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FINAL REPORT

on

REVIEW OF CURRENT INTEREST AND RESEARCH
IN WATER HYACINTH-BASED WASTEWATER TREATMENT
(Report No. BCL-OA-TFR-77-1)

by

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16. Abstracts

The status of activity in the user community for water hyacinth-based wastewater treatment was evaluated. The principal technique used was that of interviewing people who either (1) were known to be engaged in hyacinth research or development or (2) had made inquiry to NASA about hyacinth systems. About 40 non-research organizations and a similar number of research organizations were contacted. As a result of the interviews and a review of the relevant literature, it was concluded that hyacinth systems have the potential for providing a lower cost way for small cities to meet increasingly stringent effluent requirements. A limited amount of full-scale demonstration of hyacinth systems has been carried out during the past two years, but the yield of design data has been small. Several organizations are currently planning construction of experimental full-scale hyacinth-based wastewater treatment systems during 1977-1978.

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FOREWORD

The study reported herein was carried out by Battelle's Columbus Laboratories for the NASA Office of Applications, as a task under Contract No. NASw-2800. The work was done under the general supervision of Dr. A. C. Robinson, Battelle's manager for the contract. Task monitor in the Office of Applications was Mr. Nelson L. Milder, Code ET.

ACKNOWLEDGMENT

In the course of this study, a number of persons were contacted for information and opinions relative to hyacinth research or utilization. The authors are most appreciative of the cooperation of these individuals. Without this cooperation, the study could not have been completed. The final evaluations and conclusions are, of course, Battelle's responsibility, but the inputs of the respondents, most of whom are listed in the study, were essential.

TABLE OF CONTENTS

REVIEW OF CURRENT INTEREST AND RESEARCH IN WATER HYACINTH-BASED WASTEWATER TREATMENT

by

R. K. Markarian, J. E. Balon, and A. C. Robinson

INTRODUCTION AND SUMMARY

For the past three years, NASA's Office of Applications has been active in furthering the use of water hyacinths in treatment of waste waters. This activity grew out of a problem in treating chemical wastes at a NASA facility. It was decided that the best approach to this problem was a zigzag lagoon stocked with water hyacinths. This facility has now been in successful operation for more than a year.

Based on this experience, the Technology Applications Division of the NASA Office of Applications undertook to determine whether this technique might have broader application, especially to the treatment of municipal wastes. The principal NASA activities have included:

- Development of data on the characteristics of the water hyacinth when used in this application[1,2]*
- Development of data on possible uses of water hyacinths after their wastewater treatment function is completed[3]
- Implementation and operation of a hyacinth system for treating chemical wastes at a NASA facility[4]
- Cooperative demonstration programs with operators of municipal water treatment systems[2]
- Development of preliminary system design data, system designs and cost estimates[5]
- Analysis of the potential size and nature of the market for hyacinth-based municipal sewage treatment systems[5].

While the use of water hyacinths for this purpose was suggested some decades ago, and many research activities have been completed, NASA's activities, and the resulting publicity, have made major contributions to the recently increased interest in hyacinth systems. NASA has received hundreds of inquiries from U.S. government agencies, foreign governments, state and local authorities, industrial organizations and private individuals. Several organizations have recently or are currently experimenting with

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* Superscript numbers indicate references, listed at end of text.

hyacinth-based wastewater treatment systems. This technology is in a rapid state of development.

To assist in planning its future activities, NASA needed an evaluation of the current status, especially the status of activity in the user community. Who (outside of NASA) is doing experimental and/or design work? What hyacinth systems have been or are being implemented? What are the future prospects of the concept as seen by the prospective users? What is the current status of the transfer of this technology?

To investigate these questions, NASA asked Battelle to perform the study reported here. The principal technique was that of interviewing people who either (1) were known to be engaged in hyacinth research or development or (2) had made inquiry to NASA about hyacinth systems. In total, about 40 non-research organizations were contacted. A similar number of research organizations were also approached. It appears that a relatively complete coverage was achieved of the organizations engaged in hyacinth research and/or application. From the non-research community, it was necessary to select only a fraction for follow-up.

As a result of these interviews, and as a result of reviewing the relevant literature, the following conclusions emerge:

- <u>Hyacinth systems appear to have the potential for meeting a very real need</u>. It may be that they can provide a lower cost way for small cities and towns to meet increasingly stringent effluent requirements.

- <u>At present there is no technology "product" to transfer</u>. By this, it is meant that the potential buyer of a hyacinth treatment system has no source from which to design or obtain a system which (1) has demonstrated performance capabilities and cost and (2) is approved by cognizant regulatory agencies.

- <u>Within three to four years, such a product may be available, as a result of activities currently under way</u>. The natural suppliers of hyacinth treatment systems are those architect and engineering firms specializing in wastewater treatment. Unless they are persuaded that these new systems can be designed to achieve required effluent standards reliably, they will not offer the product for sale. Several such firms are known to be considering and/or experimenting with hyacinth systems. If this is done, it may yield satisfactory results, and provide at least a rough empirical base for designing additional systems. If results are unsatisfactory or inconclusive, interest in hyacinth systems could terminate.

- The quickest and most reliable approach to developing a viable product would include a set of controlled experiments, under realistic nutrient loading conditions, to determine the effects of the significant design variables. A direct attack on the uncertainties surrounding hyacinth system design would be the fastest way to complete the development phase. The required data include (1) optimal physical design (lagoon depth, area, holding time, harvesting doctrine), (2) construction and operating cost, (3) effective techniques for preventing plant escape and (4) performance of hyacinth systems under various loading conditions and temperature cycles.

- The best institutional setting arrangement for this study would be a joint effort involving (1) a wastewater treatment authority, (2) a competent and innovative engineering firm, (3) the cognizant regulatory agencies, and (4) a suitable source of funding. This type of structure will tend to establish the greatest possible credibility with potential users of the technology, facilitate transfer of the technology, and address the regulatory and environmental issues associated with the technology. Major funding by the USEPA would be particularly appropriate, in that this agency has the major long-term Federal responsibility for wastewater treatment technology, and environmental regulation. Furthermore, this is the Federal agency to which state and local authorities look for guidance. Accordingly, EPA is in a good position to foster technology transfer, if a successful product is demonstrated.

- <u>Among potential users, interest centers on wastewater treatment itself. The use, if any, to be made of the harvested hyacinth plants is not of general concern</u>.

METHODS UTILIZED

In order to achieve the objectives of the study, the following was accomplished.

- Current interests of persons who had contacted Mr. B. C. Wolverton (NASA's National Space Technology Laboratories) were assessed by telephone interviews. A questionnaire (Appendix A) was developed for this purpose. These initial contacts often provided information on other persons interested in water hyacinth use who were also contacted.

- Research organizations and individuals known to be active in water hyacinth research were contacted and unpublished data were requested. These persons were interviewed by telephone and the status of their current research was assessed when possible. Appendix B contains a listing of these research organizations.

- A literature search was conducted utilizing the Smithsonian Science Information Exchange (SSIE), the National Technical Information Service (NTIS), and the National Agricultural Library (Agricola). The purpose of the search was to aid in forming a comprehensive list of interested parties and to identify new reports which might be relevant.

- Information resulting from the above activities was examined in order to (1) evaluate the current status of water hyacinth utilization and (2) identify, if possible, the principal factors inhibiting the creation of water hyacinth-based treatment systems.

STUDY RESULTS

Status of Current Interest in Hyacinth-Based Treatment

Considerable public response has been generated by newspaper articles and technical briefs on water hyacinth-based sewage/effluent treatment systems. Letters received by NASA personnel over the past 2 years inquiring about hyacinth technology were selectively sampled, and followup telephone interviews were conducted to determine current interest in hyacinth-based treatment. Organizations contacted included consulting engineering firms, private developers, industries, academic institutions, federal and state agencies, and municipalities. No foreign inquiries were followed up in this limited survey, and no private individuals were contacted (although a large number of letters from the general public were received by NASA).

Sampling Procedure

A breakdown of the letters received by NASA, and supplied to Battelle, is presented below, by category:

Category	Quantity
Industry	34
Consulting engineers	28
Private developers	9
Academic institutions	20
Federal/state agencies	23
Municipalities	31
Students	56
Landowners/homeowners	41
Foreign	36
Total	278

Because of the constraints imposed by time and funding, it became evident that it would be impractical to contact every letter-writer. Consequently, a sample was taken of each of the first six categories above. Inquiries from students, landowners/homeowners, and foreign organizations were eliminated. The letters that remained were divided into two groups: (1) interested parties (non-research) and (2) parties that are known to have done or are doing research. Results of the survey of research institutions are detailed in the next section of this report; this section deals only with the survey of non-research organizations.

Survey Results

A questionnaire was developed to enable the telephone interviews to be conducted in a uniform manner. A total of 40 non-research institutions were contacted. Appendix A contains a listing of the basic questions asked during the interviews.

The initial question of the telephone interview was always "Are you still interested in water hyacinth-based sewage/effluent treatment systems?" This was followed by a series of questions developed to ascertain the reasons for the answer to the first question. A respondent who answered "no" to the initial question was always asked why he wasn't interested and whether he foresaw "the possibility of future interest in water hyacinth treatment systems if pilot plant studies prove them feasible and economical". Those who answered "yes" to the first question were asked whether they had "implemented any phase of a water hyacinth system". Details of the system were elicited if the answer was yes. If the answer was no, they were asked whether they planned to implement a hyacinth system in the future, and if so, when, where, and what kind of a facility.

Figure 1 summarizes the results of the survey of non-research organizations by means of a tabulation of the responses to questions that could be answered with yes/no. Of the 40 contacts made during the survey, 17 were presently interested in hyacinth-based sewage/effluent systems; 21 were not presently interested; and 2 organizations were ambivalent,

