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WATER HYACINTHS FOR UPGRADING SEWAGE LAGOONS TO MEET ADVANCED WASTEWATER TREATMENT STANDARDS: PART II

By B. C. Wolverton
Rebecca C. McDonald

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16. ABSTRACT

Field tests using water hyacinths as biological filtration agents were conducted in the Mississippi Gulf Coast Region. The plants were installed in one single cell and one multiple cell sewage lagoon systems. Water hyacinths demonstrated the ability to maintain BOD_5 and total suspended solid (TSS) levels within the Environmental Protection Agency's (EPA) prescribed limits of 30 mg/1 BOD_5 and 30 mg/1 TSS.

A multiple cell sewage lagoon system consisting of two aerated and one water hyacinth covered cells connected in series demonstrated the ability to maintain BOD_5 and TSS levels below 30 mg/1 year-round. A water hyacinth covered lagoon with a surface area of 0.28 hectare containing a total volume of 6.8 million liters demonstrated the capacity to treat 437,000 to 1,893,000 liters of sewage influent from 2.65 hectares of aerated lagoons daily and produce an effluent that met or exceeded standards year-round.

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WATER HYACINTHS FOR UPGRADING SEWAGE LAGOONS TO MEET ADVANCED WASTEWATER TREATMENT STANDARDS: PART II

INTRODUCTION

NASA's National Space Technology Laboratories (NSTL), along with most of the small Mississippi communities, utilize sewage lagoons to treat their domestic sewage. These lagoons will have to be upgraded or replaced by more expensive treatment plants to meet the more stringent secondary treatment standards by July 1, 1977, as prescribed by State and Federal Pollution Control Laws.

For several years, NASA has been experimenting with the use of water hyacinths (Eichhornia crassipes) (Mart.) Solms, a floating, freshwater plant, as an inexpensive, natural biological waste filtration system. (1, 2, 3, 4, 5, 6, 7) The objective of these experiments has been to design and perfect a system utilizing water hyacinths to upgrade sewage effluent from existing lagoon systems. This is highly preferable to the alternative of installing an entirely new waste treatment system.

This report describes the results to date from two of NASA's on-going experimental field studies being conducted on the Mississippi Gulf Coast in the vicinity of the NSTL. Experiments of a preliminary nature were conducted at the lagoon system of Bay St. Louis, Mississippi. Findings and techniques resulting from the Bay St. Louis experiments were then applied and more rigorously tested in a second experimental lagoon system at Orange Grove, a community in north Gulfport, Mississippi.

Both experimental systems were designed to determine the following parameters:

A) Growth characteristics of water hyacinths in raw sewage.
B) The efficiency of water hyacinths in purifying sewage effluents.
C) The minimum surface area coverage requirements for efficient operation of water hyacinths.
D) Maximum sustained flow rate at which water hyacinths are effective.
E) Any gross effects of water hyacinths on the lagoon environment.
F) Any problems affecting hyacinth growth which might inhibit the plants' efficiency as waste-removing agents.

Each system is described and discussed separately, both for ease of evaluation and for comparative purposes.

ANALYSES AND SAMPLING METHODS

Sampling procedures and analyses, described below, were identical for both experimental systems. Grab samples were taken two times per week on influent and effluent wastewater from all systems. Twenty-four hour composite samples were taken monthly and results correlated well with grab sample data. Influent and effluent samples were analyzed for dissolved oxygen (DO), temperature, pH, total suspended solids (TSS), total dissolved solids, total phosphorus, total kjeldahl nitrogen (TKN), total organic carbon (TOC), and five-day biochemical oxygen demand (BOD_5). All sample analyses were performed according to Standard Methods. (8) Values for the measured parameters were averaged for each monthly period. These monthly average values are contained in this report. Raw data of individual samples are maintained on file.

Limited plant harvesting was performed at the Bay St. Louis lagoon only. For maximum sustained nutrient removal, plants should be harvested on a regular basis. However, at this time efforts were directed at establishing minimum surface area coverage of water hyacinths necessary to meet the 1977 permit limitations rather than at purifying the effluent maximally. The purpose of the harvesting which was performed was to test experimental harvesting equipment designed for use in NASA's Vascular Aquatic Plant Program. Evaluation and cost studies for harvesting equipment and up-keep of water hyacinth sewage systems will appear in future reports.

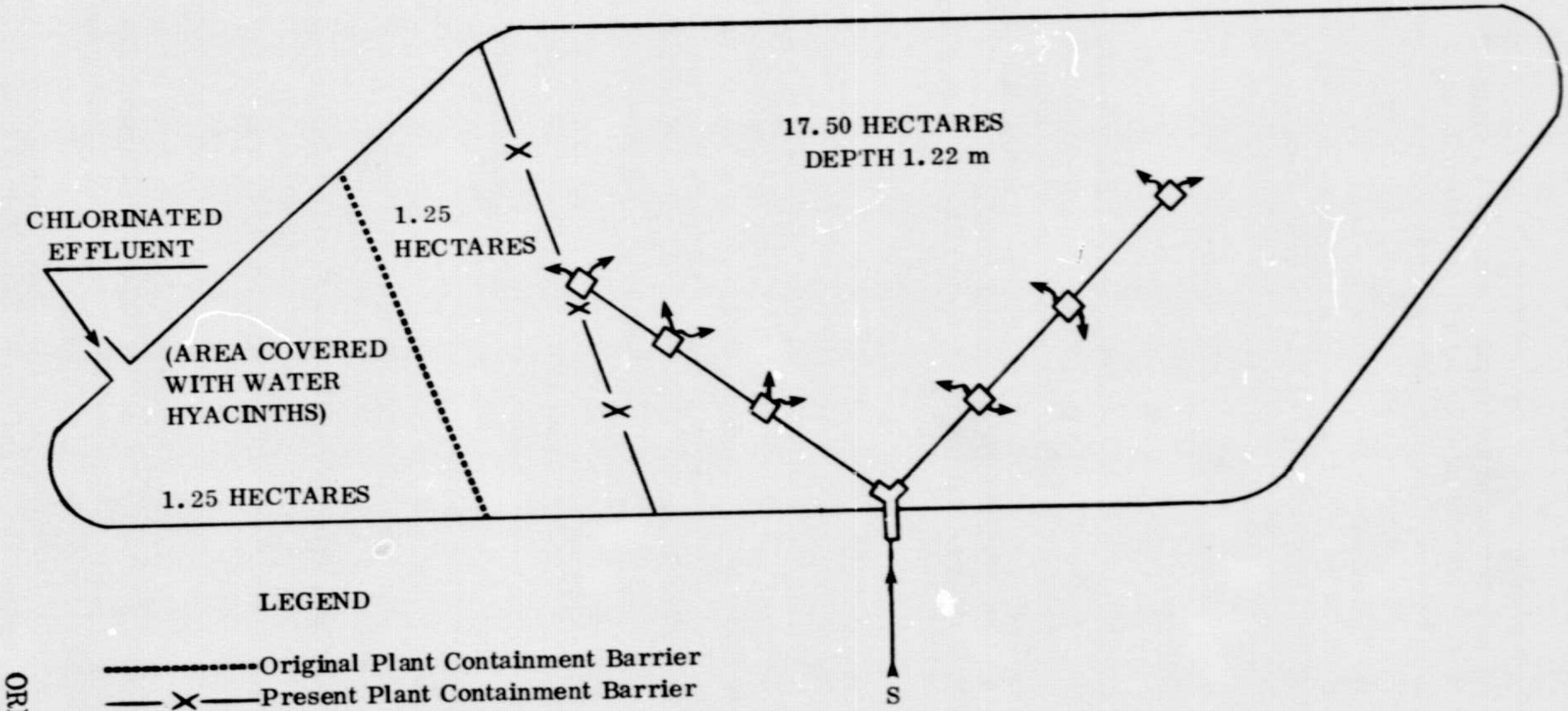
EXPERIMENT 1. BAY ST. LOUIS LAGOON SYSTEM

A. Introduction and Description

The Bay St. Louis lagoon system (Figure 1) consists of a 17.5 hectare (42-acre) single cell lagoon which receives the domestic waste from approximately six thousand residents of Bay St. Louis, Mississippi. This lagoon receives approximately 3.79 million liters per day of domestic wastewater diluted from excessive ground water infiltration.

