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AERIAL SURVEY TECHNIQUES TO MAP AND MONITOR AQUATIC PLANT POPULATIONS—FOUR CASE STUDIES

by

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

During the period from 1977 through 1981, the U. S. Army Engineer Waterways Experiment Station conducted a number of aerial survey studies in conjunction with the U. S. Army Corps of Engineers Aquatic Plant Control Research Program. These studies generally involved the use of aerial surveys to map and monitor the areal extent of aquatic macrophyte populations. Unique photointerpretation and mapping procedures and computer software for processing mapped data were developed in conjunction with these efforts. (Continued)

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20. ABSTRACT (Continued).

This report contains four of the more comprehensive case studies, as follows:

- a. Lewis Creek Reservoir, Texas. Comparison of automated and manual techniques to compute areal coverage of hydrilla (*Hydrilla verticillata*) (L.f.) Royle) on two scales of aerial photography.
- b. Lake Seminole, Alabama-Florida-Georgia. Comparison of boat and aerial surveys of giant cutgrass (*Zizaniopsis miliacea* (Michx.) Doell and Asch.).
- c. Gatun Lake, Panama. Study of hydrilla growth in a tropical environment.
- d. Lake Osoyoos, Washington. Monitoring of changes in a community dominated by Eurasian watermilfoil (*Myriophyllum spicatum* L.) during a 1-year period.

Each case study, treated independently, documents, compares, and evaluates aerial survey procedures, photointerpretation and mapping techniques, and any automated or manual methods of processing data on areal coverages of aquatic plant populations used in conjunction with the case study.

Based on the simultaneous consideration of studies in this report, the following general conclusions can be drawn:

- a. Aerial surveys are an accurate means of mapping submerged and emergent aquatic plant populations.
- b. Of the two growth forms of aquatic plants covered by the four case studies, submerged and emergent, submerged plants were more difficult to detect on aerial imagery.
- c. The four case histories provided examples of the use of three scales/ranges of nominal scale of aerial photography (1:5,000 to 1:6,000; 1:10,000 to 1:12,000; and 1:24,000) to detect and map the distribution of submerged aquatic plant populations. Maps produced from the nominal scale imagery of 1:10,000 to 1:12,000 were generally as accurate as those produced from the nominal scale imagery of 1:5,000 to 1:6,000. Photointerpretation of the 1:24,000-scale imagery was more difficult than either of the two larger scale ranges.
- d. Regardless of scale, populations of submerged plants were easier to detect on color than on color infrared imagery.

PREFACE

During the period from 1977 through 1981, personnel of the Environmental Assessment Group (EAG), Environmental Resources Division (ERD), Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES), conducted a number of studies involving the use of aerial surveys to map and monitor aquatic macrophyte populations. As a result of these efforts, the EAG has developed and made quantitative comparisons of unique photointerpretation and mapping procedures and has designed and written computer software to process mapped data on aquatic plant distributions. However, most of the procedures, computer software, and resulting end products remain undocumented except in limited form (e.g., published as parts of larger studies or in conference papers).

This report contains four of the more comprehensive aquatic plant case studies documenting the results of research using aerial imagery to detect and map the areal extent of populations of various problem macrophyte species in Lewis Creek Reservoir, Texas; Lake Seminole, Alabama-Florida-Georgia; Gatun Lake, Panama; and Lake Osoyoos, Washington. These case studies provide critical evaluation of aerial survey techniques used for mapping and monitoring submerged and emergent aquatic plant populations. Funds for the studies described herein were provided to the WES Aquatic Plant Control Research Program (APCRP) by the Civil Works Directorate, Office, Chief of Engineers, Washington, D. C., under Department of the Army Appropriation No. 96X3122, Construction General.

Mr. E. A. Dardeau, Jr., EAG, directed the analysis of the data and documentation of the case studies. Mr. J. H. Meeks, EAG, photointerpreted the imagery and mapped the various aquatic plant populations. Dr. V. E. LaGarde and Mr. R. A. Goodson, both of the EAG, developed automated procedures and wrote computer software for handling mapped data. Mr. Meeks and Ms. E. M. Causey, EAG, made manual determinations of area and verified the automated procedures. Mr. R. M. Russell, Jr., EAG, prepared the figures. Other persons making

significant contributions to this work included Messrs. K. J. Killgore, Jr., and J. M. Leonard, and Dr. B. S. Payne, all of the EAG, and Mr. S. D. Parris of the Resource Analysis Group, ERD. Dr. LaGarde and Dr. L. E. Link, Jr., Chief Environmental Constraints Group, Environmental Systems Division, EL, provided technical review. Mr. Dardeau prepared this report.

All phases of the four case studies were conducted under the direct supervision of Mr. J. K. Stoll, Chief, EAG, and under the general supervision of Dr. C. J. Kirby, Jr., Chief, ERD, and Dr. John Harrison, Chief, EL. Manager of the APCRP at the WES was Mr. J. L. Decell.

Commanders and Directors of the WES during the research and preparation of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

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
acre-feet	1233.489	cubic metres
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.609347	kilometres
square inches	6.4516	square centimetres

AERIAL SURVEY TECHNIQUES TO MAP AND MONITOR AQUATIC PLANT POPULATIONS--FOUR CASE STUDIES

INTRODUCTION

1. Mapping locations of problem aquatic plant species* and monitoring changes in populations of these species are essential to the successful planning and implementation of all phases of an aquatic plant management program (e.g., treatment operations). Aerial survey techniques, coupled with a limited amount of ground surveying, can be used to accomplish these objectives, especially where large populations are involved or where the problem plants impinge severely on the public or provate uses of a water body. Aerial surveying has proved to be an accurate and effective planning tool that becomes more efficient as the size of the problem population increases. Several remote-sensing procedures designed to study aquatic plant populations and to monitor and map changes in the distributions of these populations have been developed and are documented in the literature (e.g., Leonard 1983; Link and Long 1978; and Long 1979). The U. S. Army Engineer Waterways Experiment Station (WES) has conducted a number of studies involving the application of aerial survey techniques to aquatic plant research and management. Table 1 gives a sequential listing and pertinent data on all missions flown from 1977 through 1981 in conjunction with aquatic plant studies conducted by the WES Environmental Assessment Group (EAG).

2. In the course of conducting aquatic plant aerial surveys, the EAG developed and made quantitative comparisons of unique procedures for detecting and determining the areal extent of populations of aquatic macrophyte species at geographically and ecologically

* Native and exotic aquatic plants that adversely impact on many user interests, including navigation, water supply, etc., are referred to as problem species (Dardeau and Hogg 1983). The study by Dardeau and Hogg (1983) provides a listing of important problem aquatic plant species.

diverse water bodies. Along with the listing in Table 1, pertinent data include streams, natural lakes, and reservoirs. Some general inferences can be made about the unit area cost of flying photomissions and processing the resulting film:*

a. Generally decreases for smaller scale imagery and for larger area water bodies.

b. Usually more expensive for a stream than for that of an equal size lake or reservoir. A relatively large proportion of the imagery covering a stream is devoted to areas landward of top bank.

c. Generally reduced if a photomission can cover more than a single water body.

3. The EAG has also written computer software to process the mapped data on aquatic plant distributions prepared from aerial surveying products. However, most of the procedures, computer software, and any resulting end products or conclusions remain largely undocumented except in limited form (e.g., published as parts of larger studies or in conference papers). Four case studies involving the most significant of these undocumented procedures were selected for publication to make this information available to Corps of Engineers (CE) Districts involved in aquatic plant management programs. The four case studies are:

Case Study No.	Location	Description of Activity
1	Lewis Creek Reservoir, Texas	Compare automated and manual techniques used to determine areal coverage of hydrilla (*Hydrilla verticillata*) (L.f.) Royle) on two scales of aerial photography
2	Lake Seminole, Alabama-Florida-Georgia	Compare boat and aerial surveys of giant cutgrass (*Zizaniopsis miliacea* (Michx.) Doell and Asch.)

(Continued)

* For more general guidelines on cost see American Society of Photogrammetry (1975) and Headquarters, Department of the Army (1979).

Case Study No.	Location	Description of Activity
3	Gatun Lake, Panama	Study hydrilla growth in a tropical environment
4	Lake Osoyoos, Washington	Monitor changes in a community dominated by Eurasian watermilfoil (*Myriophyllum spicatum* L.) during a 1-year period

4. Each case study, treated independently, documents, compares, and evaluates aerial surveying procedures, photointerpretation and mapping techniques, and any automated or manual methods of processing data on areal coverage of aquatic plant populations used in conjunction with the case study.

CASE STUDY 1: COMPARISON OF AUTOMATED AND MANUAL TECHNIQUES TO COMPUTE AREAL COVERAGE OF HYDRILLA ON TWO SCALES OF AERIAL PHOTOGRAPHY FOR LEWIS CREEK RESERVOIR, TEXAS

Background

5. In April 1980, the U. S. Army Engineer District, Galveston (SWG), requested assistance in developing a problem identification and assessment plan for aquatic plant management of water bodies in the state of Texas. The WES and SWG selected Lewis Creek Reservoir as a pilot study area from among Texas water bodies having problem-level populations of aquatic macrophyte species for the following reasons:

- a. Small surface area.
- b. High water clarity.
- c. Dense coverage of hydrilla, an exotic Asian macrophyte.
- d. Higher-than-normal water temperatures (influenced by power plant operation).

6. Lewis Creek Reservoir, located 11 miles* north-northwest of Conroe, Tex., is an impoundment on Lewis Creek, a left-bank tributary of the West Fork San Jacinto River (Figure 1). Reservoir water serves as coolant for the Lewis Creek Power Plant of Gulf States Utilities Surface area of the reservoir varies seasonally and diurnally (with power plant demand); however, the average approximate water surface area at normal pool elevation (267 ft**) is 1000 acres. Parris (1981) stated that there is a 30-percent reduction in standing crop of the hydrilla population of the Lewis Creek Reservoir during late summer of each year. This unusually high reduction coincides with a noticeable drop in the pH of the water in the reservoir (Parris 1981).

Objectives and Approach

7. Objectives of this case study were to map and then to compare

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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.

** Referenced to mean sea level.

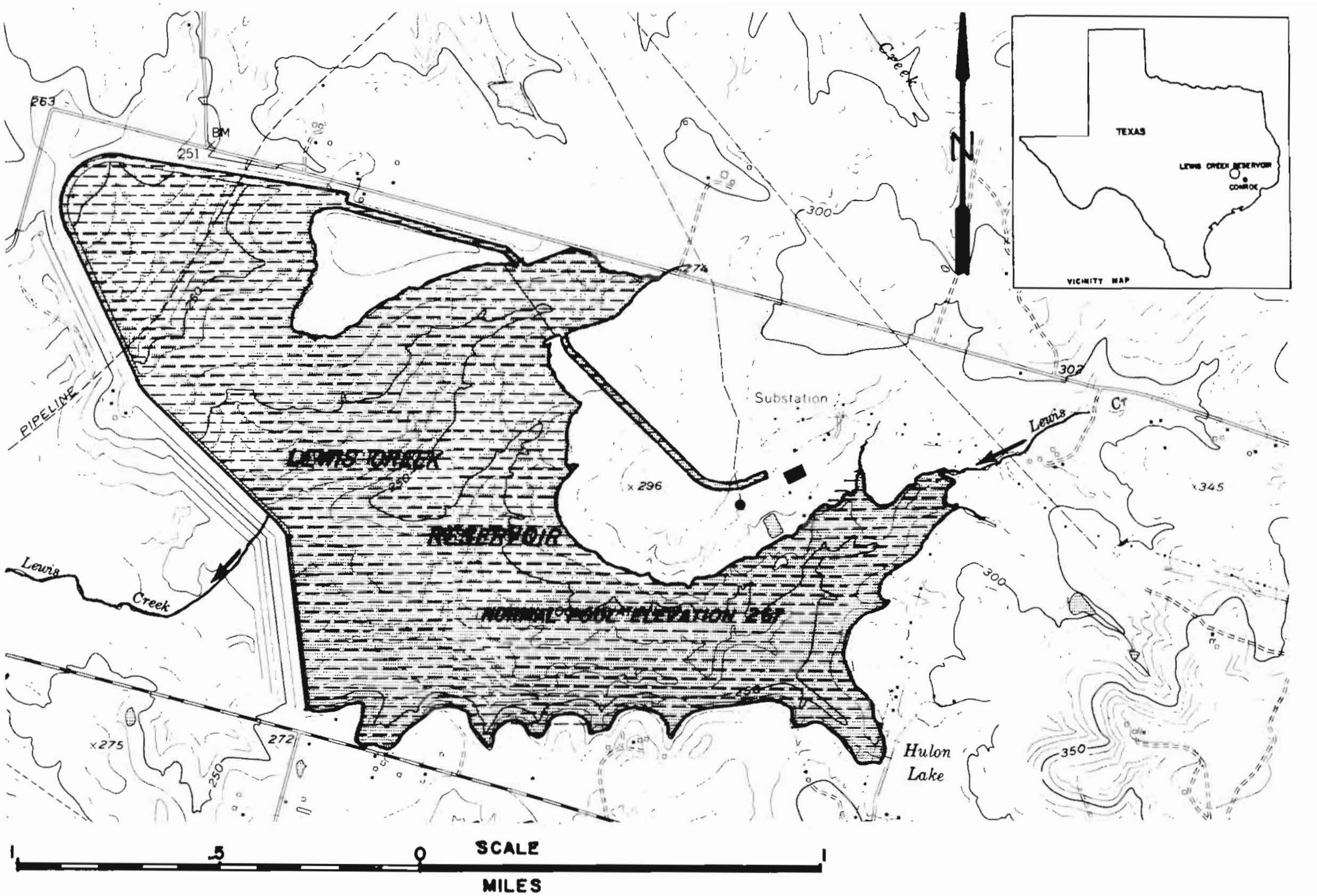

Figure 1. Lewis Creek Reservoir, Texas (adapted from U. S. Geological Survey (USGS) 1:24,000-scale topographic quadrangle for Shepard Hill, Texas, 1958 (photo-revised 1976))

the results of three techniques of determining areal coverage of hydrilla in Lewis Creek Reservoir using two scales of aerial imagery. Automated rectified, automated unrectified, and manual techniques were used with imagery flown at nominal scales of 1:6,000 and 1:12,000.