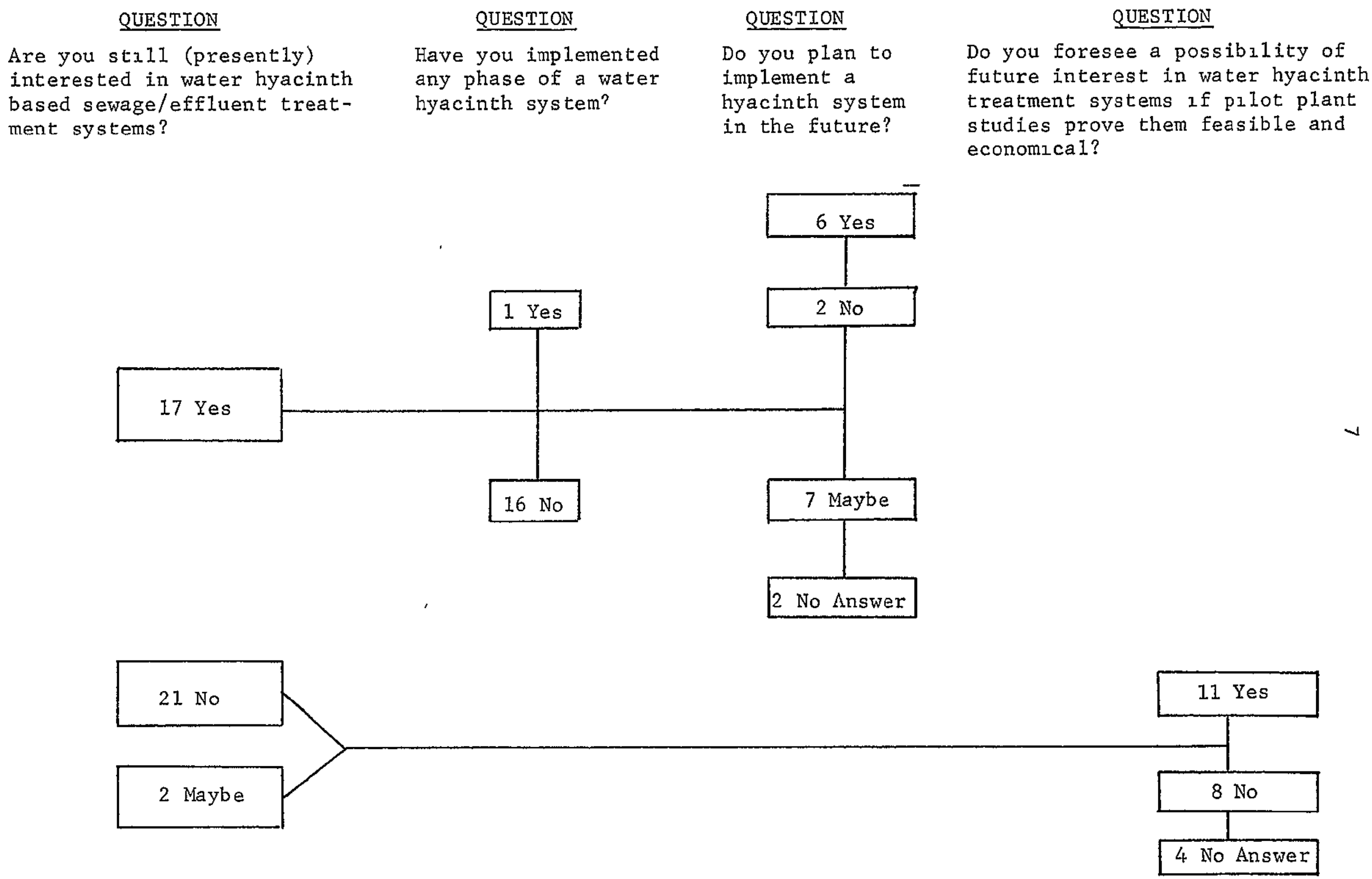


FIGURE 1. GENERAL RESPONSES TO SURVEY OF NON-RESEARCH ORGANIZATIONS

answering "maybe". Of those 21 who answered "no" to the initial question, 11 said they would be interested in the future if pilot studies prove hyacinth-based treatment systems to be feasible and economical.

Of the 17 who expressed current interest in hyacinth-based effluent treatment systems, one company was currently designing a system (Gee & Jenson, for Coral Springs; discussed later in this report). Six respondents said they planned to implement a hyacinth system in the future, and another seven said they might implement a hyacinth system in the future.

Table 1 represents a complete listing of all the non-research organizations/individuals contacted. The "comments" section of Table 1 complements Figure 1 in that it presents details on questions requiring more extensive/explanatory answers than could be tabulated in Figure 1.

Status of Research in Hyacinth-Based Treatment Systems

A listing of the contacts made with institutions/organizations known to be involved in hyacinth research is presented in Appendix B. In all, 36 research institutions/individuals were interviewed. Details of the information obtained from the research organizations found to be most active in the hyacinth wastewater treatment area are presented in the sections that follow.

Experiments at NSTL

Water hyacinth experimental facilities at NASA's National Space Technology Laboratories (NSTL) in Bay St. Louis, Mississippi, include a zigzag lagoon to remove photographic wastes and two small ponds to treat domestic wastes.[1,2,4] One of these ponds (Lagoon Number 1) is 5 acres in area and receives untreated effluent from approximately 1,000 people.

Hyacinths were placed in Lagoon Number 1 in late May of 1976, although water samples were taken and analyzed from the beginning of March. The retention time in Lagoon Number 1 is estimated to be between 50 and 150 days. The organic load placed on the lagoon is light (see Table 2) when compared to loads from small towns. Effluent has been monitored, but design variable variations have not been explored.

TABLE 1. PRESENT INTEREST OF NON-RESEARCH ORGANIZATIONS IN HYACINTH-BASED WATER TREATMENT

Organization	Presently Interested ?	Comments
	Municipalities	
Picayune, Mississippi A Franklin, City Manager	No	EPA prevented use of hyacinth in their holding pond, possible future interest if pilot plant studies prove feasibility
San Benito, Texas S. Mata, Acting City Manager	Yes	Expects permit from Texas Parks and Wildlife Department in a month, then will plant hyacinth in city lagoon system
Amador County Dept. of Public Works Jackson, California J German, Senior Civil Engineer	Maybe	No funds, EPA negative, very impressed with NSTL data, could monitor a pilot program at his facility, if funding could be obtained, wants to be put on mailing list
Guadalupe-Blanco River Authority Seguin, Texas J Arnstz	No	EPA discouragement, uncontrolled spreading, harvesting difficulties, possible future interest if pilot studies prove feasibility
Santa Maria, California Wastewater Treatment Plant B Middleton, Superintendent	Yes	Hyacinth experiments will begin upon completion of facility expansion, trickling filter plant
Chino Basin Municipal Water District Cucamonga, California Ray W Ferguson, General Manager	Yes	Would be very interested in setting up a project if funding could be obtained
Simi Valley County Sanitation District Simi Valley, California E Charland, Lab Director	No	Potential contamination problem (of creek beds), disposal problem (landfill)
Bolinas Community Public Utility District Bolinas, California L Robinson	No	Climate unsuitable
Coachella, California C. Johnson, City Engineer	Yes	Somewhat interested for industrial park wastewater treatment, wants more hard data on hyacinth systems
Brazos River Authority Waco, Texas R. Smith, Water Quality Director	No	They are water supply agency with no responsibility for wastewater treatment
	Federal, State	
Farmers Home Administration USDA, Richmond, Virginia H Nickerson, State Architect	Yes	State Board of Health and Ag people negative; is personally enthusiastic, as sanitary waste disposal is one of greatest problems he has to contend with
Maryland Environmental Services Annapolis, Maryland C. Willey, Chief, Solid Waste Services	Yes	Interested in aquaculture system for wastewater treatment, now developing list of plants native to area, hopes to get system going by end of year
USDA Agricultural Research Service Morgantown, W Virginia H Menser, Plant Physiologist	Yes	Ran into quarantine problems in obtaining hyacinth starts last year, wants to set up experimental facility this summer, if successful in obtaining plants
Illinois Natural History Survey Kinmundy, Illinois H. Buck, Aquatic Biologist	Yes	Had difficulty in obtaining hyacinths last year, may set up experiments this summer, if he can obtain plants
	Consulting Firms	
Waitz & Frye Consulting Engineers Jacksonville, Florida Neil Aikenhead, P E.	No	Concerned about labor and handling problems, lack of suitable client currently, would be interested in future if pilot plant studies prove system feasible
Gee & Jenson, Inc. West Palm Beach, Florida J. McKune, P Mullen	Yes	Now designing pilot community system for the Coral Springs Improvement District in Broward County Florida, with construction to start in 3 or 4 months
D W. Kelley, Aquatic Biologist Sacramento, California	Yes	Interested basically for Bangladesh contracts, wants to be put on mailing list
S J. Barry & Associates Baton Rouge, Louisiana S J Barry	No	Lack of development of technology is inhibiting, EPA frowns on open ponds, interested in sewage treatment for small communities, if hyacinth system data are proved
J L. Ruhle & Associates Fullerton, California J L. Ruhle	Yes	Visual aid business, incorporated slides of Bay St Louis hyacinth system in film strips

TABLE 1. (Continued)

10

Organization	Presently Interested ?	Comments
Foothill Laboratory Jackson, California H F Bailey, Director	No	Climate inhospitable, concerned about spread of hyacinth might have future interest if pilot plant studies prove feasibility
Biological Water Purification of California, Inc Newport Beach, California J. I. O'Connor	No	State Ag and EPA people asked him not to, use hyacinth, interested in reeds and bulrushes supplementing a mechanical treatment system
C A. Gryster, P E Escondido, California	Yes	Interested in hyacinth use as pig feed in Philippines
J K Timmons & Associates Richmond, Virginia J. Henson, Vice President	No	Lack of data is inhibiting currently, if concept is proved, would be very interested, wants to be put on mailing list
	Private Developers	
Christian Education Associates Santa Barbara, California A Morgan, President	Yes	Feasibility studies will begin in March to determine hyacinth treatment application, 373-acre conference center/school facility
West Molokai Venture Honolulu, Hawaii J. Schneider's secretary	No	Hotel builders
Gold Hill Mesa Corporation Colorado Springs, Colorado K. McCormick, P R	Yes	Climate precludes hyacinth, will use other aquatic plants, will start aquatic plant experiments this summer, aided by Air Force Academy scientists
	Industry	
D & H Manufacturers, Inc Springfield, Ohio R Naguit, Technical Director	Maybe	Concerned about lack of data, climate, and effect of large concentrations of heavy metal, wants to be put on mailing list
Sandoz Colors & Chemicals East Hanover, New Jersey Dr. P. Hay, Environmentalist	No	Their South Carolina chemical factory will use algae in lagoon system, waiting to see how it works, possible future interest in hyacinth
AVCO International Services Cincinnati, Ohio G Smith	No	No time to do further research into hyacinth use, sees possible use in Saudi Arabian airport sewage disposal systems
Chemetron Food/Process Systems Chicago, Illinois W Allen, R&D Manager	No	Tested hyacinth, finished protein product not economically justifiable, manufacturer of equipment for processing waste materials into useful protein
Paul F. Beich Candy Co Bloomington, Illinois P Huffman, Operations Manager	No	Inhospitable climate
Daroid Petroleum Services Channelview, Texas H Oyler	Yes	Harvesting and disposal of plants of concern, currently considering hyacinth use in secondary treatment of runoff water
Pennwalt Corporation Montgomery, Alabama K Clark, Plant Chemist	No	Conducted tests, heavy metals killed hyacinth, contamination too great
Union Carbide Corporation S. Charleston, W Virginia C. R. Lashley	No	If EPA regulations tighten in future, will consider hyacinth, can now meet regulations without hyacinth
The Heil Company Milwaukee, Wisconsin W Duske, Dehydration Engineer	Yes	Manufacturer of the Arnold Dryer, triple-drum rotary system for dehydrating high-moisture-content materials
International Flavors and Fragrances Hazlet, New Jersey H Wolff, Vice President Manufacturing	No	Inhospitable climate; high COD content of his effluent precludes hyacinth use
General Battery Corporation Reading, Pennsylvania A Chernoske	No	Inhospitable climate, experimented unsuccessfully with bulrushes in flowing stream, drought, heavy rains wrecked plants
GAF Corporation South Bound Brook, New Jersey P Bettoli, R&D	No	Hyacinth deteriorated in shipping/storage to New Jersey for testing, interested in fiber source for organic roofing felts
	Others	
University of Hawaii Marine Advisory Program Honolulu, Hawaii R Tabata, Environmentalist	Yes	Ambivalent regarding hyacinth--as pest or pollution controller, wants to be put on mailing list
St Martin's College Olympia, Washington D Crothers, Property Manager	No	Unsuitable climate

TABLE 2. MEAN LEVELS OF WATER QUALITY PARAMETERS IN NSTL LAGOON NUMBER 1 TREATED WITH WATER HYACINTHS[a]

