AQUATIC PLANT CONTROL RESEARCH PROGRAM

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IMPLEMENTATION OF THE LARGE-SCALE OPERATIONS MANAGEMENT TEST IN THE STATE OF WASHINGTON

By Elba A. Dardeau, Jr., Robert L. Lazor

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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During FY 79, the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., completed the first phase of its 3-year Large-Scale Operations Management Test (LSOMT). The LSOMT was designed to develop an operational plan to identify methodologies that can be implemented by the U. S. Army Engineer District, Seattle (NPS), to prevent the exotic aquatic macrophyte Eurasian watermilfoil (*Myrophyllum spicatum* L.) from reaching

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problem-level proportions in water bodies in the state of Washington.

The WES developed specific plans as integral elements of the LSOMT, including Test Site Selection, Monitoring, Reporting, Treatment, Public Awareness, and Training.

During FY 79, the WES accomplished a significant portion of the LSOMT, as follows:

a. Test Site Selection. Selected five test sites in the state of Washington from 13 water bodies identified by NPS as operational interest, scientific interest, or strategic importance.

b. Monitoring. Conducted remote-sensing missions, ground surveys, and diver-efficiency surveys at test sites and identified and determined limits of factors critical to the establishment, growth, and spread of Eurasian watermilfoil.

c. Reporting. Inventoried reporting techniques used for both the monitoring and treatment elements of an aquatic plant management program.

d. Treatment. Implemented and evaluated two types of mechanical treatment, a fragment barrier system and hand-pulling.

e. Public Awareness. Participated in four NPS-sponsored public meetings, two radio interviews, and preparation of two newspaper articles.

f. Training. Conducted two aquatic plant management workshops.

PREFACE

The study reported herein was conducted from 1 October 1978 through 30 September 1979 by personnel of the Environmental Assessment Group (EAG), Environmental Resources Division (ERD), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

This work is the first phase of the Large-Scale Operations Management Test (LSOMT), a 3-year effort designed to develop an operational plan to identify methodologies that can be implemented by the U. S. Army Engineer District, Seattle (NPS), to prevent the exotic aquatic macrophyte, Eurasian watermilfoil (*Myriophyllum spicatum* L.), from reaching problem-level proportions in the state of Washington. The LSOMT, which was prepared by WES, was authorized by COL J. A. Poteat, Jr., CE, and his successor COL C. K. Moraski, CE, District Engineers, NPS, as part of the NPS Aquatic Plant Management Program. Funds for this investigation and the publication of this report were provided by both NPS and by the Civil Works Directorate, Office, Chief of Engineers, Washington, D. C., under Department of the Army Appropriation No. 96X3122 Construction General.

Fieldwork was conducted during the summer and fall of 1979, and the office studies were conducted throughout FY 79 by EAG personnel. Principal investigators responsible for directing the fieldwork and for analyses of the data collected during the first year effort were Messrs. E. A. Dardeau, Jr., and R. L. Lazor, EAG. The aquatic plant management concepts presented in this report were originally developed in 1977 by Dr. D. R. Sanders, Sr., Wetland and Terrestrial Habitat Group, ERD, and Mr. J. L. Decell, Manager, Aquatic Plant Control Research Program, as part of their presentation at the 1977 meeting of the Aquatic Plant Management Society in Minneapolis, Minn. Other persons making significant contributions to the successful completion of this work included Messrs. A. M. B. Rekas, J. M. Leonard, S. D. Parris, and J. H. Meeks, and Ms. E. A. Hogg and Ms. S. Lockard, all of the EAG. Dr. Sanders and Mr. Rekas provided technical review. Special acknowledgement is made to

Messrs. D. R. Bailey and R. M. Rawson, both of the NPS, for their helpful guidance and suggestions. This report was prepared by Messrs. Dardeau and Lazor.

All phases of the FY 79 work were conducted under the general supervision of Dr. John Harrision, Chief, EL, and Dr. C. J. Kirby, Jr., Chief, ERD, and under the direct supervision of Mr. J. K. Stoll, Chief, EAG.

The Director of WES during the course of the FY 79 effort and during the preparation of this report was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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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
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609347	kilometres
miles (U. S. statute) per hour	1.609347	kilometres per hour
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.000112	kilograms per square metre
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per square foot	4.882428	kilograms per square metre
square feet	0.09290304	square metres
square inches	6.4516	square centimetres
square miles	2.589998	square kilometres

IMPLEMENTATION OF THE LARGE-SCALE OPERATIONS MANAGEMENT TEST IN THE STATE OF WASHINGTON

PART I: INTRODUCTION

Background

1. Management of an aquatic plant community becomes necessary when one or more exotic or problem native species pose an immediate or potential threat to human uses of a water body or to native biota. Depending on the magnitude of the population growth and the user-interest level, management can be implemented for one of three purposes: (a) prevention, (b) maintenance, or (c) control.

2. After a species becomes established in the water body, the pioneer colony grows until it impinges on some user interest, and, thus, becomes a problem. Site-specific factors, such as user interest, size of the water body, environmental considerations, etc., determine the level of the population that first becomes a problem. Unless some treatment is implemented at this time, further population increase will usually result in more severe impingement on user interests, thus further restricting or prohibiting the major public and private uses of the water body. If no treatment is implemented, the population will continue to grow until it occupies the entire available habitat. As the population increases and causes a more severe problem, the applicability of available management methods will become limited.

3. In 1979, the U. S. Army Engineer Waterways Experiment Station (WES), in cooperation with the U. S. Army Engineer District, Seattle (NPS), initiated a 3-year Large-Scale Operations Management Test (LSOMT) to evaluate the concept of prevention as an operational technique for managing problem aquatic macrophytes in the state of Washington (U. S. Army Engineer Waterways Experiment Station 1979). The primary objective of the LSOMT was to prevent the submerged aquatic macrophyte, Eurasian watermilfoil (***Myriophyllum spicatum*** L.), from reaching problem-level

proportions in selected water bodies within that state.

4. Eurasian watermilfoil, a member of the plant family Haloragaceae, was apparently first introduced into North America in the nineteenth century. Since 1960 it has rapidly spread across North America and has reached problem levels in most water bodies where it has become established (Elser 1969). Its broad ecological amplitude has enabled it to thrive in spring, fluvial, and lacustrine ecosystems in the southeastern United States; in estuarine environments, such as Chesapeake Bay, Currituck Sound in North Carolina (Blackburn and Weldon 1967); and in water bodies as far north as British Columbia. Eurasian watermilfoil is an aggressive competitor that often excludes existing populations of native North American aquatic macrophyte species from the aquatic ecosystem. Because Eurasian watermilfoil has reached serious problem levels in lakes of Florida and Georgia, the Tennessee River Basin, and British Columbia, intensive research and control programs have been undertaken to control this exotic species.

Aquatic Plant Management Concepts

5. Traditionally, aquatic plant managers have taken corrective action only after plant populations have impacted on one or more user interests. This emergency approach to large-scale treatment has been costly. In many instances, after the desired management level was achieved, vigilance was relaxed, and the problem recurred. In 1975, the U. S. Army Engineer District, Jacksonville (SAJ), implemented a program designed to bring the waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.), a floating aquatic plant, under control and then to maintain the population at an acceptable nonproblem level. This program has proved that a very large problem area can be reduced to a maintenance level on an operational scale. A related, but more foresighted, approach to aquatic plant management is to periodically implement operational procedures that prevent these populations from ever reaching levels that interfere with water body uses. Although prevention is not a new concept, it had not been demonstrated and evaluated on an

operational scale for treatment of an aquatic plant population until the implementation of this LSOMT.

6. The success of an aquatic plant management program, whether designed for prevention, control, or maintenance, will depend on the effective implementation of five basic elements, each at various levels depending on the situation: (a) monitoring, (b) reporting, (c) treatment, (d) public awareness, and (e) training. Each element is discussed briefly below:

a. Monitoring. Monitoring provides a means of (1) detection of colonies of problem aquatic species, (2) verification of a suspected population, and (3) assessment of the effectiveness of treatment measures. Monitoring consists of the collection and analysis of the appropriate combination of ground-survey data* and remotely sensed data. If the management objective is prevention, monitoring should emphasize ground-survey data supplemented by those derived from remote-sensing products. On the other hand, if either control or maintenance of a problem population in an aquatic plant community is the desired objective, more emphasis should be placed on the use of remote-sensing data; however, these data must be verified by ground surveys. Monitoring, which can often be readily accomplished with existing personnel, should, at the very minimum, address colony detection, determination of the areal extents of colonies of problem populations, and changes in areal extent of these colonies, including changes attributable to treatments (discussed below under c), particularly in the areas of water bodies where user interest is highest (e.g., boat-launch facilities).

b. Reporting. Reporting provides systematic procedures for transmitting pertinent monitoring or treatment data on problem aquatic plants to management. Frequency of reporting, whether connected with monitoring or treatment efforts, is a function of the frequency of these elements in an aquatic plant management program.

c. Treatment. Treatment programs are used to achieve the desired level of management of aquatic plant populations in any specified local environmental, social, or economic situation. Treatment procedures can be grouped into five major categories: (1) chemical, which involves the

* In this report, the term, "ground survey" is defined to include ground reconnaissance, ground control (i.e., "training sites" for mapping), and ground verification of data derived from remote-sensing products.

placement of a known phytotoxic substance into the water for the purpose of effecting control of one or more problem plant species; (2) mechanical, which involves any efforts to physically alter or remove aquatic plants from an area (including manual efforts); (3) biological, which involves the introduction of one or more organisms to effect control of the population of a problem aquatic plant species; (4) environmental management, which includes any induced modifications of the environment sufficient to effect reduction of the population of one or more aquatic macrophytes (e.g., lowering water levels); and (5) integrated, which involves the use of any combination of the above four categories that results in a more effective treatment than can be achieved by use of any one method alone. Both the type and scope of the applied treatment will vary for each of the three levels of management. For example, manual removal of a pilot colony of Eurasian watermilfoil adjacent to a boat-launch area is feasible in a prevention program; however, such a treatment method could not be implemented for a significantly larger population.

d. Public awareness. Public awareness involves the dissemination of information to the public to ensure awareness of aquatic plants, user impacts associated with a problem species, and available treatment programs. A public informed during the planning process (and not after all management decisions have been made) is more inclined and better able to participate in a management program when it understands the nature of both the scope of the problem and the subsequent choice of actions to be taken. This public participation often results in valuable help in implementing an aquatic plant management program, especially the monitoring and reporting elements (e.g., detection and determination of the areal extent of colonies previously unknown to management).

e. Training. Personnel involved in operational aspects of aquatic plant management must be adequately trained in all management elements. The sequence of training will depend on the level of the operational program.

Purpose, Scope, and Approach

7. Not enough was known about the establishment and spread of Eurasian watermilfoil to design an operational prevention plan, nor were there sufficient data available to confidently determine the magnitude of the potential Eurasian watermilfoil problems in the navigable waters of the state of Washington. The purpose of this study was, therefore,

to develop an operational plan based on prevention methodology. Several basic questions were addressed in the scope of this effort including:

- *a*. What is the present and potential problem level of Eurasian watermilfoil in the navigable waters in the state of Washington, including potential habitats?
- *b*. What are the major elements of a successful aquatic plant management plan based on the concept of prevention as a management approach?
- *c*. What treatment methods are available for effecting control of already-established Eurasian watermilfoil populations?
- *d*. What treatment methods are available and identifiable for application purely as a prevention method?
- *e*. What are the essential elements of a continual monitoring program that would provide for early detection and identification of a population?
- *f*. What are the training requirements of personnel involved in the various aspects of a prevention program?

The approach taken was to conduct a 3-year LSOMT that would provide the data required to answer the above questions and that would result in the identification of prevention methodologies that can be implemented to prevent Eurasian watermilfoil from reaching problem-level proportions.

PART II: COMPONENT PLANS OF THE LSOMT

8. Specific plans were developed as integral elements of the LSOMT. These plans, which were based on the five elements of aquatic plant management (defined in paragraph 6), included:

- a. Test Site Selection.
- b. Monitoring.
- c. Reporting.
- d. Treatment.
- e. Public Awareness.
- f. Training.

Each plan is discussed in the following paragraphs.