8. Two aerial photographic missions were flown over Lewis Creek Reservoir in October 1980 to obtain true color imagery at scales as close as possible to that of the specified nominal scales of 1:6,000 and 1:12,000. The contractor used Kodak Aerochrome 2448 MS film with Kodak HF-3 and HF-4 Wratten filters (Table 1). Total and unit area costs (in 1980 dollars) of flying the two photomissions and processing the film were as follows:

Nominal Scale	Cost, 1980 Dollars Total	per acre
1:6,000	$748.25	$0.75
1:12,000	505.05	0.51

Determination of Areal Coverage of Hydrilla

9. A skilled photointerpreter, unfamiliar with Lewis Creek Reservoir, mapped the areal coverage of hydrilla in the reservoir on transparent overlays of each of the two scales of photography. Boundaries of the population of this species were delineated based on tonal and textural expression. The interpreter then selected 14 common control (registration) points at easily identifiable locations around the reservoir and marked these control points on both scales of the imagery and on the 1:24,000-scale USGS topographic base map for the Shepard Hill, Texas, Quadrangle, prepared in 1958 (photo-revised 1976). Figures 2 and 3 show the areal distribution of hydrilla mapped by the photointerpreter on the transparent overlays of the nominal 1:6,000- and 1:12,000-scale imagery, respectively. These figures also indicate the location of control (registration) points.

10. As stated previously, the purpose of the study was to compare the results of three methods used to compute areal coverage of hydrilla:

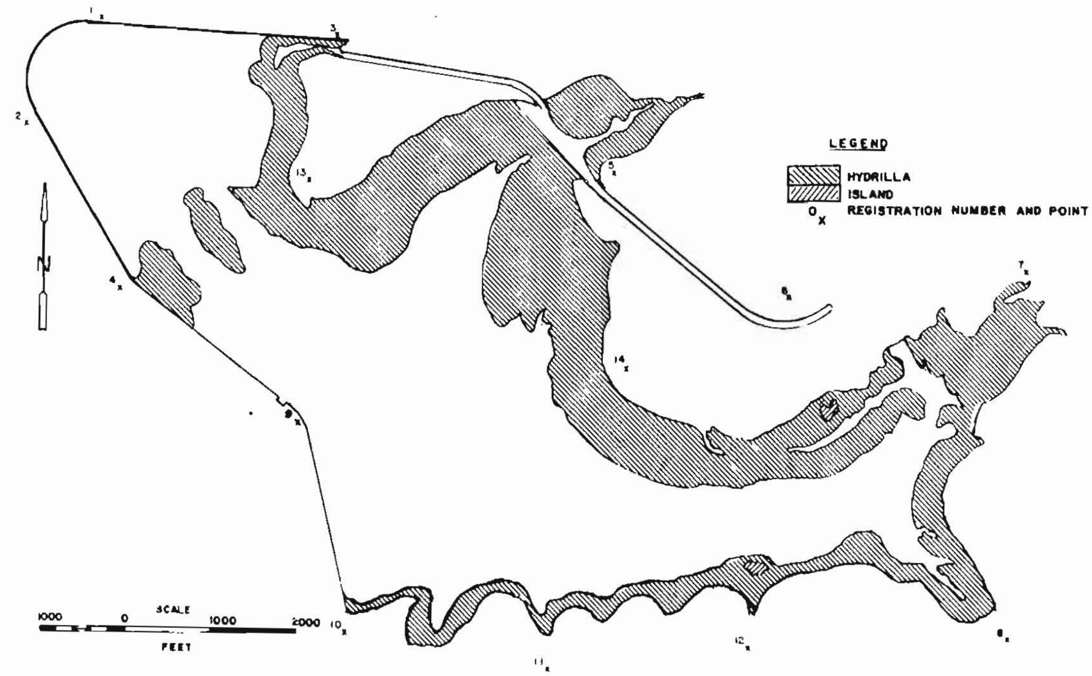

Figure 2. Areal coverage of hydrilla and locations of control (registration) points, Lewis Creek Reservoir, Texas, as mapped on overlays of the 1:6000-scale (nominal) color imagery

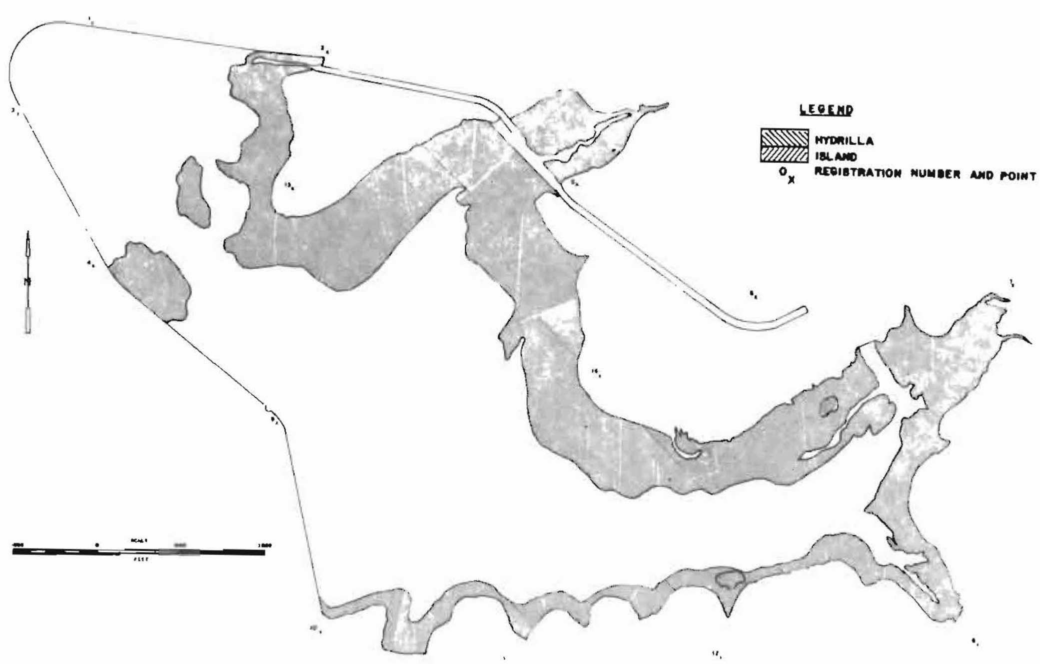

Figure 3. Areal coverage of hydrilla and locations of control (registration) points, Lewis Creek Reservoir, Texas, as mapped on overlays of the 1:12,000-scale (nominal) color imagery

automated rectified, automated unrectified, and manual. The three methods and the area values obtained for the two scales of photography are discussed in the following paragraphs and summarized in Table 2.*

Automated rectified method

11. Boundaries of the hydrilla population mapped on the transparent overlays and the control points on the two scales of imagery and on the base map were recorded automatically on magnetic tape using a digitizer (or line follower). The control points served as a means of establishing true scales and rectifying any inherent distortion in the imagery. The computer program TRANDIG read these control points, made the necessary distortion corrections, and then computed the following true scales (using a weighting technique):

Scale	
Nominal	True
1:6,000	1:6,066
1:12,000	1:12,157

Computer program AREA then read the output of TRANDIG and computed areal coverage of hydrilla (based on the rectification) as follows:

Scale	Areal Coverage of Hydrilla acres
1:6,066	350
1:12,157	334

Automated unrectified method

12. The unrectified digitizer output was used in lieu of the rectified output of TRANDIG as input to the computer program AREA. The true scales of 1:6,066 and 1:12,157 were used so that the comparisons would be on the same basis. Results were as follows:

Scale	Areal Coverage of Hydrilla acres
1:6,066	369
1:12,157	346

* Adapted from Parris, Leonard, and Payne (1981).

Manual method

13. A photointerpreter determined the areal coverage of hydrilla manually using a dot-count technique with a Bruning Areagraph Chart No. 4849, which yields 97-percent accuracy (provided that map areas are 12 $in.^2$ or more). The interpreter made dot counts of areas mapped as hydrilla on transparent overlays reproduced in Figures 2 and 3 and then converted the dot counts to acreages using the following equation:

$$A = \text{Number of dots (SF)} \quad (1)$$

where

A = areal coverage of hydrilla, acres

SF = scale factor (i.e., acreage value of one dot)
for 1:6,066 = 0.058662
1:12,157 = 0.235614

The following values were obtained manually for the two scales:

Scale	Areal Coverage of Hydrilla acres
1:6,066	351
1:12,157	350

Comparison of Methods

14. The various steps involved in determining areal coverage of hydrilla in Lewis Creek Reservoir by the three methods are shown in Figure 4, and the results presented in the discussions of the three methods are summarized in Table 2. The manual method using the 1:12,157-scale photography was the least expensive method used to compute areal coverage of hydrilla in Lewis Creek Reservoir, and it yielded an area essentially the same as the most costly method (i.e., automated rectified using the 1:6,066-scale photography).