Monthly Averages (1976)	Total Suspended Solids (mg/1)		Total Dissolved Solids (mg/1)		Biological Oxygen Demand (mg/1)		Total Kjeldahl Nitrogen (mg/1)		Total Phosphorus (mg/1)		Total Organic Carbon (mg/1)		ph		Dissolved Oxygen (mg/1)		Temperature °C	
	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF
March	78.3	17.3	454.3	316.0	137.7	9.0	9.89	7.42	3.11	1.88	62.00	19.50	6.85	7.65	2.03	3.87	24.50	21.10
April	77.4	50.0	400.8	305.2	93.3	15.7	8.80	4.36	2.92	2.11	64.00	37.40	7.02	9.09	1.14	10.80	25.10	23.90
May	74.5	38.8	409.0	339.3	121.7	14.0	10.78	3.81	2.81	2.22	37.80	37.80	7.23	8.79	1.53	7.30	26.50	24.80
June[b]	111.6	24.9	364.1	289.0	78.7	9.2	8.22	2.55	2.28	1.65	43.00	33.50	7.24	7.56	1.40	6.58	28.80	58.30
July[c]	63.2	11.5	403.2	262.5	69.6	4.8	7.82	1.92	2.22	.92	32.60	18.90	7.15	7.28	1.04	4.98	29.10	28.40
August	89.3	5.0	479.0	241.0	109.0	7.0	12.06	3.00	3.60	1.05	51.00	14.60	7.36	7.18	1.12	2.42	30.10	27.70
September[d]	68.0	6.3	423.0	297.0	140.0	5.0	10.00	1.36	5.75	1.03	54.25	13.62	7.21	6.96	1.01	5.70	24.10	24.10
October	64.0	2.9	406.0	296.0	112.0	1.8	11.26	1.97	3.08	1.10	35.00	14.00	7.18	6.96	0.90	1.50	26.80	17.00
November	80.0	2.3	383.3	267.7	131.3	1.3	13.15	3.45	3.60	.74	55.29	13.43	7.15	7.18	1.33	2.74	24.10	13.86

(a) Source Unpublished data from NASA/NSTL.

(b) Approximately 25 percent coverage with water hyacinths.

(c) Approximately 65 percent coverage with water hyacinths.

(d) Approximately 85 percent coverage with water hyacinths.

Lucedale, Mississippi

The situation at Lucedale, Mississippi, characterizes the circumstances of many small communities in the state and the county in general. Mississippi state laws, in conjunction with Federal regulations, require effluents of at least secondary treatment quality by the 1977 to 1978 time frame. Small towns, which cannot afford elaborate treatment technology, are looking for an inexpensive way of satisfying state requirements.

Lucedale was granted permission to experiment with water hyacinths. The hope was that the hyacinths could help the town meet the following standards by 1978:

• Total Kjeldahl Nitrogen	6 mg/l
• Dissolved Oxygen, of at least	4.0 mg/l
• Fecal Coliform	200 col./100 ml
• Five-Day Biological Oxygen Demand (BOD_5)	15 mg/l
• Total Suspended Solids (TSS)	30 mg/l.

These standards are stricter than normal secondary levels because the town uses a headwater stream, subject to low flows, as a receiving system. Typical future secondary standards for a lagoon system in Mississippi would require a BOD of 20 mg/l and TSS of 90 mg/l. Presently, the law requires levels of (dependent somewhat on specific circumstances) 60 and 180 mg/l for BOD and TSS, respectively. All figures are for monthly averages.

In May 1976, the Lucedale oxidation pond was seeded with water hyacinths.[6] The pond had an average depth of about 4 feet and received raw domestic sewage from the community of 2,500 people. By early July, 95 percent of the pond was covered with plants. One-third of the plants were recovered in September. The frequency of water quality analyses increased from once per week from February to May to twice a week from June through November. Monthly means for the effluent (Table 3) show a 72 percent reduction in BOD for May, when hyacinths were first introduced. By June, BOD was reduced by 89 percent. The total dissolved

TABLE 3. AVERAGE MONTHLY WATER QUALITY DATA FROM THE LUCEDALE LAGOON TREATED WITH WATER HYACINTHS[a]

Month-1976	Total Suspended Solids (mg/l)		Total Dissolved Solids (mg/l)		Biological Oxygen Demand (mg/l)		Total Kjeldahl Nitrogen (mg/l)		Total Phosphorus (mg/l)		Total Organic Carbon (mg/l)		Temperature °C	
	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF
February	276.00	124.00	383.33	348.33	229.00	44.00	39.50	22.50	12.50	10.60	115.33	104.33	--	--
March	270 75	145.50	443.75	395.25	256.50	52.50	41.60	20.53	10.75	10.56	196.00	111.67	--	--
April	253.80	100.60	431.80	425.00	258.67	63.33	36.40	18.48	11.40	9.44	137.40	101.80	23.00	24.00
May[b]	152.33	131.00	413.00	415.00	306.50	87.50	32.58	21.77	9.75	11.50	91.67	106.67	23.00	24.00
June	96.14	37.43	360.57	338.00	167.00	32.00	27.13	13.09	6.99	7.89	76.33	68.00	23.07	24.50
July	97.50	8.68	434.25	294.00	149.38	16.81	30.08	8.68	7.60	5.83	101.89	43.56	25.83	24.61
August	118.22	7.00	407.67	335.56	150.13	25.38	30.64	13.17	8.99	7.49	113.67	39.22	26.78	24.50
September[c]	164.22	12.44	387.33	371.33	172.00	22.67	29.09	15.65	9.62	8.30	84.00	44.78	26.00	23.67
October	117.71	3.23	362.14	377.71	159.00	20.43	27.64	16.58	8.36	8.79	84.14	34.43	23.00	16.83
November	128.43	3.26	349.14	354.86	173.17	16.00	34.00	17.82	8.52	8.85	93.00	39.33	20.83	13.33

(a) Source: Unpublished data NSTL, Bay St. Louis, Mississippi.

(b) Hyacinths introduced.

(c) One-third of hyacinths removed.

solids were not reduced appreciably during the summer months. The main areas which needed improvement were the BOD_5 levels and the total suspended solids. Prior to hyacinth seeding the data reflect reductions in BOD_5 comparable to post-seeding months. Total suspended solids were drastically reduced after seeding, but it is not clear whether or not this is due to the hyacinths themselves or to increased settling rates as the result of reduced mixing. Total phosphorus increased during June when the plants should have been in their most active growth phase.

Prior to hyacinth seeding, odors at the Lucedale pond had become a problem. Officials[7,8] state that odors were not present during the day with hyacinth coverage but were still present at night. Apparently anaerobic conditions prevailed at night when photosynthetic activity in all plants had stopped. Officials noted that, prior to hyacinth seeding, anaerobic conditions were reduced by aeration with a motorboat. This practice was impossible with full hyacinth coverage. The use of pump-type aerators at night is now being considered to help reduce odors. Plans are also being made with NSTL officials to create a series of oxidation ponds using hyacinths in the terminal pond.

Orange Grove, Mississippi

Studies at Orange Grove were conducted from July 1975 to July 1976.[2] Flows (Figure 2, Table 4) to the test ponds were not controllable; thus, a control pond free of hyacinths could not be established. Hydraulic load rates also varied considerably from month to month, and this also made the data difficult to interpret (Table 5).

The total suspended solids were held below state requirements throughout the year (Figure 3). Again, the extent to which the root systems may be responsible for this is unknown. Total Kjeldahl nitrogen levels and biological oxygen demands exceeded permissible limits during the early months of 1976 (Figures 4 and 5).

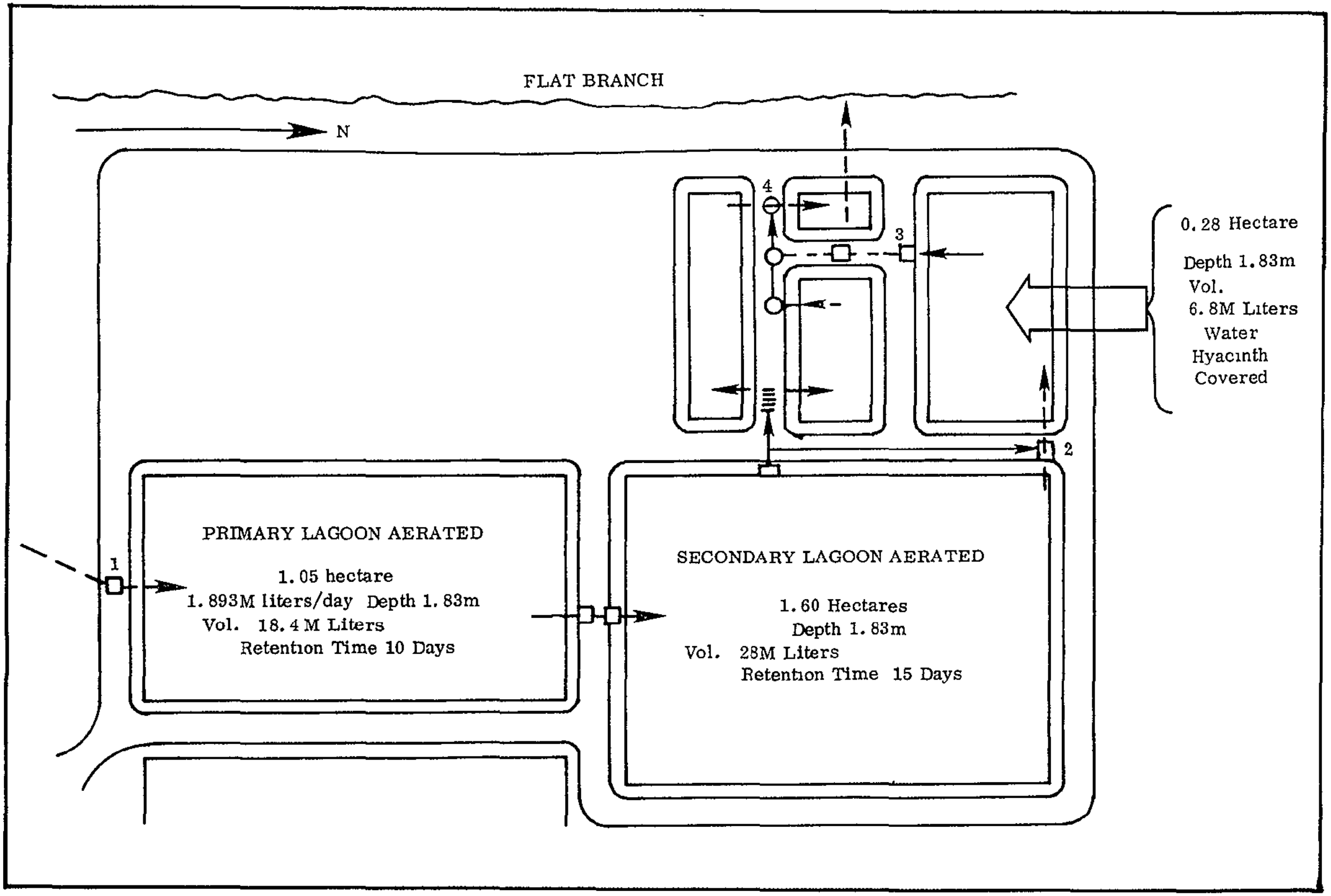


FIGURE 2. LAYOUT OF SEWAGE TREATMENT FACILITY AT ORANGE GROVE(2)

TABLE 4. AVERAGE HYDRAULIC LOADS INTO THE HYACINTH LAGOON AT ORANGE GROVE, MISSISSIPPI[2]

