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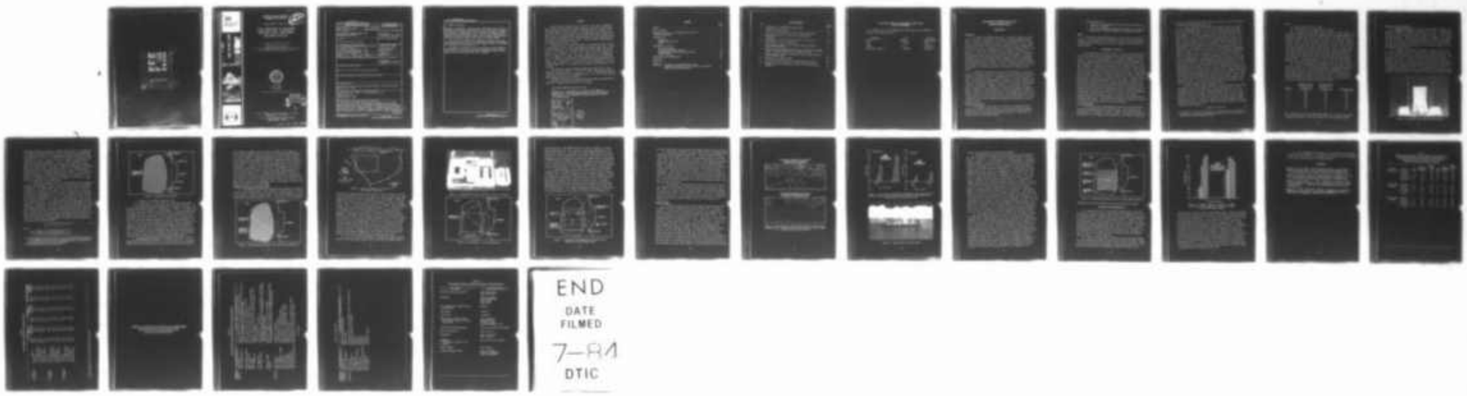

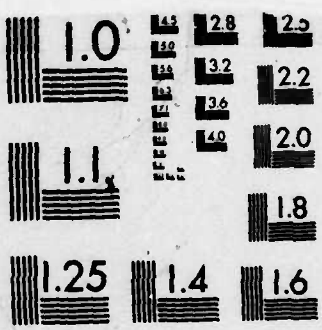

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AD-A142 222

AQUATIC PLANT CONTROL RESEARCH PROGRAM

MISCELLANEOUS PAPER A-84-3

FIELD METHODS TO MEASURE AQUATIC PLANT TREATMENT METHOD EFFICACY

by

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Final Report

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The Aquatic Plant Control Research Program (APCRP) of the U. S. Army Engineer Waterways Experiment Station (WES) is developing field techniques to measure treatment efficacy and to determine site characteristics that influence the treatment efficacy. Treatment efficacy is considered a quantitative determination of the extent and duration of changes in problem aquatic plant populations attributable to the use of a treatment method (i.e., chemical, mechanical,
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biological, environmental). Depending on the plant species, efficacy can be determined or indicated by changes in biomass, areal distribution, or height of an aquatic plant in response to treatment. Aquatic plant biomass is sampled with a WES aquatic biomass sampler; areal distribution of aquatic plants is determined by aerial photography or with an electronic positioning system; and submersed aquatic plant height is measured with a fathometer (depth recorder) used with an electronic positioning and repositioning system (AGNAV).

The APCRP has also developed field techniques to determine site characteristics that influence efficacy using commercially available instrumentation. This instrumentation can be used to measure treatment efficacy and to determine site characteristics simultaneously.

Ultimately, it is anticipated that this research will lead to more standardized methods for monitoring aquatic site characteristics and treatment method efficacy for use by those responsible for planning, applying, and measuring results of field aquatic plant control programs.

Preface

This study was conducted as part of the U.S. Army Corps of Engineers Aquatic Plant Control Research Program (APCRP) with partial funding from the U.S. Army Engineer District, Seattle. The APCRP funds for the effort were provided to the U.S. Army Engineer Waterways Experiment Station (WES) by the Office, Chief of Engineers (OCE), under Department of the Army Appropriation No. 96X3122, Construction General, 92740. Technical Monitor for OCE during this study was Mr. Dwight L. Quarles.

Investigators for the work and authors of this report were Mr. K. Jack Killgore and Dr. Barry S. Payne, Environmental Laboratory (EL), WES. Significant contributions to the successful completion of this study were made by Messrs. A. M. B. Rekas, S. D. Parris, E. A. Dardeau, and J. M. Leonard, and Ms. E. A. Hogg all of the WES. The authors would also like to acknowledge Mr. M. P. Keown for his development of the AGNAV equation presented in this report; Mr. P. Baily and Dr. V. E. LaGarde for their development of the computer programs; and Mr. B. M. Sabol for his review of the manuscript, all of the WES.

This study was conducted under the general supervision of Dr. John Harrison, Chief, EL, and Dr. C. J. Kirby, Jr., Chief, Environmental Resource Division, and under the direct supervision of Mr. J. K. Stoll, Chief, Environmental Analysis Group, all of the WES.

Commander and Director of the WES during this period was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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List of Figures

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
feet	0.3048	metres
inches	25.4	millimetres
miles (U.S. statute)	1.609347	kilometres

FIELD METHODS TO MEASURE AQUATIC PLANT TREATMENT METHOD EFFICACY

Introduction

Background

1. A variety of treatment methods (e.g., mechanical harvesters, herbicides, and biological organisms) are available for managing problem aquatic plants. To select a method that will meet a treatment objective (i.e. extent and duration of plant reduction desired), information on the treatment efficacy must be available. Operational aquatic plant management personnel rarely collect this select type of information due to temporal and monetary constraints. As a result, the effects of treatment measures must be determined by researchers before usable operational tools can be supplied to operators. The Aquatic Plant Control Research Program (APCRP) of the U.S. Army Engineer Waterways Experiment Station (WES) is currently developing rapid and accurate field techniques to measure treatment efficacy. These methods have been used successfully in the field and the data are discussed as examples in this report.

2. Consideration should be given to site characteristics in the environmental setting before and after treatment that may influence the extent and duration of treatment efficacy. If measurements of site characteristics are made in the same places as measurements of treatment efficacy, treatment sites could be classified from those site characteristics according to the expected efficacy of a treatment. Appendix A lists site characteristics that may affect treatment efficacy according to the three major treatment categories--chemical, mechanical, and biological--as well as instrumentation used by the APCRP to measure these site characteristics. This appendix should not be considered inclusive of all site characteristics and instrumentation, but is representative of the detailed background information required when selecting treatment methods.

Purpose and objectives

3. The purpose of this report is to describe field methods used to rapidly and accurately measure efficacy of aquatic plant treatment methods. The technology can be used by aquatic plant researchers in their effort to provide tools for operations personnel.

4. The objectives are:

a. Define efficacy quantitatively and qualitatively using state-of-the-art technology.

b. Describe and demonstrate equipment and methods used in aquatic plant control research studies for measurement of efficacy.

Scope

5. Definitions and methods described in this report are considered guidance in the ongoing effort of developing a single, acceptable concept of treatment efficacy and as such are subject to change as new information becomes available.

Measurement of Efficacy

6. Treatment efficacy is here defined as a quantitative determination of the extent and duration of changes in aquatic plant populations attributable to the use of a treatment method (i.e. chemical, mechanical, and biological). Changes in aquatic populations generally have been expressed in various measures of efficacy such as surface areas, height profiles, or biomass. Biomass is a measure of the aquatic plant horizontal and vertical distribution and is usually expressed in grams per square metre. Thus, one measure of treatment efficacy is a change in aquatic plant biomass. Depending on the plant species, changes in the areal distribution or height of an aquatic plant may also be correlated with changes in its biomass. In essence, by comparing before treatment measurements of the aquatic plant's biomass, areal distribution, and/or height with posttreatment measurements, change in the aquatic plant population can be quantified over time and efficacy can be expressed as percent reduction of the measured variable. The APCRP has developed methods to quantify areal distribution using both aerial photography and an electronic positioning system, height of an aquatic plant using a fathometer/electronic positioning system, and biomass using a hydraulically operated biomass sampler. These methods have been used in APCRP field studies to determine treatment efficacy and are discussed herein.