15. The following are possible reasons for differences in area values determined by all method-scale combinations:

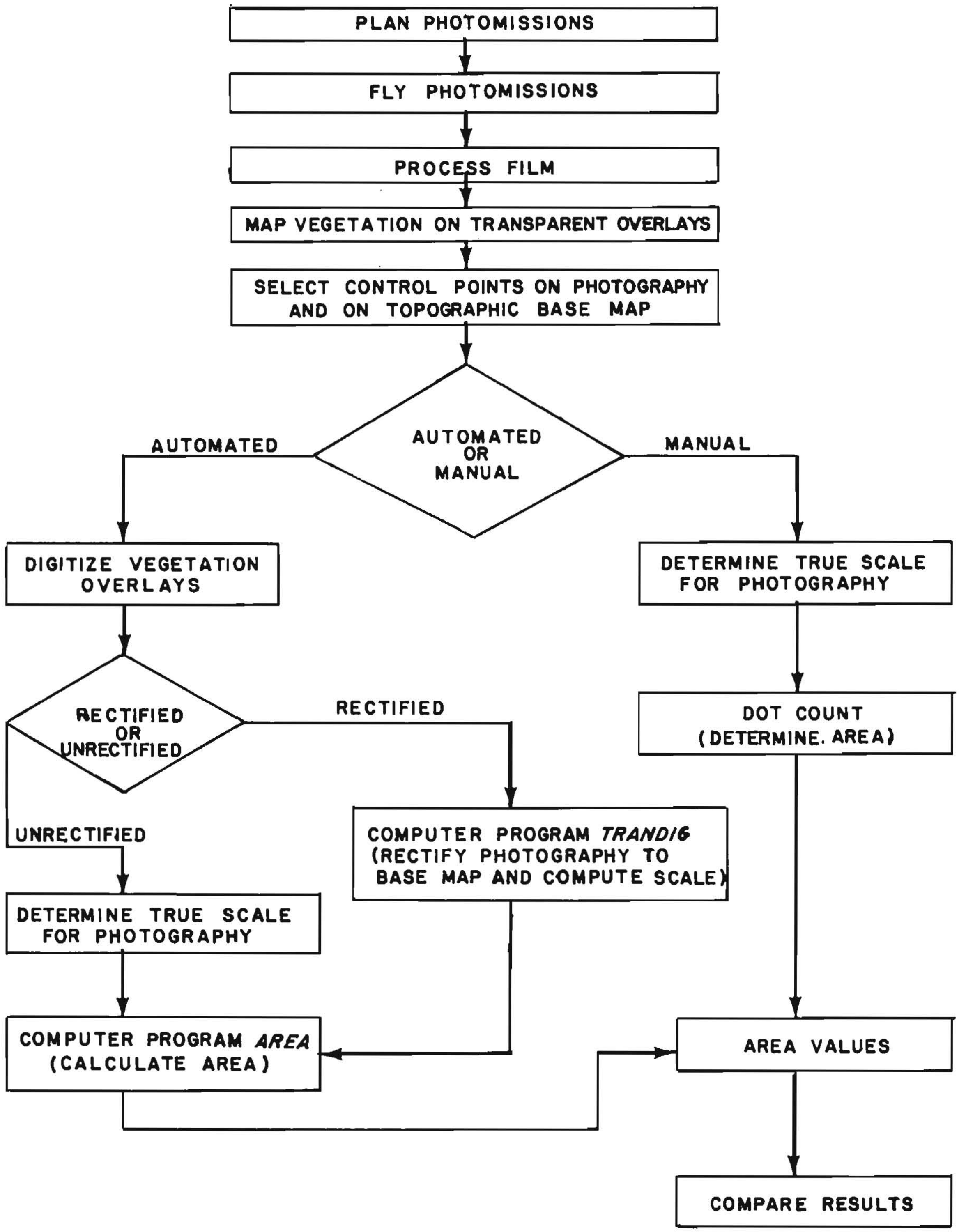

Figure 4. Flowchart of automated rectified, automated unrectified, and manual techniques used to determine areal coverage of hydrilla in Lewis Creek Reservoir, Texas

a. Resolution differences in the two scales of photography. Assuming that flight conditions, processing, and image quality are equal, there is usually better resolution on larger scale imagery. End products can be slightly different based on this fact alone.

b. Digitizing techniques. Differences in digitizing plant population boundaries and control points on the overlays for the two scales of photography can result in differences in area.

c. Rectification and computation techniques. Idiosyncrasies of the computer software used to rectify distortion on the imagery and to compute area (e.g., weighting methods) can account for slight differences in area.

d. Dot-count techniques and artifacts of the dot-count method. Errors in counting the dots or computing the area are also possible. At the scale of 1:6,066, one dot approximately equals 0.06 acre, while at the scale of 1:12,157, one dot approximately equals 0.24 acre. Any counting errors made at the smaller scale would, therefore, carry quadruple weight when compared with the larger scale. The size of some colonies on the imagery was less than the 12-in.^{2} minimum area requirement for 97-percent accuracy. Additionally, any errors made at the smaller scale could have cancelled each other out rather than being cumulative.

16. If either (or both) water body size or imagery scale increase, then cost will rise. Mapping Lewis Creek Reservoir manually was the most economic method because of the small size of the reservoir (1000 acres). The difference in cost between automated rectified and automated unrectified was negligible. The difference in cost of flying and processing imagery from the larger scale mission as compared with the same costs of the smaller scale mission (i.e., $748.25 versus $505.05) is not justifiable based on the results of this study.

CASE STUDY 2: COMPARISON OF BOAT AND AERIAL SURVEYS OF GIANT CUTGRASS IN LAKE SEMINOLE, ALABAMA-FLORIDA-GEORGIA*

Background

17. Lake Seminole is a 37,500-acre reservoir,** located on the common border of Alabama, Florida, and Georgia (Figure 5). The lake was formed by the closure of Jim Woodruff Dam on the Apalachicola River downstream from the confluence of the Flint and Chattahoochee Rivers. The U. S. Army Engineer District, Mobile (SAM), operates this reservoir for navigation, power generation, and recreation purposes. Heavy silt and nutrient inflow from the Flint River, the Chattahoochee River, Spring Creek, and Fish Pond Drain couple with the leachate from inundated limestone sinks to create an ideal habitat for numerous aquatic plants, including giant cutgrass, which has become a major problem along the 250-mile-long shoreline of the lake.

18. In the summer of 1979, SAM mapped the populations of giant cutgrass and other aquatic plants by means of a boat survey for the following reasons:

- a. To plan treatment operations.
- b. To establish baseline information so that plant populations could be monitored periodically following treatment.

In the fall of 1979, at the request of SAM, the WES scheduled a photomission to map the areal extent of giant cutgrass in Lake Seminole.

Objectives

19. Objectives of this study were to describe and identify the advantages and limitations of the boat and aerial surveys of giant cutgrass in Lake Seminole and to make a cost comparison of these two surveying techniques.

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* Principal source of the material used to prepare this case study was Leonard (1981).

** At normal pool elevation of 77 ft referenced to mean sea level.

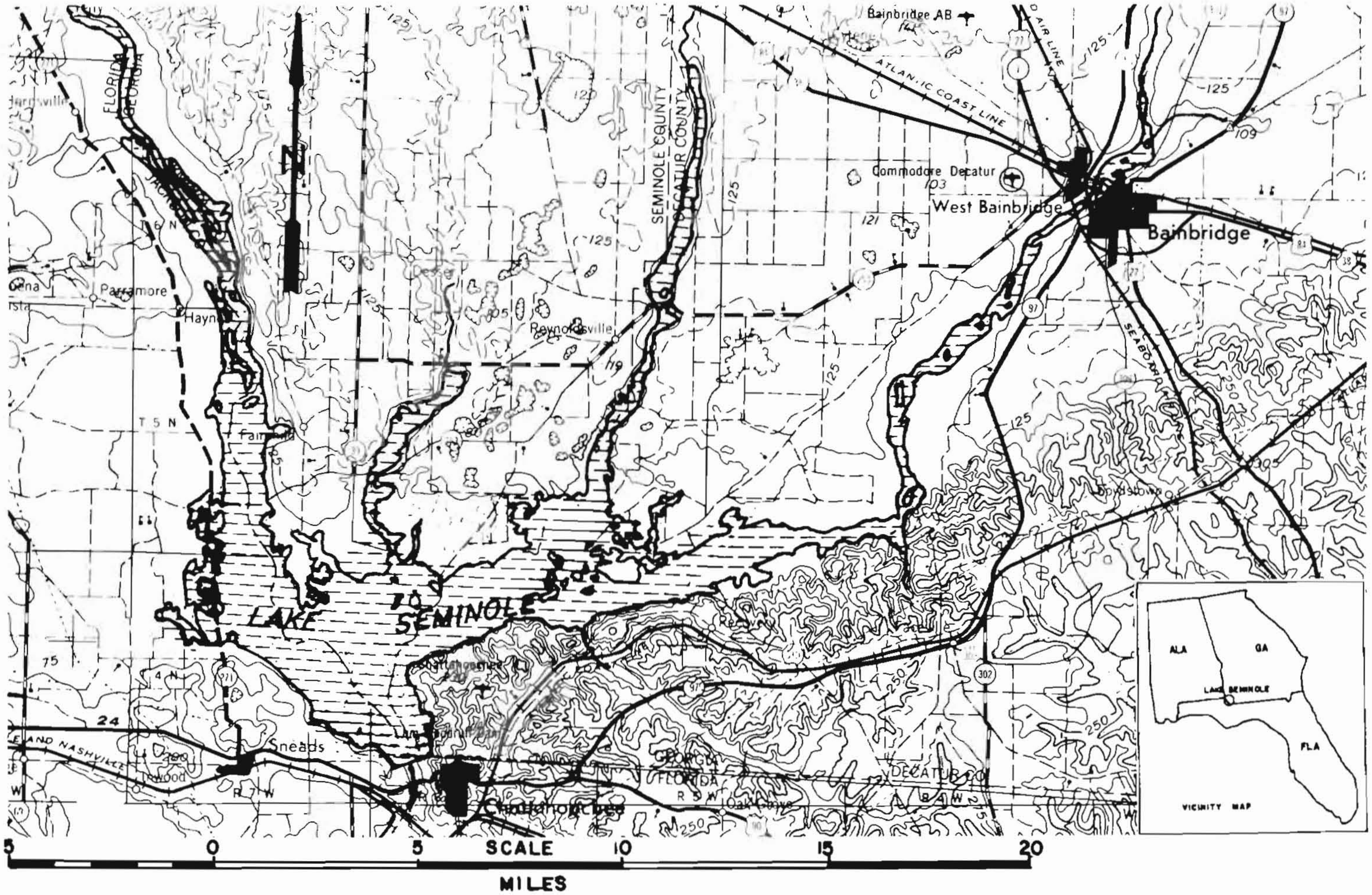

Figure 5. Lake Seminole, Alabama-Florida-Georgia (adapted from USGS 1:250,000-scale topographic quadrangle for Tallahassee, Florida-Georgia-Alabama, 1954 (limited revision 1976))

Surveys of the Giant Cutgrass Population

20. The boat and aerial surveys served as two means of determining the giant cutgrass population at Lake Seminole. Each method is described below.

Boat survey

21. A boat operator and a trained biologist from the Lake Seminole Resource Manager's Office performed a boat survey of the giant cutgrass population of this reservoir over a period of 25 working days (i.e., 50 man-days). The survey team marked the distribution of this aquatic species on a 1979 1:24,000-scale, black-and-white, semicontrolled photomosaic. The SAM performed this survey to obtain data to use in estimating the quantity of herbicide needed for management operations. Exact positions and areal extent of giant cutgrass colonies were, therefore, not considered essential. Along many reaches of the reservoir shoreline where the width of giant cutgrass band extended less than 10 ft from the shore, the team estimated the bandwidth as 10 ft to accommodate the minimum swath-width constraint of the selected applicator method. The end product of the boat survey was a map displaying approximate distribution of those colonies of giant cutgrass and adjacent areas along the reservoir shoreline that required treatment.

22. Office personnel of the Resource Manager's Office used a polar planimeter to determine the area of the reservoir requiring treatment based on the boat-survey map. Area value determined by this technique was 5500 acres; however, this value was inflated because it included both giant cutgrass colonies and the areas adjacent to these colonies that would be treated by selected application.

Aerial survey

23. The aerial survey of the giant cutgrass population in Lake Seminole included:

- *a*. Establishing ground control.
- *b*. Flying the photomission.
- *c*. Photointerpreting the aerial imagery to map distribution of giant cutgrass.

d. Visually verifying and adjusting the photointerpreted map from fixed-wing aircraft.

The WES worked cooperatively with SAM and the Lake Seminole Resource Manager's Office to accomplish these objectives.

24. Ground control. A WES field team selected three ground-control sites based on the presence of typical giant cutgrass colonies that were easily visible from the air and were accessible by boat. At each control site, field personnel positioned three reference markers (constructed by crossing two 3- by 10-ft strips of fluorescent pink plastic fabric, as shown in Figure 6, to form the vertices of a triangle). Wooden poles supported the markers at or above the water surface. The field team anchored a small boat at a point equidistant from each marker. One person in waders positioned a range pole at successive locations around the perimeters of the adjacent colonies of giant cutgrass, while personnel in the anchored boat read and recorded distances with a range finder (±10-ft accuracy) and azimuths with a Brunton compass (±5° accuracy) to define the areal extent of the giant cutgrass. Fieldwork was completed on 22 October 1979.

25. Photomission. The contractor completed the photomission on 29 October 1979 using Kodak Aerochrome 2448 MS film in combination with Kodak HF-3 and HF-4 Wratten filters at the nominal scale of 1:24,000 (Table 1). Mission cost was $7000 or $0.19/acre (1979 dollars). Products of the photomission were one roll of 9- by 9-in. color positive transparencies, one uncontrolled black-and-white index, and one set of color prints.

26. Photointerpretation. A skilled WES interpreter, unfamiliar with Lake Seminole, first located all three sets of reference markers (Figure 7) and the nearby surveyed colonies of giant cutgrass. These colonies were then used as training sites to map the areal distribution of giant cutgrass in the remainder of this reservoir. The base map was a 1979 1:24,000-scale, black-and-white, semicontrolled photomosaic (same as used for the boat survey) supplied by SAM. The interpreter traced the outline of the lake shoreline and islands onto a transparent overlay; placed color positive transparencies under the base map overlay;

Figure 6. Field team placing reference markers to establish ground control on Lake Seminole

Figure 7. Reference markers used on Lake Seminole (circled) visible on 1979 color imagery

interpreted boundaries of giant cutgrass colonies; and added the information to the base map overlay. A Bruning Areagraph Chart No. 4849, a dot-count technique, and Equation 1 were then used to measure area mapped as giant cutgrass. The scale factor used in Equation 1 for the 1:24,000-scale imagery was 0.918270,* and the area occupied by giant cutgrass as determined by the dot-count method was 2340 acres.