	Gallons/day	Litres/day
1975		
August	115,455	437,000
September	115,455	437,000
October	280,000	1,059,000
November	280,000	1,059,000
December	500,000	1,892,500
1976		
January	230,000	870,000
February	230,000	870,000
March	280,000	1,054,000
April	280,000	1,059,000
May	230,000	870,000
June	230,000	870,000
July	500,000	1,892,500

TABLE 5. AVERAGE MONTHLY DATA OF ORANGE GROVE SEWAGE LAGOON SYSTEM[2]

	Total Suspended Solids (mg/l)		Total Dissolved Solids (mg/l)		Biological Oxygen Demand (mg/l)		Total Kjeldahl Nitrogen (mg/l)		Total Phosphorus (mg/l)		Total Organic Carbon (mg/l)		pH		Dissolved Oxygen (mg/l)		Temperature C	
Raw Sewage (#1)[a] Monthly Average	142		319		150		25.73		9.27		94		7.06		1.0		25	
Data from Water Hyacinth Lagoon	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*	#2*	#3*
Monthly Average	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF	INF	EFF
July, 1975	35	9	296	201	23	7	2.23	1.03	5.80	4.41	31	22	7.8	6.5	5.8	1.8	27.0	26.0
August, 1975	35	13	294	278	26	5	2.47	1.17	5.34	4.79	24	18	7.6	6.6	6.0	2.0	27.0	26.0
September, 1975	43	6	187	183	22	7	4.44	1.07	5.03	3.77	24	15	7.2	6.7	5.5	2.2	22.0	22.0
October, 1975	48	9	195	189	25	7	3.38	1.00	4.70	3.85	29	19	7.3	6.6	6.4	2.0	21.4	20.8
November, 1975	50	10	153	155	29	15	3.27	2.00	5.18	4.53	37	23	7.4	6.7	8.0	2.1	15.2	14.4
December, 1975	52	24	154	159	32	15	2.60	2.22	5.41	5.84	33	24	7.3	6.7	7.2	2.2	15.3	14.4
January, 1976	47	16	227	239	57	24	--	--	--	--	34	27	7.3	6.7	7.4	2.6	13.3	11.7
February, 1976	67	25	239	216	135	30	8.88	7.87	6.81	7.88	34	34	6.9	6.8	4.7	2.1	17.2	16.0
March, 1976	50	25	295	241	70	28	6.86	6.34	7.22	7.79	36	38	7.0	6.8	5.3	2.4	17.7	17.1
April, 1976	88	23	320	220	65	15	9.37	3.60	7.04	5.77	42	28	7.7	6.7	4.1	2.5	21.3	19.3
May, 1976	84	14	354	246	81	8	8.50	2.62	8.24	5.85	37	21	7.2	6.4	2.2	2.2	22.5	20.1
June, 1976	42	6	243	209	60	9	8.86	2.31	6.87	5.24	40	25	7.2	6.4	2.4	2.3	25.0	23.0
July, 1976	28	6	210	189	30	10	7.75	5.10	5.91	5.46	29	17	7.3	6.7	3.4	1.2	28.0	27.0

Note: For location of sampling stations 1, 2, and 3, see Figure 2. Total Kjeldahl nitrogen and total phosphorus data not obtained during the month of January due to difficulty with necessary equipment

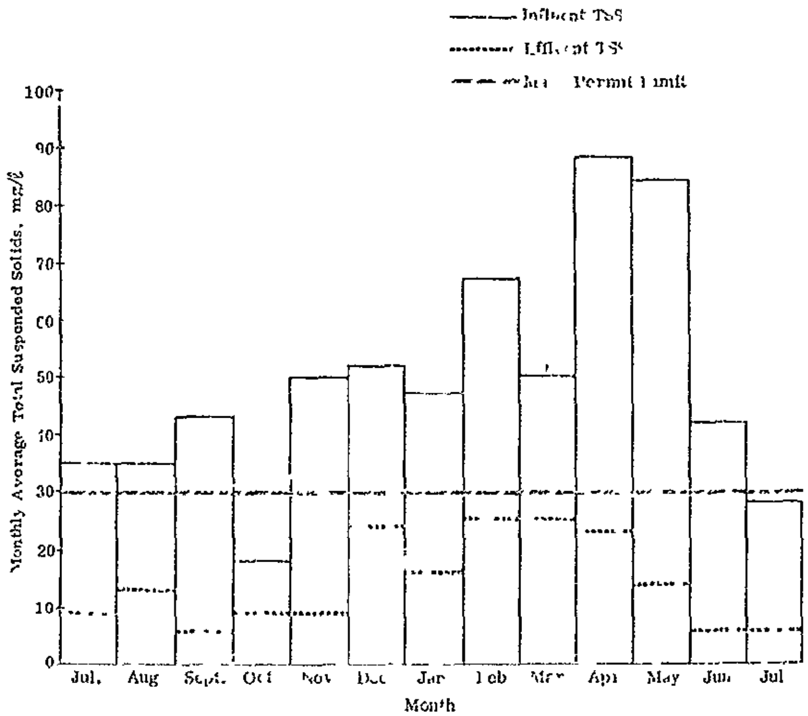


FIGURE 3. TOTAL SUSPENDED SOLIDS AT THE ORANGE GROVE LAGOON TREATED WITH HYACINTHS(2)

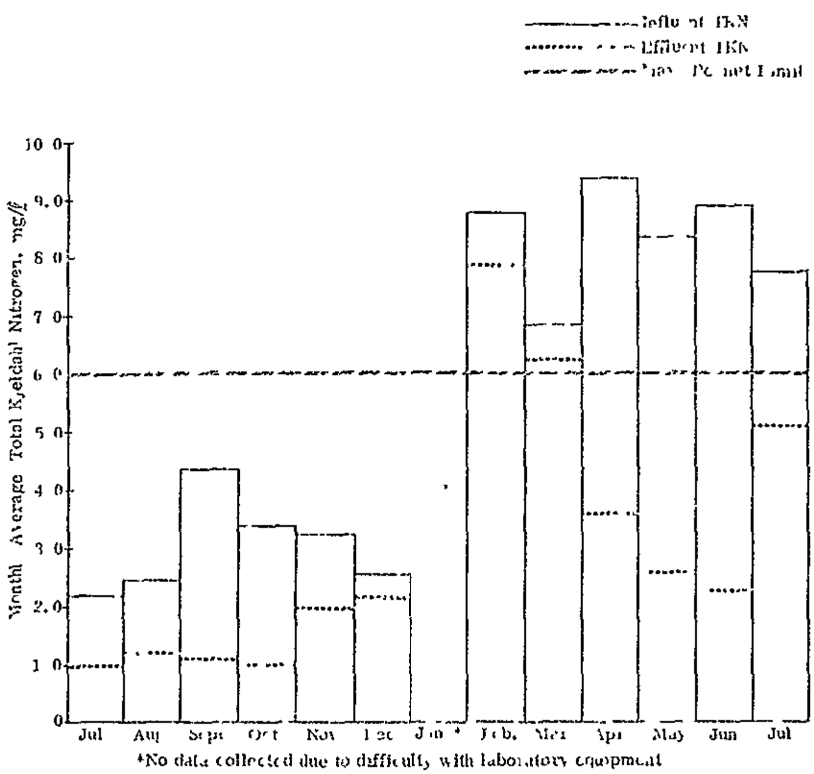


FIGURE 4. TOTAL KJELDAHL NITROGEN AT THE ORANGE GROVE LAGOON TREATED WITH WATER HYACINTHS(2)

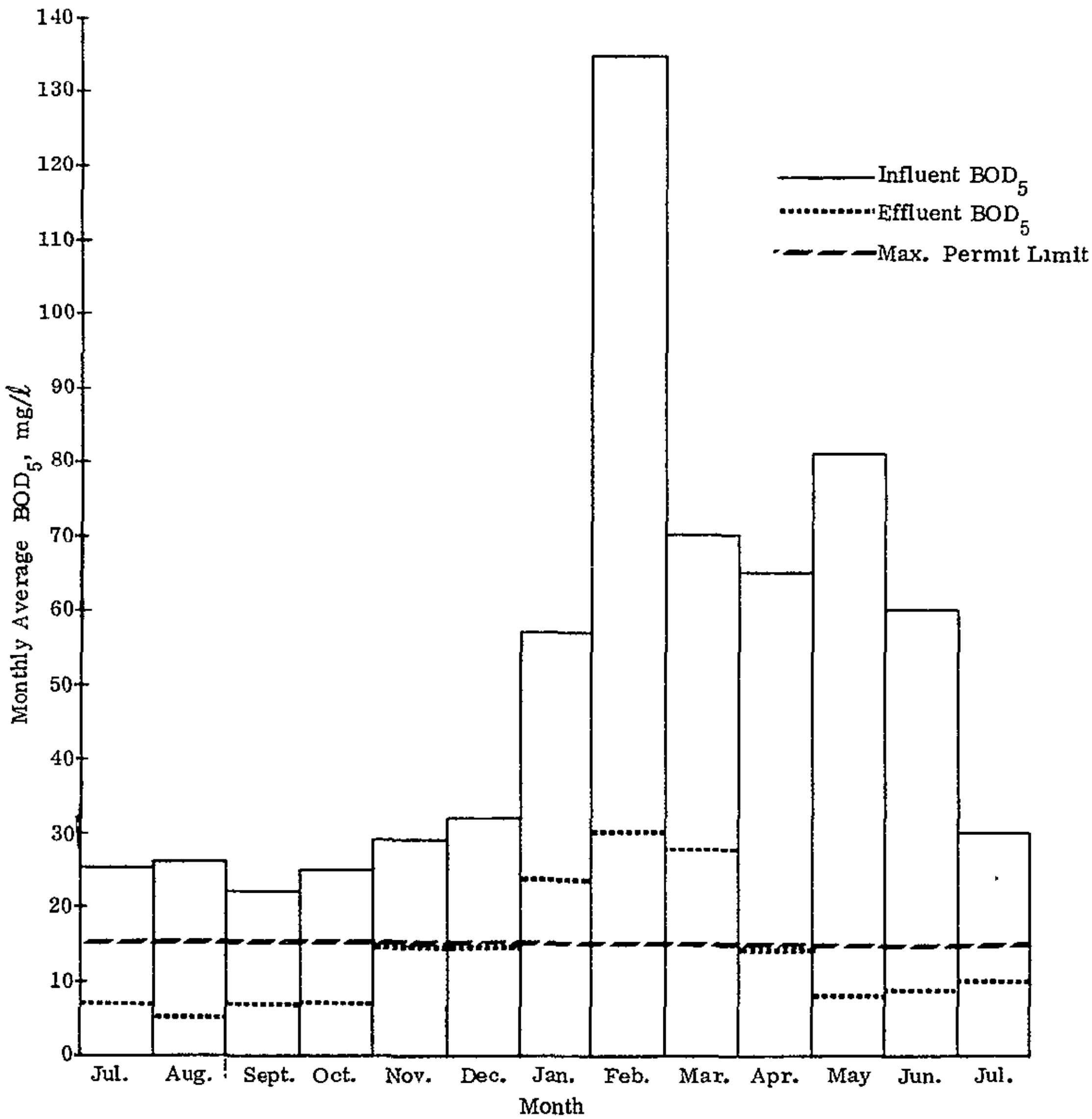


FIGURE 5. BIOLOGICAL OXYGEN DEMAND AT THE ORANGE GROVE LAGOON TREATED WITH WATER HYACINTHS(2)

An Orange Grove utility official[9] expressed satisfaction that the hyacinths were able to forestall the need for a 5 million dollar treatment facility. Officials expect that the hyacinths will continue to be used in the future. Both state and Federal officials, in addition to NSTL personnel, have been monitoring the effluent from the Orange Grove facility.

