


TECHNICAL REPORT A-78-3

MECHANICAL HARVESTING OF AQUATIC PLANTS

Report 2

Evaluation of Selected Handling Functions of Mechanical Control

By Perry A. Smith

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

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Report 2 of a Series

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The U. S. Army Engineer District, Jacksonville, is continuing their efforts toward instituting environmentally compatible, large-scale aquatic plant control and management programs. The Jacksonville District requested that the U. S. Army Engineer Waterways Experiment Station continue their efforts towards implementing an aquatic plant mechanical control system. The program was devoted to: (a) defining a conceptual framework and acquiring engineering data for developing performance criteria for selected functions inherent in

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20. ABSTRACT (continued).

mechanical harvesting, (b) soliciting concept designs from industry, and (c) purchasing a mechanical system(s) for control of aquatic plants. This report describes the field experiments conducted and the engineering data collected. A system for mechanical control of submersed plants was delivered in mid-July 1979.

SUMMARY

The U. S. Army Engineer District, Jacksonville, is continuing their efforts toward instituting environmentally compatible, large-scale aquatic plant control and management programs. Pressure from residents along the St. Johns and Withlacoochee Rivers prompted the Jacksonville District to request that the U. S. Army Engineer Waterways Experiment Station (WES) evaluate the feasibility of using mechanical harvesting systems alone or to augment other methods (e.g. biological and chemical) to manage problem aquatic plants in water bodies of interest to the Corps of Engineers (CE). This report is the second in a series on mechanical harvesting of aquatic plants. Initially, the work was devoted to the field evaluation of the most advanced, off-the-shelf aquatic plant harvesters available for immediate use. The program reported herein was devoted to defining a conceptual framework, acquiring engineering data for developing performance criteria for selected functions inherent in mechanical harvesting, and soliciting concept designs from industry.

Four functions considered essential in the mechanical control of aquatic plants include: (a) cutting (submersed plants) or dislodging (floating plants); (b) transporting, i.e., pushing, towing, hauling, or conveying the plants to a water-land interface point; (c) transferring the plants across the water-land interface; and (d) disposal (stacking the plants on land at a location near the takeout point).

This report describes a series of experiments designed to generate data pertinent to the estimation of cutting rates for submersed plants, transportation rates using natural forces as well as pushing and rafting of the plant material, and conveying rates and land storage requirements when plant disposal is obtained by natural decomposition of the plant residue. Responses from industry to develop a mechanical system for control of floating aquatic plants were not successful. Procurement of a system for mechanical control of submersed plants was initiated in the fall of 1978 and delivery was made in mid-July 1979.

The field program was successful in generating engineering data

that can be used to evaluate cutting systems for submersed aquatics and land disposal requirements for aquatic plants. However, insufficient data were generated for transporting the plants to a water-land interface storage point and transferring (i.e. conveying) the plants across the water-land interface. This was due to an inability to procure prototype test equipment that could be made to operate at capacities approaching that desired for routine operational use.

It is recommended that efforts be directed towards developing individual components to perform particular functions required to make up a complete system. Shifting emphasis so that a significant portion of the effort is directed toward these singular functions should tend to generate more interest from industry that manufactures equipment to efficiently handle forage crops. Finally, it is recommended that development of a rational method (i.e., a mechanical harvesting computer model) for determining how to employ and sequence the functions be continued.

PREFACE

This study was conducted at the request of the U.S. Army Engineer District, Jacksonville, and the Office, Chief of Engineers, which provided funds under authorization 96X4902. The investigation was conducted by P. A. Smith, Aquatic Plant Research Branch (APRB), Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES), under the direct supervision of Mr. J. L. Decell, Chief, APRB, and the general supervision of Messrs. B. O. Benn, Chief, ESD, and W. G. Shockley, Chief, MESL. The ESD is now a part of the Environmental Laboratory (EL) of which Dr. John Harrison is Chief. Mr. Decell is now Program Manager, Aquatic Plant Control Research Program, EL. Messrs. M. M. Culpepper, S. O. Shirley, and P. A. Smith of the APRB were responsible for the conduct of the field tests; this report was written by Mr. Smith.

Acknowledgement is made to Mr. Joe Joyce, Chief, Aquatic Plant Control Section, U. S. Army Engineer District, Jacksonville; Mr. Roy Smith, Floral City, Florida; Mr. Howard Grisham, Astor, Florida; and Parramore's Fish Camp, Astor, Florida, for their support during the field test. SP5 A. Kahn accomplished the theoretical work described in Appendix G.

Commanders and Directors of WES during the conduct of the study and the preparation of this report were COL J. L. Cannon, CE, and COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

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	4046.856	square metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
gallons (U. S. liquid)	0.003785412	cubic metres
horsepower (500 ft-lb/sec)	745.6999	watts
inches	25.4	millimetres
miles per hour	1.609344	kilometres per hour
miles (U. S. statute)	1.609344	kilometres
pounds (force)	4.448222	newtons
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres
square miles	2.589988	square kilometres
tons (2000 lb mass)	907.18474	kilograms
tons (2000 lb mass) per acre	0.2241702	kilograms per square metre
tons (2000 lb mass) per cubic foot	32036.979	kilograms per cubic metre

MECHANICAL HARVESTING OF AQUATIC PLANTS

EVALUATION OF SELECTED HANDLING FUNCTIONS OF MECHANICAL CONTROL

PART I: INTRODUCTION

Background

1. As part of the Corps of Engineers Aquatic Plant Control Research Program (APCRP), the U. S. Army Engineer Waterways Experiment Station (WES) is studying the feasibility of using mechanical systems alone or to augment other methods (e.g. biological and chemical) to manage problem aquatic plants in water bodies of interest to the Corps of Engineers. The overall goal is the development of a variety of techniques and equipment that can be tailored to the wide range of environmental conditions in which most problem aquatic plants are found. Due to the site-dependent nature of the problem, the method of controlling these aquatic plants must be determined as a result of careful study of the physical environment in which each plant problem exists. In addition to the type of plant, various other factors such as cultural development, recreational use, access to the water's edge, stream current flow, and even wind can often dictate the type and mix of mechanical devices required for proper removal and disposal of the plants. In addition to considerations of the efficiency of operational techniques, one must recognize that the environmental impact of the proposed control method must be considered in selecting an optimal procedure.

2. In the U. S. Army Engineer District, Jacksonville, there is public pressure to institute environmentally compatible, large-scale aquatic plant control or management. The desire of the residents along the St. Johns River for mechanical control of waterhyacinths in particular led to the initiation of the present mechanical control program. Also, the submersed plant, hydrilla, has infested many water bodies in the Jacksonville District. These factors prompted the Jacksonville District to request, in December 1975, that the WES

conduct a research program directed toward the objective of identifying cost-effective mechanical control systems for these two problem plants. Initially, the work was devoted to the field evaluation of the most advanced, off-the-shelf aquatic plant harvesters available for immediate use. Results of this work are documented in Culpepper and Decell.* The second part of the program was devoted to defining a conceptual framework and acquiring engineering data for developing performance criteria for selected functions inherent in mechanical harvesting and soliciting concept designs from industry. The next phase of the study will be a field evaluation of a prototype system designed and constructed for use in controlling submersed aquatics.

3. The functions that are normally considered essential in mechanical harvesting include:

- a. Cutting, if the plants are submersed, or dislodging, if the plants are floating.
- b. Transporting, i.e. pushing, towing, or conveying the plants to a water-land interface point.
- c. Conveying, i.e. transferring the plants across the water-land interface.
- d. Disposal, e.g. stacking the plants on land at a location near the takeout point.

The equipment, as well as the sequencing and the manner in which these functions are carried out, depends to a large degree on whether the operation is being conducted on submersed or floating plant assemblages. For example, in areas with measurable current flow and floating plant problems, the current might be employed to assist in transporting the plants to a point on the water-land interface. Conveyors would be used to lift the plants over the water-land interface and place them in stacks where they would be allowed to compress and decompose under natural conditions. An upstream cutting function will always have to be the first step in harvesting submersed aquatic plants.

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* M. M. Culpepper and J. L. Decell. 1978. "Mechanical Harvesting of Aquatic Plants; Report 1, Field Evaluation of the Aqua-Trio System," Technical Report A-78-3, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. In areas such as river or lake systems with little or no flow, transport would have to be accomplished using more energy-intensive techniques, i.e. towing or pushing the plants without lifting them from the water or removing them from the water and transporting them to the water-land interface such as is done with the Aqua-Trio system. Conveyors would then transport the plants to storage stacks where they would be allowed to compress and decompose under natural conditions.

5. At the conclusion of the evaluation of the Aqua-Trio system noted in paragraph 2, it was felt that a mechanical system could be made that would perform the essential function adequately and potentially would be:

a. Less energy intensive than present mechanical methods.

b. Capable of production rates commensurate with effective plant control.

c. Implementable in presently known problem areas of the Jacksonville District for evaluation on an operational scale.

However, the empirical engineering data needed to evaluate how best to accomplish and sequence each function were not available, and, therefore, responses to Requests for Proposals (RFP's) from industry to develop systems for both floating and submersible plants were, after review of industry proposals, not completely adequate. Procurement was initiated for a system for submersed plants, but it was felt that the specifications in the new RFP's for a system for floating plants were stated in much too general terms to ensure that efficient and reliable systems would result from any of the proposals submitted. This report describes a series of experiments designed to generate data pertinent to the estimation of cutting rates for submersed plants, transportation rates using natural forces as well as pushing and rafting of the plant material, conveying rates, and land storage requirements when plant disposal is obtained by natural decomposition of the plant residue.

Purpose and Scope

6. The study reported herein was directed toward:

a. Cutting (submersed plants only): Measuring the cutting rate and establishing the cutting efficiency of a high-quality underwater cutter.

b. Transporting: (1) establishing an empirical relation between the force required to pull or push rafts of plant material as a function of raft size and speed; (2) determining the adequacy and the ease of construction of raft booms made from off-the-shelf expedient materials; and (3) investigating, theoretically and experimentally, the direction and rate of movement of waterhyacinth propelled solely by natural force.

c. Conveying: Measuring the production rate and manual labor intensiveness of selected off-the-shelf conveyors.

d. Disposing: Establishing the relation between the percent volumetric reduction of natural decomposing plant material as a function of time.

7. Part II of this report discusses the field test program including the test sites, rationale for the experimental design, test procedures, and data collected. Part III presents an analysis of the data and its implications in the development of systems concepts; Part IV presents the discussions; and Part V presents the conclusions and recommendations.

PART II: TEST PROGRAM

Test Areas

8. For the most part, the field experiments were conducted in central Florida on the St. Johns and Withlacoochee Rivers in approximately the same location as the Aqua-Trio tests referred to in paragraph 2, where the predominant aquatic plant problems consist of waterhyacinths and hydrilla, respectively. However, hydrilla decomposition tests were conducted in the vicinity of Orange Lake (see Figure 1).

Withlacoochee River

9. The Withlacoochee River basin is a poorly drained area covering an area in excess of 400 square miles.* The river includes numerous lakes and ponding areas along its path with currents in the lakes and in the wider portions of the river very slow to still. The river bottom is sand high in organic matter. The experiments were conducted at locations where the aquatic plant problems were similar to that commonly encountered in the Jacksonville District. Figure 2 is a plan view of the Withlacoochee River showing the approximate locations of the cutting operation, the harvested material storage area, and the conveyor station at the takeout point. As can be seen in Figure 2, tests were conducted along the river from Nelson Lake to Jumper Creek. During the testing period or summer season, measurable water currents were found to be in the order of 0.12 ft/sec and these values were observed only in the narrow portions of the river. With this low-flow condition, the hydrilla were completely topped out (see Figure 3). However, in high water periods, the hydrilla can be 1 to 2 ft or more below water surface. Also, there are numerous old stumps and snags below the water surface.

Orange Lake

10. Under a contractural arrangement, the Jacksonville District was conducting a hydrilla control operation on Orange Lake. This

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* A table of factors for converting U. S. customary to metric (SI) units of measurement can be found on page 6.

a. Topped out hydrilla north of Bonnet Lake (August 1977)

b. Topped out hydrilla north of Highway 48 bridge (August 1977)

Figure 3. Plant infestation on the Withlacoochee River, Florida

operation resulted in a readily available large quantity of plant material whose natural decomposition rate could be systematically studied to yield data for estimating harvested hydrilla storage requirements. The storage area for Orange Lake was located in an abandoned orange grove at a location convenient to the takeout point (see Figure 4).

St. Johns River

11. The St. Johns River is the largest stream flowing through central Florida and it has a history of problem waterhyacinth infestation. It flows north and covers a distance of approximately 300 miles. Starting in the southern midsection of the state, the river width is a few hundred feet; in the northern areas some points are more than a mile wide. There is very little change in elevation from its beginning to its end, located in Jacksonville. There is always a measurable current in the main channel of the river; however, the large lake areas have significantly less current than the main channel.

12. There appeared to be changes in current velocity and direction at the surface of the water within the test area. Fluctuation of water level, due to wind and possible tidal factors plus a normal small water flow, does affect movement of waterhacinth. Wind in central Florida during the summer is from the south-southeasterly direction during the morning hours switching to the west-southwest during the afternoon. Two to four miles per hour is normal, with gusts up to 10 to 15 mph. It is not unusual to see plants moving upstream due to a combination of the wind and possible tidal effects during the morning hours.

13. The hyacinth mechanical control experiments were conducted on Morrison Creek (Figure 5), a cutoff from the main river channel. This oxbow had measured water current up to 0.25 ft/sec in the thalweg. The water body is 150 to 200 ft wide. The height of the bank above the water surface varied from less than 1 to greater than 10 ft. In the area where the tests were conducted, the bottom sloped gradually to 12 to 15 ft at the deepest point. A 10- to 12-ft fringe of attached waterhyacinths mixed with ditch grasses existed in the test area. Free-floating plants were common in protected coves along the outer bank

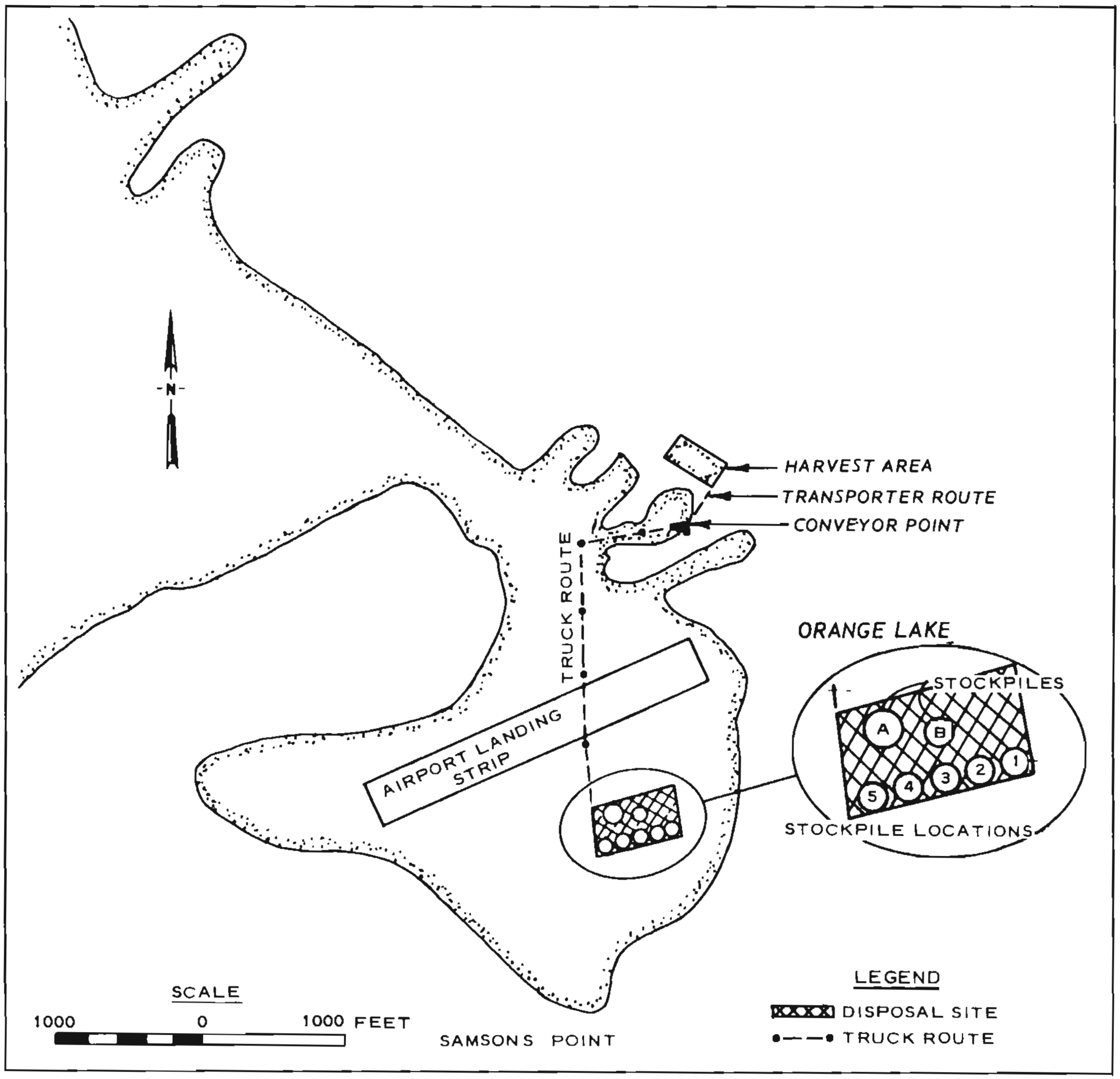


Figure 4. Test site for observing natural decomposition of hydrilla

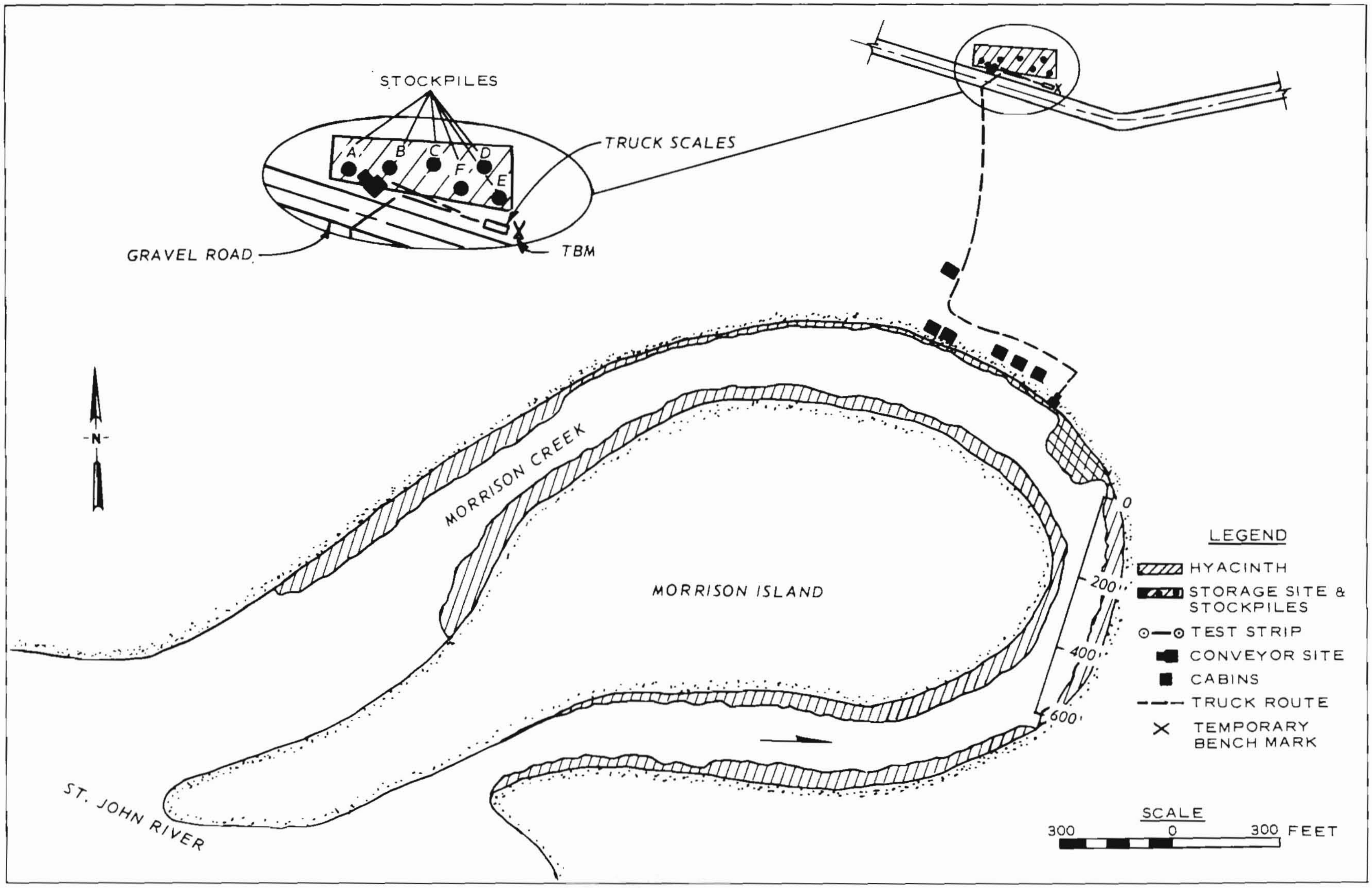


Figure 5. Test site for mechanical control of hyacinth experiments

Figure 6. Hyacinth infestation of the fringes of Morrison Creek (August 1977)

(Figure 6). Biomass quantities ranged from about 75 to 115 tons/acre.

Submersed Control Equipment and Test Procedures

14. The equipment and test procedures selected resulted from the consideration of major improvement goals in mechanical systems for aquatic plant control. First, it was hoped that, when and where possible, making better use of natural forces could aid in the control of the plants by lessening the energy requirements for control systems. Second, it was felt that through a better understanding of the capability to perform each of the basic functions comprising a system, a system could be configured that minimized the weakness of each activity. At the same time maximum use could be made of those activities that could be accomplished more efficiently. This section describes the equipment and procedures used for the experiments dealing with the cutting of the submersed plants, on-water transport of hydrilla, conveying the material across the water-land interface, and disposal of the plant biomass due to natural decomposition.

Cutting

15. As stated in paragraph 3, the plants must first be cut at some depth below the water surface and then allowed to rise such that they can be moved to the takeout point by pushing or towing after they are confined with booms or by letting them float to the takeout point with the natural currents. The cutting function was accomplished with the cutter boat manufactured by Carver Aquatics, Inc. (see Figure 7). The manufacturer's specifications for the equipment are listed in Appendix A. The cutter has the capability of making either an 8- or 12-ft cut to a depth of 4 ft.

16. The cutting production rate, in number of acres per hour, depends on the forward speed of the cutter and the amount of overlap between successive cutting passes. The Production Rate (PR) at 100 percent efficiency, i.e. no overlap, can be expressed:

$$PR = \frac{\text{cutter width} \times \text{speed}}{43{,}560 \text{ ft}^2}$$

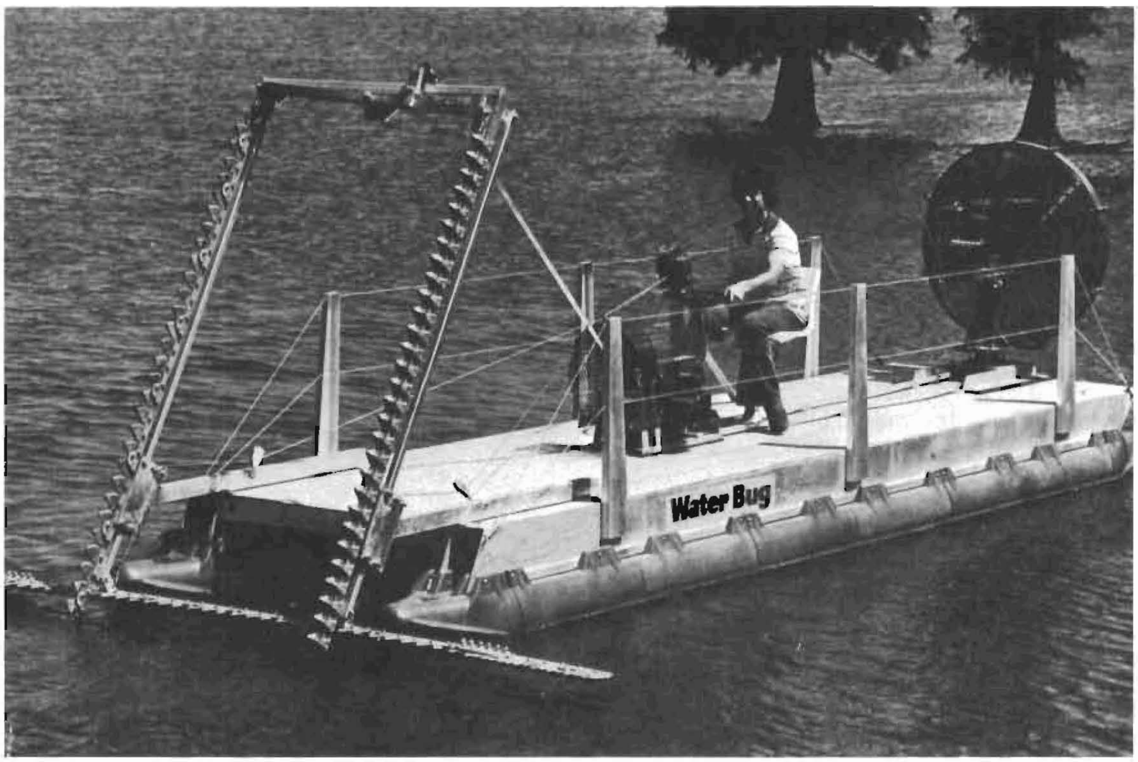


Figure 7. Equipment used for implementing the cutting function for submersed aquatics

Production Rate is measured in acres per hour, cutter width in feet, and speed in feet per hour. The actual or field PR is a more meaningful parameter to use in estimating the efficiency of the cutting function. Two types of tests were conducted such that an efficiency factor E_f could be derived. The first series of tests involved making two or four cutting passes on long lengths (1 to 3 miles in length) in the center of the Withlacoochee River from Nelson Lake to Jumper Creek. In these tests, the cutter boat was run at full throttle, if possible; however, in light vegetation the drag on the boat was sufficiently low to permit speeds that were too fast for clean cutting when the cutter bar was operating at a fixed 96 cycles/min; in this situation, the cutter was slowed to a speed that was compatible with the cutter bar rate.

