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MECHANICAL HARVESTING OF AQUATIC PLANTS

Report I

FIELD EVALUATION OF THE AQUA-TRIO SYSTEM

Volume I

by Moody M. Culpepper and Joseph L. Decell

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

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The U. S. Army Engineer District, Jacksonville, is instituting environmentally compatible, large-scale aquatic plant control and management programs. Local opposition to the use of chemicals to control waterhyacinths and the lack of a federally registered chemical to control the submersed aquatic plant hydrilla prompted the Jacksonville District to request that the U. S. Army Engineer Waterways Experiment Station evaluate the most advanced off-the-shelf aquatic plant harvesters and harvesting systems. The only equipment

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found with the potential to meet specified requirements is a three-component mechanical harvesting system, known as the Aqua-Trio, manufactured by Aquamarine Corporation of Waukesha, Wisc. This report reflects the results of the field data collection program and the analysis of the equipment performance. The report is published in two volumes. The main text and Appendixes A-E are contained in Volume I. Volume II contains Appendix F, which is a compilation of all data taken and equipment operating times recorded during the field operation.

SUMMARY

The U. S. Army Engineer District, Jacksonville, is instituting environmentally compatible, large-scale aquatic plant control and management programs. Local opposition to the use of chemicals to control waterhyacinths and the lack of a federally registered chemical to control the submersed aquatic plant hydrilla prompted the Jacksonville District to request that the U. S. Army Engineer Waterways Experiment Station (WES) evaluate the most advanced off-the-shelf aquatic plant harvesters and harvesting systems. This evaluation was to determine if such systems' productivity is sufficiently high (80 to 100 tons/hr) to control the known growth rate of the troublesome plants waterhyacinth and hydrilla. The only equipment found with the potential to meet this requirement is a three-component mechanical harvesting system, known as the Aqua-Trio, manufactured by Aquamarine Corporation of Waukesha, Wisc. The system performs the basic functions required in the harvesting of aquatic plants, i.e. cutting, loading, transporting, and unloading.

One objective of the evaluation was to generate data pertaining to the performance rates of those functions that make up mechanical harvesting. Data collection was to be carried out in a wide variety of environmental settings and operational scenarios deemed representative of those of interest to the Jacksonville District. A second objective was to determine those functions employed in the Aqua-Trio system that pace the mechanical harvesting operations. The knowledge gained in pursuing the second objective would then prove valuable in focusing the direction of the search for improved mechanical control systems. This is a continuing objective of the research.

The Aqua-Trio, described in Appendix A, was tested in the environments described in Appendix B. Operations and data collection were conducted according to the instructions in Appendix C. Equipment operating cost is given in Appendix D. Lists of literature searched and experienced persons contacted are given in Appendix E. Copies of all data taken and equipment operating times are recorded in Appendix F (Volume II).

Major findings were that (a) total Aqua-Trio system productivity was less than 10 tons/hr with the pacing component being the transport in waterhyacinth and the harvester in hydrilla; (b) of the three components of the Aqua-Trio, only the onshore conveyor had production rates that demonstrated a potential for reaching 80 tons/hr; the other components involved excessive mechanical handling of the plants; and (c) transporting the harvested material over water appeared to be the major pacing problem in developing a high-production mechanical harvesting system.

It is recommended that the search for improved mechanical systems be continued. It is further recommended that realistic performance specifications be prepared for a "Request for Proposal" to industry for the design of an advanced system. It is also recommended that a technical framework for evaluating industry designs be developed and that model development continue.

PREFACE

Personnel of the Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES), conducted the study reported herein at the request of the U. S. Army Engineer District, Jacksonville, which provided funds under authorization 96X3123.

The study was under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and B. O. Benn, Chief, Environmental Systems Division; and under the direct supervision of Mr. J. L. Decell, Chief, Aquatic Plant Research Branch (APRB). Mr. M. M. Culpepper was Project Engineer and Mr. S. O. Shirley assisted in the conduct of the field tests. This report was prepared by Mr. Culpepper and Mr. Decell. The APRB is now part of the recently organized Environmental Laboratory of which Dr. John Harrison is Chief.

Acknowledgment is made to Mr. Joe Joyce, Chief, Aquatic Plant Control Section, Jacksonville District; Mr. Emory Close, Palatka Area Engineer; Dr. Bill Haller, University of Florida; Mr. Howard Grisham, Astor, Fla.; Mr. Roy Gossard, Orange Lake, Fla.; and the Florida Highway Patrol for their support during the field tests.

Directors of WES during the conduct of the study and preparation of the report were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONTENTS

* This Appendix is bound separately as Volume II.

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
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
miles (U. S. statute) per hour	1.609344	kilometres per hour
acres	4046.856	square metres
cubic feet	0.0283168	cubic metres
cubic yards	0.7645549	cubic metres
gallons (U.S. liquid)	0.003785412	cubic metres
pounds (mass)	0.45359237	kilograms
tons (2000 lb mass)	907.1847	kilograms
tons (2000 lb mass) per acre	0.22417	kilograms per square metre
horsepower (550 ft-lb/sec)	745.6999	watts

MECHANICAL HARVESTING OF AQUATIC PLANTS

FIELD EVALUATION OF THE AQUA-TRIO SYSTEM

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 in combination with other methods, e.g. biological and chemical, to manage problem aquatic plants in water bodies of interest to the Corps. The decision that mechanical harvesting has the potential to become a viable aquatic plant control tool of use to the Jacksonville and other Corps Districts was reached after consideration of the advantages and disadvantages of mechanical harvesting and the reasons that past efforts had been abandoned.

2. Among the advantages of mechanical harvesting are the following: it provides immediate relief from the nuisance condition in the area of application; it adds no foreign substance to the aquatic environment; physical removal of the cut plant material from the aquatic ecosystem removes a high biological oxygen demand that could in extremes adversely affect marine life; the harvested vegetation, properly processed, can provide a potentially useful resource; and mechanical harvesting of submersed aquatics controls the amount of plant material removed, a desirable function, especially in the enhancement of fisheries.

3. Many of the disadvantages of mechanical harvesting are related to the low productivity and high cost of the harvesting operations compared with other methods of aquatic plant control. However, efforts to increase productivity by simply enlarging the equipment components have usually resulted in unmaneuverable machines. Further, the lack of adequate land-based disposal sites has resulted in high disposal costs.

4. Aquatic herbicides were introduced in the 1950's and their low

cost per acre of application ended the use and modification of mechanical harvesters before any increase in technical development could be realized. With the growth of environmental concern in the late 1960's, and a better knowledge of problem plant growth rates, the machines constructed became larger, less maneuverable, and more energy-intensive. Thus, attempts were made to extract plants from a fixed point on the periphery of the water body. In many cases, this was ineffective because of problems in moving the plants to the take-out point. Problems in plant material disposal have never been adequately solved, and increases in waterborne recreation and shoreline development have magnified the problems and helped discourage the use of mechanical systems.

5. For the most part, strategy for the control of aquatic plants in a given water body must be developed in full cognizance that each problem area has a specific set of environmental conditions. These specifics often dictate the optimal methodology that can be used, including the proper type and mix of mechanical devices required for the removal and disposal of the plants. For instance, a high level of cultural development and extensive recreational use of a water body will dictate that harvested plants not be thrown or stacked indiscriminately on the banks of the water body. Furthermore, limited access to land at the water's edge may often require excessive time for a waterborne transporter to deliver plant material to an accessible point on land. It must be recognized that, in addition to considerations of the efficiency of operational techniques, physical site factors and the environmental impact of a control technique must be evaluated when selecting an optimal procedure. The thrust, then, of the APCRP is to develop 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.

6. In the U. S. Army Engineer District, Jacksonville, there is intense public pressure to institute environmentally compatible, large-scale aquatic plant control and management. In particular, local interests are extremely critical of the widespread use of chemicals to control waterhyacinths in certain reaches of the St. Johns River. Also,

the submersed plant hydrilla has infested many water bodies in the District. At present, no federally registered chemical is available to control this plant. These factors prompted the Jacksonville District to request, in December 1975, that WES assist it in performing a field evaluation of the most advanced off-the-shelf aquatic plant harvesters and/or systems. Analysis of the data collected during these field investigations was to serve as a point of departure for development of efficient high-productivity mechanical harvesting systems for plant control operations.

7. In evaluating a mechanical harvesting system, a number of characteristics are considered to be desirable:

- a. Removal rate of 80 to 100 tons/hr.*
- b. Maximum use of natural forces for overwater transportation.
- c. Minimum use of land transport.
- d. Minimum energy input for all functions (cutting or dredging, transport, land-water interface transfer, disposal).
- e. Low-frequency machine handling.
- f. Noncontinuous operating cycles.
- g. Noncoincidental functions.
- h. Low maintenance.
- i. Nondisruption of aquatic system activities.
- j. Design performance rates based on plant growth rates and desired levels of control.

8. Inquiries made during the third quarter of fiscal year 1976 revealed that only one company manufactures and delivers, on a production basis, aquatic plant harvesting equipment that has some potential for success in both floating and submersed weed infestations. This company, the Aquamarine Corporation of Waukesha, Wisc., manufactures a three-component mechanical harvesting system known as the Aqua-Trio. The system performs many of the basic functions required (see paragraph 45) in the harvesting of aquatic plants (cutting, loading,

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 7.

transporting, and unloading). It therefore appeared to be an acceptable choice for studying these function performance rates in a variety of environments of interest to the Jacksonville District. For this reason, the field evaluation was conducted using this system. The disposal function was not emphasized in this study. The harvested plant material was taken by truck from the harvesting side to locations where the material could be stockpiled for subsequent use as a soil conditioner by local landowners or could be left in place for natural decomposition.

Purpose and Scope

9. The purpose of the research reported herein was twofold. The first objective was to generate data pertaining to the performance rates of those functions that make up mechanical harvesting. These data were to be obtained in a wide variety of environmental settings and operational scenarios in order that the results could be extrapolated with confidence to most of the environmental and operational conditions of interest to the Jacksonville District. The second objective was to determine those functions employed in the Aqua-Trio system that paced the mechanical harvesting operation under the various test conditions and to compare the overall system productivity with plant growth productivity to serve as a basis for developing high-productivity mechanical harvesting systems.

10. Tests were conducted at 21 sites in both river and lake environments in the Jacksonville District. Part II of this report describes (a) the Aqua-Trio system used in the tests, (b) the test sites and how they were selected, and (c) the field test procedures and data recorded during the field tests. Part III describes the data reduction and analysis method. Emphasis was placed on defining the performance parameters used in the analysis, i.e. the primary, secondary, and nonfunctional times for all components (harvester, transport, and conveyor) of the Aqua-Trio system and how these parameters varied as a function of plant type, biomass, and overwater one-way transport distance.

Part IV presents the conclusions of the study and the recommendations derived therefrom. Appendix A presents the technical specifications for the Aqua-Trio system; Appendix B contains a summary of the test site descriptions; Appendix C contains sample data sheets and definitions of the data sheet entries; Appendix D presents a summary of operational costs; and Appendix E presents lists of literature researched and of recognized experts consulted in preparation for accomplishing this study. Appendix F (Volume II) contains the field data.

PART II: FIELD DATA COLLECTION PROGRAM

Background

11. Mechanical harvesting of aquatic plants is presently being done by individuals and local, State, and Federal agencies, but the practice has not been sufficiently widespread to motivate industry to develop optimum equipment and methods to efficiently perform all the necessary functions. This fact influenced the design of the field data collection program because it was almost certain, even at the outset of the program, that the Aqua-Trio would not fill all the operational requirements of the Jacksonville District. For this reason the field tests were designed to yield data pertinent to the preparation of performance specifications for developing advanced mechanical harvesting systems.

12. First, it was desired that the data contain quantitative information to show which functions paced the harvesting operation. Because it was known that different functions could pace the operation as site conditions changed, tests would have to be conducted at sites that represented the variation existing in the Jacksonville District. Second, because the Aqua-Trio was designed primarily for harvesting submersed aquatic plants, it was not expected to work as well in floating plants. Therefore, it was not expected that simply increasing the size of the components would increase the system's performance to operational levels. Thus, the data must be able to be extrapolated, at least qualitatively, to other equipment designs.

13. This Part of the report, supplemented by Appendixes A through F, presents a description of the equipment, the test sites and how they were selected, and the test methods and resulting data.

Aqua-Trio System

14. The Aqua-Trio is a three-component mechanical harvesting system built and sold by the Aquamarine Corporation, Waukesha, Wisc.

It is composed of a harvester, a transport, and an onshore conveyor. Detailed specifications for the Aqua-Trio are presented in Appendix A.

15. The harvester (Figure 1) is barge-mounted with a diesel power

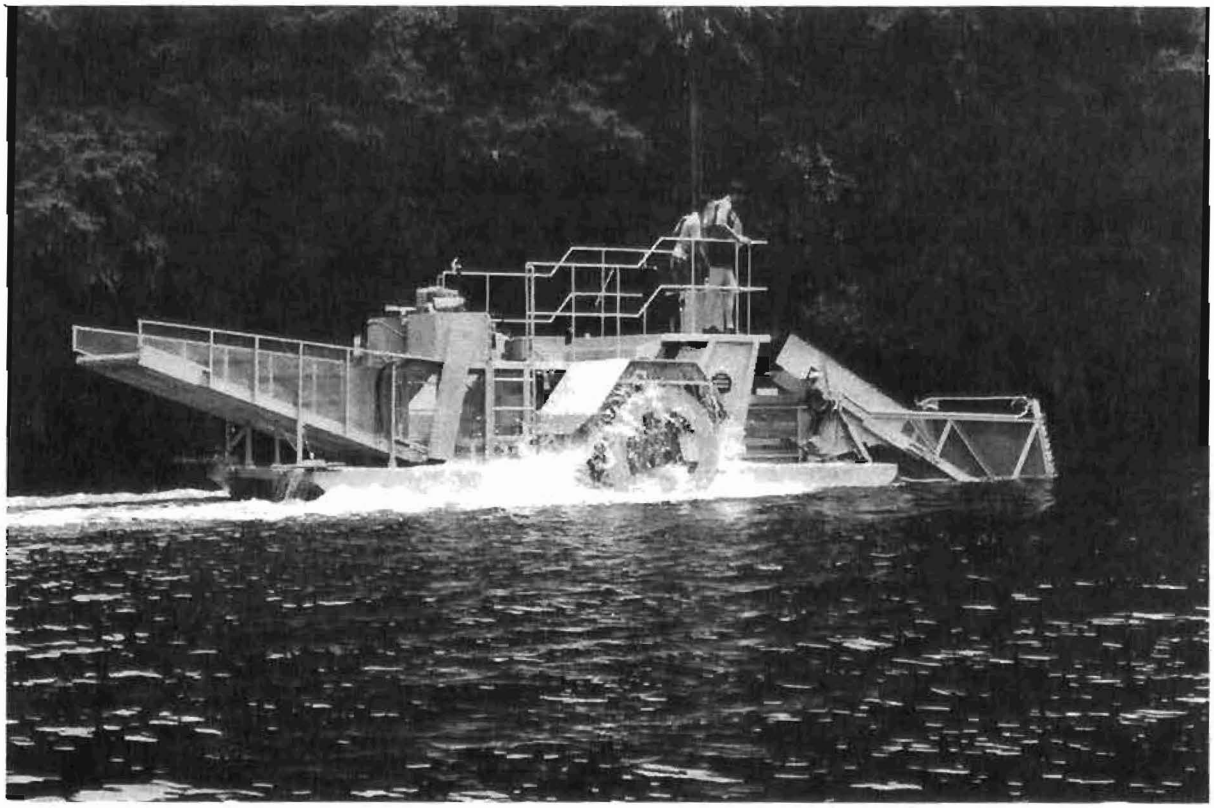

Figure 1. Harvester component of Aqua-Trio

plant driving four hydraulic pumps, which are coupled to various hydraulic motors providing power for the cutterheads, conveyors, and propulsion. The propulsion for the barge is supplied by side-mounted paddle wheels. The cutting of aquatic plants is accomplished by an arrangement of one horizontal and two vertical cutter bars. As these cutter bars sever the plants, an elevating conveyor simultaneously lifts the plants from the water and stores them in a hold on a second and third conveyor. The volume of this hold is 650 ft^3.

16. The transport (Figure 2) is identical with the harvester except that it has no cutter bars or elevating conveyor for removing

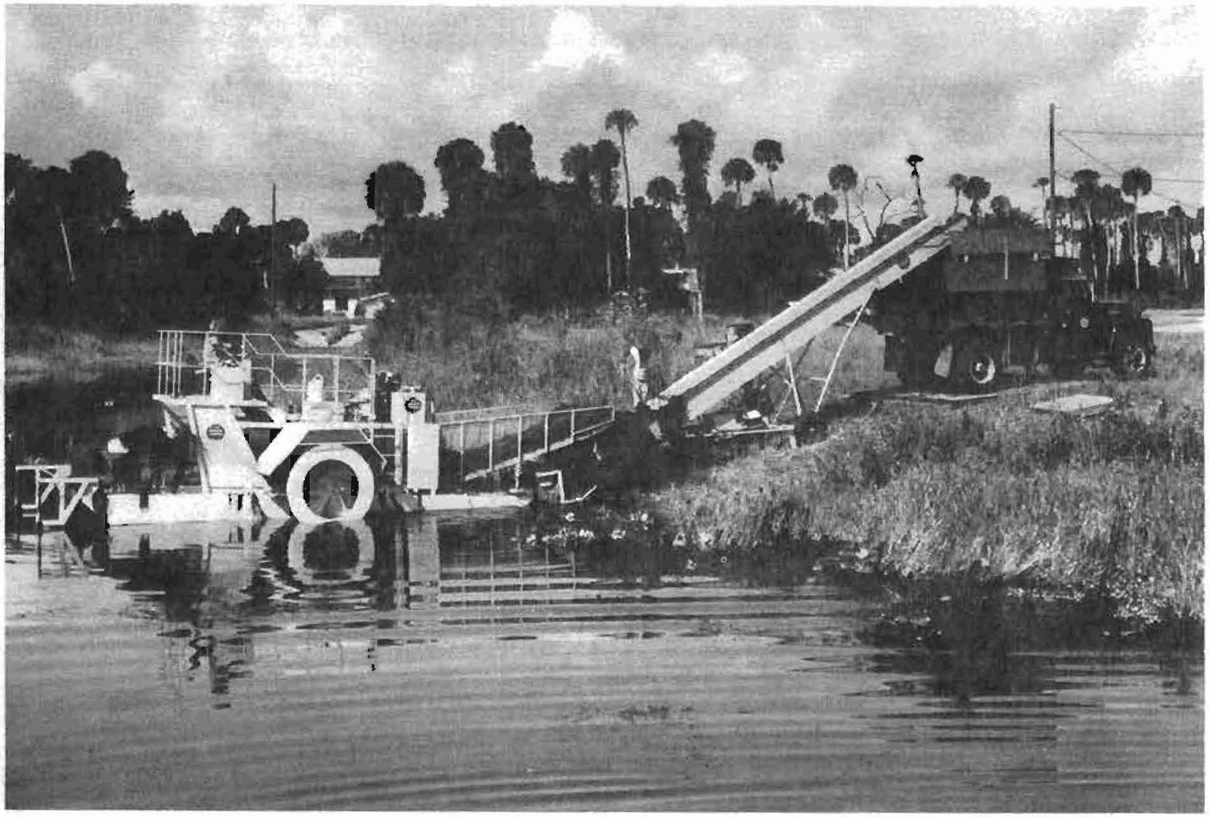

Figure 2. Transport and onshore conveyor components of the Aqua-Trio

plants from the water. The transport couples to the harvester and the plants in the hold of the harvester are transferred to the transport hold by live-bed conveyors. The hold of the transport is also 650 ft^3. The function of the transport is to move the plants from the harvester location to the location of the onshore conveyor.

17. The onshore conveyor (Figure 2) is an elevating conveyor and is always positioned at the land-water interface. The transport couples to the onshore conveyor and transfers the plants by live-bed conveyors from the transport to the onshore conveyor, which elevates the plants for dumping on the shore or into trucks for subsequent disposal.

Test Sites

Selection criteria

18. For the purpose of these tests, the Jacksonville District

identified three major types of weed infestations for use in the evaluation: waterhyacinths, hydrilla, and combinations of the two. Plant infestations exist at various biomass densities in nature. Therefore, it was desired that the sites selected have a wide range of biomass densities for both the waterhyacinths and hydrilla. Further, the plants exist in both still and slow-moving water as well as in water with current. For this reason it was decided that both river and lake conditions should be included in the program. It was desired that the sites be in areas where public use of the water body created some need for aquatic plant control. Thus, the plants removed would benefit the public as well as provide experimental data. An appropriate place for the setup of the conveyor (one with shoreline transfer points readily accessible from both the water body and the existing road network) was needed so that the operation could proceed without excessive water transport. Plant disposal areas accessible by the same road network were also necessary.

19. The ground elevation (top of bank) at the transfer points had to be 1 to 3 ft higher than the water elevation as less than 1 ft would allow water to be pushed onto the site by passing commercial boat and barge traffic. Over 3 ft would reduce the lift of the onshore conveyor to an unacceptable height in that it would be incapable of loading the trucks that were used in the tests (5-ton, 2 × 4 dump trucks). The site also had to have sufficient soil strength to support traffic and sufficient area to permit loading operations (turning around, weighing, etc.).

20. Disposal area locations were to be within 1 mile of the transfer point and had to contain sufficient area and soil strength for maneuvering and support of the truck traffic. In addition, sparse or no vegetation was desired to facilitate maneuvering and dumping operations. The minimum size of the disposal area sought was based on the 200- by 200-ft area required to store, without stacking, the plant material harvested in 7 days.

Site selection

21. Personnel from WES and the Jacksonville District examined three general areas (the St. Johns and Withlacoochee Rivers and Orange

Lake, Fla.) for sites that met the general criteria (Figure 3). Aerial reconnaissances were made over the St. Johns and Withlacoochee Rivers and Orange Lake to initiate site selection. Areas along the rivers and lake that appeared to be suitable, based on the criteria described in the preceding paragraphs, were subsequently inspected by airboat, and the most promising harvesting sites were delineated on 1:24,000-scale map sheets.

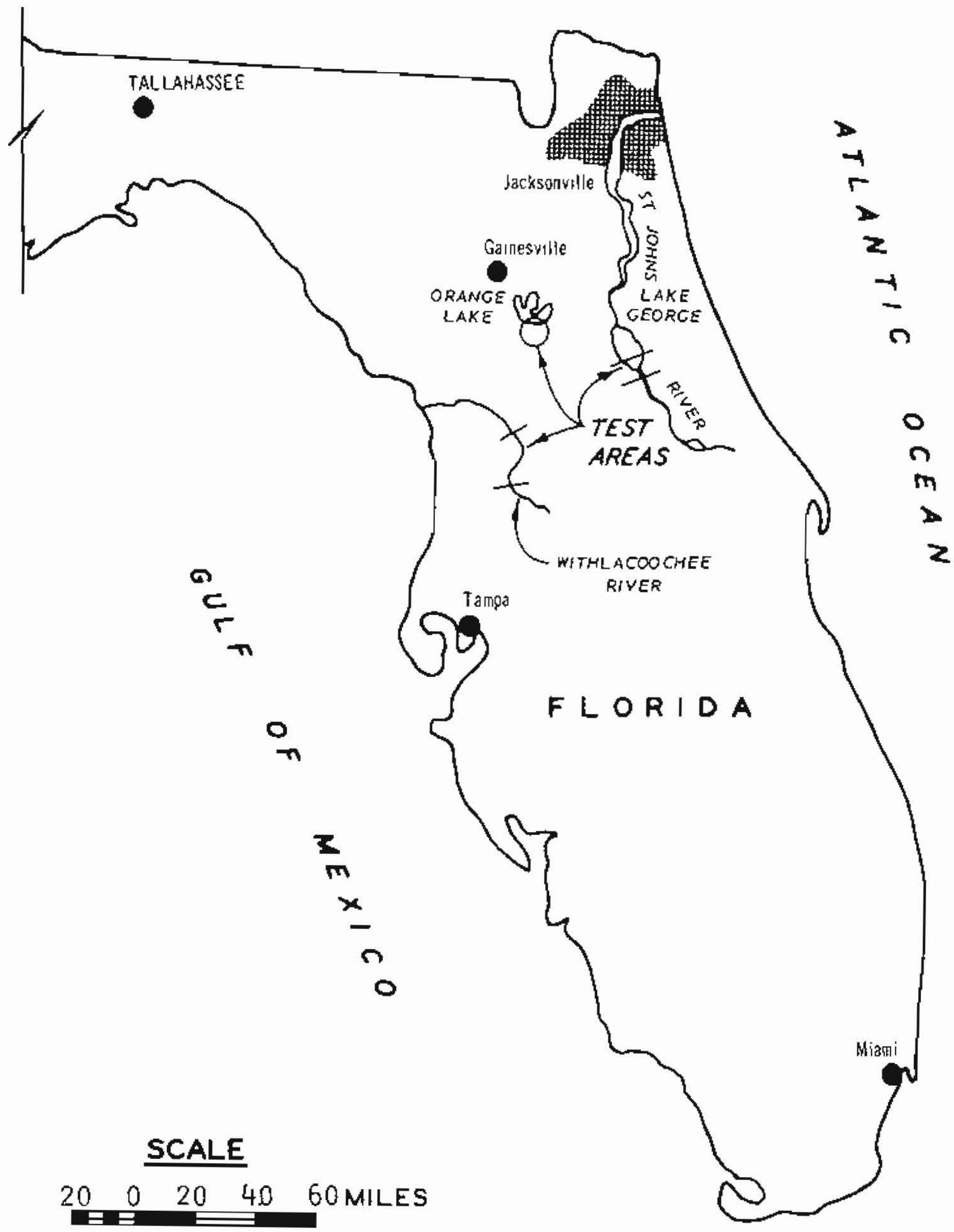

Figure 3. Test site locations

22. Further study of aerial photographs and the annotated map sheets was accomplished before final selection. All roads leading to the water body shores in the selected areas, all high ground adjacent to the water, and all possible disposal areas were outlined on overlays to the map sheets. This information provided an efficient data base for the selection of potential transfer and disposal sites for each aquatic plant infestation site that had been designated as a harvesting site. Final selection resulted in 21 sites designated for use in the field program. The Jacksonville District real estate personnel then obtained the necessary access to the transfer points and the disposal areas.

23. As can be seen in Figure 3, all the sites were located in north-central Florida. A description and layout plate of each site are given in Appendix B. The location of each waterhyacinth, hydrilla, and combination site is shown by latitude and longitude in the tabulation below. Also included in the tabulation is the plate number in Appendix B that shows each site layout.

Site	Latitude	Longitude	Plate No.
	St. Johns River - Waterhyacinth		
2AT-13	29°10'19"	81°31'47"	B1
2AT-13A	29°10'28"	81°31'50"	B2
2AT-13B1	29°10'00"	81°31'59"	B3
2AT-13B2	29°10'00"	81°31'55"	B4
2AT-13B3	29°10'00"	81°31'51"	B5
2AT-13B4	29°10'00"	81°32'04"	B6
2AT-13B5	29°10'00"	81°31'47"	B7
2AT-18A	29°11'55"	81°34'01"	B8
2AT-18B	29°12'03"	81°34'27"	B9
2AT-18C	29°11'52"	81°33'47"	B10
2AT-18D	29°12'11"	81°34'34"	B11
2AT-18E	29°12'16"	81°34'05"	B12
2AT-18F	29°12'08"	81°34'05"	B13
	Orange Lake - Hydrilla		
West	29°27'47"	82°11'18"	B14
East	29°26'25"	82°09'01"	B15

(Continued)

Site	Latitude	Longitude	Plate No.
	Withlacoochee River - Hydrilla		
Wysong Dam	28°48'38"	82°10'52"	B16
Area 2	28°44'04"	82°13'55"	B18
Area 3	28°44'07"	82°13'53"	B19
Area 5	28°44'34"	82°13'11"	B21
	Withlacoochee River - Hydrilla and Hyacinth		
Area 1	28°44'04"	82°13'49"	B17
Area 4	28°42'49"	82°13'55"	B20

24. Study of Plates B1 through B13 reveals that, except for site 2AT-13A, all harvesting operations were conducted outside the main channel of the St. Johns River. Unseasonably cold weather during the winter of 1975 and the chemical control operations of the Jacksonville District had effectively cleared the river proper, and only in protected areas were there sufficient hyacinths to conduct the harvesting operations. As shown in the tabulation above, tests were conducted in hydrilla infestations at Orange Lake and the Withlacoochee River. The Aqua-Trio was also operated in an environment containing a mixture of both hyacinth and hydrilla in two areas of the Withlacoochee River.