27. Visual verification and adjustment. Personnel from WES verified the accuracy of the photointerpreted map by making visual observations of the giant cutgrass distribution in Lake Seminole from a fixed-wing aircraft at an altitude of 500 ft. Adjustments to the boundaries of the giant cutgrass colonies resulting from this verification increased the mapped areal coverage by 11.2 percent to 2603 acres. Figure 8 is a map showing giant cutgrass distribution in Lake Seminole as mapped by the aerial survey.

Comparison of results

28. Because the objectives of the boat and aerial surveys were different, a comparison of the values for areal coverage determined by these two surveys would not be valid. The boat survey method yielded an estimate of area requiring treatment (5500 acres), while the adjusted aerial survey provided a measurement of surface area occupied by giant cutgrass (2603 acres). However, some comparisons that can be made between the two methods include identification of advantages and limitations of both types of surveys and cost comparison.

29. Advantages and limitations. In many respects, boat and aerial surveys of aquatic plant populations complement each other, as the study at Lake Seminole demonstrates. Dardeau and Lazor (1982) pointed out that both of these types of monitoring efforts are essential to an effective aquatic plant management program. The field personnel of the Resource Manager's Office used aerial imagery on which to map the areas of giant cutgrass requiring treatment, while WES personnel

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* Based on a series of measurements with a set of common control points on both the photography and the topographic map coverage of the reservoir, the 1:24,000 nominal scale was also determined to be the true scale of the photography.

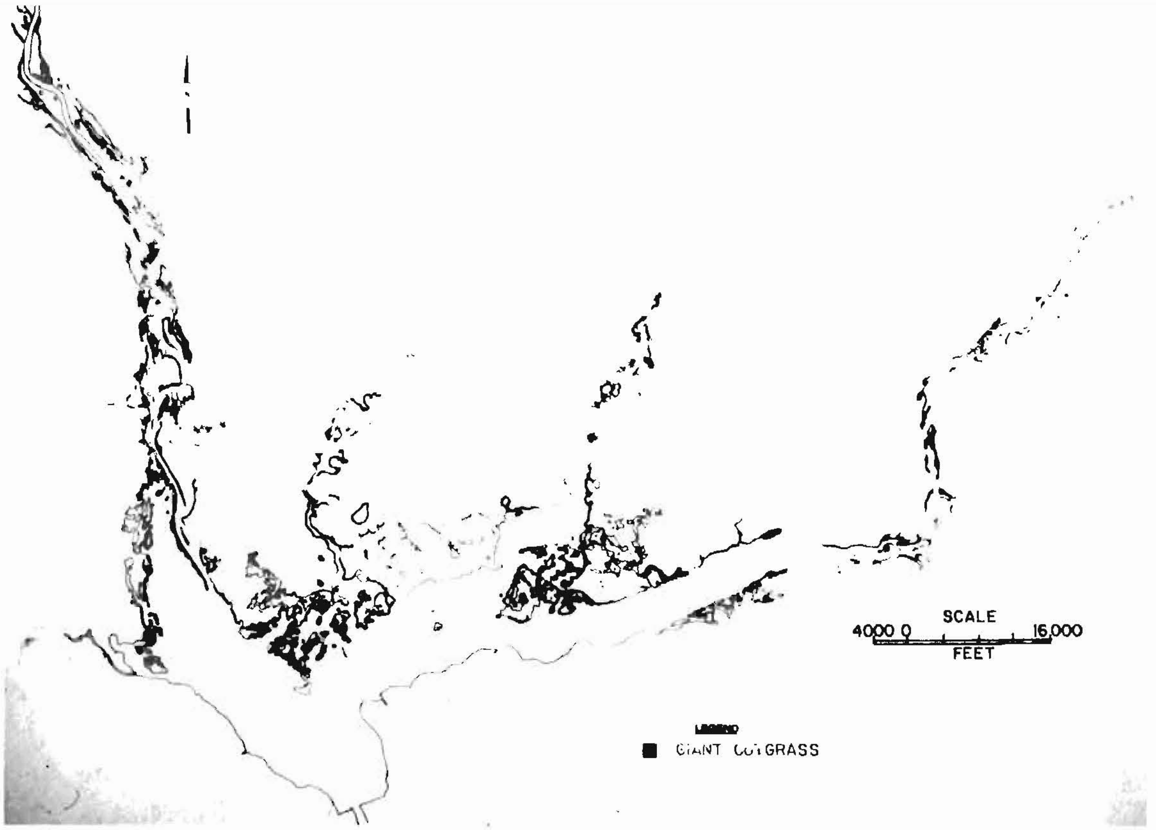

Figure 8. Distribution of giant cutgrass in Lake Seminole as mapped on 1979 color imagery

responsible for the aerial survey found establishing ground-control sites necessary for mapping the distribution of giant cutgrass. Both surveys required a base map to document population trends. There are, however, unique advantages and limitations of each type of survey, as shown in Table 3.

30. As Table 3 shows, a boat survey can be performed by in-house personnel, who also can accomplish other management objectives (e.g., water quality monitoring). Aerial surveys provide a rapid means of data acquisition and update and a permanent photographic record that can later be used to verify mapping procedures, map other species, or chart population trends. Boat surveys of Lake Seminole require 50 man-days and personnel who are skilled in field identification of giant cutgrass. Photomissions for aerial surveys must be contracted, and even when a skilled photointerpreter maps the distribution of giant cutgrass on the

resulting imagery, smaller colonies of this species cannot be detected.

31. Cost. Perhaps the most effective kind of comparison that can be made of the two methods used to survey the giant cutgrass population at Lake Seminole is that of cost. Table 4 shows the estimated costs (in 1979 dollars) of these two types of surveys, using the labor cost of a GS-12 biologist and a GS-07 technician. The comparison assumes that all phases of both surveys, with the exception of the 1:24,000-scale color photomission, which must be contracted, can be performed by the staff of the Resource Manager's Office. Cost of the photomission ($6000) is based on one set of color positive transparencies and a black-and-white uncontrolled photoindex, but does not include an extra set of color prints. Estimated unit costs (in 1979 dollars) are $0.27/acre for the boat survey and $0.21/acre for the aerial survey. Larger scale color photomissions would be costlier to fly and interpret.

32. Management personnel must decide whether a boat or aerial survey will best accomplish project objectives. Each type of survey has its advantages and limitations (Table 3). Aerial surveys, however, are much more economical for large water bodies. If there are economic constraints, then certain expenditures of either survey could be reduced, often with only a slight loss in accuracy. For example, a boat survey of a single aquatic plant species as easily identifiable as giant cutgrass could probably be performed by technicians rather than by professional personnel. The cost of an aerial survey could be reduced by not ordering a photoindex; however, mapping without an index is more difficult.

CASE STUDY 3: STUDY OF HYDRILLA GROWTH IN THE TROPICAL ENVIRONMENT OF GATUN LAKE, PANAMA

Background

33. The Panama Canal Commission (PCC), formerly the Panama Canal Company, is responsibile for maintaining navigation on the Panama Canal, a 50-mile-long intraocean waterway that was completed in 1914 across the Isthmus of Panama. Part of the canal project involved the construction of Gatun Dam on the Rio Chagres, approximately 7.3 miles upstream from its mouth on the Caribbean Sea. Gatun Dam impounds Gatun Lake, a 110,000-acre reservoir that has a capacity of 4,400,000 acre-ft* (Figure 9). Gatun Lake contains 33 miles of the canal's elevated channel between Gatun Locks (near Caribbean or Atlantic terminus) and Pedro Miguel Locks (near Bay of Panama or Pacific terminus) and provides a supply of fresh water needed to operate the locks (PCC 1977).

34. The PCC (1977) reported that colonies of aquatic macrophytes in Gatun Lake were hampering the operation of the Panama Canal. Two problem floating species were waterlettuce (*Pistia stratiotes* L.) and floating waterhyacinth (*Eichhornia crassipes* (Mart.) Solms.); however, hydrilla, a submerged species, was the greatest threat to navigation on Gatun Lake. Although the PCC cannot establish the exact date that hydrilla was introduced into Gatun Lake, the agency reported that this aquatic species was documented in the reservoir during the early 1920's (PCC 1977). Gatun Lake has proved to be an ideal habitat for the establishment, growth, and spread of hydrilla. Wind and wave action and boat propellors cut or separate viable fragments from established colonies and thus facilitate the spread of the population.

35. The WES has maintained an aquatic plant management assistance program with the PCC since 1976. The program has been mutually beneficial because it has provided the WES with a year-round test area for the

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* Surface area and capacity based on normal pool elevation of 85 ft referenced to mean sea level.

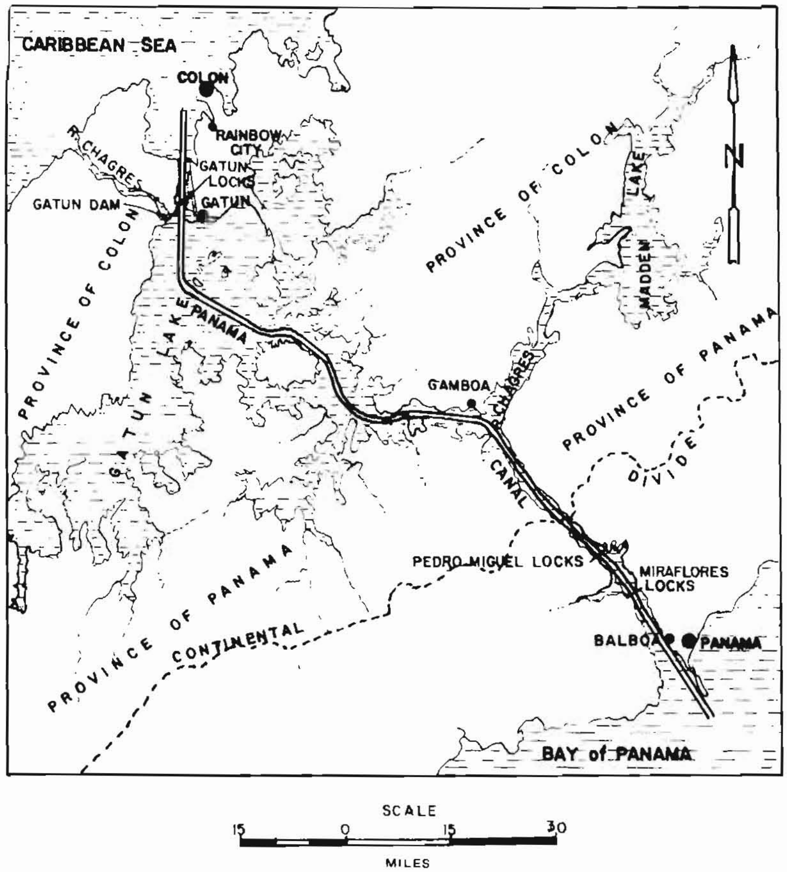

Figure 9. Map of Panama Canal showing location of Gatun Lake

evaluation of various types of chemical, mechanical, and biological treatments and has helped the PCC upgrade qualifications of its personnel and modernize its field equipment (Parris 1980). Aerial photomissions flown during 1977 and 1979 to detect and monitor the change in areal extent of the hydrilla population have been essential to the implementation of the management program.

Objective

36. The objective of this case study was to study hydrilla growth in Gatun Lake between 1977 and 1979.

Surveys of the Hydrilla Population

Ground surveys

37. Parris (1981), reporting the results of a WES ground survey in late March-early April 1980 of the hydrilla population in Gatun Lake, stated that fathometer transects showed large areas of submerged hydrilla at depths as great as 15 ft and that a PCC diver had found irregularly distributed sprigs of this macrophyte growing as deep as 30 ft. The field data indicated that, although hydrilla can survive at depths greater than 30 ft, this species will not develop topped-out surface mats in water depths greater than 20 ft. Parris (1981) identified two basic types of hydrilla colonies in Gatun Lake:

a. Type 1 colonies. These occur in backwater areas and along island shorelines. The bottom elevation drops sharply into submerged valleys (e.g., former stream channels). Topped-out mats form in the shallow areas, and there are few fully submerged hydrilla plants associated with type 1 colonies.

b. Type 2 colonies. These occur in extensive open-water areas, generally in the vicinity of dredged material disposal sites. Water depths average between 10 and 15 ft. The dredged material offers a level substrate that is ideal for hydrilla establishment and growth. These colonies are subjected to wave and current action that, when coupled with substrate variations, produces a discontinuous growth pattern of both submerged and topped-out plants over the hundreds of acres of hydrilla in the disposal areas.