Williamson Creek, Texas

In October 1974, the city of Austin established an experimental hyacinth facility (Figure 6) at the Williamson Creek Wastewater Treatment Plant. Experimentation occurred in two phases: June 1975 to February 1976, and May to August 1976. Hyacinths were grown in Sections 1 and 2 during the first phase, and in all sections during the second phase; Phases I and II had different organic loads but similar hydraulic load rates (Table 6). Samples for active sewage analysis were taken bi-weekly and samples for other water quality parameters were taken weekly.

The daily load (28,800 gal/day) was not very high during the two phases and the BOD loads were equivalent to 300 to 400 persons (Table 7). The second phase received effluent which was essentially homogenized raw sewage; the source of the effluent was a 45-acre oxidation pond. Phase I influent came from the third in a series of stabilization ponds, and thus the influent BOD was less.[10]

The study was not financed by any outside agencies. The results appear encouraging to the city of Austin, although they are not presently prepared to invest in a full-scale pilot plant. Officials would like an outside agency to help finance a pilot plant and have suggested MacAllen, a city in southern Texas, as a possible site.[11]

Officials of the Texas Water Quality Board are reluctant to give general approval to water hyacinth treatment because the hyacinth falls under the Noxious Vegetation Law. Many individuals have asked for permission to distribute the plant in stabilization ponds. The state law requires a permit before hyacinths can be introduced on an experimental basis. Apparently, officials recognize that the hyacinth is useful under site-

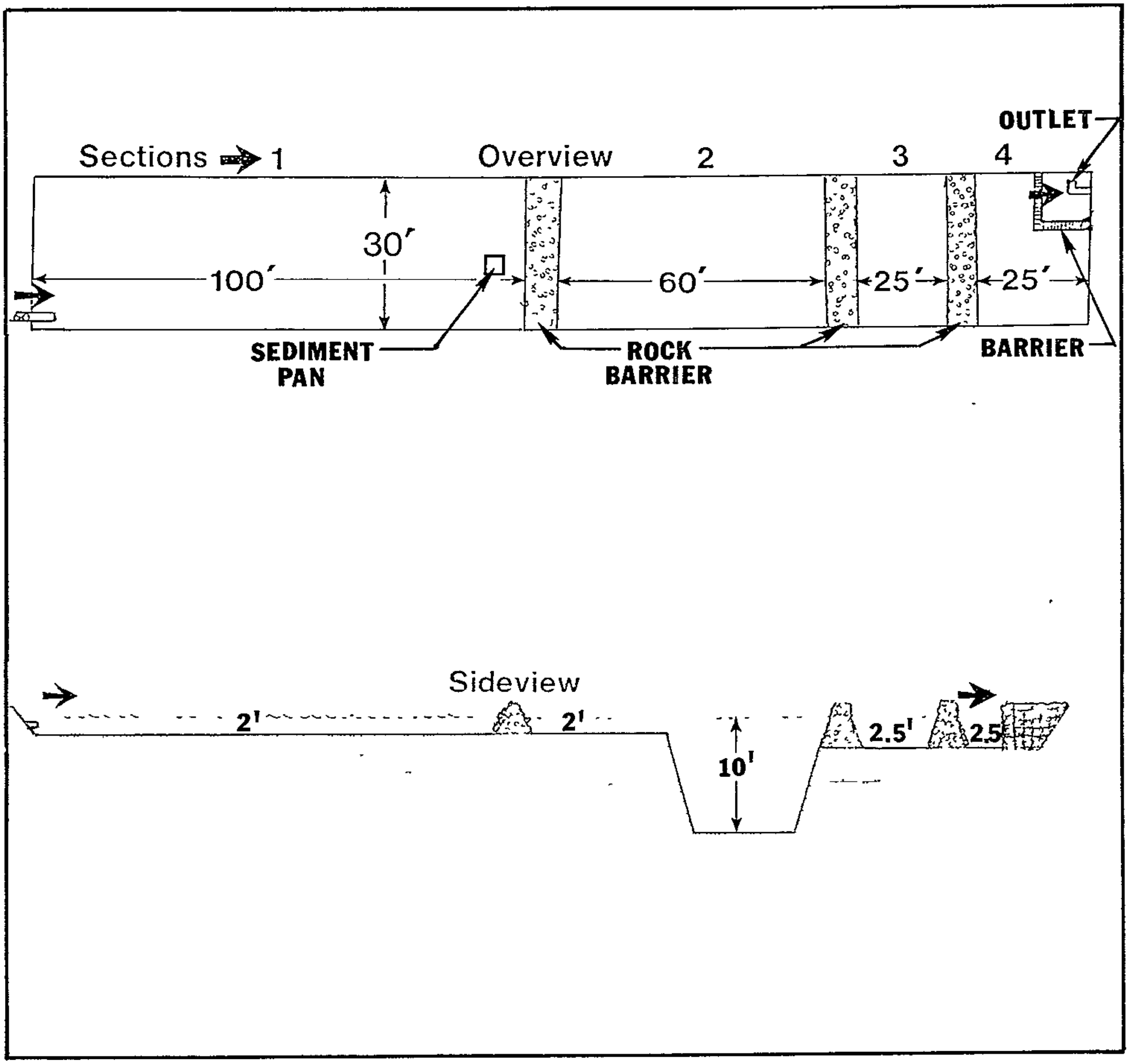


FIGURE 6. THE WILLIAMSON CREEK EXPERIMENTAL POND SYSTEM

Source: Unpublished data, Texas Department of Health Resources.

TABLE 6. TEST CHARACTERISTICS AT WILLIAMSON CREEK*

	Phase I June 1975-February 1976	Phase II May-August 1976
Hydraulic Load (gal/day)	28,800	28,800
Mean Organic Load (BOD_5 in lbs/acre/day)	38	79.7
Detention Time (days)	5.3	4.5
Mean Depth (feet)	3.3	2.8

* Source: Unpublished data, Texas Department of Health Resources.

TABLE 7. RESULTS FROM WILLIAMSON CREEK TESTS*

	Phase I June, 1975-February, 1976			Phase II May-August, 1976		
	INF	EFF	% REDUCTION	INF	EFF	% REDUCTION
Biochemical Oxygen Demand mg/l	22.5	5.2	77	46.5	5.7	87
Total Suspended Solids, mg/l	43.0	7.0	84	117.0	7.5	93
Chemical Oxygen Demand, mg/l	84.7	40.4	52	184.0	51.0	72
Total Nitrogen, mg/l	8.2	2.5	69	9.9	3.6	63
Fecal Coliform col./ 100 ml	2895	31	98	24423	363	98

*Source: Unpublished data, Texas Department of Health Resources.

specific conditions and should not be randomly introduced. Cautious enthusiasm is evident from the following news release which recently appeared in Texas newspapers.(12)

"Use of water hyacinths in treating municipal sewage may prove to be very valuable for smaller towns in some parts of the state, but such treatment ponds should not be installed until more research has been done", warns Hugh C. Yantis Jr., Executive Director of the Texas Water Quality Board.

"Two or three such ponds have been established by small towns in South Texas", Yantis said, "and we are watching them closely to see how well they work and what further research needs to be done. However, those ponds were built with the knowledge of the Water Quality Board and thus are perfectly legal. If we find, after considerable experience, that they are a viable method of treating wastes from smaller towns, the procedure would, of course, represent a saving of considerable money for the municipalities that can use them.

"We do know that the plants, by a process of metabolization, literally eat up the wastes in a pond. There is a problem, however, of harvesting the plants when ponds become overcrowded, and they multiply rapidly. There also is some question of plants breaking off and finding their way into downstream waters where they could become a serious nuisance, and we still need to learn what volume of wastes ponds of certain sizes will treat adequately. Such ponds, of course, could be used only in those parts of the state where the hyacinths will live throughout the year.

"There is a great deal yet to know about the process, and smaller cities should not become enthusiastic about the possibilities of such treatment to the extent that they might build ponds without legal authorization. It should also be understood that water hyacinths are considered a noxious weed and that the Texas Parks and Wildlife Department has jurisdiction for the control of such plants", Yantis added.

Texas experimentors designed a hyacinth culture unit based on their experience with the Williamson Creek study. This unit is designed to be used in conjunction with two to three other similar units. The design, shown in Figure 7, is a basic one which could be altered for specific needs. The units would be drained annually and plant and detrital material would be removed.

Further work is not planned at Williamson Creek. Texas officials will probably use small town systems as experimental test sites in the near future unless funding is found from an outside source. The Williamson Creek study, like many of its predecessors, was not designed with controls.

NOTE: Information received from Sherman W. Hart of the Texas Department of Health Resources during a followup telephone conversation on 2 May 1977 indicates that the situation at Williamson Creek has changed since February. Current plans are to use hyacinths in a polishing pond, in order to meet water quality standards.

Research at Southern Universities

General. A number of scientists and engineers have been working with water hyacinths at the University of Florida. Their work with hyacinths has encompassed nutrient uptake aspects (Dr. Thomas Furman), nutritional aspects (Dr. James Hentges, Dr. R. L. Shirley), and harvesting processing aspects (Dr. Larry Bagnall). Much of the work is state supported through the University and is often short term in nature. Nevertheless, a good deal of the data concerning the utilization of hyacinths as compost, feed, and silage has originated from the University.

Nutrient Uptake. The amount of hyacinth-related research accomplished since the last Battelle report on market potential of hyacinths[5] is limited. Dr. Thomas Furman, et al., recently published an article which related lagoon depth, surface area and flow rates to nutrient removal.[13] His main purpose in the work was to determine growth rates of hyacinths in secondary effluents; nutrient removal capacities of water hyacinths on a yearly basis; and nutrient removal characteristics as a function of detention time.