Test Site Selection Plan

9. The principal objective of the Test Site Selection Plan of the LSOMT was to assign appropriate treatment categories to water bodies identified by NPS as having operational interest (e.g., navigable waters). The categories chosen were:

- a. Category I (Prevention). Water bodies with nonproblem populations of Eurasian watermilfoil and with areas of potential habitat. These water bodies are in close proximity to established populations of Eurasian watermilfoil and are subject to population expansions that could impact on user interests.
- b. Category II (Maintenance). Water bodies with small problem-level populations of Eurasian watermilfoil and with large areas of potential habitat. These populations are beginning to impact on user interests.
- c. Category III (Control). Water bodies with extensive populations of Eurasian watermilfoil that significantly impact on user interests.

Additional objectives of the plan were to determine which of the identified water bodies were also of:

- a. Scientific interest to WES (based on their ecologic or geographic diversity).
- b. Strategic importance with regard to the prevention of the spread of Eurasian watermilfoil (e.g., first- or

second-order) tributaries of the Columbia River with upstream populations of this exotic macrophyte).

Monitoring Plan

10. The Monitoring Plan was designed to provide all data, including any necessary environmental considerations, required for assessing the present or potential level of Eurasian watermilfoil populations. Major emphasis was placed upon detecting developing colonies as early as possible to implement treatment measures to effectively eliminate these colonies. To accomplish this task, several independent studies and surveys were planned so that the results could be integrated to develop an operational plan.

11. The major objectives included determination of:

- a. Extent to which Eurasian watermilfoil can become a problem in the state of Washington, especially within the Columbia River Basin.
- b. Limits of important environmental factors that can affect the growth, establishment, and spread of Eurasian watermilfoil.
- c. Potential sources of Eurasian watermilfoil propagules, including those outside the state of Washington.
- d. Current status of Eurasian watermilfoil in the water bodies of interest.

To accomplish these objectives, the Monitoring Plan proposed: (a) remote-sensing missions; (b) ground surveys (including surveys of potential sources of Eurasian watermilfoil propagules); (c) diver-efficiency surveys; (d) determination of those critical environmental factors that affect the establishment, growth, and spread of Eurasian watermilfoil; and (e) assessment of problem potential of Eurasian watermilfoil.

Remote-sensing missions

12. Remote-sensing missions provide a means of rapidly determining the presence of aquatic macrophytes. Such efforts, when conducted under the appropriate conditions and specifications, result in imagery that can be used to map the general locations and areal extents of submerged aquatic macrophyte communities in the selected water bodies.

This imagery also aids in the detection of small, recently established colonies of Eurasian watermilfoil, thus permitting identification of areas requiring immediate attention for possible treatment. Long (1979) discussed the capabilities and limitations of various remote-sensing systems for mapping aquatic plant communities.

13. Remote-sensing missions can be classified as either operational or experimental. Operational missions are designed for mapping those areas containing large populations of aquatic macrophytes, while experimental missions are used to determine optimum film, filter, and scale combination(s) for detecting small developing populations. If time does not permit scheduling experimental missions prior to operational missions, then experimental missions can be flown in conjunction with operational missions to determine these optimum specifications.

14. Operational missions. Operational missions for all selected water bodies are scheduled in late summer of each year during suitable weather conditions to map the extent of the areal coverage of Eurasian watermilfoil. Suitable weather conditions for operational missions include:

- a. Cloud cover less than 10 percent.
- b. Wind speed less than 10 mph.*
- c. Minimum sun glare (surface glitter).**

Other general specifications for operational missions are:

- a. Zeiss RMK-A camera with 6-in. Zeiss lens.
- b. Film-filter combinations:
  - (1) Black and white: Kodak Double-X Aerographic (2405); Zeiss A filter.
  - (2) Color: Kodak Ektachrome EF Aerographic (S0397); no filter.
  - (3) Color infrared: Kodak Aerochrome Infrared (2443); Zeiss R filter.
- c. Optimum land exposure.

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

** Mission schedules should include consideration of water body orientation, sun angle, and haze to minimize sun glare.

d. Altitudes:

(1) 2,500 ft (1:5,000 scale)

(2) 5,000 ft (1:10,000 scale)

(3) 10,000 ft (1:20,000 scale)

e. Overlap:

(1) Forward--60 percent

(2) Side--30 percent

15. Experimental missions. The Monitoring Plan of the LSOMT proposed that two sizes and two colors of underwater targets be evaluated to determine the optimum combination(s) of film, filter, and scale for detection of the submerged aquatic macrophyte, Eurasian watermilfoil. Specifications for film, filter, and scale were identical with those of the operational missions (paragraph 14).

Ground surveys

16. Ground surveys result in: (a) the detection of populations of Eurasian watermilfoil that are too small to be seen on imagery, and (b) the verification of those populations detected on imagery. In prevention methodology, ground surveys serve as the principal source of data on the status of an aquatic plant population; however, they should be used in conjunction with remotely sensed data.

17. At each of the selected water bodies, a sufficient number of sample sites must be characterized to account for the range of growth conditions found in the water and the bottom sediment. A ground-survey team also needs to collect, preserve, voucher, and store specimen plants from each sample site. Because Eurasian watermilfoil is a submerged plant, divers are often needed to determine the extent of the population and to establish the maximum observed depths (MOD's) for growth of Eurasian watermilfoil in each water body.

18. Field teams must take a sufficient number of samples to determine the biomass (weight of plants per unit area) of Eurasian watermilfoil and associated plants inside the MOD's in the study areas. Determinations of biomass density* can then be made. The ground surveys

* Defined in this report as wet weight of plants per unit volume.

are also used to verify data derived from remote imagery.

Diver-efficiency surveys

19. Diver-efficiency surveys call for the evaluation of the capability of professional divers to areally delineate aquatic plant populations and to locate and relocate colonies and fragments of Eurasian watermilfoil.

Determination of the limits of critical environmental factors

20. A review of the literature on Eurasian watermilfoil is necessary to determine the limits of those environmental factors critical to the establishment, growth, and spread of this species. Factors selected for consideration are those related to the water, bottom sediment, current, wave action, etc. The purpose of examining the literature and determining the limits of these factors is to develop a better understanding of biologic and ecologic constraints on Eurasian watermilfoil and to determine gaps in the knowledge of these constraints so that they may be addressed in other studies.

Assessment of problem potential of Eurasian watermilfoil

21. After a thorough examination of the ground-survey and remote-sensing data and the limits of the critical environmental factors, an assessment of the problem potential of Eurasian watermilfoil at the sites selected for this study could then be made. Equally important would be elimination from further consideration of nonproblem areas of the water bodies that fall outside the limiting environmental factors (e.g., depth limitation).

Reporting Plan

22. The Reporting Plan of the LSOMT provides systematic procedures for documenting assessment of the present and potential populations of Eurasian watermilfoil in the state of Washington. This plan incorporates reporting of (a) the location of an exotic or problem native aquatic macrophyte population by both District personnel and the

public, (b) the results of monitoring and treatment programs, and (c) the cost of the aquatic plant management program.

23. The WES will have to examine reporting procedures used to assess their appropriateness in the state of Washington, and, if necessary, to modify them to meet the reporting requirements of NPS. Objectives of this plan are to develop reporting procedures for the (a) NPS monitoring program including verification of public reports of an aquatic plant population, (b) NPS treatment program, and (c) cost analysis of the NPS aquatic plant management program. The reporting procedures developed by the WES will be field tested to determine their effectiveness for use by NPS. Modifications indicated by the field testing will be incorporated into final reporting procedures.

Treatment Plan

24. Under the proposed Treatment Plan, various methods of treatment will be evaluated to determine the method best suited for preventing the spread of Eurasian watermilfoil colonies detected by the monitoring efforts. Suitability of a method will also consider economic, environmental, and social constraints. A number of treatment strategies will be deployed in an operational mode, with their objective being the elimination of Eurasian watermilfoil colonies or fragments detected by survey efforts. Both operational and experimental modes of treatment have been incorporated as integral parts of the plan. Operational studies will be conducted primarily in areas selected as key water bodies for the prevention strategy. Experimental aspects of the treatment plan will be conducted in areas where Eurasian watermilfoil is already established.

25. The next phase of the Treatment Plan is the description of the deployment of the acceptable methods. Most current treatments available for aquatic plants, although very effective in reducing the standing crop, do not always result in the elimination of problem species. For example, several available chemicals will reduce the standing crop of Eurasian watermilfoil by more than 80 percent, but the

remaining plants in the population quickly regrow to the previous population level. These methods need to be tested in operational prevention modes. Experimental tests will be conducted for 2 years, and those strategies successfully used to eliminate Eurasian watermilfoil colonies will be used on an operational basis in key water bodies.

Barrier system

26. One of the primary mechanical methods proposed for study is that of colony isolation. This approach involves the construction of a barrier system spanning a cross section of a stream. This barrier system, which is intended to prevent or retard the downstream dispersal of Eurasian watermilfoil fragments from established colonies to areas of potential habitat, consists of debris, operational, and evaluation structures, defined as follows:

a. Debris barrier. Large open-mesh barrier designed to intercept large floating material (e.g., logs) upstream from the operational barrier. It extends from slightly above the water surface to within 3 ft of the streambed to permit migration of anadromous fishes.

b. Operational barrier. Large fine-mesh structure intended to collect fragments of Eurasian watermilfoil and other aquatic macrophytes. The top of the operational barrier is placed in the same position (with respect to the water surface). Both the operational and the debris barriers have approximately the same dimensions.

c. Evaluation barriers. Two barriers, each having sets of 1-ft^2, square net sections that extend from (or slightly above) the elevation of the water surface to the elevation of the streambed. One evaluation barrier is placed upstream from the debris barrier and the other is placed downstream from the debris and operational barriers. As their name implies, these barriers are designed to evaluate the effectiveness of the operational barrier at removing Eurasian watermilfoil fragments from the water body.

27. The key to the success of colony isolation is in the design of the operational barrier. Some general requirements of operational barrier design include: (a) sufficiently fine mesh to retain small fragments of Eurasian watermilfoil; (b) sufficient rigidity to withstand rapid increases in stream velocity; (c) design that maintains function

with rapid, significant change in water level; (d) provision for adequately preventing movement of fragments over or under the barrier; and (e) removable during the winter season.

28. Evaluation barriers must be of sufficiently fine mesh (usually 1/4 in.) to retain the smallest fragments. They are designed to sample between 2 and 3 percent of the cross-sectional area of a stream. At least twice a week screens need to be removed and examined so that their contents can be weighed. Stream velocities and discharges should also be measured in conjunction with the sampling program.

Hand-pulling

29. An additional mechanical technique proposed for study in the treatment plan of the LSOMT is that of manual removal (hand-pulling) of Eurasian watermilfoil. This approach, thought to be feasible only in a small-scale prevention program, has to be tested and evaluated.

Public Awareness Plan

30. The Public Awareness Plan describes the various activities that can help inform the public of the potential problems caused by Eurasian watermilfoil, and it also includes steps being taken to prevent this species from reaching problem population levels in the state of Washington. This plan considers the use of all available means of informing Federal, State, and local officials and the public of the hazards of permitting the unchecked distribution and growth of Eurasian watermilfoil in the state of Washington. The WES and NPS have organized a multifaceted public information campaign to educate the public by describing the Eurasian watermilfoil problem and addressing the average citizen's potential involvement. Such a campaign is intended to motivate informed citizens to participate in the overall prevention effort. A broad spectrum of activities contribute to an effective public information campaign, including public meetings, brochures, newspaper articles, television, radio, magazines, special notices, and legislative efforts. The WES is participating in these wide-ranging public information activities in NPS. All public information activities are being

coordinated through the NPS Public Affairs Office (PAO).

Training Plan

31. The Training Plan outlines procedures for training personnel to accomplish the objectives of the LSOMT. Manuals, office and field workshops, seminars, and other procedures are planned to instruct personnel involved in the various elements of the LSOMT. The objective of this plan is to produce qualified personnel to implement a prevention methodology. Topics covered in the Training Plan are:

- *a.* Aquatic plant identification and population dynamics.
- *b.* Aquatic plant management concepts.
- *c.* Monitoring techniques.
- *d.* Treatment methods for chemical (including application techniques, labels, and labeling), mechanical, biological, and integrated control.
- *e.* Inventorying commercial sales outlets and informing retailers of the hazards of Eurasian watermilfoil.

PART III: RESULTS OF FY 79 FIELD TESTS

32. During FY 79, the WES accomplished a significant field portion of its LSOMT (U. S. Army Engineer Waterways Experiment Station 1979) in the state of Washington. Part III of this report will cover the work that was performed during FY 79 under each of the five component plans of the LSOMT: Test Site Selection, Monitoring, Reporting, Treatment, Public Awareness, and Training.