Photomissions

38. The WES and the PCC scheduled photomissions of Gatun Lake using Kodak Aerochrome Infrared 2443 film combined with Kodak No. 12 Wratten filter in January 1977 and in March 1979. End products of each mission were positive transparencies at the nominal scale of 1:24,000; however, there were differences in the product quality of the two sets of imagery. Even though clouds covered certain portions of Gatun Lake during the time of the 1977 overflight and obscured part of the hydrilla population, the quality of the 1977 imagery was superior to that of the 1979 imagery (Table 1). The latter set was scratched

either during exposure or processing, and these scratches hindered interpretation.

39. Interpretation of the imagery. A skilled WES interpreter delineated the areal distribution of hydrilla in Gatun Lake on overlays to the 1977 and 1979 imagery (Figures 10 and 11, respectively). Figure 12 illustrates a status of hydrilla distribution in a portion of this water body in the vicinity of Barro Colorado Island, as mapped on both the 1977 and 1979 imagery. As Figure 12 shows, hydrilla had not yet reached the Tabernilla Reach of the Panama Canal in 1977. By 1979, however, the hydrilla colonies had increased in areal extent and had begun to encroach on the Tabernilla Reach.

40. Because the product quality rating of the 1979 imagery (fair) was lower than that of the 1977 imagery (good), the interpreter found mapping the distribution of hydrilla on the latter set of imagery more difficult. Nevertheless, with the use of both the ground-survey data and the 1977 distribution map, he was able to map the 1979 distribution of this aquatic macrophyte and to determine the change in its areal extent in Gatun Lake over the 2-year period. The small nominal scale (1:24,000) of both sets of imagery, together with the limited depth penetration inherent in infrared imagery, made detection of deeper submerged portions of the colonies difficult. The interpreter probably succeeded in mapping all of the Type 1 colonies because most were topped-out in continuous mats; however, many of the plants in the Type 2 colonies were submerged or so scattered that they were difficult to detect on the small-scale infrared imagery.*

41. Determination of areal coverage. The interpreter selected a number of common control points on both sets of imagery and on the various 1:50,000-scale topographic maps covering Gatun Lake (prepared by the CE Army Map Service) and determined true scales as follows:

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* For a discussion of the water-penetration capability of various film-filter combinations, see Lockwood et al. (1974).

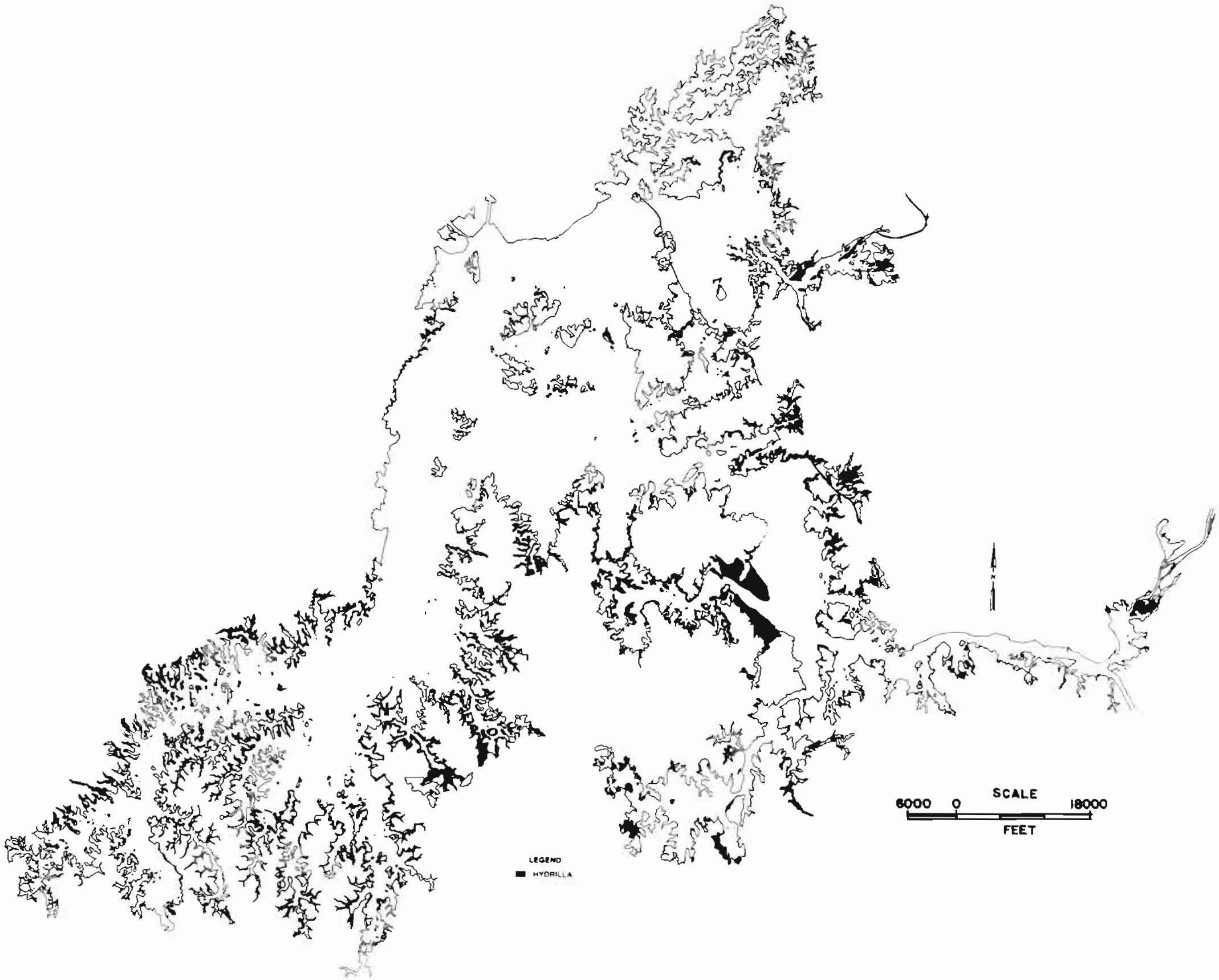

Figure 10. Areal distribution of hydrilla in Gatun Lake in 1977

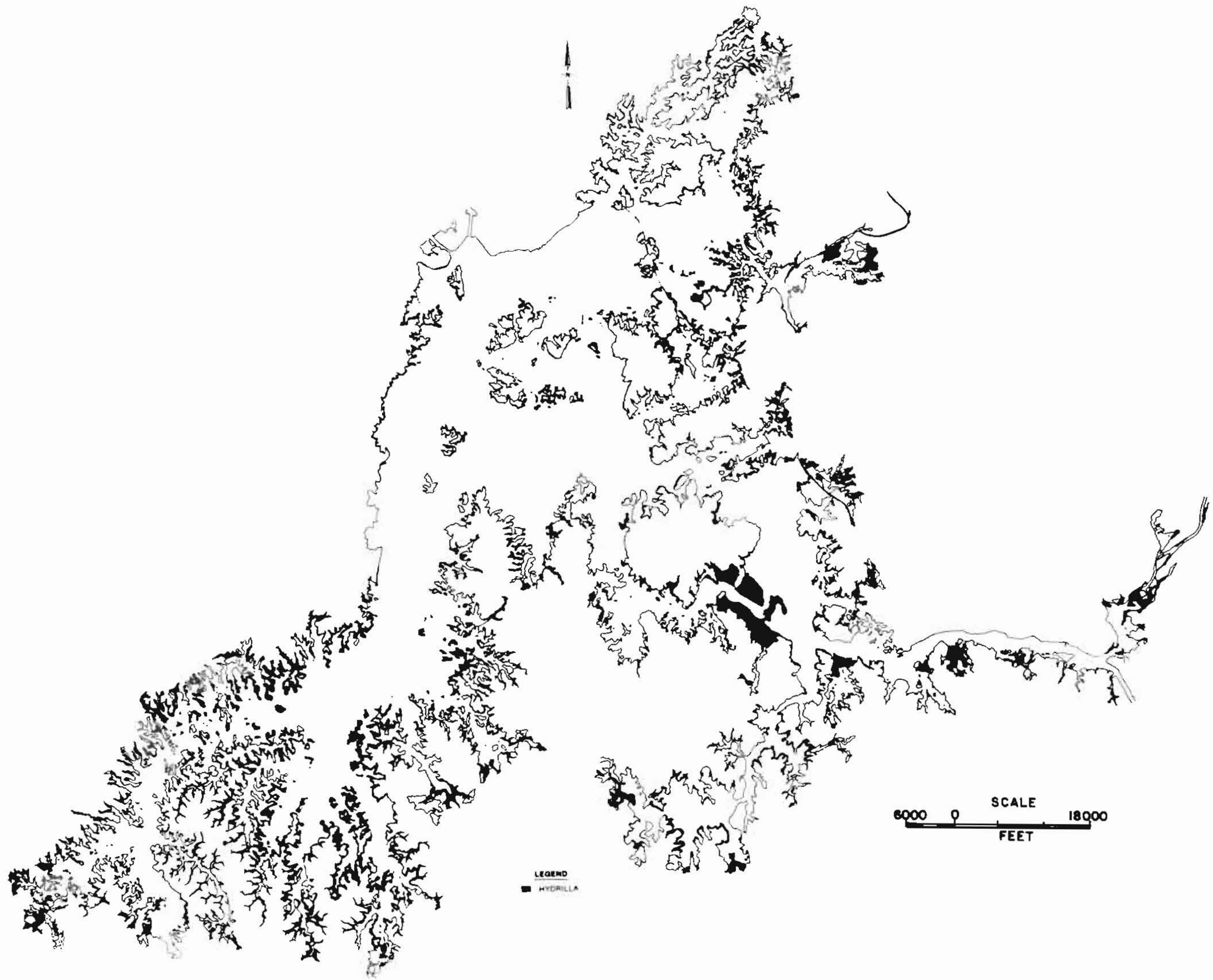

Figure 11. Areal distribution of hydrilla in Gatun Lake in 1979

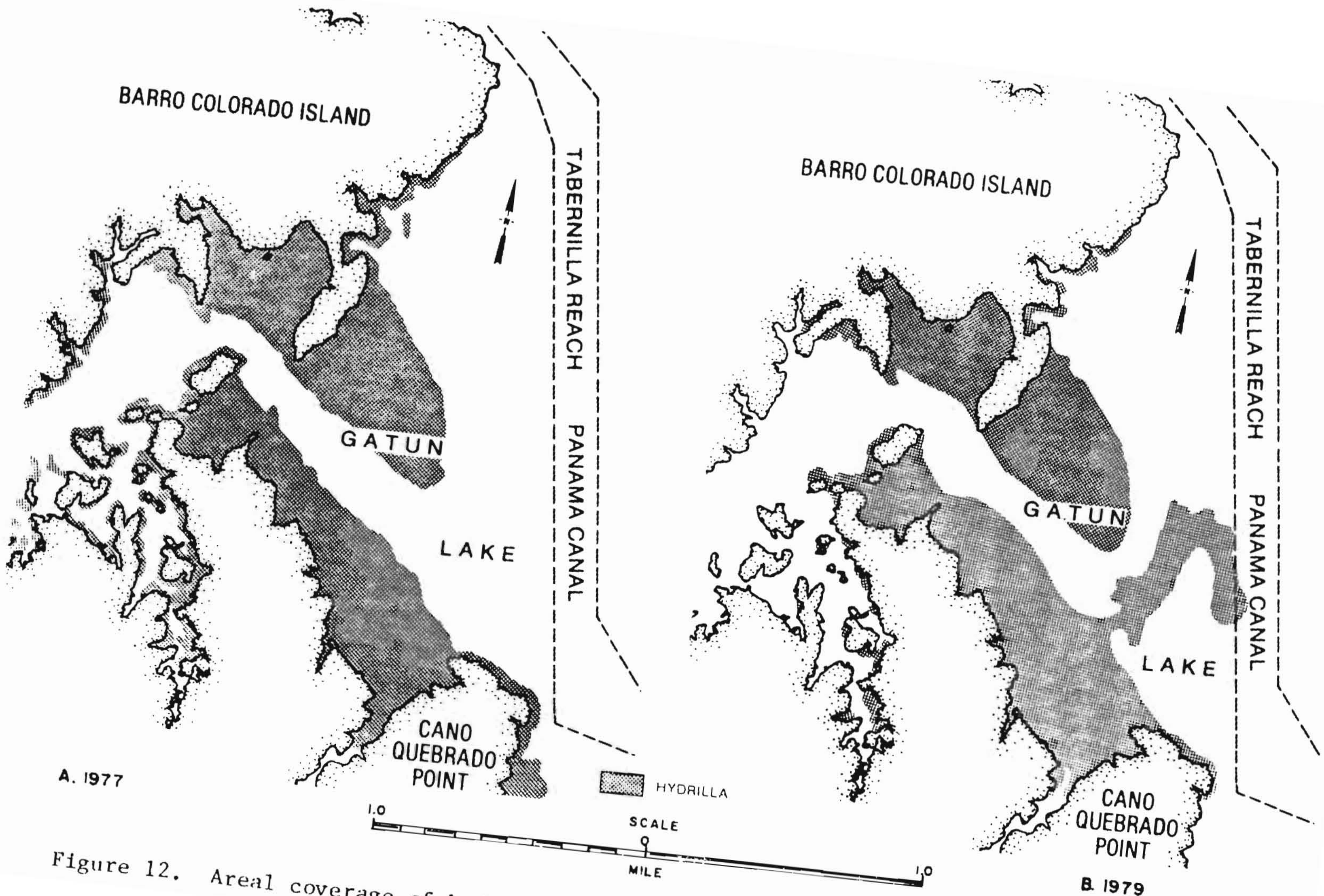

Figure 12. Areal coverage of hydrilla mapped in Gatun Lake near Barro Colorado Island