Aerial photography

7. Low altitude aerial photography has been used to map the distribution of most problem populations of aquatic plants. By obtaining aerial photography before and after a treatment, changes in the areal distribution of the plant due to the treatment can be quantified. This method is applicable

to large areas and when the aquatic plants are visible on or near the surface throughout the posttreatment monitoring.

8. Leonard and Payne (1984) outline four sequential tasks to complete an aerial photographic survey. The first task involves identifying target plant species and water bodies of a survey and identifying when the survey is to be conducted. To measure treatment efficacy, the survey should be conducted before and after treament and the area surveyed should include treatment sites and a reference site for monitoring untreated plant growth. Secondly, the photomission design must be determined. This task requires the establishment of the desired scale, format, film type, image overlap, and image products. Most aquatic plant species can be mapped from a photographic scale of 1:12,000. True color film is used to detect submersed plants while false color infrared film is recommended to detect emergent and floating species. The third task is to acquire information to be used as visual clues for the interpretation of the photographs and should be obtained at the same time as the photomission. This information concerns those conditions on the ground which are to be visually extracted from the photographs such as water depth, plant species present, location of plant colonies, plant condition, and plant growth forms. The fourth task is construction of a transparent base map showing current aquatic plant locations by tracing the shoreline of the target water body from the photographs onto a material such as mylar. Then the locations of plants are interpreted and traced onto the map and subsequent areal estimates are made. For a more detailed description on the hardware and its use, see Leonard and Payne (1984) and Dardeau (1983).

9. Areal estimates of plant communities can be made from the maps using two methods: a dot count method and a digitizer (Dardeau 1983). The dot count method consists of using a Bruning Areagraphic Chart No. 4849, with a published accuracy of 97 percent, provided that map areas are 12-in. square or greater.* The chart is divided into grids and each grid contains a random distribution of dots. The chart is placed over the areas mapped as plants on the mylar and the dots counted. The dots counted are converted to acreage using the following equation:

$$A = \text{Number of dots} \times SF \tag{1}$$

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* A table of f ctors for converting U.S. customary units of measurement to metric (SI) units is presented on page 4.

where

A = Areal coverage of plants, acres

SF = Scale factor (i.e. acreage value of one dot)

10. A digitizer can also estimate areal coverage of aquatic plants. A program was developed at the WES that computes areas of irregular shapes using a Tektronix terminal and a Tektronix 4954 digitizer. The interpreted map is placed on a tablet. Under the surface of the tablet are two grids of magnetostrictive wires, one set for the x-axis and one set for the y-axis. An acoustic wave is sent along these wires and detected by a cursor. As the operator traces the boundaries of the aquatic plants with the cursor, a change in magnetic field caused by the acoustic wave is detected. The detected signal is transmitted to the computer that converts the time between when the wave is sent and when it is received to digital information that directly relates to cursor position. This method maintains a 0.01-in. resolution and should be used when the area of aquatic plants on the map is less than 12 in. square.

11. Color aerial photography (approximate scale of 1:5,000) was used to evaluate the efficacy of a diver-operated dredge for removing Eurasian watermilfoil from seven test plots in the Okanogan River, Washington. One year after removal of Eurasian watermilfoil by the diver-operated dredge, color aerial photography was obtained of the seven test plots. Areal coverage of Eurasian watermilfoil was drawn on a scaled map overlay for each test plot and this area was digitized with the following results:

Plot No.	Approximate Areal Coverage Before Treatment, m^2	Approximate Areal Coverage After Treatment, m^2	Percent Regrowth
1	258	80	31.8
2	258	36	13.9
3	169	30	17.7
4	193	18	9.3
5	116	17	14.6
6	129	8	6.2
7	258	42	16.6

Thus, interpretation of aerial photography showed a 6- to 32-percent regrowth of Eurasian watermilfoil 1 year after removal by a diver-operated dredge.

Electronic positioning system

12. Equipment description. The Agricultural Navigator (AGNAV) is a relatively inexpensive, commercially available electronic positioning system designed to apply farm pesticides and fertilizers in straight, parallel, and evenly spaced paths. The WES has used the AGNAV to triangulate to two permanent shore locations, thus being able to position a boat or field equipment over the same sampling sites during multiple visits to the same water body. The AGNAV system measures distances up to 1 mile and thus is appropriate for most aquatic research studies.

13. The AGNAV system (Figure 1) consists of a mobile unit and two stationary repeaters (A and B). For aquatic use, the mobile unit is placed in a boat and the repeaters are placed at separate shoreline positions. The mobile unit consists of a computer-transmitter-receiver (c-t-r) with an antenna, range reader, control panel, and direction indicator display unit. The mobile unit runs on external alternating current (AC) power supply while the repeaters are powered by internal 12-V gel cell batteries. The c-t-r transmits a short (0.002 sec) burst of high frequency (154.6 MHz) radio signals 100 times each second. Both repeaters receive each signal burst, which

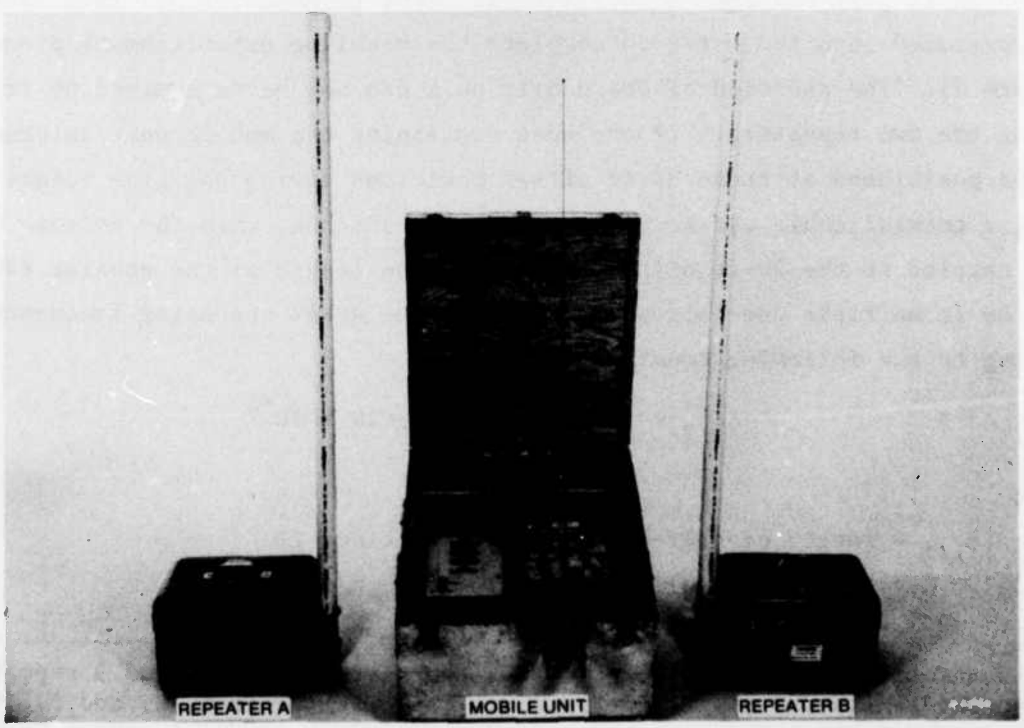

Figure 1. Components of the AGNAV positioning system

activates the repeater transmitter. Repeater A stores the c-t-r transmission for 0.0025 sec and repeater B stores it for 0.005 sec before retransmitting the signal back to the c-t-r. By sequentially delaying the repeater transmissions, the c-t-r is given time to activate its receiver and distinguish the transmissions of the two repeaters. The c-t-r counts the number of one-quarter wavelengths transmitted by each repeater and computes and displays a number on the range reader. The number or AGNAV unit corresponds to the total number of one-quarter wavelengths between the c-t-r and a single repeater. One AGNAV unit for a 154.6-MHz transmission equals 9.584 in. The range reader displays the AGNAV unit distances from the mobile unit to Repeater A, the mobile unit to Repeater B, and Repeater A to Repeater B (A, B, and P, respectively, as displayed on the range reader).*