Test Site Selection

33. Thirteen of the water bodies identified by NPS as having operational interest were chosen for evaluation by the WES as candidate test sites (Table 1). During May 1979, a WES field team made a reconnaissance of the 13 water bodies and performed the following tasks at a random number of sample sites at each water body:

- a. Determined whether or not Eurasian watermilfoil was present in the plant population.
- b. Collected, vouchered, and preserved samples of all species of aquatic macrophytes in that population.
- c. Measured conductivity, dissolved oxygen, pH, and temperature of the water.
- d. Prepared a general description of the bottom sediments.

Table 1 also shows treatment category and whether the sites had scientific interest or strategic importance (paragraph 9).

34. After the WES team completed its evaluation, the five test sites shown in Figure 1 were selected through joint NPS-WES coordination, based on the following criteria: (a) presence of Eurasian watermilfoil; (b) encompassing both fluvial and lacustrine ecosystems; (c) encompassing Category I, II, and III designations (paragraph 9); and (d) encompassing a typical range of environmental conditions found in eastern and western Washington. The sites chosen were:

- a. <u>Lake Osoyoos</u> (also known as Osoyoos Lake) - located on the United States-Canadian border in Okanogan County, Washington, and in British Columbia. It is a 5729-acre (2036 acres in the United States) natural lake on the

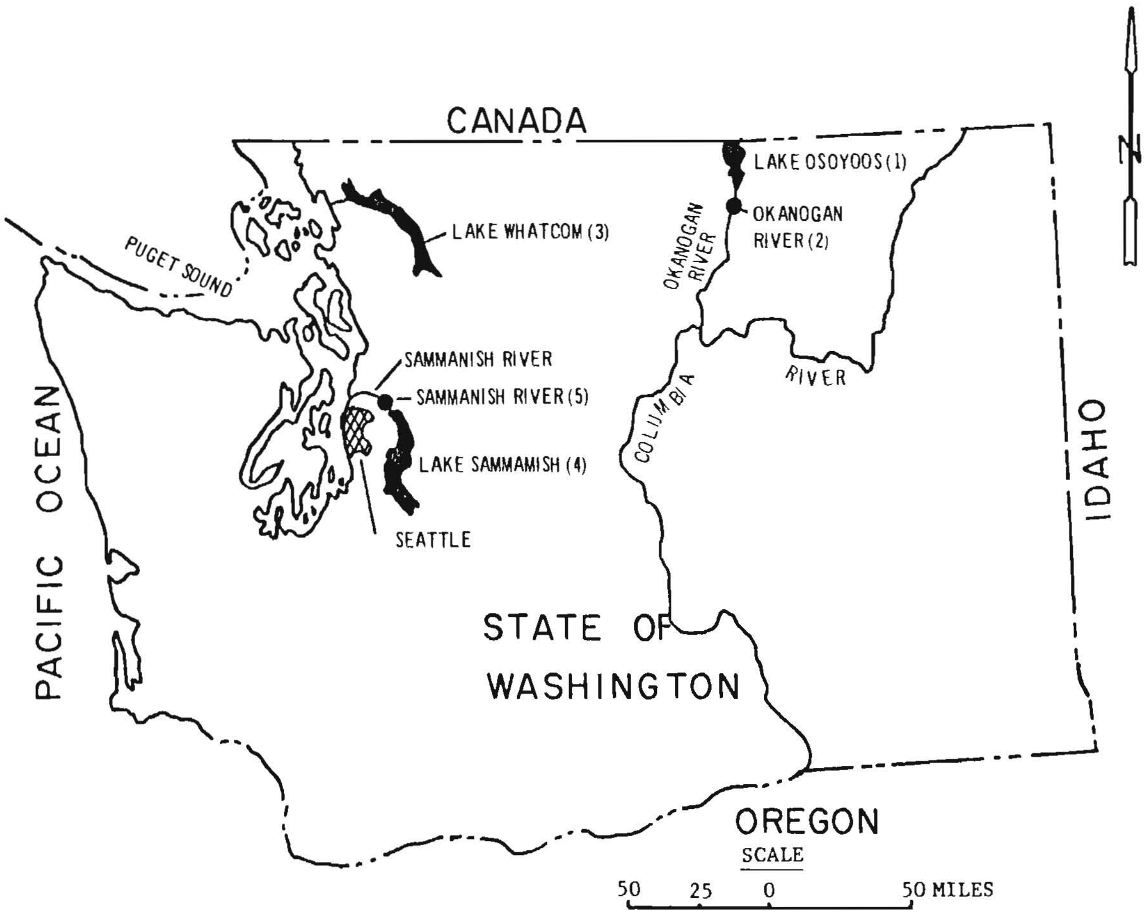

Figure 1. Locations of test sites on Lake Osoyoos, Okanogan River, Lake Whatcom, Lake Sammamish, and Sammamish River in the state of Washington

Okanogan* River (Okanogan River Miles 79.0-90.0, with Mile 82.5 being the international boundary), a right-bank tributary of the Columbia River (confluence at Columbia River Mile 533.5). The U. S. Geological Survey (USGS) maintains records of lake levels (elevations) at its gaging station designated as "Osoyoos Lake, near Oroville, Washington"** (Mile 79.5; drainage area - 3132 square miles). Elevations of record (July 1928 to the present) at this gaging station are: maximum 917.11 ft† and minimum 908.82 ft. Lake levels are

* This river is spelled "Okanagan" in Canada.

** International gaging station maintained under joint agreement with Canada.

† All elevations cited in this report are referenced to the National Geodetic Vertical Datum of 1929.

affected to some degree by upstream diversions for irrigation (44,000 acres irrigated in Canada) and by Zosel Milldam at Oroville (Mile 77.4) (USGS Annual). The Lake Osoyoos test site is classified as Category I (Prevention) with small, nonproblem levels of Eurasian watermilfoil and with large areas of potential habitat.

b. Okanogan River - also located in Okanogan County. The test site is a selected reach of the Okanogan River between Zosel Milldam (Mile 77.4) and the downstream end of Lake Osoyoos (Mile 79.0). Daily discharges of record (October 1942 to the present) at the USGS gaging station designated as "Okanogan River at Oroville, Washington"* (Mile 77.3; drainage area 3195 square miles), are: maximum 3730 cfs; mean 671 cfs; and minimum -2720 cfs (reverse flow due to backwater effect). Elevations of record (October 1942 to the present) at the USGS gaging station designated as "Okanogan River at Zosel Millpond at Oroville, Washington"* (Mile 77.41), are: maximum 916.91 ft and minimum 905.90 ft (USGS Annual). The Okanogan River test site is characterized as Category I (Prevention) with a small, nonproblem Eurasian watermilfoil population and large areas of potential habitat.

c. Lake Whatcom - a 5029-acre natural lake located in Whatcom County in the northwestern portion of the state of Washington. It serves as the principal water supply for the City of Bellingham. No lake elevation data are published. The Lake Whatcom test site represents Category II (Maintenance) with a medium, nonproblem population of Eurasian watermilfoil impacting on user interests and with large areas of potential habitat.

d. Lake Sammamish - a 4897-acre natural lake located approximately 13 miles east of Seattle, in King County, Washington. The USGS maintains records of lake elevations at its gaging station designated as "Sammamish Lake, near Redmond, Washington" (5.6 miles uplake from Sammamish River outlet; drainage area 99.6 square miles). Elevations of record (January 1939 to the present) are: maximum 34.44 ft and minimum 25.23 ft. Lake levels are affected by minor regulation on tributaries that include many small diversions for irrigation and domestic use (USGS Annual). Much of the potential habitat of Lake Sammamish has already been colonized by Eurasian watermilfoil; therefore, this test site is characterized as Category III (Control), indicating significant impact on user interests.

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* International gaging station maintained under joint agreement with Canada.

e. Sammamish River - also located in King County. It is the outlet of Lake Sammamish and drains directly into Lake Washington. The test site is that reach extending from the Lake Sammamish outlet (Mile 15.3) downstream to the highway overpass at Marymoor Park (Mile 14.4). Daily discharges of record (October 1975 to September 1978) at the USGS gaging station designated as "Sammamish River above Bear Creek, near Redmond, Washington"* (Mile 14.6; drainage area 102 square miles), were: maximum 1280 cfs; mean 198 cfs; and minimum 15 cfs. These discharges are affected by natural regulation from Lake Sammamish and by a number of small diversions for irrigation and domestic use (USGS Annual). The Sammamish River has an extensive population of Eurasian watermilfoil that significantly impacts on user interests; therefore, this test site is classified as Category II (Maintenance).

Monitoring

35. The FY 79 monitoring effort of the LSOMT was accomplished by means of a four-phase program, which included (a) remote-sensing missions, (b) ground surveys, (c) diver-efficiency surveys, and (d) determination of the limits of critical environmental factors. Each phase is covered below.

Remote-sensing missions

36. Both operational and experimental missions with the film-filter combinations at the three scales specified in paragraph 14 (1:5,000; 1:10,000; and 1:20,000) were flown during the summer and early fall of 1979 at each of the three lacustrine test sites, Lakes Osoyoos, Whatcom, and Sammamish. The results of the interpretation of imagery derived from both of these types of missions are discussed in the following paragraphs.

37. Operational missions. Operational missions were flown to map the areal extent of Eurasian watermilfoil coverage of the three lakes. For Lake Osoyoos and Lake Whatcom, black-and-white, color, and color infrared photomissions were flown at a scale of 1:10,000, while for Lake

* The USGS reports that this gaging station was discontinued on 30 September 1978.

Sammamish, a black-and-white photomission at a scale of 1:5,000 and color and color infrared photomissions at a scale of 1:10,000 were flown. Sets of imagery resulting from these missions were given to a skilled photointerpreter, who was not familiar with any of the three lakes. The interpreter delineated boundaries of the Eurasian watermilfoil populations on transparent overlays of each of the three lakes. He then determined area occupied by this species using a Bruning Areagraph Chart No. 4849, which yields 97 percent accuracy (provided that map areas are 12 in.^{2} or more) using a dot-count technique. Dot counts were then converted to area occupied by Eurasian watermilfoil, using the following equation

$$A = \text{No. of dots} \times SF \tag{1}$$

where

A = area, acres

SF = scale factor

for 1:5,000 = 0.039856

1:10,000 = 0.159420

1:20,000 = 0.637690

Each of the scale factors, therefore, represents the acreage value of one dot. The results of this interpretation are shown in Table 2.

38. All areas of the three lakes that appeared to contain Eurasian watermilfoil were tentatively delineated and later verified in the field for accuracy. In some cases, areas of dead organic material (detritus) were mapped as Eurasian watermilfoil. In those portions of the lakes where plants were growing in water depths of 15 ft or more, the photointerpreter often had difficulty in delineating actual boundaries based on only the tonal and textural characteristics of the imagery without benefit of ground-survey data. The postinterpretation ground survey showed that color imagery was the most reliable, followed by color infrared and black and white. Many areas of detritus in Lake Osoyoos had been erroneously delineated as Eurasian watermilfoil populations on the black-and-white imagery, and deeper portions of some colonies were not mapped correctly on both black-and-white or color infrared

imagery. Depth penetration also proved to be a problem at Lake Whatcom and Lake Sammamish.

39. As a further test with various combinations of scales and imagery, the interpreter focused on a representative topped-out colony (i.e., a colony in which some of the plants had reached the water surface) of Eurasian watermilfoil in each of the three lakes. He determined areas of these colonies using the 25 scale-imagery combinations* shown in Table 3. Color imagery at a scale of 1:5000 proved to be the most accurate at all three lakes when later checked in the field.

40. Although the centers of the Eurasian watermilfoil colonies were emergent, and, therefore, considerably easier to detect than totally submerged colonies, the peripheries of the colonies in the three lakes were submerged. Thus, the interpreter experienced the same difficulties (described in paragraph 38) that he encountered in mapping total populations of this species. Generally speaking, differences in colony areas (whether increases or decreases) for black-and-white and color infrared films, when compared with color film, can be attributed to the lesser depth-penetration capability of black-and-white and color infrared films. Additionally, as scale decreases, the difficulty of interpretation increases. Some differences in area can also be attributed to the manner in which colony areas had to be determined with the Bruning Areagraph Chart No. 4849 (paragraph 37). Although this dot-count method yields 97-percent accuracy for map areas of 12 $in.^2$ or greater (e.g., a population in an entire lake), the accuracy is less for smaller areas (e.g., a single colony). For example, the value of one dot at a scale of 1:20,000 (0.637690 acre) represents one third of the total area for the single topped-out colony chosen in Lake Whatcom; therefore, including or excluding a single dot when determining colony area at this scale can change the area by as much as one third.

