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TASK FINAL REPORT

on

AN ANALYSIS OF THE MARKET POTENTIAL OF WATER HYACINTH-BASED SYSTEMS FOR MUNICIPAL WASTEWATER TREATMENT

(Report No. BCL-OA-TFR-76-5)

by

A. C. Robinson, H. J. Gorman,
M. Hillman, W. T. Lawhon,
D. L. Maase, and T. A. McClure

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Approved by:

A. C. Robinson, Project Manager

B. W. Davis, Section Manager
Space Systems and Applications

BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

FOREWORD

This report was prepared under NASA Contract NASw-2800, with NASA Headquarters, Office of Applications. The work was performed by a multidisciplinary study team at Battelle Columbus Laboratories, headed by Dr. A. C. Robinson. Team members were D. L. Maase (wastewater treatment), Dr. W. T. Lawhon (aquatic biology), Dr. M. Hillman (biomass utilization), Dr. T. McClure (agricultural applications), and H. Gorman (market analysis). Several other individuals made important contributions including W. M. Jamieson (economics), A. E. Weller (engineering design), and two consultants: Professors A. J. Englande and R. Reimers of Tulane University.

In the process of performing the study, contact was made with a number of individuals involved in wastewater treatment and aquatic biology. The names of these individuals are listed in the report. Their assistance was most helpful, and is greatly appreciated. However, the data and conclusions included herein are solely the responsibility of Battelle, and they do not necessarily reflect the views of any of these helpful individuals. In the aggregate, however, their inputs were of major significance in determining the conclusions presented.

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CHAPTER 1

INTRODUCTION AND SUMMARY

Study Objective and Approach

The principal objective of this study is to estimate the potential U.S. market for tertiary municipal wastewater treatment facilities, which make use of water hyacinths. To do this, it has been necessary to deal with two major difficulties:

- there are no systems of this type currently in existence and verified design data are largely lacking
- the attractiveness of hyacinth treatment systems will depend on a number of site-specific factors such as the nature of the existing wastewater treatment facilities, the capital and labor options open to the treatment authority and the type and severity of effluent standards which are to be imposed.

The first difficulty has been addressed by developing design criteria based on available published characteristics supplemented, in some cases, by the best judgement of the design team. Also, some analyses have been made of the sensitivity of results to the major assumptions employed.

The second difficulty is particularly troublesome. Each existing or proposed treatment facility presents a different mix of problems and opportunities. Short of analyzing several thousand individual situations, there is no completely satisfactory way of dealing with this diversity.

The approach taken in this study was to develop a baseline design, which approximates the "typical" or "average" situtation under which hyacinth-based systems might be used. The total market size for tertiary treatment was then estimated for those geographical regions in which hyacinths appear to be applicable. Then the market penetration of the baseline hyacinth system when competing with conventional chemical and physical processing systems was estimated, based primarily on cost differences. Finally, a limited analysis was made of the sensitivity of market penetration to individual changes in these assumptions.

The limitations of this approach are several and obvious. In the first place, there are substantial uncertainties in predicting what the "typical" case will be, considering the fact that there are no hyacinth systems currently operational, and a time period of the order of 25 years in the future must be considered. Secondly, the variations from the "typical" case will certainly be substantial. Thirdly, individual sensitivity analyses cannot reflect the effects of multiple deviations from the baseline case.

However, until some of the fundamental points (such as the size of the lagoons required, the harvesting doctrine to be employed, and the climatic limitations) are better validated, a more comprehensive market study would not be warranted.

The principal assumptions and the principal conclusions of the study are outlined in this chapter. In the following chapters, more detail is given, and the sources of data and information are identified.

The Baseline Design

The baseline design case selected was for a city of 10,000 inhabitants located in southern Florida. It was assumed that a completely new facility was to be designed, not taking advantage of existing facilities, land, or labor resources already under control of the treatment authority. It was also assumed that rather stringent requirements would be placed on the effluent.

The southern Florida location was selected because it seems clear that water hyacinths will function the year around in this region. Further work may show that additional areas are also satisfactory, but it is relatively certain that the plants will perform the desired functions there. The design size of 10,000 inhabitants was selected because preliminary considerations showed that this was probably near the optimum size for hyacinth systems. The technical and economic characteristics of hyacinth systems tend to favor the smaller-sized treatment facilities; these are also much more numerous than the larger ones.

The requirement that a completely new facility be built is not typical. It is actually a "worst case" from the standpoint of hyacinth systems. This approach was used, however, in order to develop information on the full range of cost elements. In this way, it is relatively easy to see the effects of dropping or reducing specific elements in a particular situation. Indeed the most typical case is expected to be one involving the upgrading of existing lagoon facilities, and this was considered in developing the final market estimates.

The set of effluent requirements selected for the baseline case is one of the most stringent that has been applied to the treatment of wastewaters up to the present time. It was estimated that this will be a representative requirement in the 1980's and 1990's when hyacinth systems might be built and operating. The mechanism for setting standards for each treatment facility is rather complex, and it is by no means certain what a "typical" or "average" result will be 10 or 20 years in the future. The requirements used here (see Table 1-1) have been suggested by the State of Florida, and thus are not an unrealistic estimate of what might be imposed if present trends of increasing environmental and public health concerns continue.

Characteristics of the Water Hyacinth

The water hyacinth (*Eichornia crassipes*) is a flowering aquatic plant, native to Brazil, but now commonly found in waterways of tropical and semitropical areas around the world. It currently grows throughout Florida, in southern Georgia, Alabama, Mississippi, Louisiana, and in parts of Texas and California. The plant is sometimes found rooted in soil, but more commonly it is free-floating, drawing nutrients from the water. The individual plants are of moderate size, measuring perhaps 50cm from root tip to the top of the flower cluster. Typical weight is of the order of 1 kg, of which some 95 percent is water.

The plants form dense mats, interfering with most uses of waterways, and the hyacinth has been designated a noxious weed by the Federal Government. Under favorable growth conditions, spreading of hyacinth mats can be extremely rapid, doubling total plant mass in periods of a few weeks.

Growth rate is affected by several factors. The most significant is temperature. In southern Florida, the plant grows vigorously throughout the year. Along the Gulf Coast, however, there is comparatively little growth from November through March, though the plants survive. This is designated the "maintenance" period. Temperatures much below freezing will kill the plants entirely. Salinity and lack of dissolved oxygen will also inhibit growth. In addition, the plant is subject to damage by certain pests.

Water hyacinths can remove nitrogen and phosphorus from the water, as well as a variety of metals.

Design of Hyacinth-Based Systems for Municipal Wastewater Treatment

These characteristics of the water hyacinth have been perceived as being potentially applicable to treatment of municipal and other waste waters. The absorption of nitrogen and phosphorous, the rapid plant growth, (and correspondingly rapid depletion of the nutrients), together with the relative ease of harvesting (large plant size, free-floating) have made the water hyacinth an attractive plant choice for this purpose.

This is in fact not a new idea. Suggestions for this application date back at least to the 1940's, but recent emphasis on improved water quality has created a situation in which the hyacinth's capabilities have greater potential value.

The most effective use appears to be for tertiary treatment. The important parameters of the secondary effluent and of the tertiary effluent are the quantities of suspended solids, biological oxygen demand (BOD), nitrogen and phosphorus. Typical figures for the secondary effluent are shown in the first row of Table 1-1. The second row shows a reasonably

TABLE 1-1. TYPICAL SECONDARY EFFLUENT CHARACTERISTICS AND POSSIBLE TERTIARY EFFLUENT STANDARDS

	Suspended Solids (mg/ℓ)	BOD (mg/ℓ)	Nitrogen (mg/ℓ)	Phosphorus (mg/ℓ)
Secondary Effluent	30	35.7	21	11
Tertiary Effluent	5	5	3	1

stringent standard for tertiary effluent, based on requirements which have been imposed in Florida. The task of the hyacinth system, then, is to operate on the secondary effluent in such a way as to reduce the four parameters to the values shown for tertiary effluent.

The general approach to using water hyacinths for tertiary treatment, is to feed the secondary effluent into lagoons that are about four feet deep, and that are covered with a mat of hyacinth plants. The size of the lagoon required is dependent on several factors. The principal ones are:

- desired throughput rate
- hyacinth growth rate (rate of nutrient uptake)
- degree of nutrient removal required
- harvesting doctrine.

The first factor is a relatively obvious one. The lagoon area is proportional to the throughput rate. Several rates were considered in the analysis, but in this chapter, all lagoon areas are based on a rate of 1 million gallons per day (mgd). This flow corresponds to 3785 m^3/day, and is approximately the rate generated by a city of 10,000 inhabitants.

The second factor, that of growth rate, is subject to considerable uncertainty. Figures as high as 67 tons (dry weight) per acre-year have been estimated under ideal conditions in southern Florida. Other measurements show production as low as 4 tons per acre-year. Also, it seems clear that growth is not uniform the year around, at least in some portions of the region being considered.

Operational data for an actual sewage treatment lagoon, operating on a year-around basis, using some particular coverage and harvesting doctrine, and employing some particular throughput rate are lacking. Accordingly, it was necessary to develop certain assumptions based on the best available information. These assumptions are the following.

First, the problem of non-uniform growth was treated by defining two geographical regions, as shown in Figure 1-1. In the southern Florida region, it was assumed that plant growth takes place the year around, and that hyacinth production is not temperature-limited. In the remainder of the region, i.e., northern Florida and a strip along the Gulf Coast, it was assumed that there is a period of several months in which plant growth stops. During this "maintenance period", the plants do not die, but neither do they gain in weight. This is caused by the low temperature. During the remainder of the year, the "growth period", it was assumed that the plant growth is vigorous.

Based on present knowledge, growth rates of 20 tons/acre-year for southern Florida and 10 tons/acre-year for the rest of the region were selected for design purposes. While this requires verification in a properly-designed experiment, the general conclusions are comparatively insensitive to the value chosen.

The third factor, degree of nutrient removal required has a very significant effect on lagoon area. For example, if it is desired to meet in full the tertiary effluent standards indicated in Table 1-1, the lagoon area is estimated to be 156 acres, based on southern Florida location and 20 tons/acre-year production. If it is desired to meet the standards of Table 1-1 with the exception of the phosphorus standard, the area would be 31 acres - a five-fold reduction. In both cases, a 1 mgd throughput is assumed.

The reason for this difference in required area is that the ratio of phosphorus to nitrogen in the secondary effluent is considerably higher than the ratio in which the two are absorbed by the hyacinths. Accordingly, removal of all the nitrogen (which also results in meeting the suspended solids and BOD criteria) leaves most of the phosphorus in the water. To

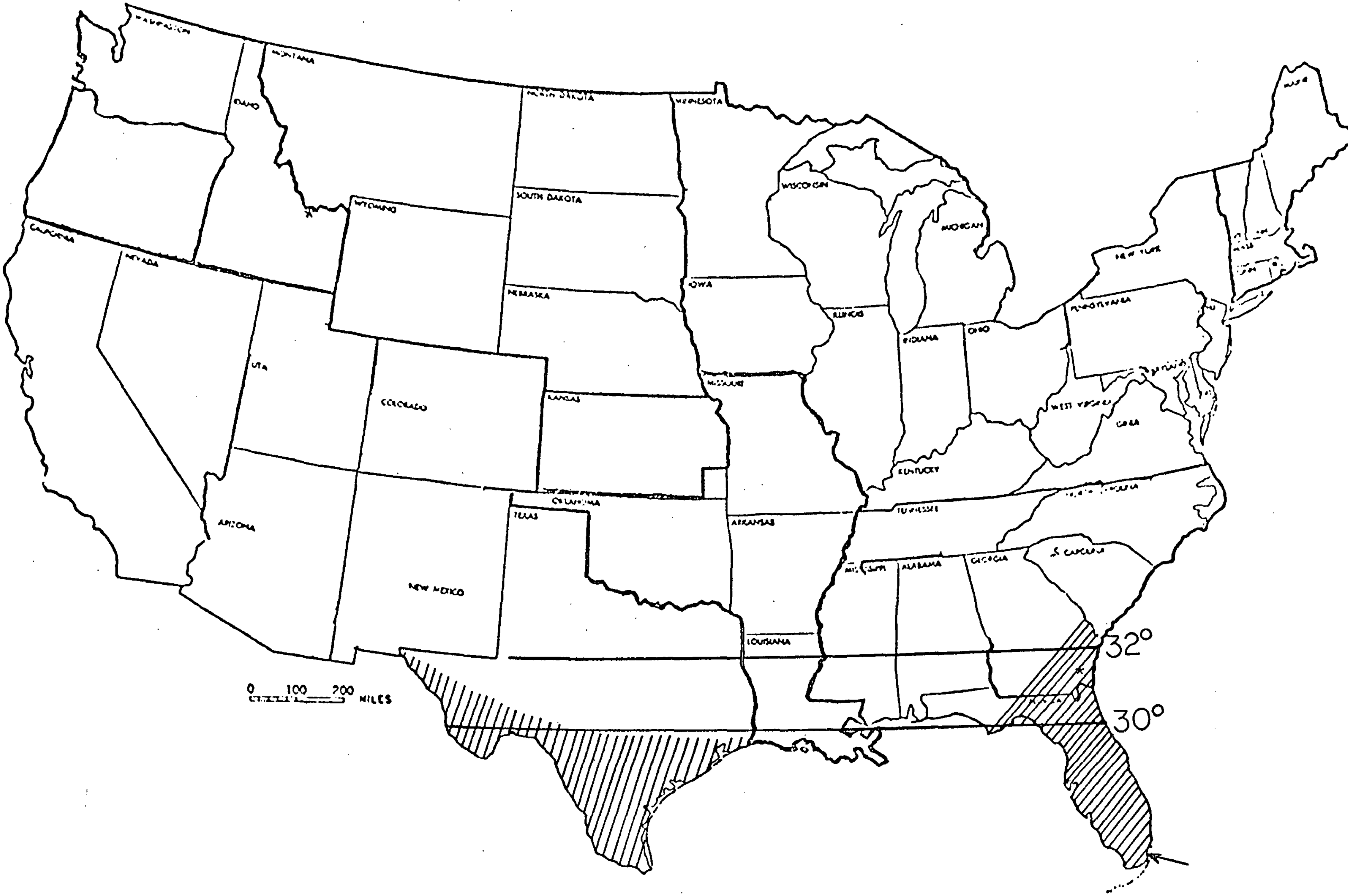

FIGURE 1-1. REGION OF APPLICABILITY OF HYACINTH WATER TREATMENT SYSTEMS[(a)]

Shaded region indicates areas in which hyacinth plants should survive the winter months. Most of the region below the 30th parallel should have year-around growth. Subtropical regions is frost-free more than 360 days/year.

remove the phosphorus, it is necessary to increase the area, and it may also be necessary to add nitrogen to the water to bring the N:P ratio to that required for assimilation.

Because of these characteristics, three different hyacinth-based concepts have been developed in this study: (1) the "nitrogen design" - a hyacinth system designed to remove the nitrogen, leaving the excess phosphorus; (2) the "phosphorus design" - a hyacinth system designed to remove both nitrogen and phosphorus (adding nitrogen if necessary); and (3) the "hybrid design" - a combined system using hyacinths to remove the nitrogen, and a chemical process (lime clarification) to remove the phosphorus.

Costs of these systems can be expected to vary over a wide range, depending on a number of local and particular circumstances. In some cases, lagoons may already be available. In others, adequate land may already be owned by the operating authority. Also, it may be that lagoon construction costs might be cut substantially by use of labor from various municipal organizations.

For cost comparison purposes, it was decided to assume that completely new facilities were to be engineered and constructed, with full market prices to be paid for land, equipment and services. The cost estimates included both operating costs and annualized capital costs. The principal elements are:

- land acquisition
- engineering
- construction
- interest
- labor costs (direct and indirect)
- maintenance and administrative costs
- materials and supplies.

Table 1-2 summarizes the results for the three types of hyacinth-based systems, based on a 1 mgd throughput. It can be seen that the phosphorous and nitrogen designs have costs in a ratio of approximately 5:1,

TABLE 1-2. PERFORMANCE AND COSTS OF HYACINTH TERTIARY TREATMENT SYSTEMS (1 mgd capacity)

Area[a], Period[b], Design[c]	Performance				Annualized Cost (¢/1000 gal)
	Suspended Solids (mg/1)	BOD (mg/1)	Nitrogen (mg/1)	Phosphorus (mg/1)	
S. Florida, Full Year Nitrogen Design	5	1.5	1	8	27.1
Other Areas, Growth Period Nitrogen Design	5	1.5	1	8	19.8
Other Areas, Maintenance Per. Nitrogen Deisgn	30	14	11	11	19.8[d]
S. Florida, Full Year Phosphorus Design	5	1.5	1	1	121.6
Other Areas, Growth Period Phosphorus Design	5	1.5	1	1	85.2
Other Areas, Maintenance Period, Phosphorus Design	30	14	11	11	85.2[d]
S. Florida, Full Year Hybrid Design	3	1.5	1	0.8	50.4
Other Areas, Growth Period, Hybrid Design	3	1.5	1	0.8	43.1
Other Areas, Maintenance Period, Hybrid Design	3	7 - 16	11	0.8	43.1[d]

(a) Two regions are considered: (1) southern Florida; and (2) other areas defined as north Florida plus a strip about 100 miles wide along the Gulf Coast.

(b) In southern Florida, it is assumed that growth is year-around and 20 tons/acre-year are harvested. In the other areas, it was assumed that growth occurs only from April through November and 10 tons/acre-year are harvested. The remainder of the year is the "maintenance period".

(c) Three systems were considered: (1) a hyacinth system designed for nitrogen removal - nitrogen design; (2) a hyacinth system designed for removal of both nitrogen and phosphorus - phosphorus design; and (3) a mixed hyacinth/chemical system for removal of both nitrogen and phosphorus - hybrid design.

(d) In the "other areas" cost/1000 gal is computed on an annual basis. Costs are shown as being the same during growth and maintenance periods, even though harvesting costs are not distributed uniformly through the year.

the same ratio as the areas of the lagoons in the two cases. The major cost elements are capital investment and harvesting. Both are approximately proportional to lagoon area, other things being equal.

During maintenance periods, neither the nitrogen nor the phosphorus design is very effective in removing pollutants. The hybrid system is substantially better in this respect, and may be capable of meeting some realistic standards on a year-around basis.

It can be seen that the phosphorus design is the most expensive, followed by the hybrid and the nitrogen designs. However, the latter may not be capable of meeting stringent standards, even in southern Florida. The two hyacinth systems which can meet stringent standards during periods of growth are the phosphorus and hybrid designs. Of these, the hybrid is cheaper by more than the factor two. Accordingly, this was selected as the baseline hyacinth system.

Competitive Systems for Municipal Wastewater Treatment

There are a number of other methods for accomplishing the removal of pollutants from the secondary effluent. Several physical and/or chemical systems have been developed and applied. The four which seem most pertinent here are:

- filtration - microscreening or multimedia (suspended solids and BOD)
- granular carbon adsorption (suspended solids and BOD)
- lime clarification (suspended solids, BOD, phosphorus)
- ammonia stripping (nitrogen).