14. When using the AGNAV system, the distance between the two repeaters (P) must be determined first because P serves as the baseline for subsequent triangulation. The AGNAV computer calculations require a 30-ft offset from the mobile unit antenna to each repeater. First, the mobile unit antenna is positioned 30 ft from Repeater A in a straight line between the two repeaters. This distance is programmed into the c-t-r. The mobile unit antenna is then placed 30 ft past Repeater B in a line-of-sight to Repeater A. This distance is programmed into the c-t-r to complete the baseline establishment procedure (Figure 2). The position of the mobile unit can now be determined by triangulating the two repeaters. If the boat containing the mobile unit antenna cannot be positioned at these 30-ft offset positions during baseline establishment, a coaxial cable can be connected to the antenna, then the antenna can be hand carried to the 30-ft offset. However, the length of the coaxial cable must be in multiple one-half wavelengths of the AGNAV operating frequency according to the following equation:**

$$\lambda_{1/2} = 1/2\ (C/F)\ (VF)\ 3.28 \times 10^{-6} \qquad (2)$$

where

$\lambda_{1/2}$ = length of half-wave matching section, ft

C = velocity of electromagnetic wave, m/sec

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* In any triangle, if the locations of two vertices (the A and B repeaters) and the lengths of all three sides are known (distance A, B, and P), the location of the third vertex can be determined.

** This equation converts feet into metres.

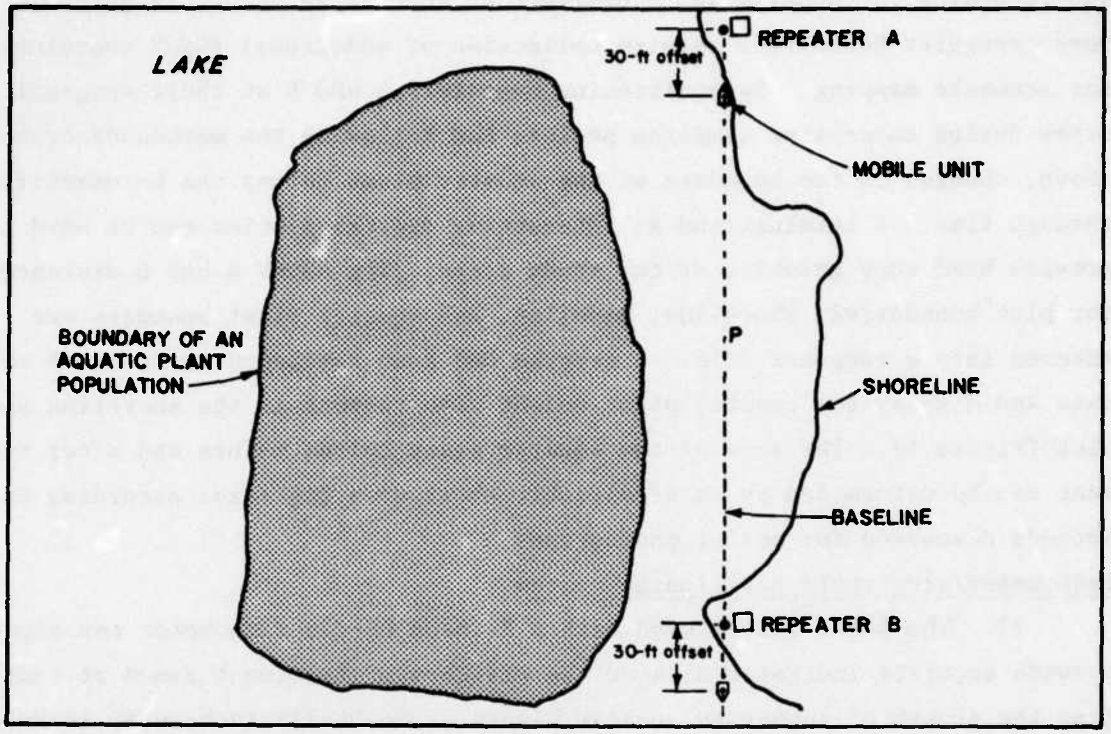

Figure 2. Establishing the baseline

F = frequency of the AGNAV transmission, MHz

VF = velocity factor of the coaxial cable (published percentage)

15. The AGNAV system's operational ability is limited by distance. The maximum distance between Repeater A and Repeater B is 2500 ft. The mobile unit can be positioned up to 5000 ft from either repeater. Distance measured using the AGNAV under ideal conditions can vary by 0.8 of the wavelength (9.584 in. with AGNAV operating at 154.6 MHz). If the transmission of the radio waves is interrupted while the AGNAV is operating, incorrect distance measurement will occur. Trees, brush, and hilly terrain can interfere with the transmission or receiving of radio waves during baseline establishment or when determining distance from the mobile unit to the repeaters. AGNAV distance errors also occur if the repeaters are not repositioned exactly at the original shoreline sites or when the 30-ft offset of the mobile unit antenna is not determined precisely after repeaters are placed during baseline establishment.

16. Measuring areal distribution. The AGNAV can be used to map and quantify areal distribution of plants. The areal distribution of an aquatic plant colony can be delineated by moving the mobile unit along the boundary

and recording the AGNAV A and B distance at successive points (Figure 3). More irregular boundaries require collection of additional AGNAV coordinates for accurate mapping. By positioning repeaters A and B at their original sites during successive sampling periods and following the method described above, changes in the boundary of the aquatic plant colony can be quantified through time. A terminal and an interactive digital plotter can be used to provide hard copy graphics of the study areas. The AGNAV A and B distances for plot boundaries, shoreline, baseline, and aquatic plant boundary are entered into a computer file. A program has been developed to retrieve the data and display the aquatic plant colony with respect to the shoreline and plot (Figure 4). The area of the aquatic plant colony before and after treatment can be determined by an areagraphic chart or a digitizer according to the methods discussed for aerial photography.

Fathometer/electronic positioning system

17. The AGNAV system used with a Ratheon DE-719 fathometer can rapidly provide accurate indicator data on the efficacy of treatment aimed at controlling the growth of submersed aquatic plants. The DE-719 fathometer is an echo depth sounder providing a permanent record of water depth, bottom topography,

