hr exposure. All residue levels following the final rinse were below the detection limits (0.1 mg ae/ℓ) except one replicate of the 2.0 mg ae/ℓ for 24-hr exposures, which was at the detection limit.

12. The posttreatment test duration was 4 weeks (28 days). This was based in part from the results of Elliston and Steward (1972), Hall et al. (1982), and Westerdahl et al. (1983). These authors evaluated herbicide effects for 6 to 10 weeks posttreatment. Maximum plant injury was observed by 4 weeks posttreatment.

13. Eurasian watermilfoil control in this study was determined by comparing the results of two efficacy evaluations at 4 weeks posttreatment: (a) visual estimates of plant injury; and (b) harvested biomass. Percent injury was examined by rating apparent injury for each replicate relative to the appearance of the reference replicates (Figures 1-3). A value of 100 percent would equal complete control, no living tissue surviving treatment. Total harvested biomass (dry weight) was determined by collecting all the plant material (living and dead) within each replicate and separating it into roots and shoots. The biomass for roots and shoots was combined for each replicate to provide total biomass. Net posttreatment biomass production was determined for each treatment by subtracting the mean biomass at the time of treatment from the total harvested biomass. A positive net biomass would indicate that plant growth continued after treatment where a zero or negative net biomass would suggest that no plant growth (measurable biomass) and/or tissue decomposition occurred after treatment. Negative net biomass could also result if the loss in biomass from tissue decomposition was greater than the biomass produced from plant regrowth.

Figure 1. Example of a reference aquarium providing no Eurasian watermilfoil control

Figure 2. Example of a 2,4-D exposure providing Eurasian watermilfoil injury

Figure 3. Example of a 2,4-D exposure providing Eurasian watermilfoil control

PART II: RESULTS AND DISCUSSION

14. Results from this study showed that Eurasian watermilfoil control was related to 2,4-D concentration and plant exposure time. The 2,4-D concentrations and exposure times that produced little or no injury to Eurasian watermilfoil were the 0.5 mg ae/ℓ for 12- and 24-hr exposures and the 1.0 mg ae/ℓ for 12-hr exposure. The percent plant injury in these aquaria, 4 weeks after treatment, was less than 20 percent (Table 2). All replicates of these combinations had healthy vegetation at the time of harvest. The harvested biomass from these aquaria was less than the references but was considerably greater than the biomass harvested from the remaining aquaria (Figure 4). The degree of initial injury was less in these treatments than in other treatments, and recovery occurred quickly. The initial response of the vegetation revealed epinasty (shoot and leaf curling) and epidermal rupture of the young tissue around the nodes, which occurred over the first few days after treatment. These 2,4-D exposures presumably interfered with biomass production early after treatment, which was exhibited by the reduction in biomass harvested compared to that of the untreated Eurasian watermilfoil.

15. Eurasian watermilfoil injury was observed in the 0.5 mg ae/ℓ for 36-, 48-, and 60-hr, the 1.0 mg ae/ℓ for 24-hr, and the 2.0 mg ae/ℓ for 12-hr exposures. Plant injury ranged from 22 to 88 percent (Table 2). All replicates within each treatment contained viable roots and shoots with the exception of the 0.5 mg ae/ℓ for 60-hr exposure, which had one replicate without viable root tissue and only one living shoot fragment. The harvested biomass from these treatments was considerably less than in the references and only slightly greater than the pretreatment biomass (Figure 4). The initial physical injury of the tissue from these exposures suggested that control might be achieved, but regrowth of the Eurasian watermilfoil occurred within the 4 week evaluation period. The new vegetation appeared to be as healthy as the untreated at harvest time.