The performance and cost of several combinations of these processes are given in Table 1-3. These systems should be applicable the year around, throughout the region of interest. It can be seem that only one of these four systems meets the tertiary effluent requirements of Table 1-1 in all respects; i.e., lime clarification with ammonia stripping and granular carbon adsorption. The others yield various degrees of lower performance at lower cost.

TABLE 1-3. PERFORMANCE AND COSTS OF COMPETITIVE TERTIARY TREATMENT SYSTEMS (1 mgd capacity)

	Performance				
Tertiary System	Suspended Solids (mg/ℓ)	BOD (mg/ℓ)	Nitrogen (mg/ℓ)	Phosphorus (mg/ℓ)	Cost (¢/1000 gal)
Lime Clarification	3	16.4	21	0.8	23.3
Lime Clarification and Multimedia Filtration	0.3	14.5	21	0.8	34.5
Lime Clarification and Ammonia Stripping	3	16.4	2.1	0.8	34.5
Lime Clarification and Ammonia Stripping and Granular Carbon Adsorption	0.3	1.6	2.1	0.8	88.9

Comparison Between Hyacinth-Based and Other Wastewater Treatment Systems

It should be clear from the preceding information that cost and performance comparisons between hyacinth and other systems is not a simple matter. In southern Florida, where the hyacinth system can operate the year around, it offers the possibility of meeting all the effluent requirements (hybrid design) at a cost of about 50 ¢/1000 gallons. The lime clarification plus ammonia stripping plus granular carbon absorption system will meet all the effluent requirements at a cost of about 89 ¢/1000 gallons. This suggests that the hyacinth system has an appreciable cost advantage, even using full costs.

If land is already owned, or if lagoons are already in existence, hyacinth system costs can be further reduced. In the case of the hybrid design, if the capital cost can be reduced to a nominal amount, the overall cost would be reduced some 20 percent, bringing the cost per 1000 gallons to about 40 cents (southern Florida). This is less than half the cost of the conventional system.

With a cost advantage of this magnitude, market penetration should be relatively complete, assuming other problems are resolved (safety, adequate design verification, etc.).

Along the Gulf Coast, the conventional systems have the advantage of giving uniform year-around performance. Depending on the standards imposed, this might be a decisive advantage, so that cost considerations do not come into play.

Hyacinth systems also entail some risk of escape of plants from the treatment facility into downstream waterways which might have been free of hyacinths otherwise. A legal liability of substantial proportions might exist. At present there appear to be no data from which to determine how likely such an escape might be. Until some data or experience are developed, this risk is likely to play a significant part in the decision as to whether to utilize a hyacinth system.

Various physical/chemical wastewater treatment systems have been built and are currently operating. Design parameters for these systems are relatively well-understood and have been operationally verified. This is not the case for hyacinth systems. Until such time as a comparable point has been reached for hyacinth systems, this fact alone could almost preclude their selection. Most operators of municipal facilities are very reluctant to take a chance on unproven technology.

As has been emphasized, data are incomplete in several respects, but based on current estimates it appears that the major points about the comparison are the following:

- hyacinth systems can perform well in southern Florida the year around.
- hyacinth systems can perform well along the Gulf Coast from April through November.
- cost comparisons are highly site specific. There are a number of potential economies in design and installation of hyacinth systems, which depend on the particular treatment facility. In the case of completely new systems, in which full costs must be borne, hyacinth systems have an appreciable cost advantage, when designed to meet stringent effluent standards.
- hyacinth systems at present entail substantially higher risks (unverified parameters and possible legal liabilities) than do competitive systems.

From the standpoint of the prospective "buyer", the hyacinth option does not <u>at present</u> look attractive, except perhaps in special cases. The cost advantages indicated by this study are as yet unverified by operating experience, and a number of other uncertainties remain. Hyacinth technology is as yet unproven. As such, it is not likely to be adopted. If, however, the safety question can be resolved, and the cost advantages are shown to be on the order of those suggested by this study, market penetration should be substantial in southern Florida. Applicability to the rest of the region will depend on the standards imposed, and on the degree to which new techniques can mitigate the effects of the dormant period.

Effects of Departures from the Baseline Assumptions

As mentioned above, it was necessary to select a baseline set of assumptions for design purposes. Some idea can be obtained of the sensitivity of results to these assumptions, by studying variations in one assumption at a time.

Effect of Throughput Rate

Hyacinth systems differ markedly from conventional systems in their sensitivity to size of the treatment facility. Unit costs (¢ /1000 gal) decrease with increasing throughput in both types of systems, but the size effect is much stronger for conventional systems. For example, increasing the throughput 10 times higher than the baseline case cuts the unit cost for conventional systems by over 50 percent. In the case of pure hyacinth systems, it is of the order of 25 percent, and the hybrid design is intermediate between the two. Thus, hyacinth systems would be more attractive for small facilities, while conventional systems would be more attractive for larger facilities.

Effect of Hyacinth Yield per Acre

The acreage required to produce a given mass of harvestable hyacinths per unit time is not accurately known. Measurements have been reported which vary by more than a factor of ten. The amount of harvestable hyacinths required to absorb a given amount of pollutant is, on the other hand, much better known, perhaps to an accuracy of 15 percent. Therefore, once the pollutant loading on a given facility is defined, the mass of harvested hyacinths (and the hyacinth harvesting cost) is relatively well-known. The lagoon area required to generate this mass is more uncertain. However, it appears that hyacinth system cost is not highly sensitive to this area requirement. For example, in the southern Florida hybrid design, hyacinth-related capital costs (land purchase, engineering, lagoon construction) are only 20 percent of the total cost, under the full-cost assumption. This cost element is less than proportional to lagoon area, so variations in the area will have only a modest effect on cost, and on cost comparisons.

Effect of Relaxed Standards

If the effluent standards to be imposed are different from those of Table 1-1, the effect on cost could be substantial. If, for example, the phosphorus requirement were deleted entirely, it would be possible to eliminate the lime-stripping portion of the hybrid design, cutting the cost approximately in half.

If the nitrogen requirement were deleted as well as the phosphorus requirement, then microscreening alone might be adequate, at a cost of less than 3 ¢/1000 gallons.

If it is desired to remove only half the nitrogen, to the order of 10 mg/l, with other standards as shown in Table 1-1, then the lagoon area could be cut in half, as could the harvesting cost. A reduction in total cost of the order of 20 percent could be expected (southern Florida hybrid design).

Other examples could be given, but it should be clear that the standards have a very important influence on system costs. This fact makes generalizations difficult. If typical standards in the 1980's and 1990's are substantially more lenient than the ones used here, the cost comparison picture might well be different, though hyacinth systems would benefit from such relaxations at least as much as conventional systems.

Utilization of Harvested Water Hyacinths

In the foregoing analysis, the final disposition of the harvested biomass was assumed to entail zero costs, after the material was hauled away from the lagoon. The cost of landfill disposition would probably not be large, though this was not considered in detail. If, however, the biomass can be utilized to yield an actual profit, the tertiary treatment costs could be offset to some degree.

To get an idea of the possible objectives, it has been estimated that the total cost for a 1 mgd hybrid facility in southern Florida is about $300 for each dry ton of water hyacinth material harvested. Thus, if a profit of $150 per dry ton could be realized, the effect would be a fifty percent reduction in the cost of waste water treatment. This would doubtless greatly alter the rate of market penetration. If, however, the profit were much less than $75 per dry ton, (a 25 percent cost reduction) the effect on market penetration would probably not be large. It follows from this, that if the products from one dry ton have a selling price less than $75, the chances of an effect on market penetration would indeed be remote. It is frequently easier to estimate the selling price (determined by competitive products now being sold in the market place) than it is to estimate production cost.

A number of possible uses of the harvested biomass were considered. In some cases, experimental work has been done on water hyacinths, in others it has been done on other organic wastes. Five uses were identified which have been the subject of enough investigation that some idea of the economic possibilities can be developed. These are summarized in Table 1-4. It can be seen that, even if the products could be produced at zero cost, the selling price, which is constrained by competition, is too low to offer much hope of assisting in market penetration.

Size and Character of the Market for Municipal Treatment Systems

The potential buyers and users of hyacinth-based treatment systems are the owners and operators of municipal wastewater treatment facilities in the geographical region of interest. It was assumed, for purposes of this study, that only cities of 50,000 population or less would be considered. For larger systems, the cost advantage for hyacinth systems becomes less. Setting the limit at 50,000 is somewhat arbitrary, but it appears to be a useful boundary.

There are currently 643 such cities in the Gulf Coast region, 167 in southern Florida. The total populations of these cities are 8,511,110 and 1,890,000 respectively. By the year 2000, the populations of these regions are projected to grow to 12,706,900 and 3,915,000. It is estimated that this growth will require upgrading of most existing facilities, and construction of approximately 200 completely new facilities.

TABLE 1-4. POTENTIAL IMPACT OF HYACINTH UTILIZATION

Use	Selling Price[a] ($)	Production Cost[a] ($)	Market Size Limit	% Reduction in Sewage Treatment Cost[b]
Methane	17.80	NA[c]	None	6
Mulch	30.00	20	Possible	10
Fertilizer	18.16	20-80	None	6
Cattle Feed	50.00	20-80	None	17
Silage	40.00	150	None	13

(a) For the amount produced per dry ton of harvested hyacinths.

(b) Based on $300/ton production cost for harvested hyacinths (1 mgd, hybrid design, south Florida) and assuming zero production cost for the product indicated.

(c) Not available.

In order to estimate the expenses to be incurred in these regions for the indicated expansions, it is necessary to consider the standards which treatment systems will have to meet during this time period. Perhaps the most significant influence here is PL 92-500, the Water Pollution Control Act Amendments of 1972. This Federal statute sets general guidelines which call for secondary treatment facilities for municipal systems by 1977, and utilization of the most practicable waste treatment technology by 1983. This latter means tertiary treatment in many, if not most situations. Accordingly, the period from 1977 through 1983 should be one of unprecedented activity in the installation of advanced wastewater treatment facilities, for which water hyacinths have potential applications.

If these requirements are to be met by conventional means, it is estimated that costs for upgrading existing systems will lie between \$340 and \$850 million. For new facilities the cost will lie between \$330 and \$500 million. Thus, the total expenditure for advanced treatment facilities could be from \$670 million to \$1.35 billion over the next 25 years, with the major portion expended during the next decade. For the southern Florida region alone, the combined figure is of the order of \$330 million.

It can, of course, be argued that it will in fact not prove possible to allocate these large sums for this purpose. This is a per capita expenditure of the order of \$100. However, laws now on the books and trends already in motion seem to imply this type of expenditure. Accordingly, it is taken as a starting point in determining the benefits to be derived from using hyacinth systems. What portion of these expenditures could be saved, if hyacinth systems were employed?

The most attractive of the hyacinth systems is the hybrid design, with costs approximately half those of a conventional system designed to meet the baseline standards. If these standards were universally imposed in southern Florida, hyacinth market penetration should be relatively complete, and the savings would be of the order of \$165 million over the next 25 years for this region alone. To the extent that less-stringent standards were imposed, the savings would be less. However, as argued above, the baseline standards appear to be reasonable ones for the period in question. To the extent that it proves feasible to apply hyacinth technology to the Gulf Coast region, the savings would be larger.

The institutional structure of the marketplace is rather complex. The actual purchasers of wastewater treatment technology are the local operators of treatment facilities. However, effluent standards are set by a variety of regional, state and Federal agencies. These same agencies play a role in reviewing local plans and approving funding of local developments.

The actual selection of a design concept is, however, ordinarily not done by the local authority. It is usually done by an Architect and Engineering (A&E) firm retained by the local authority. Naturally, the local authority can approve or disapprove the A&E's plan, but the initial impetus to selection of a hyacinth system would probably originate with the consultant. In any event, the consultant firm would carry out the actual design. It seems, then, that the A&E community will have to be "sold" on hyacinth systems if their use is to become widespread.

This means that verified design information will have to be available, that safety will have to be demonstrated, and demonstrations will have to be carried out at full scale, and probably over several growing seasons. Operational concepts, harvesting procedures and costs will have to be verified before the A&E's can afford to take a risk with a new technology.

Size and Character of the Market for Industrial Treatment Systems

The procurement of industrial wastewater treatment facilities is similar in most respects to the procurement of other industrial facilities. The treatment designer has the option of (1) applying for a permit to discharge treated wastewaters into an existing water body or (2) treating the wastewater to certain standards, and discharging it into a municipal system. This decision, as well as the decision as to whether to use hyacinth or conventional systems, is made by the plant engineering staff or by a consulting engineering firm retained for this portion of the design. In either case the full cost of the water treatment system is usually borne by the industrial firm, though some states have offered assistance in financing industrial treatment systems.

The major emphasis in industrial treatment systems is on removal of total solids, BOD and heavy metals. Nitrogen and phosphorus are of less significance in general, though there are specific industries for which these pollutants are of major concern. For example, phosphate rock production is one of the major industrial activities in southern Florida.

The total spending by southern Florida industries on upgraded and new wastewater systems to meet the 1977 and 1983 standards has been estimated as about $800 million. This is based on taking a fraction of the estimated $80 billion national expenditures, based on the size and characteristics of southern Florida industry.

A brief review of the major groupings of industrial activities in southern Florida indicates that, in most cases, there is a potential role for hyacinth-based systems, in view of the general capabilities of hyacinths for removal of various pollutants. However, until design studies and cost comparisons are carried out for each industry, the degree of market penetration which hyacinths could achieve is only speculative.

Conclusions

Based on the information currently available, the principal conclusions are the following:

- Under ideal conditions, water hyacinth-based systems can be designed which are highly effective in tertiary treatment of municipal wastewater.

- The only region of the U.S. which can probably realize this potential on a year-around basis is southern Florida. Along the Gulf Coast, hyacinth systems may give adequate performance, depending on the standards imposed.

- Hyacinth systems are particularly effective in nitrogen removal. Where stringent nitrogen standards are imposed, hyacinths could offer substantial advantages.

- For municipal systems designed to meet stringent effluent standards, hyacinth-based systems offer a possibility for appreciable cost/ savings over competitive processes in construction of completely new facilities. The cost advantage will be greater in many types of upgrading activities.

- There is no usage of the harvested hyacinths which can <u>now</u> be said to alter the cost comparison significantly. The market value of the potential products is too low to offer much hope for offsetting any substantial fraction of the cost of water treatment.

- Operationally verified design parameters are needed for hyacinth systems. Also, the problem of escape of the plants into downstream waters needs to be assessed.

- The total potential municipal market for new and upgraded facilities in southern Florida is of the order of $330 million between 1975 and 2000. There is a total potential municipal market of about $1 million in the larger Gulf Coast area in which hyacinth systems appear to have some degree of applicability. The industrial market in southern Florida will be of the order of $800 million.

- Hyacinth treatment systems are in a comparatively early stage of development. It is quite possible that further engineering development will improve the competitive position of hyacinth systems. Since the competing technologies are more mature, it is to be expected that these would benefit less from additional development.

- Present information on the characteristics of hyacinth systems is not adequate to bring about implementation on a significant scale. If, however, the potential advantages suggested by this analysis can be demonstrated and verified in actual use, market penetration should be rapid, at least in southern Florida.

- There are two potential ways to proceed: (1) carry out a substantial amount of additional research, to clarify all the mechanisms at work in hyacinth systems, after which design could confidently proceed; or (2) concentrate on full-scale demonstration programs, and confine research only to those problems which are identified. It is estimated that the second alternative will produce quicker results and at less cost.

- Further research on utilization of the harvested hyacinths appears to be of questionable value. Greater gains could be realized by cutting costs of the hyacinth system itself, especially in the area of harvesting and handling.

- Considering only the southern Florida municipal application, it appears that a reasonable estimate of the savings offered by hyacinth systems is $165 million over the next 25 years, with the largest share of this within the next decade.

CHAPTER 2

REVIEW OF HYACINTH CHARACTERISTICS

Introduction

Water hyacinth (*Eichhornia crassipes*), a perennial aquatic plant, is widely distributed in subtropical and tropical regions of the world. A native of Brazil, it has spread to South and Central America, Australia, China, India, Indo-China, Japan, South Africa, and the United States.[(2-1)*] Within the United States it is found in virtually all the southeastern coastal states even as far north as Virginia. However, the largest development of water hyacinth in the United States is found in tributaries of the Mississippi River in south-central Louisiana.[(2-1)]

The water hyacinth is a mat-forming aquatic plant. At maturity it consists of roots, rhizomes, stolons, leaves, inflorescences, and fruit clusters.[(2-1)] Roots vary little in diameter but range from 10.0 to 90.0 cm or more in length. In exposed situations they have a purplish color but are white when in darkness or when rooted in soil. The rhizomes generally are 1 to 2.5 cm in diameter and from 1 to 30 cm in length. The reproductive portion of the rhizomes tip varies in length from 1 cm in small plants to 4 cm in large. No severed tips shorter than 1 cm will reproduce and no decapitated rhizomes produce new shoots when more than 4 cm of the distal portion are removed. Occasionally they produce long internodes, or stolons, which are nearly horizontal in open conditions and occasionally reach 46 cm in length, while in closed stands they may be relatively short (5 cm) and nearly vertical in dense mats. These mats are frequently dense enough to support the weight of a man. They often become thick and peaty and commonly other plants terrestrial, wetland, emergent, submergent, and floating establish themselves on them.

In plants fully exposed to the sun, the leaves possess swollen portions of the petioles called floats.[(2-1)] These float leaves also have a membranous ligule, a subfloat, an isthmus, and a blade. No float is produced under crowded conditions or on plants rooted in soil.

The inflorescence is a lavender spike subtended by two bracts and surmounted on a stalk.[(2-1)] Each individual flower consists of a hypanthium, three sepals, three petals, six stamens, and a tricarpellate pistil containing a conical ovary, a long style, and a capitate stigma. The ovary produces about 500 ovules but only about 50 seeds per capsule.

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*Superscript numbers refer to entries in the reference list at the end of the chapter.

The plants have a water content of 93 to 96 percent; rhizomes and stolons possess the highest water content and leaf blades the lowest. All parts of the plant, except the seeds, float.[(2-1)] The specific gravity of parts, obtained by the volume-weight method, is given as follows:

	Mean Specific Gravity
Root	0.782 ± 0.045
Rhizome	0.905 ± 0.012
Stolon	0.818 ± 0.024
Float	0.136 ± 0.005
Leaf Blade	0.741 ± 0.053

Reproduction

Water hyacinths reproduce both sexually and vegetatively. Seeds produced through sexual reproduction, are either deposited on the hyacinth mat or fall into the water and sink to the bottom. Water hyacinth seeds require some type of scarification; physical, chemical, or biotic, for germination. Light is not necessary for germination. Seeds deposited on the floating mat can germinate there. No underwater germination has been observed.[(2-1)] Submerged seeds, although they will survive several years of submergence, apparently must be exposed to air before they germinate. Young seedlings (3 to 40 days) apparently do best rooted to a solid substrate; however, in plantlet stages (40-90 days) water hyacinths develop best on the water surface.[(2-1)]

Water hyacinths reproduce primarily by vegetative means. Rhizomes, located at each node of the stem, produce new offshoots. The average vegetative doubling rate for water hyacinths is 2 weeks. Penfound and Earle[(2-1)] estimate that in one 8-month growing season, ten hyacinth plants could produce 600,000 and cover an acre of water. In naturally occurring colonies, hyacinth mats have been observed migrating at a rate of 1 meter per month.