17. Data collected on each test included date; cutter operator; test location; weather conditions; water current speed; wind speed; water depth; plant type, density, and condition; cutter width and depth; cutter pass number; length of pass; and time required to make the pass. An example of the form used to record the data in the field is shown in Figure 8.

18. The second type of tests was directed toward generating efficiency data when the cutting strategy was directed towards developing large open areas in a plant infestation in a lake environment. To conduct these tests, square and rectangular plots 1 acre in size were surveyed and floating buoys were placed in each corner. Starting at one corner the cutter made successive parallel passes through the plot such that complete and clear cutting of the plant resulted. The data recorded for these tests were identical to that described in the previous paragraph. From these data, cutter speed in miles per hour, field production rate, and field efficiency were computed. The recorded and computed data for both types of tests are tabulated in Table 1.

Transporting

19. Three methods for transporting the cut plants to the takeout point were investigated: free floating, towing, and pushing. Each method was carried out as described in the following paragraphs.

20. Free floating. The free-floating tests were conducted by

Location: Withlacoochee River
(to end of Hwy. 48 & return)

Plant type: Hydrilla

Weather: Clear

Plant density: 8-10 tons/acre

Water current: 0.008 mph

Plant condition: 50% topped out, 50% 4 in. below surface

Wind current: 0-5 mph

Cutter width: 12 ft

Water depth: 3-8 ft

Cutter depth: 3-4 ft

Date: 6-28-77

Area size: 10,270 ft x 23 ft

Oper: S. Shirley

Area cut: 5.4 acres

Test No.	Pass No.	Pass Length (ft)	Cut Width (ft)	Time Elapsed (min)	Cutter Speed (mph)	Field Production Rate (ac/hr)	Field Efficiency	Remarks
2	1	10,270	12	82	1.42	2.07	100%	Good cut
2	2	10,270	11	89	1.32	1.75	92%	Two stops required due to cutter bar hitting bottom
							Av. 96%	

Figure 8. Data form used to record cutting test results

measuring the time it took the plants cut from a measured patch of hydrilla to move from the location of the patch to a towing boom secured to two 1-1/2-in. steel pipes placed in the stream on either side of the thalweg such that the secured net would trap all the severed plants. The boom consisted of a 100-ft length of 6-ft-deep, heavy duty nylon gill netting, 2-in.-square mesh. To provide proper flotation of the net, a 3/8-in.-diam braided polyfoam float line was tied to the top of the net; to ensure that the net hung vertically in the water, a 5/16-in. leadcore line was attached to the bottom. Three tests were conducted in this series in the main river channel between the location of the towing boom (Figure 9) and the Highway 48 bridge over the Withlacoochee River. The data recorded for each test included the patch size, biomass, water speed, distance traveled, and time of travel. From the distance and time data, the rate of movement of the plants was computed. All the data are shown in Table 2.

21. Towing tests. The towing tests were conducted using the plant material trapped in the free-floating tests. Once all the plant material reached the towing boom, one end was unfastened and moved by use of small flat-bottom boats to the other end, such that when the two ends were fastened together, the plant mass was completely encircled. In an attempt to keep the net depth proper during towing, each end of the net was tied to a 6-ft length of 3/4-in. galvanized pipe. These two pipes were secured together with a towing harness that kept the pipes vertical under tow. Figure 10 shows the towing boat attempting to pull an encircled mass of hydrilla through the test course. The specifications for the towing boat are given in Appendix B. Data collected during towing tests included towing force measured directly from the towing line with a calibrated Baldwin Lima Hamilton (BLH) 1000-lb load cell, readout on a battery-operated digital voltmeter, distance traveled, time of travel, water speed, and plant biomass. Because of problems encountered in completing the tests due to difficulties in keeping the plants contained, qualitative observations were also recorded. These data are shown in Table 3.

22. Pushing tests. The pushing tests were conducted along the

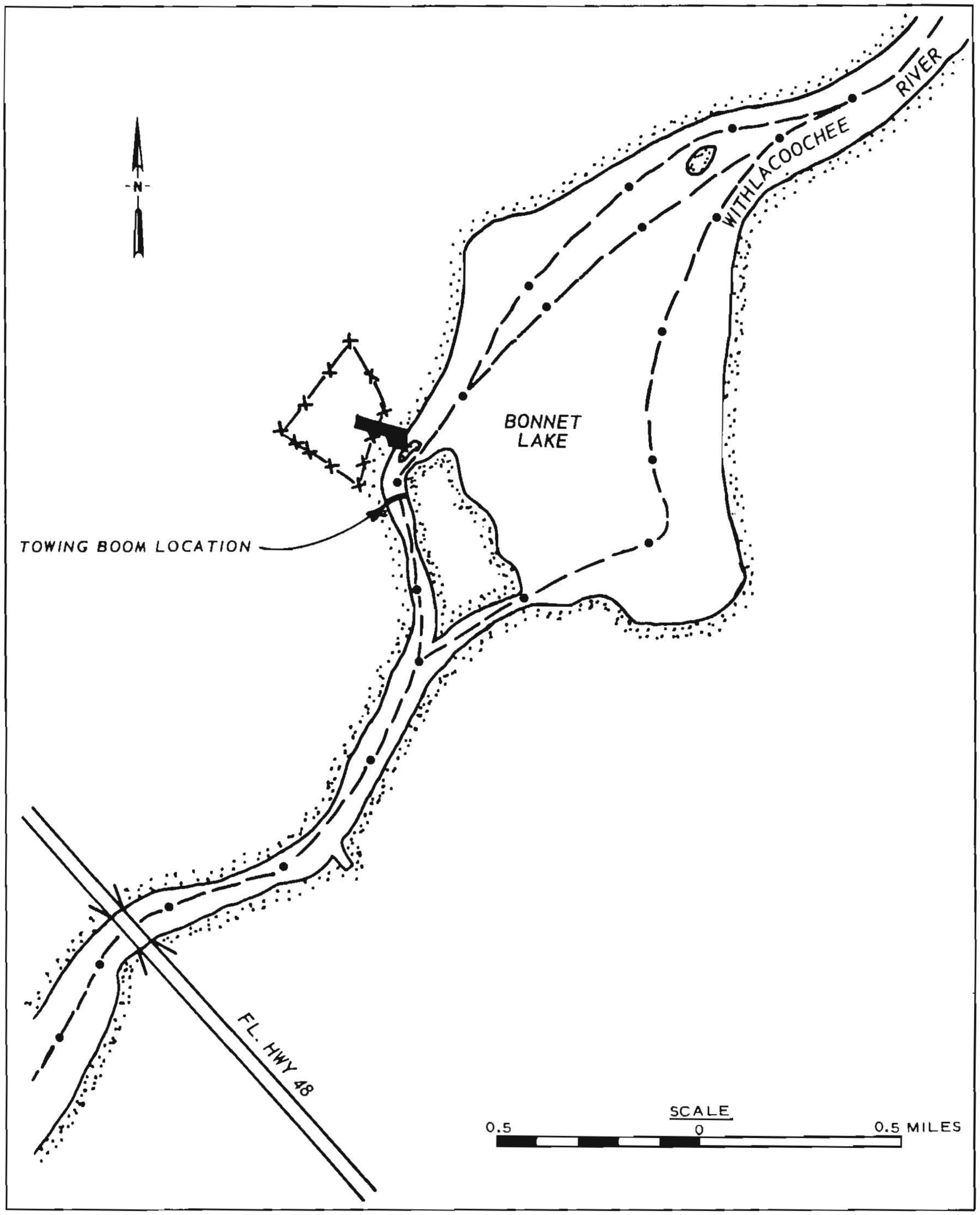
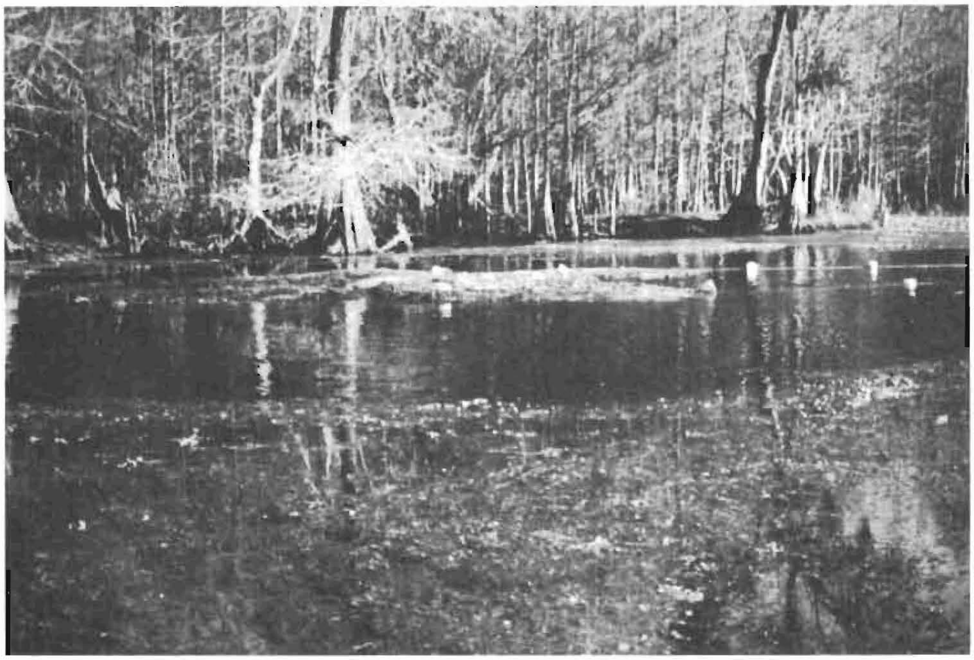


Figure 9. Location of the free-floating transport tests



a. Net in place for towing test

b. Towing boat and boom executing a towing test in hydrilla

Figure 10. Towing test in submersed aquatics

cut in Bonnet Lake (see Figure 9). The pushing rake mounted on a flat-bottom boat was used in the tests (Figure 11). The specifications for this equipment are shown in Appendix C. A load cell was placed between the upper cross-members of the pusher assembly and the electrically actuated worm gear used to raise and lower the rake so that the horizontal force required to move the rake and plant material through the water could be readily measured with a digital voltmeter. To conduct the test, plants were cut along the edge of previously cleared channels to a depth of 4 ft. These plants were then allowed to float into the open channel. The pusher boat was then driven from the clear channel directly into the floating plant mass to initiate the test. The test was continued by allowing the boat to move slowly forward in a straight line until the test had to be aborted due to loss of plant material or fouling of the engine propeller. Data collected from three typical tests are given in Table 4 and include: test number, date, biomass, distance traveled, time, pushing force, and a narrative statement of the reasons the test had to be stopped.

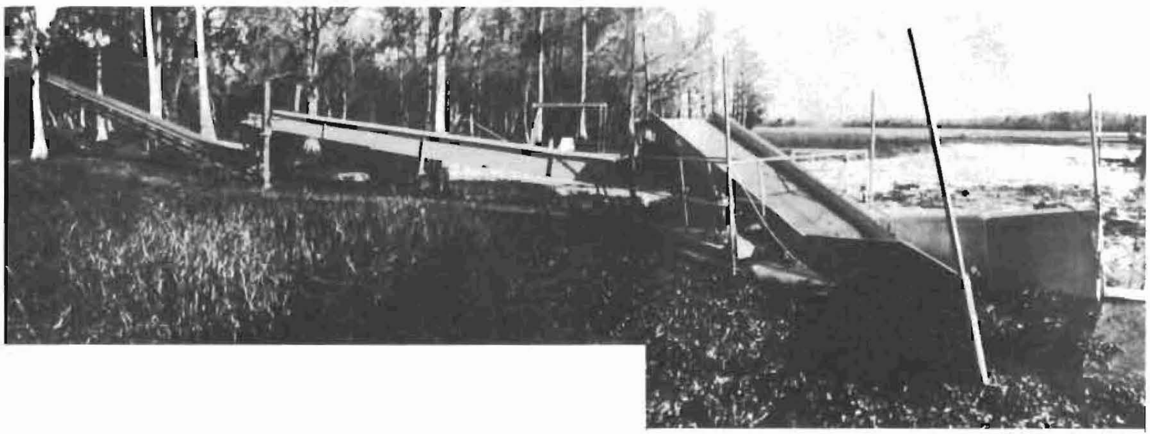
Conveying

23. Sometimes it may be permissible to dump the collected submersed plant material directly into the water body. However, this could potentially cause undesirable nutrient enrichment and it is probably more desirable to move the plants onto the shore for decomposition. To obtain equipment to accomplish this function, procurement was completed for a submersed aquatic removal elevator system that consisted of three components: a floating, elevating conveyor system; a horizontal conveyor system; and a land-based elevator conveyor. Figure 12 shows the three conveyors in place. Past experience with emersed conveyors suggested that the floating, elevating conveyor would develop water currents that would repel the incoming floating plants and thereby be a potential pacing problem in these tests. However, design and testing of advanced concepts to make a major improvement in this function was considered but deemed too time-consuming and costly to be incorporated into this study. The water-based conveyor was built from WES specifications that did not include these considerations by the Aquamarine Corporation,

a. Pusher rake in the travel position

b. Pushing rake with plants after traveling approximately 80 ft in a hydrilla biomass infestation of 12 tons/acre

Figure 11. Boat-mounted pushing apparatus



a. Floating, elevating conveyor positioned to unload directly into the horizontal conveyor and land-based elevating conveyor

b. Overhead view of land-based, elevating conveyor being used to stack hydrilla

Figure 12. Submersed aquatic plant removal elevator system

Waukesha, Wisconsin. The 32-ft horizontal conveyor was the Aquamarine Model No. W-455, and the land-based conveyor was Little Giant Model M-21, manufactured by the Portable Elevator Division, Dynamics Corporation of America, Glencoe, Minnesota. Additional descriptive material on the three components is given in Appendix D.

24. The plan for conducting the test involved setting up the three components as illustrated in Figure 12. This was intended to allow running a continuous operation by cutting plants upstream from the takeout point and allowing the plants to drift into the boomed area where they would be forced by natural elements into the throat of the floating conveyor. Because the water stage was very low at the time of the test, the floating conveyor could not be positioned in deep enough water and in sufficiently fast currents to ensure that the plants would feed properly into the conveyor throat. For this reason, the test conducted was directed more to evaluate the mechanical performance of the system rather than its throughput capacity. These tests were conducted by pushing (with one pusher boat) the plant material that floated into the boomed area into the conveyor throat where the material was subsequently manually raked onto the conveyor belt using a raker on each side of the floating conveyor. During selected tests, data on the amount of time the equipment was operated, biomass handled, and frequency and causes of malfunctions were recorded. Results of three of these tests are summarized in Table 5.

Disposal

25. As can be seen in Table 5, the biomass quantities resulting from the operations on the Withlacoochee River were small and not sufficient for meaningful evaluation of the natural decomposition of the large volumes of hydrilla that would be expected to occur in most control operations. As stated in paragraph 10, large quantities of hydrilla were being removed from Orange Lake by the Jacksonville District and the disposal tests were conducted there. The hydrilla was removed from Orange Lake with the Aqua-Trio system and subsequently trucked to the disposal site. En route to the disposal site, the loaded truck was weighed to determine the amount of material placed in each of the seven

piles indicated in Figure 13. The scale used was a Highway Load-O-Meter, Type A, load range 0 to 20,000 lb, manufactured by the Black and Decker Company. Depending on the size of the pile, the material was either dumped directly on the ground from the truck; dumped from the truck onto the ground and then stacked with a front-end loader; or dumped from the truck directly onto the ground, picked up with the front-end loader, and fed into the hopper of the land-based elevating conveyor described in paragraph 23, where it was then conveyed to the top of the stack (Figure 14). To obtain data that simulated a number of operational scenarios, the stockpiles were formed in various ways. Stockpile A consisted of a total of 40 loads--20 loads on the first day, then another 20 loads nine days later. Pile B was formed in one day by the addition of 20 loads. Pile 1, also formed in one day, only consisted of 4 loads. Pile 2 was formed by the addition of 4 loads per day for two consecutive days. A total of 12 loads was added to Pile 3--4 loads per day for three consecutive days. Pile 4 also consisted of a total of 12 loads--4 loads added each day for three consecutive days. Pile 5 was formed by adding 4 loads per day for four consecutive days to total 16 loads. The data initially collected (i.e., at the day of dumping) (Table 6) included the date, number of loads, biomass, and the volume (cumulative if dumped on existing stacks). Subsequent to stacking, volumetric data (Table 7) were collected at various intervals for about 1 year after the tests were conducted. The methods used to make the volumetric measurements are outlined in Appendix E.

Floating Control Equipment and Test Procedures

26. The functions investigated in the control of floating plants included on-water transport of waterhyacinths, conveying the material across the water-land interface, and disposal of the plant biomass due to natural decomposition. The equipment and test procedures used are set forth in the following paragraphs.

Transporting

27. In a manner similar to that described for submersed aquatics,

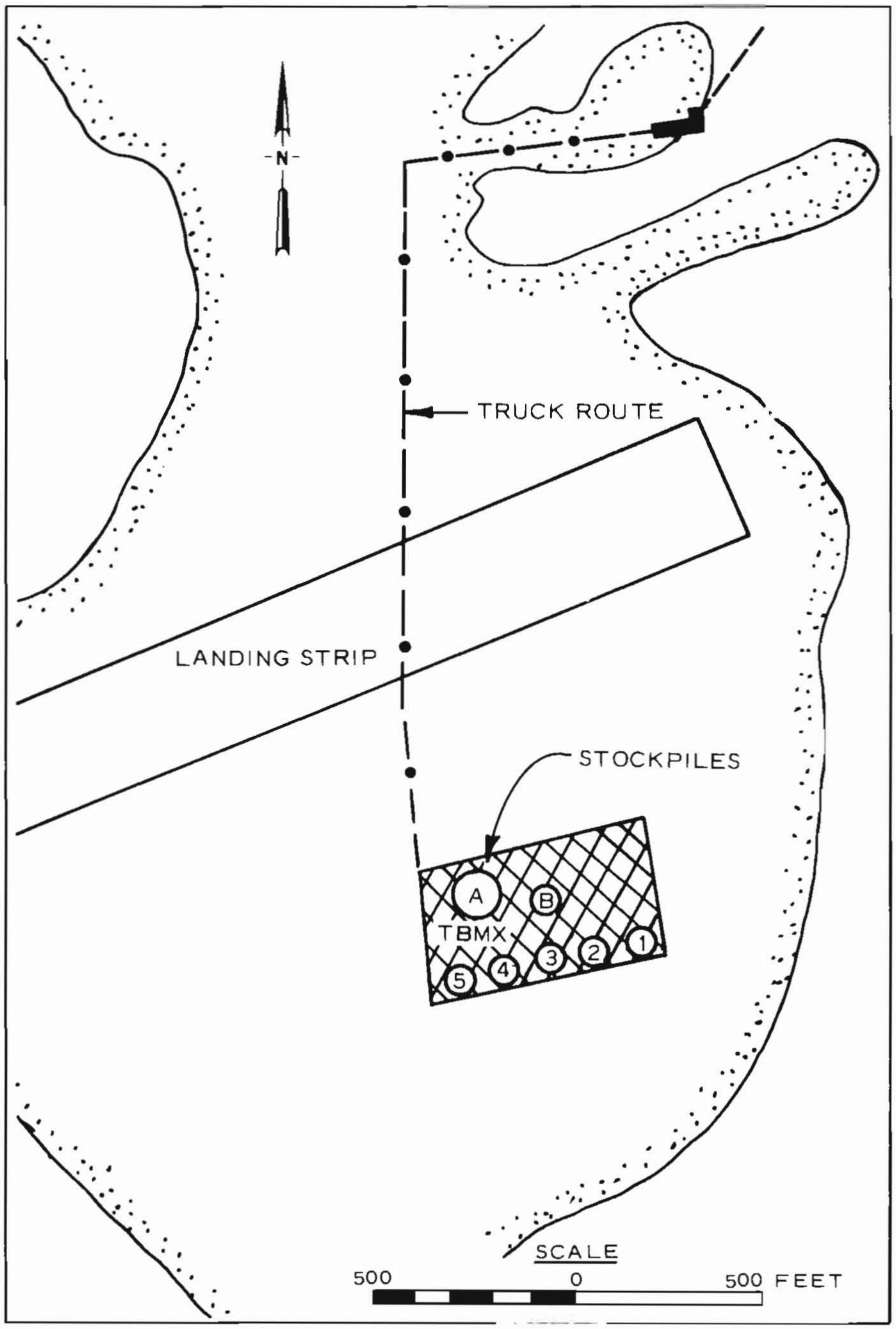


Figure 13. Layout of hydrilla disposal test stockpiles

a. Loading harvested plants into stacking conveyor

b. Stacking of harvested plants in progres

Figure 14. Storage of submersed squatics

three types of tests were conducted in regard to on-water transport, i.e., free floating, towing, and pushing.

28. Free floating. Unlike the submersed plant material, the waterhyacinth extends above the water surface and, therefore, is exposed to wind forces as well as the forces exerted by the water. For this reason, it was important to measure both the wind velocity and water speed in the free-floating tests. It was hypothesized that the floating plants would move with the wind and water currents to takeout points equipped with booms and conveyors such that external energy for on-water transport would be held to a minimum. For this reason, it was important to test the mobility of floating plants moving under natural forces in both the mainstream of the St. Johns River and in Morrison Creek. This location was considered adequate for the tests, plus it was near where other tests were being conducted and the movement of the plots could be monitored at closer time intervals without increased expense. Six plots of various sizes and shapes were chosen and several plants in each plot were tagged with high-visibility surveying tape to provide a means for visually monitoring the plots as they moved in the river. After the plots were tagged, their movement was monitored until they moved out of the test area or they lodged against the edge of the river. The location of the plants was measured on 1:25,000-scale maps at the various times indicated in Table 8. Distances traveled from the starting point for the times indicated were measured off the maps and recorded in Table 8 along with size and shape of the plot and the wind and water speed.

29. Towing. The towing tests on floating plants were conducted along a 600-ft test course marked off in the easternmost section of Morrison Creek as shown in Figure 5. The same boat, towing apparatus, and force-recording device described in paragraph 21 for the submersed plant towing tests were used in the floating plant tests. Four different sized plots were used in the test. To conduct the tests, the plots were surrounded with rope and towed at a constant rate of speed (speeds ranged from 0.5 to about 2.5 mph) along the 600-ft test course and then towed back in the opposite direction (see Figure 15).