Although the work was small in scale, it is one of the few papers which examines the design parameters of nitrogen and phosphorus removal in relation to water hyacinth treatment (Table 8). Good correlations were found between nitrogen/phosphorus uptake, detention time, and pond depth. Furman concluded that the nutrient removal capabilities of water hyacinths are directly related to surface area. It is also important to design a system so that pond depth and detention time provide a given amount of

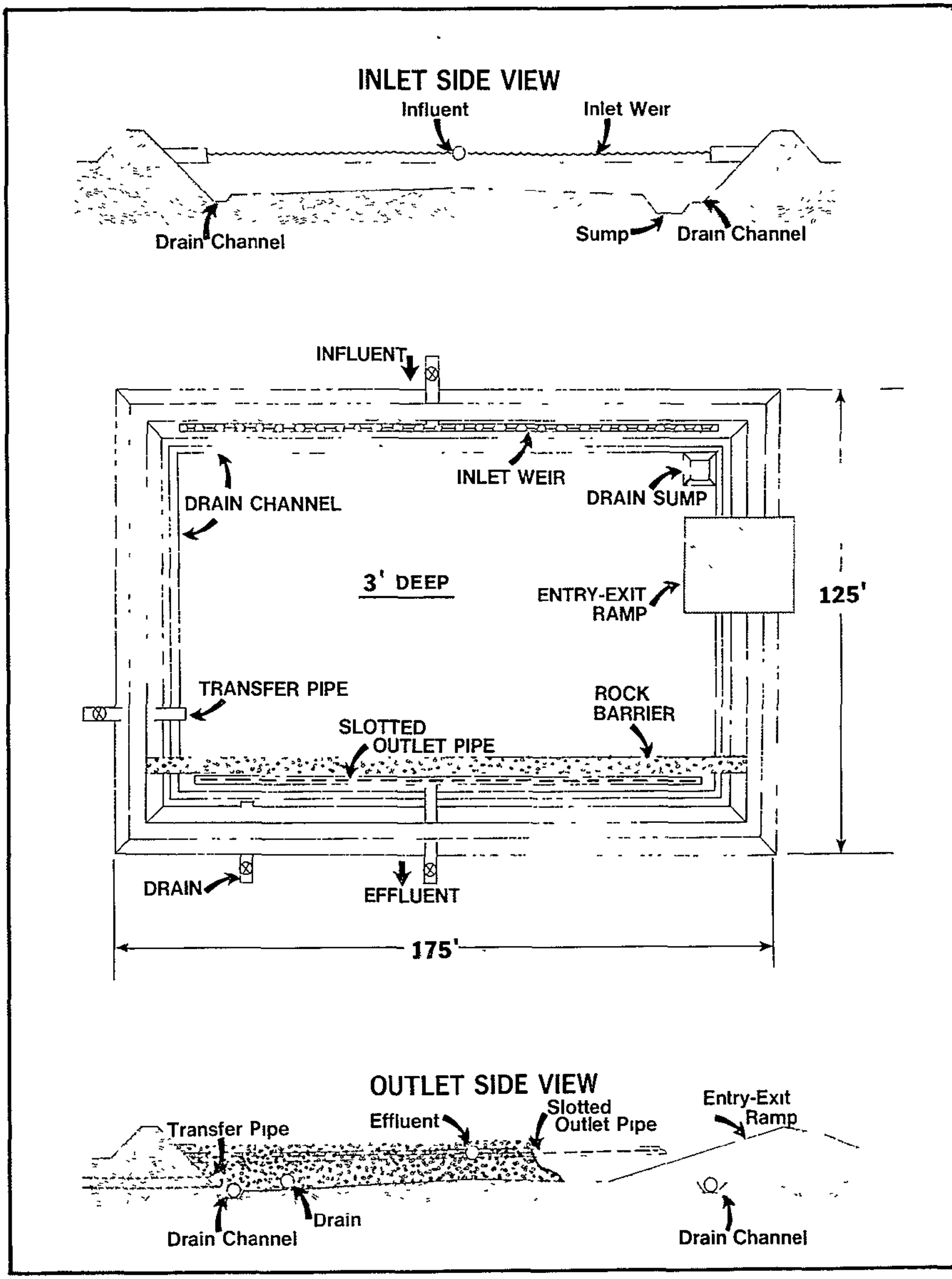


FIGURE 7. PROPOSED HYACINTH CULTURE UNIT DEVELOPED BY THE TEXAS DEPARTMENT OF HEALTH RESOURCES

Source: Unpublished data, Texas Department of Health Resources

TABLE 8. SUMMARY OF NUTRIENT UPTAKE DATA FROM THREE SMALL TEST PONDS[13]

Nutrient	Average Influent Value (mg/1)	Detention Time (h)	Average Effluent Concentrations (mg/1) 0.34 m Pond	0.64 m Pond	0.70 m Pond
PO_4-P	3.37	12	3.31	3.32	--
		24	2.69	2.87	3.17
		48	1.86	2.38	2.84
		96	--	--	1.90
Total phosphorus as P	3.44	12	3.42	3.55	--
		24	2.86	3.08	3.33
		48	1.82	2.30	2.90
		96	--	--	1.95
NO_3-N	8.08	12	8.56	8.35	--
		24	4.25	5.35	8.35
		48	1.30	3.13	5.36
		96	--	--	0.76
Organic nitrogen	3.93	12	2.57	2.88	--
		24	1.49	1.95	2.18
		48	1.42	1.78	1.37
		96	--	--	1.16
NH_3-N	1.67	12	0.92	1.25	--
		24	0.15	0.65	0.96
		48	0.00	0.07	1.12
		96	--	--	1.17
Total nitrogen	13.68	12	12.05	12.48	--
		24	5.89	7.95	11.49
		48	2.72	4.98	6.85
		96	--	--	3.09

surface area per unit flow through the pond. He found that in order to remove 80 percent of the nitrogen, 2.1 ha (5.1 acres) of water hyacinths are needed per 3800 m^3 (1 mgd). He also determined that the nutrient uptake was best during the area-increase phase or logarithmic phase of growth.

Other workers in the University have, in the past, been active with nutrient uptake aspects of hyacinths.[14,15] Presently, however, there is no work going on in this area.

Nutritional - Feed. Hentges and Shirley, et al., have been active in the nutritional aspects of hyacinths as livestock feed.[16-18] Experimentors experienced difficulties at first in silaging hyacinths, but later studies proved more successful.[19] Recent conversations with Dr. Hentges indicate that silage composed of the upper portions of the hyacinth (less roots) is more valuable to livestock than the whole plant silage. This is mainly because the ash content is drastically reduced when the roots are removed. Whole plant ash content is high, and this limits the amount of silage the ruminants can ingest. Currently, work is progressing toward the evaluation of non-root portions of ensiled Hydrilla as the major component of livestock feed. The work with water hyacinths in this area is stymied since a large-scale method of separating the roots from the plant does not yet exist. Aside from ensiling, the dried plant still has good potential as a constituent of feed.[19]

Feed experiments were recently in progress at Southern Mississippi State University.[20] Twenty percent of the cattle feed was composed of dry ground hyacinth. Feed lot experiments continued for 84 days, when frost destroyed the hyacinth supply. No detrimental effects were noted in the cattle during the study.

Feeding experiments were conducted at Florida State University using dried hyacinths, and intake was compared to intake using cottonseed hulls and sugarcane bagasse pellets. These components were used as the only source of bulky large particles in high-concentrate cattle finishing diet. Results showed that hyacinths had a replacement value at least equal to the other components. Since cottonseed hulls and bagasse pellets sell at \$40 to \$50 per ton, the earlier Battelle report[5] concluded that hyacinths would have to be priced in this range to be competitive. Again, whole plants were used in these experiments, and digestible and nutritive intake was thus limited by the high ash component.

Plant Food. In addition to animal food, hyacinths have been used as plant food.(21) Composted and mulched whole plants have been used extensively at the University of Florida. Lake Alice, adjacent to the University, provides the hyacinths; ground keepers use them as gardening mulch.

More recently Parra has used semi-dried hyacinth in sandy soils to grow Pearl Millet.(22) A factorial experiment was designed which incorporated hyacinths in soils with and without mineral fertilizers. Large differences in yield occurred between treated (with water hyacinths) and untreated soils (Table 9). As a plant fertilizer, it was concluded that water hyacinths proved more satisfactory than mineral fertilizers. This was attributed to increased water supply and availability of plant nutrients in hyacinth-treated sand.

Processing/Harvesting of Hyacinths. The person most involved in hyacinth processing and harvesting at the University is Dr. Larry Bagnall. He indicated that 60 to 80 percent of his research time has been devoted to hyacinth-related work in the past 2 years.(23) Funds for his work are from the state of Florida. Presently he is examining pressing and processing characteristics of hyacinths.(24) The main goal of his work is to develop economical engineering methods which will collect and prepare the plants for either composting or ensiling. Preliminary studies are being done on methods to separate upper portions of the plant from the roots. The upper portions alone should be a better stock for silage.

University of Florida - Summary. Generally speaking, except for Bagnall's work, no other major efforts toward the utilization of hyacinths appear to be ongoing at the University of Florida. Workers are usually using small amounts of state funds; thus, the scope of the experimentation is limited. Much of the ongoing work involves the utilization and harvesting aspects of water hyacinths. It appears that much of the nutrient uptake work, as basic research, is complete.

TABLE 9. YIELDS FROM TWO CUTTINGS OF PEARL MILLET GROWN IN WACHULA SAND WITH AND WITHOUT WATER HYACINTH AS A SOIL INGREDIENT[22]

Treatment		
Wh[(b)]	F[(c)]	Yield[(a)]
	First Harvested[(d)]	
1	1	1189
1	2	1288
1	3	1225
2	1	1765
2	2	2674
2	3	1940
3	1	2229
3	2	3017
3	3	2733
	Second Harvested[(d)]	
1	1	3245
1	2	3030
1	3	3954
2	1	6330
2	2	3530
2	3	2935
3	1	8774
3	2	5845
3	3	3821

(a) Each value is an average of four observations.

(b) Water hyacinth level (1 = 0, 2 = 15,000, and 3 = 30,000 kg/ha).

(c) Fertilizer level (1 = 0-0-0, 2 = 30-13-25, and 3 = 60-26-50 kg/ha N-P-K.

(d) Each value is an average of 36 observations.

Coral Springs, Broward County, Florida

The Coral Springs Improvement District has contracted with Gee & Jenson, Inc., an engineering and architectural firm, to construct facilities to improve the quality of the district's sewage effluent. A representative of the firm[25] stated that they were planning to add a water hyacinth polishing pond to the present treatment system. The details of the design are not final, but the hyacinth will initially treat about 100,000 gal/day. The pond will provide tertiary level treatment in an attempt to satisfy the 1980 water quality requirements of Florida.

It is interesting to note that the firm is using the study of Cornwell, Furman, et al.[13], as a basis for their design. This is apparently the only study which attempts to address the design parameters involved in hyacinth-based treatment.

Gee & Jensôn plan to begin construction of the three-phase polishing system in the spring of 1977. They hope to increase the treatment capacity in the future to one million gal/day.

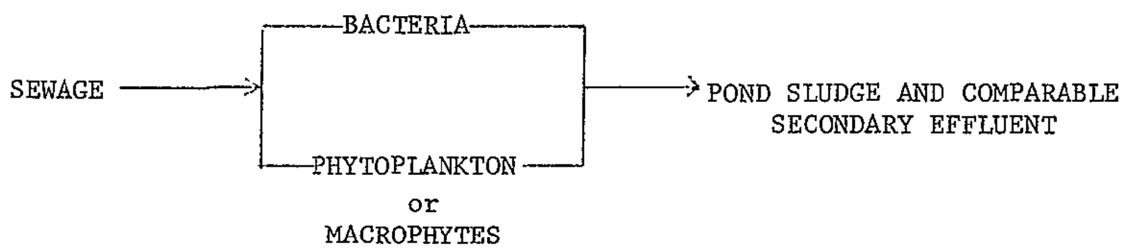
Solar Aquasystems, California

Solar Aquasystems, a subsidiary of Solar Aquafarms, Inc., is a research engineering and consulting firm in Encinito, California. The main objective of Solar Aquasystems is to design a total water reclamation system[26] utilizing an ecosystem approach (Figures 8 and 9). The unit designed to do this is called the Solar Aquacell System (patent pending). The main macrophyte used is the water hyacinth. The firm contends that their system requires 1 acre to treat 1 MGD of domestic wastewater to secondary water quality (Table 10). They base this estimate on published literature, laboratory tests, and on studies done with a small (1,500 gal/day) Aquacell system which ran for 4 months. Other tests have also been carried out which, when extrapolated, reportedly result in the following levels of production:

(1) Conventional Treatment Plant (Activated Sludge, Trickling Filter, Etc.)