Growth

Productivity

There is some question as to the actual amount of plant material produced per unit time per unit space. In most cases, projections of biomass produced have been based on "optimum" growing conditions during the period of fastest growth of the hyacinth plant.[2-2,3,4] However, neither optimum conditions nor maximal growth exist continually during the growing season.

Penfound and Earle[2-1] state that relatively little hyacinth growth occurs, in the New Orleans area, from November through February. Maximum standing crop occurs around the middle of November. Standing crop, during this growing season, is illustrated in Figure 2-1. It is shown that June and September are the months in which rapid growth occurs, with a die-back taking place during late July and August. It is possible that the die-back is due to high August temperatures. However, several other limiting factors such as nutrient availability and space availability also affect growth. No conclusion as to the reason for the die-back can be made from the available data.

Assuming that the weight of the maintenance population was approximately 16 metric tons/hectare, only 8 metric tons/hectare (3.57 tons/acre) of harvestable material were produced during the growing season depicted in Figure 2-1. However, if the die-back could be attributed to reduced nutrients or space, then management (harvesting in July and October) could increase production by approximately 8 metric tons/hectare.

Wahlquist[2-5] investigated the production of hyacinths as related to water quality. Production, during the months of April-November at Auburn, Alabama, indicated a positive response to phosphate levels (Table 2-1).

TABLE 2-1. ESTIMATED FINAL STANDING CROP OF WATER HYACINTH IN FERTILIZED PONDS AT AUBURN, ALABAMA

Fertilizer[a] Treatment	Fertilizer Amount	Metric tons, Dry Weight per Hectare
0-0-0	0	8.7
0-8-0	112 kg/ha	27.5
8-8-0	112 kg/ha	20.6

Source: data modified from Reference 2-5

(a) 2.34 kg NH_4NO_3, 1.66 kg P_2O_5

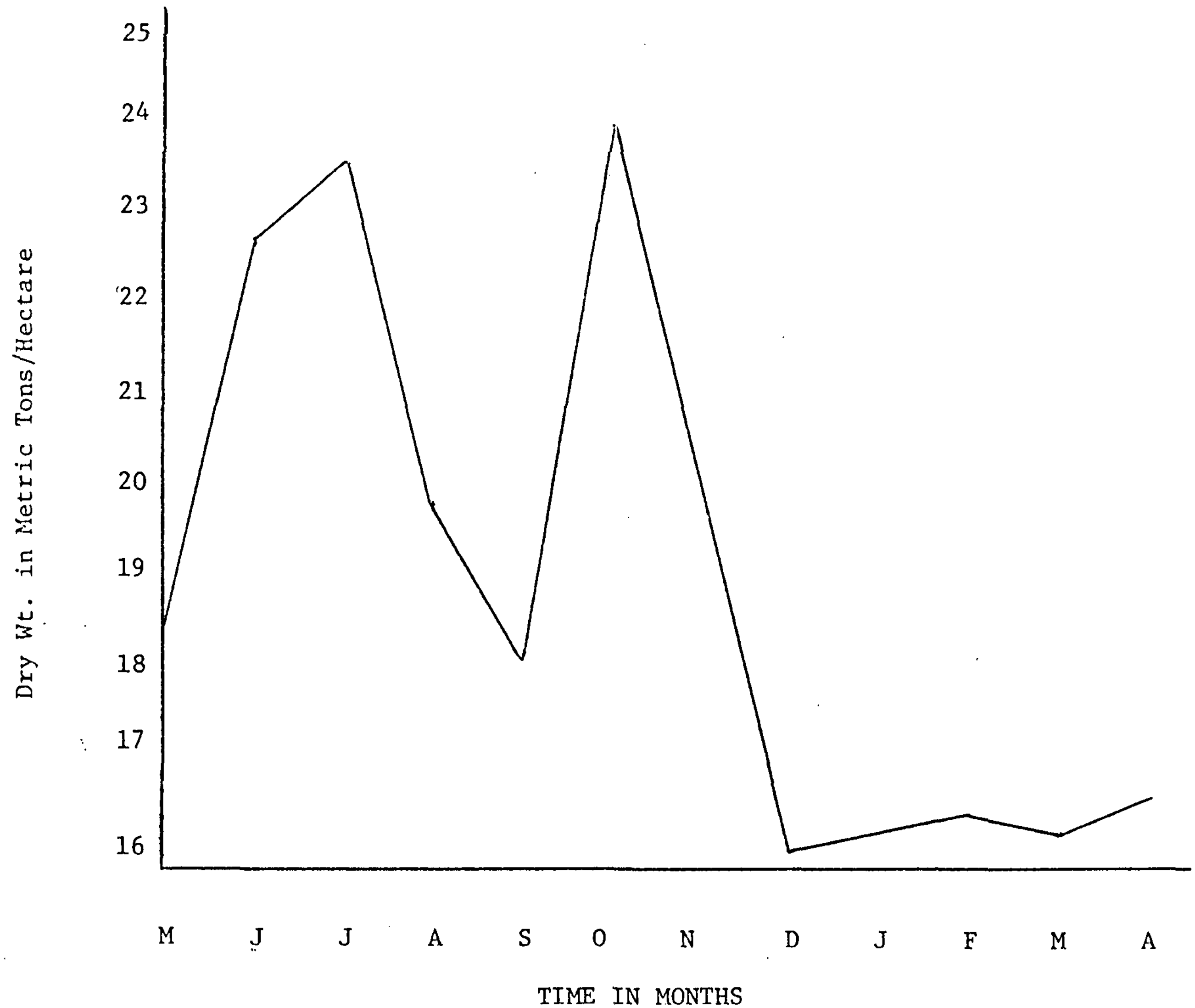


FIGURE 2-1. STANDING CROP BY MONTH

Source: data modified from reference (2-1)

Walquist had a resident population of approximately 1000 plants per test plot; no weight data of the resident population were given. However, assuming the weight of one average-sized hyacinth plant at 1 kg (95% water) Wahlquist started each trial with approximately 50/kilograms of dry plant material. As the data of Table 2-1 indicate, biomass production was rapid. Of more importance, Wahlquist's unfertilized plants produced approximately the same amount of standing crop as described by Penfound and Earle[(2-1)] (Figure 2-1). The addition of phosphorus fertilizer produced a three-fold increase in standing crop or harvestable biomass. No data are available pertaining to the effect of harvesting on biomass production.

McVea and Boyd[(2-6)] investigated the effects of water hyacinth cover on water chemistry, phytoplankton, and fish. These experiments were conducted in fertilized ponds during the growing season (May-September) at Auburn, Alabama. Sixteen applications of 1.1 kg ammonium nitrate (34% N) and 0.8 kg triple superphosphate (22% P) were broadcast over 0.04 ha ponds at 2-week intervals between February 5 and September 9, 1973. McVea and Boyd illustrated that hyacinth production is related to plant coverage as well as growing season (Table 2-2). Although there were no significant differences in hyacinth standing crop per unit area in enclosures of different sizes, total standing crop of hyacinth increased with population size[(2-6)].

There were no significant differences in the hyacinth standing crop per unit area in the enclosures of different sizes. Thus, the total crop of hyacinth was substantially proportional to the area covered and was between 19.7 and 25.2 metric tons per hectare. This is in approximate agreement with the standing crops found by Wahlquist in fertilized ponds (Table 2-1).

Westlake[(2-7)] projected annual productivity of water hyacinths in subtropical Florida (the lower one-third of the state) to be 151 metric tons/hectare per year (67.3 tons/acre per year). However, Westlake's projections assumed optimum growing conditions for all 12 months. Forester, et al, as cited by Schneider[(2-36)] found the high daily productivity of water hyacinths in

TABLE 2-2. HYACINTH STANDING CROP AT THREE LEVELS OF COVER IN 0.04-ha PONDS

Percent Cover by Hyacinth	Dry Matter Production[a]		
	kg/M^2	kg/enclosure[b]	Mectric tons/hectare[c]
5	2.58	52.2	25.8
10	2.25	91.8	22.5
25	1.97	201.8	19.7

(a) A solid line indicates no significantly differences at the 5 percent level as indicated by the Duncan's multiple range test; a broken line indicates significant differences.

(b) Enclosure represents that postion of the 0.04-ha pond, i.e., 5%, 10% or 25% in which the hyacinths were placed. Within each enclosure, 1 square meter was subsampled for comparison tests.

(c) Based on standing crop per M^2.

Florida to range from 59 to 80 metric tons/hectare per year. The authors state that these numbers may not be related to actual annual production. However, these yields represent a decrease of almost 50% from those of Westlake.

In an attempt to arrive at a realistic production regime for design purposes. Penfound and Earl's[2-1] standing crop curve has been superimposed on average maximum and minimum temperature curves for Covington, Louisiana, and Fort Myers, Florida (Figures 2-2 and 2-3). It is apparent that the standing crop and maximum temperature curves do not correlate well. From the graphs, it can be seen that April growth in Covington starts to climb rapidly when temperatures average 66 F; these temperatures are present in December at Fort Myers. Production falls quite rapidly when November temperatures average around the middle 50's F in Covington; the temperature does not go below the middle 50's F in Fort Myers. In addition, solar radiation (Langleys/day) only average 50 higher during November through May at Fort Myers; during the rest of the year, solar radiation is equal. It is concluded from this that other variables (nutritional availability, space, etc.) seem to play an important role in regulating hyacinth production.

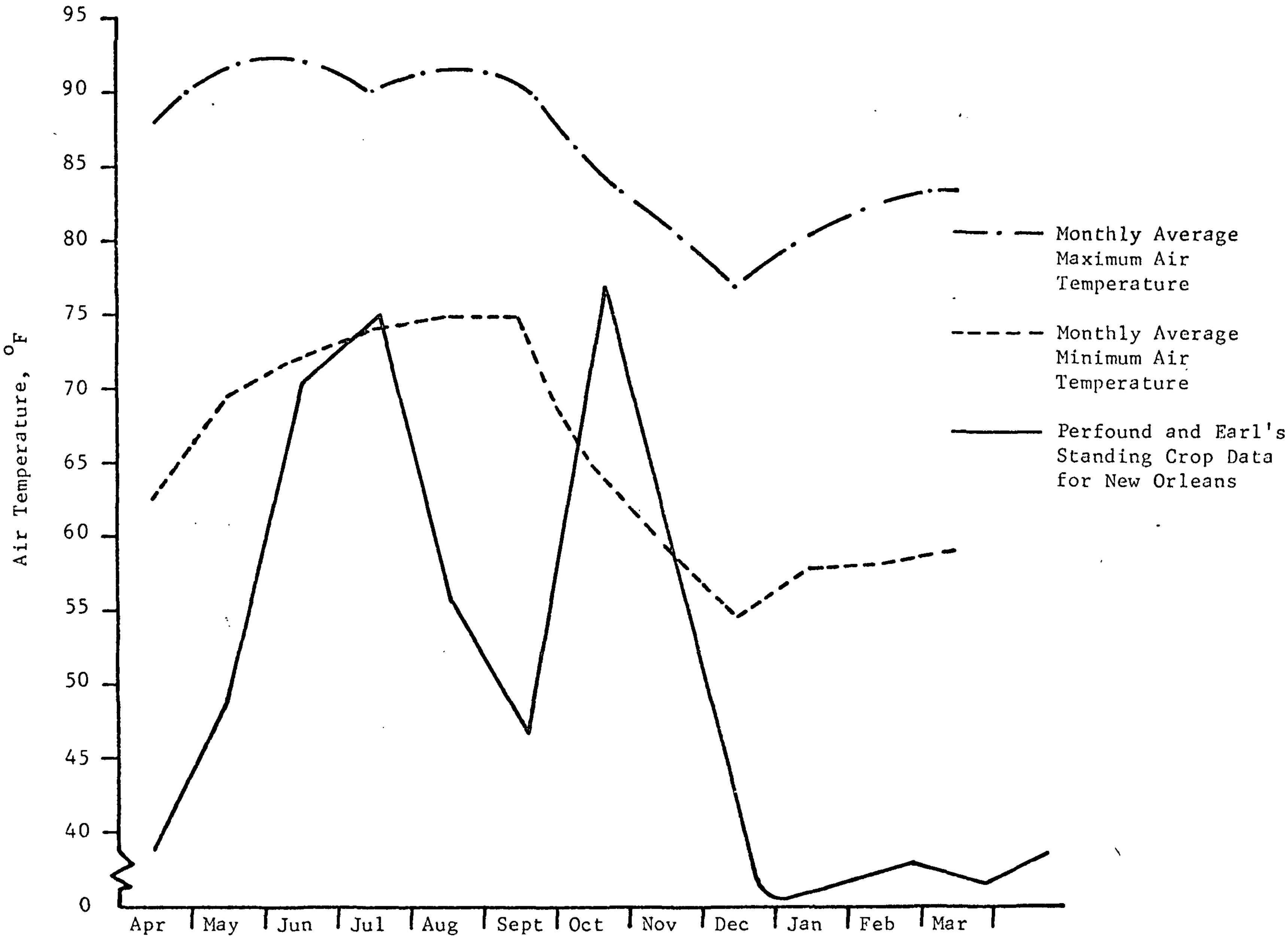


FIGURE 2-2. HYACINTH STANDING CROP IN RELATION TO AVERAGE MAXIMUM AND MINIMUM AIR TEMPERATURE AT FORT MYERS, FLORIDA (STANDING CROP ESTIMATOR FROM NEW ORLEANS AREA)

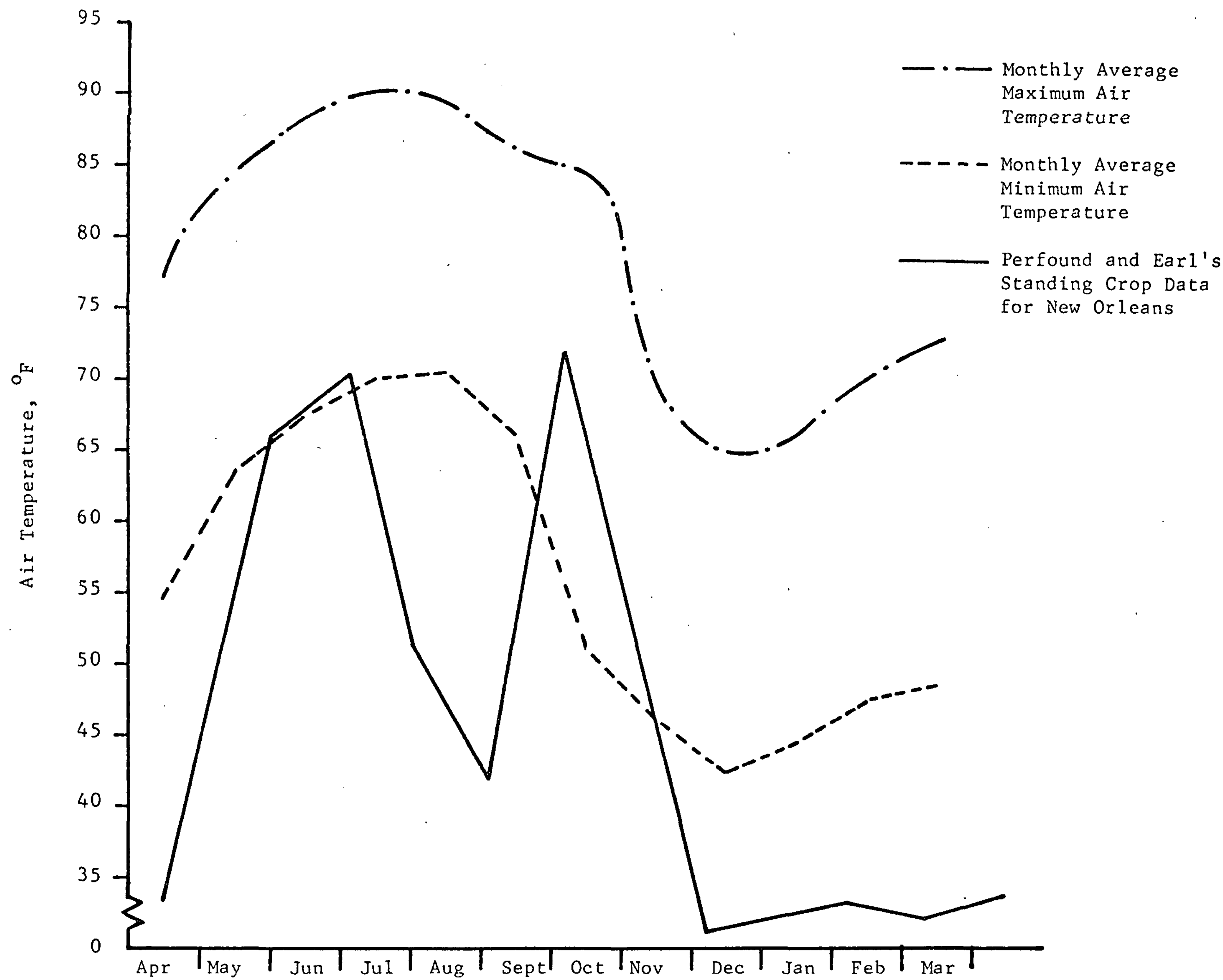


FIGURE 2-3. HYACINTH STANDING CROP IN RELATION TO AVERAGE MAXIMUM AND MINIMUM AIR TEMPERATURE AT COVINGTON, GA. (STANDING CROP ESTIMATOR FROM NEW ORLEANS AREA)

To summarize, then, available data show hyacinth production values which range from 8 to 29 metric tons/hectare per year, between 30 and 32 degrees latitude. These data involve both naturally occuring populations and controlled populations. In addition, measurements on hyacinth density and response to nitrogen and phosphorus fertilizers were documented. Based on these inputs, a range of hyacinth production potentials have been established. Values of 8, 22 and 44 metric tons/hectare per year have been used in subsequent computations. At present, it does not appear wise to confine the estimates more narrowly than this.

Only two data sources were found which pertained to water hyacinth production in south Florida. Westlake assumed optimum growing conditions throughout a 12 month growing period and calculated annual production to be 151 metric tons/hectare (67.3 tons/acre-year). Forester, <u>et al</u>, as cited by Schneider[2-36] estimated an annual production of 59.6 to 80.46 metric tons/hectare per year (26.7 to 36.1 tons/acre-year). Forester et al also stated that the data may not relate to actual conditions throughout the year. Therefore, a range of 44 to 90 metric tons/hectare per year is estimated for this region.