16. The 2.0 mg ae/ℓ for 24-hr, 1.0 mg ae/ℓ for 36-hr, and 0.5 mg ae/ℓ for 72-hr exposures produced severe plant injury, and determination of plant control was difficult. Plant injury was estimated at 77, 96, and 95 percent for the 1.0 mg ae/ℓ for 36-hr, 2.0 mg ae/ℓ for 24-hr, and 0.5 mg ae/ℓ for 72-hr exposures, respectively (Table 2). Viable shoot tissue was harvested from all replicates of the 0.5 mg ae/ℓ for 72-hr, and 1.0 mg ae/ℓ for 36-hr

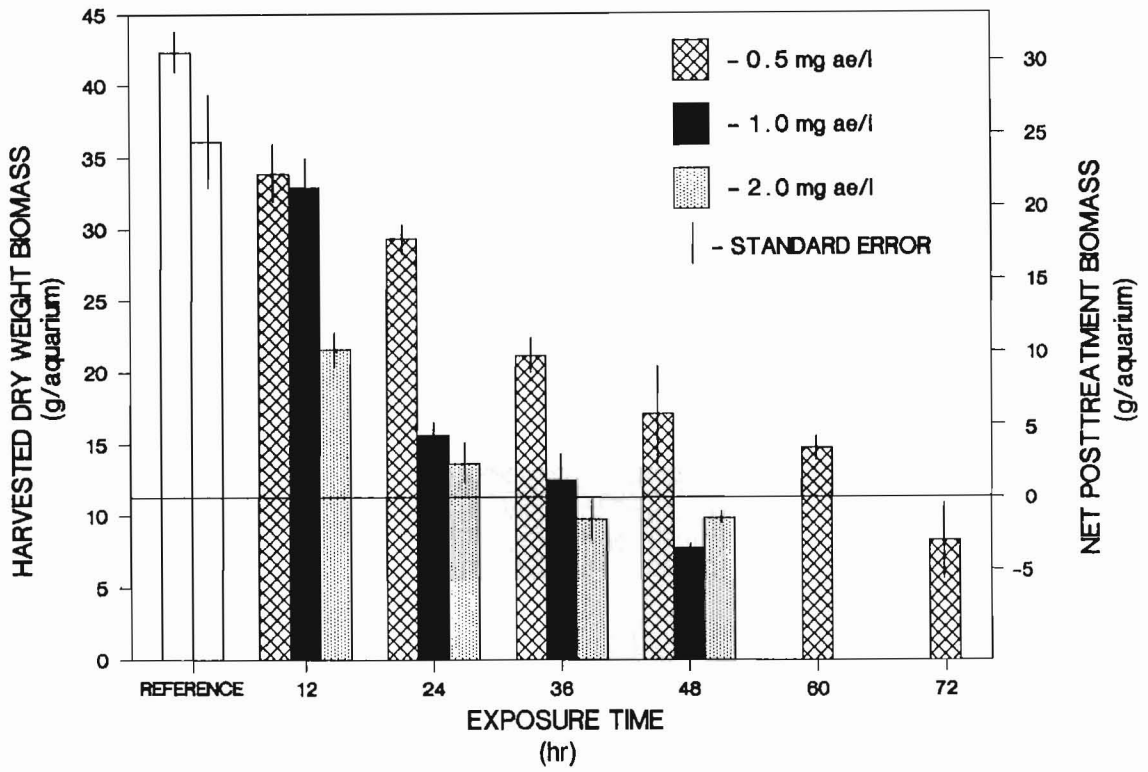

Figure 4. Harvested biomass and net posttreatment biomass production of Eurasian watermilfoil, 4 weeks after 2,4-D treatment

exposures, and from two of the three replicates of the 2.0 mg ae/ℓ for 24-hr exposure. No viable root material was harvested from latter treatment. Only two replicates contained viable root material in the 0.5 mg ae/ℓ for 72-hr, and 1.0 mg ae/ℓ for 36-hr exposures. The net posttreatment biomass from these exposures was low to negative (Figure 4). It is possible that the Eurasian watermilfoil would have reestablished within these aquaria; however, it is unlikely that the posttreatment conditions in the field would support vegetative regeneration of this nature except possibly along a shoreline.