Date of Imagery	Scale	
	Nominal	True
1977	1:24,000	1:24,483
1979	1:24,000	1:25,262

Areal coverage of hydrilla was then determined with the Bruning Areagraph No.. 4849 using Equation 1. The scale factors used in Equation 1 were 0.936750 for the 1:24,483-scale and 0.966566 for the 1:25,262-scale imagery. The following area values were determined (Parris 1980):

Date	Area, acres
1977	11,600
1979	12,140

Discussion of results

42. The PCC (1977) stated that the growth of the hydrilla population in Gatun Lake threatened the operation of the Panama Canal and that this threat had increased during the past several years. There was a 540-acre increase in areal coverage of hydrilla between 1977 and 1979. The interpretation of the two sets of color infrared imagery also shows encroachment of the hydrilla in the canal portion of the lake, thus substantiating the PCC statement.

43. Depth penetration with infrared film is limited and is less than that of color film even when flight conditions are the same. Because of the limited depth-penetration capability of the infrared film, the deeper portions of the hydrilla colonies were undetectable on the imagery. Even under the best conditions, submerged aquatic plant populations are more difficult to detect with small-scale color infrared film than with large-scale color film, and the difficulty of mapping increases when the product quality is below standard (e.g., the 1979 imagery). If the mission had been flown at a larger scale, the interpreter would have had less difficulty detecting the smaller colonies.

44. Changes in detectable areal coverage between 1977 and 1979 do not reflect changes within established colonies nor do they reflect increases in the outward expansion of submerged colonies when these increases were at depths greater than the detection capability of the film.

Whether or not the 270-acre annual increase of the hydrilla population in Gatun Lake (i.e., 540-acre increase over a 2-year time frame) is typical of the average annual growth could only be determined by interpreting areal coverage of this aquatic species on sequential sets of photography spanning a period of at least 5 years. The same approach could be used to evaluate the effectiveness of treatment measures.

CASE STUDY 4: MONITORING OF CHANGES IN A COMMUNITY DOMINATED BY EURASIAN WATERMILFOIL DURING A 1-YEAR PERIOD IN LAKE OSOYOOS, WASHINGTON

Background

45. The U. S. Army Engineer District, Seattle (NPS), initiated a 3-year Large-Scale Operations Management Test (LSOMT) in 1979 to develop an operational plan to evaluate the concept of prevention as an operational technique for managing problem aquatic macrophytes in the state of Washington. The primary objective of the LSOMT was to prevent the submerged aquatic macrophyte, Eurasian watermilfoil, from reaching problem-level proportions in the state. Among the test sites selected was Lake Osoyoos (also known as Osoyoos Lake) located on the United States-Canadian border in Okanogan County, Washington, and in British Columbia (Figure 13). Lake Osoyoos is a 5729-acre* (2036 acres in the United States) natural lake on the Okanogan River** (Okanogan River Miles 79.0-90.0; Mile 82.5 is the international boundary.). The Okanogan River a right-bank tributary of the Columbia River (confluence at Columbia River Mile 533.5). Lake levels are influenced to some degree by upstream diversions for irrigation (44,000 acres irrigated in Canada) and by the downstream Zosel Milldam at Okanogan River Mile 77.4.

46. Eurasian watermilfoil dominates the submerged aquatic plant community in Lake Osoyoos. However, other submerged potential problem species are also present in varying degrees of density and relative abundance in this water body. These subdominant species include curled pondweed (*Potamogeton crispus* L.), sago pondweed (*P. pectinatus* L.), water buttercup (*Ranunculus aquatilis* L.), Brazilian edolea (*Egeria densa* Planch.), and coontail (*Ceratophyllum demersum* L.).

47. The NPS and the WES have carried out a comprehensive field program in Lake Osoyoos and in the adjacent downstream reach of the

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* At normal pool elevation of 911 ft referenced to the National Geodetic Vertical Datum of 1929.
** The name of this river is spelled "Okanagan" in Canada.

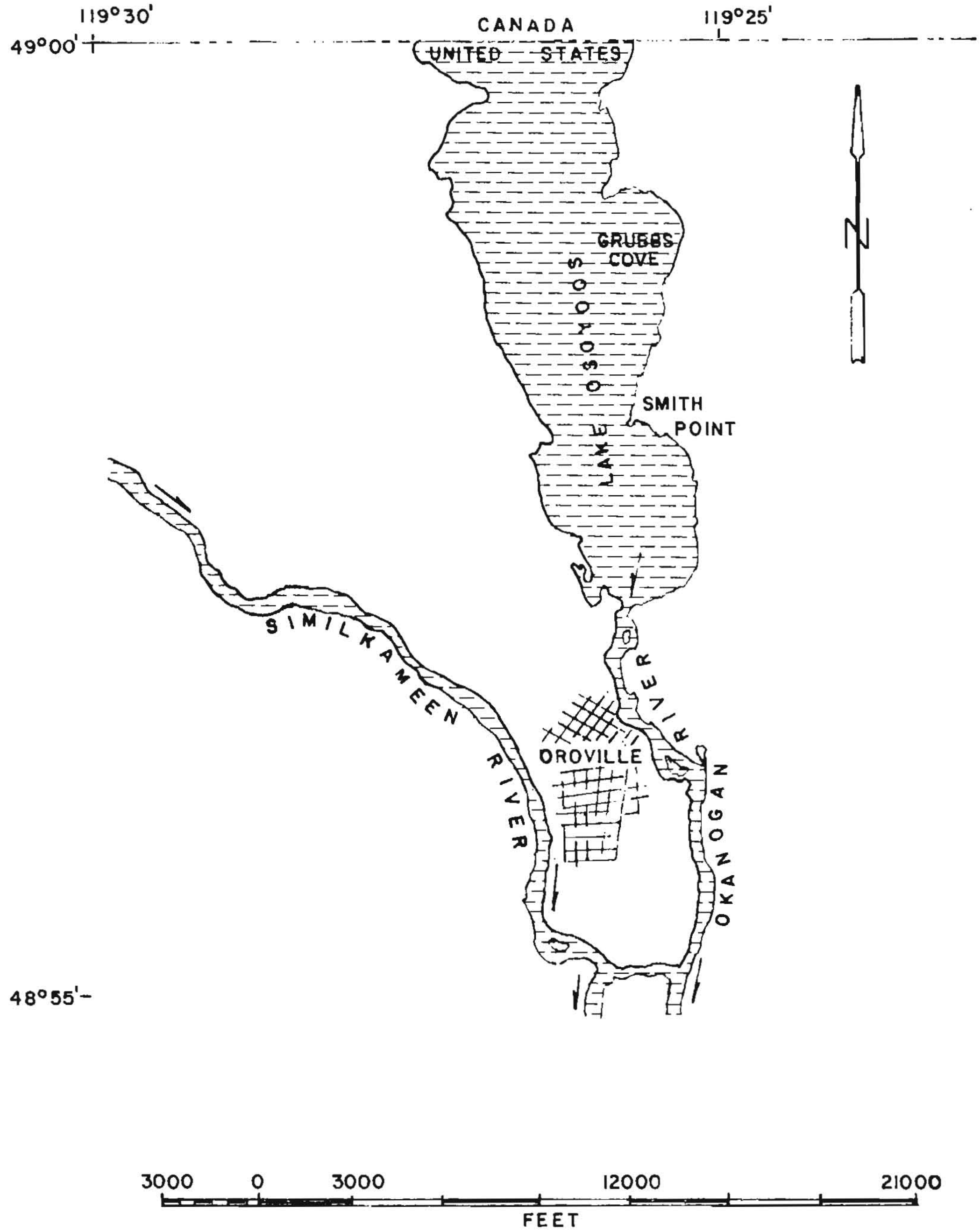

Figure 13. Lake Osoyoos, Washington (adapted from USGS 1:62,500-scale topographic quadrangle for Oroville, Washington, 1957)

Okanogan River since the implementation of the LSOMT. Analysis of biomass data and determination of the effectiveness of a Eurasian watermilfoil fragment barrier in the Okanogan River were conducted in FY 79 (Dardeau and Lazor 1982). In FY 80, WES conducted herbicide tests and monitored water quality and biomass changes as a result of these tests (Killgore 1981). As an integral part of the LSOMT, photomissions were flown in both years to detect, map, and monitor changes in the Eurasian-watermilfoil-dominated submerged aquatic plant community* in Lake Osoyoos.

Objectives

48. The objectives of this case study were to map the distribution of Eurasian watermilfoil in Lake Osoyoos on both the 1979 and 1980 imagery and to determine the change in that distribution over the 1-year period.

Surveys of Eurasian Watermilfoil Distribution

Photomissions

49. In July 1979, nine photomissions that provided complete or partial coverage of the United States portion of Lake Osoyoos were flown to evaluate nine different film-scale combinations in terms of their suitability for mapping the Eurasian watermilfoil distribution in the water body.** In October 1980, the same contractor flew a single photomission covering all of the United States' portion of Lake Osoyoos using the most reliable scale-film combination (1:5,000 color) tested in 1979.

50. 1979. Dardeau and Lazor (1982) reported that color imagery

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* Herafter referred to as the Eurasian watermilfoil distribution.

** Black-and-white, color, and color infrared film, each at nominal scales of 1:5,000, 1:10,000, and 1:20,000 (Table 1). The contractor flew partial coverage of the 1:5,000-scale and complete coverage of the other two scales of imagery.

at the largest affordable scale (1:5,000) was the most reliable film-scale combination tested for mapping Eurasian watermilfoil distribution in Lake Osoyoos; however, the 1979 1:5,000-scale color imagery provided only partial coverage of the lake. The largest scale 1979 color photography that completely covered the United States' portion of Lake Osoyoos was the 1:10,000 imagery. For the purpose of this case study, only the results of mapping using the 1979 1:10,000-scale color photography will be considered. The contractor used Kodak EF Ektachrome Aerographic S0397 film without a filter. Flying and processing costs for this mission and the other eight 1979 missions over Lake Osoyoos were $4300.

51. 1980. In 1980, WES elected to fly a single color mission at a nominal scale of 1:5,000. The 1980 mission specifications included Kodak HF-3 and HF-4 Wratten filters in combination with the same type of color film used in 1979. The WES used these haze filters, based on experience gained at other water bodies (Table 1). Cost of the 1980 photomission that covered the United States' portion of Lake Osoyoos, the 79-mile reach of the Okanogan River between Lake Osoyoos and Wells Reservoir (at the Okanogan-Columbia confluence), and a 16-mile reach of the Pend Oreille River in northeastern Washington was $5200.

Interpretation of imagery

52. The contractor flew the 1979 nominal 1:10,000-scale color coverage of the United States' portion of Lake Osoyoos without a filter. As a result, the unfiltered haze reduced the photographic contrast and depth penetration of the imagery and made interpretation of the Eurasian watermilfoil distribution somewhat difficult. The area mapped as Eurasian watermilfoil distribution on the 1979 imagery (Figure 14) was, therefore, considerably less than it was later determined to be by reinterpretation described in paragraph 54.