41. Experimental missions. As part of the remote-sensing effort of the LSOMT and in conjunction with the operational missions,

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* Black-and-white imagery for Lake Sammamish at scales of 1:10,000 and 1:20,000 was not available.

26 experimental missions were flown over Lake Osoyoos, Lake Whatcom, and Lake Sammamish to determine the detection depths for underwater targets. The target layout at each lake consisted of 4- by 4-ft sheets and 8- by 16-in. concrete blocks painted white or green placed at 5-ft-depth increments from the water surface to a depth of 25 ft. Figure 2 shows a typical target layout.

42. A skilled photointerpreter then determined which targets in each of the three lakes were detectable on each of the 26 scale-imagery combinations. Figure 3 is an example that shows the actual size of the

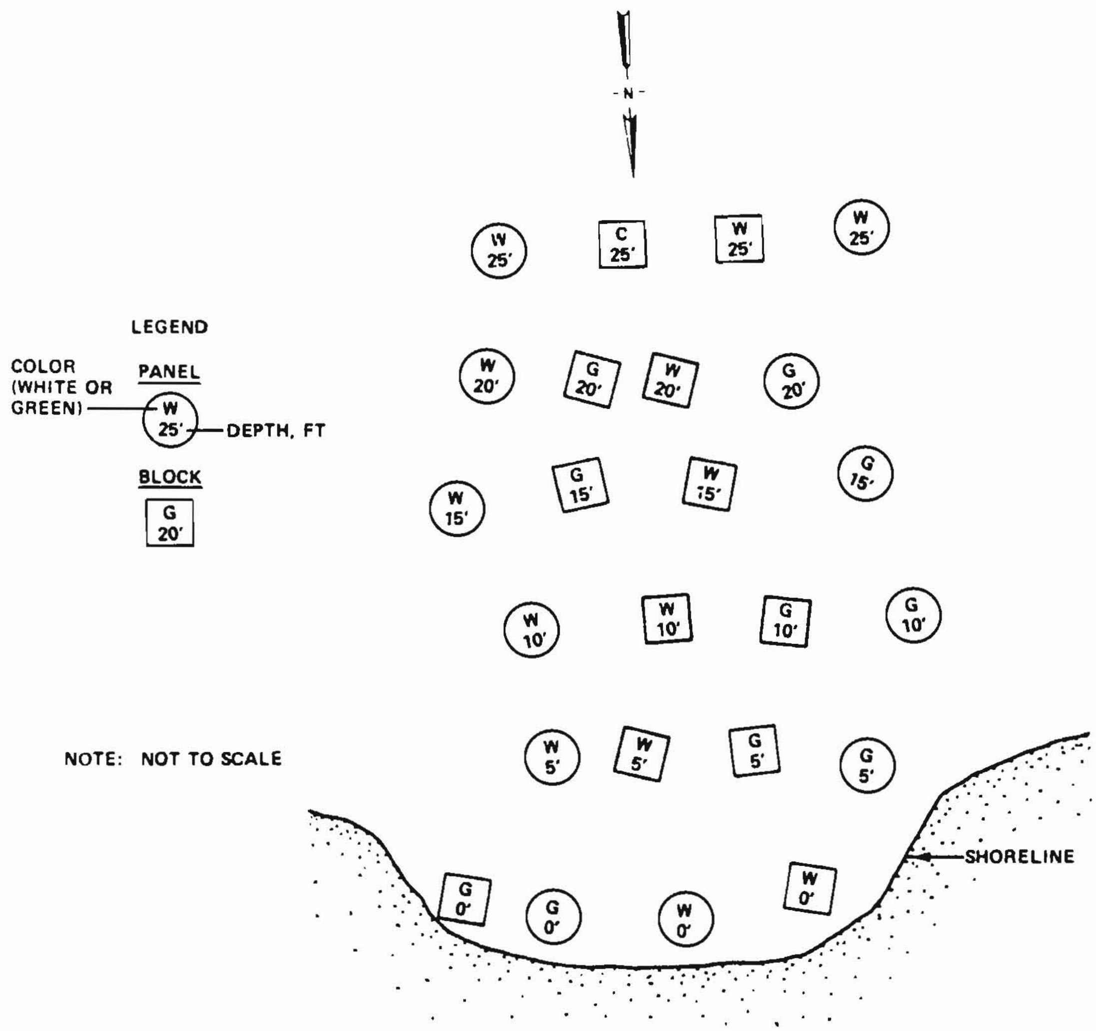

Figure 2. Layout of underwater target panels and blocks used at Lake Whatcom

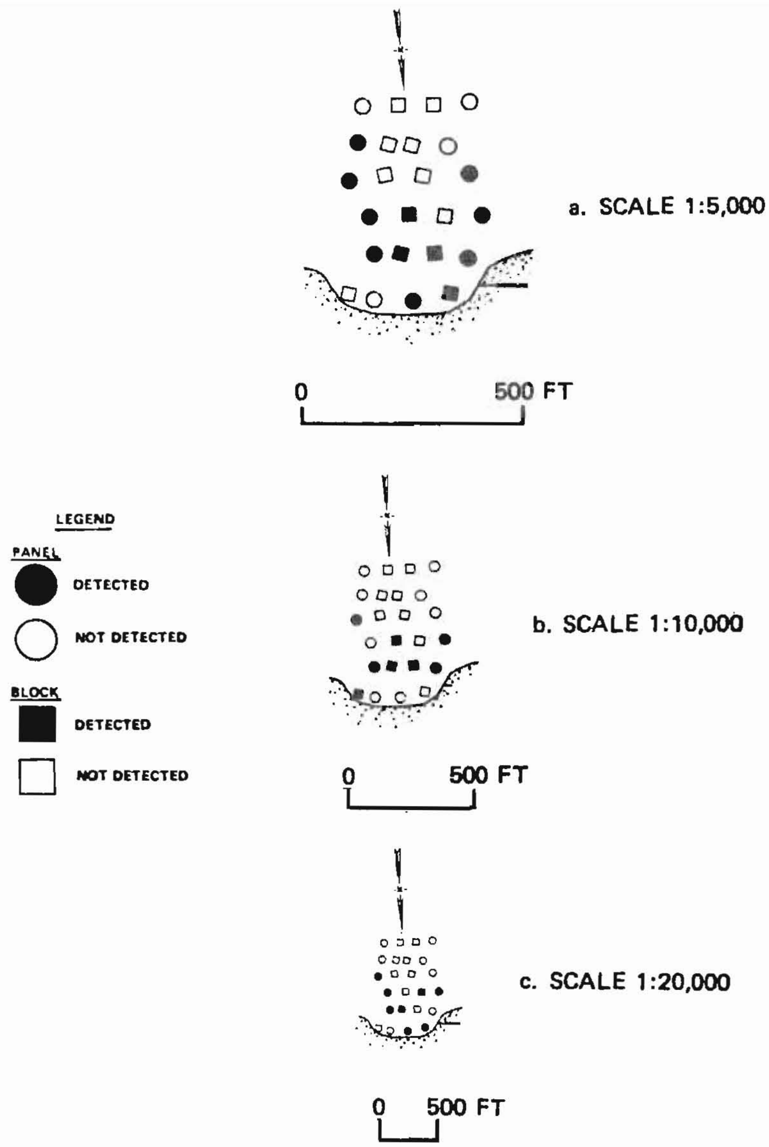

Figure 3. Underwater target panels and blocks detected on three scales of color imagery, Lake Whatcom

overlays used to map detectable and nondetectable targets in the layouts. In some instances, a deeper target of a certain type was detectable, whereas a shallower target of the same type was obscured. Table 4 gives the maximum detectable depths (using a 10X magnification) for each type of target on all of these 26 scale-imagery combinations in each lake, while Table 5 shows the average detection depths for the three lakes.

43. In a few instances, black-and-white imagery equaled the two

other types of imagery in terms of its depth-detection capability, and the 1:20,000-scale black-and-white imagery for Lake Whatcom outperformed the color infrared because of the excessive surface glitter on the latter. Generally, however, black-and-white imagery yielded shallower detection depths than either color or color infrared. Color and color infrared film, in most cases, performed similarly at all scales in all lakes; however, color imagery was easier to interpret. The results of this exercise (Table 5) also showed that white targets were easier to detect than were green targets, and panels were easier to detect than were blocks. Only under the most ideal conditions could a 20-ft-deep white panel or a 20-ft-deep green panel be detected.

44. Because of the attenuation of the reflective infrared radiation (0.7 to 0.9 μm) by water, the emulsion layer on infrared film sensitive to this portion of the electromagnetic spectrum was rendered useless for detecting underwater targets. The reflective properties of plant leaf structure made color infrared film much more suitable than color film for detection of <u>emergent</u> vegetation; however, detection of <u>submerged</u> vegetation was best accomplished with color film. In this exercise, however, underwater targets painted with colors in the green-to-red visible light range (0.5 to 0.7 μm) of the electromagnetic spectrum were used, and these objects recorded similar images on both color and color infrared films. Performance of the two films at detecting these underwater targets was influenced only by the transmittance of only the green-to-red range of the electromagnetic spectrum through the water; therefore, the recording characteristics of the two films were essentially identical. Differences in detection depths for color and color infrared film for any given scale could be attributed to differences in site conditions at the times of overflight. These site conditions included glitter and orientation of targets with respect to sun angle.* In general, larger scale imagery yielded better results than smaller scale imagery, and, as the scale was reduced, the difficulty of interpretation increased.

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* Targets were placed directly on the lake bottom, which was not, in every instance, parallel to the water surface.

Ground surveys

45. Data collected during FY 79 ground surveys consisted of both the establishment of the MOD's for growth of Eurasian watermilfoil (after which area of potential habitat was determined) and the collection of biomass samples for each of the three lacustrine test sites, Lake Osoyoos, Lake Whatcom, and Lake Sammamish.

46. Establishment of the MOD's. With the help of professional divers, the WES established the MOD for growth of Eurasian watermilfoil at the three lakes. The divers made a sufficient number of underwater observations to determine these depths at the three lakes. These MOD contours were then plotted on topographic maps and remote imagery (paragraphs 36-37) using existing hydrographic surveys. The potential Eurasian watermilfoil habitat between the shoreline and the MOD contour was then computed using Bruning Areagraph Chart No. 4849 (paragraph 37). The tabulation below shows the MOD's and the areas of potential habitat determined for each lacustrine test site, assuming, of course, that Eurasian watermilfoil was already growing at its maximum depth:

Lacustrine Test Site	MOD, ft	Area of Potential Habitat acres
Lake Osoyoos	25	425*
Lake Whatcom	25	506
Lake Sammamish	35	928

* Does not include the Canadian portion of the lake.

47. Collection of biomass samples. The information plotted on the areal maps and imagery and area computations were not sufficient to establish the total amount of vegetative matter present in a sample or to establish the density of this material. Even though two colonies of aquatic macrophytes are of identical area, one colony can be extremely dense, while the other can be very sparse. Without the quantification required to define "problem level," however, "dense" and "sparse" are qualitative expressions of limited value for planning or implementing a

treatment plan. The WES approached the problem by attempting to characterize the aquatic plant populations of Lakes Osoyoos, Whatcom, and Sammamish in terms of their biomass.

48. Maps and remote imagery of Lakes Osoyoos, Whatcom, and Sammamish were overlaid with grids, and random numbers of grid squares were selected on each. In the summer of 1979, the WES field teams then used the WES biomass sampler (Figure 4) to sample all the selected grid squares, whether or not these grid squares fell within Eurasian watermilfoil colonies. This sampler is designed to collect plant material inside a 2.87-ft^2 column that extends from the surface of the water to the lake bottom. Team members measured depth, recorded temperatures at 5-ft incremental depths, identified all plants, made wet weight determinations, and counted stem tips with each sample. (Stem tips were counted to obtain a conservative estimate of potential regrowth after fragmentation.)