30. Repeated tests were made using the same plants and increasing

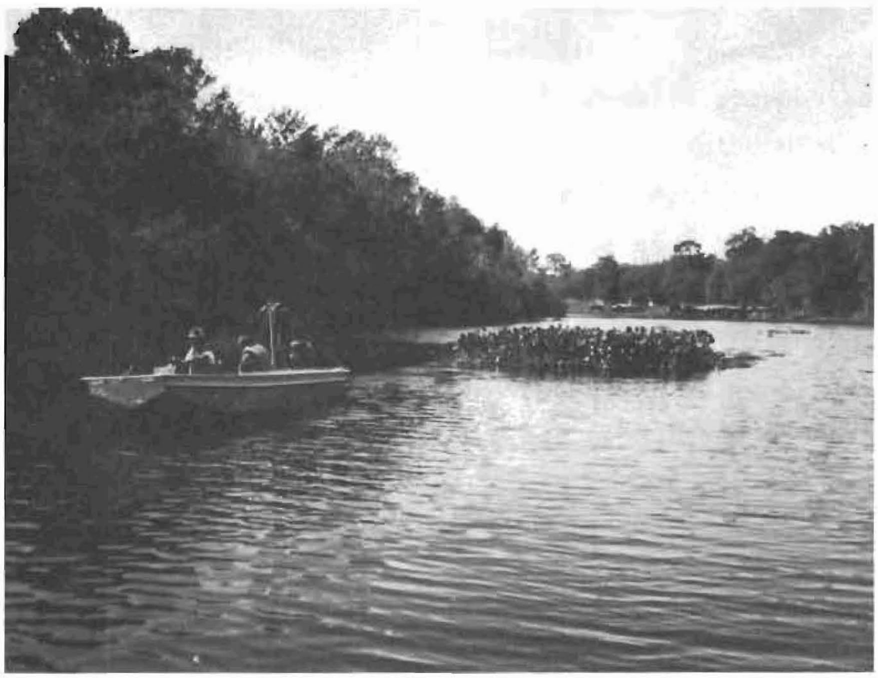


Figure 15. Floating plant towing test in progress

the towing speed until the plants would not stay in their enclosure. Another size area was chosen and repeated tests were performed. During each test, force readings were recorded every 15 sec and an average force was computed over the time taken to traverse the test course. From the traverse time an average speed in miles per hour was computed. These averages of force and speed were plotted at the end of each test and have been reproduced in Plate 1. Table 9 summarizes the other data collected, i.e., area of the plot, shape of the plot, plant height, root length, and encircled density. Also, observations made on the behavior of the plant mass under towing were recorded in the field log.

31. Pushing. The pushing tests were conducted in the same test course as was used in the towing tests described in the previous paragraphs. As with towing tests, four plots of various sizes were used. Each plot was encircled with rope to maintain its integrity during the test; then each was pushed using the pusher boat described in paragraph 22, at a constant rate of speed along the 600-ft test course and then pushed back in the opposite direction (see Figure 16). The same group of plants were again pushed, but the pushing speed was increased. This process was continued until water resistance forced the plants off of the pushing rake.

32. In preparation for the pushing experiments, tests were also conducted to determine the force required to push the expanded metal rake through the water at three different depths for various speeds. In the beginning, it was assumed that the metal rake being in the water would contribute significantly to the overall force required to transport the plants by pushing. It was observed during the pushing tests that the roots from the hyacinths formed a smooth surface on the bottom of the plot and in front of the rake; therefore, it is believed that the rake actually contributed very little, if any, to the overall pushing force requirement. As it was not possible to push the plants with the rake completely out of the water, the rake was positioned 6 in. deep in the water for all pushing tests. Plate 2 summarizes the pushing data, i.e. force versus speed for all tests. The plots were developed in an identical fashion to that described in paragraph 30 for Plate 1.

Figure 16. Pushing plant test shown in progress

Table 10 contains the description data recorded on each plot; it can be seen that all of the pushing plots used were considerably smaller than the towing plots. This was due to the physical size of the rake.

33. Conveying. To conduct the conveying tests, use was made of a wheel-mounted aquatic plant removal conveyor-elevator system. This system (Figure 17) was procured from Carver Aquatics, Minden, Louisiana, who built the system from the specifications listed in Appendix F. The tests were conducted on the north banks of Morrison Creek at the conveyor site shown in Figure 5. To get the necessary quantities of hyacinths to conduct conveying operations for an extended period, plants along the fringe of the creek were dislodged with the pusher boats and pushed into holding areas near the conveyor location (Figure 18). Ten conveying tests were conducted by measuring the time it took to convey enough plants to fill one truck (slightly over 1 ton) with the extracted plants. Pusher boats were used to feed the plants into the throat of the conveyor where they were then pulled onto the conveyor by rakers standing on either side. Table 11 lists the conveying time, biomass conveyed, plant height, and conveying rate obtained for all the tests.

Disposal

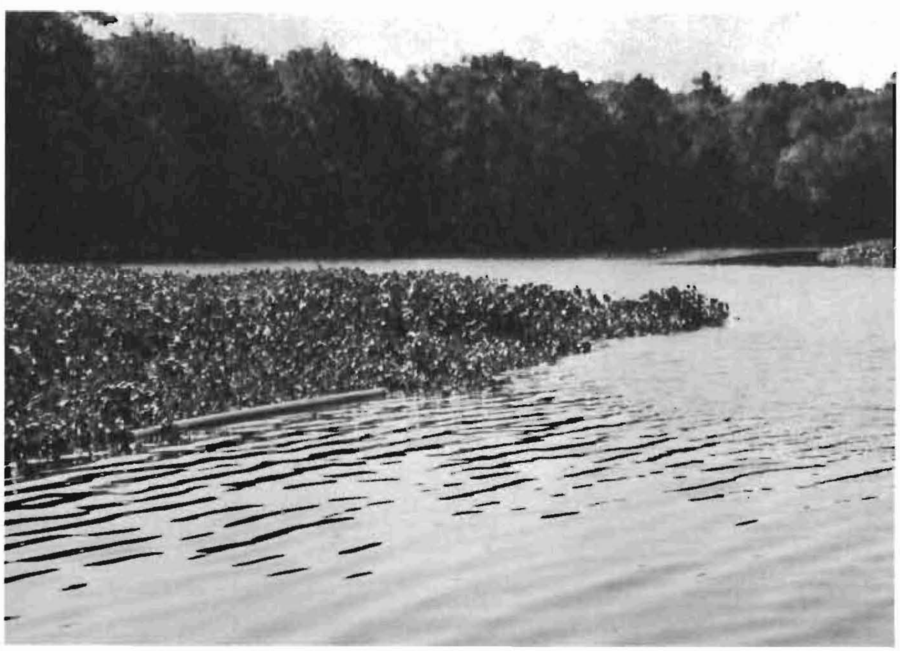
34. Even though the conveying operation described above was not capable of a production rate suitable for good plant control (i.e. 50 to 80 tons/hr), sufficient plants were removed to conduct the evaluation of the natural decomposition of large volumes of hyacinth. The hyacinth were removed from Morrison Creek with the elevating conveyor described in paragraph 33 at a private boat ramp and trucked to a weighing station at the disposal site. The dump truck (as shown in Figure 19a) with driver was weighed empty at the beginning of each work day and the weight recorded in the data log. The scale layout of the weighing system is shown in Figure 19b and was the same as that described in paragraph 25. The stockpiles were formed by dumping the weighed plants on the ground near the hopper of the land-based elevator, then picked up by the front-end loader with the bucket modified by welding tapered 2-in. pipe forks to its blade (Figure 20a), and fed into the elevator conveyor hopper. A typical hyacinth stockpile is shown in Figure 20b.

a. Side view of wheel-mounted aquatic plant removal conveyor-elevator system in operation

b. Loading view

Figure 17. Wheel-mounted aquatic plant removal conveyor-elevator system for hyacinth

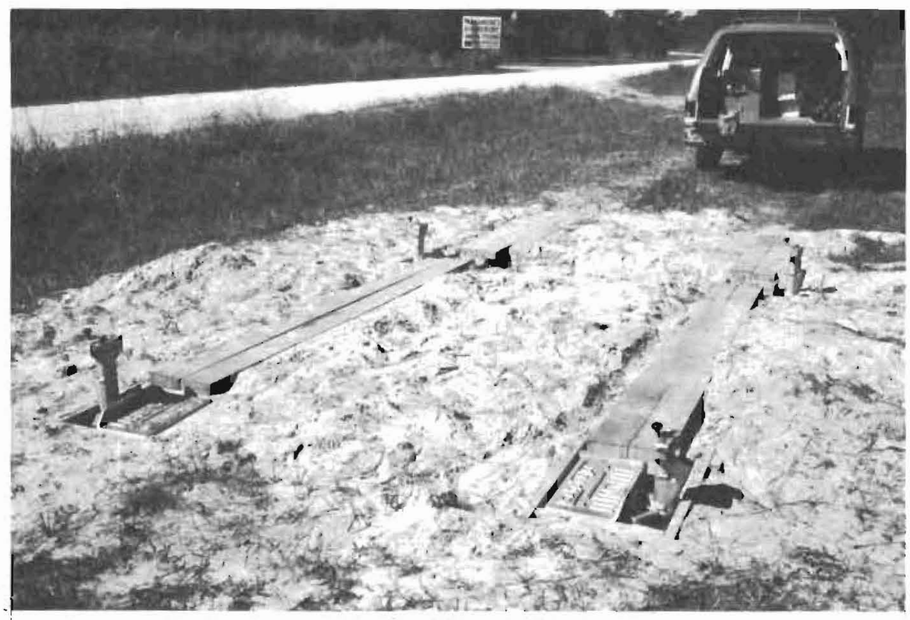
a. Pusher boat moving floating plants from fringe to the holding area



b. Holding area for floating plants

Figure 18. Floating plants in on-water storage area

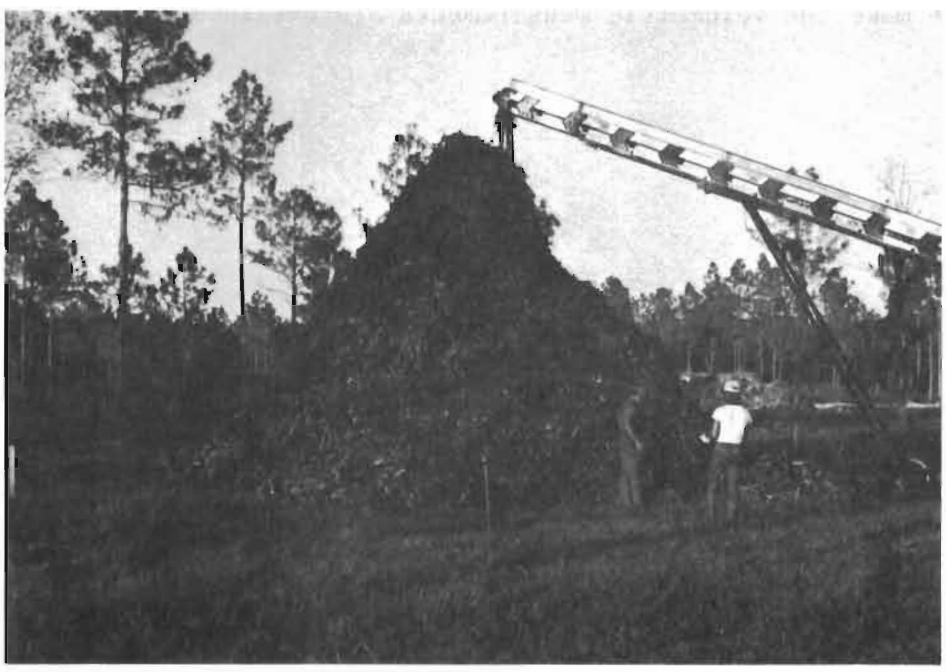
a. Weighing of empty dump truck during transporting of hyacinth to disposal site



b. Scale layout used for collecting biomass data on hyacinth

Figure 19. Plant biomass weighing station

a. Front view of land-based elevating conveyor and modified bucket used on front-end loader



b. Stockpiling of hyacinth using land-based elevating conveyor

Figure 20. Storage of floating aquatic plants

35. Six stockpiles placed as shown in Figure 21 were used to collect natural volumetric reduction data. The size and dumping interval were chosen to be representative of an operational disposal system occurring in a riverine environment. Stockpile A contained a total of 8 loads of plants placed in the same day. Pile B consisted of a total of 40 loads of plants--20 loads on the first day and then placing 20 more loads ten days later. Stockpile C was made by placing 4 loads on the first day, then 4 loads on each at two-day intervals until a total of 12 loads were reached. Pile D was formed by placing 4 loads the first day and 4 more loads two days later. Stockpile E was formed in one day by the placing of 4 loads. Pile F also was formed by 13 loads placed in one day. The initial data collected (i.e., at the day of dumping) (Table 12) included the date, number of loads, biomass, volume (cumulative if dumped on existing stacks), and density. Volumetric reduction data (Table 13) were collected at various time intervals for approximately 10 months after the stacks were completed. The methods used to make the volumetric measurements are outlined in Appendix E.

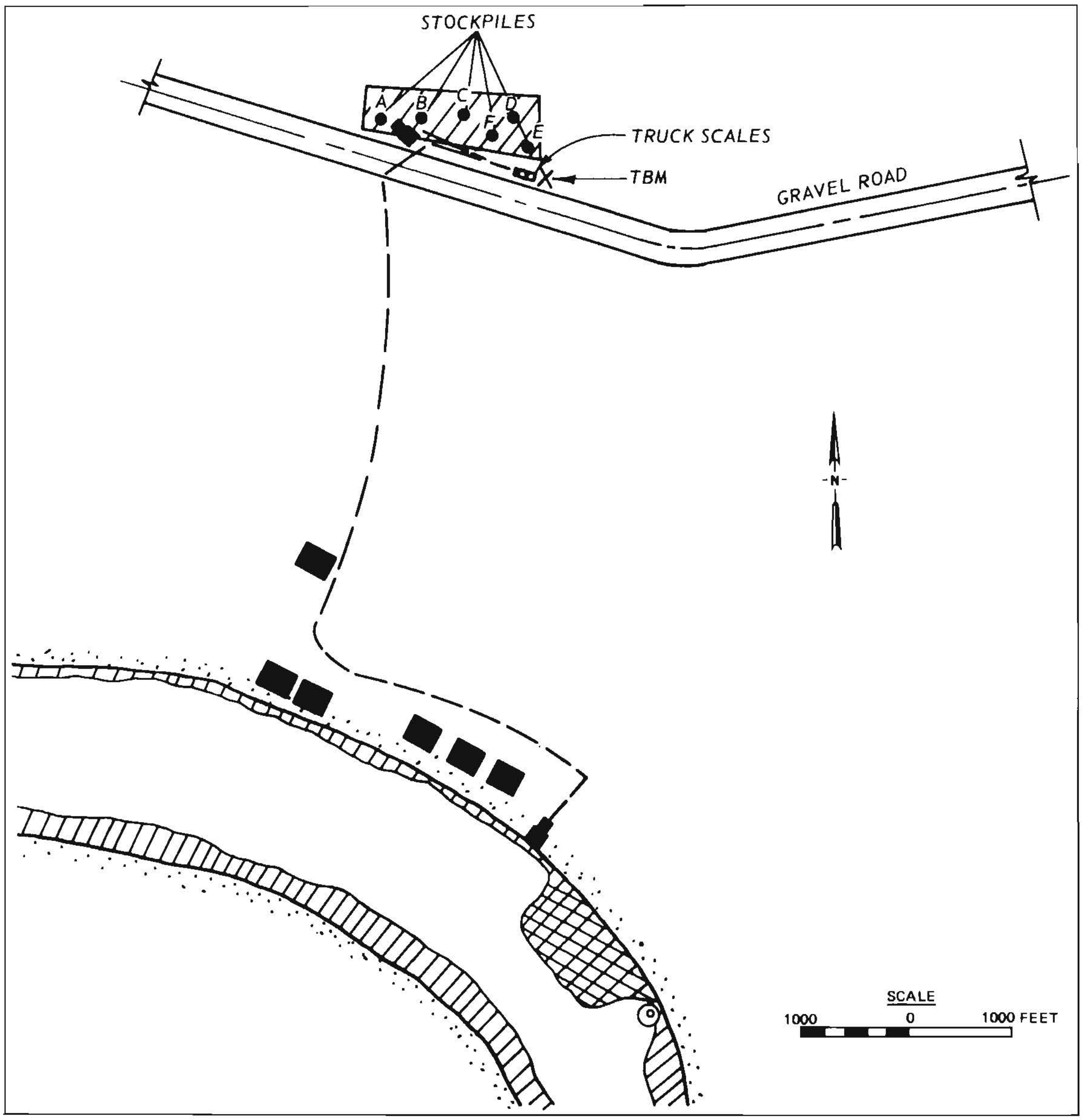


Figure 21. Layout of hyacinth disposal test stockpiles

PART III: DATA ANALYSIS

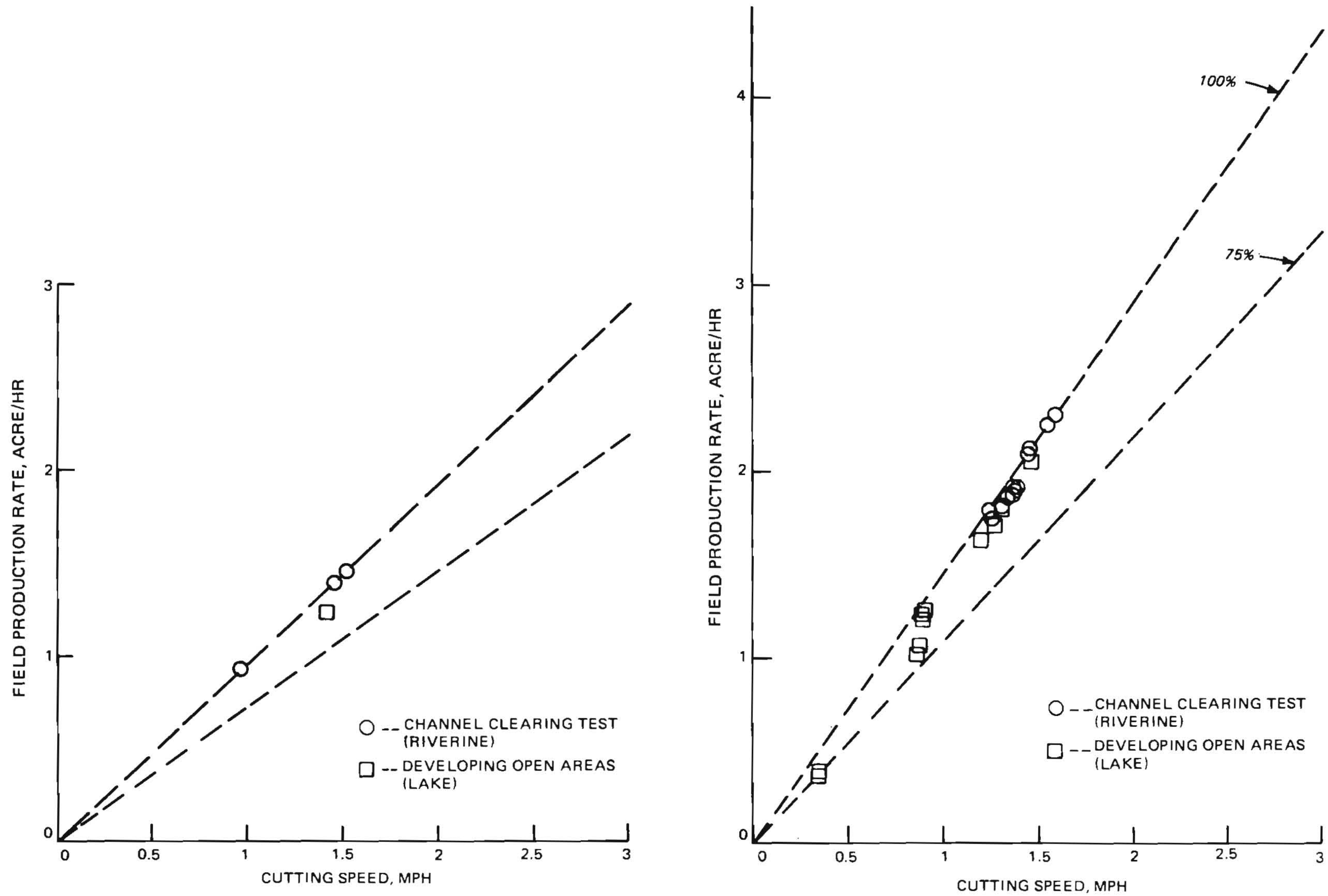
36. An analysis of the data collected using the procedures discussed in the previous section concerning both floating and submersed plants is the subject of this part of the report. In general, the analysis is directed toward deriving the data outlined in paragraph 6 and, where possible, the information has three aspects. The first deals with theoretical or intuitive projections of how well each function could be accomplished using the methods previously discussed. These projections were made prior to the conduct of the tests to assist in arriving at a test design. Next, the measured performance values are discussed and compared with the projected performance; finally, where possible, the implication of the results in regard to how they apply to the evaluation or development of one or more advanced mechanical systems is put forth.

Submersed Aquatics

Cutting

37. Prior to conduct of the field tests described in paragraphs 16 and 17, Equation 1 was used to estimate cutter field PR for cutter widths of 8 and 12 ft if the cutter traveled between 0 and 3 mph and cutting could be effected at 100 and 75 percent efficiency. From these curves, it can be seen that at high efficiency rates, productivity in excess of 4 acre/hr could be accomplished with a 12-ft cutter moving at 3 mph. It was hypothesized that the cutting efficiency would be between 75 and 100 percent due to the necessity of the operator to overlap the swaths on successive cuts. Further, it was anticipated that water speed and depth, submersed obstructions, wind speed, and plant density would further reduce the forward speed of the cutter and thus reduce the field PR. However, empirical data were not available to estimate these effects either individually or synergistically prior to the tests. As stated in paragraphs 17 and 18 and listed in Table 1, these latter parameters were measured in each test.

38. The planimetric field efficiency listed in Table 1 for the 12-ft cutter operating in riverine environments is plotted in Figure 22. In the majority of these tests, the operator had little trouble controlling the boat and the overlap between successive cuts was consistently about 1 ft. For this reason, the planimetric field efficiency ranged from 94 percent on test 25 (where four passes were cut) to 100 percent on those tests that involved only one pass. A study of Table 1 will reveal that the forward speed of the cutter moved from 1.25 mph on test 21 to 1.59 mph on test 19. The relatively fast speeds on tests 18 and 19 resulted from having a 5- to 12-mph tail wind and the fact that no stops for clearing the cutter from snags or filamentous algae were required. The effect of wind in this case was positive; however, in other cases (test 23) the effect was both positive and negative emphasizing that the cutter boat did not have sufficient power to negate adverse wind effects. Because the tests were conducted in a rather typical section of the Withlacoochee River in terms of realistic conditions expected on routine operations (i.e. snags, occasional shallow water depths, wind speed, etc.), it appears reasonable to expect the same range in overall production rates (i.e., from about 1.75 to something less than 2.3 acre/hr) if the same equipment is used in routine riverine clearing operations where a few long cutting passes are sufficient. On test 18 the operator observed that the hydrilla was quite uniform with densities ranging from 8 to 10 tons/acre which resulted in almost ideal cutting conditions for this cutting machine; whereas on test 30 the operator observed that the density varied along the pass and in the low-density areas and the cutter had to be slowed to prevent tearing the plant and to effect clear cutting. This suggests that increased translational speed of the cutter bar would result in higher field production rates. However, the same shortfall (i.e., the need for a bar that will cut at higher forward speeds) could be overcome by using a cutter made with dual blades that move longitudinally along the bar in opposite directions or possibly using smaller cutting knives so that more cuts could be completed in a given length of time.



a. 8-FT CUTTER

b. 12-FT CUTTER

Figure 22. Hydrilla cutting speed vs. field production rate with planimetric efficiency

39. Because of the rectangular layout of the lake environment clearing tests, it was anticipated that the planimetric field efficiency would be less in these environments than those resulting riverine trail clearings. The results listed in Table 1 verify this assumption. However, in most cases, even where a relatively large number of passes (≈20) were involved, the planimetric efficiency was in the order of 90 percent and, even in tests 14 and 15 where the planimetric field efficiency was between 75 and 80 percent, the reason was not because the operator was unable to control the blade but because hydrilla that was sprayed with herbicide 2 weeks prior to the cutting tests matted such that the blade guide on the cutter bar held the plant mass away from the cutter knife. In those cases the plant material bunched ahead of the boat and, after a short period, the force required for forward motion exceeded the boat's propulsion capability.

40. Figure 22 shows the average cutter speed, and therefore the field production rate, to be somewhat less than that obtained in the longer passes accomplished for riverine environments. The attempts to clear cut the rectangular area necessitated the operator to traverse a specified area whereas he often could negotiate around matted plants, snags, and other obstructions in the longer passes avoiding stops for clearing the cutter. Also, it should be noted that the production rates may be somewhat optimistic because turnaround time was omitted in these computations; however, the inclusion of this time in the computation was considered to be unrealistic because in routine operations the area to be cleared would normally be much larger than the area used in the tests, thus decreasing the adverse impact of the boundary conditions that existed in the experiments.

41. Four tests were conducted with the 8-ft cutter; however, as no appreciable increase in speed could be obtained over that obtained with the 12-ft cutter, the production rate decreased accordingly. Except for ease of moving the cutter in and out of the water and getting it ready for operations, there appears to be no advantage to using the 8-ft cutter.

Transporting

42. Free floating. Development of an efficient method for transporting the plant material from the site where control operations are being conducted to the onshore conveyor site is recognized as a major pacing problem in developing a high-productivity mechanical control system. In terms of energy consumption, the most efficient concept for transporting the cut submersed plants would be one that made maximum use of natural forces to transport the plants to the takeout point. Prior to the conduct of the tests discussed in paragraph 20, it was assumed that cut hydrilla would rise to the surface and travel with the water current to a selected point downstream. Wind was assumed to have little effect on the transport of the cut submersed plants. Table 2 summarizes the results of the three tests conducted and it can be seen that the plant and water speed are essentially the same although in test 1 the surface wind did appear to impede the plant mass to a small extent.