17. Complete Eurasian watermilfoil control occurred in the 1.0 mg ae/ℓ for 48-hr exposure and 2.0 mg ae/ℓ for 36-hr, and 48-hr exposures. Plant injury was nearly 100 percent in all three treatments (Table 2). Plant injury and death was severe enough that the harvested biomass was less than that treated (Figure 4). The 2.0 mg ae/ℓ for 36-hr exposure contained no viable shoots at the time of harvest, and the 1.0 and 2.0 mg ae/ℓ for 48-hr exposure treatments contained one replicate each with only one viable shoot fragment. The 1.0 mg ae/ℓ for 48-hr exposure had no replicates containing viable root tissue, and the 2.0 mg ae/ℓ for 36-hr, and 48-hr exposures contained only one

replicate each with measurable root biomass. As previously discussed, it is unlikely that conditions in the field would be conducive to support this kind of vegetative regeneration.

18. A summary of the results of this study is shown in Figure 5. The concentration and exposure time treatments are represented by the rectangles at the appropriate concentration and exposure time coordinates. The 2,4-D exposures that provided Eurasian watermilfoil control (1.0 mg ae/ℓ for 48-hr, 2.0 mg ae/ℓ for 36- and 48-hr exposures) are shaded in black. The 2,4-D exposures that provided severe Eurasian watermilfoil injury (0.5 mg ae/ℓ for 72-hr, 1.0 mg ae/ℓ for 36-hr, and 2.0 mg ae/ℓ for 24-hr exposures) are filled with the dense stippling. Exposures that provided partial Eurasian watermilfoil injury (0.5 mg ae/ℓ for 24-, 36-, 48-, and 60-hr, and 1.0 mg ae/ℓ for 24-hr, and 2.0 mg ae/ℓ for 12-hr exposures, are shaded with the less dense stippling. Exposures that had little to no effect (0.5 mg ae/ℓ and 1.0 mg ae/ℓ for 12-hr exposures) are not shaded. The threshold of Eurasian watermilfoil control occurred between those concentration and exposure time treatments that provided severe injury and those providing control.

19. Eurasian watermilfoil control can be expected to occur in both flowing and static water conditions if exposed to 2,4-D concentrations and times within the shaded area of Figure 3. Treatments providing concentrations and exposure times outside this shaded area (closer to the origin) should provide, at most, Eurasian watermilfoil injury with the degree of injury increasing as exposures approach the threshold of control. The likelihood of Eurasian watermilfoil control would increase for treatments providing concentrations and exposure times further within the shaded area away from the threshold.

20. The results of this study conform well with previous laboratory studies conducted by Elliston and Steward (1972), Hall et al. (1982), and Westerdahl et al. (1983) if the axes of Figure 3 were extended to include their data. Elliston and Steward (1972) tested the response of Eurasian watermilfoil to various concentrations of 2,4-D (0.5, 1.0, and 2.5 mg ae/ℓ) at different periods of exposure (1, 2, 4, 8, 16, 24, 48, and 96 hr). They found that an exposure of 48 hr to 1.0 mg ae/ℓ 2,4-D provided 100 percent Eurasian watermilfoil control. Eurasian watermilfoil was also controlled with 2.5 mg ae/ℓ 2,4-D at an 8-hr exposure. Eurasian watermilfoil was less than completely controlled within the same experiment at 0.5 mg ae/ℓ even after