49. Table 6 shows the ranges of biomass values for Eurasian watermilfoil (wet weights) for the three lakes. A higher percentage of the

Figure 4. WES biomass sampler

random grid squares sampled in Lake Sammamish contained Eurasian watermilfoil, and the biomass values of the samples collected in Lake Sammamish were considerably higher than were those collected in the other two lakes. Higher biomass values were found for Lake Osoyoos than for Lake Whatcom. The biomass values found in the samples were then projected to that area of the lakes inside the MOD contours to obtain estimates of both unit and total wet weight biomass for Eurasian watermilfoil as follows:

Lacustrine Test Site	Estimated Unit Wet Weight Biomass, lb/acre	Estimated Total Wet Weight Biomass, lb
Lake Osoyoos*	147.4	62,629
Lake Whatcom	73.2	37,026
Lake Sammamish	45,432.7	4,130,287

* Does not include the Canadian portion of the lake.

50. Because Eurasian watermilfoil is a submerged plant that grows throughout the water column, the wet weight biomass values were then converted to wet weight biomass densities by using the water depths measured with each biomass sample. Table 7 shows the range of these wet weight biomass density values found in three lakes. Shifting class values when biomass density (pounds per cubic foot) is used instead of biomass (pounds per square foot) can be attributed to the varying water depths where the biomass samples were taken, which ranged as follows:

Lacustrine Test Site	Water Depth Range of Biomass Samples, ft
Lake Osoyoos	2-9
Lake Whatcom	2-20
Lake Sammamish	2-34

Many of the samples taken in deep water had little biomass, and, thus, low biomass density, while some high biomass values in Lake Sammamish were in shallow water.

51. As an integral part of the biomass sampling program in Lake Osoyoos, Lake Whatcom, and Lake Sammamish during the summer of 1979, the WES field team made counts of numbers of stem tips in each sample containing Eurasian watermilfoil plants. Table 8 shows the ranges of values for numbers of stem tips (number per square foot) and stem-tip densities (number per cubic foot) for these three lakes.

Diver-efficiency surveys

52. Diver-efficiency surveys were conducted as part of the monitoring effort to determine whether or not professional divers could be used to survey the areal extent of Eurasian watermilfoil coverage and to locate and relocate the colonies of this problem species for possible future treatment efforts. Square test plots were chosen in Lake Osoyoos, Lake Whatcom, and Lake Sammamish. The physical descriptions of each of the test plots chosen are listed below:

Lacustrine Test Site	Test Plot No.	Area, ft^2	Depth Range, ft	Secchi Disk, ft
Lake Osoyoos	1	5,000	15-25	12
	2	10,000	15-20	12
Lake Whatcom	1	10,000	20-25	16
Lake Sammamish	1	2,500	15-25	14
	2	10,000	15-25	14
	3	250,000	15-25	14

53. These test plots were chosen in portions of the above water bodies that contained Eurasian watermilfoil populations. Plot corners were marked with buoys, and each plot was gridded. The WES field team made 10 fathometer transects to map bottom topography and vegetation height profiles in each test plot. These transects were used to aid a trained aquatic botanist in the characterization of the areal distribution of the submerged aquatic macrophyte community of each test plot; these characterizations served as the controls for the diver-efficiency surveys.

54. The WES field team gave onsite training in aquatic plant identification to two professional divers who had no experience with aquatic vegetation (although they were qualified and experienced in many

other types of diving operations). Each diver was shown and taught to identify (by bottom retrieval) the various submerged aquatic macrophyte species found in each test plot. When the two divers had satisfactorily mastered the identification of the species comprising the community in a test plot, each was individually assigned the task of areal characterization of the test plots using a systematic search procedure. For verification, each diver was also told to collect samples of all aquatic macrophyte species found in the three test plots. Bottom time in all test plots was 10 min, with the exception of Test Plot No. 3 in Lake Sammamish, where the bottom time was 20 min.

55. Table 9 shows the results of the overall characterization of the six test plots by the two divers as compared to the control characterization performed by the trained botanist (paragraph 53). To simplify the presentation, all species of aquatic macrophytes other than Eurasian watermilfoil are shown as "other vegetation." In Lake Whatcom and Lake Sammamish, the two divers generally failed to agree with each other or with the control characterizations. In Test Plot No. 1 of Lake Osoyoos, where there was only a trace of Eurasian watermilfoil, the two divers were in complete agreement with the control percentages. In Test Plot No. 2 of the same lake, there was 100-percent agreement between the divers and a 10-percent discrepancy with the control percentages.

56. When the divers were asked to locate or to relocate specific colonies of Eurasian watermilfoil in all of the test plots, they were unable to perform this task, even in the smaller test plots. However, in Lake Osoyoos, the divers could locate and relocate single fragments of this plant. Total cost (1979) of the diver-efficiency surveys at each of the three lacustrine test sites was $2700 (or a total of $8100 for the entire diver-efficiency survey). This cost included transportation to and from the lake and bottom time.

Determination of the limits of critical environmental factors

57. After compiling a list of water, sediment, wave and current, and other parameters thought to be critical to the establishment, growth, and spread of Eurasian watermilfoil, the WES began reviewing current

literature pertaining to this species to establish the limits of these critical factors.

Reporting

58. The WES performed an inventory and assessment of aquatic plant management methodologies (Dardeau and Hogg in preparation) that included reporting techniques. Fourteen CE Districts were surveyed on their practices for reporting on both the monitoring and treatment elements. None of the Districts had any special forms for reporting the status of a problem population either by their own personnel or by the public. Four Districts, SAJ, New Orleans, Savannah (SAS), and Tulsa, reported having forms for documenting treatments; however, only SAJ and SAS reported that their forms were computer-compatible. Figure 5 shows a form, "Weekly Report of Operations, Aquatic Plant Control," used by SAJ, and Figure 6 shows a sample data printout. With the possible exceptions of McGehee (1977) and U. S. Army Engineer District, Jacksonville (1978), which address reporting of treatment operations in SAJ, there is little documentation of reporting procedures used by CE Districts.

Treatment

59. During FY 79, only mechanical treatments of Eurasian watermilfoil were implemented. These treatments included the erection of a fragment barrier system on the Okanogan River and a hand-pulling exercise on both the Okanogan River and Lake Osoyoos.

Barrier system

60. In late July 1979, NPS constructed a fragment barrier system consisting of debris, operational, and evaluation barriers (as described in paragraph 26) across a 290-ft-wide cross section of the Okanogan River (Mile 77.9), 0.1 mile downstream from the Cherry Street Bridge at Oroville, Wash. Approximately 1 year earlier, the British Columbia Ministry of the Environment, Water Investigations Branch (B.C., W.I.B.) (1978) had installed several fragment barriers in the same basin in

WEEKLY REPORT OF OPERATIONS
AQUATIC PLANT CONTROL

Crew No. [1| | | |] (1-5) Period [| | |] (6-9) thru [| | |] (10-13) 19 [|] (14,15)

Watershed and Area ______________ [| | | |] (16-20) County ______________ [|] (21,22)

Cost Account No. [| | | |] (23-27) - [| | | |] (28-32) - [| | | |] (33-37) Kind of Vegetation [ ] (38) Method of Control [ ] (39)

ITEM		Sun	Mon	Tue	Wed	Thu	Fri	Sat	Totals
									CC 1 2
Equip. Rental (hrs-min)									14
									20
									26
									32
Vehicle Usage									38
									43
Crew Time (Hrs.)									48
									52
									56
Per Diem Name & Amount									60
									65
									70
									CC 1 3 Hr Min
Time Distribution	Effective Time								14
	Travel Time Vehicle								18
	Travel Time Plant								22
	Lost Time Rain								26
	Lost Time Wind								30
	Minor Repairs (Explain)								34
	Major Repairs (Explain)								38
	Other Duties								42
	Holiday or Leave								46
	Survey								50
	Inspection								54
	Preparation								58
	Removing Obstructions								62
	Miscellaneous (Explain)								66
	Total Time in Period								70
								CC 1	4 Herb. Amt.
Herbicides and Amount									14
									20
									26
									32
									38
Diluent & Conc.									
Acres Controlled									44
Wind Data	Time								
	Direction								
	Velocity								

SAMPLE

Sun	Mon	Tue	Wed	Thu	Fri	Sat

Remarks

Submitted: ______________ Approved: ______________
Crew Chief

SAJ Form 454
26 Jun 78

Figure 5. SAJ Form 454, "Weekly Report of Operations, Aquatic Plant Control (redrawn)

31 MAR 80 U S ARMY ENGINEER DISTRICT, JACKSONVILLE PROGRAM KM27002

MONTHLY SUMMARY AQUATIC PLANT CONTROL

SUMMARY BY STATE CONTRACTORS

ITEM	SFWMD	SWFWND	CITRUS	HIGLANDS	HILLSBGR	LAKE	LEE	ORANGE	POLK	G&FWFC
1-AIRBOAT	368.00	454.00	240.00	168.00	86.00	20.00	28.00	33.00	224.00	709.00
2-AIRCRAFT										112.00
3-KICKERBOAT	32.00				7.30	55.00	7.00	22.00	48.00	
11-TANK TRUCK AIRCRAFT										112.00
13-BATCH TRUCK 1 TON		213.30			60.00					
22-BARGE								47.00		
23-PONTOON BOAT								27.00		
25-HELICOPTER									8.00	
1-SEDAN										129.00
3-P.U. TRUCK 1/2 TON	32.00	251.00							88.00	
4-P.U. TRUCK 3/4 TON	400.00				135.00					736.00
5-P.U. TRUCK 1 TON			240.00			98.00	35.00			
6-BLAZER CARRYALL WAGON		10.30		168.00				129.00	184.00	108.00
CREW TIME A	432.00	431.00	230.00	168.00	190.30	82.00	35.00	161.00	280.00	881.00
CREW TIME B	296.00	391.00	200.00	168.00	176.30	48.00	35.00	157.00	280.00	941.00
CREW TIME C	88.00	90.00	30.00	136.00	70.00	3.00		125.00		157.00
TOTAL MAN HOURS	816.00	912.00	460.00	472.00	436.60	133.00	70.00	443.00	560.00	1979.00
PER DIEM A	.00	.00	.00	.00	.00	.00	.00	.00	.00	651.50
PER DIEM B	.00	.00	.00	.00	.00	.00	.00	.00	.00	662.00
PER DIEM C	.00	.00	.00	.00	.00	.00	.00	.00	.00	35.00
TOTAL PER DIEM	.00	.00	.00	.00	.00	.00	.00	.00	.00	1348.50
EFFECTIVE TIME	178.00	142.00	106.30	6.00	33.00	37.00	9.30	59.00	91.00	42.30
TRAVEL TIME VEHICLE	98.00	92.30	34.00	11.00	42.00	27.00	6.30	28.30	40.30	253.30
TRAVEL TIME PLANT	38.30	26.00	35.30	11.00	10.00			7.00	22.00	5.30
LOST TIME RAIN	6.00	21.30	5.00	8.00	2.00			10.00	1.30	37.00
LOST TIME WIND	9.30	32.00	2.00	16.00			3.00	30.00	70.30	378.00
MINOR REPAIRS	8.30		9.00		26.00	5.00			7.00	64.30
MAJOR REPAIRS	6.00		12.00		5.00		3.30		19.30	40.00
OTHER DUTIES		2.30			44.30					36.30
HOLIDAY AND LEAVE					80.00					
SURVEY			2.00	116.00	5.00	12.00				4.00
INSPECTION	52.00	6.30			10.00	6.00	8.00		5.00	36.00
PREPARATION	34.30	16.30	31.00		4.30	15.00	4.30	16.30	30.30	28.00
REM OBSTRUCTIONS	1.00	85.00			78.00	4.00		12.00	.30	80.30
MISCELLANEOUS		14.30	2.00					6.00		30.00
TOTAL TIME	432.00	441.00	239.00	168.00	340.00	106.00	35.00	169.00	288.00	1036.00
1-2,4-D AMINE	3					62		2	111	115

Figure 6. Typical printout derived from data recorded on SAJ Form 454

Canada. Both barrier systems are discussed, and the results are compared in the following pages.