Field Test Procedures

25. There were three major phases in the field operations: (a) layout of the test site, measurement of the aquatic plant biomass, and recording of general conditions at the test site; (b) conduct of the harvesting operation; and (c) recording of the time required to complete each phase of the operation. To some extent these three phases of the field procedures depended on the plant type. For this reason, they are discussed by plant type in the following paragraphs. At selected sites, the basic Aqua-Trio system was supplemented with an additional transport in an effort to determine the effect of the added component on the basic system's productivity.

Waterhyacinth

26. Test site layout and documentation. The areas to be

harvested, which ranged in size from approximately 0.1 to 32 acres as detailed in Appendix B, were identified by the project engineer and were marked off by readily visible buoys (or stakes, if one edge of the site boundary was on the land-water interface). The buoys were placed at 100-ft intervals. Where appropriate, a transit and stadia rod were used to lay out the sites; in some instances one buoy was placed at the leading edge of the plant mass to be harvested, and a 100-ft line was stretched from the first buoy to the location of the second buoy, and so on. Each site was evaluated for plant biomass homogeneity, and locations for biomass samples were selected. Normally, three samples were selected in each homogeneous area. Biomass samples were obtained by one of the two methods below.

a. A 1-m-square frame (Figure 4) was placed over the plants, and all plants within the frame were removed, counted, and 10-20 plants were weighed, thus providing a measure of the number and weight of the plants per square metre. In addition the length of the plants above and below the waterline was measured.

b. The harvester gathered all plants within a measured area, which were loaded into trucks and subsequently weighed using Hiway Load-o-Meter scales (Type A, load capacity 20,000 lb) manufactured by the Black and Decker Manufacturing Co., Townsend, Md. To obtain aquatic plant weight using these scales, each axle of the empty dump truck was weighed (Figure 5), and the sums were added to obtain a total weight of the empty truck (tare weight). The truck was then loaded with plants and each axle reweighed while loaded, and the weights were added to obtain the total weight of the loaded truck (gross weight). The loaded truck weight (gross) less the empty truck weight (tare) equaled the total aquatic plant weight.

27. In addition to obtaining the quantitative biomass data, pertinent information was recorded concerning general site conditions, including depth of water, current velocity, height of land above water, bank slope in the vicinity of the conveyor location, etc. These notes were used in preparing the site descriptions in Appendix B.

28. Conduct of the harvesting operation. Throughout the course of this study, the harvester and transport components of the Aqua-Trio system were operated by personnel of the Aquamarine Corporation, while

Figure 4. Placing the 1-m-square frame over the waterhyacinth for sampling number and weight of plants

Figure 5. Weighing a loaded truck to determine weight of harvested plant material. The scale is the Hiway Load-o-Meter, Type A, load range 0 to 20,000 lb, manufactured by the Black and Decker Co.

the conveyor and dump trucks were operated by personnel of the Palatka Area Office, CE. The Aqua-Trio was first operated in infestations of waterhyacinth in the St. Johns River at Astor, Fla. As stated in paragraph 12, the Aqua-Trio was designed to harvest submersed plants. Since it was not known how to operate the system efficiently in hyacinth infestations, several harvesting techniques were attempted before a final mode of operation was selected for the field tests. The first technique involved propelling the harvester at a slow (about 1-mph) speed directly into the hyacinth mat. The next attempt was to move the harvester along the mat fringe, as is normally done in mowing a lawn. The third method, which was finally selected, involved moving the harvester directly into the mat in a back and forth action to assist in working the plants into the holding area of the harvester.

29. The first method tried could not be used because the plants

were obstructed by the harvester superstructure and thus the plants (Figure 6) could not be moved rapidly enough into the holding area. Also, the harvester did not have sufficient thrust to force its way through the heavy mats. The second method did not prove efficient because the harvester pushed some plants into open water and the paddle wheels pulled hyacinth plants to the rear of the harvester. Then, when the transport attempted to couple with the harvester, these plants acted as a barrier that held the two pieces of equipment apart. In using the third method for harvesting hyacinth in restricted areas such as canals, the harvester would move approximately one third to one half its length into the waterhyacinth, harvesting plants as it progressed. The harvester would then back out and repeat the procedure. As this technique progressed, the plants thinned out and a new leading edge was formed. The harvesting procedure continued until the holding area of the harvester was full. The plants were then transferred to the transport and harvesting was resumed. Harvesting waterhyacinth in open waters of the river was easier to accomplish than in the restricted areas. In this environment the harvester was able to harvest along the leading edge of plants without stopping, backing, or moving over and harvesting again. In most cases, the harvesting line was approximately parallel to the shoreline. The harvester continued harvesting in this manner, along the leading edge in a straight line and reversing direction at the end of the plant mat, until the holding area on the harvester was full. At this time, a transport would couple to the harvester, and plants from the harvester were transferred to the transport. During all harvesting operations in hyacinths, individual plants and small mats were broken free and different forces including the harvester operation moved them about. Picking up these small separated mats proved to be very time-consuming, but this step was considered part of the harvesting operation.

30. After the harvester was filled, it was stopped and the transport was coupled in place. After coupling, the harvester load was transferred to the transport, which then uncoupled and proceeded at full speed and in as direct a route as possible to the onshore conveyor.

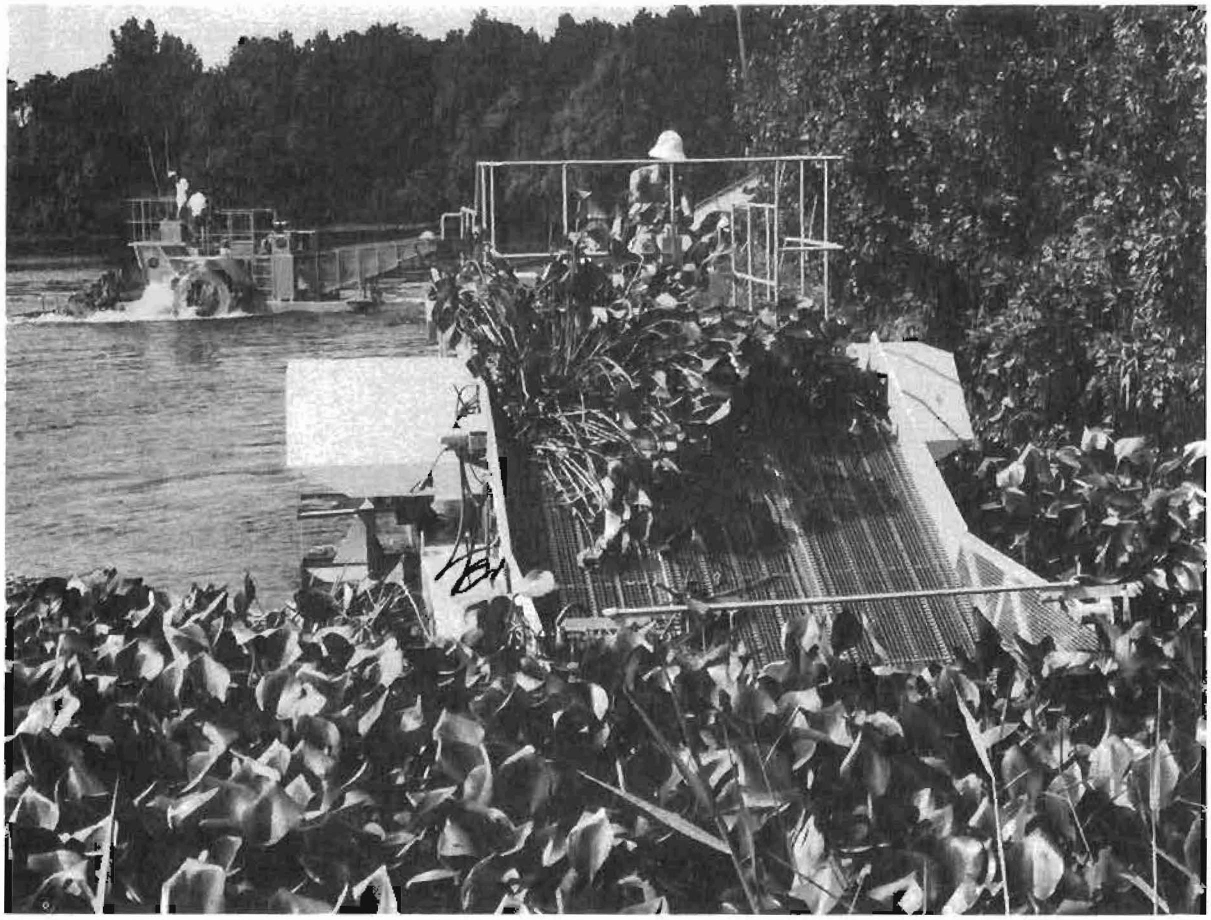

Figure 6. In heavy waterhyacinth the Aqua-Trio could not move forward continuously because the plants would catch on the operator platform and not fall into the holding area

The transport experienced minor difficulties unloading onto the onshore conveyor if an attempt was made to unload the transport too fast. The transport was capable of unloading waterhyacinth faster than the onshore conveyor could accept the plants; therefore, the transport operator had to control the speed at which the transport unloaded. These general procedures applied regardless of whether one or two transports were used in the harvesting operation.

31. The onshore conveyor was operated by the truck drivers, who were instructed to have the conveyor motor operating so that the conveyor was ready to unload the transport as soon as it was coupled to the conveyor. The conveyor disgorged the harvested material directly into the truck with which it was subsequently hauled to the designated disposal site.

32. The disposal of waterhyacinths was accomplished by trucking the plant material to preselected disposal sites (Appendix B) where it was dumped. Waterhyacinths harvested in the canals and in the St. Johns River near Astor, Fla. (sites 2AT-13 and 2AT-13A), were trucked to a large pasture (40 acres, Plate B1) where the trucks dumped the plants in piles that were distributed uniformly throughout the area. The landowners then spread the material over the ground as a mulch for newly sprigged grasses, or disced it into the ground as a soil conditioner. Figure 7 illustrates the appearance of the hyacinths after they were spread over the ground surface as a mulch.

33. Waterhyacinths harvested at sites 2AT-13B1 through 2AT-13B5

Figure 7. Harvested plants being used as mulch for newly sprigged groves, disposal site for sites 2AT-13 and 2AT-13A near Astor, Fla.

were trucked to a small pasture (Plate B3) where they were spread and disced into the ground for use as a soil conditioner.

34. Waterhyacinth harvested from the St. Johns River and Lake George (sites 2AT-18A through 2AT-18F) were trucked to a small area (Plate B8) which was built from previously dredged sand from the river. The plants were dumped from the trucks into as tight a pile as possible and later consolidated by stacking higher with a front-end loader.

35. Data recording. The specific operating instructions given to the field operators and recorders are presented in Appendix C. Not included in the instructions is a practice used on sites 2AT-18A through 2AT-18F in the St. Johns River where eelgrass, which could not be destroyed due to its importance as fish habitat, was found. At these sites the horizontal cutter bar was removed from the harvester so as not to damage or destroy the eelgrass. The hyacinth mats were cut with the vertical cutter bars, and only the floating plants were pushed up on the loading conveyor of the harvester.

Hydrilla

36. Test site layout and documentation. Almost identical procedures were used in the selection and layout of the hydrilla test sites as were described for the waterhyacinth sites in paragraph 26. However, biomass samples were obtained by only the second method described in paragraph 26. The harvester gathered plants from a measured area, and these plants were weighed after they were loaded into the truck. Pertinent site information observed by the project engineer was noted and is summarized in Appendix B.

37. Conduct of the harvesting operation. For the most part, it was possible to advance the harvester directly into the hydrilla at a continuous but slow speed (about 1 mph). If the water was sufficiently deep, and there were no underwater obstructions, the harvesting depth was 5 ft. The harvester and transports had no problem propelling themselves through the most dense topped-out hydrilla. The harvester continued harvesting in a straight line the full length of the test area. When the harvester reached the end of the test area, it was turned around to harvest adjacent to the harvested trough, returning to the

starting side of the test area. This procedure was continued until the operation was complete. During the harvesting operations, fragments of hydrilla plants were usually left floating in the water where the harvesting operations had been performed. Occasionally, however, the harvester would pass through previously harvested areas to pick up the loose, free-floating hydrilla, in an effort to minimize additional spreading of the plant due to fragmentation.

38. During the harvesting of hydrilla two transports were used most of the time. The transports traveled in as straight a line as possible between the harvester and onshore conveyor. The transport experienced minor difficulties unloading onto the onshore conveyor if an attempt was made to unload the transport too fast. The transport was capable of unloading hydrilla faster than the onshore conveyor could accept the plants; therefore, the transport operator had to control the speed at which the transport was unloaded. As described for harvesting waterhyacinth, the onshore conveyor was prepared to receive the transport and a truck was always under the onshore conveyor to receive the plants and haul them to the disposal site.

39. Hydrilla harvested from Orange Lake was trucked to nearby orange groves (see Plates B14 and B15) and dumped into piles to decompose or to be spread in the orange groves and plowed into the soil as a conditioner. Some of the hydrilla was trucked to the University of Florida, Gainesville, for use in its ongoing hydrilla research.

40. Hydrilla harvested from the Withlacoochee River was trucked to open areas in a young forest (Plates B16 and B18) and dumped into piles for decomposition.

<u>Hydrilla and hyacinth</u>

41. Two test sites on the Withlacoochee River that were infested with both hydrilla and hyacinth were used in the field program test (areas 1 and 4). At area 1, the infestation was predominantly hydrilla, and the operating procedures, test layout, and disposal techniques described for hydrilla apply to this site. At area 4, the biomass was predominantly hyacinth, and, therefore, procedures previously described for this weed type dominated the operation. However, because of the

hydrilla, the horizontal cutter bar was operated at a depth of 5 ft instead of near the surface as was done when harvesting waterhyacinth. Disposal was accomplished as described for hydrilla (paragraph 40).

Data Collection and Reduction

42. Data were collected on each component of the system, i.e. the harvester, transport, conveyor, and trucks used in the disposal operation. For this study, disposal was considered accomplished when the truck unloaded the material at the disposal site. No record was kept of the time to stack or spread the material in the disposal site as this was accomplished by the landowner.

43. Data sheets were used for each component of the system and are shown with example data in Appendix C. An attempt was made to insure that each data sheet contained the component, date, starting and ending times, weather, location, site description, load number, times, and weights. However, because it was desirable from the public interest standpoint to continue harvesting operations when data could not be recorded, some omissions occurred. The availability of data collected is summarized on pages F4-F6 of Appendix F. All available data sheets are presented in Appendix F (Volume II) of this report.

44. In addition to the quantitative recordings, observations of the equipment operations were noted by the project engineer. In addition to the analysis of the quantitative recordings, comments on the field operations are also presented in the following Part of this report.

PART III: DATA ANALYSIS AND RESULTS

Background

45. For the purpose of operational aquatic plant control, mechanical harvesting is viewed as a complete process, made up of one or more of the following basic functions: cutting, loading, transporting, unloading, and disposal. Further, it encompasses any secondary operation done on the plant such as chopping, pressing, flailing, etc., to facilitate completion of any of those functions. Restrictive definitions for the basic functions are:

a. Cutting. Cutting includes both the severing of the stalks of rooted plants and the severing of plant mats into small masses.

b. Loading. Loading is the extraction of plant material from the water and placing it on a machine for water or land transport or on land for final disposal.

c. Transporting. Transporting is the movement of plant material from one position to another.

d. Unloading. Unloading is the movement of the plant material from one machine to another or from a machine to a holding or disposal area.

e. Disposal. Disposal of plants consists of those functions that must be performed on the plant material to render its final disposition environmentally acceptable. This includes productive as well as nonproductive uses.

46. The particular functions needed in a harvesting operation, their sequence, and the rate at which they can be performed are strongly related to the physical characteristics of the environment in which they are performed. This fact is almost universally accepted. However, quantitative data relating functional performance rates to site-specific factors, such as plant type, density, and distribution; water perimeter geometry; current velocity and depth; location of water body access points; location and types of disposal sites; road network; and the level of cultural development surrounding the water body, are scarce or nonexistent. However, these relationships are needed as a basis for improving equipment and methods for mechanical harvesting.

47. It was recognized that all the relationships sought could not be readily derived from the data base generated, and summarized in Appendix F. This was true for two reasons. First, the site-dependent parameters did not vary systematically over a sufficiently wide range; and second, each item of equipment that makes up the Aqua-Trio actually performs more than one of the basic functions (paragraph 45a-c) discussed above. Because of this it was decided to direct the analysis toward defining the amount of time each component was performing its function (or functions) and defining both component and overall system productivity. For this analysis it was convenient to consider that each component spent time in the primary, secondary, and nonfunctional mode. For the function of transporting, the Aqua-Trio transport and the trucks perform essentially the same primary and secondary function in the same order. For the purpose of this evaluation, however, it was deemed more valuable to identify loading and transporting as the primary function of the transport, while these were identified secondary and primary, respectively, for the trucks. The following define these modes and illustrate the relation of Aqua-Trio functions to the basic functions of mechanical harvesting (tables referred to are in Appendix C):

- *a*. Harvester primary functional time is the time the harvester spends cutting the plant and loading the plant onto the harvester (summation of column 2 in Table C1).
- *b*. Harvester secondary functional time is the time the harvester spends unloading the plants from the harvester to the transport (summation of column 6 in Table C1).
- *c*. Harvester nonfunctional time is the time the harvester is idle, waiting, or holding for any reason (elapsed time between starting time and ending time less 30 min for lunch and less the primary and secondary functional times).
- *d*. Transport primary functional time is the time the transport spends loading the plants from the harvester to the transport and traveling loaded with plants to the onshore conveyor (summation of columns 5 and 7 in Table C2).
- *e*. Transport secondary functional time is the time the transport spends unloading the plants from the transport onto the onshore conveyor and traveling empty

from the onshore conveyor to the harvester (summation of columns 3 and 9 in Table C2).

f. Transport nonfunctional time is the time the transport is idle, waiting, or holding for any reason (elapsed time in Table C2 between starting time and ending time less 30 min for lunch and less the primary and secondary functional times).

g. Onshore conveyor primary functional time is the time spent loading plants from the transport to the onshore conveyor, carrying the plants across the land-water interface, and unloading the plants from the onshore conveyor to the truck (summation of column 9 in Table C2).

h. Onshore conveyor has no secondary functional time.

i. Onshore conveyor nonfunctional time is the time the onshore conveyor is idle, waiting, or holding for any reason (elapsed time in Table C2 between starting time and ending time less 30 min for lunch and less the primary functional time).

j. Truck primary functional time is the travel time the truck spends transporting plants to the disposal site, unloading (dumping) the plants from the truck at the disposal site, and traveling empty from the disposal site to the conveyor (summation of the elapsed time between columns 7 and 8 for each truckload in Table C3).

k. Truck secondary functional time is the time the truck spends loading plants from the onshore conveyor to the truck (summation of the elapsed time between columns 4 and 5 for each truckload in Table C3).

l. Truck nonfunctional time is the time the truck is idle, waiting, or holding for any reason (elapsed time in Table C3 between starting time and ending time less 30 min for lunch and less the primary and secondary functional times).

48. Maximum efficiency of a component requires performance of its primary function nearly all of the time. The basic design goal is to optimize the system production rate while employing efficient components. However, the system production rate must be adequate for operational use. This removal rate, as identified in paragraph 7, is 80 to 100 tons/hr. Preliminary analysis of the data in Appendixes B and F revealed that there appeared to be sufficient data to permit plotting both functional and productivity data as functions of plant type, biomass, and one-way transport travel distance. The way this was

done and the results are discussed by plant type in the following paragraphs. The last section of this Part of the report presents both the project engineer's field observations and the design implications of the quantitative data and qualitative observations.

Equipment Performance in Waterhyacinth

Component functional and nonfunctional time

49. To study the component functional (primary and secondary) and nonfunctional times, the bar graphs in Appendix F, pages F238 to F298, were sorted by both plant biomass and overwater one-way transport distance categories. The resulting grouping of these plots is shown by plant biomass and one-way distance categories in Table 1.

50. Harvester. Figure 8, compiled from the bar graphs on pages F254-F256, F259, F260, F262, and F263, shows the primary and secondary functional and nonfunctional times for each system component of the Aqua-Trio with one or two transports, presented for plant biomass of <40 to 70 tons/acre for one-way water transport distance categories of 0 to 700, >1400 to 2000, and >2000 ft.

51. The primary and nonfunctional time data in this group were averaged and are presented in Table 2 along with the averages derived from the other waterhyacinth groups in Table 1. To illustrate how Table 2 was assembled, consider the first entry in the table, i.e. "38" to the right of the slashed line in the first column. (If the number in the column is placed to the right of the slashed line, the harvesting operation was conducted using two transports.) Thus, the number 38 is the daily average percentage for primary functional time of daily total operating time (for the biomass and distance category indicated) for the harvester when two transports were used. From Figure 8 it can be seen that at test site 2AT-18F on 26 and 30 August the primary functional times of the harvester were 43 and 34 percent, respectively. Thus, the average was 38 percent. The second two entries in the second column of Table 2, i.e. 32/55, illustrate the case where data were

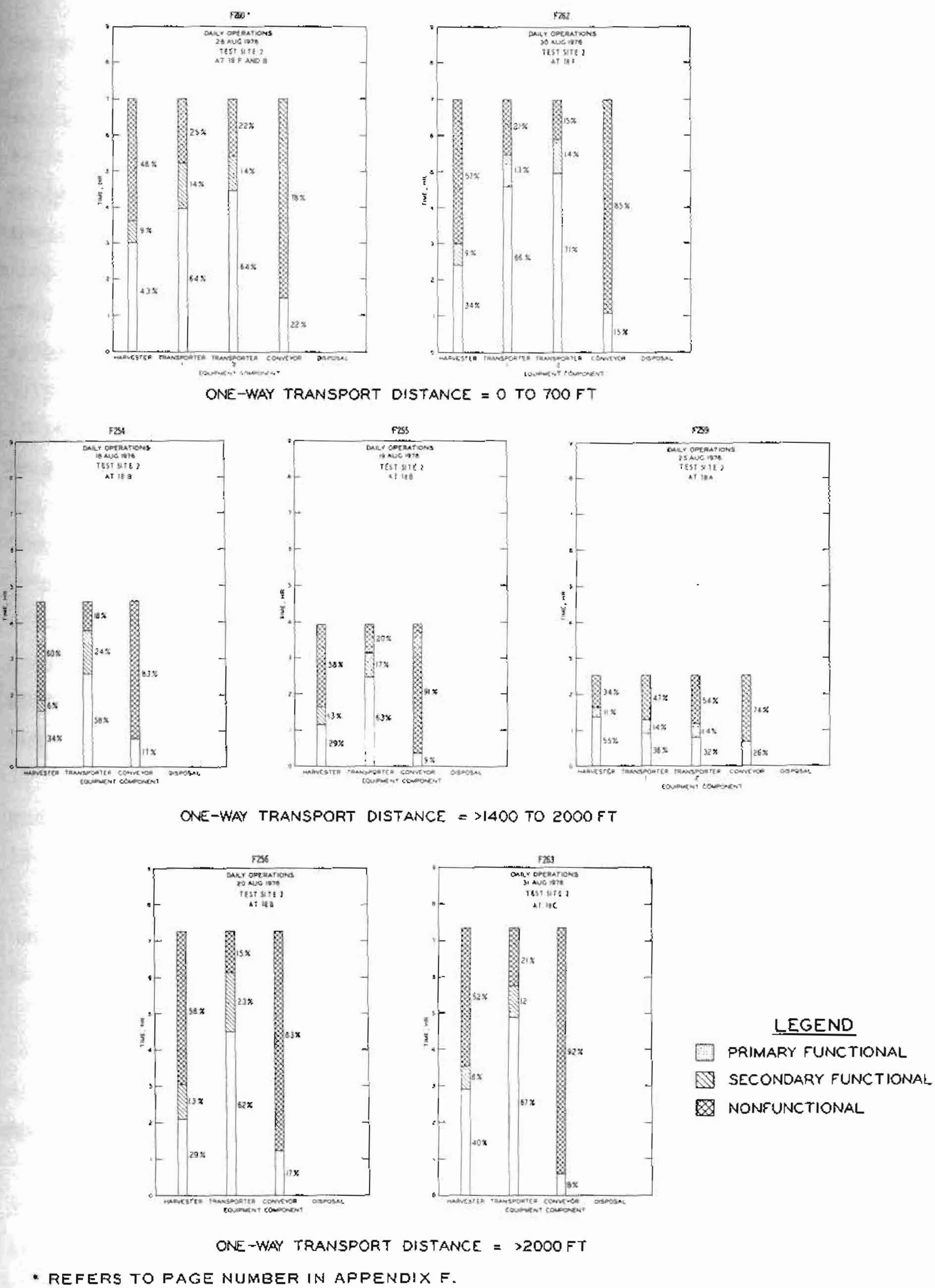

Figure 8. Distribution on primary functional, secondary functional, and nonfunctional times of Aqua-Trio operating in waterhyacinth (<40 to 70 tons per acre)

collected using both one transport and two transports in the density and distance category shown (<40 to 70 tons/acre and >1400 to 2000 ft). The number 32 represents the average percentage primary functional time derived from the data collected at site 2AT-18B on 18 and 19 August 1976 using only one transport ((34 + 29)/2 = 32, from Figure 8). The 55 to the right of the line represents the primary functional time measured at site 2AT-18A on 25 August 1976. The blank in the first column, corresponding to the distance category >700 to 1400 ft, indicates that no data were available at this distance range for the corresponding density range of <40 to 70 tons/acre.

52. Study of the average primary functional time of the harvester operating in hyacinth shows this parameter varied from 32 to 55 percent. It is interesting to note that there does not appear to be a change in harvester primary functional time with increasing biomass or one-way water transport distance. Further, from the limited data, no trend was observed when two transports were put into the system. In similar fashion the harvester nonfunctional time varied from 34 to 59 percent, and there were no strong trends observed in the nonfunctional time as a function of distance or biomass. Further, it can be seen that in most cases the harvester was nonfunctional more than 50 percent of the time. It was expected that decreasing the transport distance and using an additional transport would increase the primary functional time and decrease the nonfunctional time. However, this was not observed with the limited data, and it is believed that the major reasons these expected relations were obliterated or obscured are as follows. In the biomass range of <40 to 70 tons/acre, the harvester could harvest a load before it traveled two to three harvester lengths; in densities greater than 125 tons/acre, it could pick up a load when it traveled approximately one harvester length. The operator did not, even after repeated instructions, run the harvester at the maximum rate but at a relaxed pace that corresponded closely to the performance capacity of the transports. If the harvester had been consistently run according to instructions, no doubt the expected trends would have appeared in the data. Development of these relations would have been

inconsequential in terms of providing information for design improvement because, as primary functional rates decreased, the nonfunctional time would have increased even more than 50 percent if the plants could not be transported rapidly after they were picked up. The design goal must be to increase the primary functional time to as near 100 percent as possible and the nonfunctional time to as near 0 as possible. Greater than 50 percent nonfunctional time suggests that a mobile harvester, which must provide a temporary hold for the plants before they can be transported, will reduce the harvesting rate to the extent that this type of harvester is not practical for the range of hyacinth biomass of interest to the Jacksonville District. As previously discussed, an acceptable harvesting rate for waterhyacinth in the Jacksonville District is 80 to 100 tons/hr. As will be discussed in paragraphs 56-59, the production rate in hyacinth was often less than 5 tons/hr. Considering that this productivity was obtained when the average primary functional time was about 40 percent, an increase in primary functional time to 90 percent would yield a harvester productivity of only 11.25 tons/hr ($90/40 \times 5 = 11.25$). Review of the figures on pages F238-F266 suggests that the secondary functional time is often about 10 percent; therefore, it is reasonable to assume that the primary functional time can never be greater than about 90 percent with the three-component system. This ideal scenario, where the primary functional time is 90 percent, the secondary functional time is 10 percent, and the nonfunctional time is near zero, would yield a harvesting rate that is still seven times less than the identified requirement.