As part of the NSTL program, measurements are currently under way at Kennedy Space Flight Center, which is in the south Florida region as defined here.[2-37] When these measurements are complete, they should provide the most credible data yet on the productivity under field conditions south of the thirtieth parallel.

Limiting Factors

There is ample evidence that water hyacinth growth is limited by several environmental factors. For the purposes of this analysis, those variables which are of major concern to testing sewage treatment processes have been emphasized.

<u>Light</u>. The amount and quality of light is an important factor in the growth and development of the water hyacinth. Water hyacinth possesses floats only when growing in full sunlight and in solutions of high osmotic

pressures.[2-1] Float leaves are formed in early spring when full sunlight reaches the young plants and the average light intensity is above 500 foot-candles. Equitant leaves are produced as a definitive water hyacinth canopy is developed when light intensity ranges from 130 to 500 foot-candles. Death of the plant usually occurs under light conditions of less than 130 foot-candles.

Light also affects inflorescence.[2-1] It may either decelerate or accelerate anthesis. Exposure to light in the early part of the night interferes with the hormonal balance of the plant sufficiently to cause abnormalities in flowering. Acceleration occurs on exposure after midnight.

The quality of light is significant.[2-1] At either end of the spectrum (red or violet) flowering is considerably delayed. Flowering under a green filter is gradual and occurs ahead of the natural process.

Temperature. The greatest natural control over water hyacinth distribution is temperature. Water hyacinth cannot tolerate cold climates; it is highly susceptible to damage or death from frost. Penfound and Earle[2-1] found that death occurs immediately at air temperatures sufficiently low to cause freezing. A lengthy exposure at low temperatures which would not immediately kill the plants results in some dead tissue (Table 2-3). Experiments have shown that the rhizome tip is the most vulnerable part of the plant. Air temperatures lower than -2.2 C will usually kill the roots as well as the tops unless water temperatures stay above -2.2 C. A direct time-temperature correlation has been observed.

In winter months water hyacinth maintains itself and has a discontinuous growth habit. There is little production of new plant material from November until April 1 and maximum total production is not attained until August 1.[2-1] Although the normal flowering phase consumes only one night for completion in midseason, it requires a longer period at lower temperatures.[2-1] Even in shade the initial opening is usually delayed a full hour in the morning. On cold days, 12.8 to 18.3 C opening is delayed 6 hours. An average daily air temperature of 15.5C may delay opening as much as several days. Experimental evidence shows the following times required for complete opening: 10 C,

TABLE 2-3. EFFECT OF FREEZING TEMPERATURES ON WATER HYACINTHS

Temperature C	Hours Exposed					
	Injury			Resprouting		
	12	24	48	12	24	48
0.6	Blades	Blades	Blades	All	All	All
-2.8	Blades Floats	Leaves Killed	Leaves Killed	All	All	All
-5.0	Leaves	Leaves Killed		All	All	
-6.1	Leaves			Some		

Source: *Reference* (2-1).

5 days; 15.6 C, 4 days; 21.1 C, 2 days; 23.9 C, about 16 hours. Temperature has a similar effect on the bending of the peduncle and rachis subsequent to flowering.

The plant is also susceptible to excessive heat. It is unable to survive air temperatures of about 34.4 C for more than 4 or 5 weeks. During such periods, growth usually stops.

Salinity. Water hyacinths are also intolerant to salt water. They do not occur in streams or lakes with an average salinity greater than 15 percent of seawater (2,900 ppm of chloride).[(2-1)] In experiments with various dilutions of salt water only those plants in levels of 315 ppm Cl survived. Table 2-4 details the effect of salt and time. At 11,000 ppm Cl concentrations, death occurs so rapidly by wilting and crisping that epinasty does not take place. At all other concentrations the sequence is epinastic curvature of leaves to or below the water surface, chlorosis, and finally necrosis of plant parts in contact with water.

A relationship similar to that of temperature is readily apparent (Table 2-4). High concentration like low temperature results in immediate death; lower concentration, if prolonged, also can result in death.

TABLE 2-4. EFFECT OF SALINITY (CHLORIDE) ON SURVIVAL OF WATER HYACINTHS

Days Ex-posed	Observed Phenomenon	(Chloride Concentration in ppm)					
		11,000	5,500	2,750	1,370	650	315
2....	Crisping	Heavy	Slight	None	None	None	None
	Necrosis,[a] %	50	25	10	Slight	None	None
7....	Epinasty[b]		Marked	Slight	None	None	None
	Necrosis, %	100	80	25	10	None	None
14...	Epinasty		Marked	Marked	Marked	Slight	None
	Necrosis, %	100	95	80	50	20	5
21...	Epinasty		Marked	Marked	Marked	Marked	Slight
	Necrosis, %	100	100	90	60	40	10
28...	Epinasty		Marked	Marked	Marked	Marked	Marked
	Necrosis, %	Dis-carded	100	95	80	50	20

Note: modified from Reference (2-1); salinity converted to percent chloride.

(a) Necrosis - death of living tissue.
(b) Epinasty - downward bending of leaves or other plant parts.

Dissolved Oxygen. Water hyacinth is influenced by and influences dissolved oxygen. Poor health and reproduction has been observed in plants growing in waters with an average dissolved oxygen of 0.8 ppm; rapid growth has been observed in water of 3.5-4.8 ppm of dissolved oxygen.[2-1] These observations are based on a study in which a 7.5 m^2 hole was cut in an existing hyacinth mat and young plants introduced. The growth in this plot was compared to growth in hyacinth-free pools. Dissolved oxygen averaged 0.8 ppm in the hyacinth mat pool as opposed to a range of 3.5 to 4.8 ppm in the hyacinth-free pools. Growth and reproduction in the hyacinth pool was approximately one-fourth that of the other test areas.

The water hyacinth mat greatly affects the dissolved oxygen of the water below the mat. At a depth of 12.5 cm below the water surface the following dissolved oxygen levels have been observed: under close heavy mats

10.2 cm thick in peat, less than 0.1 ppm; under closed mats without peat, 0.5 ppm; under open mats, up to 80 percent cover, 1.5 ppm; and in open pools and ponds, 4.0 ppm.[(2-1)] Immediately downstream from large mats, dissolved oxygen levels are commonly below 1.0 ppm. There is no significant difference between plant parts in lowering oxygen tension.[(2-1)]

pH. Chadwick and Obeid[(2-8)] found water hyacinth growth to be affected by the pH of the water. They observed optimum growth at a pH 6.9–7.0; water hyacinth will grow in a pH range of 3.0 to 8.2.[(2-1)] Roots of water hyacinth exhibit decreased cell division and cell elongation at values below pH 4. Root dry-weight increases linearly to pH 6.9.

Haller and Sutton[(2-9)] found water hyacinth would grow in a range from a pH of 4.0-10.0 (Table 2-5). From Table 2-5, it is evident that maximum growth occurs in acid to slightly alkaline waters in a range somewhat larger than that established by Chadwick and Obeid. A comparison of the initial and final pH levels indicate that plants growing in either acid or alkaline water tend to change the pH toward neutrality.

TABLE 2-5. EFFECT OF pH ON STANDING CROP OF WATER HYACINTH PLANTS DURING A 4-WEEK GROWTH PERIOD

pH		
Initial	After 4 Weeks	Plant Dry Weight[(a)], g
2.0	1.9	0.0
4.0	4.6	18.3
6.0	6.8	15.4
7.0	7.6	13.3
8.0	7.3	14.5
10.0	8.7	9.4
12.0	9.4	-2.1[(b)]

Source: Reference (2-9).

(a) Values in a column connected by an unbroken line are not significantly different at the 5 percent level as determined by Duncan's Multiple Range Test: a broken line indicates significant differences. Each value is the mean of three replications.

(b) Negative value indicates a decrease in the weight from the estimated dry weight of plants originally placed in the containers.

Pests

Several pathogens including arthropods and fungi have been identified in studies concerned with water hyacinths (Table 2-6). Of the arthropods, only a few severely damage the plant.[2-10] The oribated mite, Orthogaluna terebrantis, causes extensive damage but infectations are sporadic. Of the grasshoppers, only Paroxya clavuliger is of importance. The most damaging member of the weavils is the Coleoptera Neochaetina bruchi and of the Noctuids, Arzama densa.

A number of fungi have also been identified as pathogens. Studies show the optimum temperature for disease development is in the range from 22-27 C.[2-11, 12] There is a marked decrease in severity of disease above 32 C.

Applicability of the Water Hyacinth

A number of applications for water hyacinths have been proposed in an effort to defray the cost of its control. Included are schemes for harvesting it to make compost, to extract chlorophyll and carotene, and produce concentrated high-protein cattle feed. It is also being considered for its potential in sewage treatment. These applications are vitally dependent on the nutrient value of the water hyacinth and its nutrient uptake capacity.

Nutrient Value

Studies of experimental feedings of protein extract from water hyacinth[2-13] indicate that the extract has a very low PER (protein efficiency ratio - grams gain/grams protein consumed) when compared to a more conventional protein, casein. Results showed a PER of 0.34 for water hyacinth extract; for casein it is 4.87. The low PER value is indicative of the deficiency of one or more amino acids. Those which have been measured[2-14] are shown in Table 2-7. Table 2-8 compares the amino acid composition of water hyacinth protein with that of other foodstuffs. The F.A.O. (Food and Agriculture Organization of the United

TABLE 2-6. PESTS ASSOCIATED WITH WATER HYACINTH

Pests	Geographic Location	Type of Damage	Reference
ARTHROPODS:			
Insecta			
Arachnida (Mites)			
Acarina			
Trombidiformes-Prostigmata-Tetranychidae (Spider mites)			
Tetranychus gloveri Banks	Louisiana, Texas	Severe, feeding on upper and lower leaf surface	2-18
Tetranychus tumidus Banks	Florida	Severe, feeding on upper and lower leaf surface	2-18
Sarcoptiformes-Oribatei-Galumnidae (Leaf-boring mites)			
Orthogalumna terebrantis Wallwork	Florida, Louisiana, South America, Jamaica	Strip epidermis of the upper surface of leaves	2-18, 2-19, 2-20
Leptogalumna sp.	South America	Leaf mining	2-20
Orthoptera (Grasshoppers)			
Acrididae (Short-horned grasshoppers)			
Dichromorpha viridis (Scudder)	Florida	Foliage	2-18
Schistocerca obscura (F.)	Florida	Foliage	2-18
Paroxya clavuliga (Serville)	Florida	Foliage	2-18
Metaleptea brevicornes (L.)	Louisiana	Foliage	2-18
Cornops scudderi (Bruner)	British Honduras	Moderate damage to leaves	2-19
Tettigoniidae (Long-horned grasshoppers)			
Orchelimum agile (DeGeer)	Florida	Foliage	2-18
Conocephalus sp.	Louisiana	Foliage	2-18
Coleoptera (Weevils)			
Sphenophorus sp.	Florida, Louisiana	Bore into the base of land-rooted plants	2-18, 2-19
Onychylis sp. nr. *nigrirostris* (Boheman)	Florida, Argentina	Feed on leaves	2-18, 2-19
Neochaetina bruchi (Hust.)	South America	Nibbles plant and bores stems	2-19, 2-20
Lepidoptera (Moths)			
Noctuoidea-Noctuidae			
Arzama densa Walker	Florida, Louisiana, Texas	Feed on young and tender parts; bore deep into stocks	2-18, 2-19
Noctuoidea-Arctiidae			
Diacrisia virginica (F.)	Florida, Louisiana, Texas	Feed on low herbage	2-18
Pyraloidea-Pyralidae			
Hymenia perspectolis (Hübner)	Florida	Feed externally on stems and leaves	2-18
Nymphuline spp.	Louisiana, Texas	Leaves are used for larvae cases	
Acigona ignitalis	South America	Extensive	2-20
Epipagis albiguttalis Hmps.	South America	Extensive	2-20
Samea multiplicals	Trinidad	Attacks small plants	2-19
FUNGI			
Ascomycotina			
Loculoascomycetes			
Mycosphaerella sp.	Florida (Laboratory study)	Slight	2-21
Deuteuromycotina			
Coelomycetes			
Phoma spp.	Florida (Laboratory study)	Varies-moderate to none	2-21
Botryodiploidea sp.			
Hyphomycetes			
Mycoleptodiscus terrestris	Florida (Laboratory study)	Slight to none	2-21
Acremonium (*Cephalosporium*) *zonatum*	Florida (Laboratory study)	Extensive	2-21
Bipolaris spp.	Florida (Laboratory study)	Extensive	2-21
Cercospora sp.	Florida (Laboratory study)	Extensive	2-21
Curvularia pennisetí	Florida (Laboratory study)	Slight	2-21
Perionia echinochloae	Florida (Laboratory study)	Slight	2-21
Cephalosporium zonatum	Panama, Louisiana	Zonal leaf spot	2-10, 2-22
Fusarium roseum	Florida	Necrotic lesions, preceded by chlorosis and vascular discoloration	2-10, 2-11
Myrothecium roridum	India	Necrotic lesions, moderate to extensive	2-23
Rhizoctonia solani	Florida, Panama	Severe	2-12, 2-10
Teleomycetes			
Uredo eichhorniae	South America	Rust	2-21

Nations) minimum daily requirements listed for an adult male show water hyacinth to be deficient in only two of the essential amino acids, valine and methrionine.(2-15, 2-16- 2-17) However, the amino acids composition of water hyacinth protein is generally in lower concentrations than the other foodstuffs listed. Water hyacinth may be a useable food source if used in conjunction with a balanced protein source, but nutritionally it remains inferior to more traditional food sources.

TABLE 2-7. AMINO ACID COMPOSITION OF WATER HYACINTHS, EXPRESSED AS PERCENT OF DRY WEIGHT

Protein	Percent[b]
Crude Protein	26.21
Actual Protein	19.55
Lysine[a]	1.30
Histidine[a]	0.43
Arginine[a]	1.24
Aspartic Acid	2.64
Threonine[a]	0.98
Serine	0.95
Glutamic Acid	2.46
Proline	0.97
Glycine	1.16
Alanine	1.37
Cystine	0.05
Valine[a]	1.13
Methionine[a]	0.34
Iso leucine[a]	0.99
Leucine[a]	1.77
Tyrosine	0.77
Phenylalanine[a]	1.00

Source: Reference (12-14)

(a) Essential Amino Acid.

(b) Data based on dry weight of the entire plant in this table whereas Table 2-8 is based on grams of amino acids per 100 grams of protein, and therefore comparison is difficult between the tables.

Table 2-8. AMINO ACID CONTENT OF PROTEIN IN WATER HYACINTH COMPARED TO OTHER FOODSTUFFS AND THE F.A.O. REFERENCE PATTERN (IN GRAMS PER 100 GRAMS OF PROTEIN)

Foodstuffs	Amino Acids								
	Methionine	Phenylalanine	Threonine	Lysine	Isoleucine	Valine	Leucine	Cystine[a]	Tyrosine[a]
Water Hyacinth	0.7	4.7	4.3	5.3	4.3	0.3	7.2	11.6	3.0
Clover	1.7	6.1	5.4	6.8	5.3	6.8	9.5	0.7	4.4
Rye Grass[b]	2.1	6.1	5.1	6.6	5.2	6.4	9.1	0.9	4.5
Wheat[b]	2.6	6.1	5.2	6.5	4.9	6.2	9.6	0.8	4.1
Corn[b]	2.1	5.8	4.8	6.4	6.4	6.7	9.9	0.6	4.0
F.A.O.[c]	2.2	2.8	2.8	4.2	4.2	4.2	4.8	1.9	2.8
Milk	3.4	5.7	4.5	8.2	8.5	8.5	11.3	-	5.3
Meat, poultry, fish	3.3	4.9	4.6	8.1	6.3	5.8	7.7	-	3.4
Eggs	4.1	6.3	4.3	7.2	8.0	7.3	4.2	-	4.5
Potatoes, vegetables fruits	2.3	4.5	4.1	5.7	3.6	4.4	6.6	-	5.4

Source: References (2-16 and 2-17)

(a) Non essential

(b) Data based on leaf protein concentrates not on grain protein.

(c) The F.A.O. Reference pattern is based on a diet containing an adequate protein level (1 gram protein per kilogram of body weight per day) and it details the quantity of each amino acid which should be in that protein to assure a balanced diet. For example out of 100 grams of protein 2.2 grams (2.2 g %) should be Methionine.

Seasonal variations in composition were demonstrated in the work of Boyd and Blackburn.(2-24) Table 2-9 shows that the crude protein and cellulose content peak in May at a time when dry matter is lowest. Crude protein and true protein usually follow similar trends.

TABLE 2-9. SEASONAL CHANGES IN THE PROXIMATE COMPOSITION OF WATER HYACINTH IN SOUTHERN FLORIDA, PERCENT DRY WEIGHT

Time of Collection	Percent Dry Matter	Crude Protein	Ether Extract	Cellulose
April	5.0	22.0	5.29	25.7
May	5.0	23.5	5.60	26.7
June	8.0	18.2	3.75	22.8
July	7.3	15.7	5.11	21.6
August	7.0	19.4	3.84	20.4

Source: Reference (2-24)

The relationship of protein to other constituents in the water hyacinth has been determined (Table 2-10).(2-14) The data indicate that cattle grazing on cattle these require enormous quantities for good flesh and milk production.

In addition to seasonal changes mentioned earlier the nutrient content of water hyacinth varies with location and water quality.(2-25) Table 2-11 illustrates some of these differences. The relatively high ash content of water hyacinth from the first four sites was reportedly caused by the roots being in contact with the bottom sediment. Of greater significance is the C:N ratio (23:1 average). It ranks within the 20:1 to 30:1 range of legumes and is much lower than the 90:1 ratio of most straws.

TABLE 2-10. ANALYSIS OF WATER HYACINTH

Constituent	Percentage on Moisture-Free Basis[a] Tops	Roots
Total ash	21.00	25.58
Fat (ether extract)	1.01	0.60
Crude fiber	28.08	22.01
Crude protein[b]	7.49	7.83
Nitrogen-free extract	42.43	43.98
Calcium	2.22	1.68
Phosphorus	0.48	0.47
Chlorides (as chlorine)	5.95	3.43
Chlorides (as NaCl)	9.82	5.65

Source: Reference (2-14)

(a) Sample: Water hyacinth (sun dried) plants 3 to 4 inches high collected June 26, 1946, New Orleans, Louisiana. Analysis furnished through the courtesy of Division of Forage Crops and Diseases, BPISAE, USDA.

(b) Total crude protein can be calculated by adding values for tops and roots. This total value is comparable to data in Tables 2-7 and 2-9.