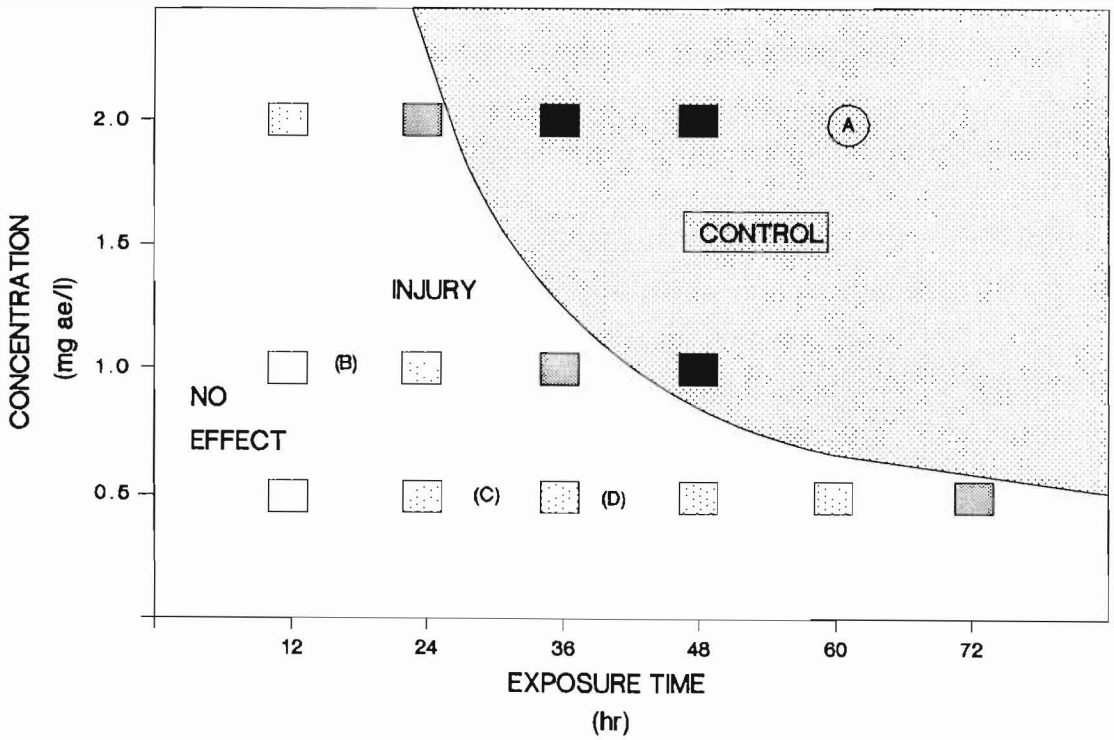

Figure 5. The 2,4-D concentration and exposure time relationships for control of Eurasian watermilfoil. The rectangles represent actual 2,4-D concentration, exposure time test coordinates. The open rectangles represent treatments providing no control. The less dense, stippled hatched rectangles represent treatments providing plant injury. The more dense, stippled rectangles represent treatments providing severe plant injury. The completely filled rectangles represent treatments providing control. The shaded area (stippled) of the graph includes the 2,4-D concentration, exposure time coordinates that should provide plant control

96 hr of exposure. The concentrations of 2,4-D used by Hall et al. (1982) and Westerdahl et al. (1983) were below the limits of this experiment. It was determined by Hall et al. (1982) that Eurasian watermilfoil may be controlled with 0.25 mg ae/ℓ and 35 days continuous exposure. The laboratory study of Westerdahl et al. (1983) found that Eurasian watermilfoil was controlled after 21 days continuous exposure to 2,4-D, ranging from an initial concentration of 1.0 mg ae/ℓ to 0.1 mg ae/ℓ when total control was established. This latter experiment was designed to simulate the 2,4-D release expected from a controlled-release formulation.

21. Herbicide residues and dissipation rates from the 2,4-D field application tests on Eurasian watermilfoil of Westerdahl et al. (1983), and

Getsinger and Westerdahl (1984) in Lake Seminole, Georgia, integrate well with the herbicide concentration and exposure time relationships presented in this study. Three of four field applications of Westerdahl et al. (1983) were documented as producing Eurasian watermilfoil injury, but plants recovered and reestablished themselves within 70 days posttreatment. One partial control application (B in Figure 5) maintained a calculated minimum 2,4-D concentration in the water of 1.0 mg ae/ℓ for a maximum exposure of 18 hr. The highest aqueous 2,4-D residue concentration collected within this treated plot was 1.3 mg ae/ℓ. The other two applications which provided only Eurasian watermilfoil injury (C and D in Figure 5) maintained a calculated minimum 2,4-D concentration of 0.5 mg ae/ℓ for a maximum exposure time of 30 and 40 hr, respectively. The highest residue concentrations collected in these two treated plots were 0.68 and 0.65 mg ae/ℓ, respectively. The one effective field application maintained a calculated minimum 2,4-D concentration of 2.0 mg ae/ℓ for a maximum exposure of 60 hr (A in Figure 5). The maximum residue concentration collected in this test plot was 3.8 mg ae/ℓ. Based on the relationships developed in the present study, this field application would be expected to completely control Eurasian watermilfoil. In fact, the Eurasian watermilfoil exposed to this field application (45 kg 2,4-D DMA ae/ha) was completely controlled for the entire growing season (Hoeppel and Westerdahl 1983).