53. Transport. It was expected that the primary and nonfunctional times of the transport would increase and decrease respectively as a function of biomass and one-way water transport distance. Although there are anomalies, these general trends can be seen in the tabulations for the transports in Table 2. The trends are stronger with regard to increasing transport distance than increasing biomass because, in the biomass range studied, the transport seldom had to wait (except when the harvester was broken down or was picking up scattered plants) for the harvester to fill. Therefore, the nonfunctional time reflects

equipment breakdown (transport, harvester, or conveyor) to some degree but primarily reflects the waiting time resulting from problems encountered in conveying the plants from the transport to the truck. This is discussed further in paragraph 54. The primary functional time ranged from 22 to 68 percent with five values above and seven values below 50 percent. Also, it can be seen in the bar graphs (pages F238-F266) that the secondary functional time was significant (about 20 percent) for all the distances shown. This reflects the time required to unload the plants onto the conveyor and that portion of the time the transport traveled empty. Obviously, significant increase in the primary functional time of the transport is possible only if downtime, as an increment of nonfunctional time, is reduced in all equipment components while loading, unloading, and travel are done more quickly to cut down on secondary functional time. From observations made in the field, the project engineer concluded that, because of the time the transport used to travel empty, secondary functional time (about 20 percent of the total) could not be reduced significantly. It was possible, however, through improvement of equipment reliability and increased operator skill (for all components of the system), to decrease nonfunctional time. To get an idea of what an increase in primary functional time, e.g. 70 percent, would mean in terms of increased transport productivity, consider the data collected on 27 July 1976, one of the more productive days of the field operation. On this day 42 loads were transported (see pages F12 and F13 at site 2AT-13). In this case the transport primary functional time was 30 percent (see page F240). If the primary functional time was increased to 70 percent, the total number of loads would have been $0.70/0.30 \times 42 = 98$. Each load weighed about 1 ton; therefore, the total amount transported would have been slightly less than 100 tons each day, which represents less tonnage than was in 1 acre at this site. Therefore, it does not appear that a simple increase in primary functional time will increase productivity enough for operational use. Additional discussion on productivity rates in waterhyacinth is included in paragraphs 56-59.

54. Conveyor. From Table 2 it can be seen that the primary

functional time of the conveyor averaged about 14 percent. It was always less than 16 percent if only one transport was used and less than 26 percent if two transports were used. A significant increase in productivity could be effected if the primary functional time was increased to near 100 percent. However, it was consistently observed in the field that as the plants were dumped from the transport to the horizontal conveyor belt on the conveyor they bunched up instead of being moved smoothly up the vertical conveyor belt. When this happened the plants had to be hand chopped and forced onto the inclined conveyor. For this reason some modification will be needed in the conveyor design before the primary functional time can approach 100 percent.

55. Trucks. Land transport was required to move the plants from the conveyor to the disposal site, and this was accomplished using from one to three trucks. Data on this part of the operation were not as complete as on the components of the Aqua-Trio, but the data in Table 2 show that the primary functional time was 8 to 51 percent. It was extremely rare for the operations to be delayed because of having to wait for the truck to return from the disposal site.

Component and system productivity

56. In the following paragraphs, component and system productivity are compared with the primary and secondary functional times to give an indication of the potential productivity of the harvesting operation. The top and bottom plots in Figure 9 show the average production rate in tons/hr of the total system, and each of the components of the Aqua-Trio system, versus average plant density and one-way overwater transport distance, respectively. The production rate for the total system was determined by dividing the total tons harvested in a given time period by the total number of hours the system was operated and is shown as the operational rate in Figures 9-12. The production rate of each component was determined by the equation:

$$\text{Production rate, tons/hr} = \frac{\text{Total tons harvested in 1 day}}{\text{Primary + secondary functional time, hr}}$$

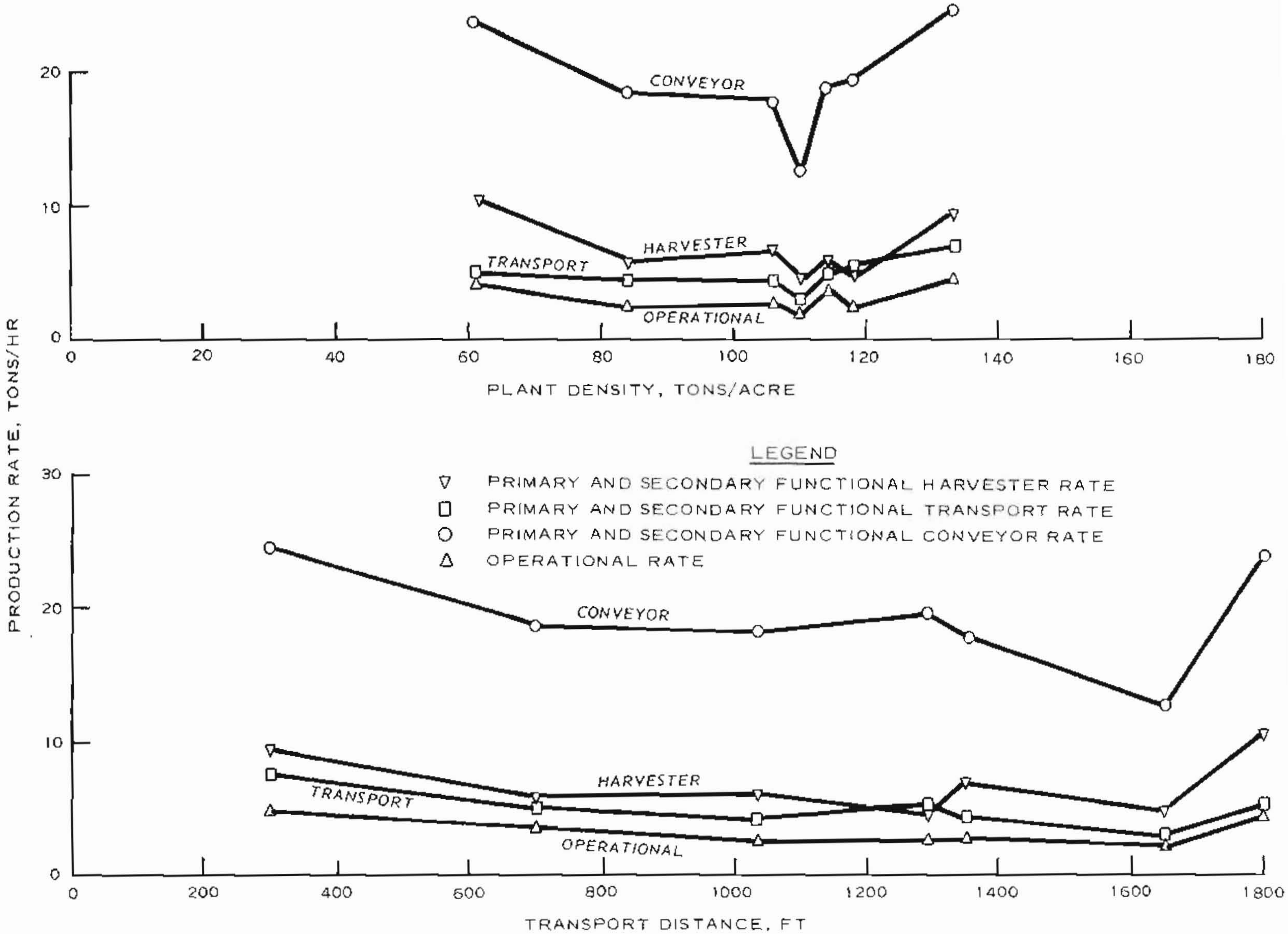

Figure 9. Aqua-Trio component and system performance in waterhyacinth

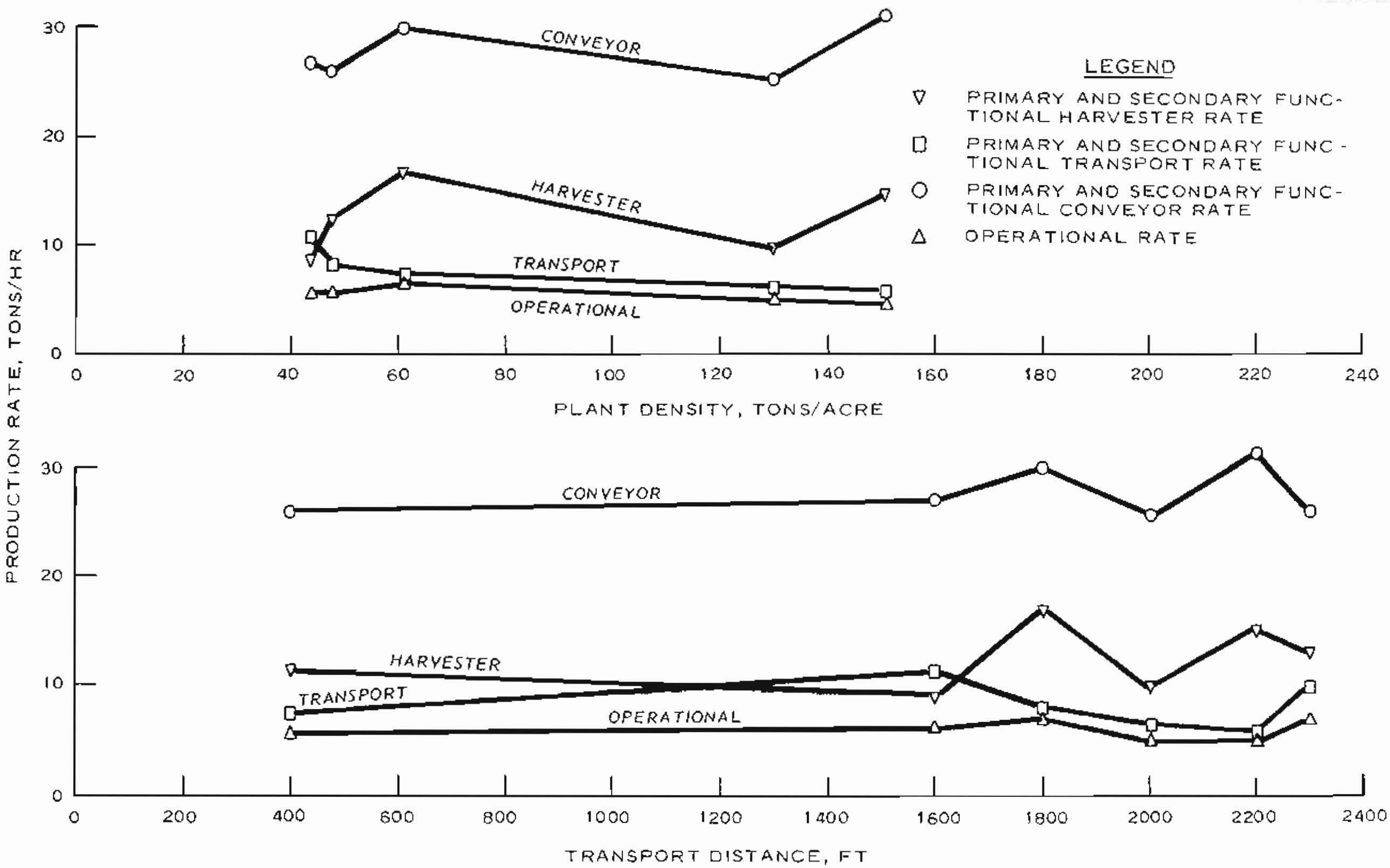

Figure 10. Aqua-Trio plus one additional transport component and system performance in waterhyacinth

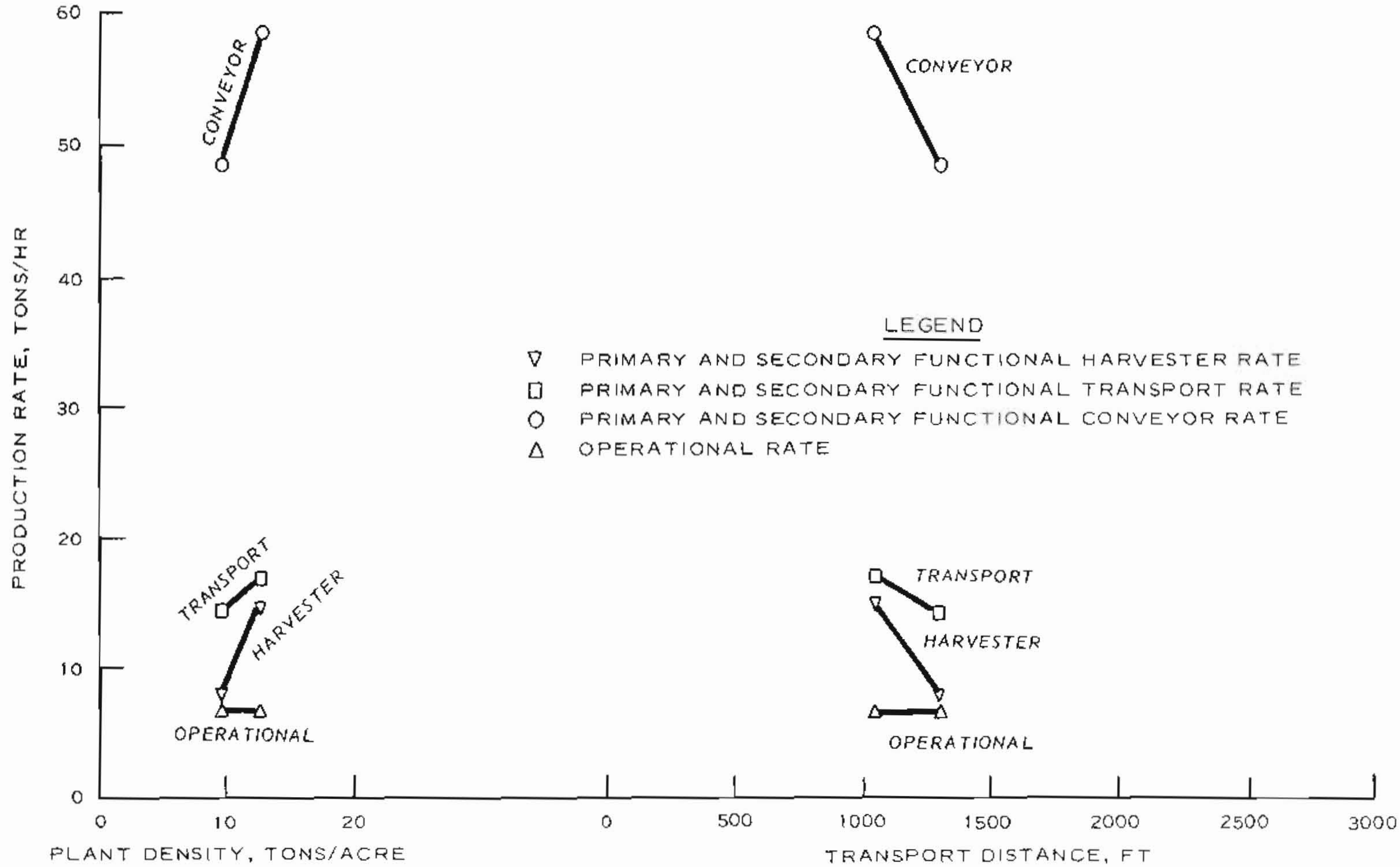

Figure 11. Aqua-Trio component and system performance in hydrilla

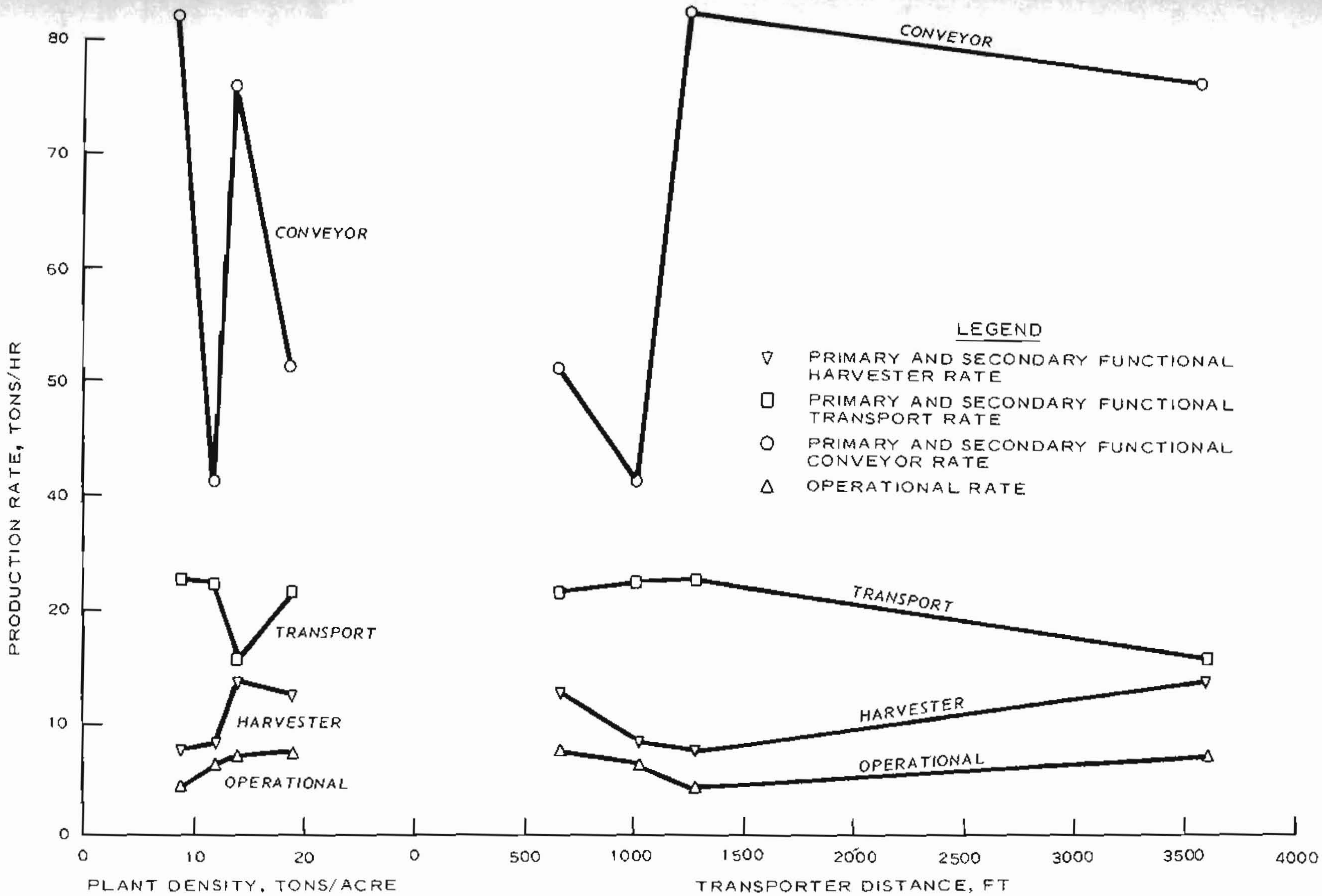

Figure 12. Aqua-Trio plus one additional transport, component, and system performance in hydrilla

The total number of tons per day was estimated by multiplying the number of loads handled by the average weight per load, which in the case of waterhyacinth was approximately 1 ton.* The data sets listed in Table 1 were studied to determine those daily operations that were conducted at sites with identical biomasses and one-way overwater transport distances. If 3 days of operations were conducted, the total weight for the 3-day period would be divided by the total primary and secondary functional time measured for the 3-day period to arrive at an average production rate for each component of the system.

57. Although some variation can be seen in the plots as a function of plant density and one-way transport distance, the trends are not as strong as expected. For example, one would expect that the harvester production would increase as a function of plant biomass because travel distance would decrease. This increase could be expected until the plants become so bulky they could not move efficiently into the harvester hold. The plots show a weak tendency for productivity to decrease as plant densities increase up to approximately 90 tons/acre and then increase slightly throughout the biomass range measured. In both the upper and lower plots, it can be seen that the transport rate most closely tracks the total system operational rate. Further, the conveyor rates are consistently greater than both the harvester and transport rates. These plots show that in the Aqua-Trio operation, given one transport, the transport consistently paced the operation for all plant densities and one-way transport distances studied. The plot for the harvester showed that its production rate was only slightly higher than the transport. Therefore it is hypothesized that if an improvement in transport productivity could be effected the system would immediately be paced by the harvester. On the other hand, the conveyor production rate, which was generally around 20 tons/hr, was significantly higher than that of either of the other components. It should be noted that the

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* Harvester loads 1-14 (see Appendix F, page F7) were weighed using scales furnished by the Florida Highway Patrol. The weights ranged from 1820 to 2280 lb. The average weight was 2069 lb or approximately 1 ton.

primary functional time recorded (Table 2) reflects the conveyor operating less than about 18 percent of the time. A procedure of gathering and moving plants to the conveyor, the efficiency of which increases the conveyor functional time by 70 percent, would produce a significant increase of the waterhyacinth conveying rate. Thus, 100 tons/hr could be conveyed, a rate which exceeds the acceptable harvesting rate for waterhyacinth.

58. In an attempt to more efficiently move the plants to the conveyor location, two transports were used on several sites. The top and bottom plots in Figure 10 show the total system and individual component productivity rates as a function of biomass and one-way overwater transport distance when a second transport is added to the Aqua-Trio system. For the most part the addition of the transport did increase the productivity of the harvesting operation as can be seen by comparing the data plotted in Figures 9 and 10. For example, there was a slight increase in overall system productivity. In Figure 9 it can be seen that the average system productivity was 3 tons/hr, whereas the plots in Figure 10 show the average productivity to be about 5.5 tons/hr, an increase of 85 percent. The use of two transports resulted in an apparent increase in harvester productivity because the operators were not operating the harvester at maximum production rates when one transport was used (paragraph 52). Therefore, when two transports were used, the harvester could increase its productivity such that the transport paced the operation, as was the case when one transport was used. The conveyor again outperformed the other system components, exceeding a production rate of 25 tons/hr. From Table 2 it can be seen that the average primary functional time of the conveyor was 22 percent when two transports were used. It follows that if this rate could be increased to 70 percent, as suggested in paragraph 57, the conveyor could handle about 80 tons/hr ($70/22 \times 25$ tons/hr), which compares favorably with the requirements previously stated.

Summary

59. The major findings in the data analyzed are:

a. Transportation of the harvested material consumed the largest percentage of the primary functional time followed by harvesting. Conveying took the least amount of time.

b. In all densities of hyacinth, the transport was the component that paced the system regardless of whether one or two transports were used.

c. In hyacinth harvesting operations, the conveyor was the only component that had potential for handling the amount of plant material per hour (80 tons/hr) of interest to the Jacksonville District.

Equipment Performance in Hydrilla

Component functional and nonfunctional time

60. Table 3 lists the primary and nonfunctional times for all components in the Aqua-Trio system as a function of the biomass categories 0 to 10, >10 to 15, and >15 tons/acre and the one-way water transport distance categories of 0 to 700, >700 to 1400, >1400 to 3600, and >3600 ft. In similar fashion to that described for waterhyacinth (paragraph 51), the table contains data for hydrilla operations conducted with one or two transports.

61. Harvester. Study of the primary functional times calculated for the harvester reveals that the primary functional times ranged from 47 to 73 percent when one transport was used and from 38 to 67 percent when two were used. This suggests that two transports did not significantly change the primary functional time of the harvester. Comparison of Tables 2 and 3 shows that the harvester primary functional values in hydrilla were considerably higher than in waterhyacinth, but, as was noted with the data for waterhyacinth, the primary functional time was not strongly correlated to either biomass or one-way water transport distance.

62. Transport. The primary functional time for the transport (when only one was used in the operation) ranged from 22 to 48 percent (Table 3), whereas, if two transports were used, it varied from 15 to 41 percent. Most of the values were below 27 percent. The corresponding values for hyacinth (Table 2) were consistently higher, which

supports the supposition that if the amount of biomass to be hauled is smaller (compare >15 tons/acre for hydrilla to >125 tons/acre for waterhyacinth), the primary functional time of the transport will be less. The use of two transports had little effect on the primary functional time of the transports. However, the project engineer observed that, given densities of 10 to 15 tons/acre, having two transports in the operation consistently decreased the amount of nonfunctional time of the harvester. This decrease resulted from the reduced amount of time the harvester spent waiting for the transport to couple with the harvester after a full load of hydrilla had been gathered.

63. Conveyor. The average primary functional time for the conveyor was always less than 14 percent regardless of whether one or two transports were used.

64. Trucks. As expected, the trucks had no problem keeping up with the harvesting operation. Their primary functional time was always less than 30 percent regardless of whether one or two transports were used, though use of two transports consistently increased their functional time.

Component and system productivity

65. The two plots in Figure 11 show the production rate of the total Aqua-Trio system (operating with one transport) as well as the production rate of the individual components as a function of plant biomass and overwater, one-way travel distance, respectively. In comparison with similar data for waterhyacinth (Figure 9) it can be seen that the total system productivity was greater (6.5 tons/hr compared with 3 tons/hr). A corresponding increase in productivity can also be seen for the harvester and transport, and there was a dramatic increase in productivity for the conveyor. Also of interest is the fact that in hydrilla the harvester could advance at a slow but continuous pace (paragraph 37). As a result, considerable time was required for the harvester hold to fill. Also, the more flimsy and less bulky hydrilla would compact in the harvester storage hold allowing the harvester to accumulate about 2.5 tons of hydrilla before it had to unload. As illustrated by the harvester productivity plot falling just above the system

productivity or operational plot in Figure 11, the harvester paced the operation instead of the transport, which did so in the hyacinth productivity results (Figure 9).

66. Figure 12 contains the same kind of data as Figure 11, the exception being that it was derived from the hydrilla tests conducted using a second transport with the Aqua-Trio system. Because two transports were used in most of the tests conducted in hydrilla, more data points were available for plotting. The bottom curve in the left plot of Figure 12, which represents operational productivity, shows that the total system productivity increased slightly with increasing biomass. Also, total system productivity increased slightly over that observed when only one transport was used. In general, both the productivity of the harvester and transport increased slightly, and the harvester component paced the operation for all biomass and transport distances. As might be expected, the lower curve in the right plot shows that total system productivity tended to decrease as one-way transport distance increased up to about 1300 ft. The apparent increase in operational productivity beyond 1300 ft is an anomaly resulting from an ad hoc change in operating procedures. During conduct of the tests from which the data plotted at 3600 ft were derived, the Aqua-Trio was experiencing repeated mechanical failures. Therefore, the long transport distance and continuous mechanical failures required that the harvester dump harvested loads back into the lake outside the harvesting area. This procedure permitted more tonnage to be harvested at the test site. The transport production rate values were derived from transported loads only and therefore properly show a decrease in productivity with an increase in transport distance. It can also be seen in Figure 12 that the conveyor productivity was relatively high in comparison to that observed when only one transport was used in the operation.

67. A study of Figures 11 and 12 in conjunction with Table 3 suggests that the Aqua-Trio harvester and transport components, whether one or two transports were used, would have difficulty in increasing their productivity to the desired 80 tons/hr. For example, the average productivity for the harvester from Figure 11, when operating with one

transport, would be about 12 tons/hr. The corresponding average primary functional time from Table 3 would be 61 percent. If this value was increased to say 90 percent, the increased harvester rate would only be 0.90/0.61 × 12 = 17.7 tons/hr or 22 percent of the required system production rate. However, if 12 tons/hr could be harvested consistently, approximately 1 acre/hr would be harvested in heavy infestations of hydrilla. Even though this is well below the stated goal, there are situations, e.g. to cut boating trails and clear dock areas, etc., where this production rate would be useful.