The content of other macronutrients shown in Tables 2-12 and 2-13 is comparable to those of most feed and forage plants.[2-25]

Nutrient Uptake and Growth Rate

An essential role of the water hyacinth in sewage treatment applications is its ability to utilize nutrients.

Dunigan et al[2-26] demonstrated a high removal of ammonia- and nitrate-nitrogen from waters in which water hyacinth was growing in the laboratory and in farm ponds (Figure 2-2). The rate of nitrate ion uptake was slower than ammonium ion. Phosphate-phosphorus uptake was less than either nitrate or ammonium ion. Field studies showed variations between

TABLE 2-11. CHEMICAL COMPOSITION BASED ON DRY WEIGHT OF WATER HYACINTHS COLLECTED FROM VARIOUS BODIES OF WATER IN FLORIDA, PERCENT

Origin	Ash	C	N	C/N ratio	P	K	Ca	Mg	Na
Lake Istokpoga (Sebring)	24.4	18.0	1.08	16.7	0.14	1.00	0.73	0.38	0.15
Lake Eden Canal (SR 532)	19.4	28.0	0.86	33.5	0.09	1.95	0.46	0.31	0.23
Lake Thonotosassa	23.0	23.0	1.17	19.7	0.33	3.35	1.49	0.29	0.21
Waverly Creek (SR 60)	25.0	33.1	2.26	14.6	0.56	3.10	1.58	0.50	0.37
Arbuckle Creek	23.4	34.9	1.90	18.4	0.23	3.35	1.06	0.49	0.28
Lake Tohopekaliga (Kissimmee)	21.7	34.0	1.69	20.1	0.60	4.70	1.56	0.71	0.53
Lake Monroe (Sanford)	20.4	32.5	2.86	11.4	0.59	5.55	1.73	0.54	0.83
Duda Canal No. 1 (Belle Glade)	20.3	39.1	1.30	30.1	0.13	3.80	1.99	0.60	0.48
St. Johns River (Astor)	20.1	36.4	2.33	15.6	0.51	6.50	1.43	0.51	0.63
W. R. Grace Landfill (Bartow)	19.0	36.4	1.86	19.6	0.59	2.72	1.99	0.56	1.54
Ponce de Leon Springs	18.5	37.5	1.74	21.5	0.33	5.40	2.34	0.50	0.47
Waverly Creek (SR 540)	18.5	38.1	1.76	21.6	0.32	4.85	1.45	0.55	0.67
Duda Canal No. 2 (Belle Glade)	17.5	37.8	1.66	22.8	0.15	4.70	2.28	0.69	0.57
Lake Alive (N. of Fla.)	17.3	38.6	1.17	33.0	0.40	3.66	2.41	0.69	0.40
Lake Apopka (Montieverde I)	15.8	38.8	1.22	31.8	0.14	4.26	2.07	0.54	0.41
St. Johns River (Palatka)	15.8	38.0	18.2	20.9	0.16	3.44	1.83	0.73	0.86
Lake George	15.4	40.2	1.48	27.1	0.21	3.21	1.91	1.86	1.24
Lake Apopka (Monteverde II)	14.9	39.8	1.36	29.3	0.09	4.08	1.96	0.60	0.21
Lake East Tohopekaliga (St. Cloud)	14.7	37.2	1.08	34.5	0.23	2.90	1.19	0.51	0.53
MEAN	19.2	34.9	1.61	23.3	0.31	3.81	1.66	0.56	0.56
Standard deviation	3.2	5.9	0.50	7.0	0.18	1.30	0.53	0.14	0.36

Source: Reference (2-25)

TABLE 2-12. ALUMINUM AND SOME HEAVY METAL CONCENTRATIONS BASED ON DRY WEIGHT OF WATER HYACINTHS COLLECTED FROM BODIES OF WATER IN FLORIDA, PPM

Origin	Al	Cr	Cu	Fe	Pb	Mn	Zn
Lake Istokpoga (Sebring)	6050	35	3	8125	20	408	53
Lake Eden Canal (SR 532)	1850	8	8	3250	ND[(a)]	295	39
Lake Thonotosassa	1950	5	5	775	10	203	27
Waverly Creek (SR 60)	6750	8	13	5625	ND	238	81
Arbuckle Creek	3250	5	3	2000	ND	225	48
Lake Tohopekaliga (Kissimmee)	6350	10	8	5125	10	560	61
Lake Monroe (Sanford)	2250	5	40	2125	ND	310	192
Duda Canal No. 1 (Belle Glade)	150	ND	5	375	10	115	15
St. Johns River (Astor)	2900	ND	8	525	ND	170	100
W. R. Grace Landfill (Bartow)	9290	10	5	1940	ND	279	18
Ponce de Leon Springs	50	3	3	800	10	615	32
Waverly Creek (SR 540)	3000	3	8	3125	ND	193	45
Duda Canal No. 2 (Belle Glade)	250	ND	8	500	ND	68	26
Lake Alice (U. of Fla.)	853	ND	10	657	10	402	69
Lake Apopka (Monteverde I)	298	ND	5	160	10	122	22
St. Johns River (Palatka)	1181	ND	10	1150	10	464	69
Lake George	904	ND	10	755	10	287	51
Lake Apopka (Monteverde II)	425	ND	5	135	20	219	39
Lake East Tohopekaliga (St. Cloud)	1050	3	8	15500	10	253	107
MEAN	2658	-	9	2772	-	286	58
Standard Deviation	2668	-	8	3765	-	147	42

Source: Reference (2-25)

(a) None detected.

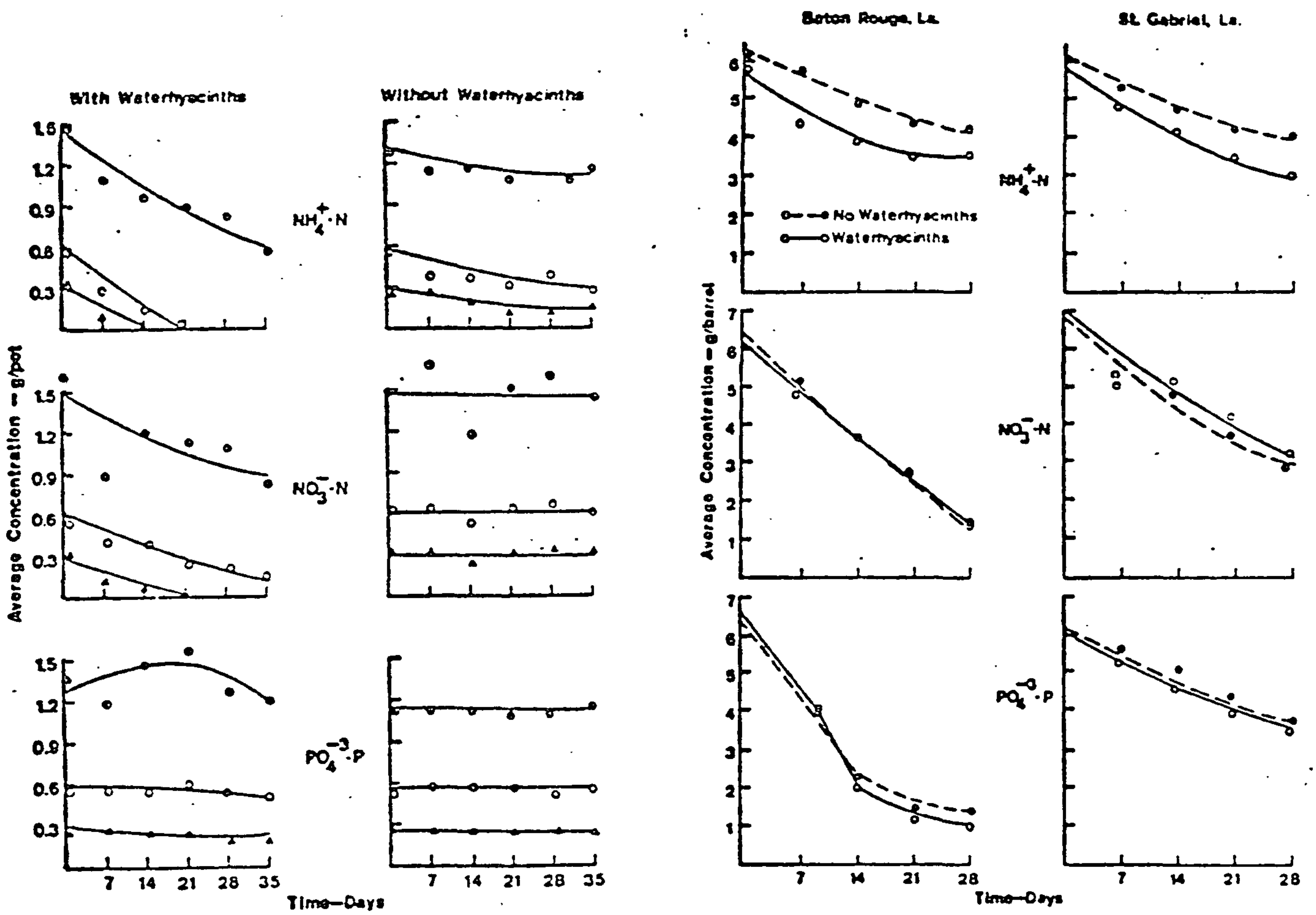
TABLE 2-13. IONS EXTRACTED WITH WATER FROM GROUND (20 μ) OVEN DRIED (70 C) WATER HYACINTHS COLLECTED FROM VARIOUS BODIES OF WATER IN FLORIDA

Origin	Cl	K	Na	Ca	Mg	P	Al	Cr	Fe	Mn	Zn
			(%)					(ppm)			
Lake Istokpoga (Sebring)	0.61	0.94	0.11	0.08	0.15	138	61	1	46	47	5
Lake Eden Canal (SR 532)	3.03	1.27	0.14	0.10	0.12	114	446	1	11	52	8
Lake Thonotosassa	2.09	0.31	0.19	0.14	0.20	2580	6	2	8	32	5
Waverly Creek (SR 60)	1.93	2.59	0.31	0.14	0.23	2360	30	4	62	27	11
Arbuckel Creek	2.04	2.75	0.19	0.07	0.52	808	61	1	48	53	16
Lake Tohopekaliga (Kissimmee)	2.75	3.52	0.37	0.10	0.38	1408	ND[a]	2	36	99	22
Lake Monroe (Sanford)	4.95	4.07	0.65	0.20	0.33	3724	ND	14	28	44	54
Duda Canal No. 1 (Belle Glade)	2.92	3.41	0.40	0.21	0.40	572	ND	2	6	35	8
St. Johns River (Astor)	3.91	4.24	0.48	0.10	0.37	3129	ND	2	11	27	31
W. R. Grace Landfill (Bartow)	2.70	2.26	1.29	0.25	0.45	3190	6	ND	48	79	3
Ponce de Leon Springs	3.03	3.74	0.36	0.18	0.27	1760	ND	1	13	109	7
Waverly Creek (SR 540)	2.97	3.58	0.52	0.08	0.38	1705	ND	3	56	44	11
Duda Canal No. 2 (Belle Glade)	6.11	6.49	0.75	0.30	0.73	990	ND	5	14	25	18
Lake Alice (U. of Fla.)	4.68	5.50	0.54	0.29	0.70	2576	ND	3	12	54	10
Lake Apopka (Monteverde I)	2.59	3.74	0.32	0.20	0.35	869	ND	1	5	32	4
St. Johns River (Palatka)	2.70	2.75	0.61	0.13	0.46	808	22	2	28	147	16
Lake George	3.08	2.64	0.94	0.11	0.56	929	22	2	24	96	15
Lake Apopka (Monteverde II)	2.20	3.19	0.13	0.11	0.34	1105	40	1	5	59	13
Lake East Tohopekaliga (St. Cloud)	1.43	2.26	0.43	0.04	0.29	512	121	2	47	449	22
MEAN	2.93	3.12	0.46	0.15	0.38	1542	-	-	35	58	15
Standard Deviation	1.27	1.47	0.30	0.08	0.16	1089	-	-	38	33	12

Source: Reference (2-25)

(a) None detected.

sites (Table 2-14) and that the plants are less effective in removing nitrate-nitrogen and phosphate-phosphorus in the field than in the laboratory or in farm ponds. Higher weight gains were recorded at Baton Rouge than at St. Gabriel.



A

In 6 liters of water, with and without one water hyacinth plant grown in a greenhouse.

B

In 220 liter bottomless barrels with and without water hyacinth plants grown in two farm ponds.

FIGURE 2-4. UPTAKE OF N AND P BY WATER HYACINTHS

Source: Reference (2-26)

TABLE 2-14. THE AVERAGE WEIGHT GAIN AND PLANT INCREASE OF WATER HYACINTHS GROWN IN FARM PONDS EXPERIMENTALLY ADJUSTED TO CONTAIN 6 GRAMS OF N OR P PER CONTAINER

Average Plant Parameters	Location: Baton Rouge, N in the form of NH_4	Baton Rouge, N in the form of NO_3	Baton Rouge, P in the form of PO_4	St. Gabriel, N in the form of NH_4	St. Gabriel, N in the form of NO_3	St. Gabriel, P in the form of PO_4
Original weight - (g)	358	383	343	355	355	340
Final weight - (g)	1618	1695	1445	1070	1225	1278
Gain in weight - percent	452	443	421	301	345	376
Final number of plants[b]	-	-	-	13	12	15

Source: Reference (2-26)

(a) Test duration: 28 days.

(b) Three plants were placed in each barrel on day 0.

McVea and Boyd[(2-6)] have shown that rates of growth and uptake of nitrogen and phosphorus are relatively uniform (Table 2-15). Although there is not great difference in production of water hyacinth per unit area in enclosures of different sizes, the total production increased with population size. Removal of nitrogen and phosphorus is correlated positively with the amount of cover.

Table 2-16 shows the correlations between pH, phosphorus and nitrogen uptake, chemical oxygen demand and season. Values for pH are highest with 7 percent cover and lowest with 10 to 25 percent. These differences were related to CO_2 uptake by phytoplankton during photosynthesis.[(2-6)] Plants absorbed considerable amounts of nitrogen and phosphorus. Some phosphorus is also lost to absorption by muds and nitrogen by denitrification in muds and ammonia volatilization, Difference in COD values (Table 2-17) reflect phytoplankton abundance.

TABLE 2-15. TOTAL DRY MATTER PRODUCTION AND N AND P UPTAKE BY WATER HYACINTH AT THREE LEVELS OF COVER IN 0.04-ha PONDS[a]

Size of Enclosures	Cover by Water Hyacinth	Dry Matter Production		Nutrient Uptake: Nitrogen	Nutrient Uptake: Phosphorus
m.	percent	kg/m^2	Kg/ enclosure	Kg/ enclosure	Kg/ enclosure
3.18 x 6.36	5	2.58	52.2	0.91	0.11
4.50 x 9.00	10	2.25	91.8	1.37	0.20
7.12 x 14.21	25	1.97	201.8	2.57	0.36

Source: Reference (2-6)

(a) Values connected by the same line in each column are not significantly different at the 5 percent level, as indicated by Duncan's Multiple Range Test; broken lines indicate significant differences.

TABLE 2-16. AVERAGES FOR pH AND CONCENTRATIONS OF SOLUBLE INORGANIC P, TOTAL P, NITRATE, AND CHEMICAL OXYGEN DEMAND (COD) IN WATERS OF 0.04-ha PONDS WITH FOUR DIFFERENT LEVELS OF WATER HYACINTH COVER[(a)]

Measurement	Percent Cover by Water Hyacinth	Date: 17 May	15 June	13 July	3 Aug.	17 Aug.	7 Sept.
pH	0	8.3	9.1	8.8	7.8	8.7	9.1
	5	8.8	7.3	9.7	7.3	9.1	8.2
	10	8.2	7.1	8.4	7.0	7.4	7.9
	25	7.5	7.5	7.4	6.8	7.0	7.0
PO_4-P, m g/liter	0	0.07	0.01	0.06	0.01	0.06	0.08
	5	0.02	0.01	0.08	0.01	0.03	0.06
	10	0.09	0.08	0.07	0.01	0.03	0.02
	25	0.12	0.01	0.08	0.01	0.01	0.01
Total P, m g/liter	0	0.20	0.15	0.20	0.13	0.35	0.32
	5	0.11	0.10	0.20	0.06	0.27	0.21
	10	0.15	0.09	0.17	0.06	0.11	0.13
	25	0.22	0.02	0.11	0.02	0.07	0.12
NO_3-N, m g/liter	0	0.17	0.19	0.29	0.19	0.08	0.01
	5	0.17	0.18	0.16	0.12	0.08	0.02
	10	0.24	0.16	0.19	0.08	0.01	0.01
	25	0.26	0.13	0.26	0.09	0.02	0.01
COD, m g/liter	0	13.8	13.9	19.6	54.2	-	30.7
	5	20.9	21.2	25.6	45.7	-	30.9
	10	15.4	15.4	17.3	34.8	-	18.9
	25	14.6	13.7	26.5	33.0	-	11.3

Source: Reference (2-6)

(a) Values connected by the same line in each column are not significantly different at the 5 percent level; a broken line indicates significant differences.

TABLE 2-17. AVERAGE CONCENTRATIONS OF DISSOLVED OXYGEN ON SELECTED DATES IN WATERS OF 0.04-ha PONDS WITH FOUR DIFFERENT LEVELS OF WATER HYACINTH COVER[a]

Date	Percent Cover by Water Hyacinth 0	5	10	25
	mg/liter			
25 July	10.8	10.4	9.9	7.7
30 July	8.5	7.3	7.4	5.5
6 Aug.	8.4	7.8	7.0	5.2
13 Aug.	9.9	8.4	7.8	5.5
17 Aug.	8.3	7.1	7.6	6.0

Source: Reference (2-6)

(a) Values connected by the same line in each column are not significantly different at the 5 percent level; a broken line indicates significance.

Haller and Sutton[2-9] examined the effect of phosphorus concentration on growth and the uptake of phosphorus by various parts of the plant. As determined by dry weight measurements, growth was greatest in a medium containing 20 ppm phosphorus (Table 2-18). Concentrations higher than 40 ppm proved to be toxic to the plant. Separation of the leaves, stems, and roots (Table 2-19) shows that weights of leaves and stems followed a growth pattern similar to the whole plant. Again, 20 ppm was the optimum concentration. Maximum accumulation occurs in 40 ppm solution. Seedlings and immature plants have higher concentrations by weight than mature plants. Lack of phosphorus in nutrient solutions apparently limits root growth.