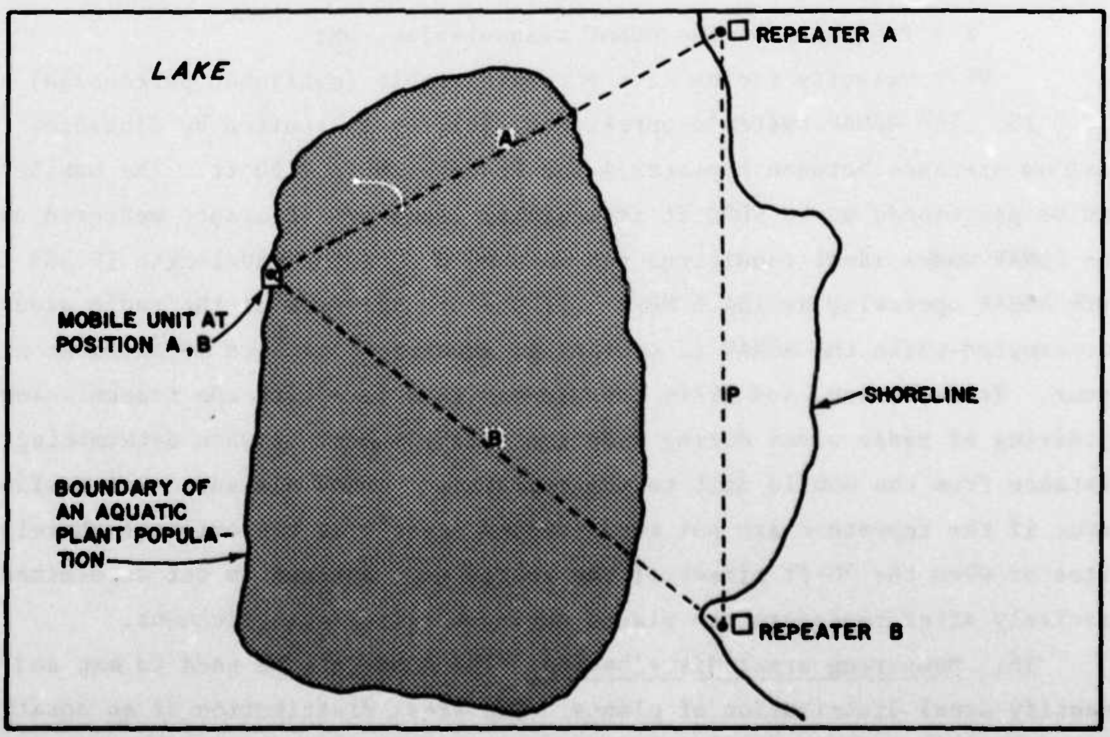

Figure 3. Delineating the boundary of an aquatic plant population

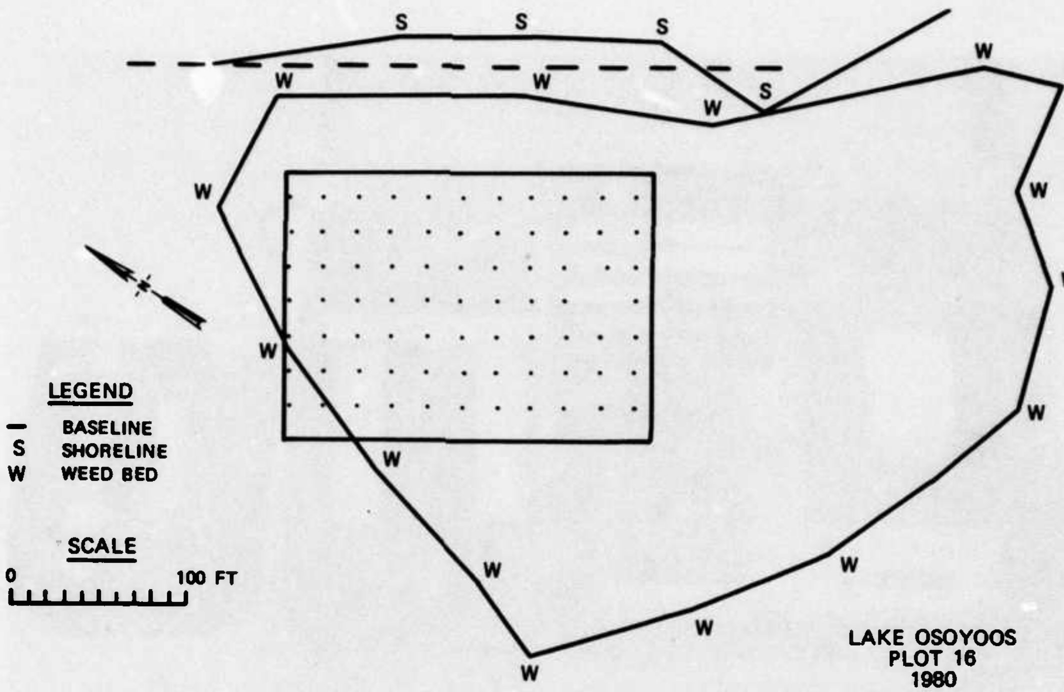

Figure 4. Hard copy display of a study plot in Lake Osoyoos, Washington

and height of submersed aquatic plant colonies. The first step is to establish an experimental plot over the treatment area using the AGNAV and a simple computer that can be carried with the mobile unit of the AGNAV. The WES has used a system consisting of a pocket-size programmable calculator, a thermal printer, direct to alternating current inverter, and magnetic cards containing programs that facilitate plot establishment (Figure 5). To establish square or rectangular plots in an aquatic plant colony, two corners positioned diagonally from each other are selected (P1 and P2) and marked with floats (Figure 6). The AGNAV A and B distances for P1 and P2 are then entered into the calculator. The calculator computes the AGNAV location of the two unknown corners (P3 and P4), the dimensions, and the area of the plot, all of which are then printed on the thermal paper. The plot area is determined by the location of the diagonal corners (P1 and P2) and can range from less than 1 acre to 320 acres. If buoys are lost or moved, the plot can be relocated easily by positioning the repeaters at their original location and moving the mobile unit until the AGNAV values for each corner are located.

18. Once a plot has been designated, straight-line transects are positioned over the plot and the aquatic plant colony using the AGNAV transect