68. From Figure 12, it can be seen that the conveyor handled 80 tons/hr of hydrilla. Therefore, this component of the Aqua-Trio can operate at the productivity goal, provided the plants can be brought to it at the proper rate.

Equipment Performance in Hydrilla and Hyacinth Combinations

Component functional and nonfunctional time

69. Four days of operations were conducted in plant infestations of both hydrilla and waterhyacinth in the Withlacoochee River; 1 day in test area 1 (see Plate B17 and page F223), and 3 days in test area 4 (pages F293, F294, and F295). In these plant combinations, the biomass density generally consisted of approximately 80 percent hyacinth and 20 percent hydrilla. On 9 November 1976, operations were being conducted in area 1 in Lake Bonnet, which was completely blocked to boat traffic by aquatic plants. Emphasis was placed on clearing an opening for boats. During this time, no records were kept on the transport, and many of the harvested loads were dumped from the harvester directly on shore. The operations were conducted in such a manner that rate information gleaned from the data could not be readily compared with other operations. On that day (see page F223), 43 loads were harvested. Each weighed an average of 2.5 tons (average of the plant weight column on page F227). The total work time for the day was 6-3/4 hr. Thus, the harvester productivity under these conditions was 16.12 tons/hr, which was higher than that measured in waterhyacinth or hydrilla. In test

area 4, the operation was conducted on all 3 days using the Aqua-Trio with an additional transport. The average primary and nonfunctional times for the harvester when two transports were used were 38 and 48 percent, respectively, which are approximately the same as the corresponding values when only waterhyacinth was harvested (Table 2) using one transport. It was expected that the values would be slightly higher, but the operations on 29 October and 1 November were hampered by mechanical breakdowns in both the transport and harvester. The problems were corrected and the operation went more smoothly on 5 November 1976 as reflected on page F295 which shows the harvester primary functional time to be 52 percent.

70. On 1 November 1976 the primary functional and nonfunctional times measured for the transport were 35 and 47 percent, respectively. Because the biomass was large, 75 tons/acre, and the overwater transport distances were long, >3600 ft, the transport was expected to pace the operation as was the case in waterhyacinth. Several times during the day the harvester had mechanical breakdowns, resulting in even poorer performance in this component than was expected. Even so, the transport paced the operation on all 3 days.

71. The average conveyor primary functional time over the three days was 12 percent for two transports. As expected, the conveyor had sufficient capacity to handle the harvested material efficiently.

72. The average primary functional and nonfunctional times for the trucks were 19 and 71 percent, respectively. All the harvested material was easily hauled as was observed in single infestations of waterhyacinth or hydrilla.

Component and system productivity

73. As expected, and as stated in paragraph 70, in the 75-tons/acre plant biomass range, the transport paced the operation even though two transports were used. The productivity of the transports barely exceeded the total system productivity, i.e. 10.1 compared with 9.4 tons/hr. The harvester productivity was 17.4 tons/hr, whereas the conveyor productivity rate was over 60 tons/hr. These production rates were computed as described in paragraph 56. The daily

average harvested plant weight was divided by the daily average primary and secondary functional times for each component and the daily average system operating time presented on pages F293-F295. This supports the previous observations in hydrilla and waterhyacinth harvesting operations that the conveyor is the only component of the system with potential production rates approaching the harvesting rate requirements in the Jacksonville District.

Qualitative Field Observations

74. During the harvesting operation the project engineer made notes concerning aspects of the operation that in one way or another continually affected system productivity. These notes are summarized in the following paragraphs.

75. The propulsion of the harvester by paddle wheels worked efficiently except in river currents above 2 mph and/or winds exceeding 15 mph. The propulsion force of the harvester was not sufficient to advance it through dense mats of hyacinths. As the harvester worked on the front or leading edge of a hyacinth mat, the paddle wheels would pull or propel plants to the rear of the harvester. This moved hyacinths to an area that had already been harvested and sometimes prevented the transport from coupling with the harvester. The harvester would often have to clean up these loose plants before normal operations could resume.

76. The loading conveyor of the harvester experienced difficulties in hyacinth. The vertical cutter bars could not cut dense mats of hyacinth when the harvester was operated at full speed. Nor was it possible to separate the hyacinths on the loading conveyor from the hyacinth mat in the water when the harvester became loaded. To achieve this necessary separation, the loading conveyor was raised out of the water and the harvester backed away, pulling the plant mat apart. This operation proved time-consuming.

77. As hyacinth plants traveled up the loading conveyor, they had to pass under the operator's platform before dropping to the live-bed

storage hold. Large hyacinth plants often jammed at this point and had to be manually pushed past the platform.

78. The cutter bars on the front conveyor of the harvester lacked sufficient power to operate normally in dense stands of hydrilla. The hydrilla plants would stop the cutter bars, and the drive motors would have to be reversed to clear the plants and start the cutting action again. Also, the loading conveyor did not have sufficient power to transfer large heavy loads of hydrilla out of the water and into the storage hold. The loading conveyor was so constructed that when the harvester cut 5 ft under water, the angle of the conveyor was approximately 45 deg below the horizontal. In this position, layers of hydrilla having an in situ density of 10 to 13 tons/acre or greater could not be transferred up the conveyor. The harvester had to stop and the loading conveyor had to be raised above the water surface before the hydrilla plants could be transferred to the horizontal live-bed conveyor of the storage hold.

79. During harvesting operations plant particles collected under the conveyor belts and became wrapped around the conveyor sprockets, thus increasing the sprocket diameter. This increased diameter placed added stress on the belts and bearings, causing several failures. At times, the additional stress was so great that the hydraulic motors were unable to turn the sprockets. The occurrence of this condition necessitated the belts being removed and the sprockets cleaned at frequent intervals.

80. To load the live-bed storage hold to maximum capacity the plants were allowed to fall to the live-bed and collect on top of one another until the holding area was filled. The live-bed storage conveyor handled heavy loads (up to 6000 to 8000 lb) of hydrilla. Plants also wrapped around the sprockets of this conveyor causing the same problems as experienced with the loading conveyor.

81. When the harvester and transport were fully loaded, the draft was approximately 20 in. at the rear of each machine and approximately 6 in. in front. This uneven loading sometimes caused problems when the transport attempted to dock at the onshore conveyor or

attempted to couple with the harvester because the docking mechanisms could not be aligned.

82. The speed at which plants were unloaded onto the onshore conveyor was limited due to the onshore conveyor design. As plants were unloaded onto the onshore conveyor there was a continual jam due to the narrowness of the conveyor receiver compared with the width of the unloading conveyor on the transport.

83. The harvester was never able to "clean" an area in only one pass. In hyacinth, plants were separated from the mats and floated into previously harvested areas. In hydrilla, the harvesting operation left cut plants floating in the harvested areas. To correct these conditions, additional passes in previously harvested areas were made.

Operational Costs

84. The derivation of the costs incurred for harvesting waterhyacinths and hydrilla is presented in Appendix D. Because of the research nature of the operation, the cost calculated is considered to be high in comparison to long-term operational costs. In this project, harvesting hyacinth with the Aqua-Trio costs $36.79 per ton. With hyacinth ranging in densities from 50 to 150 tons/acre, the cost would be $1840 to $5519 per acre. Harvesting hydrilla with the Aqua-Trio cost $20.20 per ton. Topped-out hydrilla plants range in densities from 10 to 22 tons/acre and, therefore, would cost $202 to $444 per acre to harvest.

85. The cost of chemical control of waterhyacinth is about $26 per acre. Therefore, the cost data developed on the project clearly show that, as expected, mechanical harvesting with the Aqua-Trio cannot compete from a cost standpoint with chemical control. However, chemical control for hydrilla is estimated to be about $200 per acre and the Aqua-Trio costs are only slightly higher than this. This suggests that the Aqua-Trio might be competitive for extracting submersed plants (see Figures 11 and 12).

Summary Comments

86. The results presented in preceding paragraphs emphasize that the Aqua-Trio system cannot harvest waterhyacinth and hydrilla at rates and costs operationally acceptable to the Jacksonville District. However, one component of the system, the onshore conveyor, with only minor modification, can handle hydrilla, waterhyacinth, and combinations of the two at rates in excess of the 80-tons/hr rate defined as being acceptable. During the course of the study, a literature review was made and people with experience in mechanical harvesting were contacted (see Appendix E). From the field studies and experience of people contacted, it appears that the major unresolved problem in arriving at a viable concept for mechanical harvesting is designing a scheme for transporting across the water and aggregating the plants at a takeout point at the land-water interface in such a manner that the overall system is not energy-intensive. Such a system would be one that maximizes the use of natural forces and minimizes the use of unnatural forces. In brief, the concept for transporting floating aquatic plants is based on the assumption that locations can be found on river systems where the natural current can be used to move floating plants growing on the fringe of the river to active booms that deflect and force the hyacinths to a buffer or holding area. Here the plants are confined by movable booms that can be manipulated by a small tractor or winch to concentrate and guide the hyacinths to a conveyor. The conveyor then lifts the plants over the land-water interface and drops them into a chopper so that they can be easily handled with a relatively small transporter-elevator. The transporter-elevator stacks the chopped hyacinths at a location where they are allowed to compress and decompose under natural conditions. It is anticipated that under most natural conditions, the hyacinths growing along the river's edge will have to be forced into the moving water from time to time to continue their movement downstream. For this reason, the concept calls for use of small, but specially equipped, hyacinth-pusher boats.

87. It is envisioned that several installations such as those

discussed would have to be established at carefully selected locations on the river system to effect control. The distance between installations, the amount of plant material handling, the size of the holding area, and the size of the land storage area required are extremely site-dependent.

88. The concept for submersed plants is intended for application in areas such as river or lake systems with little or no flow. However, the concept is equally applicable to floating plants in low-flow environments. The approach is quite similar to that outlined previously for floating plants in riverine environments in that the plants are moved in the water to the takeout point. They are then transferred across the land-water interface by a conveyor and distributed in the land storage area using a transporter-elevator. In contrast to the flowing water concept, however, several additional items are needed. In particular, cutter boats must be used to sever the submersed plants, allowing them to float to the water surface. Towboats trailing a boom are then used to encircle the cut plants for rafting to the takeout point where the plants are forced by the boom, a pivot piling, and a winch or small tractor into a flail and gathering device that feeds them into the conveyor. At least one pusher boat is needed to deal with cut plant material lodged in or around shore obstructions by pulling it into water areas open enough to permit encirclement by the towing boats.

89. As stated earlier and from the above description of the concepts, it becomes apparent that transport of the harvested plants to the takeout point will pace productivity and, therefore, priority should be placed on developing and verifying by field tests a solution to this problem. As illustrated from the results of the field tests (Figures 9-12), overall system productivity is less than the smallest productivity of any of the components. For this reason, quantitative productivity data on all facets of both concepts are needed to assist in the preparation of realistic design specifications and to provide data for evaluating competing designs.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

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

- a. Total Aqua-Trio system productivity was considerably less than 10 tons/hr in hydrilla, less than 5 tons/hr in waterhyacinth, and less than 10 tons/hr in combinations of waterhyacinths and hydrilla (Figures 9-12, and paragraph 73). The productivity of the transport consistently paced the system productivity when the Aqua-Trio was used in infestations of hyacinth and hyacinth and hydrilla (Figures 9 and 10 and paragraphs 59 and 73). When operations were conducted in hydrilla, the harvester paced the system productivity (Figures 11 and 12).
- b. Of the three components of the Aqua-Trio, only the conveyor consistently had production rates that clearly demonstrated potential for approaching or exceeding the 80-tons/hr requirement specified for operational use. The other components employed concepts that required excessive mechanical handling of the plant material. They probably cannot be modified to increase productivity significantly, except through use of a prohibitive amount of energy. For this reason, it is concluded that the Aqua-Trio or other harvesting systems that employ excessive mechanical handling of the plant material are too energy-intensive to be used operationally for most problem conditions of interest to the Jacksonville District.
- c. Transporting the harvested plant material from the harvesting site to the onshore conveyor location on the land-water interface appears to be the major pacing problem in developing a high-productivity mechanical harvesting system (paragraph 86).

Recommendations

91. It is recommended that the search for improved mechanical systems for harvesting aquatic plants be continued. It is further recommended that these concepts be evaluated over the normal length of the growing season to (a) evaluate and optimize the performance of each concept, and (b) acquire engineering data for improvement of present

designs or development of new concepts and equipment design. It is further recommended that as soon as sufficient engineering data are available to prepare realistic performance specifications as a function of site conditions, a "Request for Proposal" for the design of an advanced mechanical harvesting system be prepared and submitted to industry.

92. It is further recommended that a technical framework for evaluating industry proposed designs be developed to insure that the best system is procured for operational testing. Such design evaluation techniques require that the performance potential of each design be predicted for all significant environments and operational conditions. Due to the nonfeasibility of manufacturing and experimentally testing each design in each site condition, these predictions can only be made through the use of a deterministic simulation model. At the present time, an operational first-generation mechanical harvesting simulation model exists at WES. It is recommended that the model development be continued and verified as engineering data from future model development efforts become available. Once the model is proven adequate, it is recommended that this model be used as an aid to evaluating the industry proposed designs resulting from the previously mentioned request for proposal.

Table 1

Page Number in Appendix F of Bar Graphs Containing Percentage of Primary and Secondary and Nonfunctional Time by Plant Type

One-Way Transport Distance, ft	No. of Trans- ports	Plant Biomass, tons/acre				
		<40-70	>70-90	>90-110	>110-125	>125
		Waterhyacinth				
0-700	1				F246	F238,
	2	F260, F262				F240-F242
>700-1400	1		F249, F251	F243-F244 F247-F248	F245	
>1400-2000	1	F254-F255	F239	F252-F253		F261
	2	F259				F257-F258 F264-F266
>2000	1	F256 F267				
		Hydrilla and Waterhyacinth				
>1400-3600		*				
>3600	1		F295			
	2		F293-F294			
		Hydrilla				
		0-10		>10-15		>15
0-700				F298 and F284-F292		
>700-1400	1	F276-F279		F268-F271		
	2	F280-F283		F267 and F272-F275		
>1400-3000	1			F296		
	2			F297		

* 15 tons/acre hydrilla and waterhyacinth were harvested at the Withlacoochee River test site at Area 1 on 9 November 1976 (see data on page F223). However, records were not kept because recorders were not available. These missing records made it impossible to plot bar graphs for these data.

Table 2

Percent Primary Functional and Nonfunctional Times of Harvesting Equipment Operating in Waterhyacinth

Transport Distance ft	Plant Density, tons/acre									
	Harvester					Transport				
	<40-70	>70-90	>90-110	>110-125	>125	<40-70	>70-90	>90-110	>110-125	>125
					Primary Functional Time					
0-700	/38			52/	41/	/66			23/	24/
>700-1400		41/	38/	45/			22/	46/		
>1400-2000	32/55	48/	41/		39/39	60/34	41/	40/		68/56
>2000	34/					64/				
					Nonfunctional Time					
0-700	/53			43/	50/	/21			56/	59/
>700-1400		54/	56/	50/			68/	34/		
>1400-2000	59/34	44/	56/		51/51	19/50	36/	34/		16/30
>2000	55/					18/				

Transport Distance ft	Plant Density, tons/acre									
	Conveyor					Truck				
	<40-70	>70-90	>90-110	>110-125	>125	<40-70	>70-90	>90-110	>110-125	>125
					Primary Functional Time					
0-700	/18			15/	15/					32/
>700-1400		8/	16/		4/			22/	8/	
>1400-2000	13/26	14/	14/		11/18		51/			
>2000	12/									
					Nonfunctional Time					
0-700	/82			85/	85/					58/
>700-1400		92/	84/	96/				58/	89/	
>1400-2000	87/74	86/	86/		89/82		46/			
>2000	88/									

Note: 1 transport/2 transports.

Table 3

Percent Primary Functional and Nonfunctional Times of Harvesting Equipment

Operating in Hydrilla

Primary Functional Time

Transport Distance ft	Harvester 0-10	Harvester >10-15	Harvester >15	Transport 0-10	Transport >10-15	Transport >15	Conveyor 0/10	Conveyor >10-15	Conveyor >15	Truck 0/10	Truck >10/15	Truck >15
0-700			0/38			0/23			0/11			0/[illegible]
>700-1400	73/57	63/67		27/15	22/17		14/6	10/9		18/29	5/22	
>1400-3600		47/64			48/41			14/13			29/28	
>3600												

Nonfunctional Time

Transport Distance ft	Harvester 0-10	Harvester >10-15	Harvester >15	Transport 0-10	Transport >10-15	Transport >15	Conveyor 0/10	Conveyor >10-15	Conveyor >15	Truck 0/10	Truck >10/15	Truck >15
0-700			0/47			0/62			0/56			0/68
>700-1400	19/33	30/27		48/79	63/74		86/94	89/91		68/52	74/65	
>1400-3600		44/17			47/52			86/87				57/62
>3600												

Note: 1 transport/2 transports.

APPENDIX A: TECHNICAL SPECIFICATIONS FOR THE AQUA-TRIO

1. The Aqua-Trio mechanical harvesting system consists of three major components, an H-650 harvester, a T-650 transport, and an S-650 onshore conveyor. Technical specifications for these three components are presented in the following paragraphs. Also described are the mobilizer and spreader bar assemblies, which can be conveniently used to transport the system from one water body to another.

H-650 Harvester*

Flotation barge

2. The flotation barge is 24 by 10 by 2 ft, with internal angle framework fabricated of 11-gage welded steel. Four heavy-steel lifting eyes are provided on the barge for loading or unloading the harvester with a crane. The barge has three tested watertight compartments.

Front-end elevating conveyor No. 1

3. The conveyor has a porous belt 90 in. wide, comprised of three 30-in.-wide belts of 1- by 1-in. flat-wire galvanized-steel mesh. A 1-7/16-in.-diam drive shaft contains eighteen 4-3/8-in.-pitch-diam sprockets. The conveyor is powered by one hydraulic motor through a flexible coupling. The idler pulley is a 4-in.-diam steel tube mounted on 3-in., threaded take-ups. The conveyor bed is made up of multiple channels and T-bars the full length of the conveyor. The leading edge of the conveyor consists of two vertical 5-ft-long cutter bars and one horizontal 8-ft-long cutter bar. All three cutter bars are reciprocally driven by two hydraulic motors with Pitman rod arrangements and a flexible push-pull cable between the cutter bars. The conveyor can be raised out of the water to a horizontal position or lowered to a maximum cutting depth of 5 ft below the surface of the water. This movement is accomplished through the use of two pressure-compensated 2-in.-diam hydraulic rams.

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* From Aquamarine Corporation Technical Specification No. 200-5.

Weed storage
hold conveyor Nos. 2 and 3

4. The hold is 7 ft wide, 3 ft deep, and 30 ft long. The full length of the bottom of the hold consists of a live-bed of the same 1- by 1-in. fabric as the front-end conveyor. The horizontal segment (conveyor No. 2) of the live-bed and the inclined segment (conveyor No. 3) of the live-bed can each be separately controlled by the operator. As the weeds come up the No. 1 conveyor and are dumped onto the live-bed, the operator moves the weeds rearward as they reach a 3-ft depth. The hold can store as much as 650 ft^3 or 10,000 lb of weeds, whichever is reached first during harvesting. The speed of the live-bed allows the hold to be emptied in 70 sec. Each segment of the live-bed is driven by a 16-sprocket drive shaft with the idlers on threaded take-ups for precise fabric-belt tensioning.

Propulsion system

5. Reversible paddle wheels are mounted at the midpoint of the barge on the starboard and port sides. They are shielded by large fenders that minimize the throwing of water. A removable hydraulic motor has the paddle splined to its output shaft. Each paddle wheel can be set continuously at 0 to 50 rpm independently, forward or reverse, from the operator's console.

Power plant

6. An air-cooled, 2-cycle, Deutz diesel engine develops 32 hp at 2400 rpm. Included is a permanently mounted, 25-gal filtered fuel tank. The engine is mounted on a heavy base plate which is, in turn, mounted to the platform on four isolation mounts. The engine drives four hydraulic pumps: one variable displacement pump for each of the two paddle wheels, one fixed pump for the two segments of the live-bed and the rams that control the depth of cut, and one fixed pump for the front-end elevating conveyor and cutter bars. Next to the main power plant are mounted five solenoid-regulated, three-position, four-way valves for control from the operator's console. Hydraulic plumbing is accomplished throughout by the use of 1/2-in. steel pipe with flexible hydraulic hose connections at the end of each pipe. All hydraulic circuits are

protected by relief valves and replaceable hydraulic filters. All systems are served by one 25-gal hydraulic reservoir with a breather and visual-level indicator. The engine has a remote-control electric starter and oil pressure, temperature, and generator charge warning lights.

Snap-lock coupling device

7. At the discharge end of the harvester, two pressure-actuated snap-lock couplings are provided for aligning and holding the harvester to either the transport or the onshore conveyor during transfer of weeds while allowing relative vertical displacement as the load transfers.

Operator's console

3. The operator's console is mounted on a raised bridge at the forward end of the harvester and over the weed hold. The floor of the bridge is of expanded metal, allowing the operator to see into the hold for continuous control of weed depth. Live-bed controls are National Electrical Manufacturers' Association (NEMA) 4-ft switches, and paddle wheel controls are push-pull cable control levers.

9. Controls are as follows: The segments of the live-bed are controlled with the left foot with a two-position foot pedal. The paddle wheels are controlled by two hand levers, one for each paddle. Depth of cut is controlled with the right foot through the use of a rocker-pedal switch. Toe down lowers the cutter; heel down raises the cutter. Facilities are furnished for remote control of the live-bed at the onshore conveyor site. A side-mounted control console contains the three engine warning lights, an ignition lock and key, accelerator and choke remote-control knobs, and two waterproof toggle switches that control the No. 1 conveyor belts (FORWARD - OFF - REVERSE) and the cutters (CUT - OFF - JAM). The console electrical enclosure is rated NEMA 12 and has a hinged, full-access door. The operator's seat is adjustable for height, tilt, and leg length.

Weight and dimensions

10. The weight of the H-650 harvester is 13,000 lb. The overall dimensions are 39 ft long by 9.5 ft high by 15 ft wide at the paddle

wheels. Removal of the paddle wheels brings the maximum width down to 10 ft for over-the-road hauling with the mobilizer assembly.

T-650 Transport*

Components

11. The transport consists of a flotation barge, a weed storage hold, a propulsion system, a power plant, a snap-lock coupling device, and an operator's console. Specifications for these components are the same as those for the harvester (paragraphs 2 and 4-9).

Weight and dimensions

12. The weight of the T-650 transport is 10,400 lb. The overall dimensions are 30 ft long by 9.5 ft high by 15 ft wide. Removal of the paddle wheels brings the maximum width down to 10 ft for over-the-road hauling using the mobilizer assembly.

S-650 Onshore Conveyor**

13. The capacity of this conveyor is 500 ft^3/min. It conveys a stream of weeds 3 ft wide and 1 ft deep at 165 ft/min. The conveying member consists of two parallel chains with angle cross cleats fixed between them. The chains are driven by a hydraulic motor directly coupled to the sprocketed drive shaft. The conveyor is a 32-ft-long inclined conveyor equipped with an 8-ft-wide hopper to take the output of an H-650 harvester or a T-650 transport. Set horizontally into the hopper is a 5-ft-long cross conveyor that causes the weeds to transfer onto the inclined 3-ft-wide belt. A snap-lock coupling device that fits any unit of the Aqua-Trio is furnished under the input hopper. Under the conveyor's hopper is a light, polyethylene float, which supports the input end of the conveyor in the water, allowing complete versatility in serving steep, rocky, or muddy shorelines. The inclined portion of

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* From Aquamarine Corporation Technical Specification No. 201-4.
** From Aquamarine Corporation Technical Specification No. 202-3.

the conveyor is supported on over-the-highway rubber tires and can be towed by a truck at high speed.

14. The function of this onshore conveyor is to elevate the weeds to about 11 ft for loading into a pile or on trucks. The standard drive for this unit is a 24-hp gasoline engine driving a hydraulic pump. The pump runs two hydraulic motors on the conveyor.

15. To speed launching and pullout of the onshore conveyor, a towing A-frame equipped with a lunette ring for a truck-mounted pintle hook on the front bumper is furnished on the S-650 axle. After attaching the lunette ring to the towing vehicle, a winch on the lunette ring pulls down on the high end of the conveyor. This raises the input and float end. Launching then can be accomplished by simply driving the truck toward the water and releasing the winch when the conveyor is in place.

16. Special wheel chocks are furnished to (a) keep the S-650 from rolling into the lake, (b) restrict movement of the conveyor, and (c) absorb impact during coupling of the transport or harvester.

17. The weight of the S-650 shore conveyor is 3400 lb. The conveyor packaged for export shipment consists of one 33- by 4- by 2-ft crate and one 10- by 5- by 4-ft crate or a total of about 450 ft^3.

Mobilizer and Spreader Bar

Mobilizer assembly

18. To move both the harvester and the transport over the highway, a mobilizer assembly is available. It consists of two axles bearing four wheels with pneumatic tires. The rear axle has an adapter that allows the mobilizer to be pinned to the back end of either the harvester or the transport while it is still in the water. The front axle of the mobilizer assembly has a telescoping towing tongue. The rear axle has a main horizontal pivot pin, which allows all the wheels to stay in contact with the highway no matter what condition of curve or bank the highway might have. To remove the equipment from the water, the tow bar is extended and fastened to the towing truck, and the equipment is

pulled onshore and thence to the new harvesting site at a maximum speed of 15 mph. The equipment is then launched, and the mobilizer is removed and hauled onto the shore. The two axles are bolted together creating a small four-wheel trailer, which may then be hauled back to pick up any remaining equipment in similar fashion. The mobilizer assembly weighs 700 lb and can be packaged into about 120 ft^3 for export shipment.

Spreader bar

19. A spreader bar is fabricated of steel in a heavy box configuration for lifting the harvester and the transport with a 12,000-lb-capacity crane. Its function is to spread the hoisting chains 10 ft apart to hoist the harvester or the transport. The spreader bar weighs 200 lb and can be packaged into about 8 ft^3 for export shipment.

APPENDIX B: SITE DESCRIPTIONS AND SITE MAPS

Site 2AT-13--Hyacinth--133 tons/acre

1. Site 2AT-13 was a small canal off the St. Johns River (see Plate B1). The canal was 80 ft wide at its mouth and increased to 214 ft over an approximate length of 600 ft. The site comprised 1.3 acres, and the water averaged 8 ft in depth and was almost nonmoving and clear of obstructions. The banks of the canal were almost vertical, and the water level was about 3 ft below the top of the banks. The ground adjacent to the canal was covered with 4- to 5-ft-high weeds, which greatly reduced wind effect on the harvesting operation.

2. Plants in this canal were large (stem and leaf height 43 in. and root length 26 in.), with an average density of 133 tons/acre.

3. The takeout point was so located that the plants could be conveyed to a level grass field with sufficient soil stability to afford trafficability by the dump trucks.

4. The truck route to the disposal site was 2.5 miles in length with 0.1 mile unsurfaced and 2.4 miles surfaced. The 0.1 mile of unsurfaced road was adjacent to the onshore conveyor and consisted of an open grass field with sufficient soil strength for truck traffic with one exception. At the intersection of the unsurfaced road and the surfaced roadway (0.1 mile from the onshore conveyor) was a 50-ft-wide area of loose sand that had to be bridged with aluminum landing mat. The 2.4-mile surfaced two-lane roadway had four stop signs going to the disposal site and only one stop sign returning to the onshore conveyor.