The massive size of the lagoon promotes the excessive growth of algae. Particularly in the summer months, excess algal growth and decomposition increase the effluent total suspended solids and causes anaerobic conditions, resulting in offensive odors that contribute to air pollution and affect nearby residents.

In March 1975, NASA's National Space Technology Laboratories entered into a joint program with the City of Bay St. Louis in which NASA's Experimental Water Hyacinth



LEGEND

- - - - - Original Plant Containment Barrier
—— × —— Present Plant Containment Barrier

Figure 1. Bay St. Louis Sewage Lagoon

Sewage Purification System would be evaluated utilizing a portion of the Bay St. Louis sewage lagoon. A 1.25 hectare area of the lagoon was fenced off around the effluent point. Enough water hyacinths were initially introducted into the system to cover approximately 0.10 hectare. The plants were very prolific when grown in this sewage system, and the 1.25-hectare (3-acre) area was completely covered by late June. This area proved to be too small to be effective in treating this large lagoon; therefore, the retainer fence was moved, increasing the size of the enclosed area to 2.5 hectares (6 acres). By September, water hyacinths had achieved total coverage of this increased area.

B. Results

1. Growth Rate

The growth rate of the water hyacinths was monitored on a weekly basis from April to June 1975. As shown in Figure 2, significant growth occurred during the months of May and June. During this two-month period, the water hyacinths increased in surface coverage approximately six percent to ten percent (average eight percent) a day. One hectare of water hyacinths contained approximately 218 metric tons of biomass. These data indicated an average growth rate of approximately 17.5 metric tons of wet biomass per day during ideal growing conditions.

2. Other Parameters

Once the water hyacinths had achieved a coverage of 2.5 hectares, their effects on decreasing the BOD_5 and TSS levels in the sewage effluent became obvious (Table 1). Over a four-month period, the BOD_5 dropped from 22 mg/1 to an average of 16 mg/1 and the total suspended solids were reduced by 88 percent in the effluent from a background level of 125 mg/1 to 15 mg/1. The substantial reduction in BOD_5 and total suspended solids is graphically depicted in Figures 3 and 4, respectively.

C. Problems and Discussion

In December, approximately 5,000 coots (Fulica americana) invaded the open waters of this lagoon and proceeded to consume the plants. These water hyacinths, badly damaged by the coots and by the unusually cold weather during December and January (refer to temperature chart, Figure 5), were no longer capable of effectively treating these wastewaters and were removed from the lagoon.

Data from this experiment suggest that a single cell lagoon containing four to five surface hectares covered with water hyacinths and a retention time of 12 days or longer should be capable of meeting the sewage effluent standards of the City of Bay St. Louis without producing offensive odors.

The present lagoon is much too large and will require diking off four to five hectares, leaving approximately 12.5 hectares which could be de-eutrophied with water hyacinths or drained. Decreasing the lagoon size would help to retain the heat from the raw sewage which is rapidly dissipated in the present large lagoon. Complete coverage of a smaller sewage lagoon hopefully would discourage coots from using this lagoon by eliminating free space for landing and surface feeding. If the coot problem were to persist, noise devices

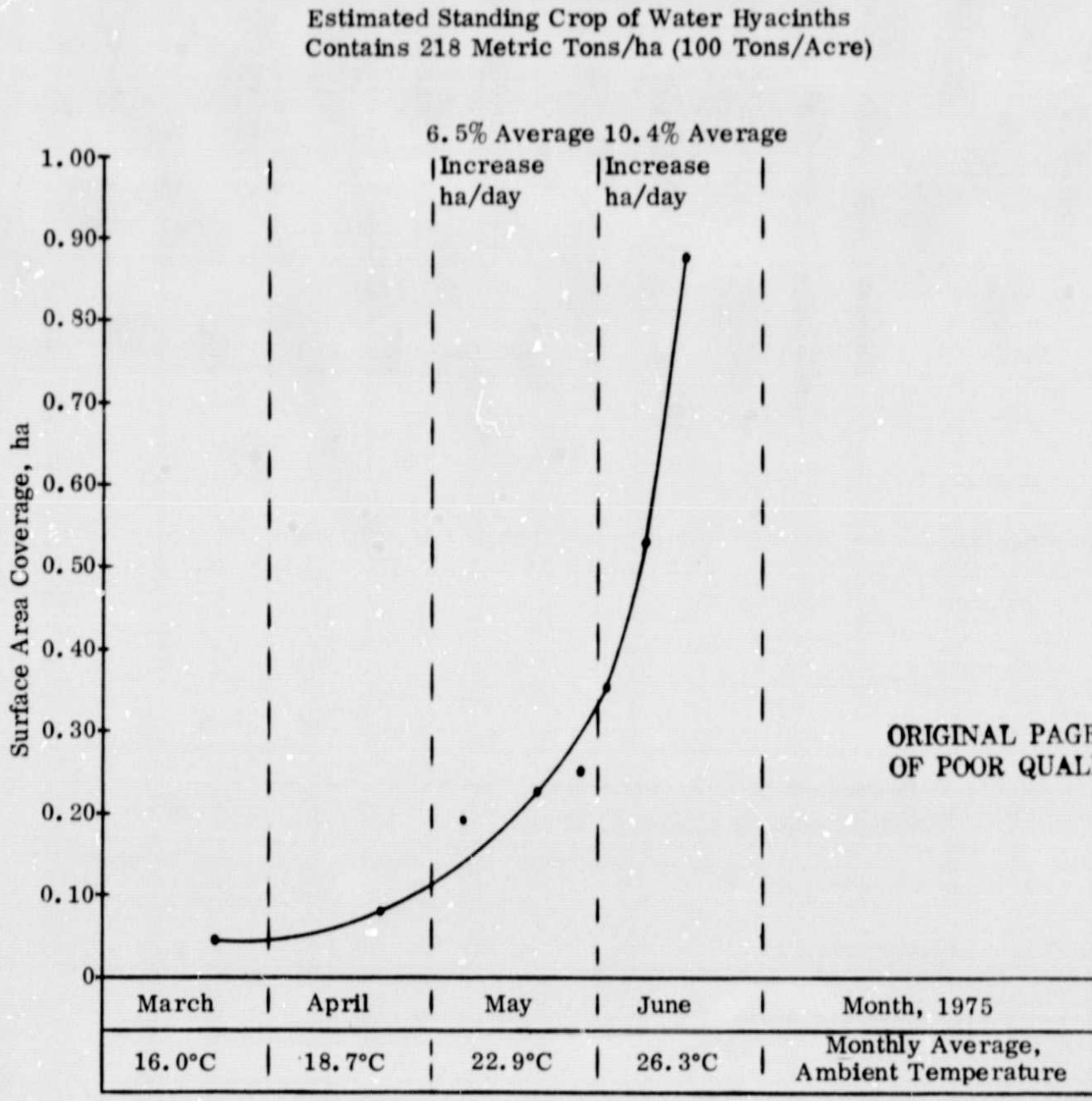


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Figure 2. Data on Growth Rate of Water Hyacinths After Initial Stocking of Plants in Bay St. Louis Lagoon Until Testing of Experimental Harvesting Equipment Began.