A number of investigators have examined the ability of water hyacinth to take up various heavy metals.[2-27-30] Sutton and Blackburn[2-27] showed that it is effective in the removal of copper (Figure 2-5). Lead and mercury are removed in amounts of 0.176 and 0.150 mg/g dry plant material

TABLE 2-18. DRY WEIGHT OF WATER HYACINTH PLANTS GROWN IN NUTRIENT SOLUTIONS WITH DIFFERENT PHOSPHORUS CONCENTRATIONS

Phosphorus Concentration, ppm	Plant Dry Weight,[a] g			
	Leaf	Stem	Root	Total
0	4.4	6.0	6.8	17.2
5	7.8	10.9	3.5	22.2
10	9.2	12.6	3.9	25.6
20	11.7	16.5	4.4	32.6
40	8.6	10.7	3.9	23.2

Source: Reference (2-9)

(a) Values in a column connected by the same line are not significantly different at the 5 percent level, as determined by Duncan's Multiple Range Test; a broken line indicates significant differences. Each value is the mean of three replications.

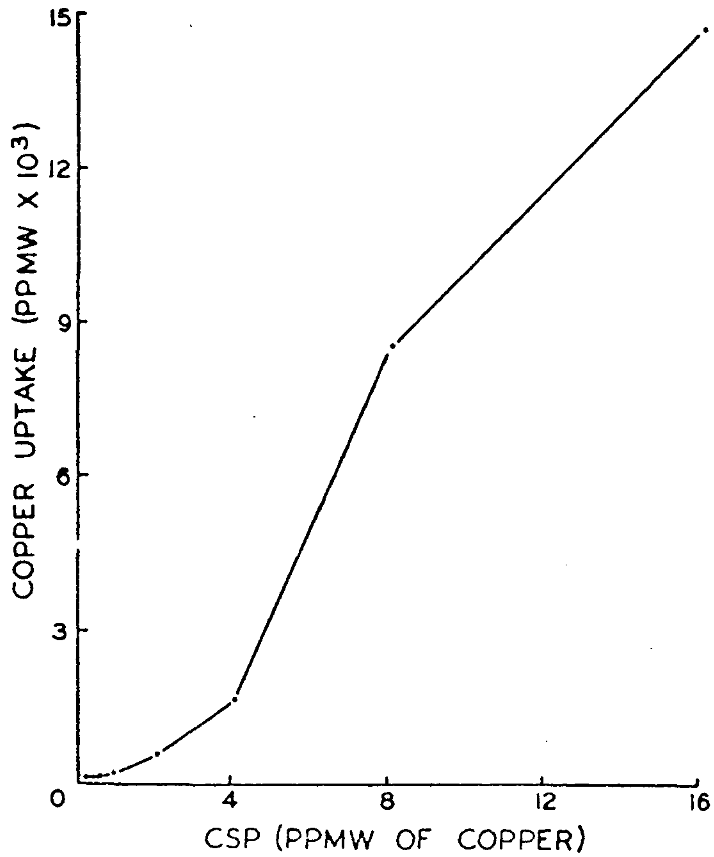
TABLE 2-19. PHOSPHOROUS CONTENT OF THE LEAVES, STEMS, AND ROOTS OF WATER HYACINTH PLANTS GROWN IN NUTRIENT SOLUTIONS WITH DIFFERENT PHOSPHORUS CONCENTRATIONS

Phosphorus Concentration, ppm	Phosphorus Content[a], mg/g dry plant wt			
	Leaf	Stem	Root	Total[b]
0	1.17	0.71	0.96	0.98
5	4.96	3.00	1.97	3.77
10	6.77	4.80	3.12	5.52
20	8.16	6.73	6.05	7.22
40	8.80	9.30	9.26	9.07

Source: Reference (2-9)

(a) Values in a column connected by the same line are not significantly different at the 5 percent level, as determined by Duncan's Multiple Range Test; a broken line indicates significant differences. Each value is the mean of three replications.

(b) Phosphorus content of the whole plants was calculated using the percent of plant weight in the leaves, stems, and roots and the phosphorus content of these parts as a weighted average.



CONCENTRATION OF CSP (COPPER SULFATE PENTAHYDRATE) EXPRESSED AS PPMW OF COPPER

FIGURE 2-5. UPTAKE OF COPPER BY WATER HYACINTH

Source: Reference (2-27)

from distilled water and river water in a 24-hour period.[(2-29)] Cadmium and nickel are absorbed and concentrated in amounts of 0.67 mg and 0.50 mg/g of dry plant material, respectively, when exposed for a 24-hour period to waters polluted with from 0.578 to 2.00 ppm of these toxic metals.[(2-30)]

A similar study was made for the removal of phenol. It is taken up from distilled water, river water, and bayou water at a rate of 36 mg/g of dry plant material over a 72-hour period.

Scarbrook and Davis(2-31) compared the growth of water hyacinth in well water and 25 percent sewage. They observed a dry weight of 59.0 g in well water and 736.6 g in 25 percent sewage after 23 weeks. Initial dry weight of the plants was 2.0 g. These numbers represent a production of .1 and 1.2 metric tons/hectare for the entire growing season. The nitrogen, phosphorus and potassium contents of the plants are shown in Figures 2-6 through 2-8.

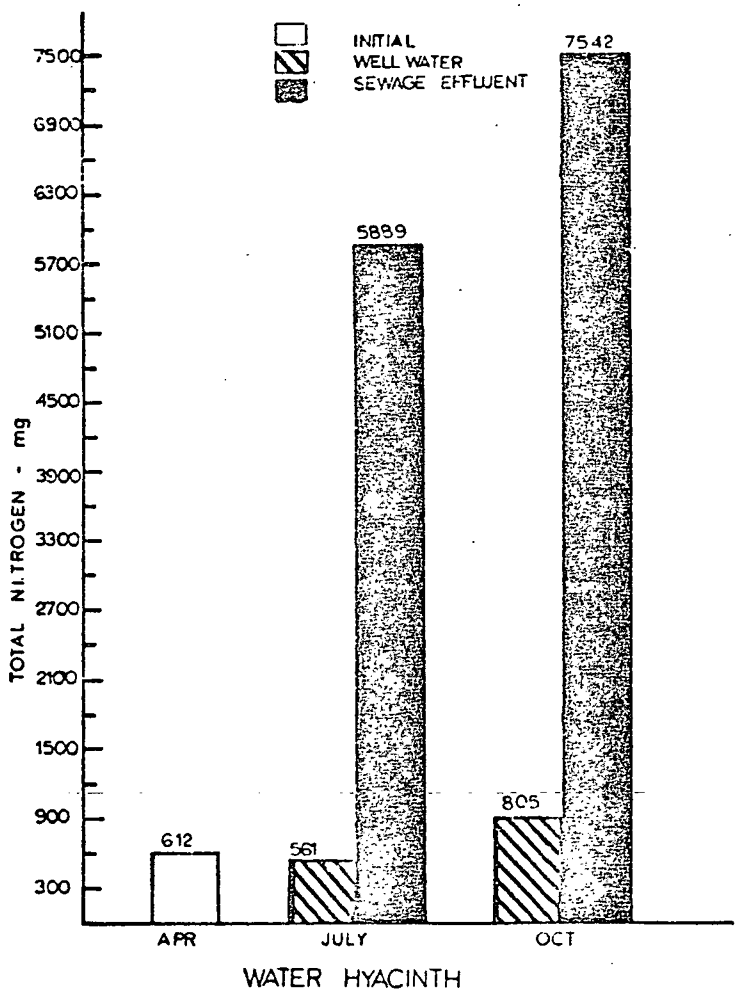


FIGURE 2-6. NITROGEN CONTENT OF WATER HYACINTH WHEN STOCKED IN APRIL, AT THE JULY HARVEST, AND THE SUM OF THE JULY AND OCTOBER HARVESTS

Source: Reference (2-31)

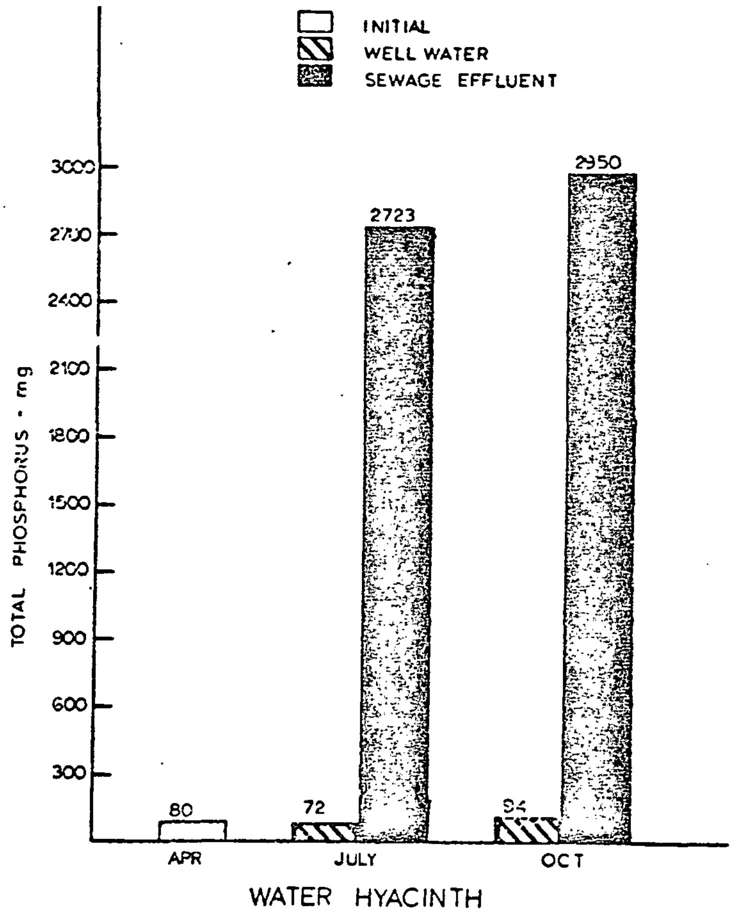


FIGURE 2-7. PHOSPHORUS CONTENT OF WATER HYACINTH WHEN STOCKED IN APRIL, AT THE JULY HARVEST, AND THE SUM OF THE JULY AND OCTOBER HARVESTS

Source: Reference (2-31)

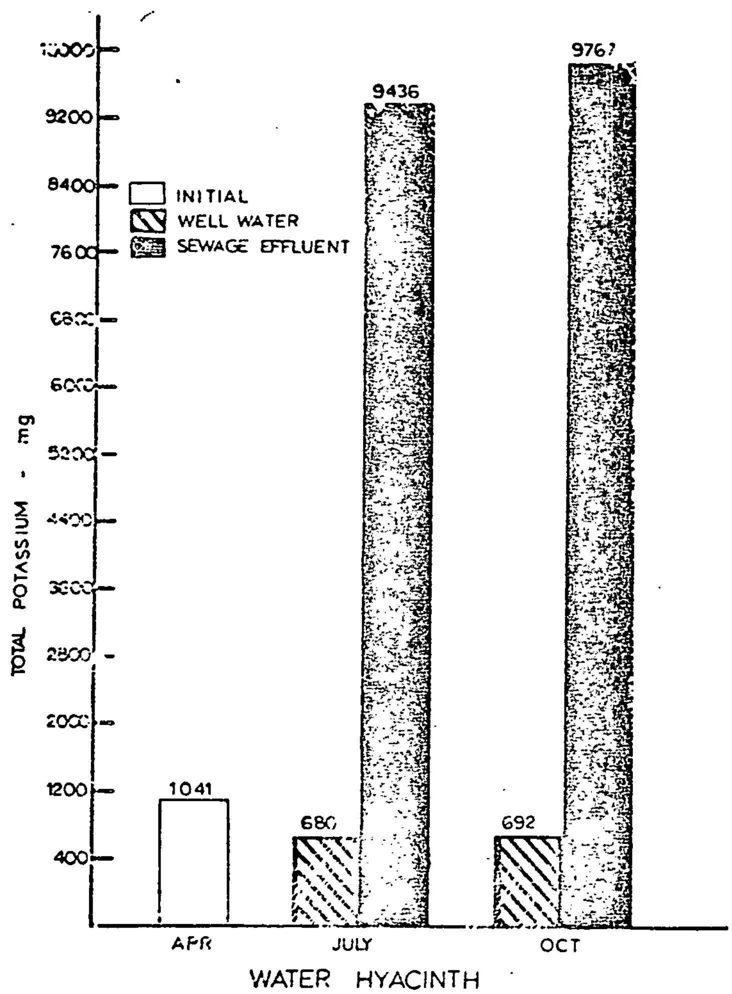


FIGURE 2-8. POTASSIUM CONTENT OF WATER HYACINTH WHEN STOCKED IN APRIL, AT THE JULY HARVEST AND THE SUM OF THE JULY AND OCTOBER HARVESTS

Source: Reference (2-31)

The plants absorbed 6.93 g nitrogen, 2.87 g phosphorus, and 8.73 g potassium.

A similar study was reported by Ornes and Sutton.[2-32] They observed a maximum uptake of 5,500 mg of P/g dry weight of plant material when the level of available phosphorus in the effluent was 1.1 mg/ml. Phosphorus in the effluent was reduced from 1.4 mg/ml to 0.2 mg/ml by 5 weeks with an 80 percent decrease reported in the first 3 weeks. Crude protein of the plants harvested after 1 week was 20 percent, but decreased to 9 percent by the end of the growth period.

Influent-effluent samples were analyzed in another study by Wolverton et al (Table 2-20).[2-33] The increase in total organic carbon in the control plants was reportedly due to heavy algae growth.

Analysis of the initial effluent wastewater used in these studies for toxic trace metals showed the following concentrations[2-33]: < 0.008 ppm Pb, < 0.001 ppm Cd, < 0.01 ppm Cu, < 0.02 ppm Ag, < 0.05 ppm Ni, < 0.08 ppm Zn, < 0.001 ppm Hg, < 0.01 ppm Sr, < 0.007 ppm Co. The results of the analysis of the digested roots of water hyacinths grown for a period of 2 weeks in effluent sewage water were: 0.063 ppm Pb, < 0.001 ppm Cd, < 0.01 ppm Cu, < 0.02 ppm Ag, < 0.05 ppm Ni, 0.58 ppm Zn, < 0.001 ppm Hg, < 0.01 ppm Sr, < 0.007 ppm Co.

The potential effectiveness of water hyacinth as a waste treatment process is outlined in NASA unpublished data given in Table 2-21. These data are preliminary in nature; no conclusions can be made at this time.

Limiting Factors and Conclusions

This review has pointed out several factors that limit the growth and nutrient uptake rate of water hyacinth. They are:

- Seeds require some form of scarification - physical, chemical or biotic - for germination.
- Death of the plant occurs when light intensity falls below 130 fc.
- Anthesis and plant growth are dependent upon light and temperature.

TABLE 2-20. EXPERIMENTAL ANALYSIS OF INFLUENT AND EFFLUENT SEWAGE WASTEWATER CONTAINING WATER HYACINTHS AND CORRESPONDING CONTROLS FREE OF PLANTS

ANALYSIS		INFLUENT Container No. 1	INFLUENT Container No. 2	INFLUENT Container No. 3 (Control)	EFFLUENT Container No. 1	EFFLUENT Container No. 2	EFFLUENT Container No. 3 (Control)
pH	Initial	7.05	7.05	7.05	8.80	8.80	8.80
	7-Day	7.30	7.40	7.75	7.30	7.40	8.90
	14-Day	7.30	7.40	7.90	7.20	7.20	8.20
Total Suspended Solids (ppm)	Initial	-	-	-	109.0	109.0	109.0
	7-Day	-	-	-	17.0	33.0	96.0
	14-Day	-	-	-	46.0	8.0	93.0
Total Kjeldahl Nitrogen (ppm)	Initial	16.1	16.1	16.1	1.76	1.76	1.76
	7-Day	-	1.35	13.2	0.55	0.32	1.53
	14-Day	<0.20	<0.20	8.36	<0.20	<0.20	1.50
Total Phosphorus (ppm)	Initial	5.60	5.60	5.60	4.50	4.50	4.50
	7-Day	1.25	3.25	4.90	0.57	0.57	4.01
	14-Day	0.75	3.00	4.25	<0.06	<0.06	3.38
BOD_5 (ppm)	Initial	72.0	72.0	72.0	21.6	21.6	21.6
	7-Day	2.60	1.90	28.0	5.16	4.9	20.3
	14-Day	-	-	-	3.90	3.10	12.5
Total Organic Carbon (ppm)	Initial	-	-	-	94	94	94
	7-Day	-	-	-	59	60	98
	14-Day	-	-	-	<6	<7	120
Dry Plant Weight (Grams)		14.6	6.1	Control Free of Plant	9.9	7.2	Control Free of Plant

"Indoors, well lighted, 25 ± 5 C"

Source: Reference (2-33)

TABLE 2-21. NATIONAL SPACE TECHNOLOGY LABORATORIES, VASCULAR PLANT PROJECT PRELIMINARY FIELD TEST DATA - ORANGE GROVE

DATES	TOTAL PHOSPHORUS Mg/l		KJELDAHL NITROGEN Mg/l		DISSOLVED OXYGEN Mg/l		TOTAL SUSPENDED SOLIDS Mg/l		TOTAL DISSOLVED SOLIDS Mg/l		BIOCHEMICAL OXYGEN DEMAND Mg/l		TOTAL ORGANIC CARBON Mg/l		pH	
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT
BASELINE DATA - PRIOR TO STOCKING LAGOON																
5-13-75	5.25	6.75	11.1	7.0	7.0	9.1	22	40	188	212	-	-	10	12	7.8	8.7
5-14-75	5.60	6.30	12.1	6.4	3.4	5.0	51	75	224	282	15	26	30	42	7.4	7.1
5-21-75	4.60	5.00	8.3	3.2	3.0	6.0	24	35	201	154	-	-	31	32	7.9	7.9
5-22-75	4.30	4.60	8.0	3.3	4.5	7.9	9	39	224	198	22	31	24	32	7.9	8.5
6-4-75	4.30	4.70	1.4	1.4	9.5	8.4	49	58	190	227	29	40	39	43	9.0	9.1
AVERAGE	4.81	5.47	8.2	4.3	5.5	7.3	31	49	205	214	22	32	27	32	8.0	8.3
FIELD TEST DATA - AFTER STOCKING WATER HYACINTHS[(a)]																
7-9-75	4.25	4.10	1.5	0.64	5.8	3.4	29	1.3	260	226	33	3	27	18	7.6	6.7
7-10-75	3.80	3.60	1.6	1.00	6.0	1.9	42	3.6	323	159	20	19	35	31	7.5	6.4
7-11-75	4.60	4.30	1.5	0.73	5.4	2.7	23	1.3	170	150	-	-	30	24	7.2	6.5
7-14-75	3.80	3.20	1.3	1.20	5.2	1.7	43	0.9	198	185	-	-	26	24	7.5	6.5
7-15-75	4.30	3.60	3.2	1.60	6.7	1.9	44	9.3	182	150	-	-	30	24	8.4	6.6
AVERAGE	4.15	3.76	1.8	1.03	5.8	2.3	36	3.3	227	174	26	11	29.6	24	7.6	6.5

(a) Stocking of Water Hyacinths Occurred 7/1/75.

Source: NASA unpublished data.