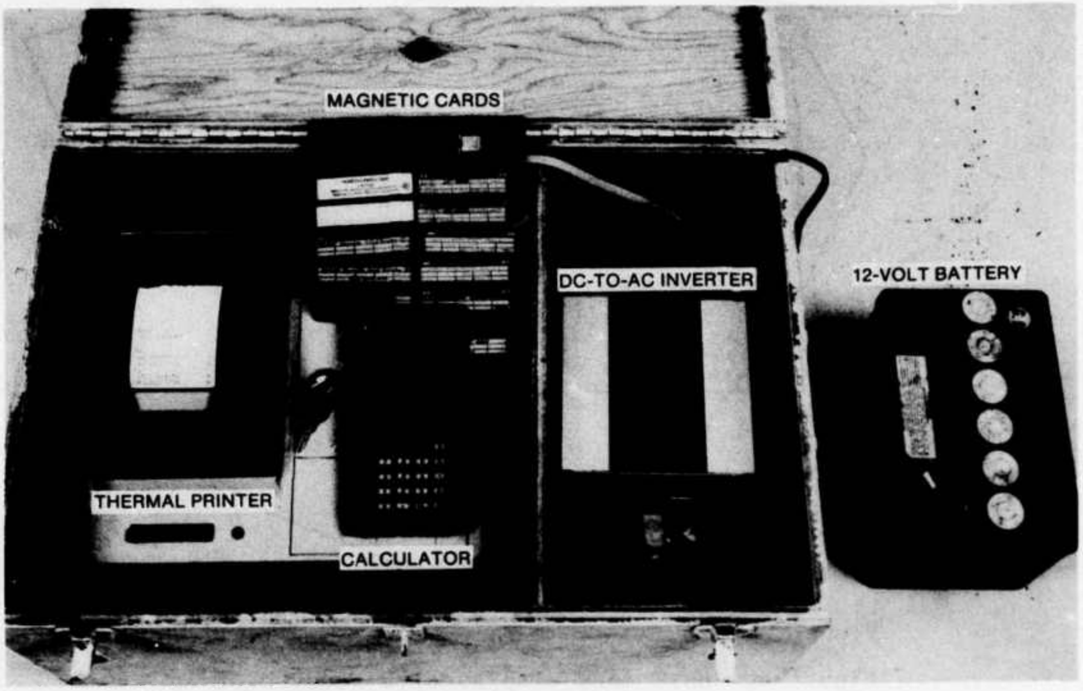

Figure 5. Programmable calculator and printer set up for field use

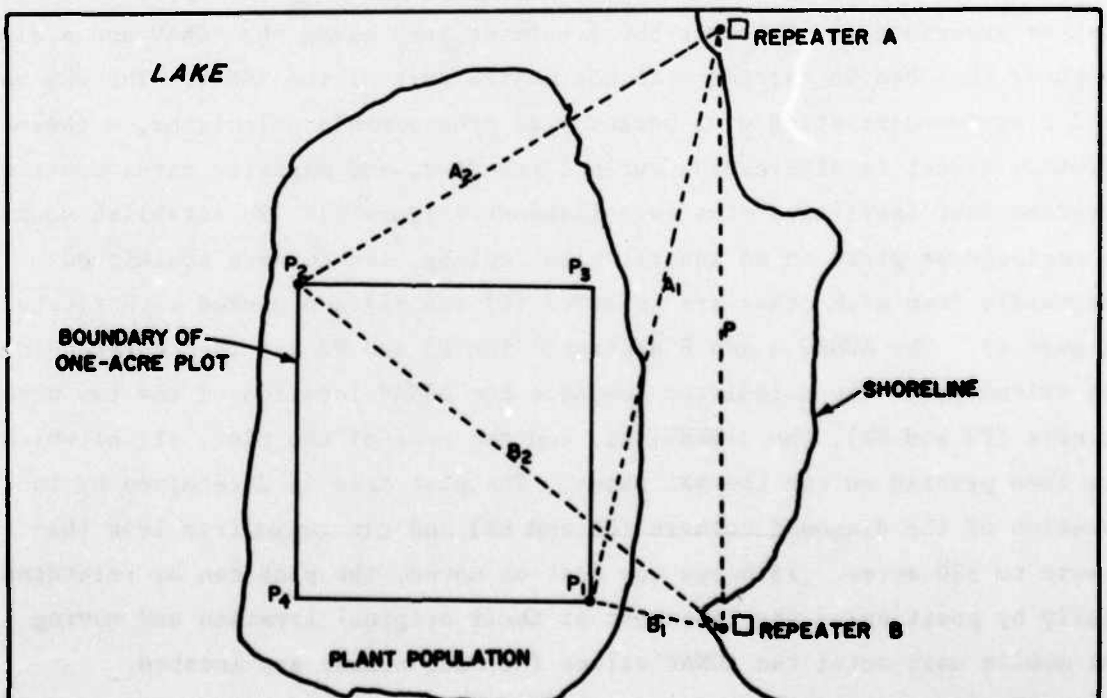

Figure 6. Establishing a 1-acre treatment plot

positioning system. The AGNAV control panel allows the operator to select transect swath distances. Each transect is positioned perpendicular to the baseline and directed in a straight line using the AGNAV direction indicator display unit. While traveling over each transect, event marks are put on the fathometer paper at appropriate intervals and an AGNAV location corresponding to each event mark is recorded (Figure 7). By always positioning Repeaters A and B in the same location, plant height throughout the plot can be determined along the same transects at various times after the initial sampling period.

19. Computer-generated contour maps can be produced from the AGNAV/fathometer data. The AGNAV locations for each event mark along each transect are entered into a spatially arranged data base. Then the fathometer tracings are interpreted and digitized at each event mark for plant height (and water depth) using a terminal and an interactive digital plotter. A computer program has been written which interpolates plant height and water depth between digitized event marks, thus increasing the number of data points used for producing the maps. The computer mathematically manipulates the parallel sets of plant height (or water depth) to generate isoline drawings of the

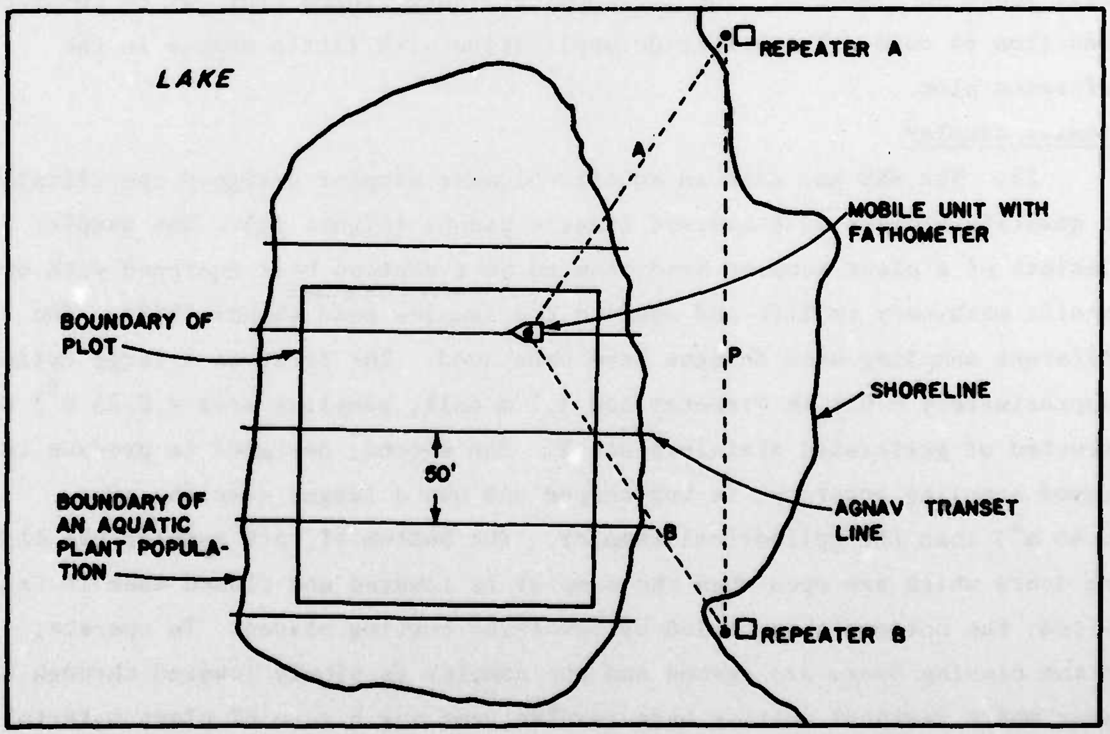

Figure 7. Positioning a fathometer over an aquatic plant population using the AGNAV system

vertical and horizontal distribution of the submersed aquatic plant population.

20. Experimental treatment plots were established in the Okanogan River, Washington, using the AGNAV (Killgore 1984). Isoline drawings of Eurasian watermilfoil plant height were made for one experimental herbicide treatment plot to demonstrate a visual measure of efficacy. Plant height was determined before and 1 month after herbicide application using the AGNAV/fathometer method. The AGNAV locations were entered into a data base and the fathometer tracing was interpreted and digitized according to the method described in paragraph 19. The results are shown in Figure 8. Each isoline in Figure 8 represents a specific height (e.g. 2 ft) of Eurasian watermilfoil within the plot. By visually comparing the plot before and 30 days after treatment, one can see that the Eurasian watermilfoil was virtually eliminated except for the upper one third of the plot.

21. The fathometer tracings obtained for each test plot were also manually interpreted to obtain an average plant height and water depth within a plot (Table 1). Percent change in average height was determined by comparing the plant heights within a plot on different dates. These results are graphically shown in Figure 9. The treatment efficacy ranged from 40- to 80-percent reduction 64 days after herbicide application with little change in the reference plot.

Biomass sampler

22. The WES has used an aquatic biomass sampler designed specifically to quantify biomass of submersed aquatic plants (Figure 10). The sampler consists of a plant sampler head mounted on a pontoon boat equipped with hydraulic machinery to lift and operate the sampler head (Sabol 1983). Two different sampling head designs have been used. The first is a large cylinder (approximately 0.6 m in diameter and 1.1 m tall, sampling area = 0.25 m^2) constructed of perforated stainless steel. The second, designed to produce improved sampling accuracy, is box shaped and has a larger sampling area (0.40 m^2) than the cylindrical sampler. The bottom of each sampler has closing doors which are open when the sampler is lowered and closed when it is raised; the bottom is encircled by revolving cutting blades. To operate, bottom closing doors are opened and the sampler is slowly lowered through the water while vertical cutting bars revolve, cutting a core of plant material in the water column. At the desired depth or bottom, the bottom doors are closed and the sampler is raised. Plant material is removed through the side door and