Table 1. Bay St. Louis, MS Sewage Waste Treatment Lagoon
(17.5 Hectare Surface Area)

Month 1975	BIOCHEMICAL OXYGEN DEMAND, BOD_5 (mg/ℓ)		TOTAL SUSPENDED SOLIDS, TSS (mg/ℓ)	
	Influent	Effluent	Influent	Effluent
April	40	22	74	125
May	75	16	62	148
*June	73	17	52	37
July	69	19	58	80
August	53	20	104	68
**September	58	20	47	9
October	27	11	42	8
November	20	18	48	18
December	52	14	60	26

NOTE: 0.10 Hectare surface area stocked with water hyacinths during last week of March, 1975

*1.25 hectare coverage

**2.50 hectare coverage

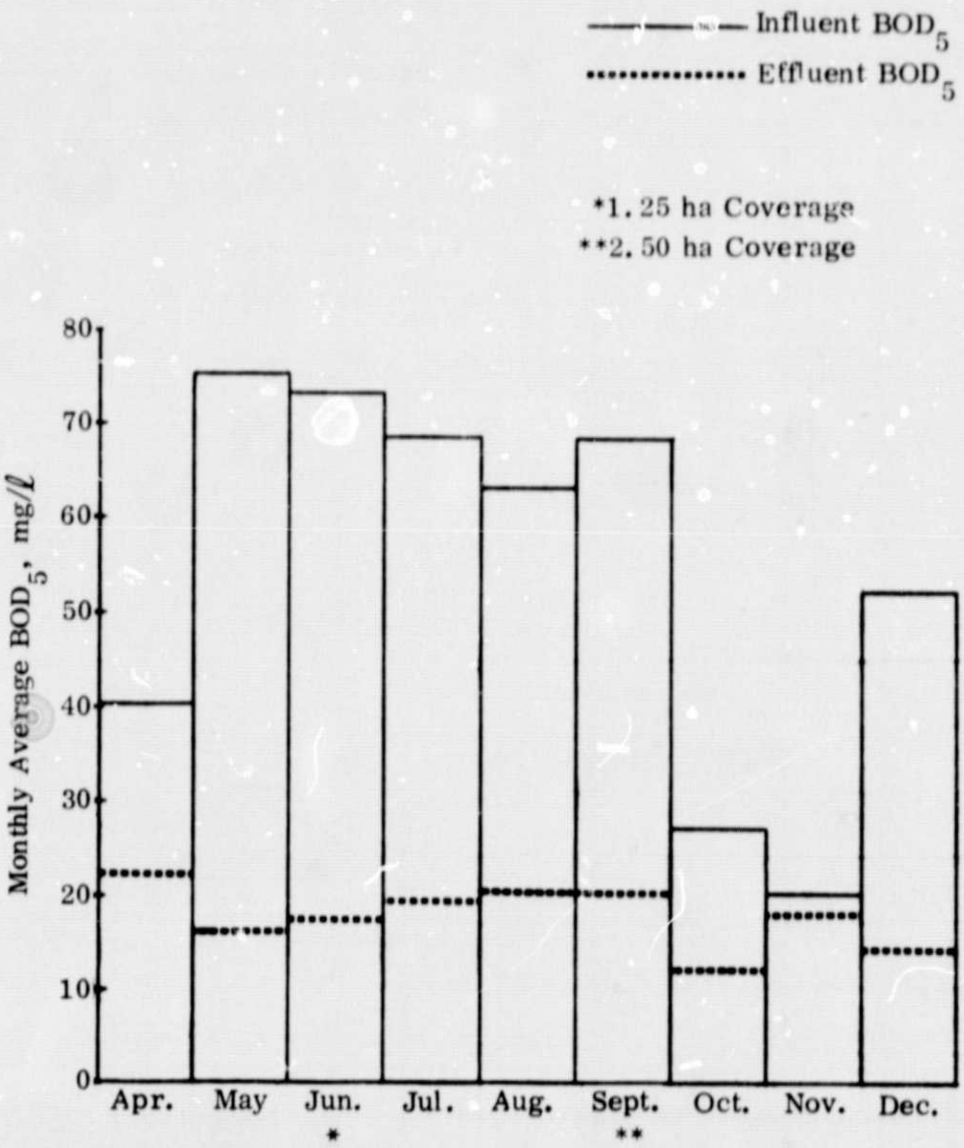

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Figure 3. BOD_5 Versus Time for the Bay St. Louis Lagoon