- Water hyacinth is susceptible to death and damage from frost or long-term exposure to temperatures above 34.4 C. Rhizome tips and infloresscense are affected first.
- Water hyacinth cannot tolerate 2.0 percent salt solutions.
- Water hyacinth requires a pH of 3.0 to 10.0 for growth.
- Optimum temperature for disease development is 22 to 27 C.
- Phosphorus concentrations higher than 40 ppm are toxic to water hyacinth.
- Water hyacinth removes nitrogen and phosphorus in a ratio of 5:1; thus nitrogen supply is one limiting factor for phosphorus removal.
- Water hyacinth growth appears to be seasonal; the length of the growing season bring controlled by temperature
- A review of annual temperature and solar radiation data (Tables 2-22 to 2-25) indicate that conditions for hyacinth growth should exist, in Southern Florida throughout the year
- Water hyacinth productivity is apparently affected by space, nutrient availability, temperature, dissolved oxygen and content and chloride concentration of the water body
- Available data indicate that there is a possibility that maximum production per unit time may occur in two time periods, spring and fall. However, the data are limited; nutrient availability and space, or both, may have accounted for Penfound and Earl's standing crop data.[2-1]
- The effect of harvesting on water hyacinth productivity has not been addressed due to a lack of data
- Plant tissue produced in early spring contains the greatest percentages of essential protein, amino acids and minerals.

TABLE 2-22. MONTHLY MINIMUM TEMPERATURE C

		January	February	March	April	May	June	July	August	September	October	November	December
Texas	Northern third	-6.7	-6.7	-1.1	4.4	10.0	15.6	15.6	15.6	10.0	4.4	-1.1	-6.7
	Central third	-1.1	-1.1	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	-1.1
	Southern third	4.4	4.4	10.0	15.6	15.6	21.1	21.1	21.1	21.1	15.6	10.0	4.4
Louisiana	Northern third	-1.1	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	-1.1
	Central third	4.4	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4
	Southern third	4.4	4.4	10.0	10.0	15.6	21.1	21.1	21.1	21.1	10.0	4.4	4.4
Mississippi	Northern third	-1.1	-1.1	4.4	10.0	10.0	15.6	21.1	15.6	15.6	10.0	4.4	-1.1
	Central third	-1.1	-1.1	4.4	10.0	15.6	15.6	21.1	15.6	15.6	10.0	4.4	-1.1
	Southern third	4.4	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4
Alabama	Northern third	-1.1	-1.1	-1.1	4.4	10.0	15.6	15.6	15.6	15.6	4.4	-1.1	-1.1
	Central third	-1.1	-1.1	4.4	10.0	15.6	15.6	21.1	15.6	15.6	10.0	4.4	-1.1
	Southern third	4.4	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4
Florida	Northern third	4.4	4.4	10.0	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4
	Central third	4.4	4.4	10.0	10.0	15.6	21.1	21.1	21.1	21.1	15.6	10.0	10.0
	Southern third	10.0	10.0	15.6	15.6	15.6	15.6	21.1	21.1	21.1	21.1	15.6	15.6
Georgia	Northern third	-1.1	-1.1	-1.1	4.4	10.0	15.6	15.6	15.6	15.6	4.4	-1.1	-1.1
	Central third	-1.1	-1.1	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	-1.1
	Southern third	4.4	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4
South Carolina	Northern third	-1.1	-1.1	-1.1	4.4	10.0	15.6	15.6	15.6	15.6	10.0	-1.1	-1.1
	Central third	-1.1	-1.1	4.4	10.0	10.0	15.6	21.1	15.6	15.6	10.0	4.4	-1.1
	Southern third	4.4	4.4	4.4	10.0	15.6	15.6	21.1	21.1	15.6	10.0	4.4	4.4

Source: Reference (2-34)

TABLE 2-23. MONTHLY MAXIMUM TEMPERATURE °C

		January	February	March	April	May	June	July	August	September	October	November	December
Texas	Northern third	15.6	15.6	21.1	26.7	26.7	32.2	37.8	37.8	32.2	26.7	21.1	15.6
	Central third	21.1	21.1	26.7	26.7	32.2	32.2	37.8	37.8	32.2	32.2	21.1	21.1
	Southern third	26.7	26.7	32.2	32.2	37.8	37.8	37.8	37.8	37.8	32.2	26.7	26.7
Louisiana	Northern third	15.6	21.1	21.1	26.7	32.2	37.8	37.8	37.8	32.2	32.2	21.1	15.6
	Central third	21.1	21.1	26.7	26.7	32.2	37.8	37.8	37.8	32.2	32.2	21.1	15.6
	Southern third	21.1	21.1	26.7	26.7	32.2	32.2	37.8	37.8	32.2	32.2	26.7	21.1
Mississippi	Northern third	15.6	15.6	21.1	26.7	32.2	37.8	37.8	37.8	32.2	26.7	21.1	15.6
	Central third	15.6	21.1	21.1	26.7	32.2	37.8	37.8	37.8	32.2	26.7	21.1	15.6
	Southern third	21.1	21.1	26.7	26.7	32.2	37.8	37.8	37.8	32.2	32.2	26.7	21.1
Alabama	Northern third	15.6	15.6	21.1	26.7	32.2	32.2	37.8	37.8	32.2	26.7	21.1	15.6
	Central third	15.6	21.1	21.1	26.7	32.2	37.8	37.8	37.8	32.2	26.7	21.1	15.6
	Southern third	21.1	21.1	26.7	26.7	32.2	37.8	37.8	37.8	32.2	32.2	21.1	21.1
Florida	Northern third	21.1	21.1	26.7	26.7	32.2	37.8	37.8	37.8	32.2	32.2	26.7	21.1
	Central third	26.7	26.7	26.7	32.2	32.2	37.8	37.8	37.8	32.2	32.2	26.7	26.7
	Southern third	26.7	26.7	32.2	32.2	32.2	37.8	37.8	37.8	32.2	32.2	32.2	26.7
Georgia	Northern third	15.6	15.6	21.1	26.7	32.2	32.2	37.8	32.2	32.2	26.7	21.1	15.6
	Central third	15.6	21.1	21.1	26.7	32.2	37.8	37.8	37.8	32.2	26.7	21.1	21.1
	Southern third	21.1	21.1	26.7	26.7	32.2	37.8	37.8	37.8	32.2	32.2	26.7	21.1
South Carolina	Northern third	15.6	15.6	21.1	26.7	32.2	32.2	32.2	32.2	32.2	26.7	21.1	15.6
	Central third	15.6	21.1	21.1	26.7	32.2	37.8	37.8	37.8	32.2	26.7	21.1	15.6
	Southern third	21.1	21.1	21.1	26.7	32.2	37.8	32.2	32.2	32.2	26.7	21.1	21.1

Source: Reference (2-34)

TABLE 2-24. MONTHLY SUNSHINE HOURS

		January	February	March	April	May	June	July	August	September	October	November	December
Texas	Northern third	220	220	280	300	320	360	360	340	300	260	260	220
	Central third	200	200	260	260	300	340	360	340	280	260	220	200
	Southern third	160	160	220	240	280	320	340	320	280	260	200	160
Louisiana	Northern third	160	160	220	240	300	320	320	320	280	260	200	160
	Central third	160	160	220	240	300	320	300	300	260	260	200	160
	Southern third	160	160	220	240	300	300	280	280	260	260	200	160
Mississippi	Northern third	140	160	220	260	300	320	320	320	280	260	200	140
	Central third	140	160	220	260	300	300	300	300	260	260	200	160
	Southern third	160	160	220	260	300	300	280	280	260	260	200	160
Alabama	Northern third	140	160	200	260	300	300	280	280	260	260	180	140
	Central third	160	160	220	260	300	300	280	280	260	260	200	160
	Southern third	180	180	240	280	320	320	300	300	260	260	220	180
Florida	Northern third	200	200	240	280	320	300	280	280	240	260	200	180
	Central third	220	220	260	280	300	280	260	260	220	240	200	200
	Southern third	240	240	280	300	280	260	280	280	220	220	220	220
Georgia	Northern third	160	160	220	260	300	300	280	280	260	260	180	140
	Central third	180	180	240	280	320	320	300	280	260	260	200	160
	Southern third	200	200	240	280	320	300	300	280	240	240	220	180
South Carolina	Northern third	160	180	240	280	320	300	280	280	260	260	200	180
	Central third	180	200	240	280	320	320	280	280	260	260	220	180
	Southern third	180	200	260	300	340	320	280	280	260	260	220	180

Source: Reference (2-34)

TABLE 2-25. DAILY MEANS OF TOTAL SOLAR RADIATION (DIRECT AND DIFFUSE) INCIDENT ON A HORIZONTAL SURFACE GM.CAL.CM^2 DAY (LANGLEYS/DAY)

		January	February	March	April	May	June	July	August	September	October	November	December
Texas	Northern third	250	300	400	500	600	750	650	600	500	400	300	250
	Central third	250	350	450	550	650	650	650	600	550	400	350	300
	Southern third	300	400	500	650	550	550	600	550	550	400	300	250
Louisiana	Northern third	250	250	350	450	550	550	550	500	450	400	250	200
	Central third	250	300	400	450	550	550	550	500	450	400	300	200
	Southern third	300	300	400	450	550	550	550	500	450	400	300	250
Mississippi	Northern third	200	250	350	450	550	550	550	500	450	350	250	200
	Central third	250	300	400	500	550	550	550	500	450	400	250	200
	Southern third	250	300	400	500	550	550	550	500	450	400	300	250
Alabama	Northern third	200	250	350	450	550	550	550	500	450	350	250	200
	Central third	250	300	400	500	550	550	550	500	450	400	300	200
	Southern third	300	300	400	550	600	550	550	500	450	400	300	250
Florida	Northern third	300	350	400	550	600	550	550	500	450	400	300	250
	Central third	300	400	450	550	600	550	550	500	450	400	350	300
	Southern third	350	400	500	550	600	550	550	500	450	400	350	300
Georgia	Northerh third	200	300	350	450	550	550	550	500	450	350	300	200
	Central third	250	350	400	500	550	550	550	500	450	350	300	200
	Southern third	250	350	400	500	550	550	550	500	450	350	300	200
South Carolina	Northern third	200	300	400	500	550	550	550	500	400	350	300	200
	Central third	250	300	400	500	550	550	550	500	450	350	300	200
	Southern third	250	300	400	500	550	550	550	500	450	350	300	200

Source: Extrapolated data from reference (2-35)

REFERENCES FOR CHAPTER 2

2-1. Penfound, W. T. and T. T. Earle. 1948. The biology of the water hyacinth. Ecol. Mono. 18:447-478.

2-2. Yount, J. N. 1964. As cited by Wolverton et al. 1975. Application of vascular aquatic plants for pollution removal, energy and food production in a biological system. NASA Tech. Memorandum TM-X-72726. National Space Technology Laboratories. Bay St. Louis, Mississippi. 15 p.

2-3. Steward, K. K. 1970. Nutrient removal potentials of various aquatic plants. Hyacinth Control Journal 8:34-35.

2-4. Dymond, G. C. 1948. The water hyacinth: a cinderella of the plant world. p 221-227. IN: J. P. J. Van Vuren. Soil fertility and sewage. Dover, New York.

2-5. Wahlquist, Harold. 1972. Production of water hyacinths and resulting water quality in earthen ponds. Hyacinth Control Journal. 10:9-11.

2-6. McVea, C. and C. E. Boyd. 1975. Effects of water hyacinth cover on water chemistry, phytoplankton and fish in ponds. Journal of Environmental Quality. 4:375-378.

2-7. Weatlake, D. F. 1963. Comparisons of plant productivity. Biol. Rev. 38:385-425.

2-8. Chadwick, M. J. and M. Obeid. 1966. *Eichhornia crassipes* and *Pistia stratiotes*. The Journal of Ecology. 54:563-575.

2-9. Haller, W. T. and D. L. Sutton. 1973. Effect of pH and high phosphorus concentrations on growth of water hyacinth. Hyacinth Control Journal. 11:59-61.

2-10. Gangstad, E. O., J. J. Raynes and C. F. Zeiger. 1974. Biological control of water hyacinth with insect enemies. Technical Report 6, Aquatic Plant Control Program. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, 7 p.

2-11. Rintz, R. E. and T. E. Freeman. 1974. *Fusarium roseum* pathogenic to water hyacinth in Florida. Appendix D in: Aquatic Plant Control Program, Technical Report 8, Aquatic Weed Control with Plant Pathogens, U. S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, D1-D3.

2-12. Freeman, T. E. and F. W. Zettler. 1974. A disease of water hyacinth with biological control potential. Appendix C in: Aquatic Plant Control Program, Technical Report 8, Aquatic Weed Control with Plant Pathogen, U. S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, C1-C3.

2-13. Liang, J. K. and R. T. Lovell. 1971. Nutritional value of water hyacinth in channel catfish feeds. Hyacinth Control Journal. 9:40-44.

2-14. Boyd, C. E. 1968. Freshwater plants: a potential source of protein. Economic Botany. 22:359-368.

2-15. Taylor, K. G., R. P. Bates and R. C. Robbins. 1971. Extraction of protein from water hyacinth. Hyacinth Control Journal. 9:20-22.

2-16. Taylor, K. G. and R. C. Robbins. 1968. The amino acids composition of water hyacinth (Eichhornia crassipes) and its value as a protein supplement. Hyacinth Control Journal. 7:24-25.

2-17. Gerloff, E. D., I H. Lima, and M. A. Stahman. 1965. Amino Acid Composition of Lead Protein Concentrates. Agricultural and Food Chemistry 13:139-143.

2-18. Gordon, R. D. and J. R. Coulson. 1974. Field observations of arthropods on water hyacinth. Appendix B in: Aquatic Plant Control Program Technical Report 6. Biological Control of Water Hyacinth with Insect Enemies. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, B1-B37.

2-19. Bennett, F. D. 1970. Insects attacking water hyacinth in the West Indies, British Honduras and the U.S.A. Hyacinth Control Journal 8:10-13.

2-20. Spencer, N. R., D. D. Perkins, F. D. Bennett and E. O. Gangstad. 1970. Insect enemies of aquatic weeds. Appendix D in: Aquatic Plant Control Program Technical Report 6. Biological of Water Hyacinth with Insect Enemies. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, D1-D21.

2-21. Freeman, T. E., R. Charudattan and K. Conway. 1974. Exploration, pathogenicity, and integrated control. Appendix I in: Aquatic Plant Control Program Technical Report 8. Aquatic Weed Control with Plant Pathogens. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi, I1-I9.

2-22. Rintz, R. E. 1974. A survey for diseases of water hyacinth in the Panama Canal zone. Appendix G in: Aquatic Plant Control Program, Technical Report 8, Aquatic Weed Control with Plant Pathogens, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, G1-G5.

2-23. Ponnappa, K. M. 1970. On the pathogenicity of Myrothecium roridum - Eichhornia crassipes isolate. Hyacinth Control Journal 8:12-20.

2-24. Boyd, C. E. and R. D. Blackburn. 1970. Seasonal changes in the proximate composition of some common aquatic weeds. Hyacinth Control Journal 8:42-44.

2-25. Parra, J. V. and C. C. Hortenstine. 1974. Plant nutritional content of some Florida water hyacinths and response by pearl millet to incorporation of water hyacinth in three soil types. Hyacinth Control Journal 12:85-90.

2-26. Dunigan, E. P., R. A. Phelan and Z. M. Shamsuddin. 1975. Use of water hyacinth to remove nitrogen and phosphorus from eutrophic waters. Hyacinth Control Journal. 13:59-61.

2-27. Sutton, D. L. and R. D. Blackburn. 1971. Uptake of copper by water hyacinth. Hyacinth Control Journal 9:18-20.

2-28. Wolverton, B. C. 1975. Water hyacinths for removal of phenols from polluted waters. NASA Technical Memorandum TM-X-72722. National Space Technology Laboratories, Bay St. Louis, Mississippi. 16 p.

2-29. Wolverton, B. C. and R. C. McDonald. 1975. Water hyacinths and alligator weeds for removal of lead and mercury from polluted waters. NASA Technical MEmorandum TM-X-72723. National Space Technology Laboratories, Bay St. Louis, Mississippi. 12 p.

2-30. Wolverton, B. C. 1975. Water hyacinth for removal of cadmium and nickel from polluted waters. NASA Technical Memorandum TM-X-72721. National Space Technology Laboratories. Bay St. Louis, Mississippi. 9 p.

2-31. Scarsbrook, E. and D. E. Davis. 1971. Effect of sewage effluent on growth of five vascular aquatic species. Hyacinth Control Journal. 13:56-58.

2-32. Ornes, W. H. and D. L. Sutton. 1975. Removal of phosphorus from static sewage effluent by water hyacinth. Hyacinth Control Journal. 13:56-58.

2-33. Wolverton, B. C., R. M. Barlow and R. C. McDonald. 1975. Application of vascular aquatic plants for pollution removal, energy and food production in a biological system. NASA TM-X-72726, National Space Technology Laboratories, Bay St. Louis, Mississippi. 14 p.

2-34. The National Atlas of the United States of America. U.S. Department of the Interior, Geological Survey, Washington, D.C., 1970.

2-35. Luf, G. O. G., J. A. Duffie and C. O. Smith. 1966. World distribution of solar radiation. Solar Energy Laboratory, University of Wisconsin, Madison.

2-36. Schneider, T. R., "Efficiency of Photosynthesis as a Solar Energy Converter", Energy Conservation, 13 77-84, 1973.

2-37. Private Communication, Jim Perris, Kennedy Space Flight Center, October 2, 1975.

CHAPTER 3

DESIGN OF HYACINTH SYSTEMS FOR TREATMENT OF MUNICIPAL WASTEWATER

Municipal Wastewater Characteristics

Generally, municipal wastewater effluent characteristics are influenced by (1) the domestic water system including the water supply source, treatment, and storage and conveyance system; (2) inorganic and organic compounds contained in industrial and domestic wastewaters from the service area; (3) inflow and infiltration into the wastewater collection system, and (4) the type and reliability of wastewater treatment employed.

Domestic Water Supply Considerations

Pure water is not found in nature. All water supplies contain various dissolved and suspended substances, e.g. carbonates, sulfates, chlorides, phosphates and nitrates along with various metal ions. Their presence and relative abundance is influenced by several factors including surface runoff, geochemistry of the watershed, atmospheric fallout, man-created effluents, and biological and chemical processes occurring in the water itself. Many are essential to life processes and direct the structure and function of aquatic ecosystems. They serve as nutrients in productivity, create osmotic stress, and impart toxicity.

Operations associated with storage, treatment, and conveyance of municipal water supplies affect wastewater characteristics. Entrained and induced constituents resulting from the level and type of treatment operations (e.g. coagulation with iron, alum, lime, etc., and disinfection with chlorine) and minor additions of metal ions picked up from the conveyance system (e.g. copper, zinc, etc.) also affect its quality.