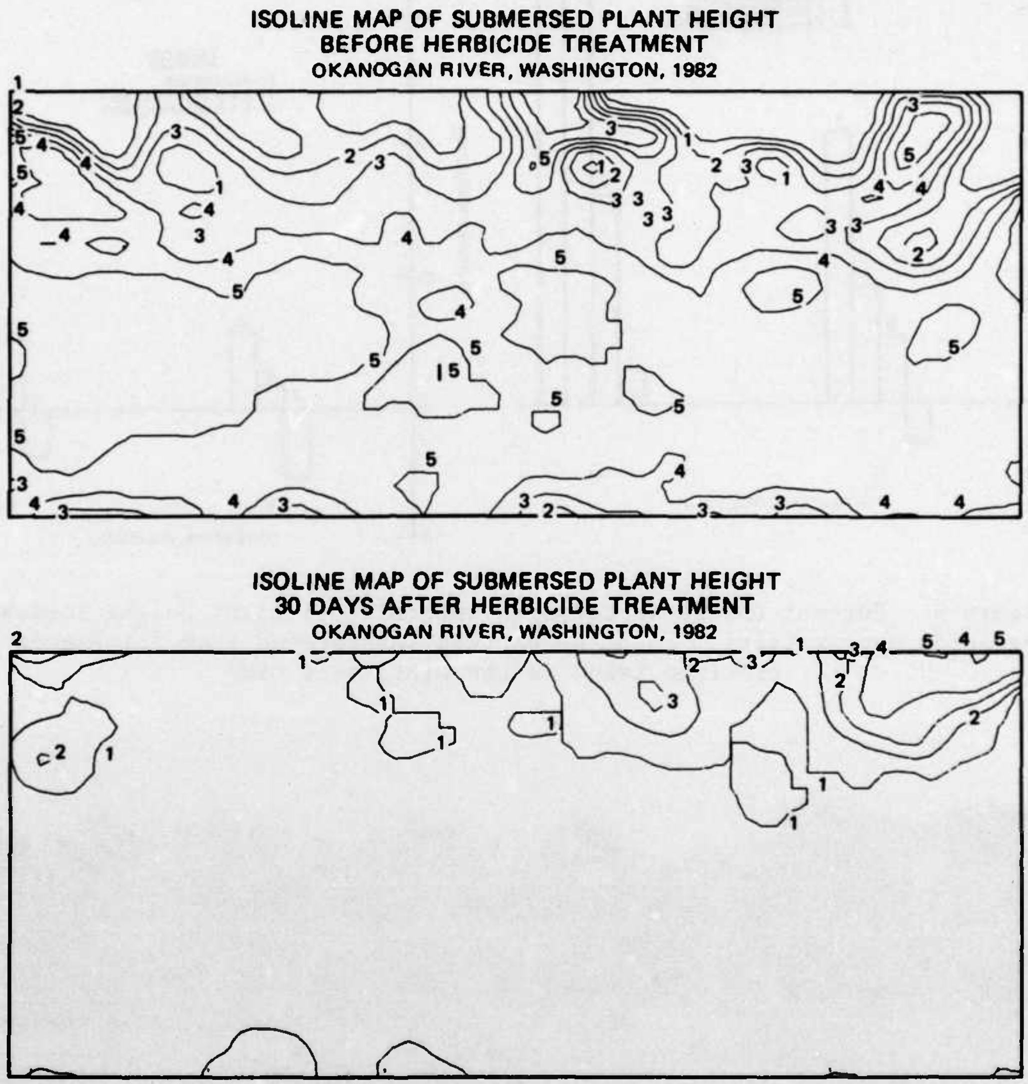

Figure 8. Isoline maps of an experimental herbicide treatment plot showing changes of submersed aquatic plant height over time. Blank areas indicate no plants detected

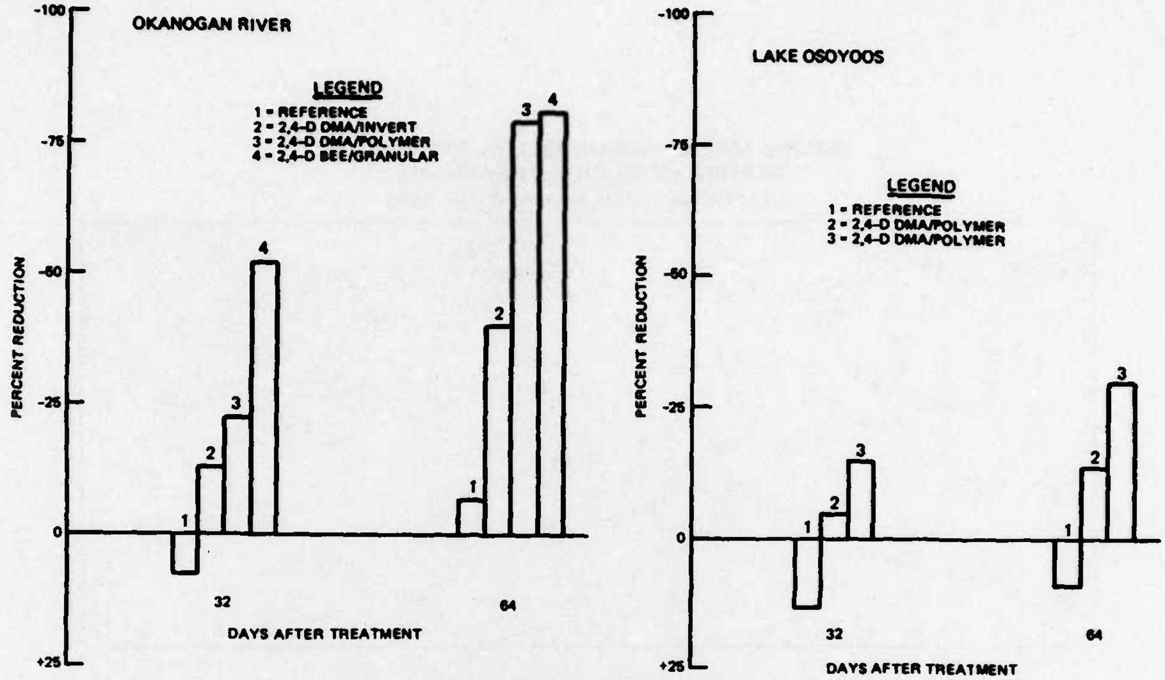

Figure 9. Percent change in Eurasian watermilfoil plant height following herbicide applications. Plant height was interpreted from fathometer tracings taken in the plots over time

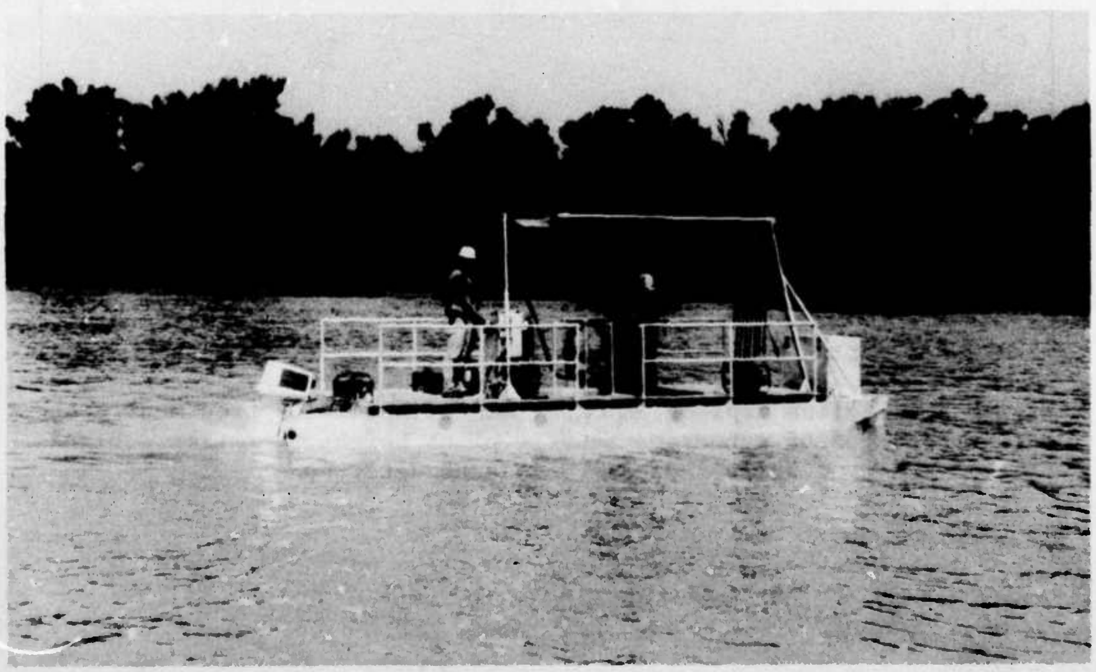

Figure 10. The WES aquatic biomass sampler

its wet, dry, and ash-free dry weights are determined.