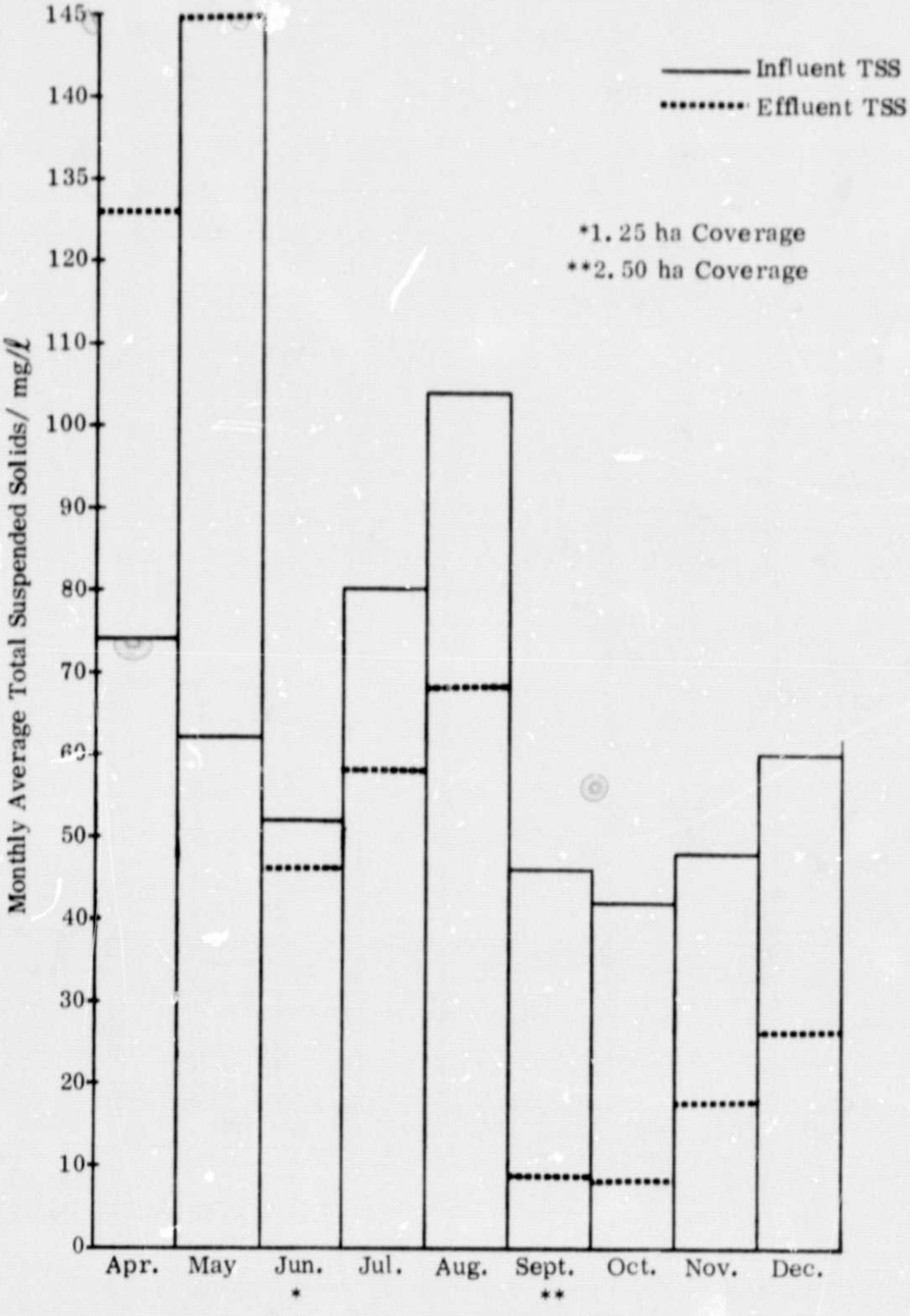
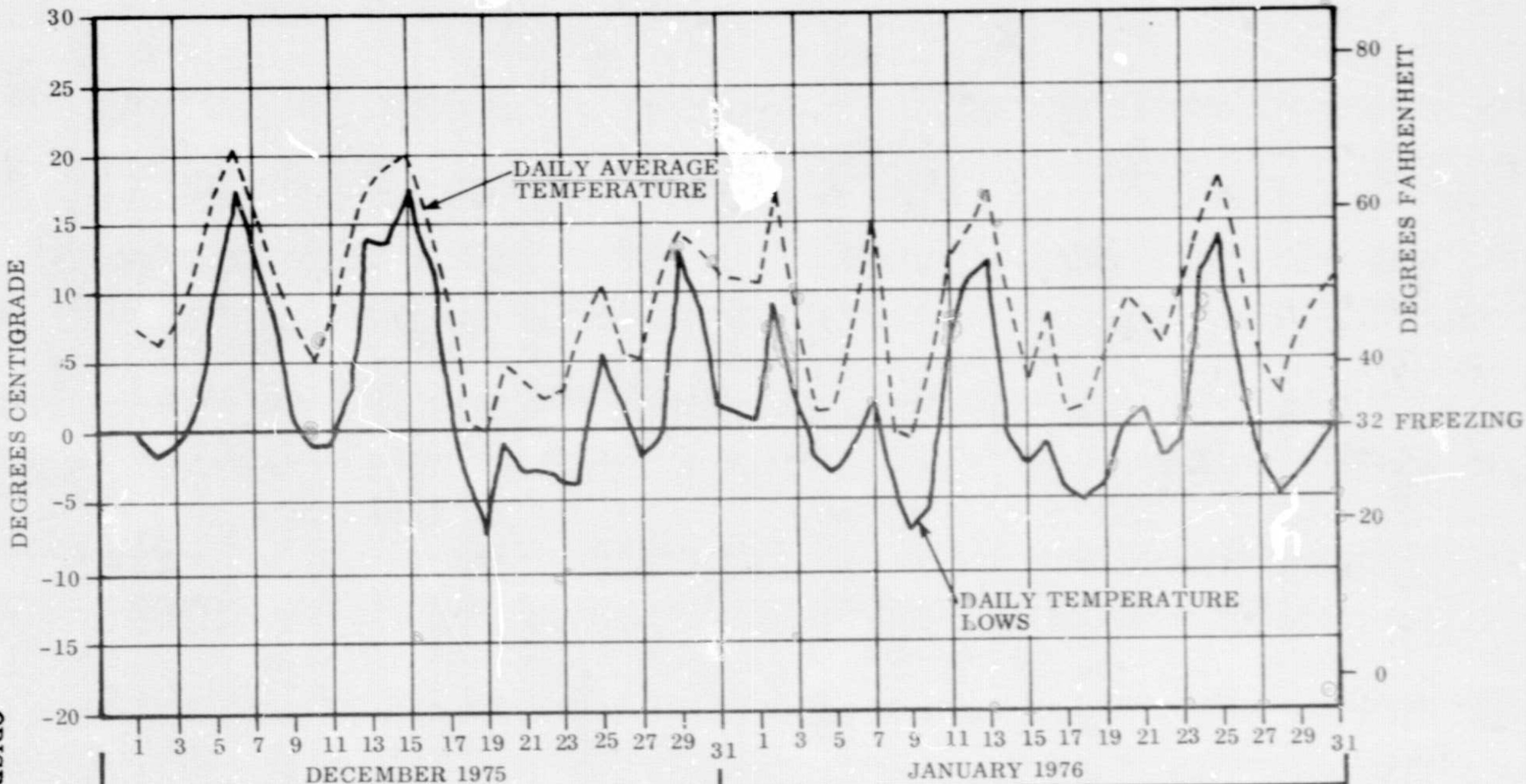


Figure 4. Total Suspended Solids Versus Time for the Bay St. Louis Lagoon



HISTORICAL DATA	HISTORICAL DATA
13-YEAR AVERAGE TEMPERATURE = 11.3°C	13-YEAR AVERAGE TEMPERATURE = 10.3°C
DECEMBER '75 AVERAGE TEMPERATURE = 9.5°C	JANUARY '76 AVERAGE TEMPERATURE = 8.0°C
13-YEAR AVERAGE MINIMUM TEMPERATURE = 5.3°C	13-YEAR AVERAGE MINIMUM TEMPERATURE = 3.7°C
DECEMBER '75 AVERAGE MINIMUM TEMPERATURE = 3.8°C	JANUARY '76 AVERAGE MINIMUM TEMPERATURE = 0.5°C*

* Lowest on NSTL Records (records maintained since 1963)

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Figure 5. NSTL Climatological Data for December, 1975, and January, 1976

similar to ones used by the military to keep birds from military air fields could be installed.

D. Conclusions

The Bay St. Louis sewage lagoon experiment established or reaffirmed the following points:

1. Water hyacinths will thrive on raw sewage; the high nutrient levels present in this medium stimulate rapid growth.

2. A smaller (four to six hectares) water hyacinth-covered lagoon would be most efficient in serving the residents of Bay St. Louis. A system of this size would produce a sewage effluent of excellent quality, well within the 1977 standards.

3. If water hyacinths are to be used in only a section of a large lagoon, the selection(s) not containing water hyacinths should be aerated to eliminate excess algal growth.