43. From the test results and field observations, it appears that transport using natural forces has potential not presently being exploited in mechanical control operations. For example, observations made while cutting approximately a 6-mile trail operationally from the south end of Nelson Lake to the confluence of Jumper Creek and the Withlacoochee River (see Figure 2) showed that the material would move out of the cut area downriver in low-flow conditions even though the trail was narrow (23 to 40 ft) and sinuous. Very little of the plant material cut in this operation was found downstream as far as Wysong Dam. It appeared that most of the material was dispersed by boat traffic induced by waves that transported the material to the top of plants growing along the fringe of the river where it tended to decompose. Although the experimental data and the qualitative field observations are not conclusive, it is the author's opinion that in many reaches of the highly hydrilla-infested Withlacoochee River, just cutting 23-ft-wide trails, 4 ft deep, on a monthly interval during growing seasons would probably suffice to keep the river open for many recreational uses. However, to implement this technique or variations of it that involve extracting from the river periodically on the Withlacoochee River or similar rivers, requires

that operations people develop an understanding of natural flow patterns of the river over the stages repeated during the hydrilla growing season so that cutting schedules and the location of cutting lanes and takeout points could be selected properly.

44. Towing. Following the concept of using less energy to mechanically control aquatic plants, the analysis of the results of the tests described in paragraph 21 of containing cut submersed plants within a net and towing the plants to an on-the-water holding area addresses two major points. First, as stated in paragraph 6, it was desirable to study the case with which readily available off-the-shelf materials could be used as expedient containment and rafting booms. Next, it was important to get an idea of the relationship between towing force and speeds for various quantities of plant material. Since there were no data available on the towing forces required to tow mats of plants, preliminary tests using a large work barge to simulate a large mat of about 3 tons of plants were conducted. It was estimated that a towing force between 500 and 1000 lb would provide the towing speeds of up to about 3 mph which would provide a reasonable transportation rate. Therefore, it was projected that a modified (for ski-towing), 18-ft flat-bottom boat with a 50-hp outboard motor would have a sufficient forward thrust for the towing tests, and, as indicated in paragraph 21, this equipment was used for the tests.

45. In general, as can be seen from Table 3, the results on both aspects of this test were unsatisfactory. In fact, even after considerable trial and error, the booms made from readily available materials could not be made to contain even 1 ton of plant material long enough to complete the desired number of tests to generate the force-speed relations. In almost every case, once the plants were encircled and a towing force was exerted on the boom, the plant material would form a dense ball at the back of the boom netting. As the towing force was maintained, the ball was forced deeper in the water where it tended to rotate in the direction of forward motion. This rotation caused the net to travel over the top of the ball and abruptly release. During the test, no towing speeds greater than 0.65 mph were recorded and the maximum towing

force measured was 248.3 lb. In this case, only 750 lb of material was being towed. This suggests that towing forces for submersed aquatics would be rather excessive for speeds considered necessary for an operational system. It is emphasized, however, that the results are not conclusive since the inability to contain the plants made it impossible to determine more useful information on the forces required to tow various quantities of plants over the desired speed range. It is felt that any additional efforts should be first directed toward development of more efficient plant containment methods and only if these are successful would more comprehensive tests in towing submersed aquatics be warranted.

46. Pushing. Another factor considered in the concept of using less energy to transport aquatic plants from one point to another was the use of pusher boats equipped with remote controllable rakes mounted on their front. As stated in paragraph 6, the primary objectives of the pushing tests were to measure the force required to push various size plots of plants at various speeds. As with towing described above, no pushing force data were available as a guide to determine equipment needs. Therefore, assumptions were made that a smaller boat and motor could be used for pushing tests because the 10-ft expanded metal rake would limit the biomass of plants being pushed. The procedures and equipment used to conduct the pushing tests are described in paragraph 22.

47. As with towing submersed plants, the results of the tests showed that transporting submersed plants by pushing would be relatively unproductive. Table 4 shows that the pusher rakes used could only contain 175 to 340 lb of material for relatively short distances as evidenced by the fact that a complete test of pushing plants for 600 ft was never accomplished. As the rakes full of plant material moved forward, even at slow speeds, forces induced by the forward motion worked the plant material loose where it consistently became entangled around the motor propeller and caused the tests to be aborted. Typical speeds and forces for the three selected partial tests tabulated in Table 4 ranged from 0.62 to 1.62 mph and 43.8 to 115.5 lb, respectively, which is slightly faster and required less force than observed in the

towing tests. However, this was anticipated because the plant material was considerably less.

48. It is the opinion of the author, drawn from the field tests, that pushing as a means of transporting previously cut submersed aquatics to an on-the-water holding area or takeout point is not practical for an operational system. In certain cases, pushing submersed material is practical. For example, it was determined during channel clearing efforts conducted as a related effort to these tests that plants once in front of the rake can be transported a short distance by lifting the forward edge of the rake. This method was used to place plants cut during channel clearing operations onto uncut plants on the fringe of the river and also to dislodge plants and place them in the main channel so that they would move down the river with the current flow.

Conveying

49. The conveying of aquatic plants was the only component of the Aqua-Trio test* that was considered to have adequate production throughout. The function of the conveyors in that system was to unload the transported barge and to elevate the conveyed plants and dump them into an awaiting truck. The reason the conveyors met the design criteria (up to 70 tons/hr) was because the cut plants were contained in the holding area of the transporter where they could be efficiently conveyed into the hopper. A fundamental difference in the functional requirement for the aquatic plant removal elevator system used in this test program was the fact that it had to remove the plants from the water which was anticipated to be a problem.

50. The Conveying Rate (CR) in tons per hour for a conveyor can be estimated by the relationship:

$$CR = P_d \times A_f \times S_b \qquad (2)$$

where

P_d = density of the plant material on the belt, tons/ft^3

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* Culpepper and Decell, op. cit., p 8.

A_f = frontal area of the plant mass on the belt, belt width × height of conveyor sides. In this instance, the height is 1 ft

S_b = belt speed, ft/hr

This relationship was used to estimate the production rates of each component of the conveying system described in paragraph 23 for a plant density of 0.0075 tons/ft^3 (15 lb/ft^3) for belt speeds of 4800 to 6000 ft/hr (80 to 100 ft/min) as follows:

	A_f	S_b	CR
Land-based elevating conveyor	1.75	4800	63.0
	1.75	6000	78.75
Horizontal conveyor	3.0	4800	108.0
	3.0	6000	135.0
Floating elevating conveyor	4.0	4800	142.5
	4.0	6000	180.0

The above estimates suggest that it is reasonable to expect conveying rates approaching 75 tons/hr, which is 45 tons/hr more than required by the specifications used in purchasing the submersed aquatic plant removal elevator system (Appendix D).

51. Table 5 summarizes the data collected on three typical conveying tests and illustrates that the conveying rates for the total system range from 2.6 to 4.7 tons/hr. This rate is very much less than that expected from just considering the potential of the individual conveyors. Although there were some malfunctions in the operation that decreased the throughput to some degree, as expected the major reason for the poor performance was that indicated in paragraphs 23 and 24; i.e., the floating conveyor could not be placed in deep enough water and in sufficiently fast currents to permit the plants to feed efficiently into the conveyor throat. It should be noted that even at these low rates, intensive manual labor was required to rake the plant material onto the conveyor.

52. Raking had to be used in the operations because the conveyor created water movement away from the base of the conveyor. It was not determined how fast the natural currents would have to be to overcome this characteristic of conventional conveyors; however, it is felt that

in many situations in the Jacksonville District, the water current would be too slow to permit use of a conventional conveyor that depended primarily on a belt moving into the water from the underneath side of the conveyor and lifting the plant up on the top side. However, it is felt that designs for water-based conveyors that employ overhead raking mechanisms could be developed and subsequently constructed that would overcome the turbulence problem discussed above. One such experimental conveyor* was built by the University of Wisconsin and tested at Buffalo Lake with encouraging success.

53. Based on the results shown in Table 5 and observations of the field engineer on the project, it seems apparent that a conventional water-based conveyor system such as the one used in this field program will not be able to overcome the turbulence problem in low-flow conditions often encountered in plant-infested waters; therefore, it is concluded that research to develop a new water-based conveyor is needed.

Disposal

54. A major objective of the analysis of the data collected in the disposal tests was to develop a way to readily estimate the land area required to stockpile the large volumes of material that must be extracted from the water in many operational situations. In most cases, easements for the land used for stockpiling must be obtained from private land owners and these agreements are easier to reach if the land area is small. Also, stockpiling the material can, under some conditions, result in nitrate and nitrite enrichment of the in situ forage materials that will eventually grow through the decomposed material such that it can be harmful to livestock. For this reason, it is prudent to fence off the stockpiles if they are placed in livestock grazing areas and it is sensible to make the fenced-in area as small as possible.

55. Prior to the field investigation, it was felt that the freshly stacked material would reduce in volume rapidly at first as a

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* S. C. Robinson, D. F. Livermore, and R. G. Koegel. 1975. "Progress Report, The Buffalo Lake Project," Department of Mechanical Engineering, University of Wisconsin, Madison, Wisconsin.

result of its own weight and slower as time went on due to decomposition. For this reason, it was assumed that the volume of land storage required, in cubic yards, could be estimated by the exponential equation:

$$V_b = V_a \, e^{-\alpha T} \tag{3}$$

where

V_b = volume at end of time interval under consideration, cubic yards

V_a = volume at beginning of time interval under consideration, cubic yards

α = alpha value

T = time, days

This assumption appears to be supported by the information in Figure 23 that shows selected cross sections and photographs of stockpile B at various data collection intervals. However, the plots in Plate 3 of volumetric data tabulated in Table 7 suggest more strongly that stockpiles of hydrilla do reduce, in general, as hypothesized. However, some variation in volumetric reduction rate is apparent; for example, the data for plot A which represent the situation where 44,325 lb was dumped on 13 Aug and an additional 61,740 lb was placed on the pile 9 days later. In this case, the curve after the ninth day appears slightly steeper than after the first day. This more rapid reduction does not appear to be the case for the smaller stockpiles where similar data are plotted, i.e. stockpile 5. In these cases, the decay portion of the plot is almost parallel, suggesting that volumetric reduction is occurring at a constant rate even though both old and new plant material is in the stockpile. Because these data suggest that new material placed on existing stockpiles either decays at the same rate or faster, it appears that the same equation form can be used in both cases to estimate volumetric reduction.

56. After it appeared that the volumetric reduction could be represented by Equation 3, the value of α for hydrilla had to be derived for the measured data using the relationship:

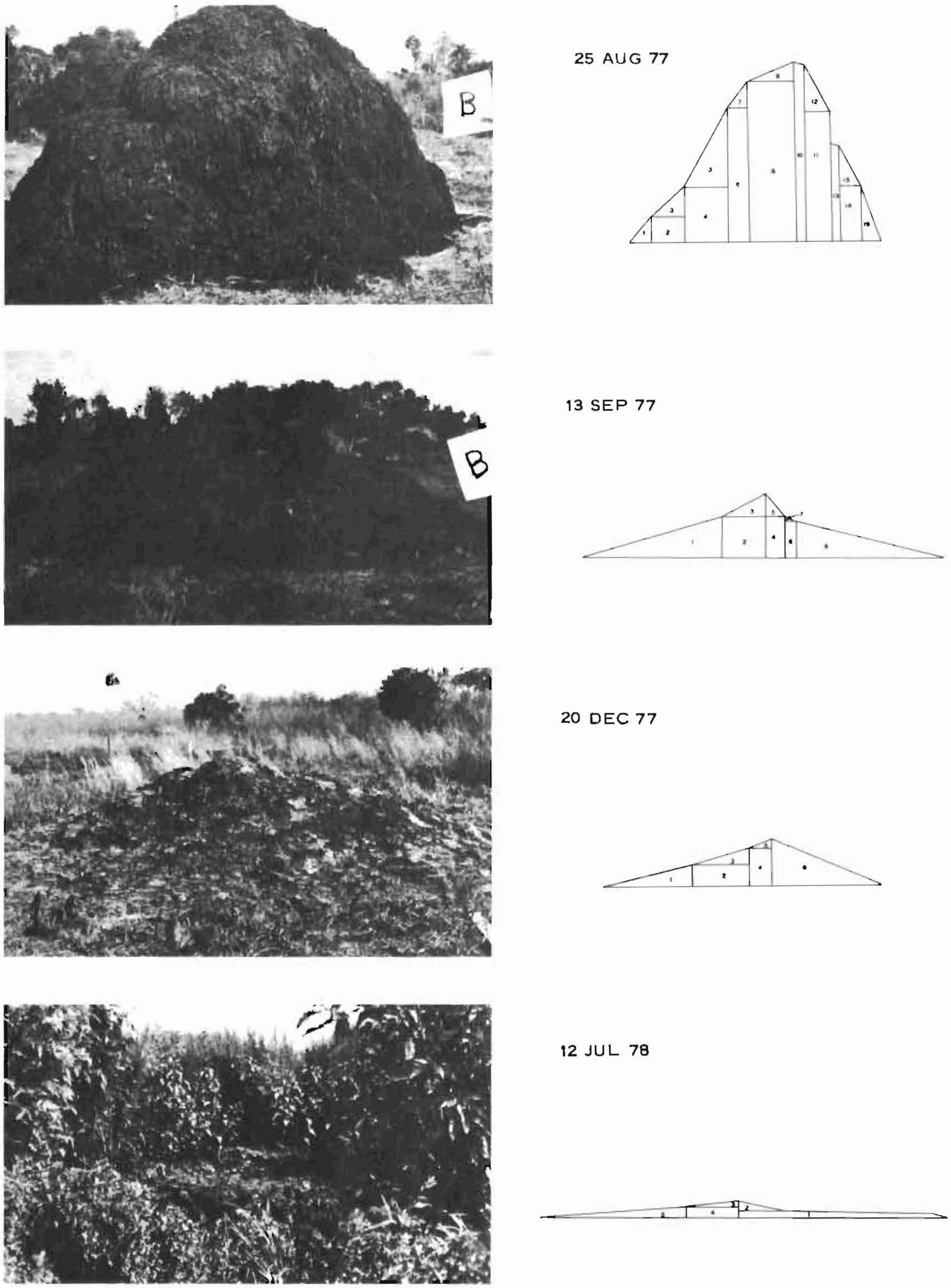


Figure 23. Appearance and sketch of hydrilla stockpile B at various data collection intervals

$$\alpha = \frac{\ell n V_a - \ell n V_b}{t} \tag{4}$$

where

α = volumetric reduction rate

ℓn = natural logarithm

V_a = volume at the beginning of the time interval under consideration, cubic yards

V_b = volume at the end of the time interval under consideration, cubic yards

t = time, days

57. Each curve in Plate 3 was analyzed individually for the total time of record and it was found that the resulting curve did not fit the data as well as desired. A more satisfactory fit was obtained, however, when the time intervals were broken up as follows:

$$t \leq 10 \text{ days}$$
$$t = 10\text{-}20 \text{ days}$$
$$t > 20 \text{ days}$$

To arrive at a relationship for use in predicting the volumetric reduction of any stockpile, the α values obtained for each stockpile in the time intervals listed above were averaged and are:

$$\alpha_t = \leq 10 \text{ days} = 0.1151$$
$$\alpha_t = 10\text{-}20 \text{ days} = 0.0512$$
$$\alpha_t > 20 \text{ days} = 0.0118$$

The α's were used to derive the relationship shown in Figure 24 which provides a convenient aid to estimate storage volumes required for those control operations in hydrilla where the cut plants are removed from the water and stored without further processing.

58. It appears that, in most operations, volume storage requirements would not be severe after 30 days (minimum interval between cutting of submersed plants); the volume would only be about 17 percent of the original as shown in Figure 24. However, it should be kept in mind that if fish are caught up in the hydrilla during the gathering operation, their decay will cause objectionable odors to emanate from the stockpile.

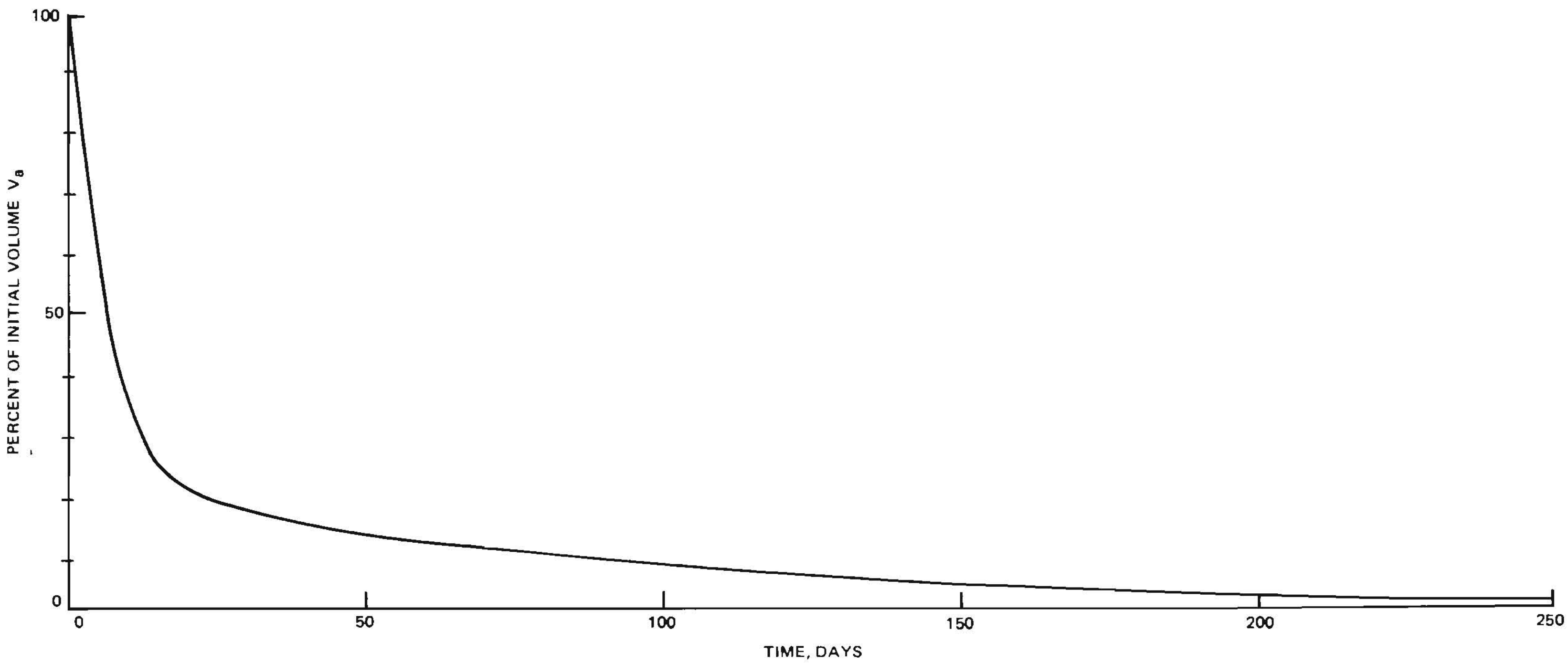


Figure 24. Percent of initial hydrilla stockpile remaining as a function of storage time

For this reason, stockpile locations should be sought away from areas in proximity to high density human activity.

Floating Aquatics

59. This section presents the results of the transporting, conveying, and disposal tests described in paragraphs 26-35. Three methods of transporting were studied (i.e., free floating, towing, and pushing) and are discussed in the following paragraphs.

Transporting

60. In preparation for the conduct of the field study, an attempt was made to derive an equation that could be used to estimate the plant movement as a function of air and water velocity. The hope was that the equation could be used in conjunction with long-term records of these parameters to estimate likely locations along the St. Johns River for large assemblages of hyacinth plants. Wind and water forces induce movement in individual hyacinths and mats in an extremely complex way. Equations were eventually derived that might be useful for estimating plant movement, but they were not available for use in planning the fieldwork. However, it seems reasonable to assume that they will be applicable to future work and, for this reason, the derivations are included as Appendix G of this report.

61. Intuitive judgment was used in designing the simple test described in paragraph 28. The primary objective was to develop empirical data on plant movement and related wind and water velocity from which inferences could be made in regard to how plants could migrate downriver under natural forces. Table 8 summarizes the measured data from which the plant movement versus time plots shown in Plate 4 were derived. Distance moved ranged from 225 ft (Plot 3) to over 4000 ft (Plot 6). Even the relatively good movement observed for Plot 6 demonstrates the adverse effect wind can have on the movement of the plants. In this case, the plants moved at a rate of approximately 532 ft/hr $\left(\frac{4125\ \text{ft}}{7.75\ \text{hr}}\right)$, whereas the average water speed was about 0.25 ft/sec or 900 ft/hr. Thus, the plants moved at 60 percent of the water speed for the best case observed.

62. A study of the information in Table 8 gives clues to why the plants moved as observed. The plants were traveling in the main channel (see Figure 5), not in Morrison Creek. Little wind was observed until about 1230 hr which at that time was measured to be 0 to 3 mph coming from the east. At this point in the river, the plants are protected from easterly wind by bank heights that vary from 3 to 5 ft above the water surface. Also, tall woody vegetation provides additional protection. At 1530 hr the wind speed increased and shifted direction such that it was coming from the south which tended to be blowing in the same direction the plants were moving.

63. The reason the plants moved the short distance in Plot 3 is easily extracted from Figure 5 and Table 8. The water going into Morrison Creek from the main channel creates a tangential force on the plants that makes them tend to move to the left bank. Also, at 0942 hr, the time the plants were observed to be lodged against the bank, a light wind (0 to 2 mph) was blowing from the west which tended, along with the water currents, to keep the plants lodged against the left bank of Morrison Creek.

64. The remaining plots tended to have similar movement characteristics; i.e., during the morning hours movement in the direction of water flow was observed. As the wind became progressively stronger in the late morning or early afternoon, the plants were slowed, eventually stopped, and finally forced upstream. Plot 5 illustrates an exception in that the wind started gusting from the southwest about 1630 hr and broke the plants loose from where they were lodged against the left side of the river and permitted the plants to continue downstream.

65. From the field observations, it is obvious that the plants are affected to a large degree by wind forces. During the test period, the wind tended to blow from the south-southeast during the morning hours, and in this period there was always a downstream movement of the plants. In the afternoon, the wind tended to come from the west to southwest and this tended to have an adverse effect on the downstream movement of the plants. However, as the wind died down in the evening, the plants again would proceed downriver causing a net gain in downstream

movement in each case except the observation of Plot 3. Although the data collected are not complete enough to be used as a basis for predicting plant movement under the variety of conditions in the Jacksonville District, it does suggest that use of the natural forces for transporting plant material in a control operation has potential. It seems reasonable to study further the movement of plants due to natural forces using a combination of experimental tests augmented by the theoretical considerations presented in Appendix G.

Towing

66. Towing floating plants has been used successfully in large control operations such as the program carried out routinely by the Panama Canal Company near the confluence of the Chagres River and the main channel of the Panama Canal. Towing plants using makeshift booms and small boats is also a common practice by private landowners living in the vicinity of the St. Johns River. Even though towing is a relatively common practice, almost no quantitative information could be found that related the force required to pull rafts of plant material as a function of raft size and speed. It was hypothesized that even though anticipated speeds in excess of 3 mph would probably not be practical, towing had significant potential as a low-cost, low-energy transportation mode. Both capital costs and operating costs were potentially low because the towing boat, in many cases, could be small, and the towing boom could be constructed from relatively inexpensive, off-the-shelf material. Comparatively little energy would be required because the plants would not have to be lifted from the water and no special processing would be performed prior to removing the plants from the water.

67. As stated in paragraph 30, the data collected for the four plots towed are presented in Plate 1. Four sizes of plots were towed (530, 615, 1017, and 1791 sq ft), both with and against the current. The encircled density ranged from 85 to 125 tons/acre. In all cases, towing could be accomplished against the current (0.25 ft/sec or 0.17 mph) at 1 mph with a towing force less than 100 lb. As expected, the smaller raft could be contained more securely permitting faster towing than was possible with the larger rafts. In this case, towing speeds of 2.25 mph

were obtained with the towing force approaching 300 lb before the material was forced under the boom by the retardation or drag of the water on the moving plants. The speeds obtained for Plots 2 and 3 were slightly less than 1.5 mph and, as expected, the force increased at a faster rate for the larger mats. Speeds in excess of 1 mph for Plot 4 caused a very sharp increase in force. This phenomenon resulted in this case and not for Plots 1, 2, and 3 because of the difference in behavior of the plants. The root systems on Plots 1, 2, and 3 (and Plot 4 at speeds less than 1 mph) bent back and up against the bottom of the raft forming a smooth, streamlined contact with the water. However, on Plot 4, at speeds greater than 1 mph, the top portion of the plants on the leading edge of the raft tended to be pulled into the water. This caused an abrupt increase in the frontal area of that portion of the raft that is submersed, which, in turn, induced a presumably larger bow wave that appeared to increase in size as additional force was applied; i.e., the force was being used to move water as well as the plants.