SEWAGE → BACTERIA → SLUDGE AND SECONDARY EFFLUENT

(2) Conventional Treatment Lagoons (Aerobic, Anaerobic, Facultative, Aeraged)



(3) The Solar AquaCell System

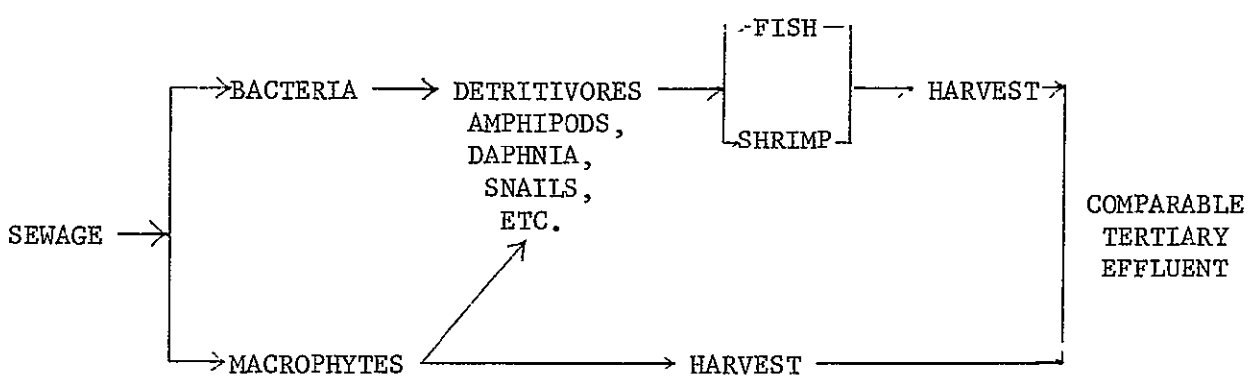


FIGURE 8. COMPARISON OF THE MAIN TREATMENT PROCESSES OF CONVENTIONAL SYSTEMS WITH THE SOLAR AOUACELL SYSTEM*

* Source: Solar Aquasystems, Inc.

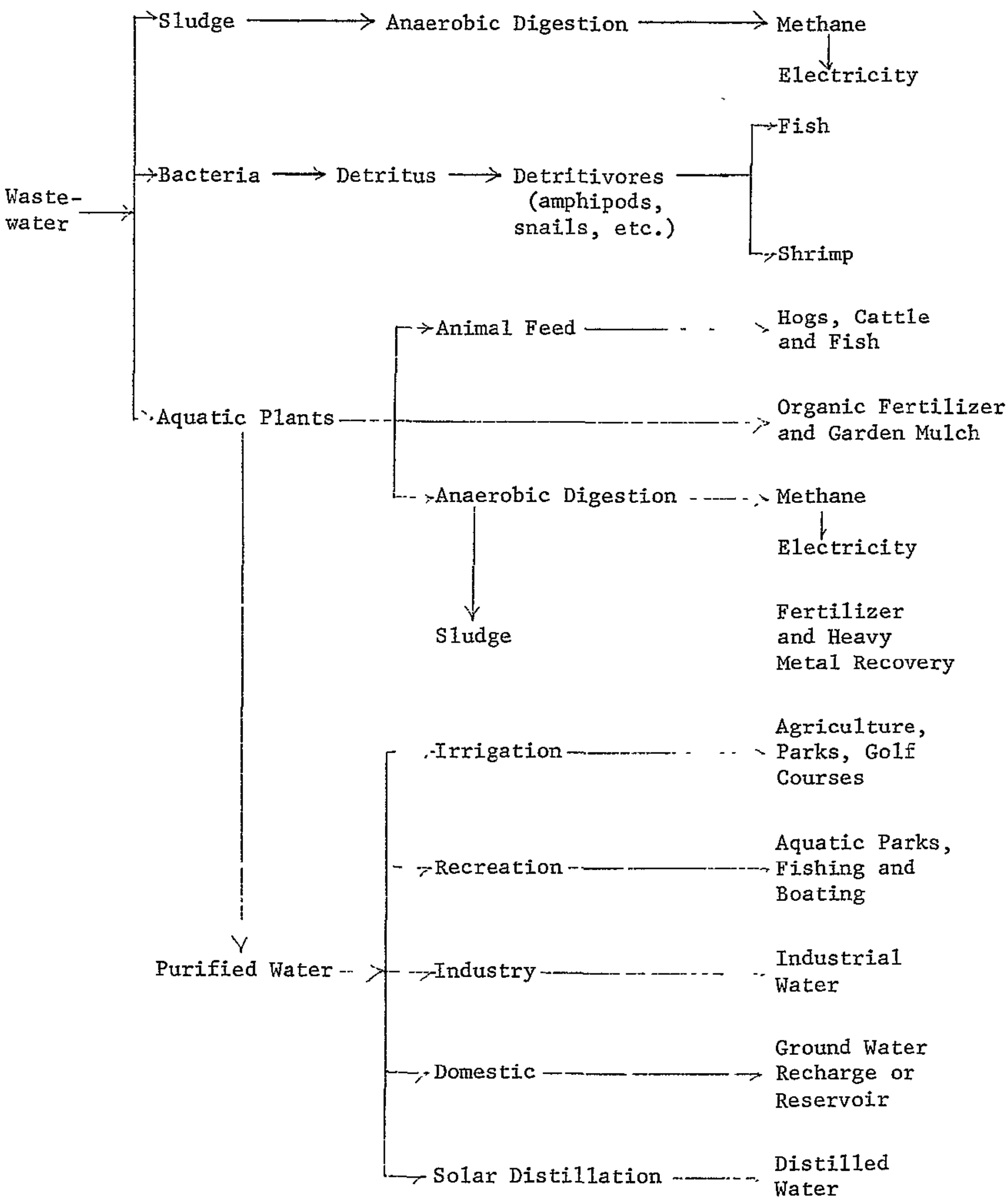


FIGURE 9. NUTRIENT FLOW SCHEME AND POTENTIAL END PRODUCTS FROM THE SOLAR AQUACELL PROCESS*

* Source: Solar Aquasystems, Inc.

TABLE 10. COMPARISON OF THE AVERAGE WASTE REMOVAL EFFICIENCY OF CONVENTIONAL SECONDARY TREATMENT AND THE SOLAR AQUACELL TREATMENT PROCESSES[d]

Parameter	Raw Wastewater	Conventional Secondary Effluent	Secondary Solar Aquacell Effluent[a]	Tertiary Solar Aquacell Effluent[a]
BOD	200ppm	80% removal	90% removal	99% removal
Suspended solids	240ppm	80% removal	90% removal	99% removal
Coliform (MPN/100ml.)	10^7	99% (chlorination)	99% (ozone)	99% (ozone)
TDS	variable	no reduction	10-20% reduction	10-30% reduction
Heavy metal	variable	5-71% removal[b]	90% removal[c]	95% removal[c]
Toxic organic	variable	little reduction	80% removal[c]	90% removal[c]
Nitrogen	35-50ppm	no reduction	60% removal	95% removal
Phosphorus	10-20ppm	no reduction	30% removal	50% removal
Retention time	--	1-3 hours	2 days	4-6 days total

(a) Based on results of Solar Aquasystem's 1500 gallon per day pilot demonstration system; influent water having received primary treatment of one half-hour sedimentation, and influent temperature 65°F or greater.

(b) Zemansky, G. M., "Removal of Trace Metals in Conventional Waste and Wastewater Treatment". Ph.D. thesis, University of Colorado, Department of Civil and Environmental Engineering (1973).

(c) Projected from literature data.

(d) Source: Solar Aquasystems, Inc.

Macrophytes	60-110 ton/acre/year (dry weight)
Detritovores	30-50,000 lbs/acre/year
Fish	5,000-10,000 lbs/acre/year*
Shrimp	2,000-5,000 lbs/acre/year*.

The firm is presently engaging in negotiations with the city of San Diego in the hope that a demonstration project (1 MGD; approximate cost of 3 to 4 million dollars over 3 years) can be built. Mr. Richard King, Director of Utilities for the city of San Diego, reports that so far the Federal EPA and the state Water Resource Control Board appear to be receptive to the plan.(27) The city is also being advised by James M. Montgomery Consulting Engineers, Inc., of LaJolla, California.(28)

If plans go ahead as scheduled, construction of the facility will begin in spring or summer of this year. The project will be funded through a grant from the Environmental Protection Agency.

The hyacinths in the Solar Aquacell project are used in conjunction with other trophic levels. This is not the approach normally conceived of by NASA when the phase "water hyacinth treatment" is used. Solar Aquafarms contends that the more diverse system will be more effective, stable, and flexible than a system which depends on the introduction of a single trophic level (i.e., the hyacinth). The more complex system may or may not turn out to be more advantageous. The high number of components in the system could be viewed as a liability as well as an asset. General ecological theory dictates that more diverse systems are also the more stable systems. Whether or not this theory is applicable to systems subject to diverse, manmade perturbations, remains to be seen. Many of the operational details of the Solar Aquacell System could not be reviewed by the Battelle staff. Therefore, it is unknown whether or not consideration has been given to migrant species, toxic algal substances, and similar problems which could arise in the system. The 60 to 110 tons/acre/year productivity levels for hyacinths exceed the estimates of a number of authors.(5,29,30) Such high estimates often result from the extrapolation of data from studies done during peak growing periods.

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* The firm believes that some supplemental feeding may be necessary to sustain higher yields.

Despite the many questions which can be raised regarding the Aquacell system, it appears that potential benefits to the city of San Diego outweigh the risks involved in employing the unit.

U.S. Environmental Protection Agency

A telephone conversation with an official in the USEPA's Office of Research and Development revealed that the USEPA has done no research with water hyacinths. He indicated that most of the culture type of research has been done in Ada, Oklahoma. This work was in relation to land-based wastewater treatment. Discussions with personnel at the Oklahoma EPA indicated that no hyacinth research was planned for the immediate future. The USEPA official did encourage further research in hyacinths although he himself was not familiar with the details of the treatment process. Apparently he has had discussions with NASA officials about the possibility of a joint NASA/EPA study demonstrating hyacinth use in wastewater treatment.

Disney World's EPCOT

EPCOT refers to Walt Disney World's Experimental Prototype Community of Tomorrow.[31] WED Enterprises (planners for the EPCOT community) held a meeting in July 1976 to discuss the various systems to be included in expanding the treatment facilities in Disney World. A major component will be a sewage treatment system which utilizes water hyacinths to treat secondary effluent. A zigzag production canal will be created which has a minimum retention time of 2 days, a depth of 1 to 4 feet, and a process capacity of 100,000 gal/day. Other components of the EPCOT facility are:

- Harvester/chopper
- Water quality measurement system (automatic)
- Anaerobic digestion
- Product gas conditioner
- Sludge dryer
- Biomass press
- Alcohol fermenter.

The system will be designed to achieve the water quality characteristics cited below:

	Input mg/1	Output mg/1
Biochemical Oxygen Demand (BOD_5)	10-20	5
Suspended Solids	10-20	5
Total Nitrogen	5-15	3
Total Phosphorus	2-3	1

Construction and initial experiments are scheduled to begin in the spring of 1977. Discussions with planners indicate that they are on schedule.[31] Their goals in water treatment appear to be realistic ones, but will be very much dependent on the final configuration and expense of the zigzag lagoon. The dimensions of the lagoon were not divulged in the report and were still subject to ongoing design studies.

WED Enterprises has no plans for researching the many aspects of their hyacinth system. Only a water quality monitoring system is planned. They are interested in cooperating with a research organization in order to gain as much scientific and technological information from the treatment system as possible.[32]

DISCUSSION OF DEVELOPMENT STATUS

Since Battelle's last report[5] on the market potential of water hyacinths, a limited amount of new data on the subject has evolved. An attempt has been made in this report to review some of the most important contributions to date. Due to scope and time limitations, some available information has perhaps been overlooked. Nevertheless, the work presented includes the major contributions and is representative of the current research and development trends in water hyacinth utilization.