Coots, if they are permitted to feed on water hyacinths, may greatly decrease the efficienty of the system. In any permanent sewage treatment system utilizing water hyacinths, procedures must be taken to eliminate or minimize invasion by these birds.

EXPERIMENT 2. ORANGE GROVE LAGOON SYSTEM

A. Introduction and Description

Before the introduction of water hyacinths, the existing system at Orange Grove, Mississippi, was free of offensive odors, but it did not meet the standards imposed by the State of Mississippi Air and Water Pollution Control Commission. (Effluent quality before the introduction of water hyacinths is presented in Part I of this paper, October 1975). (3)

In June 1975, NASA's National Space Technology Laboratories entered into a joint experimental program with Orange Grove to evaluate the use of a water hyacinth-covered lagoon as a simple, economical way of reducing suspended solids, BOD_5, and nutrient levels from aerated lagoon effluent.

A 0.28 hectare (0.7-acre) surface area lagoon containing a total volume of 6.8 million liters (1.5 million gallons) had been newly constructed to receive the effluent from a secondary, aerated lagoon. The present system consists of two large aerated lagoons followed by three parallel unaerated lagoons (Figure 6). The daily flow rate into the third lagoon varied from 437,000 1 (116,000 gallons) to 1,893,000 1 (500,000 gallons) as shown in Figure 7. This lagoon was initially stocked with sufficient water hyacinths to cover one-half of the surface area.

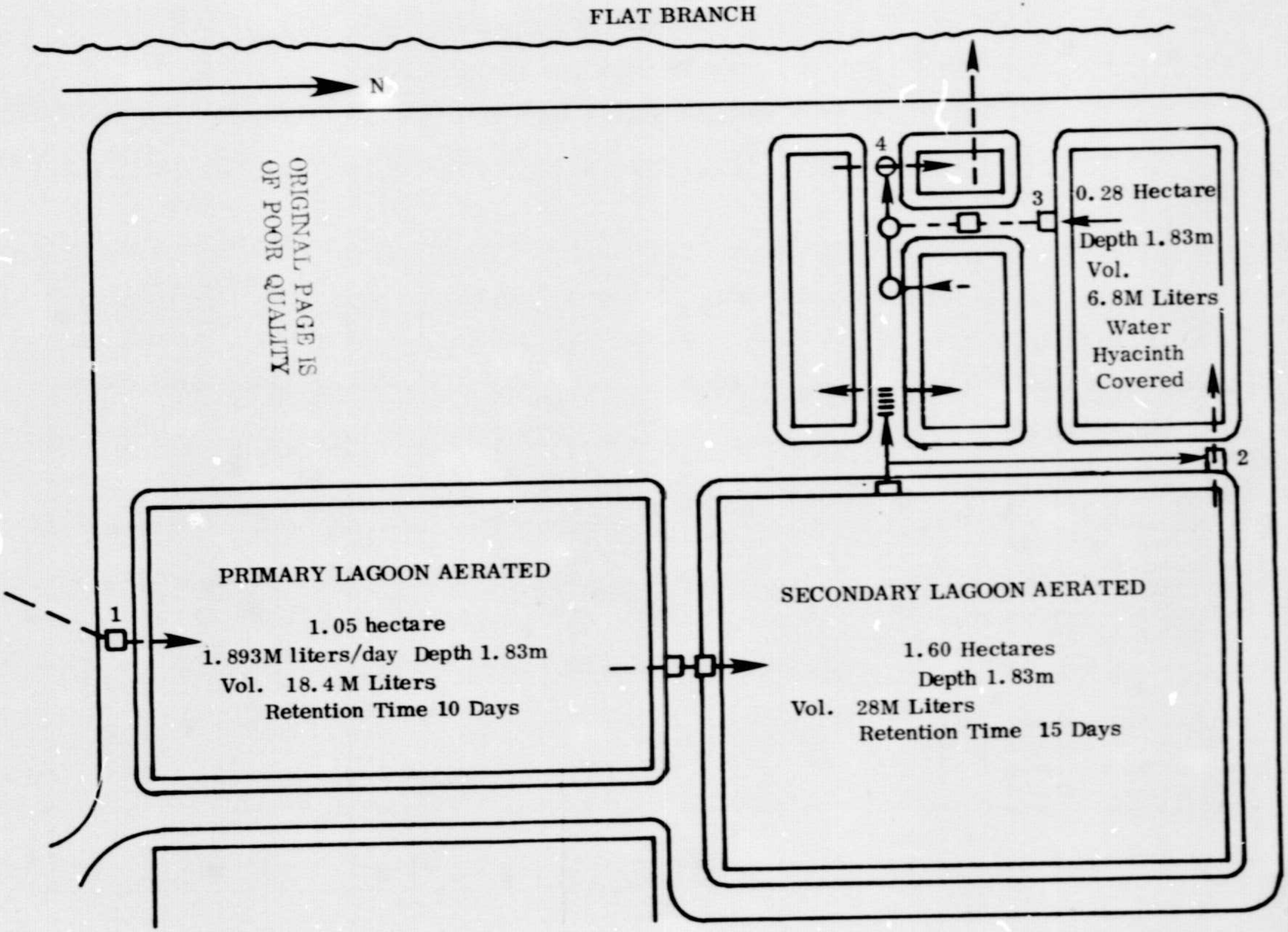
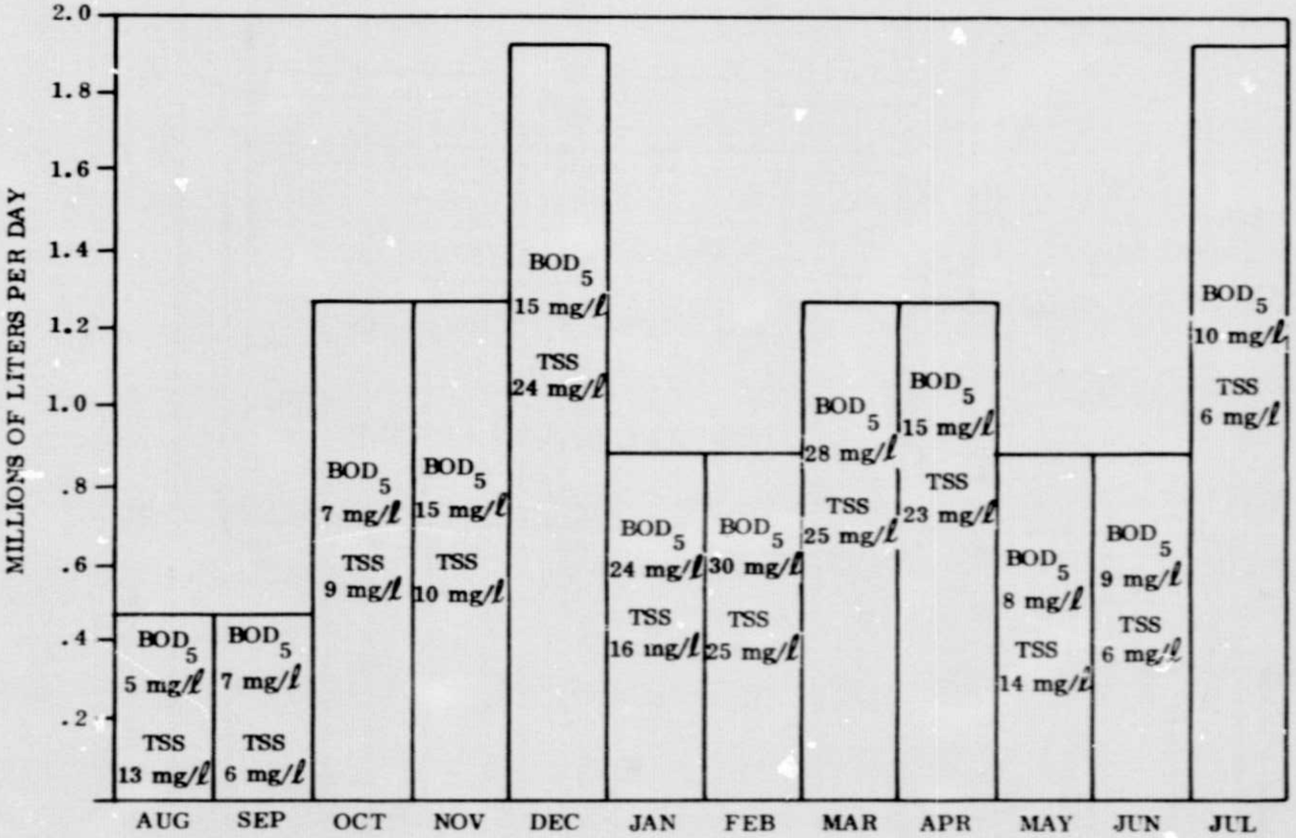