68. Due to the relatively small size of the plots, the towing tests were carried out with little difficulty. It should be noted that in many plant control operations, the desired throughput would require raft sizes close to 0.25 acres. Figure 25, an extrapolation of data shown in Plate 1, shows the force required to pull various size rafts at 1 mph. Because only four data points are available, any conclusions are suspect; however, it does show that forces approaching 1000 lb would be required to tow 0.25 acres of hyacinth at 1 mph. Further, the way the towing boom was employed in the tests resulted in the towed mass taking on a teardrop shape. A new boom design, perhaps made up of rope fastened to a floating rigid bar that could be pulled horizontal to the forward motion of the boat, might be useful in overcoming this difficulty. In summary, it is felt that towing appears to be viable in transporting floating plants; however, improved equipment and tactics for implementing the towing function in a variety of operational contexts are needed.

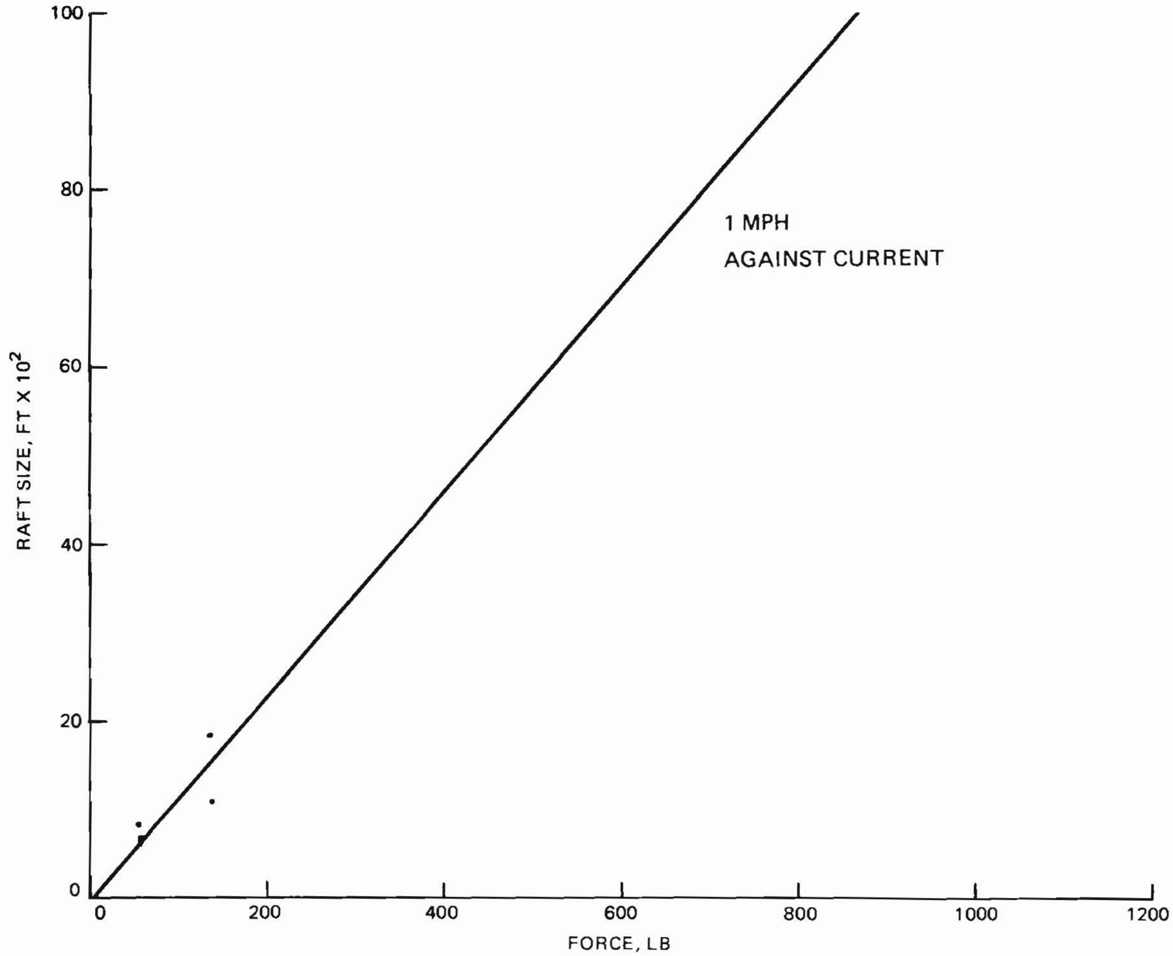


Figure 25. Estimated force for various plot sizes being towed at 1 mph

Pushing

69. As discussed in paragraph 31, pushing tests were conducted in the same areas as the towing tests and the resulting data are shown in Table 10 and Plate 2. Four sizes of rafts were pushed ranging in size from 78.5 to 530 sq ft. Speeds in the vicinity of 1.5 mph were reached in all plots with forces ranging from 75 to 140 lb.

70. As noted in the previous paragraph, movement of small-sized plots such as that used in this test program would be impractical for most control operations if this were the only transportation mode used. However, the pusher boats are considered very appropriate for tasks such as pushing fringe plants into the current where they can proceed on downstream under natural forces. The sequencing and the employment intensity of each method for optimal transporting are inextricably tied to the environmental conditions existing at the location of the control operation. For this reason, it is felt that three technical problems must be overcome. First, a simple straightforward method must be developed for analyzing and subsequently portraying the plant response to wind and water forces. This is needed so that potential plant movements and aggregation points can be routinely identified. Second, improved towing equipment and methods are needed; third, straightforward procedures for making trade-offs between the three transportion modes as a function of production throughput are needed.

Conveying

71. As noted in paragraph 33, Table 11 lists the results of the conveying tests conducted in the St. Johns River test site. The conveying rates ranged from 7.24 to 9.76 tons/hour, which is considered ineffective for most control operations. Also, it should be noted that these rates were computed for short intervals of time, i.e. from 6.8 to 11.4 min (Table 11); therefore, rates representative of sustained operations would be somewhat less. As with hydrilla, the theoretical production rate was much greater than that observed in the field; i.e., using Equation 2 (paragraph 50), the anticipated production for the 4-ft-wide conveyor moving 5 lb/ft^3 hyacinths at 6000 ft/hr would be 60 tons/hr. The major reason for the low productivity of the conveyor in the hyacinth

tests was similar to the reasons experienced in the hydrilla tests; i.e., the motion of the belt in the water generated water movement away from the conveyor. This movement caused the plants to have a tendency to pile up a short distance from the conveyor. To overcome this problem, rakers had to expend considerable effort to force the plants over the retarding force generated by the conveyor. As stated in paragraph 24 it is felt that no conventional off-the-shelf conveyor can be readily modified to overcome this deficiency. For this reason, alternative concepts that employ devices such as piston or impeller-driven pumps and/or hume reels with augers should be investigated as more promising near-term solutions for getting the plants across the water-land interface. However, it seems reasonable to expect that an overhead conveyor that pulls the plants up onto a conveyor positioned just above the water surface could be made workable by careful design. Because conveyors are inherently efficient, research to develop one especially for extracting hyacinths is worthwhile.

Disposal

72. The problem of disposal of hyacinths is greater than for hydrilla simply because of the larger volume of material. Also, it was anticipated that the coarse structure of the plants would cause less rapid volumetric reduction due to both compression under its own weight and natural decomposition. Comparison of the information on Figure 26 with corresponding hydrilla information on Figure 23 indicates that this assumption was correct. Further, quantitative information on the volumetric reduction of hyacinth stockpiles is shown in Plate 5. As with the similar plots for hydrilla, it is apparent that the volumetric reduction for hyacinth follows an exponential decay. The data plotted in Plate 5 were analyzed using procedures identical to those described in paragraphs 54-56 for hydrilla. The α values for $t \leq 10$ days, $t = 10$-20 days, and $t < 20$ days were derived as follows: 0.1089, 0.0349, and 0.0107. These values were then used in Equation 3 to generate the plot shown in Figure 27. Comparison of this curve with the corresponding one for hydrilla in Figure 24 shows clearly that the hyacinth stockpiles reduce in volume slower than their hydrilla counterparts.

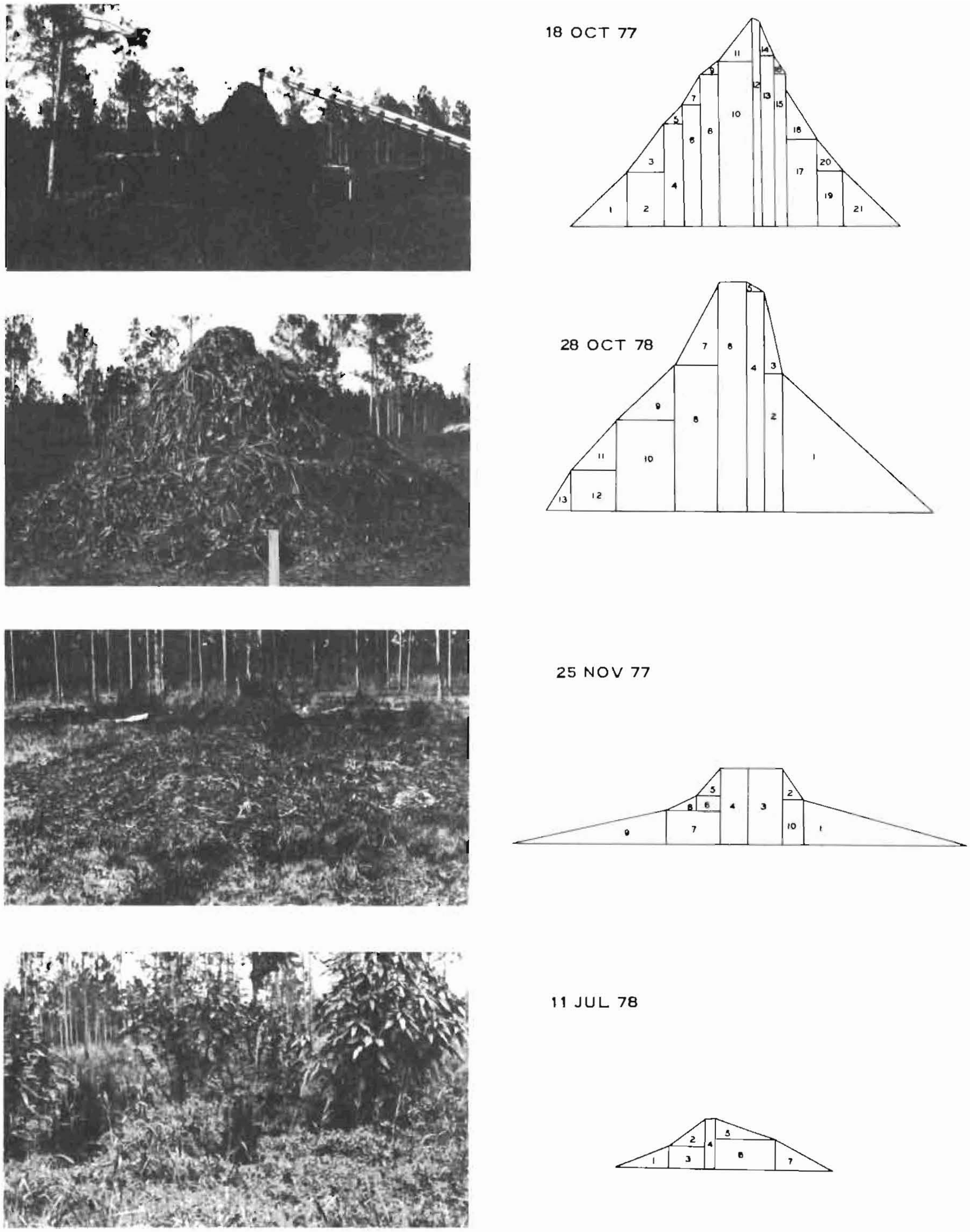


Figure 26. Appearance and sketch of hyacinth stockpile B at various data collection intervals

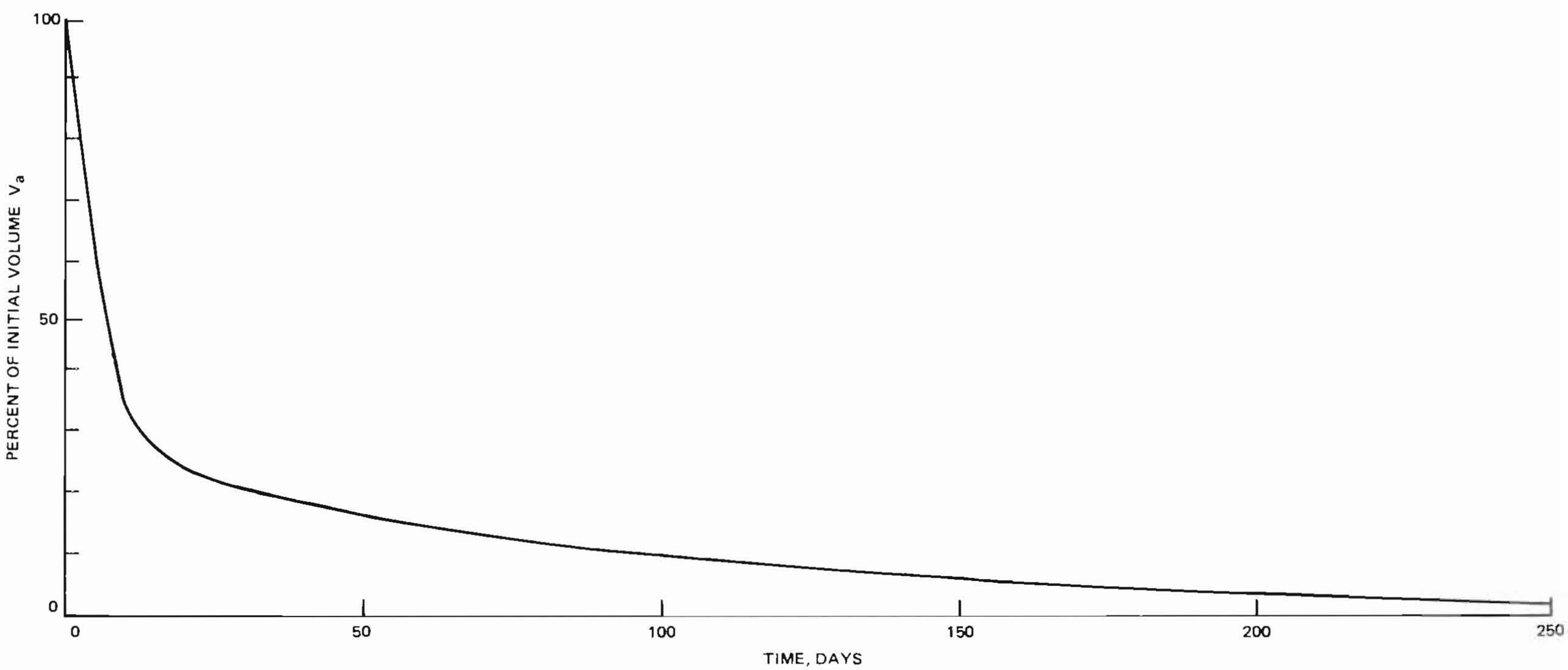


Figure 27. Percent of initial hyacinth stockpile remaining as a function of storage time

For example, the hyacinth stockpile was approximately 22 percent of its original volume at the end of 30 days, whereas the hydrilla had reduced to 17 percent of its original value. In many operational control situations, hyacinth disposal by stockpiling is viable and the curve in Figure 27, used in conjunction with volumetric reduction data listed in Table 13, can be used to estimate storage volume requirements. If stockpiling is used, it is recommended that the same precautions outlined in paragraph 54 for hydrilla in regard to placing hyacinth stockpiles near high-use areas or exposing them to forage animals be followed; i.e. stockpiles should be fenced until it can be positively stated that the decaying material will not result in nitrate poisoning in animals.

PART IV: DISCUSSION

73. The preceding paragraphs present quantitative data and their implication in regard to improving the ability to accomplish selected functions in the mechanical control of aquatic plants. Although attempts were made to interpret the data in light of experiences gained through the conduct of the field test program carried out in 1976, 1977, and 1978 and in discussions with university and industry personnel, considerable limitations in the analysis remain. Fundamentally, it is felt that the data generated fall short of expectations due to the inability to procure prototype test equipment that could be made to operate at throughput approaching that desired for routine operational use. This was true even though the equipment was well built and operated without serious malfunction; this fact emphasizes that its design was inadequate. It is obvious that the throughput of a mechanical system will be somewhat less than the capacity of the most inefficient functional component and, as recent experience has demonstrated, most of the mechanical handling functions important to the successful execution of the low-energy concepts outlined in paragraphs 3-4 could not be adequately executed. This suggests that the development of a truly acceptable low-energy mechanical system will not be accomplished until fundamental problems in over-water transport and plant removal at takeout points are solved. It is felt, however, that the inadequacies in existing mechanical control equipment are more the result of inattention or lack of emphasis by the technical and industrial community than technological pacing problems.

74. It is interesting to consider mechanical harvesting equipment development in the agriculture industry where a major thrust has been improving the ability to handle large volumes of forage materials. As a point of fact, the forage harvesting industry supports extensive university research and others directly involved in the design of new equipment. Over the years, user feedback has provided extensive trial and error evaluation of design concepts that continue to generate empirical design

rules for equipment important to the wide variety of economically important forage crops. This has permitted the development of excellent systems that permit routine handling of forage material at a commercially reasonable cost. It is important to note that it took considerable time and effort to arrive at the existing high level of expertise in the agriculture industry; however, economic considerations continue to find the need for better performance.

75. Conclusions that can be drawn from the agriculture industry experience have both positive and negative connotations. There is little doubt that major improvements on equipment performance for the mechanical control of aquatic plants can be realized; however, their improvements will take time and will require considerable attention to the details on each function to be employed in the system. To date, the mechanical aquatic plant control program has not taken this fully into account; i.e., the efforts have been directed towards procuring complete systems that would work in many operational concepts, and not directed towards developing the individual functions required to make up a complete system. At this point, it appears prudent to shift emphasis so that a significant portion of the effort is directed toward these singular functions. This will permit contracting a much larger number of activities, each of which could be more precisely defined in RFP's. This would increase the probability of a successful procurement at potentially lower cost. The increased number of contracts would also tend to generate more interest from industry but it is highly unlikely that industry benefits in the form of profits would be sufficient to duplicate successes experienced in the agriculture industry. Once it has been demonstrated that each function can be executed efficiently, rational design of a complete system would be straightforward, provided a deterministic method was available to predict the performance of each component for all significant environments and operational conditions. For these reasons, the following priority in development of efficient ways to implement the mechanical control of aquatic plant is suggested:

Development Priority

Submersed Aquatics

Transporting
- Free Floating
- Towing
- Barging

Conveying: removal of plants from on-the-water storage area

Floating Aquatics

Transporting
- Towing
- Barging

Conveying: removal of plants from on-the-water storage area

Finally, it is suggested that development of a rational method for determining how to employ and sequence the functions be continued.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

76. As a result of the study reported herein, the following conclusions are presented:

a. Cutting submersed aquatics at production rates in excess of 2.3 acre/hr was demonstrated using a 12-ft cutter under ideal conditions; as conditions become less favorable, the production rate decreased and production averages for riverine and lake environments were 1.94 acre/hr and 1.24 acre/hr, respectively. As this is less than targeted in paragraph 37, additional work on cutter development is needed.

b. Tests using natural forces, i.e. water current, to transport previously cut aquatic plants were conducted with positive results as shown in Table 3. Even though documented tests were not conducted on the movement of plants for the entire 6-mile section cut of the river, the plants were observed to flow out and disperse as described in paragraph 42. When the moving cut plants came in contact with netting or other material used to form an on-water storage area, the plants began to stack vertically in the water column and were difficult to remove as described in paragraphs 23 and 24.

c. Although many attempts were made at conducting towing tests to generate the data required to draw a scientific conclusion of forces and speeds to tow various areas of plants, limited data were compiled. The reason for the limited data was because the plants could not be contained with simple expedient materials (nets, floats). It is concluded (paragraph 45) that with present materials and methods, it is not cost-effective to use towing in a mechanical system for control of submersed aquatics.

d. Pushing of submersed aquatics at speeds that would be considered to be of an operational rate was not accomplished during this field exercise. From the field data recorded (Table 4) and observations, one must conclude that further development is needed for this to become a cost-effective and viable part of a mechanical control system.

e. Conveying of aquatic plants has long been considered the most practical method of transporting plants from water bodies to land disposal points, yet very small efforts have been made towards properly designing a system that will accomplish this at an operational rate. It is concluded (see Table 5) at this time that no complete conveying system exists that adequately fulfills the requirements of removing plants from on-water storage areas. The major problem with conveying is maintaining the proper feed of plants to the conveyor.

f. A water-based elevating conveyor (paragraph 52) capable of independently extracting cut submersed plants from water bodies with slow or no current of at least 30 tons/hr is needed.

g. Due to rapid natural decomposition, land area requirements for stockpiling hydrilla will be minimal in most mechanical control operations where the cut plant is stored without further processing as described in paragraph 58.

h. Transporting floating plants using natural forces has potential; however, a better understanding of the relation between wind- and water-induced movement is needed before this transportation mode can be optimally employed. If the low-energy concepts described in paragraph 6 are to be employed, the transportation function will have to employ a combination of free floating, towing, and pushing (paragraph 59). For pushing and towing to be a viable transportation mode, new towing equipment must be developed (paragraph 68).

i. Moving hyacinths across the water-land interface at the desired operational rates with conventional off-the-shelf conveyors is not practical because of the difficulty in getting the plant material upon the moving platform (paragraph 71).

Recommendations

77. The following recommendations are presented:

a. It is recommended that studies should be conducted with the goal of developing an efficient way to implement each of the various functions listed at the end of Part IV (paragraph 75).

b. In order to make maximum use of the low-energy requirement of transporting cut submersed aquatics, it is recommended that future mechanical control research programs include a study on transporting of aquatics by free-floating methods. It is envisioned that the section of the Withlacoochee River between Highways 44 and 48 would be an ideal place to conduct a feasibility study as described in paragraph 43.

c. It is recommended that conveyor design for cut submersed plant removal be initiated to effect an overall low-energy, cost-effective mechanical control system. Also, other methods of plant removal should be considered.

d. If aquatic plant stockpiles are located in livestock grazing areas, it is recommended that they be fenced to avoid unlikely accidental poisoning of animals. It is anticipated that plants stacked as done in this program could possibly cause toxic levels of nitrites and nitrates in natural forage growing through the stockpiles under certain conditions that are not quantitatively understood. However, other methods of disposal that make use of processed plants, e.g. chopped hydrilla slurry, would probably not concentrate the nitrites and nitrates to the toxic level. However, the relation between the amount of untreated or slurred material and resulting increases in potential toxicity of the forage materials is not known and should be investigated (see paragraphs 54 and 72).

e. Development of a method for predicting the movement of floating plants as a function of wind and water forces is recommended.

f. Development of improved towing equipment and towing methods is recommended.

g. It is recommended that work on developing special conveyors for getting hyacinth across the water-land interface be continued (paragraph 71). In addition, investigations of using alternate equipment and methods for performing this function should be accomplished in the hope of providing a near-term solution.

h. It is recommended that further work be directed toward development of a single equipment item capable of cutting at least 4 acre/hr. Consideration should be given to: use of cutter bars with dual action knives, increased number of knives per unit length, increased sickle bar speed, and providing sufficient power to move the boat and cutter reliably through the plant infestation at a speed of at least 3 mph.