61. The NPS barrier system. The cost (1979) for design, construction, operation, and maintenance of the NPS barrier system was $95,000. This system was operated for a 12-week period from late July until mid-October 1979. During the sampling period, a contractor was responsible for collecting material that had accumulated on the three types of barriers. No stream velocity readings were taken in conjunction with the barrier operation; however, on 4 April 1979, WES personnel measured stream velocities at various depths from five different positions along the cross section of the Okanogan River from the Cherry Street Bridge (Mile 78.0). These readings are reported (in feet per second) in the tabulation below. Table 10 shows an excerpt from the latter part of the

	Distance from Right (North) Bank, ft				
Depth, ft	40	80	120	160	200
Surface	0.1	0.4	0.4	0.4	0.2
1	0.1	0.4	0.4	0.4	0.2
2.5	0.1	0.2	0.2	0.2	0.3
4	--	0.2	0.2	0.2	0.2
5	--	0.1	0.1	0.1	--

discharge record for the USGS gaging station, "Okanogan River at Oroville, Washington" (paragraph 34). It covers the 12-week operational period of the barrier system in 1979 and presents discharge data for the same days of the preceding 2 years (USGS Annual).*

62. No debris measurements were made; however, the debris barrier was cleaned on the same schedule (usually two or three times weekly) as the other two types of barriers. Wet weights of the vegetative material collected on the operational barrier were obtained, and average weekly percentages of Eurasian watermilfoil were determined from several

* Because discharge data from this gaging station for the period following Water Year 1979 (1 October 1978-30 September 1979) have not yet been published (USGS Annual), those values for October 1976 (Water Year 1977) were substituted for October 1979 (Water Year 1980).

representative samples. Table 11 summarizes the weekly totals and percentages (by wet weight) of Eurasian watermilfoil collected on the operational barrier during the 12-week period from 29 July-20 October 1979. It shows a generally declining total wet weight of vegetative material but an increasing percentage of Eurasian watermilfoil found in the samples. During the first week (29 July-4 August), the height of the growing season, only 5.3 percent (19 lb of 357 lb total wet weight) of the vegetative material collected was Eurasian watermilfoil, whereas in the twelfth week (14-20 October), when fragmentation was in progress, the percentage of Eurasian watermilfoil had reached 34.8 (80 lb of 230 lb total wet weight). Figure 7 shows the wet weight of material collected on the operational barrier during those 12 weeks.

63. The evaluation barriers were in place for 11 weeks, their

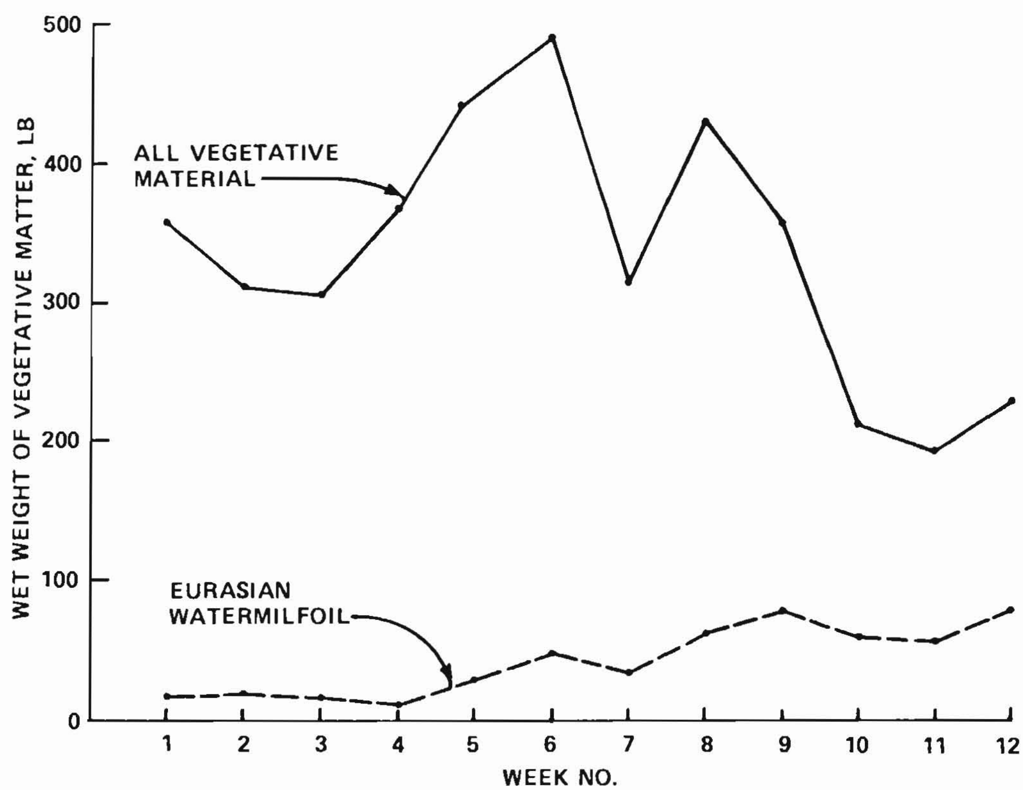

Figure 7. Wet weights of Eurasian watermilfoil and of all vegetative material collected on operational fragment barrier, Okanogan River, Oroville, Wash., during the period 29 July-20 October 1979

last week of operation being 7-13 October 1979. These barriers consisted of five sets of six vertically arranged square net sections evenly spaced across the Okanogan River cross section. Evaluation barrier No. 1, upstream from both the debris and operational barriers, served as the control for the experiment. Evaluation barrier No. 2 was downstream from all other structures. Tables 12 and 13 show the vertical distribution (by wet weight) of vegetative material collected on each section of Evaluation barriers No. 1 and No. 2, respectively. Figure 8 portrays these data graphically. No percentages of Eurasian watermilfoil were determined for these samples.

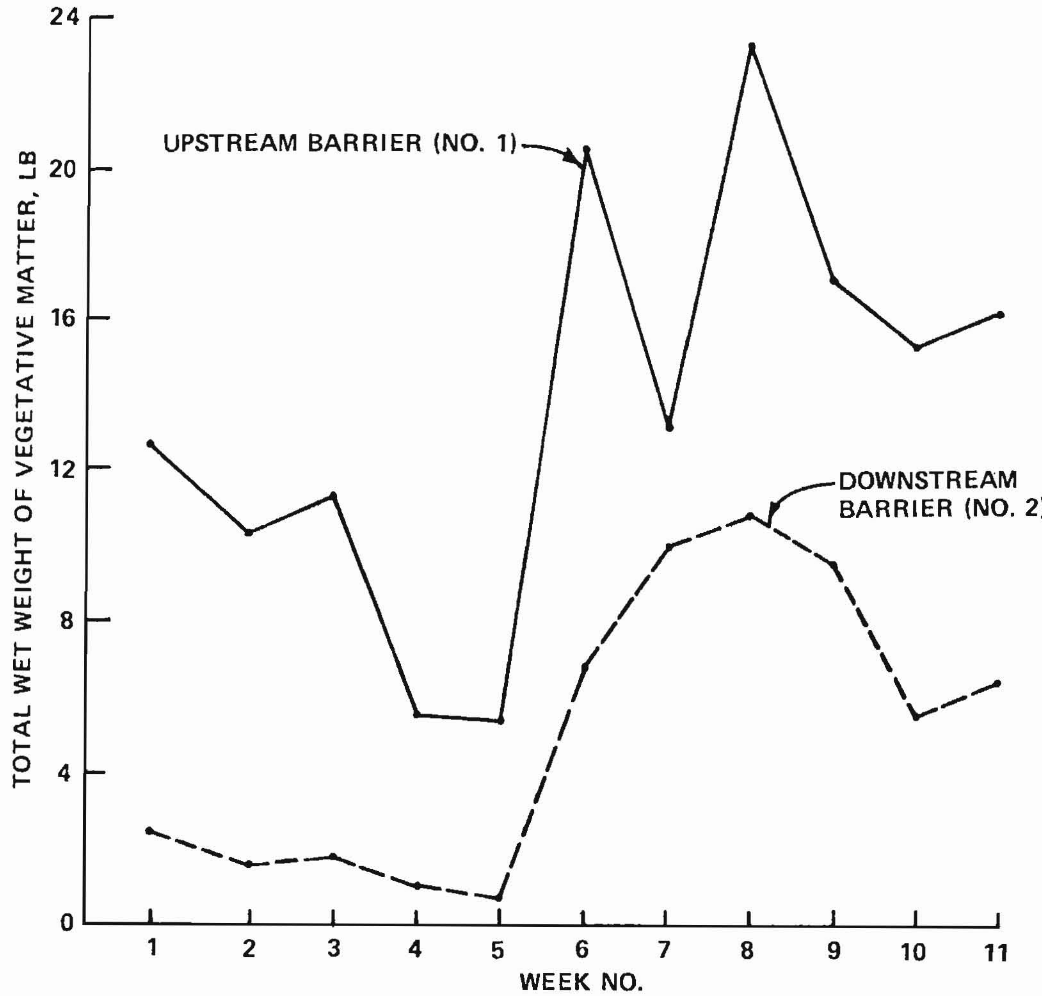

Figure 8. Total wet weight of material collected on upstream and downstream evaluation fragment barriers, Okanogan River, Oroville, Wash., during the period 29 July-13 October 1979

64. An overwhelming majority of the material collected on the control barrier (No. 1) was intercepted in the net sections sampling the 0- to 1-ft depth range. Although lesser total weights were collected each week on the downstream barrier (No. 2), these weights had a more even vertical distribution, indicating that the operational barrier was performing as designed and that some fragments had passed beneath the operational barrier. Effectiveness values were determined using the wet weights of Evaluation barriers No. 1 and No. 2 for the same weekly period as follows:

$$\text{Percent effectiveness} = \left(\frac{\text{Wet Weight No. 1 - Weight No. 2}}{\text{Wet Weight No. 1}}\right) \times 100 \qquad (2)$$

Analysis of the effectiveness of the barrier system is shown in Table 14 and in Figure 9. These values ranged from a low of 23.6 percent during week No. 7 (9-15 September) to a high of 86.1 percent during week No. 5 (26 August-1 September). The average weekly effectiveness was 66.2 percent.

65. Improved design of the operational barrier during FY 80 resulted in a more efficient operation. These improvements included a mechanism that allowed for adjustment of the angle of the barrier screen with the fluctuating flows. A contractor still cleaned the barrier twice each week, but he no longer weighed the contents or determined the percentage of Eurasian watermilfoil. In addition, no evaluation barrier screens were installed; therefore, effectiveness was no longer measured.

66. British Columbia barrier system. During 1978, the B.C., W.I.B. constructed several fragment barriers in the Canadian portion of the Okanagan River Basin. This agency, reporting on this system of barriers, stated that these barriers had effectivenesses ranging from 86 to 97 percent. Because these values seemed to be rather high when compared with the effectiveness of the NPS barrier system downstream from the Cherry Street Bridge (Table 14), the WES decided to examine the method in which their effectivenesses were calculated.