5. The disposal site was a 40-acre cleared field with sufficient soil strength to provide good trafficability by trucks.

Site 2AT-13--Hyacinth--83 tons/acre

6. Site 2AT-13A was in a slack water area of the St. Johns River (see Plate B2). Spatterdock was found growing in this area, and the hyacinths collected in this stationary plant growth. The water averaged

2-1/2 ft in depth at this site and was clear of obstructions. Plants in this area were medium-sized (average stem and leaf height 32 in. and average root length 20 in.), with an average density of 83 tons/acre.

7. The onshore conveyor was in the same position as for site 2AT-13; thus, the same haul roads and disposal site were used as for site 2AT-13.

Sites 2AT-13B1, -B2, -B3, -B4, and -B5--Hyacinth--118, 114, 106, 84, and 110 tons/acre, Respectively

8. The sites were on a series of small connecting canals forming a residential waterfront community. The canals were 65 to 80 ft wide and 750 to 1250 ft long. The average water depth was approximately 6 ft, and, at the time the harvesting operation was conducted, there were a few floating logs in the water. Slope of the canal banks was approximately 45 deg, and the adjacent ground was covered with 2- to 3-ft high weeds. During the operation, there was little or no wind in these small canals. Plates B3-B7 show the layouts of these sites.

9. Plants in these canals had stem and leaf heights of 13 to 31 in. and root lengths of 16 to 31 in. and had an average density of 106 tons/acre.

10. The onshore conveyor was positioned on the top bank of a canal that had sufficient soil stability to support the conveyor and truck traffic. The top bank elevation was 3 ft above water level.

11. The onshore conveyor location was at the end of a 100-ft-long unsurfaced driveway that led to a paved street. The unsurfaced drive supported all truck traffic except for one soft area that was bridged with an aluminum landing mat. The haul road to the disposal area was 1.1 miles in length, and half of the roadway was surfaced and half unsurfaced.

12. The disposal site was a recently cleared 2-acre field. The plants were randomly dumped from the trucks and left to decay.

Site 2AT-18A--Hyacinth--44 tons/acre

13. This site was located on the St. Johns River near the mouth

of Blue Creek at the south end of Lake George (see Plate B8). The harvest area was a small cove into which plants had blown. There was very little if any water current in this area. Eelgrass was growing in this area in a water depth of 1 to 3 ft. There were several posts and other obstructions in the area.

14. The onshore conveyor was located on the riverbank adjacent to a boat launching ramp. A concrete retaining wall 1-1/2 ft above the water supported the top bank. The top bank was a sodded area for boat ramp traffic and provided sufficient soil strength to support all truck traffic without rutting.

15. The disposal site was a 1.5-acre area cleared of small trees (8 to 12 ft tall) and bushes with cabbage palms and was approximately 200 ft from the conveyor location. The trucks dumped the plants and a front-end loader restacked them.

Site 2AT-18B--Hyacinth--61 tons/acre

16. This site was located on the west bank of the St. Johns River at its junction with Lake George. The harvest area was very similar to site 2AT-18A in that it was a natural catch basin containing eelgrass. The river current was minimal, and winds off Lake George moved plants into the cove. The water depth ranged from 1 to 3 ft, and there was very little current and few obstructions.

17. The onshore conveyor and disposal sites were the same as those used for site 2AT-18A. Plate B9 shows the details of this site.

Site 2AT-18C--Hyacinth--48 tons/acre

18. This site was located at the mouth of Blue Creek on the east bank. The water depth ranged from 1 to 3 ft, and there was very little current.

19. The onshore conveyor site and disposal site were again the same as those used for site 2AT-18A. Plate B10 shows the details of this site.

Site 2AT-18D--Hyacinth--151 tons/acre

20. This site was located in the shallows on the south shore of Lake George just west of the entrance to the St. Johns River. This area had a water depth of 1 to 2 ft and had eelgrass growing in it. Slight to no current was observed in the area. Winds off Lake George moved plants into the area.

21. The onshore conveyor site and disposal site used were the same as those used for sites 2AT-18A, -B, and -C. Plate B11 shows the layout of this site.

Site 2AT-18E--Hyacinth--130 tons/acre

22. This site was located off the south shore of Lake George to the east of the entrance to the St. Johns River. This area had a water depth of 1 to 2-1/2 ft and had eelgrass growing in it. Some hydrilla was also found in the area. No current was observed, and winds on Lake George moved plants into the area. During operations, the harvester and transports occasionally ran aground. Plate B12 shows the details of this site.

23. The conveyor site and disposal site used during operations at this site were the same as those used for sites 2AT-18A-D.

Site 2AT-18F--Hyacinth--48 tons/acre

24. This site was located on the east bank of the St. Johns River at its junction with Lake George. This area was only 1 to 2 ft deep and was covered with eelgrass. Very little, if any, current was observed in the area, and the plants were moved there primarily by wind.

25. The onshore conveyor site and disposal site used were the same as those for sites 2AT-18A-E, as shown on the location map in Plate B13.

Orange Lake West--Hydrilla--13 tons/acre

26. This site was located off Samsons Point in Orange Lake. The harvesting area was covered with topped-out hydrilla and extended 2300 ft into the lake from the shore. The average water depth of the area was 10 to 12 ft.

27. The onshore conveyor was located on the bank of a canal that was used by residents in the area. The top of the bank was 6 ft above water level and had a 10 percent slope to the water. This high lift caused minor problems during truck loading operations because the onshore conveyor did not reach high enough for a full load to drop into the truck. After heavy rains (1/2 in. or greater), the trucks began to rut the soil, and it became necessary to use an aluminum landing mat for a roadway between the conveyor and the surfaced roadway, a distance of 100 ft. The 0.4-mile haul road to the disposal site was surfaced for less than 0.2 mile. The unsurfaced portion was a field road into an abandoned orange grove where the disposal site was located between rows of orange trees. The plants were dumped into piles as close to one another as possible and covered approximately 1 acre.

28. Strong winds frequently blew across the large, open lake and prevented efficient operation of the harvester and transport. Plate B14 shows the layout of this site.

Orange Lake East--Hydrilla--10 tons/acre

29. This site was located in the southeast corner of Orange Lake. The harvest area was approximately 70 percent covered with topped-out hydrilla and 30 percent with hydrilla that was 1 to 2 ft below the water surface. The water depth in the harvest area was 4 to 6 ft. The water between the harvest area and onshore conveyor location was 1 to 3 ft deep and was partially covered with spatterdock.

30. Because of the importance placed on spatterdock by fishermen, only one trail for the transport was cut from the harvesting area to the onshore conveyor.

31. The onshore conveyor was located on the edge of an abandoned orange grove. The top bank was flat and 1 ft above the water elevation. The 0.2-mile haul road into the orange grove was unsurfaced loose sand. Plate B15 shows the details of this site.

Wysong Dam Site--Hydrilla--20 tons/acre

32. This site was located on the Withlacoochee River upstream of Wysong Dam. The current in this area was approximately 0.5 mph and had very little effect on harvesting operations. Water depth was 4 to 6 ft. The hydrilla was topped-out and very dense.

33. The onshore conveyor was located on the east riverbank. The bank had a gradual slope and caused no trouble with truck loading operations. The top bank was level and sodded and had sufficient soil strength to support truck traffic.

34. The disposal site consisted of a 1.0-acre area where the trucks dumped plant material between trees. The material was dumped in piles as close together as possible and was left to decay. Plate B16 shows this site in detail.

Area 1 Bonnet Lake--Hydrilla and Hyacinth--15 tons/acre

35. This site was located in Bonnet Lake on the Withlacoochee River. The lake was completely clogged with dense topped-out hydrilla, and small mats of hyacinth were also found at the south end of the area. No current was observed in the area. The water depth was greater than 5 ft.

36. The onshore conveyor was located at Trails End Fish Camp approximately 3000 ft downstream, as shown in Plate B17. This location was very cramped and only a one-lane gravel drive led to the conveyor. A very flat slope from water's edge to the drive gave the onshore conveyor sufficient lift to load trucks. Boat docks adjacent to both sides of the conveyor location required careful operation of the transports. A firm gravel road led 0.5 mile to the disposal site, which

consisted of mowed grasses under live oak trees. The plants were dumped as close together as possible and were left in piles to decay.

Area 2 Bonnet Lake--Hydrilla--15 tons/acre

37. This site was located on Bonnet Lake adjacent to one of two canals entering the lake. This area was covered with dense topped-out hydrilla. The water was greater than 5 ft deep and had little or no current.

38. The locations of the onshore conveyor and disposal site were the same as those used for Area 1, as shown in Plate B18.

Area 3 Bonnet Lake--Hydrilla--15 tons/acre

39. This site was located on Bonnet Lake adjacent to the second of two canals entering the lake, as shown in Plate B19. The area was covered with dense topped-out hydrilla, and the water was greater than 5 ft deep and had little or no current.

40. The onshore conveyor location and disposal site used were the same as those used for Area 1.

Area 4 Bonnet Lake--Hydrilla and Hyacinth--75 tons/acre

41. This site was located on Bonnet Lake adjacent to the island at the south end of the lake, as shown in Plate B20. This area was covered with both hydrilla and hyacinth. Water in the area was greater than 5 ft deep and had very little current. A few obstructions such as logs or tree limbs were in the area.

42. The onshore conveyor site and disposal site were the same as those for Area 1.

Area 5 Withlacoochee River--Hydrilla--22 tons/acre

43. This site was located on the east side of the Withlacoochee

River directly across from Trails End Fish Camp. There was a 0.5-mph current along the outer edge the harvest area, and the water depth varied from 4 to 10 ft. The area was covered with dense topped-out hydrilla and also contained small mats of hyacinth.

44. The onshore conveyor site and disposal site were the same as those indicated for Area 1. Plate B21 shows the layout of this site.

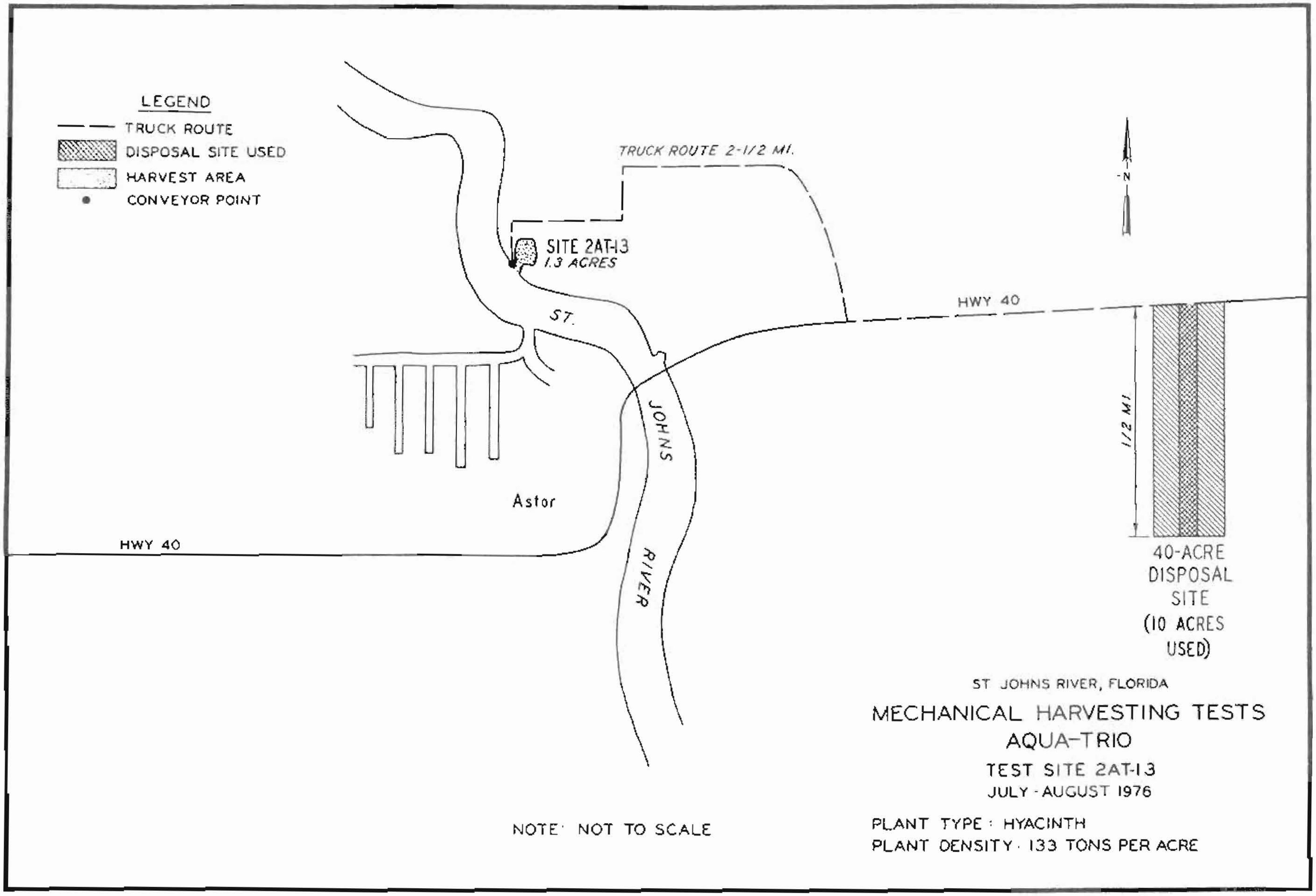
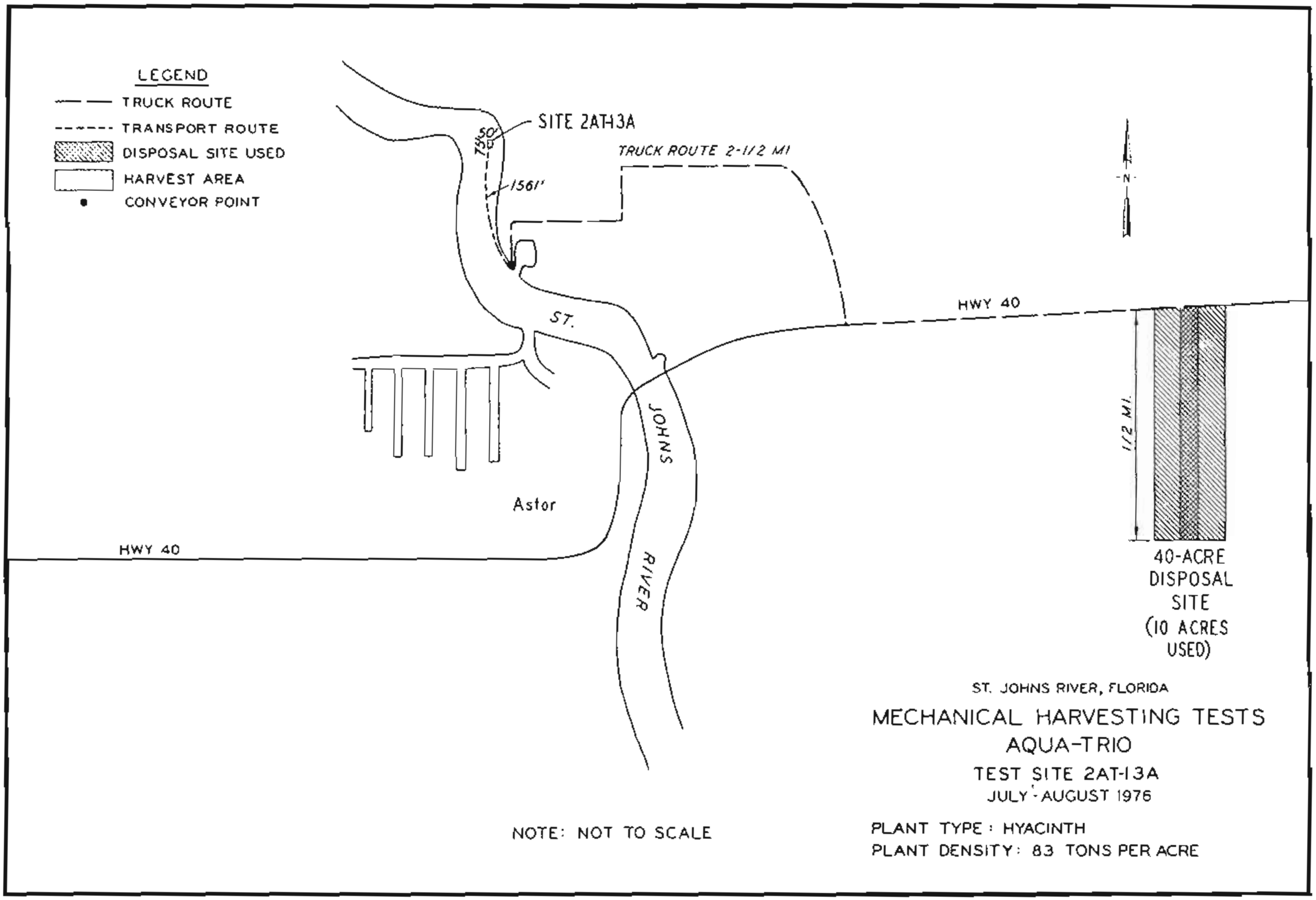
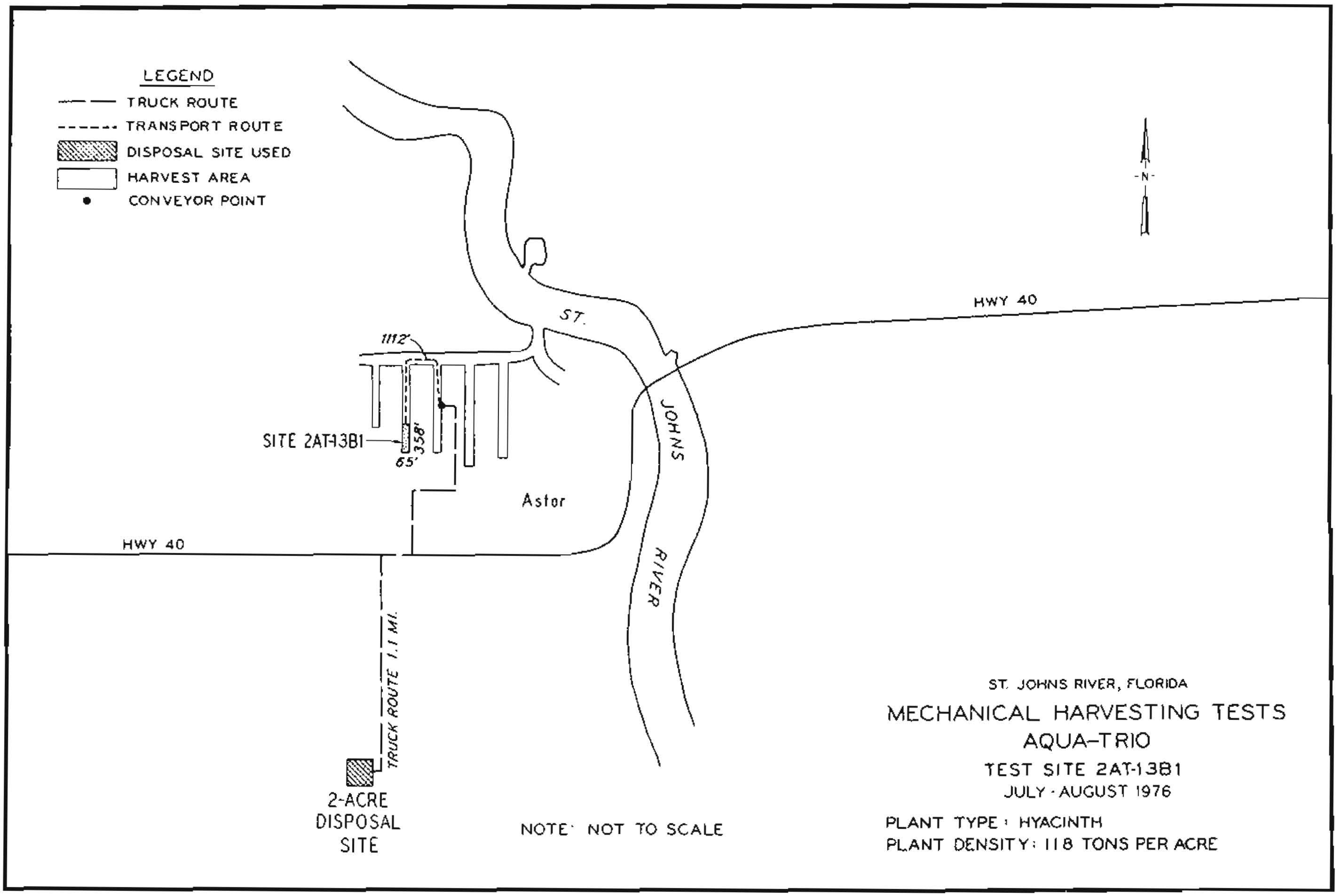

LEGEND
TRUCK ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
TRUCK ROUTE 2-1/2 MI.
N
SITE 2AT-13
1.3 ACRES
HWY 40
ST. JOHNS RIVER
Astor
HWY 40
1/2 MI.
40-ACRE DISPOSAL SITE (10 ACRES USED)
ST JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13
JULY - AUGUST 1976
NOTE: NOT TO SCALE
PLANT TYPE: HYACINTH
PLANT DENSITY: 133 TONS PER ACRE

PLATE B1

PLATE B2

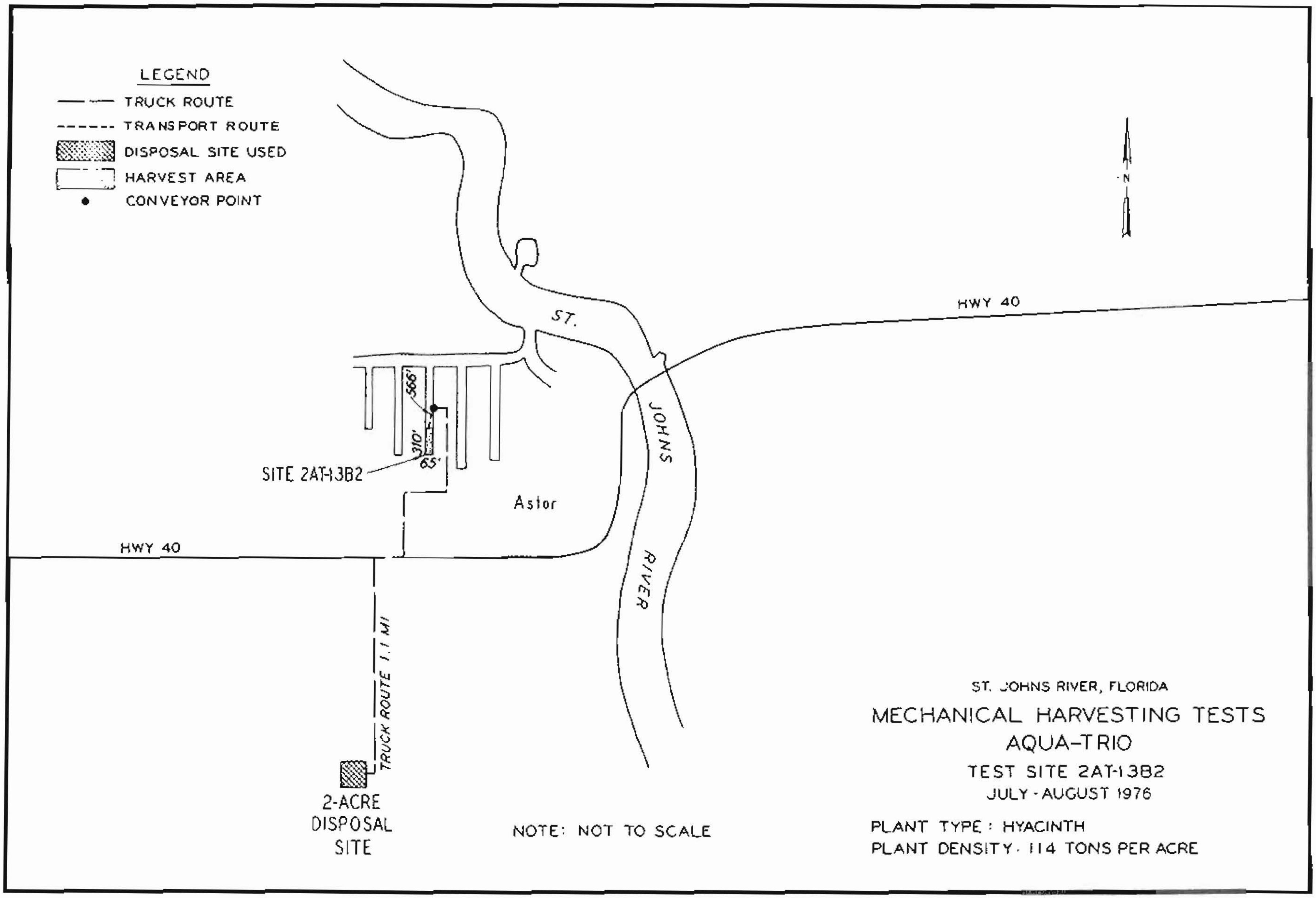

LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
SITE 2AT-13A
50'
75'
1561'
TRUCK ROUTE 2-1/2 MI
N
HWY 40
ST.
JOHNS
RIVER
Astor
HWY 40
1/2 MI.
40-ACRE DISPOSAL SITE (10 ACRES USED)
ST. JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13A
JULY - AUGUST 1976
PLANT TYPE : HYACINTH
PLANT DENSITY : 83 TONS PER ACRE
NOTE: NOT TO SCALE



LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
N
ST. JOHNS RIVER
HWY 40
HWY 40
1112'
358'
65'
SITE 2AT-13B1
Astor
TRUCK ROUTE 1.1 MI.
2-ACRE DISPOSAL SITE
NOTE: NOT TO SCALE
ST. JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13B1
JULY - AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 118 TONS PER ACRE

PLATE B3

PLATE 84


LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
N
ST. JOHNS RIVER
HWY 40
HWY 40
566'
310'
65'
SITE 2AT-13B2
Astor
TRUCK ROUTE 1.1 MI
2-ACRE DISPOSAL SITE
NOTE: NOT TO SCALE
ST. JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13B2
JULY - AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 114 TONS PER ACRE