Figure 6. Orange Grove Sewage Lay-Out



1975

August	437,000 Liters
September	437,000 Liters
October	1,059,000 Liters
November	1,059,000 Liters
December	1,892,500 Liters

1976

January	870,000 Liters
February	870,000 Liters
March	1,059,000 Liters
April	1,059,000 Liters
May	870,000 Liters
June	870,000 Liters
July	1,892,500 Liters

Raw Sewage:

Avg. BOD_5 = 150 mg/ℓ

Avg. TSS = 142 mg/ℓ

Figure 7. Sewage Flow Rates Into Orange Grove Water Hyacinth Covered Lagoon And BOD_5 And Total Suspended Solid (TSS) Effluent Average From Eight Analysis Per Month

B. Results

As in the Bay St. Louis Lagoon System, water hyacinths again demonstrated the ability to purify the sewage effluent substantially. Each parameter measured is discussed below.

1. Total Suspended Solids

The water hyacinth-covered lagoon demonstrated the ability to reduce the total suspended solids year-round from a yearly average influent level of 49 mg/1 to a yearly average effluent level of 14 mg/1. This level, constituting a 71 percent reduction, is well within the 30 mg/1 maximum set by the Mississippi Air and Water Pollution Control Commission. Average monthly data are presented in Table 2 and depicted graphically in Figure 8.

2. BOD_5

The BOD_5 of the wastewaters entering the lagoon averaged 50 mg/1 on a year-round basis. After the introduction of water hyacinths, this level was reduced by approximately 70 percent (Table 2). The 15 mg/1 maximum allowable standard was achieved on a yearly average basis. BOD_5 values of effluent waters were well within this value for all months except January through March 1976. Freezing temperatures occurring during this period killed the tops of the water hyacinths, and the decay of this large amount of biomass elevated the BOD_5 levels to a high of 30 mg/1 during the month of February. However, this does not indicate that water hyacinths are incapable of dealing with high influent BOD_5 levels. After the system regained equilibrium in the spring of 1976, the plants effected a 90 percent reduction of BOD_5 influent levels during May 1976 (Figure 9).

3. Total Kjeldahl Nitrogen

As shown in Figure 10 and Table 2, water hyacinths successfully reduced the level of this nutrient below the maximum allowable level of 6 mg/1 for all months except February through March 1976. The reason for excess nutrient levels during this period was described in the above section. Excluding these two months, the yearly average level for total kjeldahl nitrogen was 2 mg/1. Even when the data from these months are taken into account, the yearly average of 3.02 mg/1 is well below the prescribed limits.

4. pH

As shown in Table 2, water hyacinths maintained the pH of the effluent within the prescribed limits of 6.0 to 7.8 during all months. In addition, the plants created a "buffer" effect, reducing the magnitude of pH fluctuations.

5. Dissolved Oxygen

As expected, water hyacinths substantially reduced the concentration of dissolved oxygen, from an average of 5.3 mg/1 to an average of 2.1 mg/1. However, due to natural aeration in mixing, the DO concentration reached or exceeded the minimum

Table 2. Average Monthly Data of Orange Grove Sewage Lagoon System

	Total Suspended Solids, mg/l		Total Dissolved Solids, mg/l		Biochemical Oxygen Demand (BOD_5), 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)* Monthly Average	142		319		150		25.73		9.27		94		7.06		1.0		25	
Data from Water Hyacinth Lagoon / Monthly Averages	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent	#2* Influent	#3* Effluent
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	26
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	26
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	22
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	23
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	27

* For location of sampling stations 1, 2, and 3, see Figure 2

Note: Total Kjeldahl nitrogen and total phosphorus data not obtained during the month of January due to difficulty with necessary equipment.