23. Sampling methods using the biomass sampler will vary according to the research objectives. The WES has used two sampling methods to quantify changes in biomass over time attributable to a treatment method: random and nonrandom sampling. Both methods require that an experimental plot be established over the aquatic plant colony and treatment site using the AGNAV according to the methods discussed in paragraph 17. The first method involves random sampling within square or rectangular plots. The WES has used a programmable calculatory program that superimposes a grid over the plot. The size of an individual grid square is determined by the operator. Each grid square is numbered beginning at plot corner location P2. Five grids are randomly selected by the calculator program and these grid numbers, with calculated AGNAV A and B values for the center of each grid, are printed on thermal paper. These randomly selected grids then can be located using the AGNAV's positioning system and marked with a buoy (Figure 11). The biomass sampler is then positioned over the buoy and a sample taken. Additional grid numbers and locations can be generated by the program in groups of five. The A and B values for a specified grid can also be requested. The AGNAV positioning system can also be used to carry out nonrandom sampling within a plot. The mobile unit is positioned at the desired sampling site and the AGNAV A and B distances are recorded. A buoy is placed to work the site and a biomass sample is taken. This unique site can be found during any subsequent sampling period as long as the original positions of Repeaters A and B were marked.

24. The biomass sampler was used in Lake Osoyoos, Washington, to quantify changes in Eurasian watermilfoil biomass due to herbicide treatments (Killgore 1984). Biomass sampling points were established over each herbicide treatment plot using a nonrandom sampling design approach and samples were taken. The aquatic plants were separated according to species, and the wet, dry, and ash-free dry weights of the aquatic plants were determined. Each biomass sampling point was again located 1 and 2 months after treatment using the AGNAV, and the biomass samples were taken and analyzed the same as the pretreatment samples (Table 2). Using ash-free dry weight of Eurasian watermilfoil, samples taken 1 and 2 months after treatment were compared to pretreatment samples and a percent reduction was determined over time as a measure of efficacy (Figure 12). By 84 days after application, Eurasian watermilfoil ash-free dry weight was reduced 66 to 96 percent in the

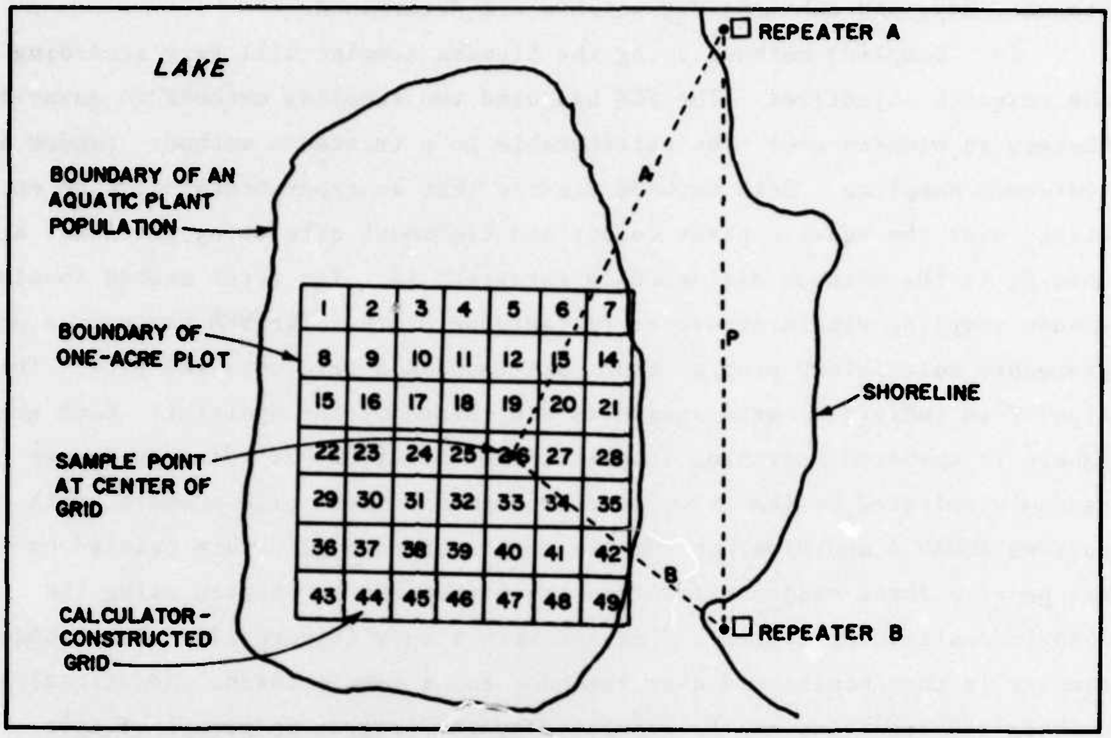

Figure 11. Establishing sampling points for random sampling approach

treatment plots while the reference plot biomass decreased 50 percent.

Conclusions and Recommendations

25. Treatment efficacy is a quantitative determination of the extent and duration of changes in aquatic plant populations attributable to the use of a treatment method. Treatment efficacy can be determined from measurements of biomass, areal distribution, and/or height profiles. Treatment efficacy can be expressed as a percent reduction of the measured variable over time by obtaining and comparing measurements before and after treatment. Furthermore, untreated plant growth should be monitored along with the treated aquatic plant populations in order to ensure that conclusions made on treatment efficacy are unique to the treatment and not influenced by other environmental characteristics (e.g. natural senesence).

26. Biomass is sampled using a hydraulically operated biomass sampler and is best expressed as grams per square metre ash-free dry weight. Changes in the areal distribution or boundaries of aquatic plant population are determined by interpreting aerial photography and mapping the aquatic plant