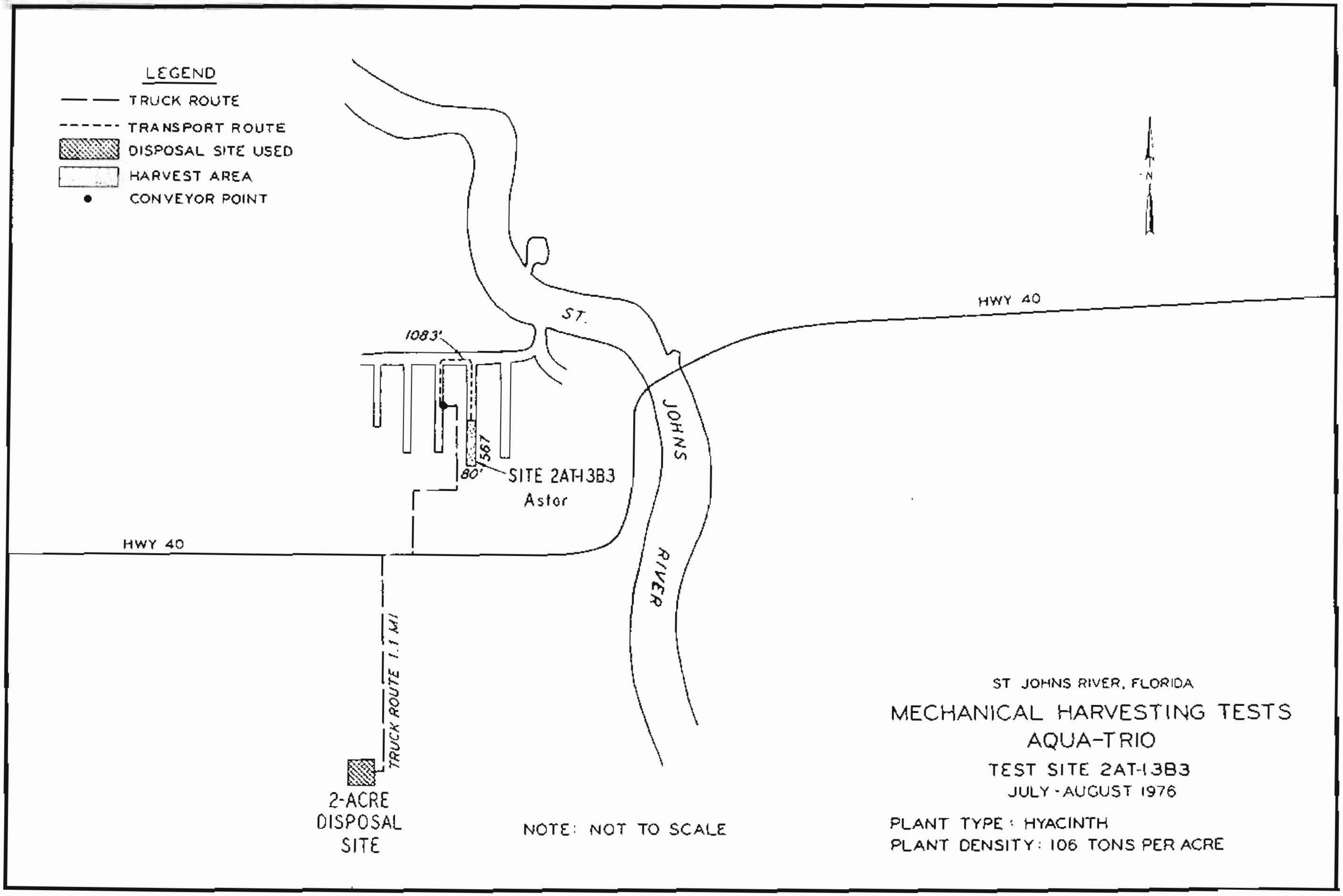
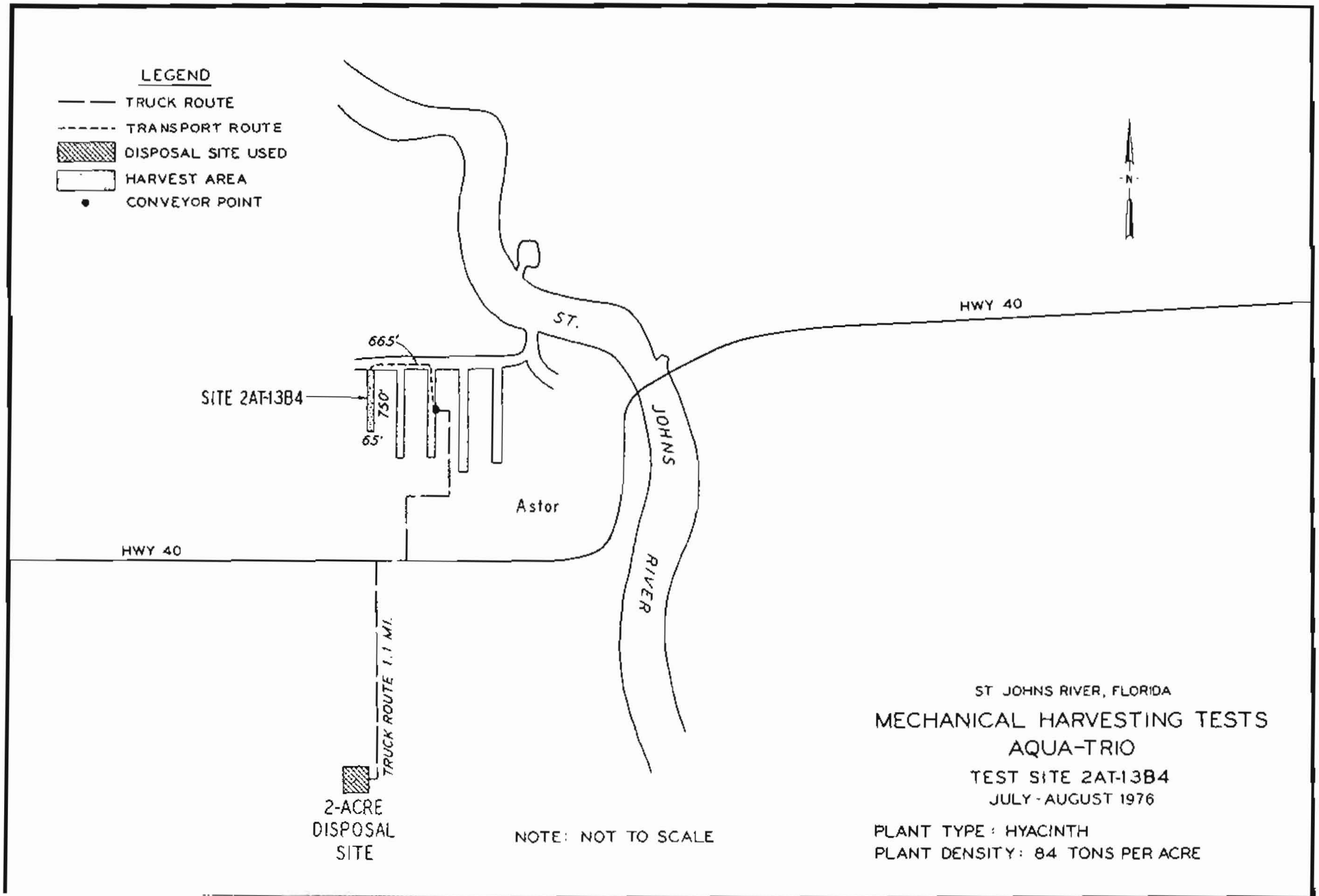

LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
ST. JOHNS RIVER
HWY 40
HWY 40
1083'
567
80'
SITE 2AT-13B3
Astor
TRUCK ROUTE 1.1 MI
2-ACRE DISPOSAL SITE
NOTE: NOT TO SCALE
N
ST JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13B3
JULY - AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 106 TONS PER ACRE

PLATE B5

PLATE B6


LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
N
ST. JOHNS RIVER
HWY 40
665'
SITE 2AT-13B4
750'
65'
Astor
HWY 40
TRUCK ROUTE 1.1 MI.
2-ACRE DISPOSAL SITE
NOTE: NOT TO SCALE
ST JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13B4
JULY - AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 84 TONS PER ACRE

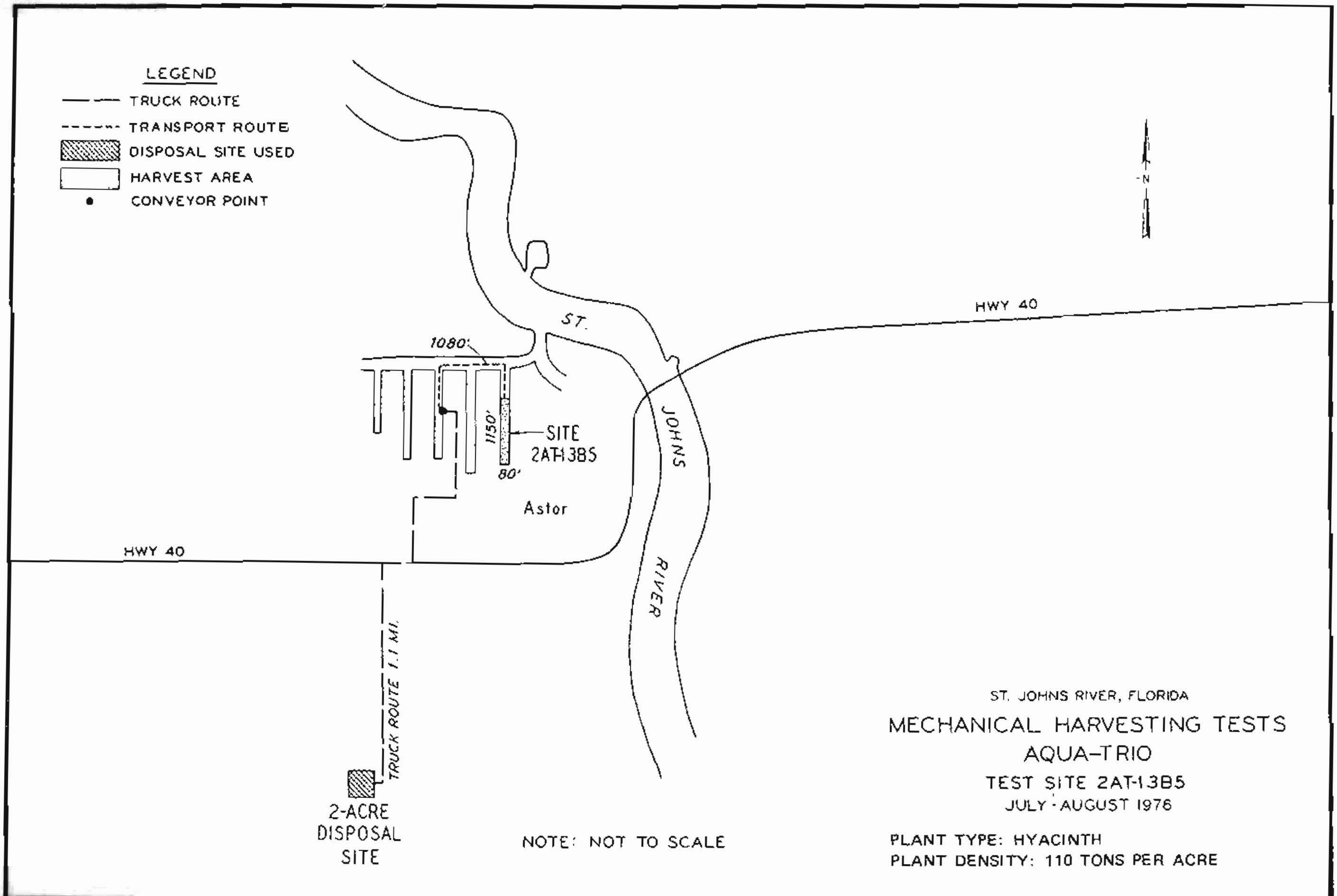
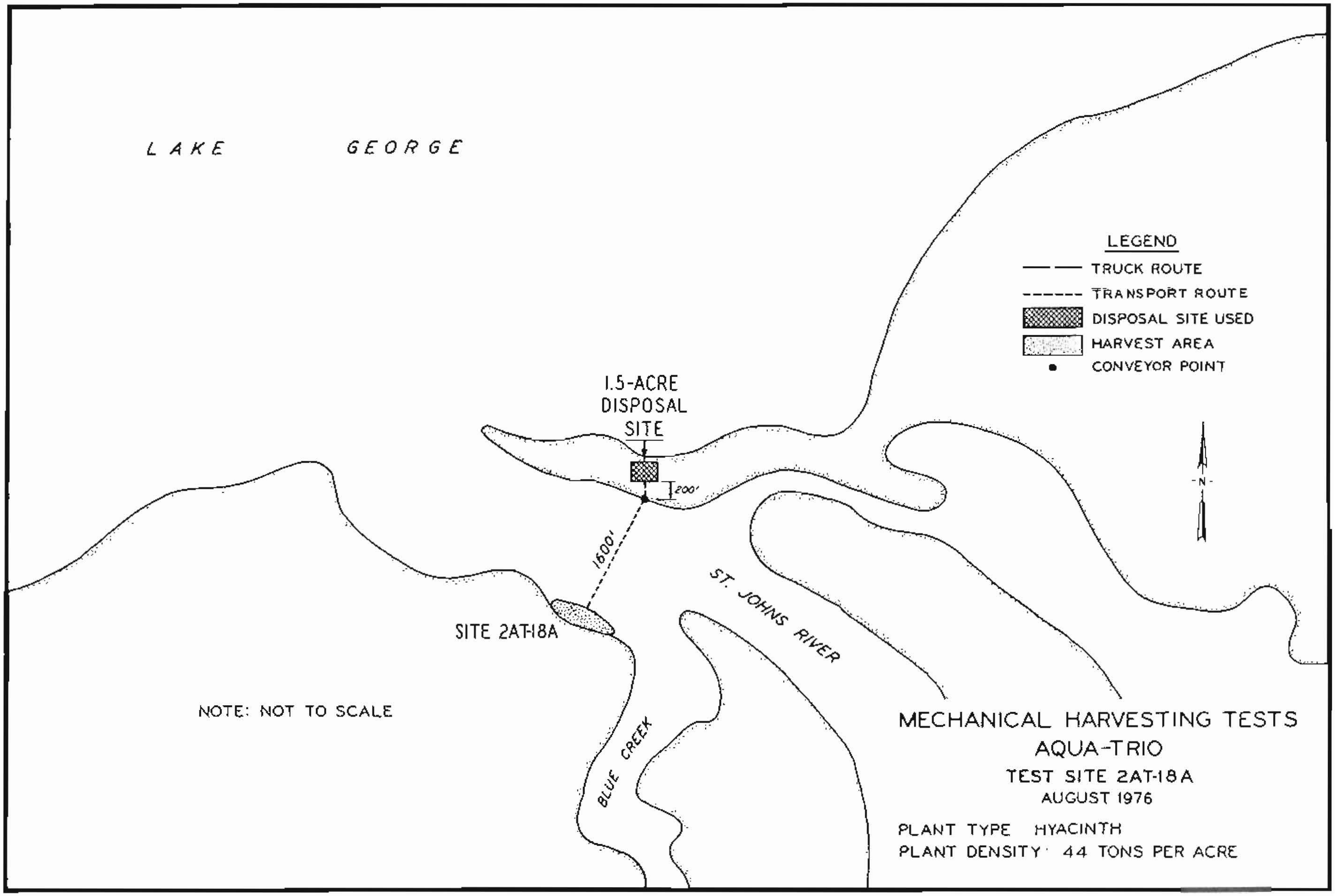

LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
N
ST. JOHNS RIVER
HWY 40
HWY 40
1080'
1150'
80'
SITE 2AT-13B5
Astor
TRUCK ROUTE 1.1 MI.
2-ACRE DISPOSAL SITE
NOTE: NOT TO SCALE
ST. JOHNS RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-13B5
JULY - AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 110 TONS PER ACRE

PLATE B7

PLATE B8


LAKE GEORGE
LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
1.5-ACRE DISPOSAL SITE
200'
1600'
N
ST. JOHNS RIVER
SITE 2AT-18A
BLUE CREEK
NOTE: NOT TO SCALE
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18A
AUGUST 1976
PLANT TYPE HYACINTH
PLANT DENSITY: 44 TONS PER ACRE

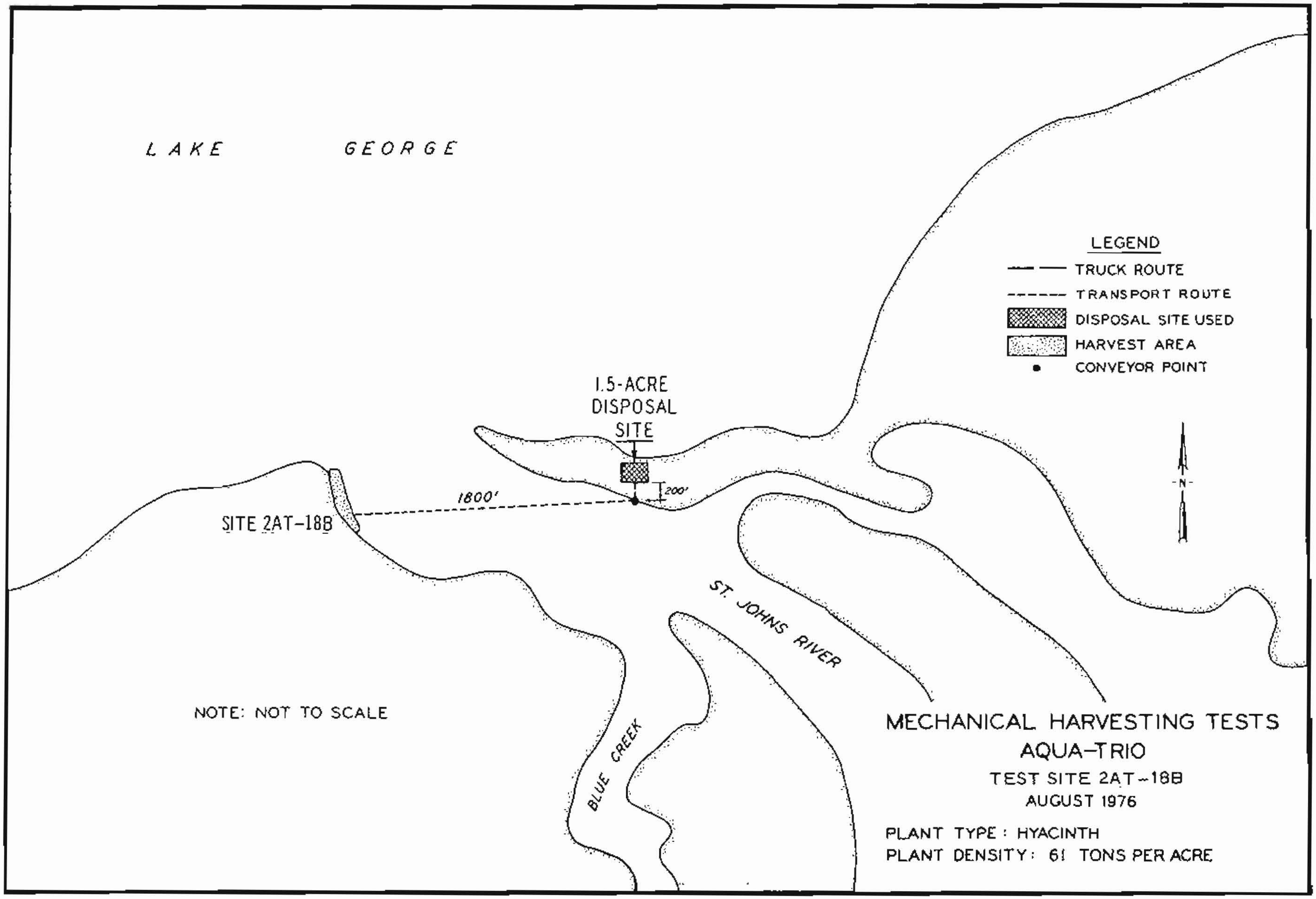
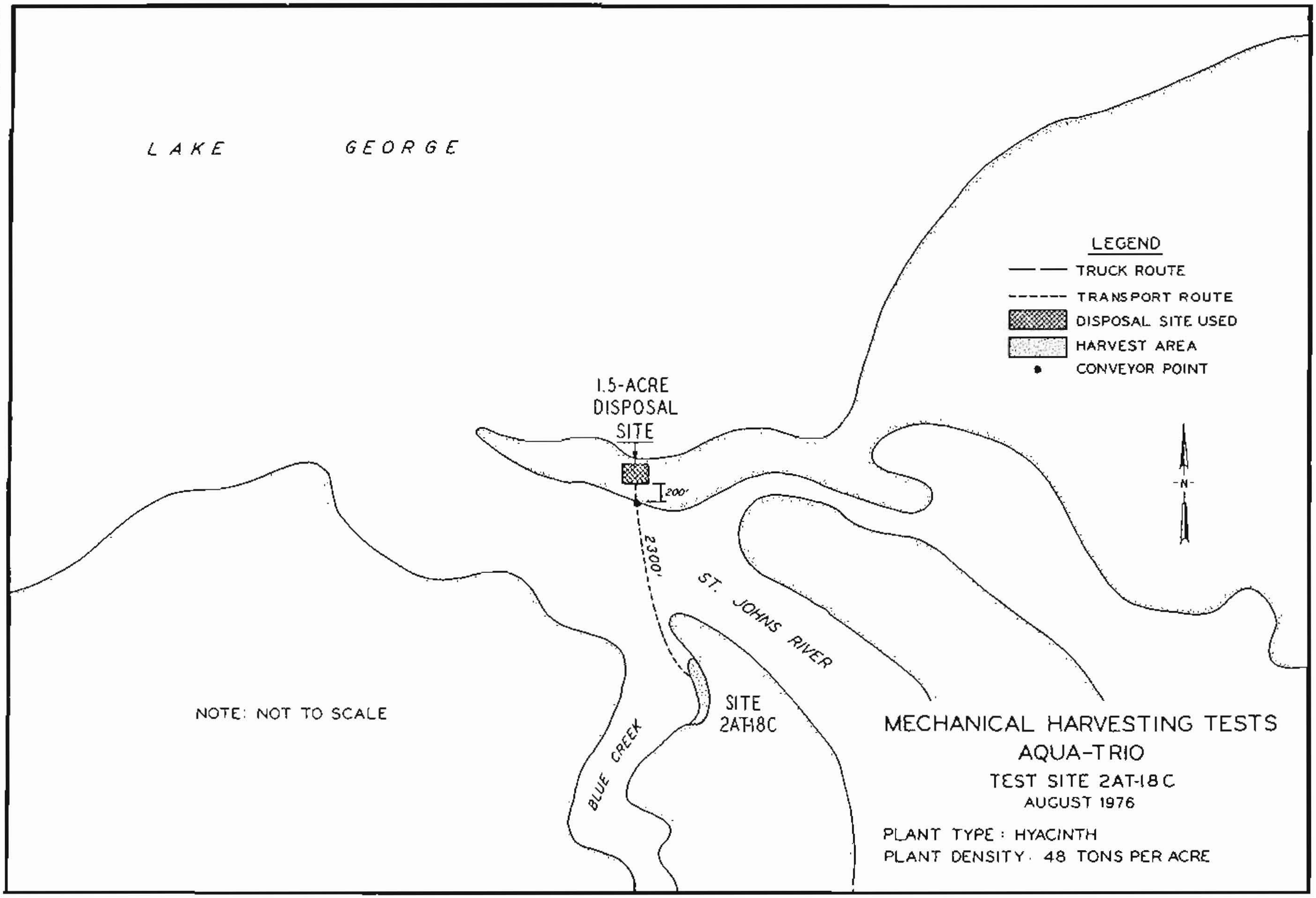

LAKE GEORGE
LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
1.5-ACRE DISPOSAL SITE
200'
1800'
SITE 2AT-18B
ST. JOHNS RIVER
BLUE CREEK
N
NOTE: NOT TO SCALE
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18B
AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 61 TONS PER ACRE

PLATE B9

PLATE B10



MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18C
AUGUST 1976

PLANT TYPE: HYACINTH
PLANT DENSITY: 48 TONS PER ACRE

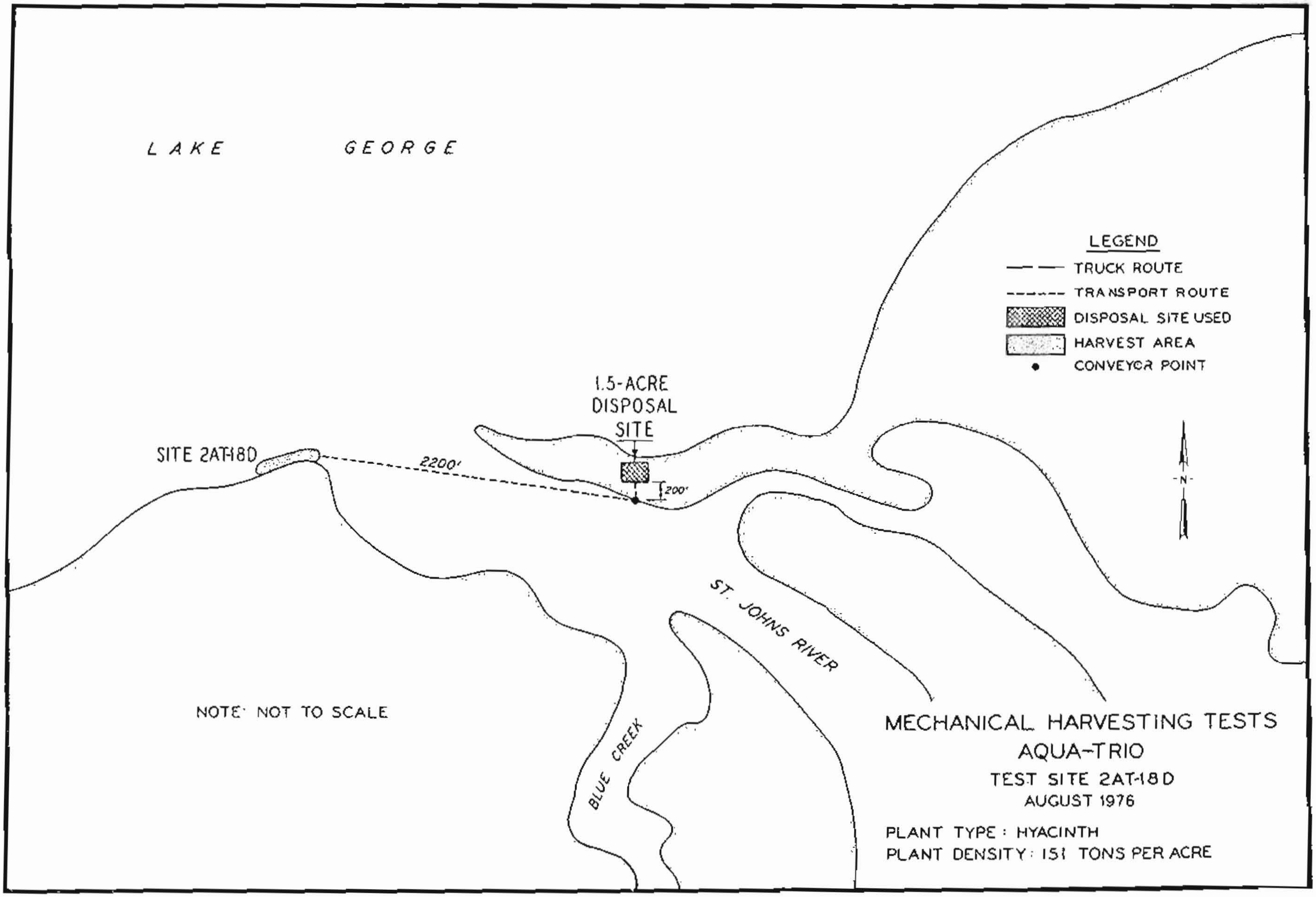
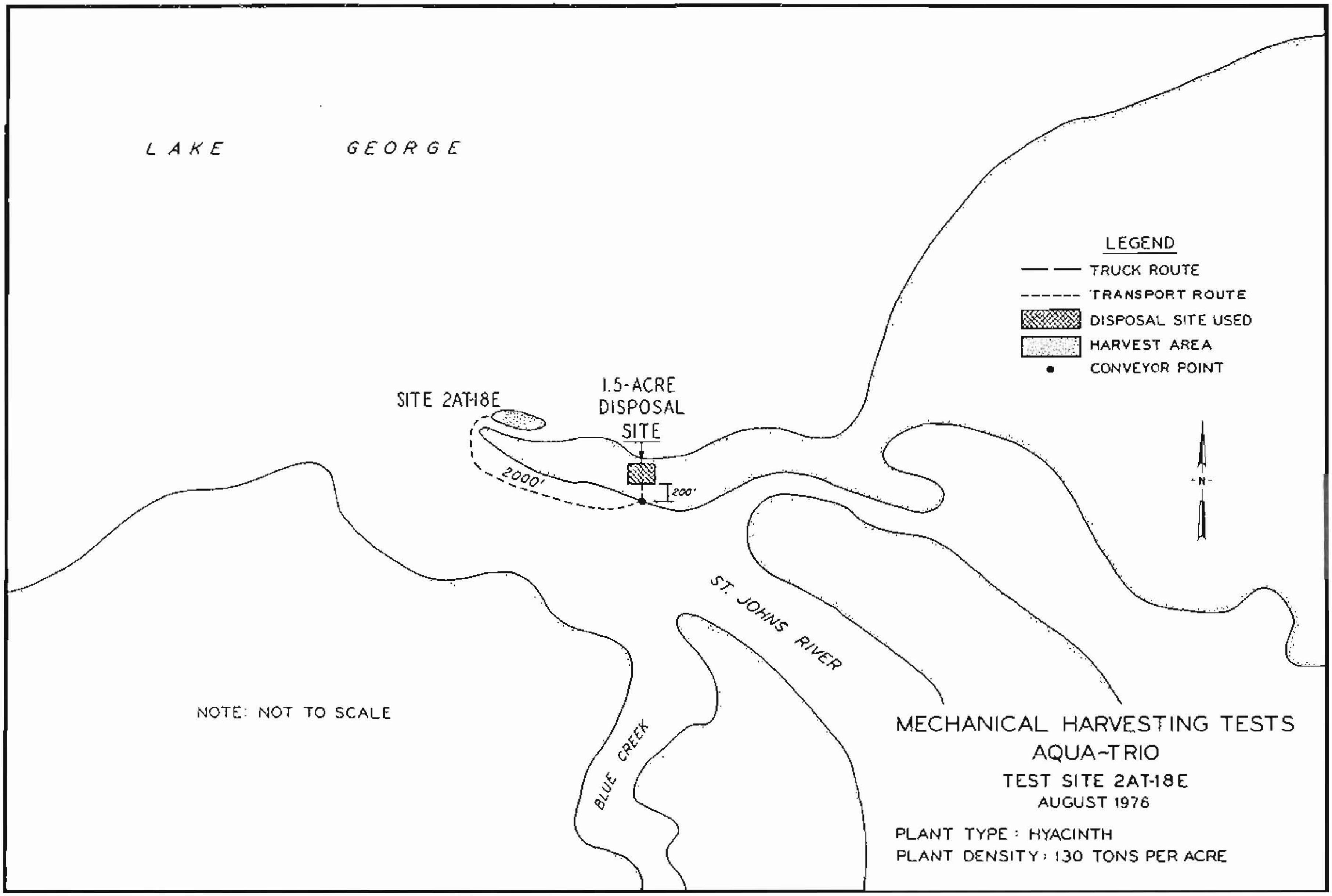