22. The aqueous 2,4-D concentrations of Getsinger and Westerdahl (1984) were low (0.071 to 0.130 mg ae/ℓ), barely above the threshold levels determined by Hall et al. (1982) and Westerdahl et al. (1983). Exposure times required at these low concentrations to completely control Eurasian watermilfoil are extremely long, as previously indicated. The estimated concentration and exposure times calculated from these field applications would be expected, based on the results of the past and present laboratory research, to produce Eurasian watermilfoil injury but not complete control. The Eurasian watermilfoil treated in this field test (Getsinger and Westerdahl 1984) exhibited approximately 60 to 85 percent control, followed by vegetative regrowth and reestablishment of the Eurasian watermilfoil standing crop.

23. Results from field studies conducted by Lim and Lozoway (1976) and British Columbia Water Investigative Branch (1980) with 2,4-D and Eurasian watermilfoil in lakes of the Okanagan Valley, British Columbia, Canada, follow the same trends as the aforementioned field work and relate well with

relationships developed in the laboratory. Maximum aqueous 2,4-D residues collected by Lim and Lozoway (1976) were 0.14 and 0.06 mg ae/ℓ within the two treated plots on the second day after treatment. Residues were below detection 72 hr after treatment. These concentrations were below the concentration limits of the presented research but would be expected to produce various degrees of injury if the developed relationships (Figure 5) were regressed to lower concentrations. Both 2,4-D field treatments (Lim and Lozoway 1976) did injure the Eurasian watermilfoil, and growth was reduced in comparison to the untreated reference plot. However, vegetative control was not achieved. The ineffectiveness of control was concluded, by these authors, to be the result of low residue concentrations combined with the short exposure times.

24. Similar efficacy results occurred in field tests conducted by British Columbia Water Investigations Branch (1980) where different systems containing Eurasian watermilfoil were treated with 2,4-D. Again, aqueous 2,4-D residue concentrations were low and exposure times varied among the systems treated. An entire lagoon with no input of water from flowing streams or rivers was treated with a combination of different application rates in different areas. The overall treatment provided a maximum 2,4-D residue concentration of 1.26 mg ae/ℓ near the surface on the day of treatment and 4.0 mg ae/ℓ near the bottom of the water column 6 days after treatment. Residues near the bottom averaged 0.68 mg ae/ℓ for the first ten days and were still detected 22 days after treatment. As shown in Figure 5, these concentrations and exposure times would fall within the area of Eurasian watermilfoil control. Eurasian watermilfoil control in this lagoon was achieved for the entire growing season and continued into the next growing season (British Columbia Water Investigations Branch 1980). The other sites treated by the British Columbia Water Investigations Branch (1980) were conducted in sections of large lakes, and the Eurasian watermilfoil efficacy within these treatments was highly variable. No relationship seemed to exist between the different treatment rates and the resulting 2,4-D concentrations. The variability in efficacy was presumed to be influenced by water movement and the physiological condition of the plants at the time of treatment.

PART III: CONCLUSIONS AND RECOMMENDATIONS

25. The results of this study conclude that there is a definite relationship between 2,4-D concentration and exposure time for controlling Eurasian watermilfoil. The degree of Eurasian watermilfoil injury increases with increasing concentrations and exposure times until a threshold is achieved, above which, Eurasian watermilfoil control can be predicted. The results from this study are comparable to and supported by previous laboratory field study results.