Table 1

Summary of Hydrilla Cutting Data, Withlacoochee River

Test No.	Date	Test Area Length ft	Test Area Width ft	Water Speed mph	Water Depth ft	Wind Speed mph	Plant Density tons/acre	Cutter Depth ft	No. Passes	Pass Length ft	Elapsed Time min	Cutter Speed mph	Field PR acres/hr	Planimetric Field Efficiency percent	Remarks
							12-ft Cutter, Riverine Environment								
1	6-27-77	8,606	23	0.08	2-6	0-3	6-8	2-4	2	8,606	143	1.37	1.91	96	On return pass submerged snags caused two stops to free blade
2	6-28-77	10,270	23	0.08	3-8	0-5	8-10	3-4	2	10,270	171	1.37	1.91	96	On return pass two stops were required due to cutter hitting bottom.
3	7-19-77	14,678	23	0.08	3-8	0-7	8-10	3-4	2	14,678	256	1.30	1.82	96	Hyacinths caused stop, backup, and start operation
4	7-20-77	5,280	12	0.08	2-6	0-5	6-8	3-4	1	5,280	41.5	1.48	2.10	100	Test aborted, cam operating cutter bar broke
6	7-27-77	14,678	23	0.08	2-8	0-5	6-8	2-4	2	14,678	264	1.27	1.76	96	Gusty headwind
18	8-28-77	3,800	12	0.08	3-10	5-12	8-10	3-4	1	3,800	27.9	1.54	2.25	100	Tailwind
19	8-28-77	14,678	12	0.08	2-8	5-12	6-9	2-4	1	14,678	105	1.59	2.31	100	Tailwind
20	8-29-77	3,129	23	0.08	3-10	5-12	5-7	3-4	2	3,129	53.3	1.34	1.86	96	
21	8-30-77	4,408	23	0.08	3-10	5-15	8-12	3-4	2	4,408	80.5	1.25	1.75	96	
22	8-30-77	3,911	12	0.08	3-8	5-12	6-8	3-4	1	3,911	30.5	1.46	2.12	100	
23	8-30-77	3,324	23	0.08	3-6	5-15	6-10	3-4	2	3,324	55.5	1.37	1.90	96	Head and tail winds
24	8-30-77	6,359	23	0.08	3-10	5-15	8-12	3-4	2	6,359	112.3	1.29	1.80	96	Windy, hard to steer
28	11-18-77	4,194	23	0.10	2-10	0-5	6-10	2-4	2	4,194	71	1.35	1.89	96	Two stops to clear cutter bar
29	11-21-77	3,000	23	0.08	2-8	0-4	6-10	2-4	2	3,000	50.5	1.35	1.88	96	
30	11-22-77	14,678	23	0.15	2-7	0-3	4-10	2-4	2	14,678	259.5	1.29	1.80	96	
							12-ft Cutter, Lake Environment								
5	7-25-77	800	45	0	3-8	0-3	8-10	3-4	4	800	30.4	1.20	1.63	94	Sprayed waterhyacinths caused stop and start operations

(Continued)

(Sheet 1 of 2)

Table 1 (Concluded)

Test No.	Date	Test Area Length ft	Test Area Width ft	Water Speed mph	Water Depth ft	Wind Speed mph	Plant Density tons/acre	Cutter Depth ft	No. Passes	Pass Length ft	Elapsed Time min	Cutter Speed mph	Field PR acres/hr	Planimetric Field Efficiency percent	Remarks
							12-ft Cutter, Lake Environment (Continued)								
11	8-12-77	1,210	34	0	3.5-6.0	5-10	10-15	3.5-4.0	3	1,210	45.6	0.91	1.25	94	Gusty head wind, filamentous algae caused cutting difficulty
12	8-12-77	1,210	34	0	3.5-6.0	5-10	10-15	3.5-4.0	3	1,210	46.2	0.89	1.23	94	One stop to clear blade snag
13	8-12-77	1,210	34	0	3.5-6.0	7-12	10-15	3.5-4.0	3	1,210	46.5	0.89	1.22	94	Light rain, one stop to clear blade, filamentous algae
14	8-13-77	209	209	0	3-6	0-3	10-15	3-4	19	209	130.6	0.35	0.37	≈75	Sprayed hydrilla matted such that cutter readily became clogged, 75 percent area cleared
15	8-13-77	209	209	0	3-6	0-3	10-15	3-4	20	209	135.5	0.35	0.38	≈80	Same as above ≈85 percent area clearance
16	8-13-77	209	209	0	3-8	0-5	8-12	3-4	19	209	51.6	0.88	1.07	92	Gusty winds
17	8-13-77	209	209	0	3-8	0-7	9-12	3-4	20	209	51.5	0.87	1.02	87	Excessive overlap between passes to ensure clear cutting
25	9-1-77	1,956	23	0.08	3-8	5-15	6-12	3-4	4	1,956	68.0	1.31	1.79	94	Windy, cross winds caused steering difficulty
26	9-1-77	2,738	23	0.08	3-8	5-15	6-8	3-4	2	2,738	42.5	1.47	2.05	96	Occasional head wind
27	11-16-77	1,000	56	0.12	3-10	0-2	6-8	3-4	5	1,000	44.8	1.27	1.72	93	One stop, hit river bottom
							8-ft Cutter, Riverine Environment								
7	8-11-77	5,208	8	0	2-6	0-5	6-10	2-4	1	5,280	41	1.46	1.42	100	
9	8-11-77	5,280	8	0	1-6	0-10	6-10	1-4	1	5,280	62	0.97	0.94	100	Operation slow, wind was blowing previously cut material into cutter path
10	8-11-77	10,560	8	0	1-6	0-5	6-10	1-4	1	10,560	79	1.52	1.47	100	
							8-ft Cutter, Lake Environment								
8	8-11-77	1,320	29	0	3-6	0-10	6-10	3-4	4	1,320	42.7	1.41	1.24	91	

(Sheet 2 of 2)

Table 2

Summary of Transport Data for Free-Floating Tests on Hydrilla

Test No.	Date	Water Speed mph	Patch Area sq ft	Biomass tons	Distance Traveled miles	Time hr	Plant Speed mph	Remarks
1	7-19-77	0.08	5,750	0.75	0.19	2.6	0.07	Surface wind appeared to retard the flow of the plants slightly
2	11-16-77	0.12	13,000	1.31	0.28	2.4	0.12	Very still day; plants had large clear channel to move in; a few of the cut plants drifted to the edge of the stream
3	11-18-77	0.10	7,500	0.95	0.79	10-12	0.7	This cut was a winding trail through the east side of Bonnet Lake. The channel was cleared enough for fishermen boat traffic at the end of the test

Table 3

Summary of Transport Data for Towing Tests on Hydrilla

Test No.	Date	Water Speed mph	Estimated Plant Biomass lb	Distance Traveled ft	Time min	Towing Speed mph	Towing Force lb	Remarks
1	11-19-77	0.14	1031	220	5.3	0.47	176.5	As towing force was increased, plants formed a ball in back portion of net. Plants then came out from under bottom of net
2	11-19-77	0.14	1670	125	6.4	0.22	201.7	Pulled very slowly, but plants still came out from under net on the sides and back
3	11-19-77	0.14	750	356	9.2	0.65	248.3	Plants formed a dense ball in back of net. They then flattened out and came up behind the net

Note: Unable to make a complete towing test.

Table 4

Summary of Transport Data for Pushing Tests on Hydrilla

Test No.	Date	Water Speed mph	Estimated Plant Biomass lb	Distance Traveled ft	Time min	Plant Speed mph	Pushing Force lb	Remarks
1	11-19-77	0.14	340	30	0.21	1.62	115.5	Operated pusher rake 9 in. deep in water, unable to keep plants in rake; they went under boat and became tangled on propeller
2	11-19-97	0.14	250	72	0.57	1.44	84.6	Operated pusher rake slower and only 6 in. deep in water attempting to keep plants in front of rake. Unable to keep plants in rake
3	11-19-77	0.14	175	125	2.3	0.62	43.8	Operated pusher boat very slow, but still unable to keep plants in front of rake.

Note: For clearing a channel, the rake was raised to its highest position, clearing most of the plants on the rake from the water; the plants were then transported to the nearby fringe where they were dumped.

Table 5
Summary of Conveying Data on Hydrilla

Test No.	Date	Biomass tons	Operating Time hr	Conveying Production Rate tons/hr	Number of Malfunctions	Remarks
1	11-16-77	4.7	1.0	4.7	0	Required extensive raking, two rakers and one pusher boat. No mechanical problems with conveyors
2	11-16-77	9.4	2.5	3.8	2	Same requirements as above, land-based conveyor caused two short interruptions in operations: V-belt jumped off pulley, and engine choked down from overload of plants
3	11-18-77	4.1	1.6	2.6	2	Continued to rake plants onto conveyor. Sprocket on land-based conveyor broke, replaced sprocket. Motor on floating conveyor drowned out, dried off and re-started. Started raining--test aborted. Major problem is getting plants on floating conveyor belting

Table 6

Data On Hydrilla Stockpiles

Date	No. of Loads	Biomass lb	Volume cu yd	Density lb/cu yd	Accumulated Biomass, lb
		Stockpile A			
13 Aug	20	44,325	95.2	465.6	44,325
22 Aug	20	61,740	304.5	--	106,065
		Stockpile B			
25 Aug	20	57,102	206.1	277.1	57,102
		Stockpile 1			
15 Aug	4	13,180	16.7	789.2	13,180
		Stockpile 2			
15 Aug	4	11,930	29.0	411.4	11,930
16 Aug	4	13,485	34.7	--	25,415
		Stockpile 3			
15 Aug	4	12,280	9.9	1240.4	12,280
16 Aug	4	13,560	30.0	--	25,840
17 Aug	4	13,250	56.3	--	39,090
		Stockpile 4			
15 Aug	4	11,740	14.0	838.6	11,740
16 Aug	4	12,355	25.1	--	24,095
17 Aug	4	11,565	49.1	--	35,660
		Stockpile 5			
15 Aug	4	12,470	23.6	528.4	12,470
16 Aug	4	14,650	41.6	--	27,120
17 Aug	4	13,090	61.0	--	40,210
18 Aug	4	11,045	77.5	--	51,255

Table 7

Measured Volume of Hydrilla Stockpiles*

Date	Stockpile A	Stockpile B	Stockpile 1	Stockpile 2	Stockpile 3	Stockpile 4	Stockpile 5
13 Aug 77	95.2						
15 Aug 77	46.7		16.7	29.0	9.9	14.0	23.6
16 Aug 77	41.2		13.6	34.7	30.0	25.1	41.6
17 Aug 77	38.4		13.3		56.3	49.1	61.0
18 Aug 77							54.9
19 Aug 77	36.1						
22 Aug 77	304.5		8.6	17.0	33.3	32.8	77.5
25 Aug 77	122.2	206.1		12.3	23.4	26.4	63.4
13 Sep 77	46.2	46.4	4.1	9.4	14.1	14.9	26.6
27 Sep 77	32.4	33.1	3.1	11.1	11.5	16.2	21.4
12 Oct 77	37.0	26.8	1.5	10.1	6.0	12.6	23.0
20 Dec 77	31.2	32.6	1.5	4.4	4.3	13.0	16.4
13 Feb 78	23.5	6.0		2.8	6.9	9.0	20.9
21 Jul 78	1.9	0.6		0.19	0.72	5.6	4.9

* Measured in cubic yards.

Table 8

Summary of Transport Data for Free-Floating Tests on Waterhyacinth

---

Plot #1 | Shape: 44 by 28 ft | 21 Sep 77
Area: 1232 sq ft

Time: 0835 hr

Plants are located approximately 500 ft downstream (north) of boat ramp at Parramores Camp Site. Plants are 26 ft from right bank of river.

Wind: 0 mph
Streamflow: 0.25 ft/sec

Time: 1142 hr

Plants are 2100 ft further downstream. They are in the middle of the old river channel.

Wind: 0 mph
Streamflow: 0.25 ft/sec

Time: 1300 hr

Plants have moved an additional 165 ft and at the present time are standing still. Wind is beginning to blow.

Wind: 0 to 3 mph from 245 deg
Streamflow: 0.25 ft/sec

Time: 1625 hr

Plants have moved back up the river approximately 1230 ft due to the wind force against the leaves of the plants.

Wind: 0 to 3 mph from 215 deg
Streamflow: 0.25 ft/sec

Time: 0800 hr | 23 Sep 77

Unable to locate plot within 4-mile section of the river.

(Continued)

Plot #2   Round: 30 ft diam   23 Sep 77
Area: 706.5 sq ft

Time: 0830 hr

Plants are 35 ft north of boat ramp at Parramores Camp Site. The plants are in middle of stream, bend of old river.

Wind: 0 mph
Streamflow: 0.20 ft/sec

Time: 0930 hr

Plants are 490 ft further downstream (north) from original position. Plants are within 10 ft of right bank (outside bend of river).

Wind: 0 to 2 mph from 270 deg
Streamflow: 0.20 ft/sec

Time: 1250 hr

Plants are 165 ft further downstream and lodged against other plants on the right bank of the river.

Wind: 0 mph
Streamflow: 0.20 ft/sec

Time: 1505 hr

Plants are still lodged against other plants as in previous check.

Wind: 0 mph
Streamflow: 0.20 ft/sec

Time: 1632 hr

Plants have moved 80 ft back up river (southeast) away from other plants and bank.

Wind: 0 to 5 mph from 240 deg
Streamflow: 0.20 ft/sec

(Continued)

Table 8 (Continued)

Plot #3 — Round: 22 ft diam; Area: 379.9 sq ft — 23 Sep 77

Time: 0840 hr

Plants located 330 ft downstream from south entrance to Morrison Island in Morrison Creek. Plants are one third distance from left bank. Other small patches around.

Wind: 0 mph
Streamflow: 0.18 to 0.25 ft/sec

Time: 0942 hr

Plants are 245 ft further downstream (east) in old river channel from original position. Plants are against left bank of river and caught against other plants.

Wind: 0 to 2 mph from 270 deg
Streamflow: 0.25 ft/sec

Time: 1212 hr

Plants are still in the same position as the previous check.

Time: 1510 hr

Plants are still in the same position as the previous check.

Time: 1640 hr

Plants are still in the same position as the previous check.

Plot #4 — Shape: 28 by 20 ft; Area: 560 sq ft — 23 Sep 77

Time: 0850 hr

Plants are located in main river channel midway between entrances to old river at Morrison Island. Many plants floating in river today, probably due to the thunderstorms and winds every evening.

Wind: 0 mph
Streamflow: 0.25 to 0.30 ft/sec

(Continued)

Time: 0950 hr

Plants are 825 ft further downstream (north) of original position. Empty oil barge and tug came by going downstream while observing plants. Plants were within 30 ft of the tow, but tow had no noticeable effect on the plants.

Wind: 0 to 2 mph from 320 deg
Streamflow: 0.25 to 0.30 ft/sec

Time: 1215 hr

Plants have moved an additional 330 ft further downstream and are against the left bank of the river.

Wind: 0 to 2 mph from 30 deg
Streamflow: 0.25 ft/sec

Time: 1515 hr

Plants have moved 165 ft further downstream and are still against the left bank.

Time: 1646 hr

Plants are still in the same position as the previous check.

Plot #5 Shape: 32 by 23 ft 23 Sep 77
Area: 736 sq ft

Time: 0858 hr

Plants are located 3300 ft downstream (north) from south entrance to Blue Creek. Plants are near midstream in main channel of river.

Wind: 0 mph
Streamflow: 0.20 to 0.25 ft/sec

(Continued)

Time: 1000 hr

Plants are 490 ft further downstream (north) from original position. Plants are against left bank of river.

Wind: 0 to 1 mph from 320 deg
Streamflow: 0.25 ft/sec

Time: 1222 hr

Plants have moved an additional 165 ft and are still against the left bank of the river.

Wind: 0 to 2 mph from 25 deg
Streamflow: 0.25 ft/sec

Time: 1525 hr

Plants are still in the same position as the previous check.

Time: 1652 hr

Plants have moved an additional 325 ft and are near midchannel and moving. Light rain and gusting wind.

Wind: 0 to 5 mph from 220 deg
Streamflow: 0.25 ft/sec

Plot #6 Round: 19 ft diam 23 Sep 77
Area: 283.4 sq ft

Time: 0915 hr

Plants located in main river channel in front of Jungle Den Restaurant. Many small groups and single plants floating in river.

Wind: 0 mph
Streamflow: 0.20 to 0.25 ft/sec

(Continued)

Table 8 (Concluded)

Time: 1015 hr

Plants are 400 ft further downstream (north) and are within 15 ft of the right bank of the river. Still many small patches of plants floating in the river.

Wind: 0 to 2 mph (gusty, cannot determine direction, probably from northeast)
Streamflow: 0.25 ft/sec

Time: 1230 hr

Plants are approximately 1400 ft further downstream and near south entrance to Morrison Island.

Wind: 0 to 3 mph from 65 deg
Streamflow: 0.25 ft/sec

Time: 1535 hr

Plants have moved an additional 1560 ft near entrance to south end of Blue Creek.

Wind: 0 to 5 mph from 165 deg
Streamflow: 0.25 ft/sec

Time: 1700 hr

Plants have moved an additional 775 ft downstream and are near right bank of river. Raining.

Wind: 0 to 7 mph from 210 deg
Streamflow: 0.25 ft/sec

Table 9

Summary of Transport Data for Towing Tests on Waterhyacinth

Plot #1
Area: 530 sq ft
Shape: Round
Plant height: 24 to 32 in.
Root length: 12 to 26 in.
Encircled density: ≃85 tons/acre

Plot #2
Area: 615 sq ft
Shape: Round
Plant height: 20 to 36 in.
Root length: 12 to 26 in.
Encircled density: ≃85 tons/acre

Plot #3
Area: 1017 sq ft
Shape: Round
Plant height: 28 to 38 in.
Root length: 12 to 26 in.
Encircled density: ≃125 tons/acre

Plot #4
Area: 1791 sq ft
Shape: Round
Plant height: 26 to 40 in.
Root length: 12 to 28 in.
Encircled density: ≃100 tons/acre

Table 10

Summary of Transport Data for Pushing Tests on Waterhyacinth

Plot #1
Area: 78.5 sq ft
Shape: Round
Plant height: 26 to 34 in.
Root length: 12 to 24 in.
Encircled density: ≃90 tons/acre

Plot #2
Area: 176.5 sq ft
Shape: Round
Plant height: 23 to 36 in.
Root length: 10 to 26 in.
Encircled density: ≃80 tons/acre

Plot #3
Area: 314 sq ft
Shape: Round
Plant height: 26 to 38 in.
Root length: 12 to 25 in.
Encircled density: ≃110 tons/acre

Plot #4
Area: 530 sq ft
Shape: Round
Plant height: 24 to 32 in.
Root length: 12 to 26 in.
Encircled density: ≃85 tons/acre

Table 11

Summary of Conveying Data on Waterhyacinth

Test No.	Conveying Time, min	Biomass Conveyed, lb	Plant Height, in.	Conveying Rate, tons/hr
1	8.2	2380	18-32	8.71
2	8.8	2630	18-32	8.97
3	7.9	2570	18-32	9.76
4	6.8	1640	18-26	7.24
5	8.4	2590	18-32	9.25
6	7.6	2469	18-32	9.75
7	7.8	2264	18-32	8.71
8	8.3	2612	18-32	9.44
9	8.1	2365	18-32	8.76
10	11.4	3060	18-38	8.05

Table 12

Data on Hyacinth Stockpiles

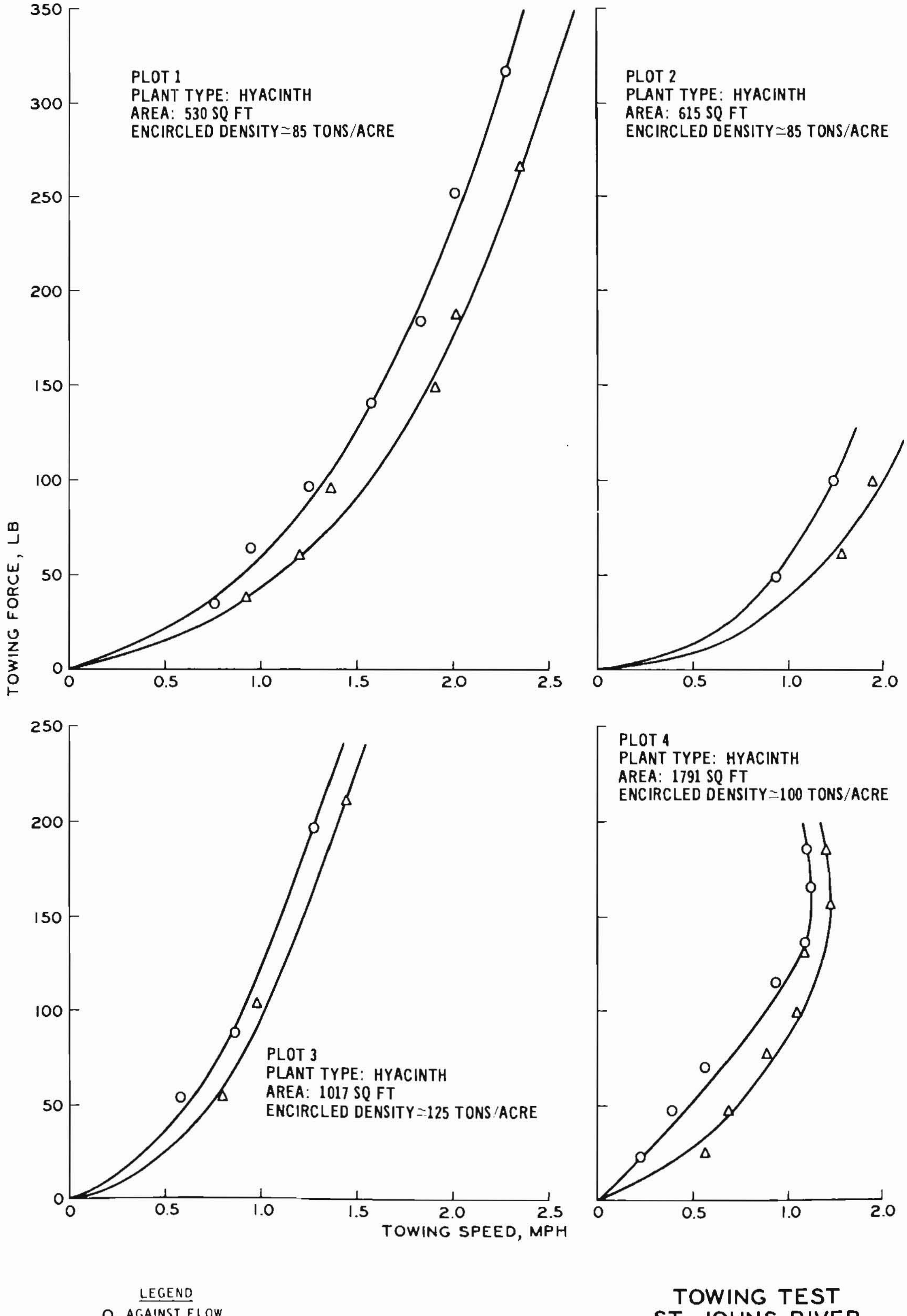
Date	No. of Loads	Biomass lb	Volume cu yd	Density lb/cu yd	Accumulated Biomass, lb
		Stockpile A			
30 Sep	8	19,055	66.6	286.1	19,055
		Stockpile B			
18 Oct	20	39,280	105.0	374.1	39,280
28 Oct	20	48,780	161.3	--	88,060
		Stockpile C			
27 Oct	4	10,245	37.3	274.7	10,245
29 Oct	4	8,740	55.8	--	18,985
31 Oct	4	11,480	72.4	--	30,465
		Stockpile D			
27 Oct	4	7,735	35.0	221.0	7,735
29 Oct	4	9,960	45.7	--	17,695
		Stockpile E			
27 Oct	4	9,290	27.4	339.0	9,290
		Stockpile F			
31 Oct	13	31,490	73.4	429.0	31,490

Table 13

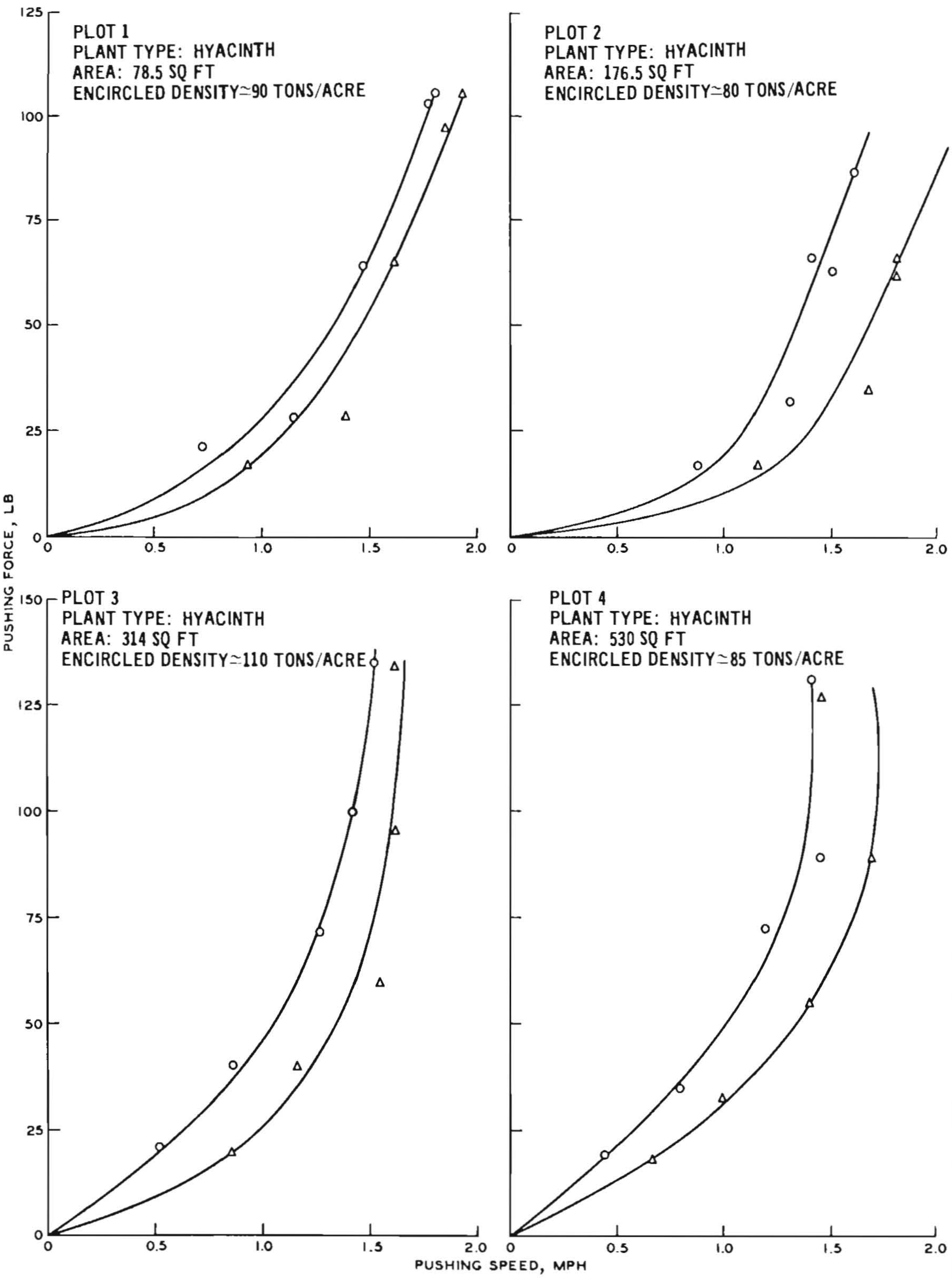
Measured Volume of Hyacinth Stockpiles*

Date	Stockpile					
	A	B	C	D	E	F
30 Sep 77	66.6	--	--	--	--	--
18 Oct 77	--	105.0	--	--	--	--
26 Oct 77	13.1	59.9	--	--	--	--
27 Oct 77	--	--	37.3	35.0	27.4	--
28 Oct 77	--	161.3	--	--	--	--
29 Oct 77	--	--	55.8	45.7	--	--
31 Oct 77	--	--	72.4	--	--	73.4
7 Nov 77	8.9	51.3	28.2	20.1	13.6	28.8
25 Nov 77	7.6	37.0	18.5	11.0	7.8	22.2
20 Dec 77	8.4	35.7	13.9	10.2	6.2	20.6
13 Feb 78	3.8	25.3	8.2	4.4	2.0	8.2
11 Jul 78	0.39	5.3	1.64	0.50	0	2.1

* In cubic yards.