We are now closer to large-scale treatment systems using hyacinths than we were in 1975. The three current major efforts, eventually involving 100,000 gallons a day or more, are: the EPCOT community in Disney World, the Coral Springs system planned by Gee & Jenson, and the treatment system planned by the city of San Diego. These projects should all enter construction phases in 1977. They are all experimental. Hopefully, design parameters will be evaluated in these systems. This will yield valuable information to the civil engineering firms who will take on a good deal of the promotional responsibility of hyacinth-based systems.

Utilization of Hyacinths

The technology involved with hyacinth utilization directly affects the impetus behind the development of hyacinth-based treatment systems. The development of commercial utilization of hyacinths is dependent on a steady supply of plants. Many uses have been found for the plant. These uses are not perfected yet, but hold a great deal of promise. Composting presently appears to be the most economically and technologically sound use for hyacinths. However, this relatively simple use requires a steady supply of plants whose size is between set limits. Harvesting methods for handling the bulky plants are needed. The economics of all these factors are important, but are beyond the scope of the present work. It is, however, necessary to distinguish between the economics of hyacinth end-product utilization and the economics of using the plant for effluent treatment. The prospects of ensiling hyacinths at a commercial level are limited mainly by the lack of a dependable year-round supply of the plant. A feed lot adjacent to a dependable supply would reduce transportation expenses and thus facilitate utilization.

Research has progressed at the University of Florida, and now more valuable uses for hyacinths are being examined. Silage using the whole plant is a possible use, but silage composed of only the upper portions of the plant is even more promising. Again, a steady supply of plants is necessary for commercial marketing.

Several development activities for use of hyacinth plants are being pursued in the Philippines[33]. Among the products being considered are papers and fiberboard building materials. Many of these processes depend on manual separation of plant components. Unless a mechanical means can be found for doing this, these developments may not be applicable to U.S. conditions. In any case, further development work is required, and these utilization possibilities will probably play no role in near-term decisions on hyacinth system construction.

Hyacinth Wastewater Treatment

To many small communities, primarily interested in upgrading their effluent, utilization of the plant is not important. The cost/benefit factor has been the major motivating force in generating enthusiasm in hyacinth treatment. Generally, small communities cannot afford advanced treatment technology and they look to the water hyacinth as a way to avoid major expenses. Many communities only have a lagoon system to treat raw wastewater. The cost of increasing the number of lagoons and adding a final hyacinth polishing pond is reasonable. Studies have yielded encouraging data on this type of arrangement.

However, a review of the work done to date shows that there exists no proper, experimentally verified basis on which to design hyacinth-based systems to meet given effluent standards. In the limited number of full-scale experiments (Lucedale, Orange Grove, Williamson Creek) controls were lacking, and very limited ranges of design parameters were explored.

The acquisition of more design parameter information will, in all likelihood, accelerate the transfer of hyacinth-based treatment to small communities. More design information will further the acceptance of hyacinth systems in the engineering community. This, in turn, will give state authorities the confidence needed to allow construction of the systems at the municipal level.

STATUS OF THE HYACINTH INNOVATION

The process of technological innovation has been rather extensively studied over the past fifteen years. The factors at work in the conception, development and diffusion of innovations have been studied, and these studies can be used to evaluate the status of this particular innovation, and its prospects for the future.

Development and Diffusion

The first observation is that hyacinth wastewater treatment systems are still in the development phase. There exists no source from which a prospective buyer can obtain a system with known characteristics, which is legal to use, and whose risks are well understood. Until such systems are available, the actual application, or diffusion phase, cannot begin. The immediate questions then are: (1) how close is the end of the development phase, and (2) what actions are most likely to end the development phase in a way that will facilitate diffusion.

As mentioned above, work will shortly be started on several new full-scale hyacinth treatment facilities. While it is true that none of these initiatives currently involve plans for development of the comprehensive engineering data which Battelle feels to be desirable, much new information will certainly be developed. It is quite possible that results will be sufficiently favorable that further similar facilities will be implemented. Proceeding in this way, it is possible that over a number of years, a reasonably good understanding of hyacinth systems will evolve, and the development phase could blend rather gradually into the diffusion phase.

There are, however, at least two difficulties with this scenario. One is that the experimental programs could turn out to be unsuccessful or inconclusive because of factors which go unidentified. A concept which is actually valuable could, then, be erroneously rejected.

Another problem is the timing. History shows that development programs ordinarily span some decades. Even allowing for what has already been accomplished, the laissez-faire scenario could require ten years or more to begin appreciable diffusion. If hyacinths are to make the greatest contribution to wastewater treatment technology, however, 1983 is a major benchmark. One of the major driving forces behind upgrading of wastewater treatment is the new standards which will go into effect in that year. Small towns are caught between the 1983 requirements and their lack of resources to build conventional chemical treatment facilities. Once this date has passed, a major source of "market pull" on new treatment technologies will probably disappear. This market pull would be a major factor in diffusion of the technology, but in order to take advantage of this, it would be necessary to accelerate completion of the development phase. It would, in fact, be highly desirable to have development completed by about 1980, because diffusion also takes appreciable time.

In most successful innovations which have been studied, there was a single individual who pushed the concept from some point near the conception to some point near the end of the development phase. This person is called the "technological entrepreneur". He is sometimes the inventor of the innovation, but more frequently it is someone else who devotes his career to bringing about the completion of the development phase. In the hyacinth case, no such individual can be identified. For the past three years, Billy Wolverton of NASA NSTL has been filling this role, at least to some degree. NASA Headquarters has, over the same period, been a consistent advocate of the concept and could be viewed also as a technological entrepeneur. If NASA were to terminate its efforts at this point, history seems to suggest that the chances of successful completion of the development phase would be diminished. It appears, then, that NASA should maintain its advocacy role through the end of the development phase.

Turning now to the prospects for the diffusion phase, the existence of a market pull situation has already been mentioned. This arises in large part from existing environmental legislation, but this seems to be only a partial explanation. The amount of interest that has been shown by the news media, and the general public, as well as potential users of the technology, suggests that this technology is very consistent with the current public mood. This is most unusual in the innovation process, and it suggests that diffusion should be quite rapid in those applications for which hyacinths are suited. It is even possible that interest is strong enough to bring about applications for which hyacinths are inappropriate. Very seldom does an innovator have to concern himself with this risk.

To summarize, the current status is that the development phase is not yet complete, but market pull is already in evidence. Prospects for completion of the development phase are good, but timeliness is a question, in view of the 1983 standards. Diffusion of the innovation, once it is developed, should be quite rapid, if development is completed well prior to 1983.

Institutional Aspects

An important part of any innovation is the nature of the organizations and individuals involved, and their motivations. The principal organizations concerned in this case are: (1) the various water treatment authorities in the regions to which hyacinths are applicable; (2) the engineering firms serving those treatment authorities; (3) the cognizant regulatory agencies, from USEPA to the various state, regional and local authorities concerned with water treatment, environmental quality and public health, (4) NASA; and (5) public agencies concerned with development of water treatment technology. Details will vary from one treatment situation to another, but it seems reasonable to conclude that implementation of a hyacinth system will be a complex operation, involving many parties. This will be particularly true in the early stages of diffusion.

First, however, is the problem of completing the development phase within this institutional framework. Who will do the development work, and how will it be funded? As already mentioned, work is proceeding, funded by either local authorities or private developers. The parties involved in this work are persuaded that workable systems can be constructed and operated at reasonable cost. They are not, however, committed to an exploration of the full range of engineering variables.

Accordingly, it is suggested that the best approach would be to seek out a situation in which a water treatment authority, working with a competent and innovative engineering firm, would be willing to undertake a proper program of experimentation and to make the results generally available. This would probably require partial Federal funding, but it seems to be the most rapid and cost-effective means of completing the development phase, and laying a basis for the diffusion phase.

At the same time, it will be necessary to address the problem of plant escape. This is primarily a regulatory problem, and it seems that the natural leadership would lie with the USEPA. It will be necessary to develop (1) containment criteria, based on categories of downstream waters, (2) containment techniques, and (3) methods for testing containment techniques against standards.

CONCLUSIONS AND RECOMMENDATIONS

Based on data collected in this study, and on past work, the present situation can be described as follows:

- A developed technology for hyacinth-based wastewater treatment does not yet exist
- There is an unusually strong interest in hyacinth treatment systems, considering their current state of development
- Many persons who have examined the concept feel that it may offer substantial cost advantages over conventional methods
- Those persons expressing doubts about the concept most often mention the scarcity of data on system performance, system design or problems of plant escape
- Lack of methods for utilizing harvested hyacinths is not often cited as an inhibiting factor
- A limited amount of full-scale demonstration of hyacinth systems has been carried out during the past two years, but the yield of design data has been small
- Several organizations are currently planning construction of experimental full-scale hyacinth-based wastewater treatment systems during 1977-1978
- The role of NASA work in bringing about this increased interest was substantial.

Looking toward the future, it seems quite possible that development of the concept will continue to grow, and that hyacinth systems will come into common use without further action on the part of NASA. However, the probability of success will be increased, and the prospects for helping small towns to meet the 1983 standards will be improved if NASA continues to play the advocacy role it has followed for the past 3 years. Specifically, it is recommended that NASA undertake the following activities (jointly with other organizations as indicated):

- An Experimental Study of Design Parameters. Specifically, measurements should be made to establish the relationships between harvesting rates, detention time, flow, organic load, lagoon depth, surface area and temperature cycle. This should be done jointly with the USEPA, a wastewater treatment authority, an engineering firm and possibly a state or regional regulatory agency.
- A Study of the Plant Escape Problem. A study should be made of the techniques for preventing introduction of hyacinths from treatment lagoons into downstream waters. Safety standards and test methods also should be considered. This should be done jointly with the USEPA and an engineering firm.
- An Information Dissemination Program. Assuming the results of the above two efforts are successful, the final NASA activity should be to initiate the diffusion phase by bringing the technology to the attention of (1) wastewater treatment authorities, (2) engineering firms and (3) regulatory agencies. This could be done by a combination of mailings, workshops, technical papers and direct contact. This should be done jointly with the USEPA.

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APPENDIX A

QUESTIONS USED IN EVALUATING PRESENT INTEREST IN WATER HYACINTH WASTEWATER TREATMENT SYSTEMS

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QUESTIONS USED IN EVALUATING PRESENT INTEREST IN WATER HYACINTH WASTEWATER TREATMENT SYSTEMS

The following listing includes the types of questions that telephone contacts were asked during interviews:

(1) Are you still interested in water hyacinth-based sewage/effluent treatment systems?

(2) Have you implemented any phase of a water hyacinth system?
   - (a) Any problems?
   - (b) Areas of needed research?
   - (c) How long has it been operating?
   - (d) Can you send us more information?

(3) Do you plan to implement a hyacinth system in the future?
   - (a) When?
   - (b) Where?
   - (c) What type of facility?

(4) What areas of research or applied technology do you think are needed?

(5) Who has been advising you in the planning and/or construction phases?

(6) Do you know of any research groups or individuals actively pursuing water hyacinth research or application?

(7) What discouraged you at the time you were interested?

(8) Have you been in contact with any groups doing water hyacinth research or application during the past year?
   - (a) If yes, who?
   - (b) Briefly, what are they doing?

(9) Do you foresee a possibility of future interest in water hyacinth treatment systems if pilot plant studies prove them feasible and economical?

APPENDIX B

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