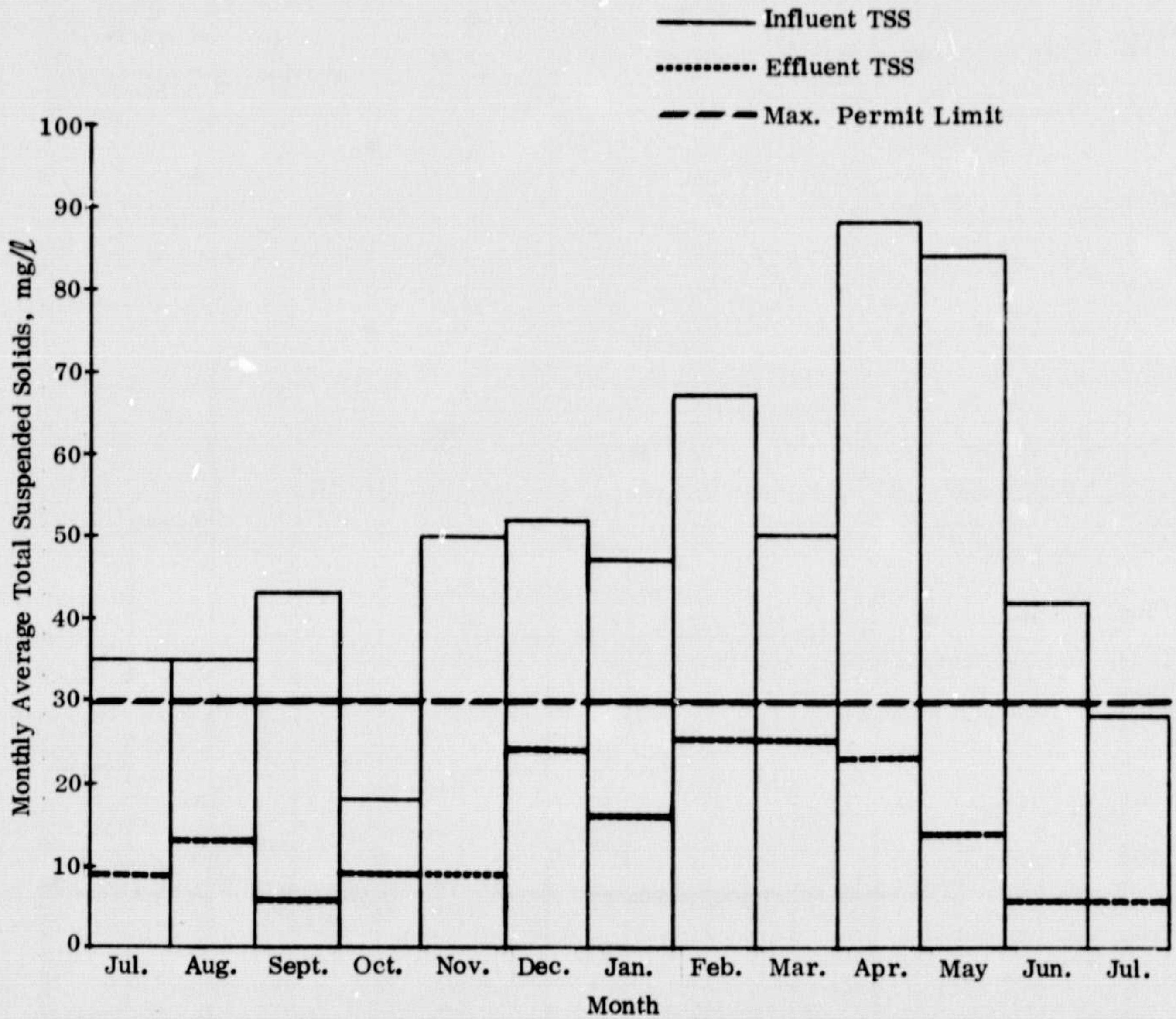


Figure 8. Total Suspended Solids Versus Time for the Orange Grove Secondary Lagoon Covered With Water Hyacinths

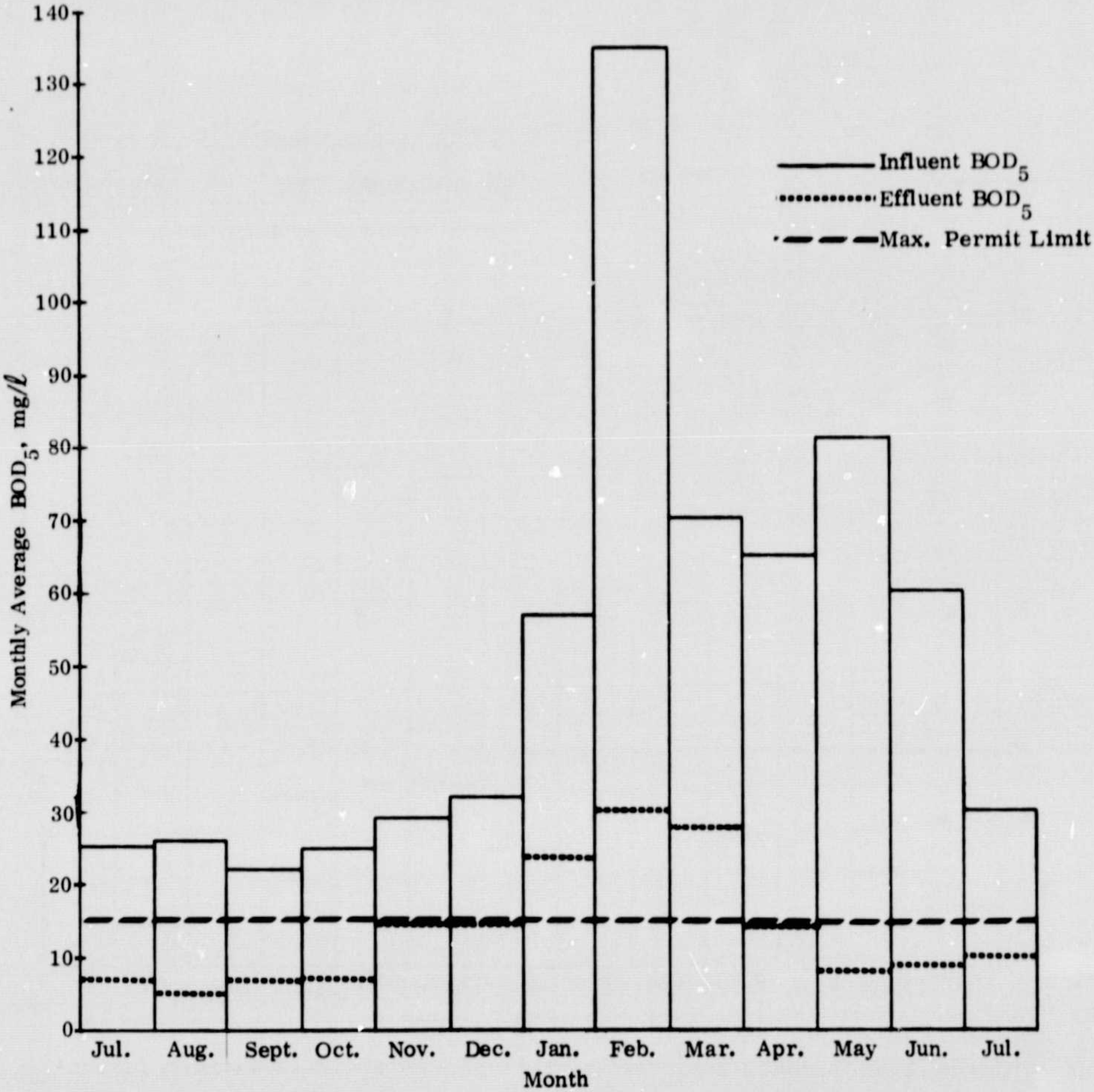


Figure 9. BOD_5 Versus Time for the Orange Grove Secondary Lagoon Covered with Water Hyacinths