26. From the results of this study, the following recommendations are made:

a. Further field verification of the laboratory results is needed. Prior to the application of 2,4-D on Eurasian watermilfoil, water exchange and/or flow velocity should be determined and their influences assessed on herbicide persistence and dissipation. Anticipated field exposure times can then be compared with these laboratory results to determine the required application concentration needed to provide Eurasian watermilfoil control.

b. New herbicides and controlled-release systems should be developed for aquatic environments influenced by water movement. Herbicides which require a very short contact time with the plants, i.e. a few minutes to a couple of hours, should provide sufficient contact time for controlling plants in flowing water environments. Likewise, controlled-release systems which release conventional herbicides for a long duration, i.e. several days to weeks, would permit prolonged plant exposure to achieve plant control.

c. Application techniques need to be evaluated and perhaps redesigned for treating aquatic environments influenced by water movement. The objective should be to prolong delivery of conventional herbicides to provide the necessary plant exposure. New application techniques using better adjuvants, for sticking liquid herbicides to plant surfaces, controlled-release formulations, and porous pipes suspended in the water column may provide a mechanism for prolonging delivery of the herbicide to the plants.

d. Further development of herbicide concentration and exposure time relationships for all registered aquatic herbicides is needed to assist developers and applicators in improving existing formulations and application techniques.

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Table 1

Experimental Protocol

Concentration mg 2,4-D ae/ℓ	Exposure Time hr	Experimental Run*
0.5	12	2
0.5	24	1
0.5	36	2
0.5	48	1
0.5	60	2
0.5	72	1
1.0	12	2
1.0	24	1
1.0	36	2
1.0	48	1
2.0	12	2
2.0	24	1
2.0	36	2
2.0	48	1
0.0	0	1
0.0	0	2

* Run 1 was conducted in August 1987; run 2, in October 1987.

Table 2

Percent Injury and Harvested Biomass of Eurasian Watermilfoil

4 Weeks After 2,4-D Treatment

Treatment mg ae/ℓ-hr Exposure	Percent Injury	Harvested Biomass g-dry weight		
		Roots	Shoots	Total
0.5-12	0-2	3.583	27.41	30.99
	0-2	5.397	33.91	39.31
	0-2	4.062	27.18	31.24
0.5-24	20	2.138	26.59	28.73
	10	2.961	28.08	31.04
	20	2.986	25.13	28.12
0.5-36	20	1.566	19.34	20.91
	35	1.250	21.87	23.12
	10	1.168	18.18	19.35
0.5-48	90	0.322	10.47	10.79
	90	0.252	18.94	19.19
	85	0.379	20.79	21.19
0.5-60	70	0.322	14.11	14.43
	60	0.018	16.35	16.37
	95	0.000	13.51	13.51
0.5-72	95	0.197	4.28	4.48
	95	0.000	7.12	7.12
	95	0.000	13.32	13.32
1.0-12	0-2	3.000	26.32	29.32
	0	4.255	29.32	33.58
	5	3.438	32.30	35.74
1.0-24	90	0.503	17.08	17.58
	85	0.294	13.76	14.05
	90	0.196	15.06	15.26
1.0-36	60	0.376	13.64	14.02
	90	0.124	8.90	9.02
	80	0.000	14.44	14.44
1.0-48	99	0.000	7.68	7.68
	99	0.000	7.24	7.24
	99	0.000	8.28	8.28
2.0-12	40	0.709	18.99	19.70
	20	1.724	21.75	23.47
	5	1.717	19.92	21.64
2.0-24	95	0.000	10.92	10.92
	95	0.000	14.46	14.46
	99	0.000	15.53	15.53

(Continued)

Table 2 (Concluded)

Treatment mg ae/ℓ-hr Exposure	Percent Injury	Harvested Biomass g-dry weight		
		Roots	Shoots	Total
2.0-36	99	0.146	12.37	12.52
	99	0.000	8.15	8.15
	99	0.000	8.51	8.51
2.0-48	99	0.379	9.73	10.11
	99	0.000	9.02	9.02
	99	0.000	10.32	10.32
Reference (Run-1)		6.364	33.07	39.70
		7.129	37.09	44.22
		7.484	35.54	43.02
Reference		4.649	28.25	32.90
		5.761	33.52	39.28
		(2.397)*	(17.35)	(19.75)

* Not used in data analysis.