53. The 1980 mission specifications, which provided for a larger nominal scale of 1:5,000 and for HF-3 and HF-4 filters, yielded a more interpretable product. Increased depth penetration made detection of deeper fringes of the submerged aquatic plant colonies possible and also provided a more realistic measure of areal coverage (Figure 15).

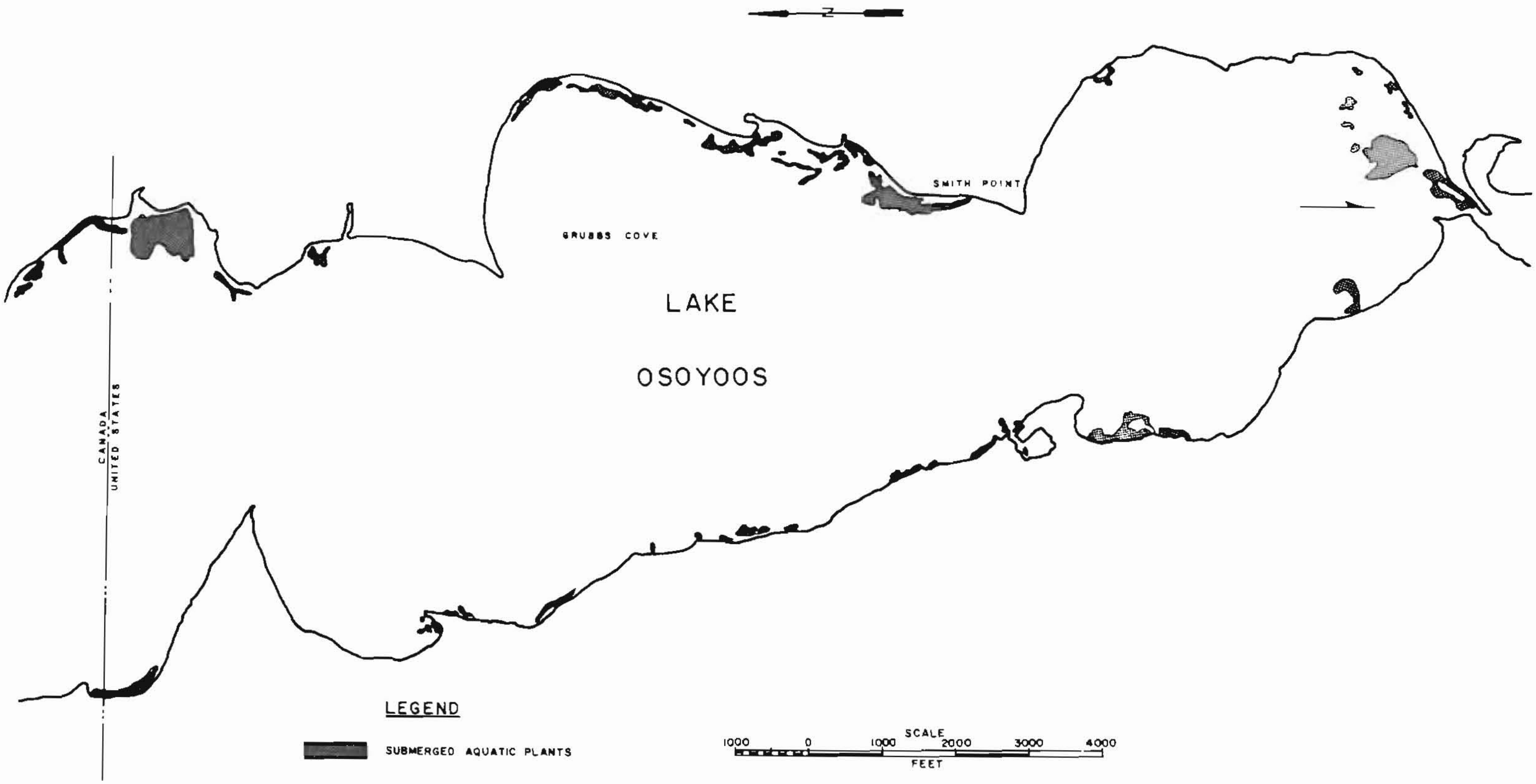

Figure 14. Areal distribution of the Eurasian-watermilfoil-dominated submerged aquatic plant community in Lake Osoyoos mapped from 1979 color imagery

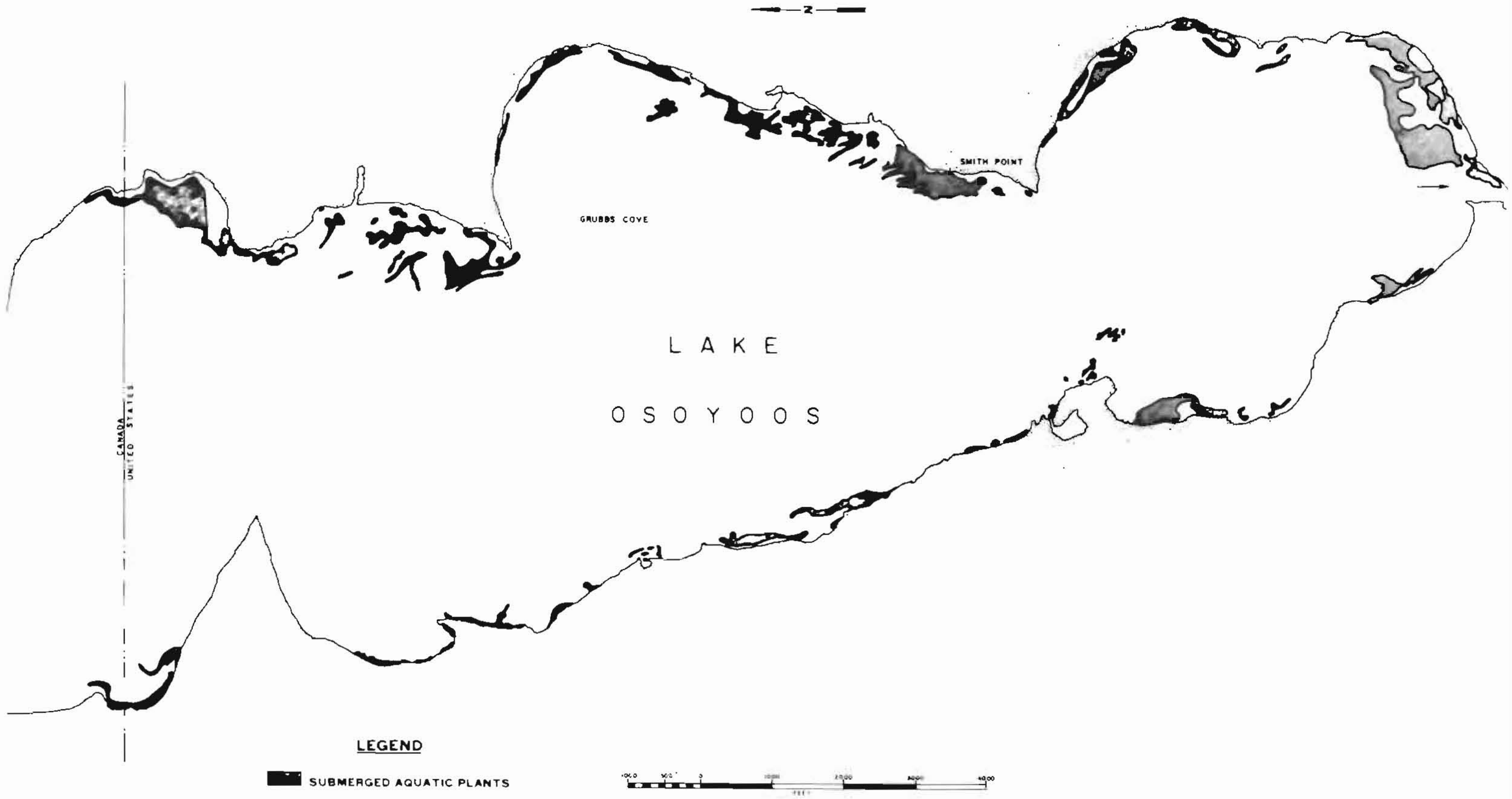

Figure 15. Areal distribution of the Eurasian-watermilfoil-dominated submerged aquatic plant community in Lake Osoyoos mapped from 1980 color imagery

54. Because there was such an obvious discrepancy in area mapped as Eurasian watermilfoil distribution on the two sets of photography, the WES reinterpreted the 1979 imagery using the completed 1980 distribution map (Figure 15) as a guide. The interpreter now had the benefit of larger scale, higher contrast photography (1980) and a year of field experience to guide him in his reinterpretation of the 1979 areal distribution of Eurasian watermilfoil. Thus, he was able to recognize many previously undetected colonies because his attention could be directed to specific portions of the lake where Eurasian watermilfoil was now known to occur. The revised 1979 areal distribution map (Figure 16), although considerably different from that originally mapped (Figure 14), provided a more accurate picture of the Eurasian watermilfoil distribution in 1979. Differences in the revised 1979 and 1980 mapped distributions were now attributable to a year of growth, rather than to differences in scale and film-filter combination.

Determination of areal coverage

55. The interpreter selected a number of common control points on both sets of photography and on the 1:62,500-scale topographic map for the Oroville, Washington, Quadrangle (prepared by the USGS in 1957) to determine true scales as follows:

Date of Imagery	Scale	
	Nominal	True
1979	1:10,000	1:10,980
1980	1:5,000	1:5,600

The Eurasian watermilfoil distribution was then mapped with the Bruning Areagraph No. 4849, using Equation 1. The scale factors used in Equation 1 were 0.192195 for the 1:10,980-scale and 0.049990 for the 1:5,600-scale imagery. Area values were as follows:

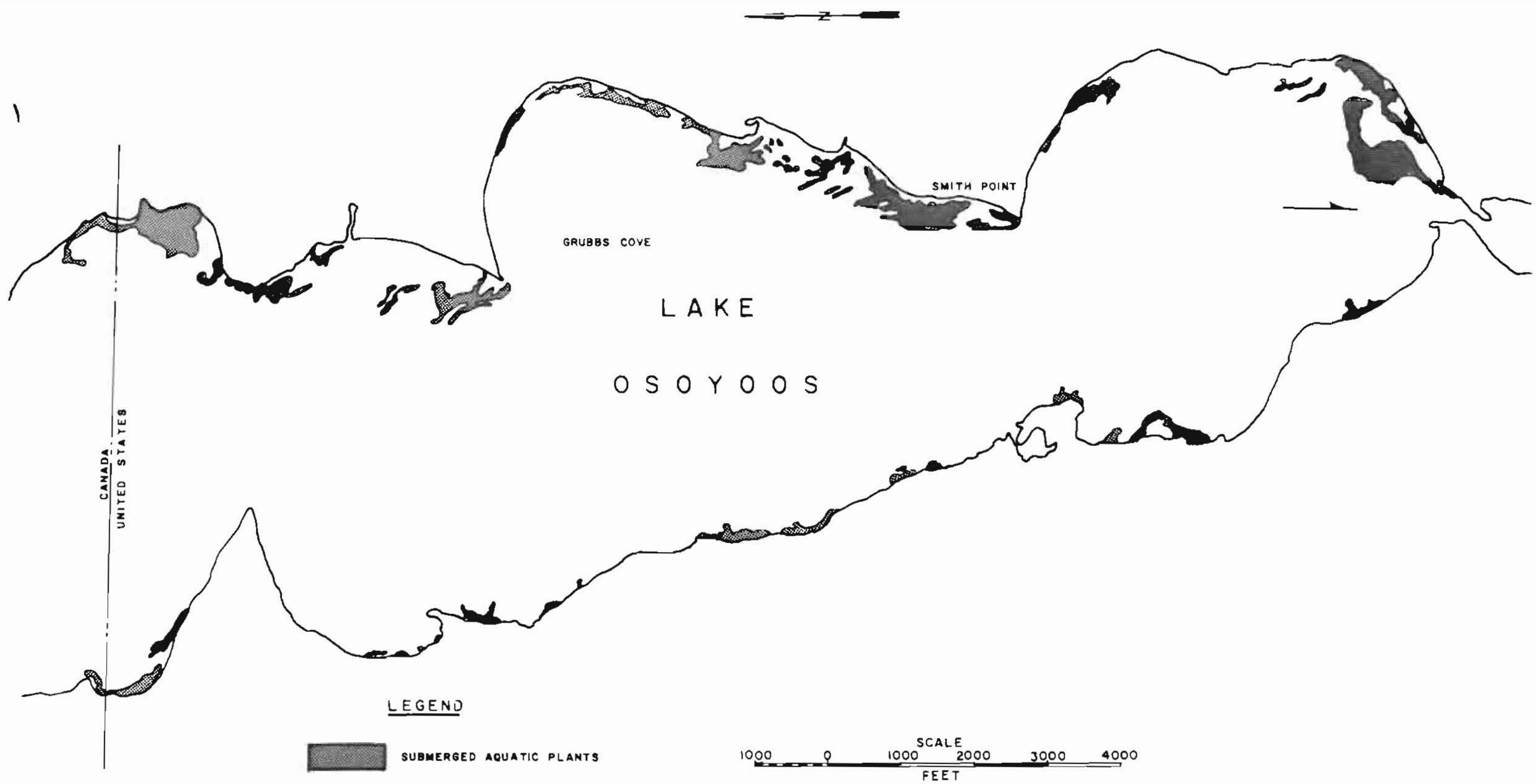

Figure 16. Revised distribution of the Eurasian-watermilfoil-dominated submerged aquatic plant community in Lake Osoyoos mapped from 1979 color imagery using 1980 distribution (Figure 15) as a guide

Date	Area, acres
1979 preliminary	33*
revised	115
1980	132

* The 30 acres reported by Dardeau and Lazor (1982) was based on a nominal scale of 1:10,000.