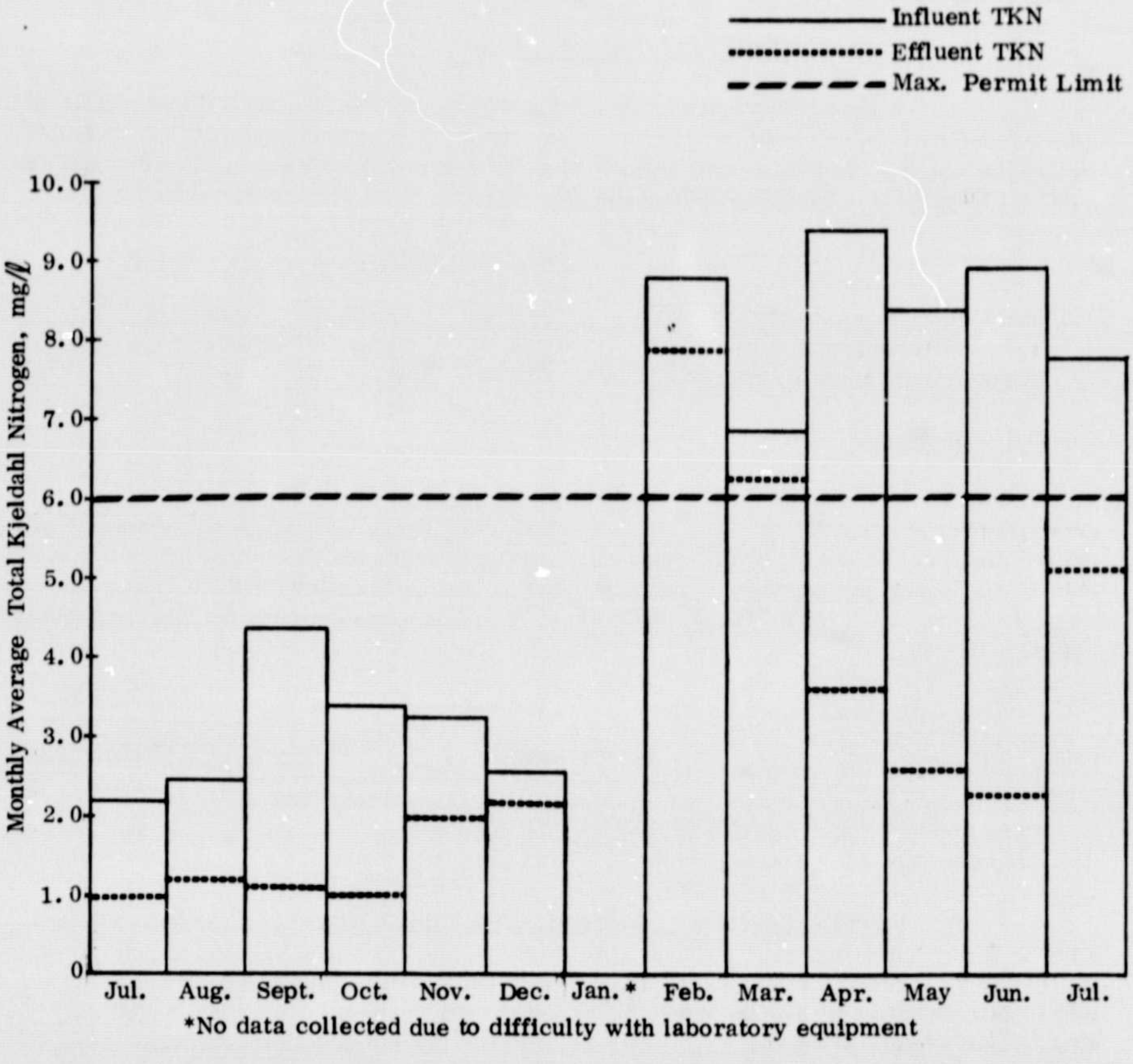


Figure 10. Total Kjeldahl Nitrogen Versus Time for the Orange Grove Secondary Lagoon Covered with Water Hyacinths

specified level of 5.0 mg/1 by the time the effluent enters the drainage ditch. There was no noticeable odor of hydrogen sulfide, the "rotten egg" by-product produced under extreme anaerobic conditions.

6. Water Temperature

Water temperature (Table 2) was slightly but not significantly lowered throughout the year. This effect is perhaps due to shading and evaporative cooling.

7. Dissolved Solids and Other Nutrients

Although there are no maximum levels specified for total dissolved solids, total organic carbon and total phosphorus, a decrease in these nutrients will have a beneficial effect in retarding eutrophication of the receiving bodies of waters. The percent reduction of these nutrients in the effluent is presented in Table 2 and summarized below:

	Influent	Effluent	% Reduction
Total Phosphorus, mg/1	6.13	5.43	11%
Total Dissolved Solids, mg/1	244	210	14%
Total Organic Carbon, mg/1	33	23	30%

C. Discussion

The results from the Orange Grove experimental system substantially increased understanding of the efficiency and limitations of water hyacinths as agents for sewage effluent purification. In particular, experimental evidence indicates that water hyacinths in a nonaerated lagoon are capable of reducing TSS and BOD_5 of aerated effluent wastewaters by 74 percent, and 90 percent, respectively, year-round in a system with the following specifications:

Surface Area of Hyacinth Lagoon	1.0 hectare
Total Capacity	24.3 million liters
Depth	1.83 meters
Flow Rate	2.03 million liters/day
Retention Time for Hyacinth Lagoon	12 days
Retention Time for Entire System	37 days

Even when the flow rate is as high as 97.2 million liters/day, so that retention time in the hyacinth lagoon is reduced to three days, the system is capable of maintaining BOD_5 and TSS levels of the sewage effluent well within the limits prescribed by the EPA and local authorities all but three months of the year if no protective cover is utilized through the winter months.

One major limitation of this system of sewage purification is that its efficiency is greatly reduced by long bouts of below-freezing temperatures. In order to be utilized on a year-round basis in locations where winter freezes occur regularly, the hyacinths will require protection with a greenhouse or other heat-conserving device. Other general problems and potential solutions are enumerated in the following paragraphs:

1. Aeration

When water hyacinths completely cover lagoon surfaces, natural aeration from the surrounding atmosphere is minimized. During that portion of the diel cycle when photosynthetic activity is at a minimum, dissolved oxygen concentration within the lagoon can drop precipitously. These conditions favor activity by anaerobic bacteria, which produce large quantities of the highly odorous hydrogen sulfide as a metabolic by-product. In order to minimize undesirable production of hydrogen sulfide, lagoon waters must be kept aerated. This may be achieved through the installation of mechanical aerators which operate during the night, when the water hyacinths are not actively photosynthesizing. A more economical and ecologically sound alternative is to harvest water hyacinths periodically during the peak growth months, to keep the lagoon partially open to natural aeration. Harvested water hyacinths can be composted and used as organic fertilizers and soil conditioners. On a larger scale, the harvested water hyacinths can also be processed into food, feed products, and biogas.

2. Plant Pests

a. The spider mite, (Bryobia praetiosa), often infests water hyacinths and can produce extensive damage if left untreated. Normally, these plants require spraying with insecticides such as malathion one to four times a summer to free the plants of this common pest.

b. Coots, (Fulica americana), mentioned previously, are potentially very damaging to water hyacinths in locations which provide winter nesting areas. They can perhaps be best discouraged from consuming these plants by installing inexpensive noise devices that generate sound frequencies (inaudible to humans) which repel the birds.

3. Chlorination

Although water hyacinths have proven to be highly effective in removing excess nutrients from sewage influents, they do not remove certain micro-organisms known to be present in wastewater, such as fecal coliform bacteria. Chlorination should be used to treat the effluent for elimination of these organisms.

A final treatment with water hyacinths following chlorination could possibly eliminate any of the carcinogenic chlorinated hydrocarbons formed during the chlorination process. Such a system is presently being designed for installation and evaluation at Orange Grove.

D. Conclusion

In conclusion, water hyacinths provide a means of sewage treatment which is sound both economically and ecologically. In this time of increasing ecological awareness and tightening purse strings, such a system is not only desirable, but essential.

Research presently being conducted will provide solutions to minor problems such as ensuring year-round operation, and discouraging insect and bird pests.

For their capabilities of purifying wastewaters, for their high nutrient level and resulting potential to be converted to food, feed, fertilizer, and energy sources, water hyacinths must surely be recognized as The Plant of the Future.

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APPROVAL

WATER HYACINTHS FOR UPGRADING SEWAGE LAGOONS TO MEET ADVANCED WASTEWATER TREATMENT STANDARDS: PART II

By B. C. Wolverton
Rebecca C. McDonald

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the NSTL Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Alan M Payne

for HENRY F. AUTER
Director, Applications Engineering
National Space Technology Laboratories