67. The Canadian installations consisted of a floating barrier (equivalent to the NPS operational barrier), a trash barrier (equivalent

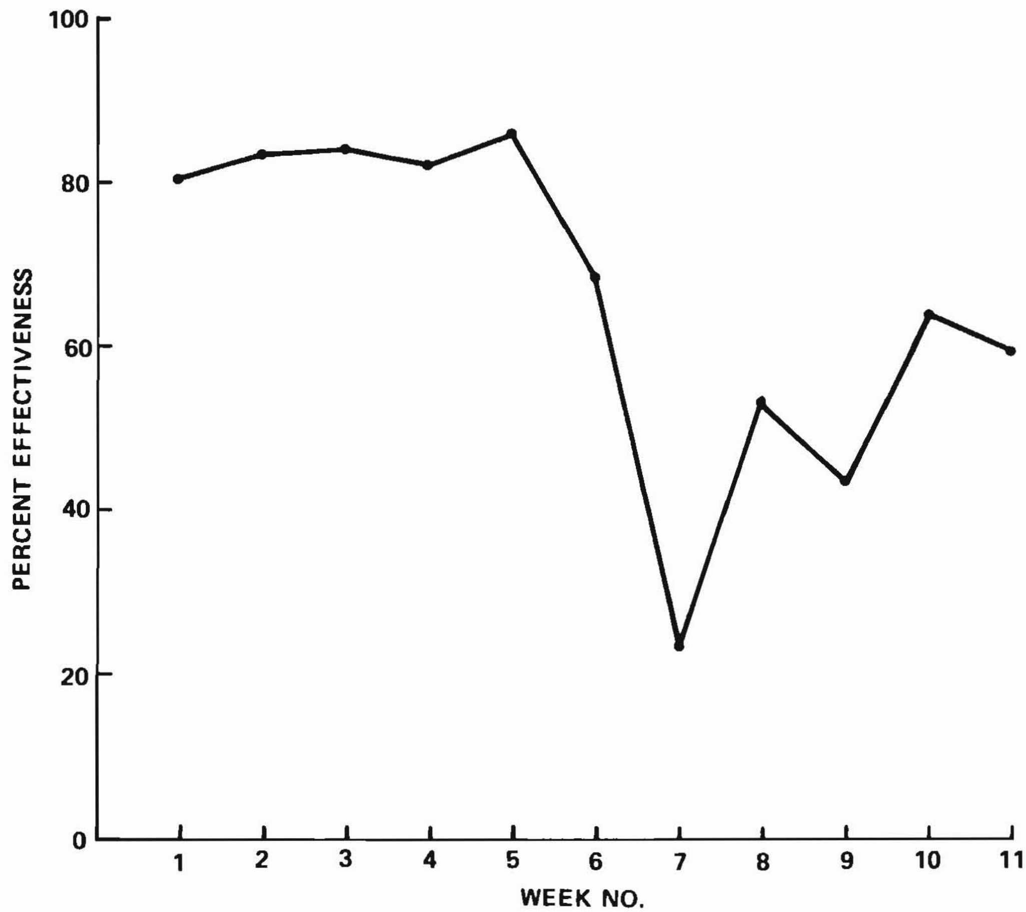

Figure 9. Percent effectiveness of operational fragment barrier, Okanogan River, Oroville, Wash., during the period 29 July-13 October 1979, based on wet weight of material collected on upstream (No. 1) and downstream (No. 2) evaluation barriers

to the NPS debris barrier), and an upstream sampling cage (equivalent to one set of the net sections of the NPS upstream evaluation barrier). The trash barriers were not placed at all sites. There was no equivalent of the NPS downstream evaluation barrier. The sampling cage was used to monitor the weight of material of a number of water columns along the axis of the floating barrier; these weights were then compared with those collected on an equivalent area of the floating barrier during the same time period. The B.C., W.I.B. reported

> In fact the method had inherent weaknesses, which were not overcome during 1978. In particular, no investigation was made of the downstream escapement of milfoil fragments from the barrier or the sampling

> cage. The possible deflection of fragments either over or under a barrier as a result of current, wave or wind action should not be ignored when evaluating the results of this particular project (British Columbia Ministry of the Environment, Water Investigations Branch 1978).

Because no provision had been made for a downstream evaluation barrier, true effectiveness had not been measured.

Hand-pulling exercise

68. During late summer 1979, a WES field team conducted a special exercise designed to evaluate the efficiency of small-scale hand removal of Eurasian watermilfoil at two test plots on the Okanogan River (No. 1 and No. 2) and one test plot on Lake Osoyoos (No. 3). Below are data on each of the test plots used for the hand-pulling exercise:

	Test Plot		
	No. 1	No. 2	No. 3
Area treated, ft^2	1470	612	150
Estimated percent areal coverage	25	35	30
Average water depth, ft	2.5	3.0	3.0
Bottom sediment	Silt (over gravel)	Sand and gravel	Silt (in crevices between pieces of stone riprap)*
Underwater visibility	Poor	Good	Good

* Test plot located over the toe of a stone breakwater.

The test plots were enclosed with 0.25-in. mesh capture nets attached to floats. The team measured and characterized each of the test plots, recorded numbers of man-hours and wet weights of Eurasian watermilfoil removed, and made estimates of percent success (in terms of areal coverage) of clearing and root removal at each test plot. Table 15 summarizes this 1979 exercise.

Public Awareness

69. The WES participated in four NPS-sponsored public meetings, two radio interviews, and preparation of two newspaper articles. Another important area of WES contribution was in the preparation of NPS information brochures for the public in FY 79. The WES coordinated all publicity activities of the LSOMT with the Chief, PAO, NPS.

Training

70. Two aquatic plant management workshops were conducted by the WES in cooperation with the NPS during the summer and fall of 1979 for planning, engineering, and operational staff of Federal, State, and local agencies in the state of Washington. Most of these agencies were represented at the workshops, which provided primary training that emphasized aquatic plant identification and population dynamics, but which also covered the remainder of the topics outlined in the Training Plan of the LSOMT (paragraph 31).

PART IV: SUMMARY AND CONCLUSIONS

Summary

71. The WES is evaluating the concept of prevention methodology as a management objective for Eurasian watermilfoil in the state of Washington by means of the LSOMT, a 3-year effort implemented in FY 79. There are six component plans of the LSOMT that were developed based on traditional aquatic plant management concepts. During FY 79, accomplishments were made under each component plan.

Test Site Selection

72. Five test sites were selected from 13 water bodies identified by NPS as having operational interest, scientific interest, or strategic importance. These were Lake Osoyoos, Okanogan River, Lake Whatcom, Lake Sammamish, and Sammamish River.

Monitoring

73. During FY 79, the monitoring effort consisted of (a) remote-sensing missions, (b) ground surveys, (c) diver-efficiency surveys, and (d) determining limits of critical environmental factors. Both operational and experimental photo missions were flown. The operational missions were designed to map the areal extent of Eurasian watermilfoil coverage at Lake Osoyoos, Lake Whatcom, and Lake Sammamish using various scale-imagery combinations, and the experimental missions were designed to determine the detection depths for underwater targets. Ground-survey data collection efforts consisted of the establishment of the MOD's for growth of Eurasian watermilfoil and the collection and analysis of biomass samples taken in the three lakes. Diver-efficiency surveys were conducted to determine whether or not professional divers could be used to survey the areal extent of Eurasian watermilfoil coverage. The WES is reviewing literature to determine limits of critical factors thought to be critical to the establishment, growth, and spread of Eurasian watermilfoil.

Reporting

74. The WES performed an inventory of reporting techniques used

for both the monitoring and treatment elements of an aquatic plant management program.

Treatment

75. Two types of mechanical treatment were implemented and evaluated during FY 79. These included the erection of a fragment barrier system on the Okanogan River at Oroville, Wash., and a hand-pulling exercise at two sites on the Okanogan River and one site on Lake Osoyoos. The barrier had an average effectiveness of 66.2 percent during its period of operation, based on the wet weight of the vegetative material collected on the upstream and downstream evaluation barriers. The total wet weight of vegetative material collected each week generally declined; however, the percentage (by wet weight) of Eurasian watermilfoil increased to as much as 34.8 percent when fragmentation was in progress.

Public Awareness

76. The WES participated in four NPS-sponsored public meetings, two radio interviews, and preparation of two newspaper articles.

Training

77. Personnel from the WES conducted two aquatic plant management workshops in cooperation with NPS during the summer and fall of 1979.

Conclusions

78. Conclusions can be drawn in the areas of monitoring and treatment, based on the FY 79 effort of the LSOMT.

Monitoring

79. Large-scale (i.e., 1:5,000) color imagery proved to be the most reliable for mapping either the areal extent of Eurasian watermilfoil coverage in a water body or a representative topped-out colony. The smaller scales (i.e., 1:10,000 and 1:20,000) required more time for interpretation. Color and color infrared imagery performed equally well when used to detect painted underwater targets; however, performance of these two films at detecting these targets was influenced only by the transmittance of the green-to-red visible light range (0.5 to 0.7 μm) of the electromagnetic spectrum through the water. The recording

characteristics of color and color infrared film were, therefore, essentially identical. Differences in detection depth capabilities of color and color infrared film could be attributed to differences in site conditions at the times of overflight. In a prevention program such as this, however, remote-sensing data should be supplementary to those derived from ground surveys.

80. The determination of the MOD limits the area of interest of a water body to only that portion that is a potential habitat for Eurasian watermilfoil, assuming, of course, that Eurasian watermilfoil was already growing at its maximum depth. Biomass samples taken randomly within the MOD served to quantitatively characterize the populations of Eurasian watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish. Computation of biomass density values also proved to be an important means of quantifying the distribution of this aquatic macrophyte that grew throughout the water column.

Treatment

81. The most effective treatment method implemented in FY 79 was the fragment barrier constructed by NPS on the Okanogan River near Oroville, Wash. Although the FY 79 data indicated that a certain percentage of Eurasian watermilfoil fragments always escaped downstream, the barrier proved to be a means of retarding this downstream dispersal. The improved design resulted in a more efficient operation; however, determination of the degree of efficiency is no longer possible because no evaluation data were collected after FY 79.

82. The hand-pulling exercise demonstrated that manual removal of Eurasian watermilfoil plants was feasible on only a small scale. Such an exercise is limited by bottom conditions, water depth, size of the area treated, and time and fiscal constraints. This treatment method should be attempted only in small high-use areas (e.g., boat-launch areas) where the presence of Eurasian watermilfoil impacts on user interests and where the implementation of other treatment methods is infeasible.

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Table 1

Water Bodies Selected by NPS for Evaluation by WES as Candidate Test Sites

Water Body	Reconnaissance Priority	Operational Category*	Scientific Interest	Strategic Importance
Lake Washington (Union Bay)	1	III	X	
Wells Reservoir, Columbia River	2	I	X	
Lake Sammamish	3	III	X	
Okanogan River	4	I	X	X
Lake Osoyoos	5	I	X	X
Yakima River	6	I		
Lake Chelan	7	I	X	
Banks Lake	8	III		X
Sammamish River	9	II	X	X
Lake Whatcom	10	II	X	
Rufus Woods Lake (Chief Joseph Reservoir), Columbia River	11	I	X	
Snohomish River	12	I	X	
Billy Clapp Lake	13	II	X	

* The Roman numerals under the Operational Category column indicate whether the waterbodies were designated as Prevention (I), Maintenance (II), or Control (III), as defined in paragraph 9.

Table 2

Total Areal Coverage of Eurasian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish as Interpreted from Aerial Imagery

Test Site	Type of Imagery	Total Area acres
Lake Osoyoos (Secchi disk - 12 ft, lake bottom - sand	Scale 1:10,000	
	Black and white	36*
	Color	30*
	Color infrared	37*
Lake Whatcom (Secchi disk - 16 ft, lake bottom - silt)	Scale 1:10,000	
	Black and white	13
	Color	7
	Color infrared	4
Lake Sammamish (Secchi disk - 14 ft, lake bottom - sand)	Scale 1:5,000	
	Black and white	3
	Scale 1:10,000**	
	Color	11
	Color infrared	11

* Does not include Canada.
** No 1:10,000-scale black-and-white imagery was available for Lake Sammamish.

Table 3

Detection of Representative Topped-Out Colonies of Eurasian Watermilfoil in Lake Osoyoos, Lake Whatcom, and Lake Sammamish Using Various Scale-Imagery Combinations

Test Site	Area, acres: Black and White	Area, acres: Color	Area, acres: Color Infrared
Lake Osoyoos		Scale 1:5,000	
(Secchi disk - 12 ft, lake bottom - sand)	11.2	9.8	11.1
		Scale 1:10,000	
	10.8	11.5	11.0
		Scale 1:20,000	
	12.1	12.1	13.4
Lake Whatcom		Scale 1:5,000	
(Secchi disk - 16 ft, lake bottom - silt)	0.9	2.1	1.0
		Scale 1:10,000	
	0.8	1.1	0.8
		Scale 1:20,000	
	1.3	1.9	1.3
Lake Sammamish		Scale 1:5,000	
(Secchi disk - 14 ft, lake bottom - sand)	0.9	1.2	0.7
		Scale 1:10,000	
	*	1.3	0.8
		Scale 1:20,000	
	*	1.9	1.9

* Black-and-white imagery of Lake Sammamish at scales of 1:10,000 and 1:20,000 was not available.