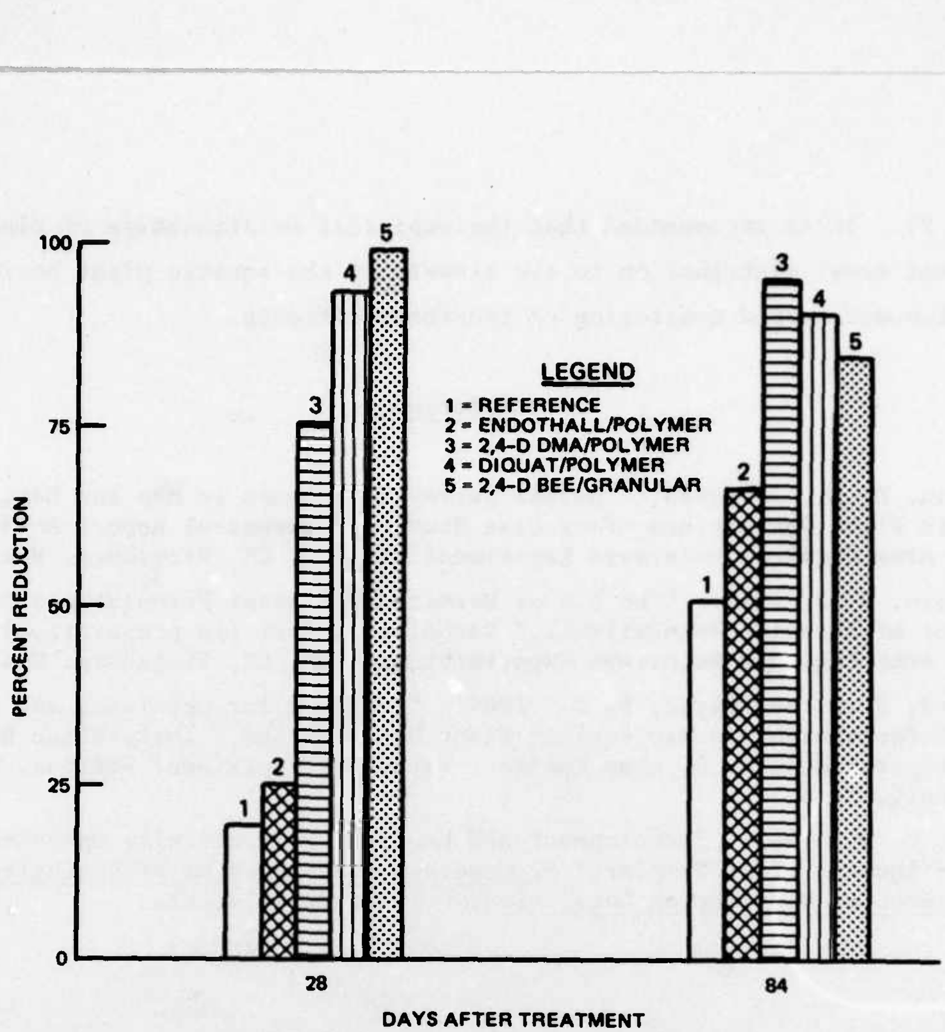

Figure 12. Changes in Eurasian watermilfoil biomass following herbicide treatments. Biomass was sampled using the WES biomass sampler

locations, or by using an electronic positioning system to delineate the boundary according to point locations relative to the shoreline and entering these locations into a computer file. The computer file subsequently retrieves the data and graphically displays the aquatic plant colony onto a hard copy. Areal distribution can be quantified using an areagraphic chart or computer-linked digitizer and is expressed as square metres or hectares. The height of an aquatic plant colony is quantified using a fathometer positioned by an electronic positioning system. The fathometer tracings are interpreted for plant height (and water depth) and can either be entered into a computer which provides isoline maps showing aquatic plant height profiles of the treated area, or an overall mean plant height of the treated area can be calculated. Any sampling point (i.e., for biomass, areal distribution, and height) can be relocated using an electronic positioning system in order to quantify changes in the same aquatic plant population over time.

27. It is recommended that the empirical relationships of plant height or plant areal distribution to the biomass of the aquatic plant be investigated to allow more rapid monitoring of treatment efficacy.

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Table 1

Mean Eurasian Watermilfoil Plant Heights and Water Depth for Experimental Herbicide Treatment Plots Determined by Manually Interpreting Fathometer Tracings

Date	Plot	Mean	Standard Deviation	Plant Height cm	Mean	Standard Deviation	Water Depth m
Pretreatment	Reference	1.4	0.7	48	1.8	0.3	48
	Treatment 1	1.5	0.3	32	1.6	0.2	32
	Treatment 2	0.9	0.8	48	1.3	0.6	48
	Treatment 3	1.5	0.8	80	1.9	0.5	80
32 days post-treatment	Reference	1.5	0.7	46	1.9	0.3	46
	Treatment 1	0.7	0.5	38	1.5	0.4	38
	Treatment 2	0.7	0.6	48	1.3	0.3	48
	Treatment 3	1.3	0.7	64	1.7	0.2	64
64 days post-treatment	Reference	1.3	0.6	42	1.9	0.4	42
	Treatment 1	0.3	0.3	32	1.5	0.5	32
	Treatment 2	0.2	0.3	42	1.3	0.4	42
	Treatment 3	0.9	0.6	59	1.7	0.5	59

Table 2

Mean Eurasian Watermilfoil Biomass Values*

		Wet Weight		Dry Weight		Ash-Free Dry Weight	
Date	Plot	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Pretreatment	Reference	2146.2	970.1	313.9	142.2	147.9	57.7
	2,4-D BEE/granular	420.0	505.6	64.6	76.2	15.8	19.9
	2,4-D DMA/polymer	1003.1	1192.6	154.9	127.3	57.1	58.0
	Diquat/polymer	2325.6	1171.8	331.1	159.6	122.7	61.2
	Endothall/polymer	882.7	546.2	122.2	82.4	55.3	48.7
Day 28 post-treatment	Reference	1798.7	848.6	274.9	161.6	118.8	116.2
	2,4-D BEE/granular	20.4	44.7	2.5	5.6	1.5	5.6
	2,4-D DMA/polymer	445.6	996.3	85.0	190.1	14.1	31.5
	Diquat/polymer	214.9	157.1	24.3	17.3	6.7	5.2
	Endothall/polymer	488.6	750.0	55.3	90.3	41.3	79.2
Day 84 post-treatment	Reference	1473.8	657.1	163.8	99.5	72.7	36.7
	2,4-D BEE/granular	67.6	114.2	6.2	9.9	2.4	4.3
	2,4-D DMA/polymer	24.5	38.1	3.1	5.4	2.5	4.1
	Diquat/polymer	325.6	184.2	34.3	35.9	11.5	5.3
	Endothall/polymer	308.1	280.8	34.7	42.3	19.0	11.9

* Biomass samples collected by the WES biomass sampler.

Appendix A: A Review of Site Characteristics and Measurement Techniques That May Influence Treatment Method Selection and Treatment Efficacy

Table A1

Site Characteristics That May Affect Treatment Efficacy

Treatment	Site Characteristic	Possible Effects on Treatment Efficacy
Chemical	Plant species	Plant susceptibility to active ingredient of herbicide
	Plant biomass density	Effective application rate for different biomass and penetration of herbicide throughout the aboveground biomass
	Water/current velocity	Reduced contact time of the herbicide to the plant
	Water circulation	Loss of herbicide from the treatment area
	Water depth	Dilution of the herbicide causing a noneffective concentration
	Water temperature	Herbicidal action to the plant and herbicide breakdown in the aquatic environment
	Air temperature	Loss of herbicide to evaporation
	Major ions in water	Herbicidal action to the plant, herbicide breakdown in the aquatic environment, formation of marl on the epidermis or cuticle of the plant, herbicidal absorption
	Dissolved oxygen	Herbicidal breakdown in the aquatic environment
	Sediment	Herbicidal breakdown in the aquatic environment, herbicidal absorption, penetration of the herbicide to belowground biomass
Mechanical	Plant species	Fragmentation, regrowth
	Plant biomass	Carrying capacity of machine
	Water depth/plant height	Percent removal of aboveground biomass
	Water velocity	Maneuverability for maximum biomass removal
	Water body shape	Maneuverability for maximum biomass removal
	Bottom topography	Underwater obstructions
	Turbidity/visibility	Locating aquatic plants for maximum biomass removal
	Wind velocity and direction	Maneuverability for maximum biomass removal

(Continued)

Table A1 (Concluded)

Treatment	Site Characteristic	Possible Effects on Treatment Efficacy
Mechanical (Cont'd)	Sediment type	Removal of belowground biomass
	Shoreline development	Disposal sites
Biological	Plant species	Nutritional level or food preference that affect reproduction
	Plant distribution	Dispersal and density of organism
	Air temperature	Mortality
	Water depth fluctuations	Mortality
	Water velocity	Dispersal
	Wind velocity and direction	Dispersal
	Water temperature	Mortality
	Plant biomass	Population density

Table A2

Instrumentation Used to Measure Site-Specific Characteristics

Instrument	Site Characteristic
Electronic positioning system	Plant distribution Water body shape
Fathometer	Bottom topography Plant distribution Plant height Water depth
Core sampler/pipe dredge/hand-held scoop dredge	Sediment
Turbidimeter	Turbidity
Secchi disk	Visibility
Digital water quality analyzer (with logger, computer interface, and computer)	Water temperature pH (major ions) Dissolved oxygen Conductivity (major ions)
Colorimetric/spectrophotometer	Major ions (alkalinity, hardness)
Water velocity meter	Water velocity
Fluorometer	Water circulation Water velocity
Anemometer (with logger, interface, and computer)	Wind velocity and direction
Biomass sampler	Plant biomass
Aerial photography camera	Water body shape Shoreline development Plant distribution

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