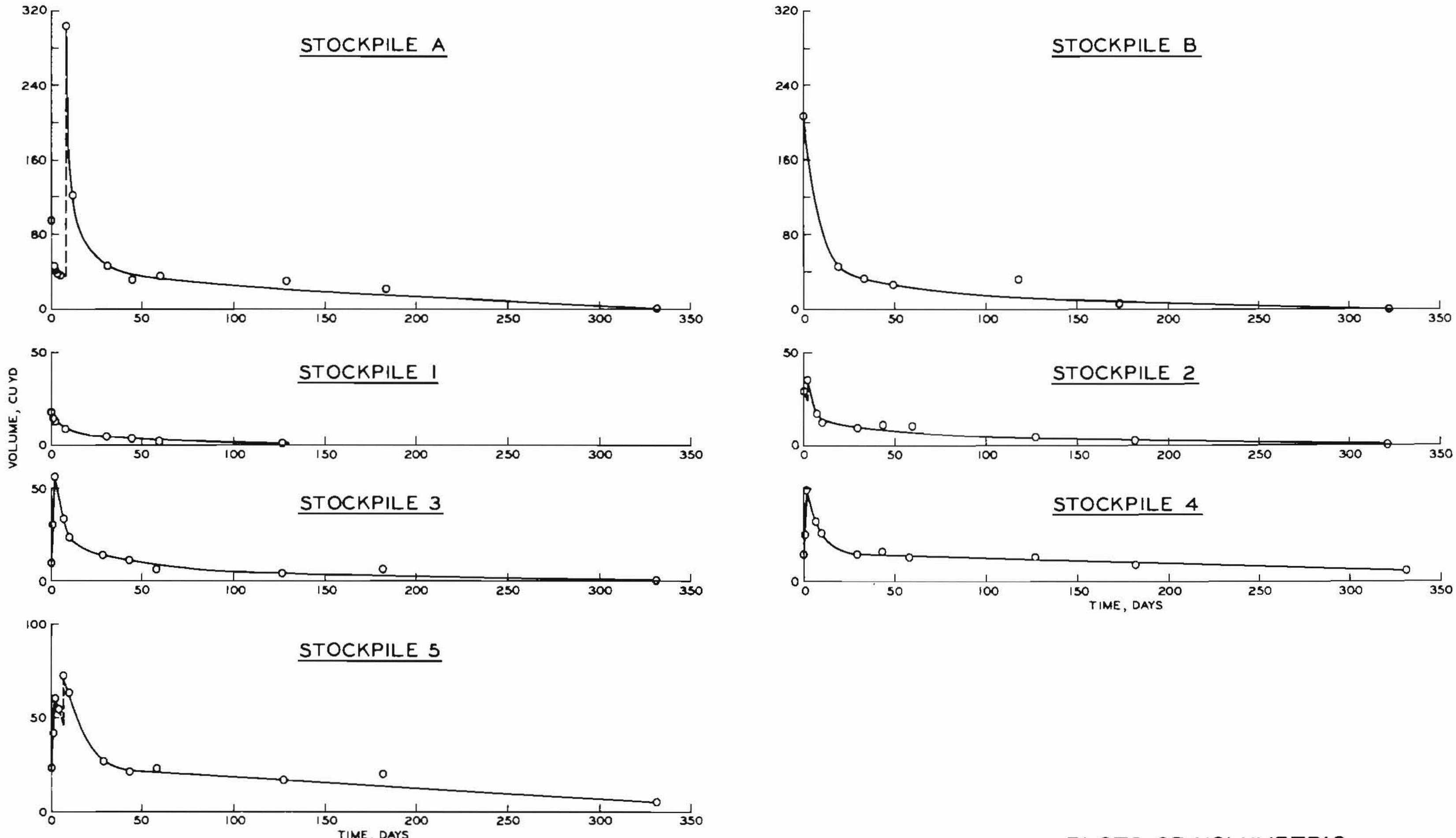


TOWING TEST
ST. JOHNS RIVER
CURRENT FLOW: 0.37 FPS

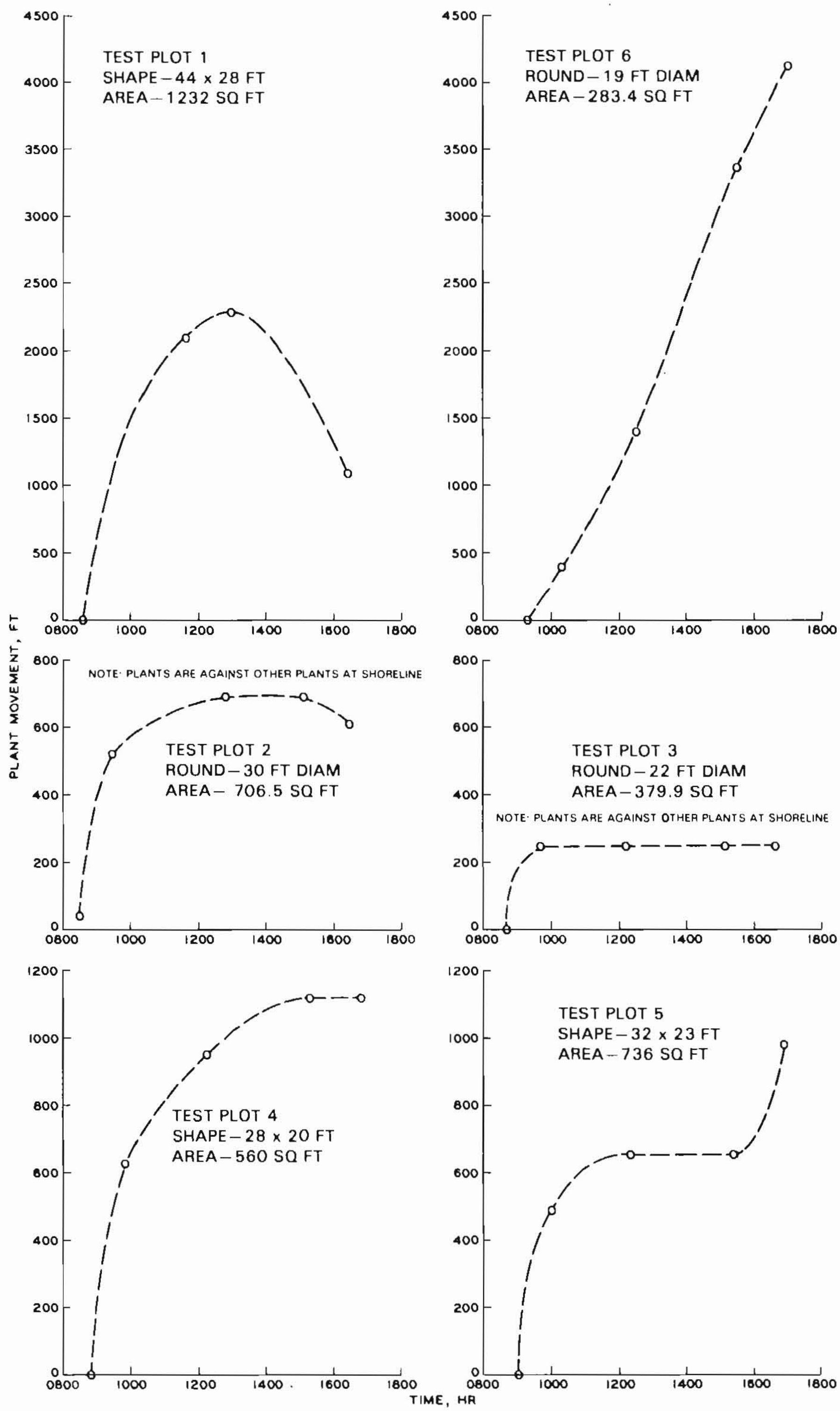


PUSHING TEST
ST. JOHNS RIVER
CURRENT FLOW: 0.25 FPS

PLATE 2

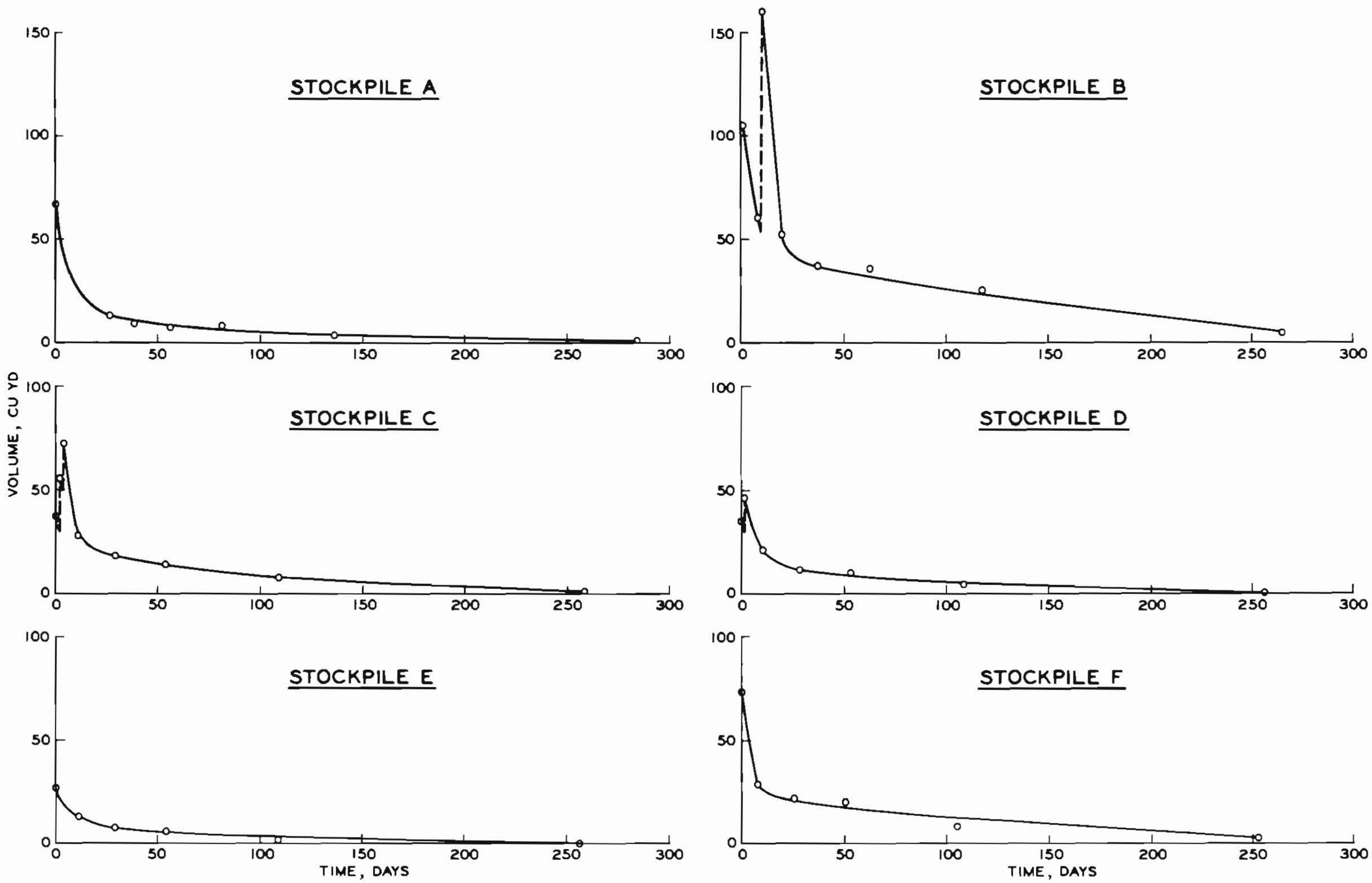


PLOTS OF VOLUMETRIC
REDUCTION OF STOCKPILES OF HYDRILLA
STOCKPILES A, B, AND 1-5



FREE FLOATING TEST
ST. JOHNS RIVER
PLANT TYPE: HYACINTH

PLATE 4



PLOTS OF VOLUMETRIC
REDUCTION OF STOCKPILES OF HYACINTH
STOCKPILES A-F

PLATE 5

APPENDIX A: SPECIFICATIONS FOR THE MECHANICAL CUTTER

General Intent

1. It is the general intent of these specifications to describe a twin pontooned craft designed for the purpose of cutting submersed aquatic vegetation in rivers, canals, and lakes.

Principal Specifications

2. The principal specifications are as follows:

a.	Length	20 ft 0 in.
b.	Width	5 ft 0 in.
c.	Pontoon height	1 ft 5 in.
d.	Bottom of hull to deck level height	2 ft 3 in.
e.	Deck width	5 ft 0 in.
f.	Deck length	20 ft 0 in.
g.	Basic hull weight	1900 lb
h.	Basic hull rating	40 hp

Construction

3. Flotation of the mechanical cutter is provided through 16 foam-filled polyethylene pontoons 17 in. in diameter. The pontoons are sectioned for replacement with a bolted attachment.

4. The deck is 60 in. by 240 in. of nonskid aluminum, all welded. All bolts and nuts are cadmium plated. All components are constructed with galvanized low carbon steel.

Propulsion

5. Propulsion is accomplished via a 360-deg infinite rotation air propulsion unit. The engine is a 10-hp, single cylinder Briggs &

Stratton with centrifical air-cooled clutch. A metal guard (OSHA approved) completely encircles the propeller.

Steering

6. Steering is provided through infinite rotation by endless chain connected to a steering wheel.

Throttle Control

7. Speed control is adjustable at any degree of rotation by a foot-controlled throttle.

Cutter Bar

8. The cutter bar consists of three reciprocating bars, two vertical and one horizontal. The horizontal cutting range is 12 ft with a highway travel of 8 ft. The vertical cutting range is 4 ft and can be increased as an option. The cutter bar operates at 96 cycles per minute. All parts are electroplated; all bolts and nuts are cadmium plated. The bar can be raised and lowered by an electric deck hoist (12 V DC).

Cutter Bar Propulsion

9. The cutter bar is propelled by a single cylinder, air-cooled, 5-hp Briggs & Stratton engine. Engine reduction is:

- a. 6:1 @ the engine
- b. Second reduction engine to torque limiter

Transmission of power to the cutter bar is as follows:

- a. Torque limiter (manual adjustment)
- b. Universal joints for degree change
- c. Slip shaft to control degree change
- d. Mechanical linkage to cutter blades

Performance Data (Manufacturer)

10. Cutting speed is 2 mph, and maximum speed is 5 mph. Average acres cut is 2 to 3 acres, depending on the type and density of vegetation.

Trailer

11. The trailer has a welded steel frame, single axle, and a capacity of 3000 lb. It has operating lights, and its tires are 6.50 by 13 special service.

Optional Equipment

12. Optional equipment includes:

- a. Electric winch--cutter bar control
- b. Tandem axles on trailer
- c. Hydraulic-operated cutter bar
- d. Cutting depth below 4 ft
- e. Padded operator's chair
- f. Metal operator's canopy
- g. 12-ft aluminum rake

Warranty

13. The mechanical cutter is fully warranted for 90 days.

APPENDIX B: SPECIFICATIONS FOR THE TOWBOAT

General Intent

1. It is the general intent of these specifications to describe the aluminum boat used for the towing of aquatic plants during the field test program in central Florida during FY 77.

Principal Specifications

2. The principal specifications are as follows:

a.	Length	18 ft
b.	Beam width	68 in.
c.	Bottom width	52 in.
d.	Material gauge	0.072 in.
e.	Basic hull weight	335 lb
f.	Basic hull rating	75 hp

Construction

3. The towboat is made of all-welded aluminum with a flat bottom and V-shaped bow. Flotation is built-in in the bow and seats.

Propulsion

4. Propulsion is provided by a long shaft, 50-hp Mercury outboard motor with two 6-gal fuel tanks. The motor has an electric start.

Steering

5. The towboat is equipped with a console steering wheel.

Towing Stand

6. A device similar to a water ski towing stand was mounted in the aft section of the boat. An electronic load cell was attached to the upper end of the stand for recording the towing forces. Recording equipment was housed in a weatherproof container aboard the boat.

Performance Data

7. Performance data are as follows:

a.	Weight of craft without operator	725 lb
b.	Maximum speed forward	25 mph
c.	Maximum speed reverse	6 mph
d.	Maximum turning radius	65 ft
e.	Range at full throttle	16 miles

Trailer - Highlander

8. Trailer specifications are as follows:

a.	Model	T-14-8
b.	Series	809165
c.	Tires	4 by 12 LRB
d.	Axles	Single
e.	Lights	Madatory
f.	Weight	400 lb
g.	Capacity	1020 lb

Warranty

9. The towboat is fully warranted for 90 days.

APPENDIX C: SPECIFICATIONS FOR THE PUSHER BOATS

General Intent

1. It is the general intent of these specifications to describe the all-aluminum flat bottom pusher boat, designed for the moving of aquatic vegetation from the cutting areas to the shoreline or into a shore-mounted harvesting machine or elevator.

Principal Specifications

2. The principal specifications are as follows:

a.	Length	14 ft
b.	Beam width	68 in.
c.	Bottom width	48 in.
d.	Material gauge	0.072
e.	Basic hull weight	322 lb
f.	Basic hull rating	25 hp

Construction

3. The pusher boats are made of all-welded aluminum with crimp and tuck construction for additional strength. The pusher boats have built-in flotation in the bow and aft sections and a 3-G braced transom

Propulsion

4. Propulsion is provided by a long shaft, 20-hp Mercury outboard motor with a 6-gal fuel tank.

Steering

5. Steering is provided through a center-mounted console.

Front-Mounted Pushing System

6. The pushing system consists of a 10-ft-wide expanded metal rake. The rake is raised and lowered by a foot-controlled, 12-V electric actuated cylinder. The rake is detachable for transporting.

Performance Data (Design)

7. Design performance data are as follows:

a.	Weight of craft without the operator	700 lb
b.	Maximum speed forward	15 mph
c.	Maximum speed reverse	4 mph
d.	Maximum turning radius	45 ft
e.	Range at full throttle	20 miles

APPENDIX D: SPECIFICATIONS FOR THE SUBMERSED AQUATIC PLANT REMOVAL ELEVATOR SYSTEM

General Intent

1. It is the general intent of these specifications to describe the elevating and horizontal conveyor system used for the purpose of removing previously cut submersed plants from an on-the-water storage area during the field test program in central Florida during FY 77.

Description

2. This conveying system is comprised of a platform supported on metallic pontoons (held in place with standpipes) with an elevating conveyor capable of being raised (3 ft above the water surface) and lowered (3 ft below the water surface). The elevator shall not make an angle greater than 30 deg with the water surface and be at least 4 ft wide with flared front extending to 8 ft wide over a distance of 4 ft. The elevator system shall be capable of removing cut submersed aquatic plants from the water and convey the plants to a height of not less than 6 ft above the water surface and then releasing the entangled plants onto the 32-ft horizontal conveyor. The purpose of the horizontal conveyor is to transfer the plants to the shore and deposit them into the hopper of the stocking conveyor. The complete operation shall be contained so as not to litter the water with dropped vegetation and shall provide a harvesting rate of 30 tons/hr.

Operation

3. The system shall be of such design as to permit preparation for transport, emplacement, and harvesting by a crew of three or less. The system shall have sufficient maneuverability to be towed forward or backward in the water as required for positioning. It shall be operable

for not less than 4 hr of continuous operation with no more than 10 min per hour downtime for such functions as unclogging machinery, lubrication, operator fatique, or refueling the engine. Additionally, it shall be capable of operation in normal winds (up to 20 mph) and rain. The entire system shall be self-contained, requiring no external power source to operate, and shall be powered by either a gasoline or diesel engine.

Conveyance

4. A trailer for use in transporting the system over standard roads to and from harvesting sites shall be provided. The trailer shall conform to all applicable safety requirements for road transport (e.g., brakes, lights, etc.) and shall be capable of being towed in the loaded condition with a standard, commercial 3/4-ton truck. Physical dimensions of the system and the transport configuration shall not exceed 8 ft in width and 13 ft, 6 in. in height.

Safety Features

5. The system shall conform to any applicable mandatory OSHA safety requirements and as a minimum contain safety guards or covers to protect operators from accidentally placing hands, feet, or legs on, or falling into, either rotating, moving, or high temperature parts during operation or maintenance of the system. Adequate protection shall be provided to prevent operators from falling overboard.

Warranty

6. Manufacturers standard warranty shall apply to this equipment.

APPENDIX E: VOLUMETRIC DETERMINATION OF STOCKPILES

1. Field measurements to determine the volume of the stacks of the decomposing hydrilla and hyacinth were made. First, a stake was placed at the center of the stockpile site. Then, four markers (1 by 4 posts) were placed on the quarter points of a circle at known distances from the center stake or marker. Each stake was numbered by starting at one and proceeding counterclockwise to reach the fourth stake. Thus, stockpile A would have four stakes numbered A1, A2, A3, and A4. This is shown in Figure E1. A temporary bench mark (TBM) was established and

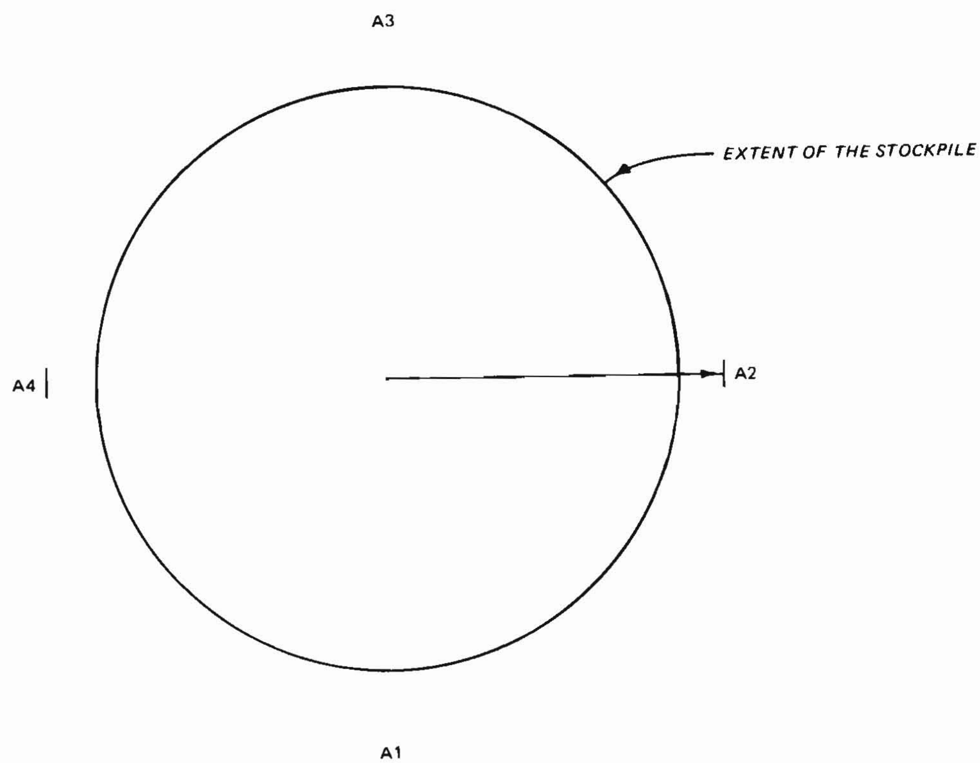


Figure E1. Stockpile site layout

the elevation of the ground at the center of the stockpile was computed in reference to the TBM. Distance measurements from the four reference points to the periphery of the stockpile were made to determine the stockpile base diameter. A transit was used to determine the vertical angle needed to compute stockpile height. Photographs taken perpendicular to section A2-A4 and A1-A3 were used to estimate and sketch to scale the respective cross-sectional shapes between the measured height and base diameter (see Figure E2).