Discussion of results

56. The interpreter delineated all colonies of submerged aquatic plants, regardless of the density or relative abundance of Eurasian watermilfoil and other competing species. The revised 1979 area value for the Eurasian watermilfoil distribution (115 acres) showed that a much larger percentage (27 percent) of the 425 acres of surface area of potential habitat in the United States' portion of Lake Osoyoos* was occupied by the submerged aquatic plants than the preliminary 1979 value of 33 acres (8 percent) had indicated. Change in areal coverage between 1979 and 1980 was 17 acres, indicating a detectable outward areal expansion of 15 percent in the boundaries of the individual colonies. To determine whether or not the 17-acre change in area was indicative of the average annual growth of the submerged aquatic plant community in that water body would require interpretation of sequential sets of photography spanning a period of at least 5 years. Additionally, annual changes in areal extent do not reflect intercolonial changes in biomass or in the level of competition.

* Area of potential habitat based on the surface area of the lake between the shoreline and the 25-ft maximum-observed-depth contour at normal pool elevation (911 ft) (Dardeau and Lazor 1982).

CONCLUSIONS

57. Based on the simultaneous consideration of studies in this report, the following general conclusions can be drawn:

- a. Aerial surveying is an accurate means of mapping submerged and emergent aquatic plant populations.
- b. Of the two growth forms of aquatic plants covered by the four case studies, submerged and emergent, submerged plants were more difficult to detect on aerial imagery.
- c. The four case histories provided examples of the use of three scales/ranges of nominal scale of aerial photography (1:5,000 to 1:6,000; 1:10,000 to 1:12,000; and 1:24,000) to detect and map the distribution of submerged aquatic plant populations. Maps produced from the nominal scale imagery of 1:10,000 to 1:12,000 were generally as accurate as those produced from the nominal scale imagery of 1:5,000 to 1:6,000. Photointerpretation of the 1:24,000-scale imagery was more difficult than either of the two larger scale ranges.
- d. Regardless of scale, populations of submerged plants were easier to detect on color than on color infrared imagery.

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Table 1

Aquatic Plant Aerial Surveys Conducted by the EAG, 1977-1981

Location (CE District)	Area, acres	Bottom Sediment	Secchi Disk ft	Problem Species	Photomission* Date	Photomission* Contractor**	Product and Processing Cost, dollars Total	Product and Processing Cost, dollars per acre	Nominal Scale	Film Type	Film Number	Wratten Filter No.	Product Quality Rating† Negative	Product Quality Rating† Positive Trans-parency	Product Quality Rating† Print	Product Quality Rating† Photo Index	Suitability for Application
Gatun Lake, Panama	110,000	Variable	20	Hydrilla	Jan 77	--	--		1:24,000	Color IR	2443	12	--	7	--	--	Good
					Mar 79	--	--		1:24,000	Color IR	2443	12	--	5	5	--	Fair
Lake Osoyoos, Wash.†† (Seattle)	2,036	Sand	12	Eurasian watermilfoil	Jul 79	1	$4300		1:5,000	B&W	2405	HF-3	7	--	7	6	Good
										Color	S0397	--	--	7	--	6	Very good
										Color IR	2443	12	--	6	--	--	Good
									1:10,000	B&W	2405	HF-3	7	--	7	6	Good
										Color	S0397	--	--	7	--	--	Very good
										Color IR	2443	12	--	6	--	--	Good
									1:20,000	B&W	2405	HF-3	7	--	7	--	Good
										Color	S0397	--	--	7	--	--	Very good
										Color IR	2443	12	--	6	--	--	Good
Lake Whatcom, Wash. (Seattle)	5,029	Silt	16	Eurasian watermilfoil	Jul 79	1	4400		1:5,000	B&W	2405	HF-3	8	--	8	6	Good
										Color	S0397	--	--	8	7	6	Very good
										Color IR	2443	12	--	8	--	--	Good
									1:10,000	B&W	2405	HF-3	8	--	8	6	Good
										Color	S0397	--	--	8	--	--	Very good
										Color IR	2443	12	--	8	--	--	Good
									1:20,000	B&W	2405	HF-3	8	--	8	6	Good
										Color	S0397	--	--	8	--	--	Very good
										Color IR	2443	--	--	8	--	--	Good
Lake Sammamish, Wash. (Seattle)	4,897	Sand	14	Eurasian watermilfoil	Jul 79	1	4300		1:5,000	B&W	2405	HF-3	7	--	7	6	Good
										Color	S0397	--	--	7	7	6	Very good
										Color IR	2443	12	--	6	--	--	Good
									1:10,000	B&W	2405	HF-3	7	--	7	6	Good
										Color	S0397	--	--	7	--	--	Very good
										Color IR	2443	12	--	6	--	--	Good
									1:20,000	Color	S0397	--	--	7	--	--	Very good
										Color IR	2443	12	--	6	--	--	Good
Lake Seminole, Ala.-Fla.-Ga. (Mobile)	37,500	Silt	--	Giant cutgrass	Oct 79	2	7000	0.19	1:24,000	Color	2448	HF-3 HF-4	--	8	8	--	Very good

(Continued)

* All missions flown with a Zeiss 9- by 9-in. camera and Zeiss lens having a 6-in. focal length.
** 1--Aerial Mapping Service, Portland, Oreg. (Seattle District flew mission, contractor processed film).
2--Woolpert, Mobile, Ala.
† Number indicates quality on a scale of 1 to 10, with 10 = excellent.
†† United States' portion of the lake.

Table 1 (Concluded)

Location (CE District)	Area, acres	Bottom Sediment	Secchi Disk ft	Problem Species	Photomission Date	Photomission Contractor	Product and Processing Cost, dollars Total	Product and Processing Cost, dollars per acre	Nominal Scale	Film Type	Film Number	Wratten Filter No.	Product Quality Rating Negative	Product Quality Rating Positive Trans-parency	Product Quality Rating Print	Product Quality Rating Photo Index	Suitability for Application
Lewis Creek Reservoir, Tex. (Galveston)	1,000	Variable	14	Hydrilla	Oct 80	2	748	0.75	1:6,000	Color	2448	HF-3 HF-4	--	8	8	8	Very good
							505	0.51	1:12,000	Color	2448	HF-3 HF-4	--	8	8	8	Very good
J. D. Murphee Wildlife Management Area, Tex. (Galveston)	8,500	Organic silt	2	Waterhya-cinth and alligatorweed	Oct 80	2	2133	0.12	1:12,000	Color	2448	HF-3 HF-4	--	8	8	8	Very good
										Color IR	2443	12	--	9	8	8	Very good
Wallisville Lake, Tex. (Galveston)	20,000	Variable	12	Waterhyacinth	Oct 80	2	928	0.05	1:12,000	Color	2448	HF-3 HF-4	--	8	8	8	Very good
San Marcos River, Tex.	233 (16 river miles)	Sandy silt	--	Waterhyacinth and hydrilla	Oct 80	2	990	4.25	1:6,000‡	Color	2448	HF-3 HF-4	--	--	--	--	--
Okanogan River and Lake Osoyoos, Wash.†† (Seattle)	2,600 (83 river miles)	Sand	12	Eurasian watermilfoil	Oct 80	1	5200‡‡	1.02	1:5,000	Color	S0397	HF-3 HF-4	--	9	--	--	Excellent
Pend Oreille River, Wash. (Seattle)	2,500 (16 river miles)	Variable	14	Eurasian watermilfoil	Oct 80	1	‡‡		1:5,000	Color	S0397	HF-3 HF-4	--	9	--	--	Excellent
Okanogan River and Lake Osoyoos, Wash.†† (Seattle)	2,600 (83 river miles)	Sand	12	Eurasian watermilfoil	Oct 81	1	2676	1.03	1:5,000	Color	S0397	HF-3 HF-4	--	9	--	--	Excellent
Columbia River, Wash. (Seattle)	11,100 (92 river miles)	Sand	12	Eurasian watermilfoil	Oct 81	1	1824	0.16	1:10,000	Color	S0397	HF-3 HF-4	--	9	--	--	Excellent

†† United States' portion of the lake.
‡ Mission flown at 1:12,000 scale instead of the contracted 1:6,000 scale, so products rejected.
‡‡ $5200 includes cost of coverage of Okanogan River, United States' portion of Lake Osoyoos, and Pend Oreille River.

Table 2

Comparison of Six Scale-Method Combinations Used to Compute Areal Coverage of Hydrilla in Lewis Creek Reservoir, Texas*

Scale	Areal Coverage, acres			Estimation Difference, percent		
	Automated Rectified (I)	Automated Unrectified (II)	Manual (III)	$\left(\frac{I - II}{I}\right) \times 100$	$\left(\frac{II - III}{II}\right) \times 100$	$\left(\frac{I - III}{I}\right) \times 100$
1:6,066 (A)	350	369	351	-5.4	+4.9	-0.3
1:12,157 (B)	334	346	350	-3.6	-1.2	-4.8
	Scale Difference, percent					
$\left(\frac{A - B}{A}\right) \times 100$	+4.6	+6.2	+0.3			

* Adapted from Parris, Leonard, and Payne (1981).

Table 3

Advantages and Limitations of Boat and Aerial Surveys of Giant Cutgrass in Lake Seminole

Type of Survey	Advantages	Limitations
Boat	Can be performed by in-house staff Can be used to accomplish other management objectives	Requires 50 man-days Requires personnel skilled in field identification of giant cutgrass
Aerial	Provides a rapid means of data acquisition and update Yields a photographic record for future reference	Contractor necessary to fly photomission Requires photointerpretative skills Interpreter cannot detect small colonies on imagery

Table 4

Estimated Costs of Boat and Aerial Surveys of Giant Cutgrass in Lake Seminole

Type of Survey	Activity	Estimated Cost 1979 Dollars
Boat	Labor	
	Survey (1 GS-12, 1 GS-07, 25 man-days each)	$ 8,800
	Area determination (1 GS-07, 3 man-days)	500
	Boat operation (25 days)	500
	Base map (copy of existing semicontrolled photomosaic)	200
	TOTAL	$10,000
	or	$0.27/acre
Aerial	Labor	
	Ground control (1 GS-12, 1 GS-07, 2 man-days each)	$ 700
	Interpretation and area determination (1 GS-07, 7 man-days)	900
	Photomission (1 roll 1:24,000-scale color positive transparencies, 1 black-and-white index (uncontrolled); no color prints)	6,000
	Base map (copy of existing semicontrolled photomosaic)	200
	TOTAL	$7,800
	or	$0.21/acre

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Dardeau, Elba A.
Aerial survey techniques to map and monitor aquatic plant populations--four case studies / by Elba A. Dardeau, Jr. (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. : available from NTIS, 1983.
44, [5] p. : ill. ; 27 cm. -- (Technical report ; A-83-1)
Cover title.
"January 1983."
Final report.
"Prepared for Office, Chief of Engineers, U.S. Army."
At head of title: Aquatic Plant Control Research Program.
Bibliography: p. 43-44.

1. Aquatic weeds. 2. Computer programs 3. Maps. 4. Photographic interpretation. 5. Photography, Aerial. I. United States. Army. Corps of Engineers.

Dardeau, Elba A.
Aerial survey techniques to map and monitor aquatic : ... 1983.
(Card 2)

Office of the Chief of Engineers. II. Aquatic Plant Control Research Program. III. U.S. Army Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; A-83-1.
TA7.W34 no.A-83-1