Table 4

Detection of Underwater Target Panels and Blocks Using Various Scale-Imagery Combinations

Test Site	Imagery	Detection Limit (Water Depth), ft White Panel	White Block	Green Panel	Green Block
Lake Osoyoos (Secchi disk - 12 ft, lake bottom - sand)		Scale 1:5,000			
	Black and white	20	10	10	0
	Color	20	15	20	10
	Color infrared	20	10	20	15
		Scale 1:10,000			
	Black and white	15	10	5	5
	Color	20	10	5	5
	Color infrared	25	10	10	5
		Scale 1:20,000			
	Black and white	10	0	0	0
	Color	20	0	10	0
	Color infrared	20	15	15	15
Lake Whatcom (Secchi disk - 16 ft, lake bottom - silt)		Scale 1:5,000			
	Black and white	10	0	5	0
	Color	20	10	15	5
	Color infrared	15	15	10	5
		Scale 1:10,000			
	Black and white	10	0	0	0
	Color	15	10	10	10
	Color infrared	15	15	10	15

(Continued)

Table 4 (Concluded)

Test Site	Imagery	Detection Limit (Water Depth), ft: White Panel	White Block	Green Panel	Green Block
Lake Whatcom (continued)		Scale 1:20,000			
	Black and white	10	0	0	0
	Color	15	5	10	10
	Color infrared*				
Lake Sammamish (Secchi disk - 14 ft, lake bottom - sand)		Scale 1:5,000			
	Black and white	15	10	0	0
	Color	20	15	15	10
	Color infrared	15	15	15	15
		Scale 1:10,000			
	Black and white	10	10	0	0
	Color	10	10	5	10
	Color infrared	15	10	15	10
		Scale 1:20,000			
	Black and white**				
	Color	10	5	10	10
	Color infrared	15	10	15	5

* Obscured by glitter, no data.

** No 1:20,000-scale black-and-white imagery was available for Lake Sammamish.

Table 5

Average Detection Depths* for Lake Osoyoos, Lake Whatcom, and Lake Sammamish

Scale-Imagery Combination	Average Detection Depth, ft			
	White		Green	
	Panel	Block	Panel	Block
Scale 1:5,000				
Black and white	15.0	6.7	5.0	0
Color	20.0	13.3	16.7	8.3
Color infrared	16.7	13.3	15.0	11.7
Average	17.2	11.1	12.2	6.7
Scale 1:10,000				
Black and white	13.3	3.3	1.7	1.7
Color	15.0	10.0	6.7	8.3
Color infrared	18.3	11.7	11.7	10.0
Average	15.0	9.4	6.7	6.7
Scale 1:20,000**				
Black and white	10.0	0	0	0
Color	15.0	3.3	10.0	6.7
Color infrared	11.7	8.3	10.0	6.7
Average	11.1	4.4	7.5	5.0

* Based on data contained in Table 4.

** Black-and-white and color infrared values are averages for only two lakes due, respectively, to unavailability of data and obscuration by glitter.

Table 6

Wet Weight Biomass Values for Eurasian Watermilfoil in Lakes Osoyoos, Whatcom, and Sammamish

Test Site	Total No. of Samples Taken	No. of Samples Containing Eurasian Watermilfoil	No. of Samples Represented by Each Range of Biomass Values for Eurasian Watermilfoil psf (wet weight)		
			<0.01	0.01-<0.1	≥0.1
Lake Osoyoos	145	11	8	2	1
Lake Whatcom	146	12	11	1	
Lake Sammamish	96	31	15	8	8

Table 7

Wet Weight Biomass Density Values for Eurasian Watermilfoil in Lakes Osoyoos, Whatcom, and Sammamish

Test Site	Total No. of Samples Taken	No. of Samples Containing Eurasian Watermilfoil	No. of Samples Represented by Each Range of Biomass Density Values for Eurasian Watermilfoil pcf (wet weight)			
			<0.001	0.001-<0.01	0.01-<0.1	≥0.1
Lake Osoyoos	145	11	5	4	2	
Lake Whatcom	146	12	7	5		
Lake Sammamish	96	31	12	8	10	1

Table 8

Numbers of Stem Tips and Stem Tip Densities for Eurasian Watermilfoil in Lakes Osoyoos, Whatcom, and Sammamish

Test Site	Total No. of Samples Taken	No. of Samples Containing Eurasian Watermilfoil	No. of Eurasian Watermilfoil Samples Containing Stem Tips	No. of Stem Tips/ft^2		Stem Tip Density No./ft^3	
				Maximum	Minimum	Maximum	Minimum
Lake Osoyoos	145	11	6	11.5	0.7	3.8	0.2
Lake Whatcom	146	12	8	3.7	0.4	0.7	0.04
Lake Sammamish	96	31	31	98.1	0.4	25.3	0.01

Table 9

Results of Diver-Efficiency Surveys

Test Plot Location and No.	Percent Areal Coverage Eurasian Watermilfoil	Other Vegetation	No Vegetation
Lake Osoyoos			
Test Plot No. 1			
Control	Trace	0	100
Diver 1	Trace	0	100
Diver 2	Trace	0	100
Test Plot No. 2			
Control	30	20	50
Diver 1	30	10	60
Diver 2	30	10	60
Lake Whatcom			
Test Plot No. 1			
Control	25	25	50
Diver 1	45	35	20
Diver 2	5	15	80
Lake Sammamish			
Test Plot No. 1			
Control	20	40	40
Diver 1	10	10	80
Diver 2	25	25	50
Test Plot No. 2			
Control	20	40	40
Diver 1	45	45	10
Diver 2	20	10	70
Test Plot No. 3			
Control	30	20	50
Diver 1	65	35	0
Diver 2	25	0	75

Table 10

Mean Daily Discharge Values for the USGS Gaging Station at Oroville, Wash., Covering the Periods 29-31 July 1977, 1978, 1979; August and September 1977, 1978, 1979; and 1-20 October 1976, 1977, 1978*

	Discharge, cfs											
	July			August			September			October		
Day	77	78	79	77	78	79	77	78	79	76	77	78
1				121	320	201	279	505	325	754	554	555
2				129	320	201	277	505	329	748	544	555
3				135	311	201	281	515	357	736	528	550
4				133	311	197	284	525	395	670	517	550
5				136	320	201	283	530	405	556	507	555
6				153	306	197	297	540	430	568	496	555
7				155	246	197	300	580	430	568	496	560
8				174	212	201	295	625	425	574	496	560
9				198	212	201	291	625	430	574	491	571
10				218	216	209	294	625	420	580	486	576
11				226	203	225	290	636	425	580	481	638
12				221	203	225	285	646	415	586	465	675
13				219	212	225	298	625	415	586	465	696
14				218	216	221	313	620	415	580	460	711
15				277	224	225	303	610	410	574	450	701
16				308	250	221	305	570	405	574	440	784
17				292	264	221	305	545	405	574	435	859
18				283	273	221	315	540	400	568	430	821
19				273	292	225	323	525	366	568	435	800
20				270	311	246	332	520	325	568	435	794

(Continued)

* Source: USGS (Annual).

Table 10 (Concluded)

	Discharge, cfs											
	July			August			September			October		
Day	77	78	79	77	78	79	77	78	79	76	77	78
21				260	325	267	341	520	320			
22				254	335	267	356	520	320			
23				248	360	276	356	525	320			
24				262	453	203	373	530	325			
25				286	505	320	385	540	325			
26				293	505	320	389	550	325			
27				292	495	362	503	555	325			
28				286	510	381	575	560	325			
29	106	325	201	290	510	343	572	560	325			
30	110	325	209	290	505	325	558	565	325			
31	113	325	201	281	495	325	--	--	--			

Table 11

Vegetative Material Collected on Operational Barrier, Okanogan River, Oroville, Wash., 29 July-20 October 1979

Week No.	Week Period	No. of Days Sampled	No. of Samples Collected	Total Wet Weight of All Vegetative Material lb	Total Wet Weight of Eurasian Watermilfoil lb	Percent (by Wet Weight) Eurasian Watermilfoil
1	29 Jul-4 Aug	3	14	357	19	5.3
2	5-11 Aug	3	15	310	22	7.1
3	12-18 Aug	3	15	306	16	5.2
4	19-25 Aug	2	20	365	13	3.6
5	26 Aug-1 Sep	2	10	440	31	7.0
6	2-8 Sep	3	10	486	49	10.1
7	9-15 Sep	3	10	310	37	11.9
8	16-22 Sep	3	10	428	65	15.2
9	23-29 Sep	3	15	355	79	22.3
10	30 Sep-6 Oct	3	15	162	48	29.6
11	7-13 Oct	3	15	192	60	31.2
12	14-20 Oct	2	10	230	80	34.8

Table 12

Total Wet Weights (pounds) of Vegetative Material Collected on All Nets of Evaluation Barrier No. 1 (Upstream) Okanogan River, Oroville, Wash., 29 July-13 October 1979

Depth Range Sampled ft	Week Number*										
	1	2	3	4	5	6	7	8	9	10	11
0-1	10.66	8.49	9.66	4.71	4.52	18.58	10.92	16.71	12.37	8.34	9.45
>1-2	1.16	0.90	0.80	0.39	0.35	1.36	0.91	2.51	2.06	3.38	3.62
>2-3	0.37	0.29	0.36	0.18	0.22	0.72	0.54	1.47	1.07	1.18	1.39
>3-4	0.25	0.29	0.29	0.19	0.13	0.50	0.44	1.33	1.05	1.21	0.94
>4-5	0.19	0.15	0.15	0.08	0.09	0.26	0.36	0.98	0.50	1.03	0.63
>5-6	0.02	0.03	0.02	<0.01	0.01	0.05	0.03	0.02	0.04	0.04	<0.01
Total for entire cross section	12.65	10.15	11.28	5.55	5.32	21.47	13.20	23.02	17.09	15.18	16.03

* Weeks 1-11 are the same periods as those shown in Table 11.

Table 13

Total Wet Weights (pounds) of Vegetative Material Collected on All Nets of Evaluation Barrier No. 2 (Downstream) Okanogan River, Oroville, Wash., 29 July-13 October 1979

Depth Range Sampled ft	Week Number*										
	1	2	3	4	5	6	7	8	9	10	11
>0-1	0.55	0.40	0.46	0.37	0.31	4.67	3.73	4.20	3.38	0.95	1.69
>1-2	0.46	0.31	0.35	0.23	0.17	0.94	1.69	1.97	3.06	1.30	1.67
>2-3	0.61	0.36	0.29	0.16	0.11	0.58	1.34	1.74	1.53	1.13	1.35
>3-4	0.42	0.24	0.25	0.08	0.09	0.38	1.18	1.32	1.02	0.97	1.24
>4-5	0.41	0.28	0.31	0.11	0.06	0.19	1.51	1.19	0.56	1.05	0.52
>5-6	0.06	0.07	0.10	0.03	0.03	0.04	0.64	0.37	0.10	0.09	0.04
Total for entire cross section	2.51	1.66	1.76	0.98	0.77	6.80	10.09	10.79	9.65	5.49	6.51

* Weeks 1-11 are same periods as those shown in Table 11.

Table 14

Percent Effectiveness of the Barrier System, Okanogan River Oroville, Wash., 29 July-13 October 1979

Week No.*	Total Wet Weights of Vegetative Material Collected for Entire Okanogan River Cross Section, lb: No. 1 (Upstream)	No. 2 (Downstream)	Percent Effectiveness of Barrier System $\left(\frac{\text{Wet Wt No. 1} - \text{Wet Wt No. 2}}{\text{Wet Wt No. 1}}\right) \times 100$
1	12.65	2.51	80.2
2	10.15	1.66	83.6
3	11.28	1.76	84.4
4	5.55	0.98	82.3
5	5.32	0.74	86.1
6	21.47	6.80	68.3
7	13.20	10.09	23.6
8	23.02	10.79	53.1
9	17.09	9.65	43.5
10	15.18	5.49	63.8
11	16.03	6.51	59.4
	150.94	56.98	Average 66.2

* Weeks 1-11 are the same periods as those shown in Table 11.

Table 15

Eurasian Watermilfoil Hand-Pulling Exercise on the Okanogan River and Lake Osoyoos, Late Summer 1979

	Sample Site		
	No. 1 Okanogan River	No. 2 Okanogan River	No. 3 Lake Osoyoos
No. of field personnel involved	4	3	2
Man-hours required			
Setup	1.5	2.0	1.5
Dismantling	1.0	0.8	0.5
Hand-pulling	7.3	3.5	3.5
Total	9.8	6.3	5.5
Estimated percent success (areal) at removal of Eurasian watermilfoil from colonies			
Eurasian watermilfoil dominant	95	90	95
Other species dominant	40	80	90
Estimated percent success (areal) at root removal	35	50	90
Total wet weight of Eurasian watermilfoil pulled, lb	17.49	45.86	13.21

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During FY 79, the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss., completed the first phase of its 3-year Large-Scale Operations Management Test (LSOMT). The LSOMT was designed to develop an operational plan to identify methodologies that can be implemented by the U. S. Army Engineer District, Seattle (NPS), to prevent the exotic aquatic macrophyte Eurasian watermilfoil (*Myrophyllum spicatum* L.) from reaching

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