LAKE GEORGE
LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
1.5-ACRE DISPOSAL SITE
SITE 2AT-18D
2200'
200'
N
ST. JOHNS RIVER
BLUE CREEK
NOTE: NOT TO SCALE
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18D
AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 151 TONS PER ACRE

PLATE B11

PLATE B12


LAKE GEORGE
LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
SITE 2AT-18E
1.5-ACRE DISPOSAL SITE
2000'
200'
ST. JOHNS RIVER
BLUE CREEK
N
NOTE: NOT TO SCALE
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18E
AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 130 TONS PER ACRE

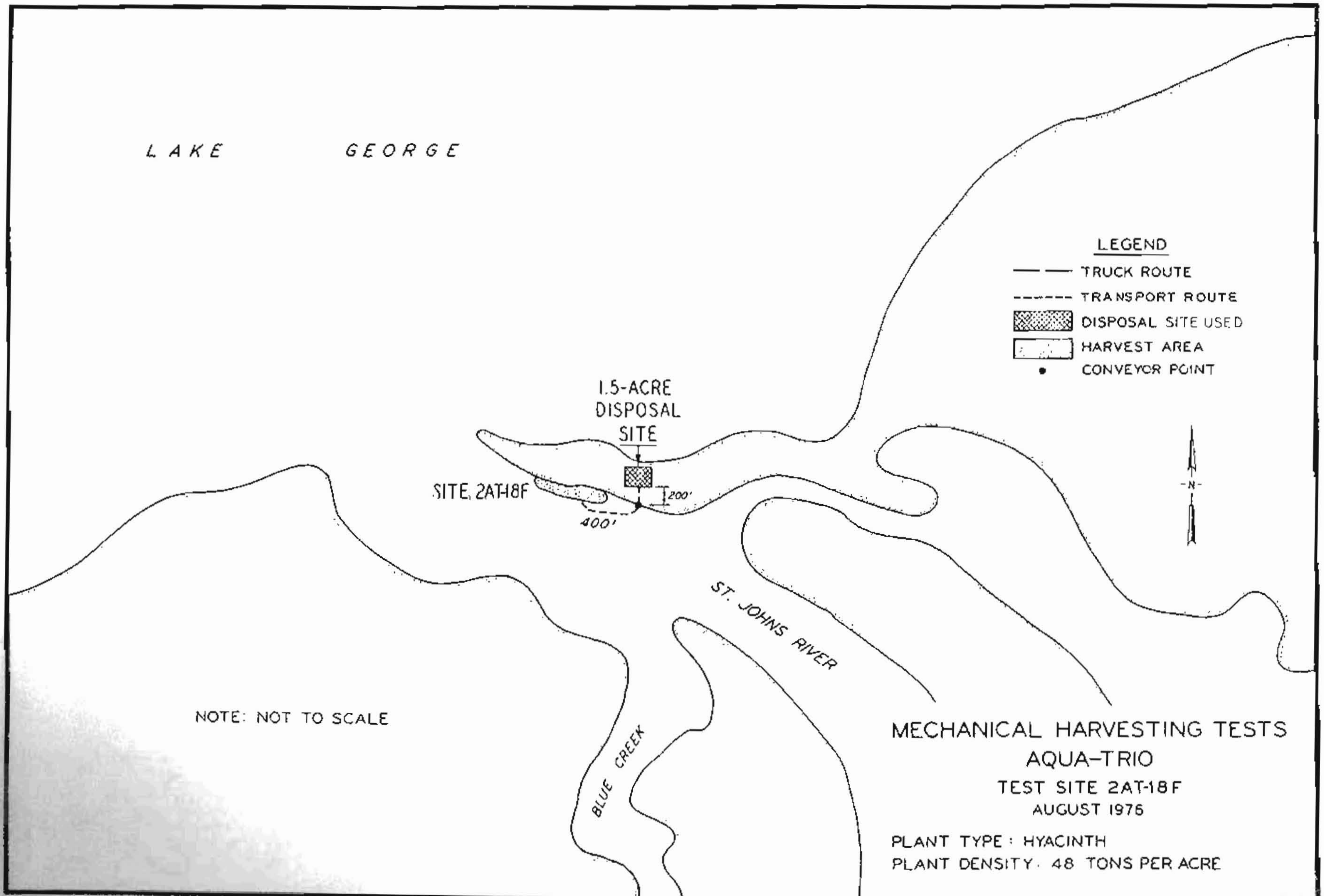
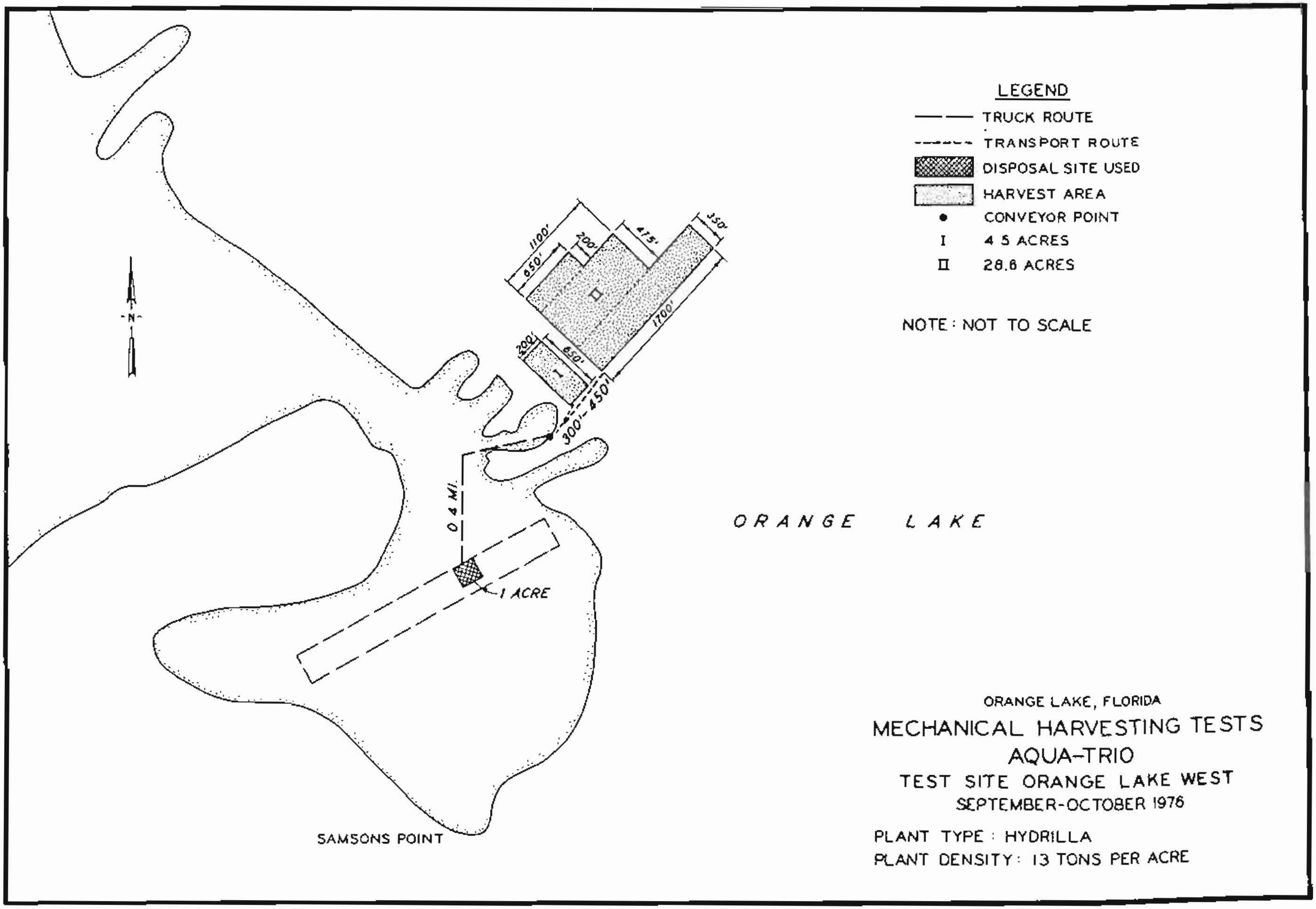
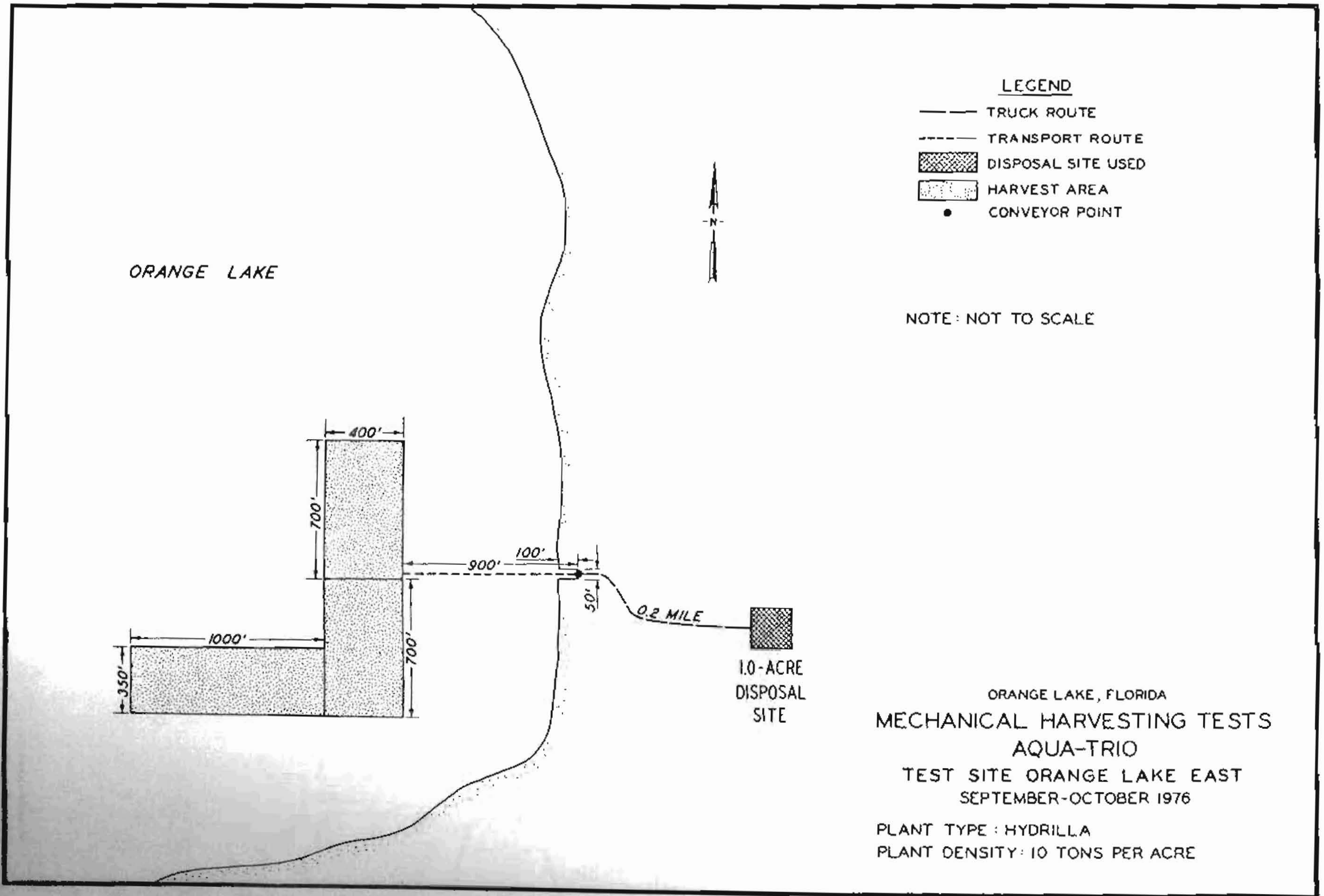

LAKE GEORGE
LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
1.5-ACRE DISPOSAL SITE
SITE 2AT-18F
200'
400'
N
ST. JOHNS RIVER
BLUE CREEK
NOTE: NOT TO SCALE
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE 2AT-18F
AUGUST 1976
PLANT TYPE: HYACINTH
PLANT DENSITY: 48 TONS PER ACRE

PLATE B13

PLATE B14


LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
I 4 5 ACRES
II 28.6 ACRES
NOTE: NOT TO SCALE
1100'
650'
200'
475'
350'
1700'
200'
650'
300'-450'
0 4 MI.
1 ACRE
ORANGE LAKE
SAMSONS POINT
ORANGE LAKE, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE ORANGE LAKE WEST
SEPTEMBER-OCTOBER 1976
PLANT TYPE: HYDRILLA
PLANT DENSITY: 13 TONS PER ACRE



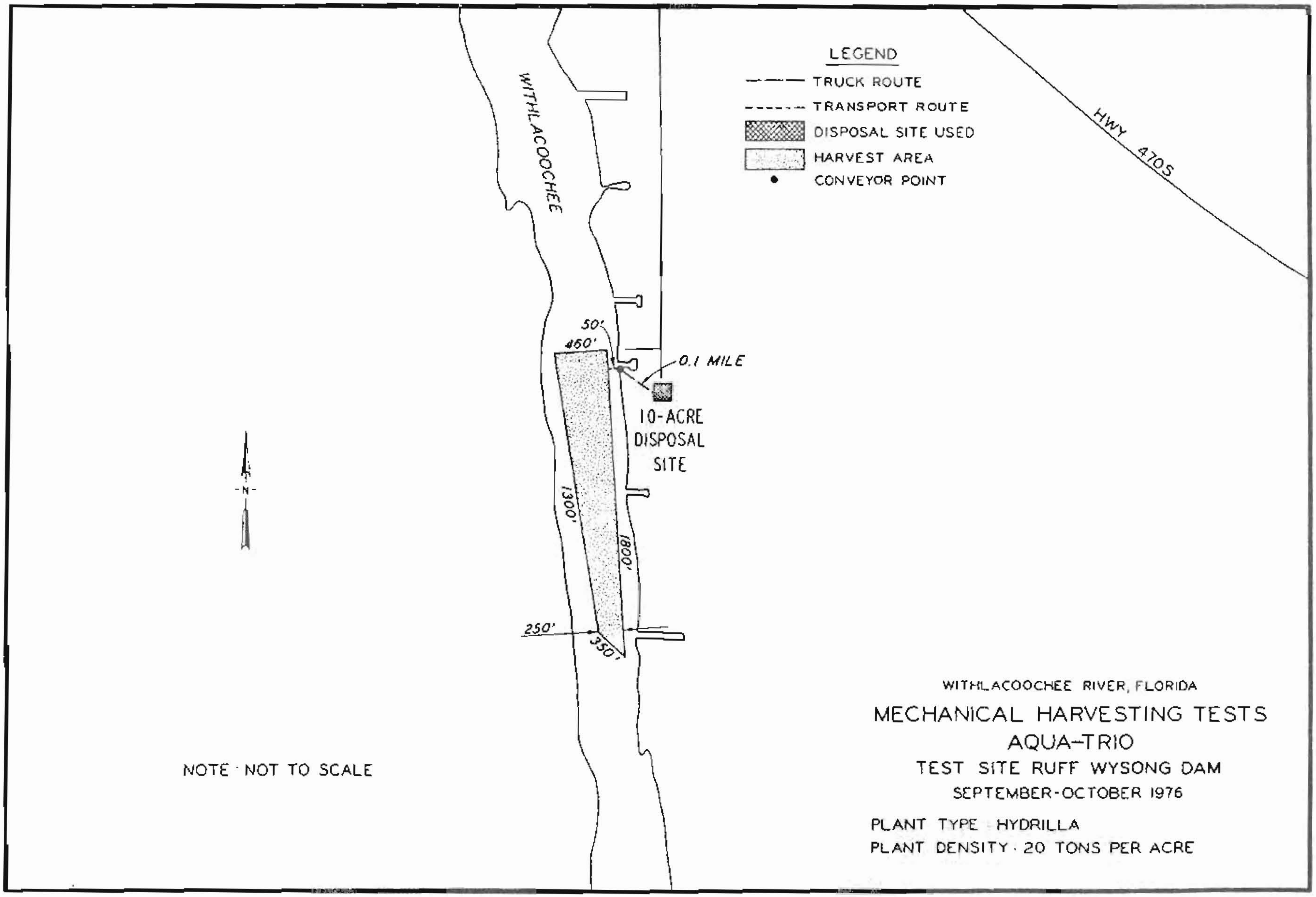
ORANGE LAKE, FLORIDA

MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE ORANGE LAKE EAST
SEPTEMBER-OCTOBER 1976

PLANT TYPE: HYDRILLA
PLANT DENSITY: 10 TONS PER ACRE

PLATE B15

PLATE B16



WITHLACOOCHEE RIVER, FLORIDA

MECHANICAL HARVESTING TESTS

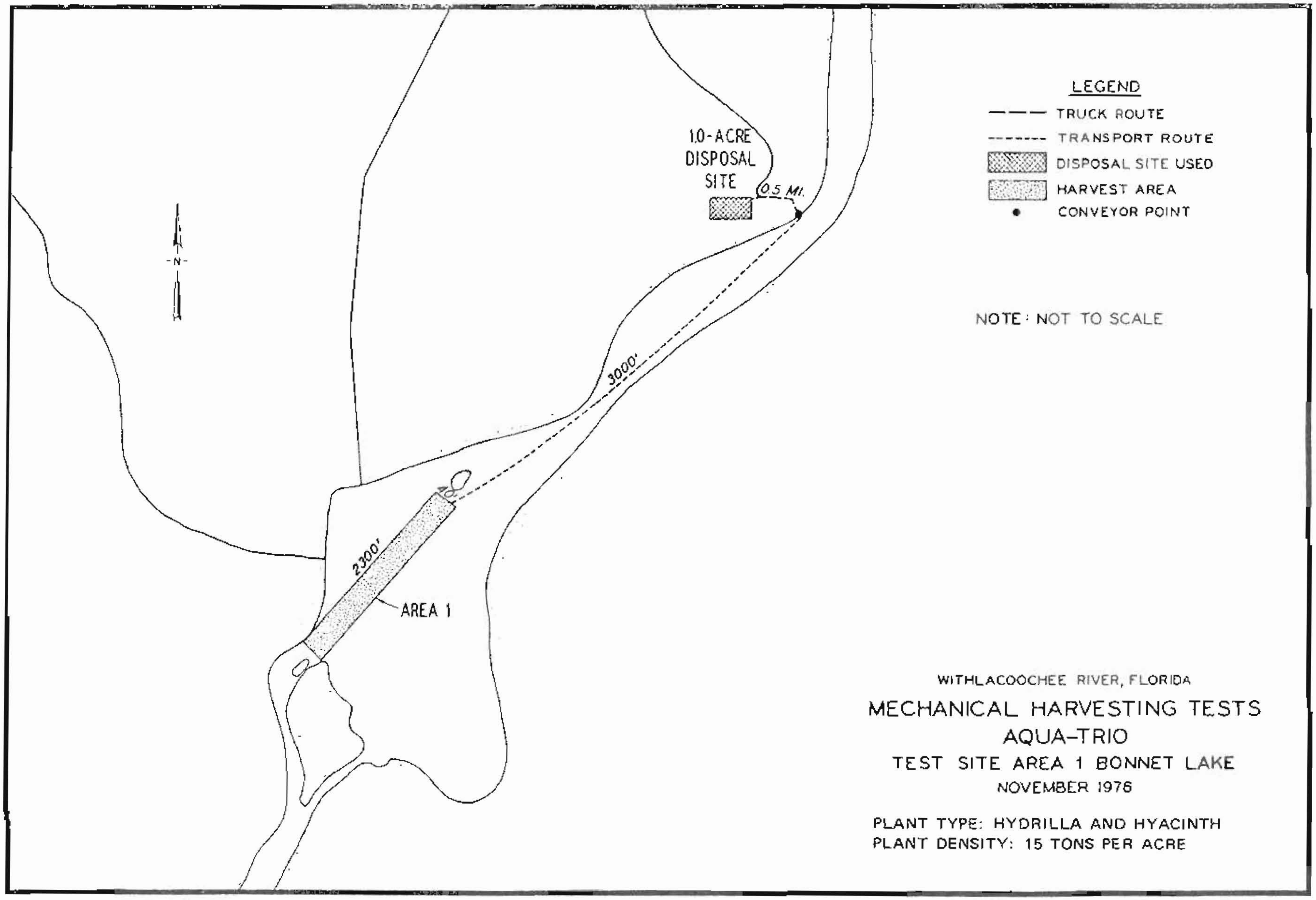
AQUA-TRIO

TEST SITE RUFF WYSONG DAM

SEPTEMBER-OCTOBER 1976

PLANT TYPE: HYDRILLA

PLANT DENSITY: 20 TONS PER ACRE



WITHLACOOCHEE RIVER, FLORIDA

MECHANICAL HARVESTING TESTS

AQUA-TRIO

TEST SITE AREA 1 BONNET LAKE

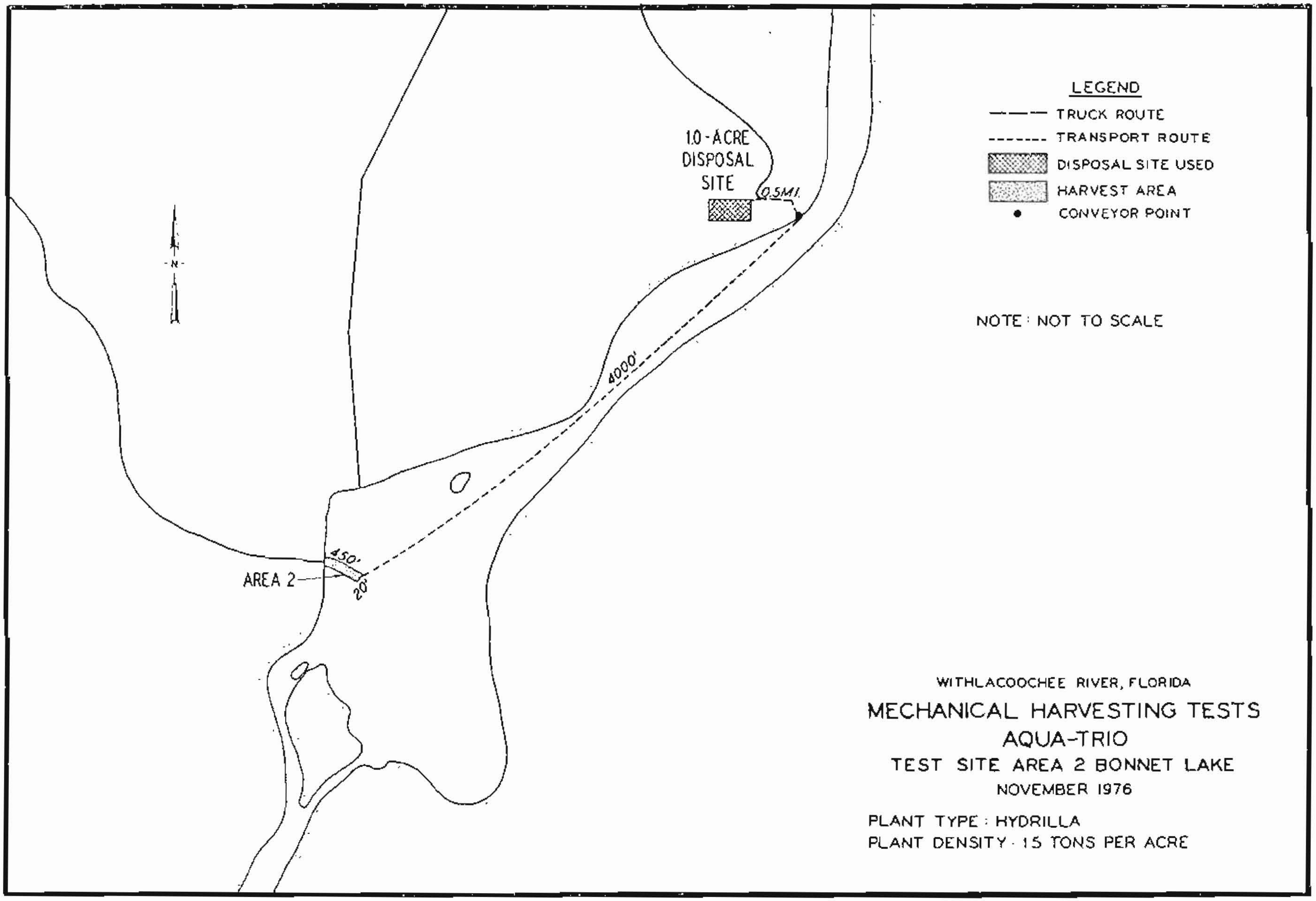
NOVEMBER 1976

PLANT TYPE: HYDRILLA AND HYACINTH

PLANT DENSITY: 15 TONS PER ACRE

PLATE B17

PLATE B18


LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
NOTE: NOT TO SCALE
1.0-ACRE DISPOSAL SITE
0.5 MI.
4000'
450'
20'
AREA 2
N
WITHLACOOCHEE RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE AREA 2 BONNET LAKE
NOVEMBER 1976
PLANT TYPE: HYDRILLA
PLANT DENSITY: 15 TONS PER ACRE