2. As can be seen in Figure E2, the sketch was then divided into a series of right triangles and rectangles. This permitted the use of the equations below to compile the volume of the total stockpile by summing the volume observed by rotating the area of each cross-sectional element in section A2-A4 180 deg. The same computation was repeated for elements in section A1-A3. The average of these two computations yielded the volumes of the stockpile. The equations are:

a. Volume, in cubic yards, of a revolved triangular section (rotated 180 deg)

$$V = \frac{\pi bh(1/3b + a)}{54} \qquad \text{(A1)}$$

b. Volume, in cubic yards, of a revolved rectangular section (rotated 180 deg)

$$V = \frac{\pi bh(1/2b + a)}{27} \qquad \text{(A2)}$$

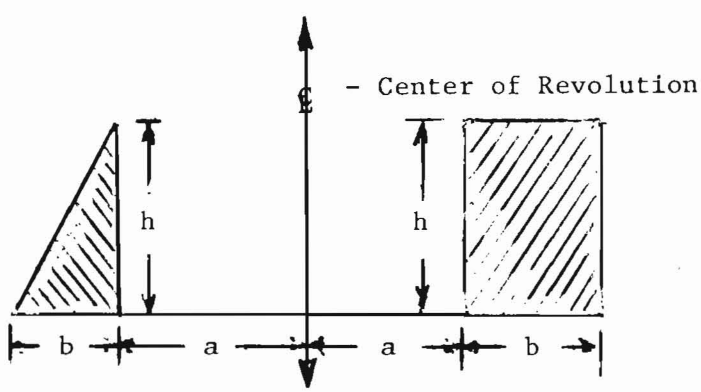
where

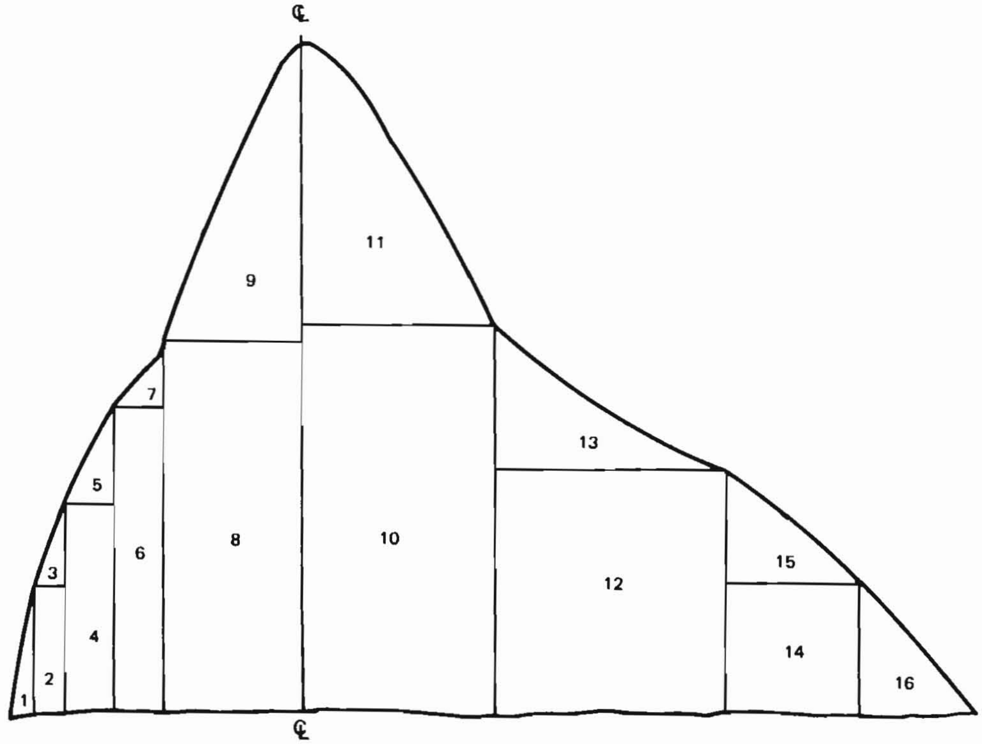
V = volume, cu yd

b = width of base of section, ft

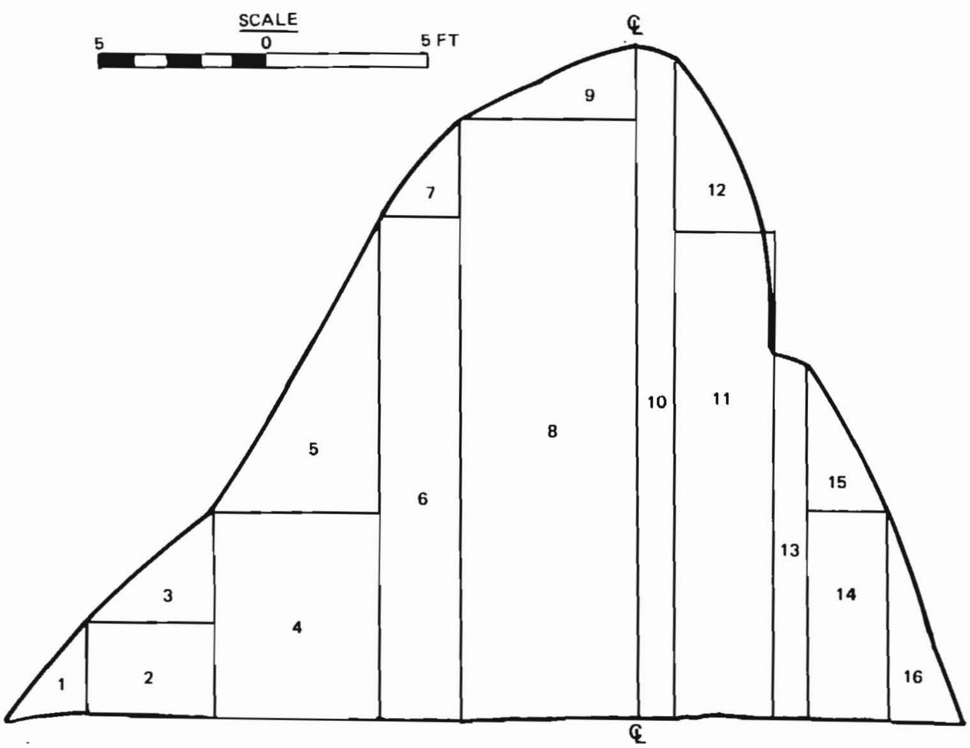
h = height of section, ft

a = distance from center of revolution to inside edge of section, ft





a. SECTION A1 - A3



b. SECTION A2 - A4

Figure E2. Sections sketched to scale from field measurement and ground photographs

APPENDIX F: SPECIFICATION FOR WHEEL-MOUNTED AQUATIC PLANT REMOVAL ELEVATOR CONVEYOR SYSTEM

General Intent

1. It is the general intent of these specifications to describe the wheel-mounted aquatic plant removal elevator-conveyor system used for the purpose of removing floating plants (hyacinth) from an on-the-water storage area during the field test program in central Florida during FY 77.

Principal Specifications

2. The principal specifications are as follows:

a.	Overall conveyor length	28 ft
b.	Conveyor width	4 ft
c.	Sides of conveyor	1 ft
d.	Dumping height	14 ft
e.	Towing height	9 ft
f.	Conveyor chain (#67H)	130 ft
g.	Conveyor flights (angle iron)	3 by 3 by 1/4 in.
h.	Power system	10-hp engine

Construction

3. The elevator-conveyor system is constructed of all-welded steel with the material and gauge being cor-ten and 10 gauge, respectively.

Propulsion

4. The system is towable using a standard commercial 3/4-ton pickup truck with a bumper hitch.

Warranty

5. The manufacturers standard warranty applies to this equipment.

APPENDIX G: MOVEMENT OF FLOATING PLANTS UNDER NATURAL FORCES*

Objective

1. The objective of this appendix is to set up equations of motion of free-floating aquatic plants in rivers.

Assumptions

2. It is assumed that the body (plant) motion is, generally, one of dynamic equilibrium. This means that the accelerations of the body are small, thus making it possible to move at an approximately constant velocity. If the variations in wind and water velocities over the time period for which the distance of movement is to be predicted are small, then this assumption is valid.

3. It is also assumed that there will be two net forces acting on the body: one due to the air and the other due to the water. The force resulting from air pressure should be assumed to be proportional to the area of the body exposed to it and to the square of the velocity of the air relative to the body. The force exerted by the water (the velocity of which will be much lower than that of the air) is proportional to the velocity of the body relative to that of the water and the cross section of its exposed area.

Equations

To determine force due to air

4. To determine force due to air, use the following equation:

$$F_a = K_a A_a V^2 \qquad (1)$$

---

* This appendix was written by A. Kahn, Environmental Laboratory, U. S. Army Engineer Waterways Experiment Station.

where $\overline{F}$, $\overline{V}$ are vectors = $K_a A_a / V_a - V_b/2\ (V_a - V_b)/(V_a - V_b)$ in vector form. Also:

$$F_v = -K_v A_\ell\ (V_b - V_\ell) \qquad (2)$$

where

- F_a = force due to air (due to wind and air resistance combined; even under conditions of no wind, the resistance offered by air to the motion of the body in water must be taken into consideration)
- K_a = drag coefficient due to air
- A_a = cross-sectional area of body exposed to air
- V^2 = velocity vector
- V_a = velocity of the air (vector term) relative to body
- V_b = velocity of the body
- F_v = viscous retardation of movement of body through water (in direction opposite to the velocity of the body relative to the water)
- K_v = drag coefficient due to viscous retardation of the water
- A_ℓ = cross-sectional area of body exposed to liquid
- V_ℓ = velocity of the liquid relative to body

5. <u>Case 1.</u> This force F_v will reduce to zero, when $V_b = V_\ell$, i.e., body velocity equals that of the water. The total force on body is:

$$F_{total} = F_a + F_v \qquad (3)$$

When dynamic equilibrium exists, this force will be zero (corresponding to constant body velocity).

$$F_{total} = F_a + F_v = 0 \quad \text{or} \quad F_a = -F_v \qquad (4)$$

which is

$$K_a A_a \frac{V_a - V_b^2}{(V_a - V_b)} \quad (V_a - V_b) = K_v A_\ell\ (V_b - V_\ell) \qquad (5)$$

where K_a and K_v are constants which are functions of medium viscosity, density, and surface area of object exposed to the medium, i.e.,

$$K = K\left(\mu_{medium}, \rho_{medium}, A_{object}\right) \tag{6}$$

where K is a resistance coefficient.

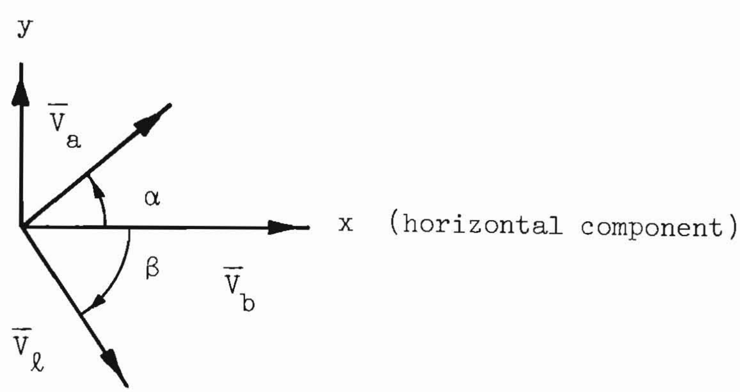
6. To solve for V_b from Equation 6

$$\begin{aligned} K_aA_a\left(V_a - V_b\right)\left(V_a - V_b\right) &= K_vA_\ell V_b - K_vA_\ell V_\ell \\ - V_b\left[K_aA_a\left(V_a - V_b\right) + K_vA_\ell\right] &= -\left[K_vA_\ell V_\ell + K_aA_a\left(V_a - V_b\right)V_a\right] \end{aligned} \tag{7}$$

i.e.,

$$\left[K_aA_a\left(V_a - V_b\right) + K_vA_\ell\right]V_b = K_aA_aV_a\left(V_a - V_b\right) + K_vA_\ell V_\ell \tag{8}$$

7. <u>Case 2.</u> For cases when $V_b \neq V_\ell$, consider the inclination of body to the wind and water directions. See illustration below



where

α = angle between $\overline{V}_b$ and $\overline{V}_a$

β = angle between $\overline{V}_b$ and $\overline{V}_\ell$

Also $\gamma = \alpha + \beta$ = angle between the wind and water directions (angle can be measured). Knowing γ, β can be found, or vice versa.

8. Writing down velocity vectors in terms of their unit vectors and components, gives:

$$V_b = V_b \times \hat{i} \text{ assuming \underline{only} horizontal motion} \tag{9}$$

$$V_a = (V_a \cos\alpha)\,\hat{i} + (V_a \sin\alpha)\,\hat{j} \tag{10}$$

$$V_\ell = (V_\ell \cos\beta)\,\hat{i} + (V_\ell \sin\beta)\,\hat{j} \tag{11}$$

The term can then be defined:

$$\left(V_a - V_b\right)^2 = \left(V_a \cos\alpha - V_b\right)^2 + \left(V_a \sin\alpha\right)^2$$

$$= V_a^{\,2} \cos^2\alpha + V_b^{\,2} - 2\, V_a\, V_b \cos\alpha + V_a^{\,2} \sin^2\alpha$$

$$= V_a^{\,2} (\cos^2\alpha + \sin^2\alpha) + V_b^{\,2} - 2\, V_a\, V_b \cos\alpha$$

We know that $(\cos^2\alpha + \sin^2\alpha = 1)$, thus $\left(V_a - V_b\right)^2 = V_a^{\,2} + V_b^{\,2} - 2\, V_a V_b \cos\alpha$

$$\left(V_a - V_b\right) = \left(V_a^{\,2} + V_b^{\,2} - 2\, V_a V_b \cos\alpha\right)^{1/2} \tag{12}$$

Inserting this value and the values of V_b , V_a , and V_ℓ in Equation 8, gives:

$$\left[K_a A_a \left(V_a^{\,2} + V_b^{\,2} - 2\, V_a V_b \cos\alpha\right)^{1/2} + K_v A_\ell\right] V_b\, \hat{i}$$

$$= K_a A_a \left\{\left[\left(V_a \cos\alpha\right)\hat{i} + \left(V_a \sin\alpha\right)\hat{j}\right]\left[V_a^{\,2} + V_b^{\,2} - \left(2\, V_a V_b \cos\alpha\right)^{1/2}\right]\right\} + K_v A_\ell\left[\left(V_\ell \cos\beta\right)\hat{i} + \left(V_\ell \sin\beta\right)\hat{j}\right] \tag{13}$$

Now unit vectors $\hat{i}$ and $\hat{j}$ correspond to x and y directions in rectangular cartesian coordinates or x - component becomes:

$$\left[K_a A_a \left(V_a^{\,2} + V_b^{\,2} - 2\,V_a V_b \cos\alpha\right)^{1/2} + K_v A_\ell\right] V_b$$

$$= K_a A_a V_a \cos\alpha \left(V_a^{\,2} + V_b^{\,2} - 2\,V_a V_b \cos\alpha\right)^{1/2} + K_v A_\ell V_\ell \cos\beta \qquad (14)$$

Then j or y - component becomes:

$$K_a V_a A_a \sin\alpha \left(V_a^{\,2} + V_b^{\,2} - 2\,V_a V_b \cos\alpha\right)^{1/2} = -K_v A_\ell V_\ell \sin\beta \qquad (15)$$

9. The solution is to write equations in the form:

$$V_b = \frac{C_3\,Z\cos\alpha + C_4\cos(\gamma - \alpha)}{C_1\,Z + C_2} \qquad (16)$$

$$\alpha = \sin^{-1}\frac{-C_4\sin(\gamma - \alpha)}{C_3\,Z} \qquad (17)$$

where

$C_1 = K_a A_a$

$C_2 = K_v A_\ell$

$C_3 = K_a A_a V_a = C_1 V_a$

$C_4 = K_v A_\ell V_\ell = C_2 V_\ell$

$Z = \left(V_a^{\,2} + V_b^{\,2} - 2\,V_a V_b \cos\alpha\right)^{1/2}$

Constraints: $\gamma = \alpha + \beta$ = measurable

10. To use the Raphson-Newton iteration method for nonlinear equations, write Equations 16 and 17 in this form:

$$f_1\,(V_b,\ \alpha) = V_b - \frac{C_3\,Z\cos\alpha + C_4\cos(\gamma - \alpha)}{C_1\,Z + C_2} \qquad (18)$$

$$f_2\,(V_b,\ \alpha) = \alpha - \sin^{-1}\frac{-C_4\sin(\gamma - \alpha)}{C_3\,Z} \qquad (19)$$

Find the partial derivatives of these functions f_1 and f_2 with respect to V_b and α , i.e.:

$$\frac{\partial f_1}{\partial V_b} , \quad \frac{\partial f_1}{\partial \alpha} , \quad \frac{\partial f_2}{\partial V_b} + \frac{\partial f_2}{\partial \alpha} \tag{20}$$

First:

$$f_1 (V_b, \alpha) = V_b - \frac{C_3 Z \cos \alpha + C_4 \cos (\gamma - \alpha)}{C_1 Z + C_2} = 0 \tag{21}$$

and

$$f_2 (V_b, \alpha) = \alpha - \sin^{-1} \left[\frac{-C_4 \sin (\gamma - \alpha)}{C_3 Z} \right] = 0 \tag{22}$$

$$Z^2 = V_a{}^2 + V_b{}^2 - 2 V_a V_b \cos \alpha$$

$$\frac{\partial Z}{\partial V_b} = \frac{1}{Z} \left(V_b - V_a \cos \alpha \right) \tag{23}$$

$$\frac{\partial Z}{\partial \alpha} = \frac{V_a V_b}{Z} \sin \alpha \tag{24}$$

$$\frac{\partial f_1 (V_b, \alpha)}{\partial V_b} = 1 - \frac{1}{\left(C_1 Z + C_2 \right)^2} \left[\left(C_1 Z + C_2 \right) C_3 \cos \alpha \frac{\partial Z}{\partial V_b} \right.$$

$$\left. - C_3 Z \cos \alpha + C_4 \cos (\gamma - \alpha) C_1 \frac{\partial Z}{\partial V_b} \right] \tag{25}$$

$$\frac{\partial f_1 (V_b, \alpha)}{\partial \alpha} = - \frac{1}{\left(C_1 Z + C_2\right)^2} \left\{ \left(C_1 Z + C_2\right) \left[C_3 Z (- \sin \alpha) + \cos \alpha \frac{\partial Z}{\partial \alpha} + C_4 \sin (\gamma - \alpha)\right] + \left[C_3 Z \cos \alpha + C_4 \cos (\gamma - \alpha)\right] C_1 \frac{\partial Z}{\partial \alpha} \right\} \tag{26}$$

$$\frac{\partial f_1 (V_b, \alpha)}{\partial \alpha} = - \frac{1}{\left(C_1 Z + C_2\right)^2} \left\{ \left(C_1 Z + C_2\right) \left[C_3 \left(- Z \sin \alpha + \cos \alpha \frac{\partial Z}{\partial \alpha}\right) + C_4 \sin (\gamma - \alpha)\right] + C_1 \frac{\partial Z}{\partial \alpha} \left[C_3 Z \cos \alpha + C_4 \cos (\gamma - \alpha)\right] \right\} \tag{27}$$

$$\frac{\partial f_2}{\partial V_b} = - \left[\frac{1}{\sqrt{1 - \frac{C_4^2 \sin^2 (\gamma - \alpha)}{C_3^2 Z^2}}} \right] \left[\frac{C_4 \sin (\gamma - \alpha)}{C_3 Z^2} \frac{\partial Z}{\partial V_b} \right] \tag{28}$$

$$\frac{\partial f_2}{\partial \alpha} = 1 - \frac{1}{\sqrt{1 - \frac{C_4^2 \sin^2 (\gamma - \alpha)}{C_3^2 Z^2}}} \left\{ \frac{C_4}{C_3} \left[\frac{\sin (\gamma - \alpha)}{Z^2} \frac{\partial Z}{\partial \alpha} + \frac{1}{Z} \cos (\gamma - \alpha) \right] \right\} \tag{29}$$

$$D = \frac{\partial f_1}{\partial V_b} \frac{\partial f_2}{\partial \alpha} - \frac{\partial f_1}{\partial \alpha} \frac{\partial f_2}{\partial V_b} = (26) \times (30) - (28) \times (29) \tag{30}$$

i.e., $D = (26) \times (30) - (28) \times (29)$

where D is the denominator. Then

$$\Delta V_b = \frac{f_2 \frac{\partial f_1}{\partial \alpha} - f_1 \frac{\partial f_2}{\partial \alpha}}{D} = \frac{(23)(28) - (22)(30)}{(26)(30) - (28)(29)} \tag{31}$$

$$\Delta \alpha = \frac{f_1 \frac{\partial f_2}{\partial V_b} - f_2 \frac{\partial f_1}{\partial V_b}}{D} = \frac{(22)(29) - (23)(26)}{(26)(30) - (28)(29)} \tag{32}$$

Select any starting values of V_b and α and iterate until the increments ΔV_b and $\Delta\alpha$ become zero or insignificant.

To determine K
values for air and water

11. The procedure for floating plants is to conduct towing tests (waterhyacinth in their natural floating position) using the force equation:

$$F_{measured} = F_{total} - F_{total\ drag} = \text{plant mass (accel.)} \tag{33}$$

At constant velocity of plants (zero acceleration):

$$F_{measured} = F_{total} - F_{total\ drag} = 0$$

$$F_{total} = F_{measured} + F_{total\ drag} = 0$$

Thus:

$$F_{measured} = -F_{total\ drag} \tag{34}$$

$$F_{total\ drag} = F_a + F_v = K_a A_a (V_a \cos \alpha - V_b) - K_v A_\ell (V_b - V_\ell \cos \beta)$$

$$- F_{total\ drag} = K_v A_\ell (V_b - V_\ell \cos \beta) - K_a A_a (V_a \cos \alpha - V_b) = F_{measured} \quad (35)$$

$$C_1 = A_\ell (V_b - V_\ell \cos \beta)$$

$$C_2 = A_a (V_a \cos \alpha - V_b)$$

$$F_{measured} = K_v C_1 - K_a C_2 \quad (36)$$

Graphical deter-
mination of K values

12. As the water velocity and thus the body (plant) velocities are usually small, the major variables affecting K values would be V_a , α , A_a , and to some extent A_ℓ . Thus, the measurements should cover the range of the average wind velocities and the most practical plant areas (which can be towed without the plants going under it with the plants in their natural floating position). The average wind velocity range is limited to the duration of the test. Thus, these K values would be applicable only in the specified range of the different variables. At least three tests should be conducted to get one set of dependable K_v and K_a values for a fixed value of the variables involved. To determine K values graphically:

$$F_{measured} = K_v C_1 - K_a C_2 = K_v \left[A_\ell \left(V_b - V_\ell \cos \beta\right)\right] - K_a \left[A_a \left(V_a \cos \alpha - V_b\right)\right] \quad (37)$$

This is a linear type equation where m (slope) = K_v

and

$$\text{let } c \text{ (intercept)} = -K_a\left[A_a\left(\cos\alpha - V_b\right)\right] \quad (38)$$

Conduct field towing tests from station 1 to 2 where

$V_b = V_{boat}$ (boat speed to be held constant during test)

V_ℓ = average flow between stations 1 and 2

For average values of V_ℓ , V_a , α , and β between points 1 and 2, plot towing force (average) versus total area of different test plots. From the curve, determine slope and intercept. Thus

$$\text{slope} = K_v \quad \text{and intercept} = -K_a\left[A_a\left(\cos\alpha - V_b\right)\right]$$

and K_v and K_a can be determined.

13. The procedure for submersed plants is to carry out another test with cut and topped out submersed plants. Using

$$F_{measured} = -F_{total\ drag} \quad (39)$$

$$-F_{total\ drag} = K_v A_\ell (V_b - V_\ell \cos\beta) - K_a A_a (V_a \cos\alpha - V_b) \quad (40)$$

A_a is much smaller than A_ℓ , thus the second item may be ignored. This gives

$$-F_{total\ drag} = F_{measured} = K_v A_\ell (V_b - V_\ell \cos\beta)$$

Let $C_3 = A_\ell(V_b - V_\ell \cos\beta)$. Therefore:

$$F_{measured} = K_v C_3 \quad (41)$$

From here K_v can be determined.

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.

Smith, Perry A

Mechanical harvesting of aquatic plants; Report 2: Field evaluation of low-energy concepts / by Perry A. Smith. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.

73, [43] p., 5 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; A-78-3, Report 2)

Prepared for U. S. Army Engineer District, Jacksonville, Jacksonville, Fla., and Office, Chief of Engineers, U. S. Army, Washington, D. C.

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