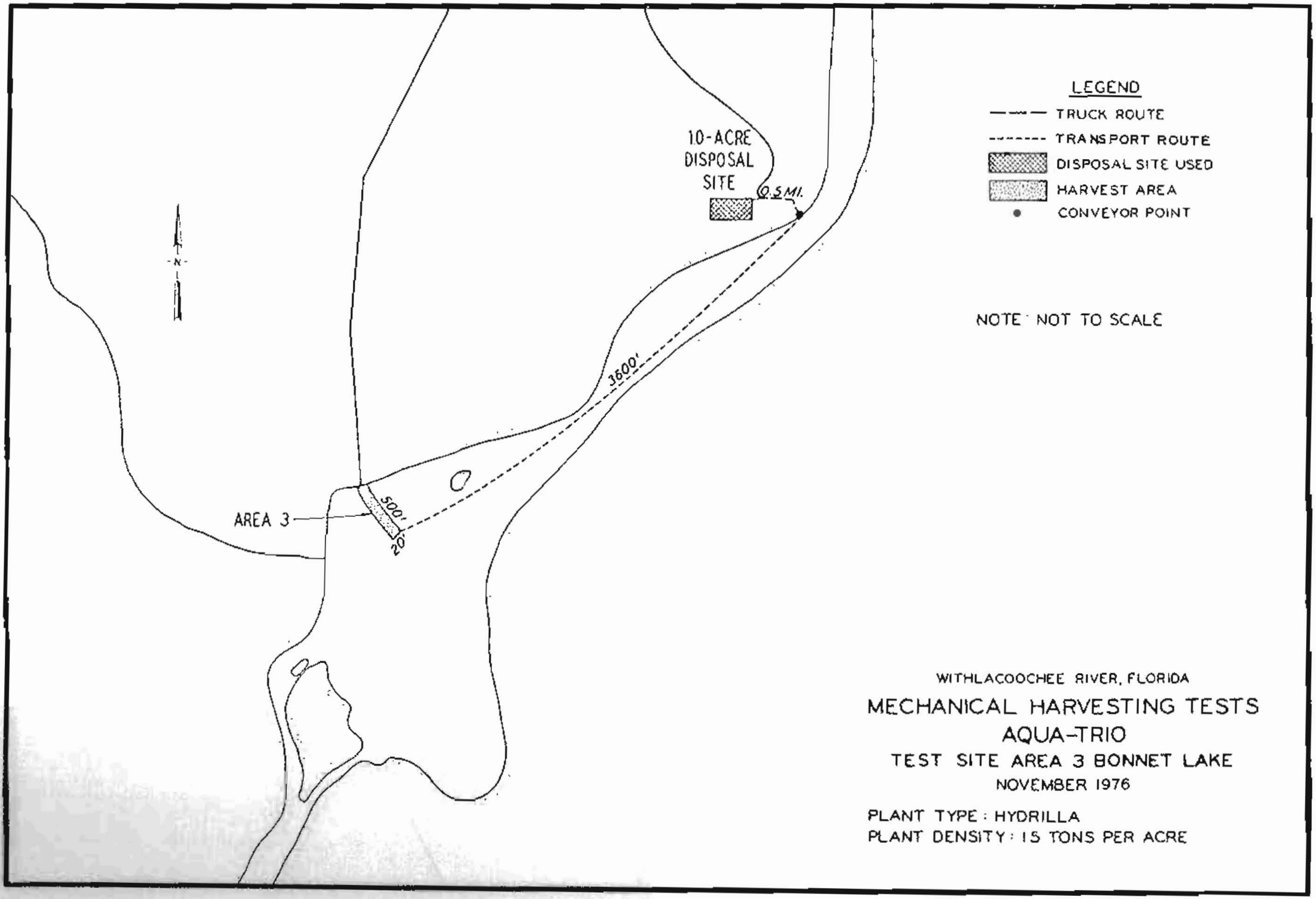
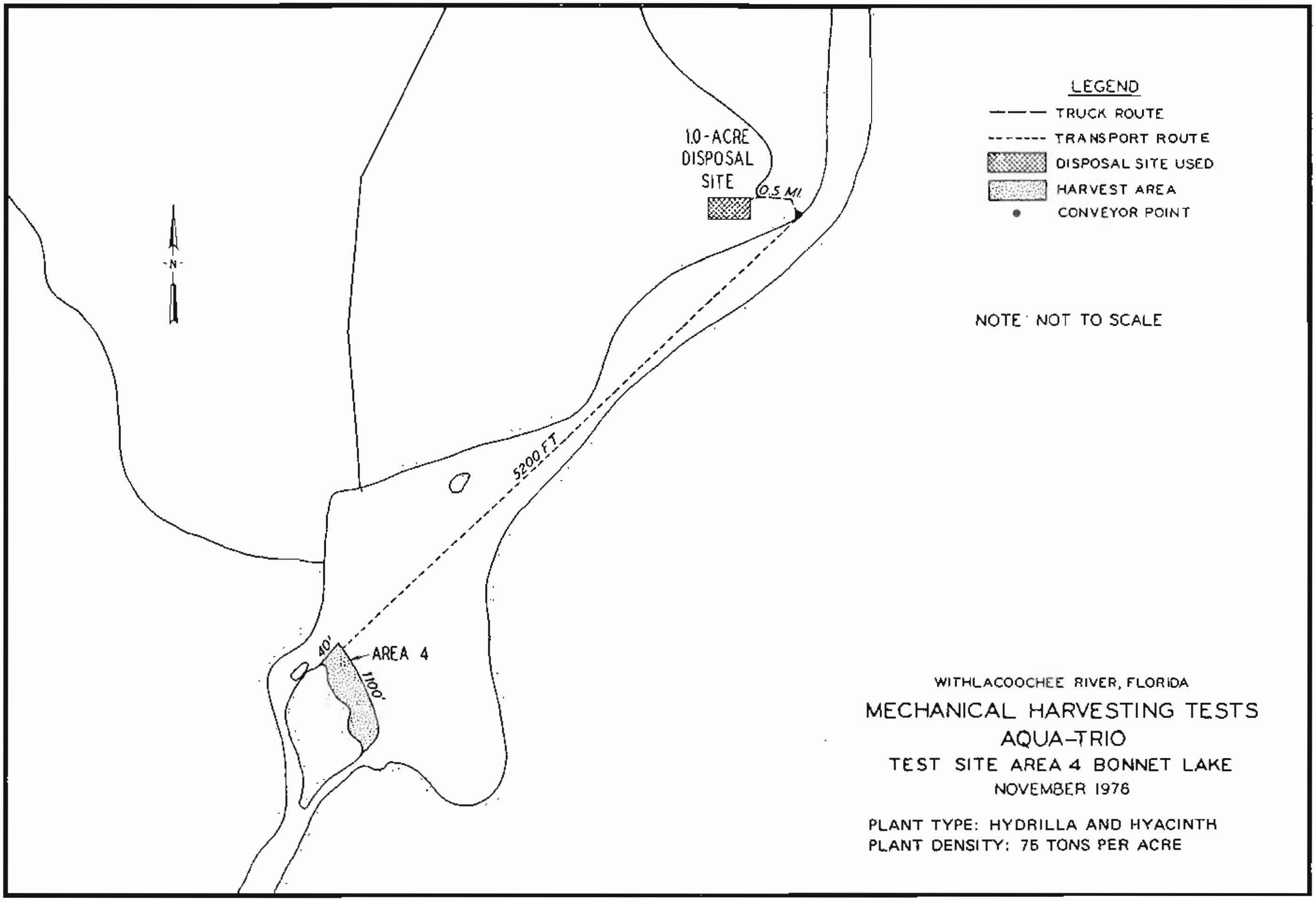
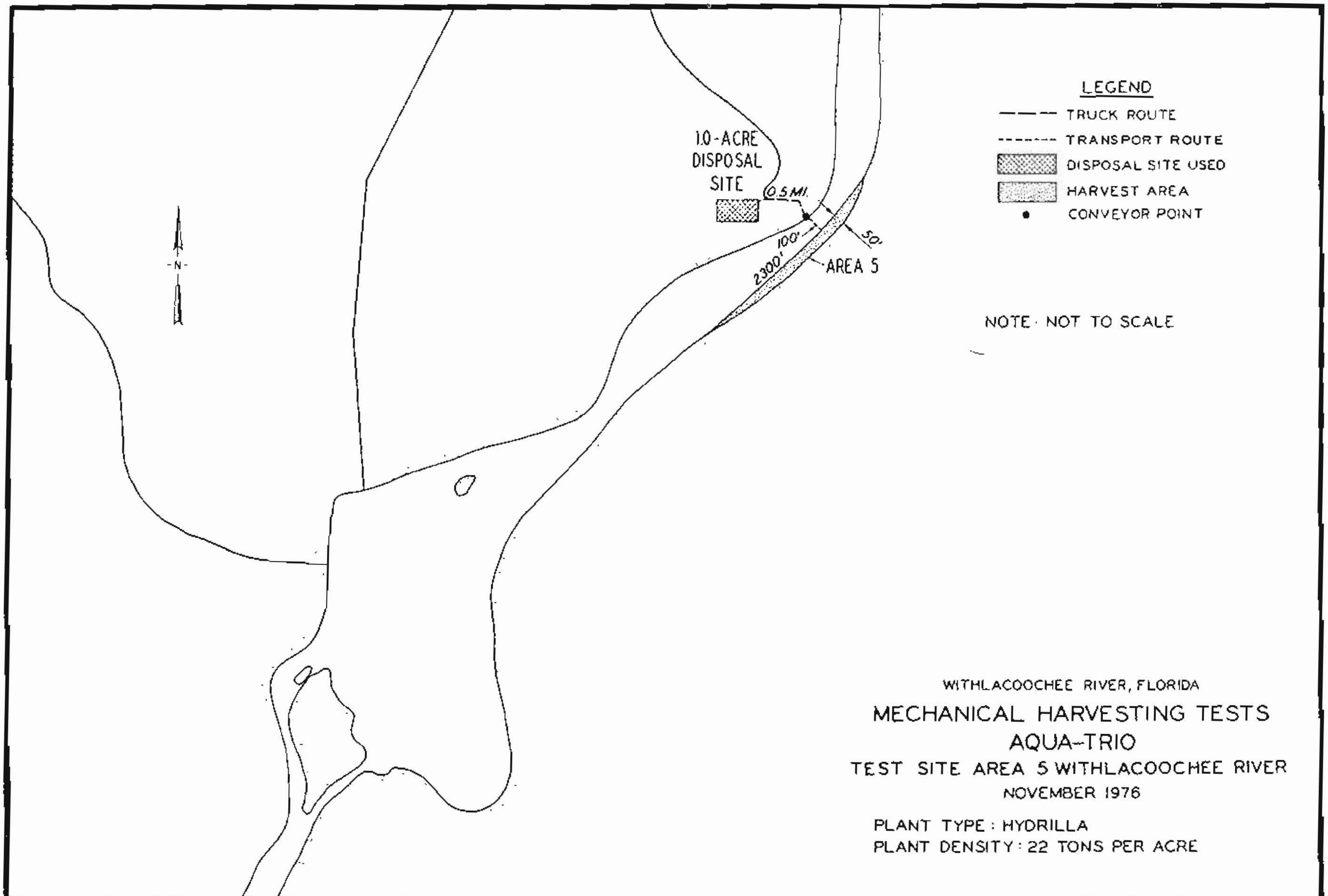

LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
10-ACRE DISPOSAL SITE
0.5 MI.
N
3600'
500'
20'
AREA 3
NOTE: NOT TO SCALE
WITHLACOOCHEE RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE AREA 3 BONNET LAKE
NOVEMBER 1976
PLANT TYPE: HYDRILLA
PLANT DENSITY: 15 TONS PER ACRE

PLATE B19

PLATE B20


LEGEND
TRUCK ROUTE
TRANSPORT ROUTE
DISPOSAL SITE USED
HARVEST AREA
CONVEYOR POINT
NOTE: NOT TO SCALE
1.0-ACRE DISPOSAL SITE
0.5 MI.
5200 FT
N
40'
AREA 4
1100'
WITHLACOOCHEE RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE AREA 4 BONNET LAKE
NOVEMBER 1976
PLANT TYPE: HYDRILLA AND HYACINTH
PLANT DENSITY: 75 TONS PER ACRE



WITHLACOOCHEE RIVER, FLORIDA
MECHANICAL HARVESTING TESTS
AQUA-TRIO
TEST SITE AREA 5 WITHLACOOCHEE RIVER
NOVEMBER 1976

PLANT TYPE: HYDRILLA
PLANT DENSITY: 22 TONS PER ACRE

PLATE B21

APPENDIX C: INSTRUCTIONS TO OPERATORS AND DATA RECORDERS, DEFINITIONS OF DATA SHEET ENTRIES, AND DATA SHEETS

1. The data collected during this study were tabulated as shown in Tables C1-C4 of this appendix. These tables are samples of actual data sheets and illustrate the methodology employed in collecting raw values. From such data, the time history of each load of harvested aquatic plants can be reconstructed from time of harvesting to time of disposal. In addition, each event can be identified in proper sequence as can the elapsed time for some events. Finally, the weight of each load provides the necessary data for calculating harvesting rates. The methods of collecting these data will be discussed in the following paragraphs.

2. A data collection technician was stationed on each component of the Aqua-Trio system and logged the times of occurrence of certain events and the elapsed time of some events, as noted on the respective data sheets.

Instructions to Operators and Data Recorders

3. All technicians were instructed to synchronize their watches prior to initiating a day's operation. They were further instructed not to be influenced by events or actions of other components of the system but to simply record, by their own best judgment, the times to be noted on their respective data sheets. They were told that the data sheets must be complete, and, if some extraordinary event took place, they were to make a note of it in the remarks section of the data form.

4. The operators of each component of the Aqua-Trio system were instructed to operate their respective components at their maximum operating rate at all times. For example, the harvester operator was instructed to harvest a load of plants at the maximum rate possible, and not slow down his harvesting rate to accommodate the transport, should the transport be pacing the operation. The harvester operator was instructed to harvest and then wait, if necessary, for the

transport, and the data recorder was instructed to note the delay. By the same reasoning, if the harvester was pacing the operation, the transport operator was instructed to perform his functions at a maximum rate and note any reason for extraordinary delays.

Definitions of Data Sheet Entries

5. The following are explanations of each column of the identified data sheet:

Harvester Record	
Column 1	The number of the plant load for a given day.
Column 2	Elapsed time between the first plants entering the harvester conveyor and the last plants entering the storage hold.
Column 3	Estimated by relative position of harvester to buoys spaced at 100-ft intervals in the harvest area.
Column 4	Chronological time (clock) when the transport completed hookup with the harvester.
Column 5	The number of the transport hooking up to the harvester at the time indicated in Column 4.
Column 6	Elapsed time to transfer the load from the harvester to the transport as measured from the time plants began entering the transport to the time the last plant material entered.
Column 7	Chronological time (clock) when the transport unhooked from the harvester.
Column 8	Chronological time (clock) when the first plant material appeared on the harvester conveyor.
Column 9	Idle time after the harvester was loaded until the transport hooked up to the harvester.
Column 10	Remarks.

Transport Record	
Column 1	The number of the plant load for a particular transport for a given day.

Column 2	Chronological time (clock) when the transport unhooked from the onshore conveyor.
Column 3	Time required for the empty transport to travel from the onshore conveyor to the harvester.
Column 4	Chronological time (clock) when the transport completed hookup with the harvester.
Column 5	Elapsed time between the first plants entering the storage hold and the last plants entering the storage hold.
Column 6	Chronological time (clock) when the transport completed unhooking from the harvester.
Column 7	Time required for the full transport to travel from the harvester to the onshore conveyor.
Column 8	Chronological time (clock) when the transport completed hookup with the onshore conveyor.
Column 9	Elapsed time between the first plants leaving the transport and the last plants leaving the transport.
Column 10	Remarks.

Truck Record

Column 1	Identification of the transport delivering a particular plant load.
Column 2	The number of the plant load hauled by a given truck.
Column 3	Chronological time (clock) when the truck parked under the conveyor ready to receive a load.
Column 4	Chronological time (clock) when the first plants entered the truck.
Column 5	Chronological time (clock) when the last plants entered the truck.
Column 6	Weight of the plants on the truck (these data taken from the Plant Weight Record, Column 9).
Column 7	Chronological time (clock) when the truck departed the conveyor.
Column 8	Chronological time (clock) when the truck returned to the conveyor site.
Column 9	Remarks.

Plant
Weight
Record

Column 1	Weight of loaded truck's left-front wheel.
Column 2	Weight of loaded truck's right-front wheel.
Column 3	Weight of loaded truck's left-rear wheel.
Column 4	Weight of loaded truck's right-rear wheel.
Column 5	Sum of the weights in columns 1 and 2.
Column 6	Sum of the weights in columns 3 and 4.
Column 7	Sum of the weights in columns 5 and 6 (gross weight).
Column 8	Weight of the empty truck (tare weight).
Column 9	Weight of the plants on the truck (net weight). (These data are entered on the Truck Record, column 6.)
Column 10	Truck load number.

Table C1

HARVESTER RECORD

hydrilla

Date: 21 Sep 76 Starting Time: 0740 Ending Time: 1520 Weather: Sunny & warm afternoon - light rain

Location: Orange Lake West

Density: 13 tons/acre

1 Load No.	2 Time to Harvest Load min:sec	3 Dist. Traveled to Harvest Load ft	4 Transporter Hookup hr-clock	5 Transporter No.	6 Time to Transfer Load min:sec	7 Transporter Unhook hr-clock	8 Resume Harvest hr-clock	9 Waiting on Transporter min:sec	10 Remarks
1	16:43	1600	0803	1	1:56	0805	0805	-	
2	19:30	2200	0825	2	5:09	0826	0826	-	
3	26:55	2500	0855	1	2:59	0859	0900	-	Trouble with belts on harvester.
4	21:16	2200	0922	2	2:30	0924	0925	-	
5	18:51	1900	0945	1	1:31	0947	0948	-	
6	18:35	1900	1008	2	5:09	1009	1010	-	
7	24:42	2200	1035	1	1:41	1037	1038	-	
8	23:37	2500	1102	2	1:47	1104	1104	-	
9	21:48	2200	1128	1	2:47	1133	1134	-	Wait for transport 1:40.
10	18:33	1850	1153	2	1:33	1155	-	-	Stop for lunch.
11	17:38	1850	1315	1	1:41	1317	1318	-	
12	18:13	1900	1337	2	27:09	1405	1406	-	Trouble with belts - 27:09.
13	21:14	2200	1428	1	1:22	1430	1430	-	
14	19:42	2100	1450	-	1:17	1452	1452	-	
15	19:59	2000	1513	-	2:15	1515	-	-	Last load.
16	6:24	250	-	-	-	-	-	-	

Table C2

TRANSPORT RECORD

hydrilla

Transporter No. 1

Date: 21 Sep 76 Starting Time: 0740 Ending Time: 1525 Weather:

Location: Orange Lake West

1 Load No.	2 Conveyor Unhook hr-clock	3 Empty Travel Time min:sec	4 Harvester Hookup hr-clock	5 Time to Load min:sec	6 Harvester Unhook hr-clock	7 Full Travel Time min:sec	8 Conveyor Hookup hr-clock	9 Unload Time min:sec	10 Remarks
1	0742	5:10	0802	2:03	0804	3:25	0808	2:37	
2	0811	4:15	0855	2:40	0858	4:20	0903	4:50	Hydrilla stuck on shore conveyor
3	0908	4:10	0945	1:30	0947	4:45	0952	2:55	
4	0955	4:05	1035	1:41	1037	5:40	1043	2:05	
5	1045	4:25	1128	2:50	1131	4:45	1136	2:27	
6	1250	4:13	1315	1:50	1317	4:21	1121	2:41	
7	1324	5:25	1428	1:35	1430	3:56	1434	3:02	Talk with supervisor 2:00
8	1439	5:30	1512	2:02	1514	3:30	1518	4:28	

TRANSPORT RECORD

hydrilla

Transporter No. 2

Date: 21 Sep 76 Starting Time: 0740 Ending Time: 1500 Weather: Clear & warm

Location: Orange Lake West

1 Load No.	2 Conveyor Unhook hr-clock	3 Empty Travel Time min:sec	4 Harvester Hookup hr-clock	5 Time to Load min:sec	6 Harvester Unhook hr-clock	7 Full Travel Time min:sec	8 Conveyor Hookup hr-clock	9 Unload Time min:sec	10 Remarks
1	0742	3:18	0823	1:02	0824	5:50	0830	3:31	Wait on harvester
2	0835	4:48	0920	2:33	0923	5:12	0929	3:55	" " "
3	0933	3:34	1006	1:02	1007	5:08	1012	3:29	" " "
4	1018	5:15	1059	1:51	1101	5:58	1107	3:55	" " "
5	1111	6:14	1150	1:35	1152	3:19	1156	3:47	Lunch
6	1248	5:14	1335	20:02	1403	5:45	1409	3:42	Wait on harvester
7	1413	4:32	1447	2:47	1450	6:26	1457	4:25	

Table C3

TRUCK RECORD

hydrilla

Truck No. 2

Date: 21 Sep 76 Starting Time: 0745 Ending Time: 1530 Weather: Hot and sunny Truck Volume 5 cu yd

Roadway Conditions: Dry

Location: Orange Lake West

One-way Mileage (from conveyor to disposal: 3/10 miles)

1 Transporter No.	2 Truck Load No.	3 At Conveyor hr-clock	4 Start Loading hr-clock	5 Finish Loading hr-clock	6 Load Weight lb	7 Leave Conveyor hr-clock	8 Return to Conv. Site hr-clock	9 Remarks
1	1	0745	0746	0750	-	0751	0758	Load No. 1 from 9-20-76 - dry load
1	2	0759	0807	0810	-	0811	0815	
2	3	0821	0831	0835	-	0836	0842	
1	4	0843	0903	0909	-	0910	0919	
2	5	0919	0929	0935	-	0936	0941	
1	6	0942	0950	0954	-	0955	1000	
2	7	1001	1014	1018	-	1019	1024	
1	8	1025	1042	1045	-	1046	1050	
2	9	1051	1110	1113	-	1114	1120	
1	10	1121	1136	1140	-	1141	1146	
2	11	1147	1157	1201	-	1247	1254	
1	12	1255	1320	1323	-	1324	1330	
2	13	1331	1411	1414	-	1415	1420	
1	14	1421	1433	1436	-	1437	1443	
2	15	1444	1457	1502	-	1503	1510	
1	16	1517	1518	1522	-	1523	1530	

Table C4

PLANT WEIGHT

hydrilla

Truck No. 2

Truck Volume 5

Date: 29 Sep 76

Location: Orange Lake East

Scale Readings, lb				Front Axle Total lb	Rear Axle Total lb	Truck Total lb	Empty Truck Weight, lb	Plant Weight lb	Truck Load No.
Left Front	Right Front	Left Rear	Right Rear						
3440	3150	6220	6250	6590	12,470	19,060	11,600	7110	1
3500	3100	6650	5700	6600	12,350	18,950	11,600	7350	2
3400	3520	6010	5410	6920	11,420	18,340	11,600	6740	3
3340	3230	6870	5750	6570	12,620	19,190	11,600	7590	4
3350	3120	6050	5310	6470	11,360	17,830	11,600	6230	5
3450	3210	6260	5600	6660	11,860	18,520	11,600	6920	6
3330	3160	5770	5220	6490	10,990	17,480	11,600	5880	7
3550	3470	6430	5750	7020	12,180	19,200	11,600	7600	8
3500	3200	6300	5570	6700	11,870	18,570	11,600	6970	9
3350	3130	5840	5490	6480	11,330	17,810	11,600	6068	10
3460	3350	5550	5510	6810	11,060	17,870	11,600	6128	11
3460	3300	5980	5670	6760	11,650	18,410	11,600	6668	12
3350	3260	6030	5990	6610	12,020	18,630	11,600	6888	13
3620	3230	6640	5600	6850	12,240	19,090	11,600	7348	14
3390	3250	5970	5510	6640	11,480	18,120	11,600	6378	15
3490	2620	5660	4800	6110	10,460	16,570	11,600	4828	16

APPENDIX D: FIELD PROGRAM MECHANICAL HARVESTING COSTS

1. Mechanical harvesting of waterhyacinth and hydrilla was accomplished using the Aqua-Trio and the Aqua-Trio with an additional transport.

2. Practically all harvesting operations in waterhyacinth were with the basic Aqua-Trio and two dump trucks. Daily cost of equipment was:

a. Harvester cost with mobilizer, supervisor, operator, and other field cost: $406.39 equipment + $18.39 mobilization fee* = $424.78 per day.

b. Transport cost with operator: $120.78 equipment + $18.39 mobilization fee = $139.17 per day.

c. Onshore conveyor: $34.20 equipment + $18.39 mobilization fee = $52.59 per day.

d. Dump truck (two) with drivers: $80.00 truck (two) + $67.68 driver (two) = $295.36 per day.

e. Disposal cost: One GS-12 real estate man, 10 days @ $210 per day; $2100 ÷ 63 working days = $33.33 per day.

f. Total daily cost = $945.23 per day.

3. Waterhyacinth was harvested for 29 days along the St. Johns River, canals adjacent to the St. Johns River, and Lake George. During this time, a total of 745 tons of waterhyacinth was harvested. Based on the data stated above, the cost of harvesting waterhyacinth was $36.79 per ton, computed as follows: 29 days × $945.23 per day = $27,411.67; $27,411.67 ÷ 745 tons = $36.79 per ton.

4. Almost all of the mechanical harvesting operations in hydrilla were conducted using the same equipment as used in waterhyacinth operations, except an additional transport and only one dump truck were used. Daily cost was:

a. Harvester cost with mobilizer, supervisor, operator, and other field cost: $406.39 equipment + $18.39 mobilization fee = $424.78 per day.

b. Transport (two) cost with operator: $120.78 equipment (two) + $18.39 mobilization fee (two) = $278.34 per day.

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* Total mobilization costs prorated on a per day-per component basis.

c. Onshore conveyor: $34.20 equipment + $18.39 mobilization = $52.59 per day.

d. Dump truck with driver: $80.00 truck + $67.68 driver = $147.68 per day.

e. Disposal cost: 10 days @ $210 per day; $2100 ÷ 63 working days = $33.33 per day.

f. Total daily cost = $936.72 per day.

5. Hydrilla was harvested for 34 days on Orange Lake and the Withlacoochee River. During this time, a total of 1,577 tons of hydrilla was harvested. Based on the data above, the cost of harvesting hydrilla was $20.20 per ton computed as follows: 34 days × $936.72 = $31,848.48; $31,848.48 ÷ 1,577 tons = $20.20 per ton.

APPENDIX E: DATA SOURCE MATERIAL

1. The preliminary assessment of mechanical harvesting as a technique of removal and control of problem aquatic plants was based on information gained from both published materials and persons of recognized expertise. To credit these sources and make them available for future reference, lists by category are included below.

2. Access to the below-listed materials and persons may best be achieved by direct contact with the sponsoring institutions cited.

List of Literature Searched

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List of Persons Contacted on Mechanical Harvesting

1. Mr. John Neal
   Limnos, Ltd.
   22 Roe Ave.
   Toronto, Ontario M5M 2H7

2. Mr. Forrest Ware
   Florida Game and Fresh Water Fish Commission
   2202 Lakeland Hills Blvd.
   Lakeland, Florida 33801

3. Dr. William T. Haller
   Asst. Professor, Aquatic Plant Research
   University of Florida
   Gainesville, Florida 32611

4. Dr. B. C. Wolverton
   NASA
   Bay St. Louis, Mississippi

5. Mr. Brate Bryant
   Aquamarine Corporation
   Waukesha, Wisconsin 53186

6. Mr. Sam Winfrey
   University of Florida
   Gainesville, Florida 32611

7. Dr. Dick Koegel
   University of Wisconsin
   Madison, Wisconsin 53715

8. Mr. Al Carver
   Carver Aquatics
   Minden, Louisiana 71055

9. Dr. Larry Bagnall
   Department of Agricultural Engineering
   University of Florida
   Gainesville, Florida 32611

10. Mr. George Suciu
    Zero Defects Design Limited
    Box 74
    Montreal, P. Q. H3P 3B8

11. Dr. Bill Johnson
    Kansas State University

12. Dr. H. D. Bruhn
    Department of Agricultural Engineering
    University of Wisconsin
    Madison, Wisconsin

13. Mr. Gordon Baker
    Central and Southern Florida Flood Control District
    West Palm Beach, Florida

14. Dr. Ed Freeman
    University of Florida
    Gainesville, Florida 32611

15. Mr. Rue Hestard
    Florida Game and Fresh Water Fish Commission
    Tallahassee, Florida

16. Mr. Neal Spencer
    U. S. Department of Agriculture
    Gainesville, Florida

17. Mr. Frank Wilson
    Winter Haven, Florida

18. Mr. Ralph Shaver
    Environmental Research and Technology, Inc.
    Concord, Massachusetts