Service Area Considerations

The composition of untreated sewage is highly dependent on the proportion and nature of a community's commercial and industrial base. Wastewater characteristics are also affected by the affluence of the municipal residential area. Each resident of a community contributes as much as 70-100 gallons (265-380 liters) of wastewater per day.[3-1] The increasing household use of marketed chemical compounds (cleaning materials, soaps, drugs, etc.) affect wastewater characteristics. The increased use of garbage grinders[3-2] and disposable paper produces add to the solids contributed by households. Even the residential diet may affect wastewater characteristics. As an example, the daily normal digestion/excretion of zinc is estimated at about 10 mg/person. However, the concentration of zinc in fresh food ranges from less than one part per million (ppm) in fruits to 50 ppm in legumes.[3-3] Higher amounts are contained in yeast, mushrooms, and seafood with oysters containing as much as 2200 ppm.[3-4]

The characteristics of untreated sewage or raw sewage may be classified according to physical, chemical, and biological properties. A most significant physical characteristic of sewage is its total solids content. This includes floating, suspended, colloidal and dissolved matter. The solids content of untreated sewage is compared with fresh water in Table 3-1. An average unit emission rate for suspended and dissolved solids is 1.03 and 0.162 pounds (467 and 73.5 grams) per capita day, respectively.[3-5] The physical appearance of fresh sewage is usually grey while septic or stale sewage is black. However, industrial inputs, when present, can mask this differentiation. The odor of sewage can be dominantly attributed to the presence of volatile compounds such as hydrogen sulfide, indol, skatol and mercaptans.[3-6] The temperature of municipal sewage is relatively constant, at 10 to 21 C.

The chemical characteristics of untreated sewage are compared with natural fresh water in Table 3-2. As shown in the table, sewage is generally well-buffered and exhibits of pH near 7. The biochemical oxygen demand of raw sewage is about 40 times that of natural fresh water. The primary macronutrients, nitrogen and phosphorus, are present in raw sewage at mean concentrations of 40 and 10 mg/1, respectively. The metals which are also considered as micronutrients can be present at concentrations deleterious to the biological environment, including man. Other metals which are of particular concern in regard to potential toxic effects include cadmium, chromium, lead, mercury, and nickel.

TABLE 3-1. SOLIDS IN FRESH WATER AND UNTREATED SEWAGE
(All units are in mg/l unless otherwise specified)

Constituent	Natural Fresh Water[a] Median	Natural Fresh Water[a] Normal Range	Typical Untreated Sewage[b] Median	Typical Untreated Sewage[b] Normal Range
Solids, Total	200	0-1000	700	350-1200
Dissolved, Total	169[c]	72-400[c]	500	250-850
Fixed	69	50-120	300	145-525
Volatile	100	20-280	200	105-325
Suspended, Total	50	25-400[c]	200	100-350
Fixed	20	18-120	50	30-70
Volatile	30	8-280	150	70-275
Settleable Solids (ml/liter)	2	1-4	10	5-10

(a) Estimated.
(b) Reference (3-7).
(c) Reference (3-5).

TABLE 3-2. CHARACTERISTICS OF FRESH WATER AND UNTREATED SEWAGE
(All units are in mg/l unless otherwise specified)

Constituent	Natural Fresh Water[c] Median	Natural Fresh Water[c] Normal Range	Typical Untreated Sewage[d] Median	Typical Untreated Sewage[d] Normal Range
pH, Units	7.5	5.0-10.5	7.0+0.5	
Biochemical Oxygen Demand, 5-Day, 20 C ($BOD_5 \cdot 20^o$)	10	5-50[a]	200	100-300
Chemical Oxygen Demand, COD	30	15-160[a]	500	250-1000
Total Organic Carbon, TOC	10	5-40[a]	200	100-300
Fats, Grease and Oil	<0.5	--[a]	100	50-150
Chlorides, Cl	13.0	0.01-100	50[b]	30-100[b]
Sodium, Na	12.0	1.0-1000[a]		
Fluorides, F	0.4	0.0001-1		
Silica, SiO_2	7.1	1-30		
Sulfate, SO_4	26.0	1.0-1000		
Alkalinity, $CaCO_3$	90.0	20-1600	100[b]	50-200[b]
Carbonate, CO_3	--	10 (Ground Water)		
Bicarbonate, HCO_3	46.0	1.0-500		
Non-Carbonate	34.0	0-500		
Macronutrients				
Nitrogen (as total N)	1.1	0.5-10[a]	40	20-85
Organic	0.03	0.01-3[a]	15	8-35
Free Ammonia, NH_3	0.05	0.01-2[a]	25	12-50
Nitrates, NO_3	0.7	0.01-5	0	0
Nitrites, NO_2			0	0
Phosphorus (as total P)	0.05	0.001-1.0[a]	10	6-20
Organic	0.02	0.001-0.05[a]	3	2-5
Inorganic	0.03	0.001-0.5[a]	7	4-15
Potassium, K	1.6	0.01-10		
Calcium, Ca	26	1.0-1000		
Magnesium, Mg	6.25	1.0-200		
Sulfur, S				

TABLE 3-2. CONTINUED

Constituent	Natural Fresh Water (c) Median	Natural Fresh Water (c) Normal Range	Typical Untreated Sewage (e) Median	Typical Untreated Sewage (e) Normal Range
		Micronutrients		
Boron, B	0.03	0.01-10	--	--
Copper, Cu	0.008	0.0001-0.1	0.1	<0.02-9.6
Iron, Fe	0.02	0.01-0.5	0.9	<0.1-13
Manganese, Mn	--	0.0001-0.2	0.14	<0.02-0.95
Molybdenum, Mo	0.005	0.0001-0.1	--	--
Zinc, Zn	0.025	0.0001-0.1	0.18	<0.02-18
		Other Trace Elements		
Aluminum, Al	0.054	0.0001-0.1		
Arsenic, As	0.015	0.005-1.1		
Barium, Ba	0.043	0.0001-0.1		
Cadmium, Cd	0.003	0.0005-0.2	<0.02	<0.02-1.1
Chromium, Cr	0.0004	0.0001-0.1	<0.05	<0.05-5.8
Cobalt, Co	0.0009	0.0001-0.1	<0.05	-- (8)
Lead, Pb	0.006	0.0001-0.1		
Mercury, Hg	0.002	0.0001-0.8	0.0013	<0.0001-0.0068
Nickel, Ni	0.001	0.0001-0.1	0.1	<0.1-2.0
Rubidium, Rb	0.001	<0.001		
Silver, Ac	0.0002	<0.001	0.05	<0.05-0.6
Strontium, Sr	0.110	0.01-10		
Titanium, Ti	0.002	0.0001-0.1		
Vanadium, V	0.004	0.0001-0.1		

(a) BCL estimates.

(b) Value should be increased by the amount in the carriage water.

(c) Reference (3-5)

(d) Reference (3-7)

(e) Reference (3-8)

Table 3-3 contains a list of the major microorganisms found in untreated sewage. Bacteria are predominant. Some may be plant pathogens. Viruses are also present but are fewer in number. Since they are obligate parasites, they are dependent on the presence of the hosts they infect.

Sewage Collection System Considerations

The design and integrity of the wastewater collection system can alter wastewater characteristics. Treatment plant operations are affected by increased loads (hydraulic and solid) due to captured urban stormwater runoff (combined sewers and/or groundwater infiltration). Stormwater runoff reaching the sewage treatment plant often transports various "street refuse" (litter, dirt, bird and animal droppings, air pollution fallout particles, oils, chemical compounds, etc.). Groundwater infiltration into the collection system can dilute the sewage which frequently results in increased treatment costs per capita and/or inadequate treatment.

Sewage Treatment Plant Considerations

Sewage treatment plant effluent composition depends on the character of the untreated sewage and also on the type of wastewater treatment employed. Conventional sewage treatment processes are generally classified as primary and secondary. Primary treatment follows pretreatment operations such as screening, grit removal and oil separation (see Figure 3-1). The removal of floating and suspended solids is the object of primary treatment. Primary treatment can involve sedimentation, flotation, and/or filtration with and without the aid of chemical additions.

Secondary treatment normally refers to biological processes. The objective of secondary treatment processes is the breakdown or stabilization of organic matter. As legally defined, secondary treatment requires a minimum of 85 percent removal of influent volatile suspended solids and biochemical oxygen demand.[3-10] Commonly used secondary

TABLE 3-3. BIOLOGICAL CHARACTERISTICS OF FRESH WATER AND UNTREATED SEWAGE

(All units are in number/100 ml unless otherwise specified.)

Organism	Natural Fresh Water[a]	Typical Untreated Sewage[b]
Bacteria		$3 - 18 \times 10^6$
Coliforms	200-20,000	$0.5 - 1 \times 10^6$
Clostridium Perfringens		507
Fecal Streptococci		$5 - 20 \times 10^3$
Mycobacterium Tuberculosis		Present
Pseudomonas Aerdginosa		102-7000
Salmonella		4-12
Shigella		Present
Fungi		Present
Nematodes		200-2500/G
Protozoa		Present
Virus	< 1	10-500
Yeasts		10-80

(a) Reference (3-5).
(b) Reference (3-9).

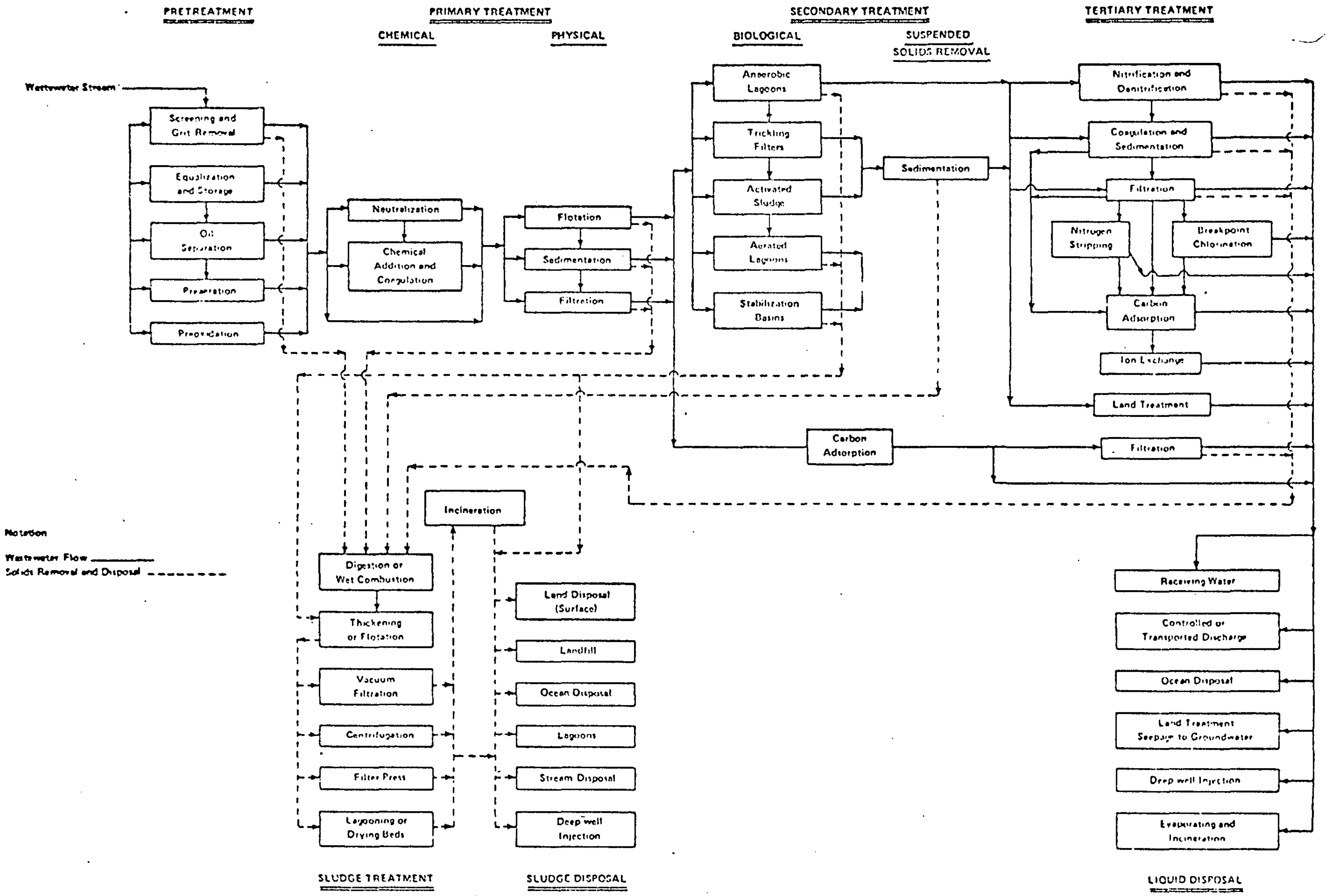


FIGURE 3-1. WASTEWATER-TREATMENT SEQUENCE: PROCESS SUBSTITUTION DIAGRAM

treatments include trickling filters, activated sludge and oxidation ponds. The resulting effluent composition from these conventional secondary and primary treatment processes is compared with public water supply recommendations in Table 3-4.

The median and normal range of secondary effluent characteristics shown in Table 3-4 are based on values reported from several treatment plants in the United States. The data reflect the expected high variability of secondary effluent quality as related to site and situation specific differences of the service areas and treatment operations. Because of the uncertainties associated with the lack of repetitive and independent analyses, the reported data depicting micronutrient and other trace element concentrations can only be interpreted as indications of the constituents present and the order of magnitude of their concentrations in secondary effluents.

In addition to the annual median differences in secondary effluent quality from plant to plant, each treatment plant's effluent quality varies with time. Municipal wastewater effluents discharged from a conventional treatment process varies daily, weekly, seasonally, and yearly. Sewage characteristics can vary daily by more than a factor of three.[3-12] Effluent compositions can also vary weekly in response to vocation/advocation pursuits of the municipal residents. Effluent quality can also vary seasonally due to the environmental exposure (temperature, precipitation, etc.) of sewage treatment systems.

Table 3-5 demonstrates seasonal and yearly variability of a secondary effluent. The table includes the range of yearly averages ('63-'70) of effluent quality from Pennsylvania State University's secondary treatment plant. As shown in the table, the yearly averages of many of the constituents varied by more than a factor of two in the eight years of monitoring. Furthermore, the range in effluent concentrations for a single year (1971) was more than an order of magnitude for some of the constituents considered.

TABLE 3-4. CHEMICAL CHARACTERISTICS OF PUBLIC WATER SUPPLY RECOMMENDATION AND CONTINUALLY TREATED SEWAGE

(All Units are in mg/l Unless Otherwise Specified)

Constituent	Public Water Supply Recommendations (3-5)	Primary Treatment Typical (3-6) Median	Primary Treatment Typical (3-6) Normal Range	Secondary Treatment Typical (3-6) Median	Secondary Treatment Typical (3-6) Normal Range	Trickling Filters (3-6) Median	Trickling Filters (3-6) Normal Range	Activated Sludge (3-6) Median	Activated Sludge (3-6) Normal Range	Oxidation Ponds (3-6) Median	Oxidation Ponds (3-6) Normal Range
Total dissolved solids		1400	935-1900	1139	917-1330	1170	780-1500	917	605-1235	1330	204-2330
pH, units	5.0-9.0	7.4	6.8-7.7	7.6	7.4-7.75	7.15	7.3-8.1	7.4	7.1-7.7	7.75	7.0-8.3
Biochemical oxygen demand, 5-day, 20C (BOD_8 • 20°)	--	152	110-216	35.7	17-70	17	6-40	20	6-40	70	65-74
Total organic carbon, TOC	0.3 (chloroform) 1.5 (alcohol extract)										
Fats, grease and oil	0										
Chlorides, Cl	250	461	264-657	200	138-276	276	158-352	185	107-299	138	19-239
Fluorides, Fl	1.4-2.4 (50-90°F, air)										
Sulfates, SO_4	250	180	70-298	300	224-360	317	115-600	224	86-330	360	10-762
Alkalinity, $CaCo_3$	--	635	131-1040	--	--	491	305-640	--	--	682	--
Sodium, Na	--	329	209-460	272	192-267	267	150-370	192	101-260	257	38-390
				Macronutrients							
Nitrogen (as total N)	--	37	21-51	21	16-23	16	11.2-25.2	23	12-33.4	23	15-40.2
Free ammonia, NH_3	0.5	23	11.6-41	10.3	5.9-17	5.9	0.0-9.3	17	12-30	8	0.8-18
Nitrates, NO_3	10.0	0.3	0-1.4	3.6	0.7-613	6.3	0.0-14.2	3.9	0-12	0.7	0.0-2.7
Phosphorus (as total P)	--	11	7.5-14	10.9	6.7-13	13	9.1-16.9	12.9	9.4-16	6.7	4.2-9.4
Potassium, K	--	22	13-33	16	14-20	14	13-17	20	13-36	14	7-21
Calcium, Ca	--	96	11.9-134	74.7	52-92	80	30-120	52	17-110	92	23-178
Magnesium, Mg	--	34	3.4-46	45	38-50	50	41-61	37	26-47	48	1-91
Sulfur, S	--	--	--	--	--	--	--	--	--	--	--
				Micronutrients							
Boron, B	1.0	1.2	0.6-1.0	0.9	0.7-1.2	0.7	0.3-1.5	0.7	--	1.2	0.33-1.4
Copper, Ca	1.0	60	--	70	40-100	70	--	40	--	100	--
Iron, Fe	0.3	830	--	240	169-390	160	--	320	--	390	--
Manganese, Mn	0.05	35	--	17	10-30	10	--	10	--	30	--
Molybdenum, Mo	--	--	--	--	--	--	--	--	--	--	--
Zinc, Zn	5.0	750	--	115	60-200	85	--	60	--	200	--
				Other Trace Elements							
Arsenic, As	0.1	2	--	5.7	3-8	3	--	8	--	6	--
Barium, Ba	1.0	--	--	--	--	--	--	--	--	--	--
Cadmium, Cd	0.010	--	--	--	--	--	--	--	--	--	--
Chromium, Cr	0.05	0	--	5.7	0-10	0	--	10	--	7	--
Lead, Pb	0.05	55	--	15	10-20	15	--	10	--	20	--
Mercury, Hg	0.002	--	--	--	--	--	--	--	--	--	--
Selenium, Se	0.01	--	--	--	--	--	--	--	--	--	--
Silver, Ag	0.001	--	--	--	--	--	--	--	--	--	--

TABLE 3-5. VARIABILITY OF SECONDARY EFFLUENT[a] WITH TIME[b]
(All units are in mg/l unless otherwise specified.)

Constituent	Range of Yearly Averages 1963-1970	1971 Range	1971 Average
pH	7.3-8.0	--	7.6
Chlorides, Cl	38.9-60.6	--	--
Nitrogen (as total N)			
Free Ammonia, NH_3	5.3-15.7	0-5.0	0.9
Organic nitrogen	2.8-7.8	0-7.0	2.4
Nitrates, NO_3	4.2-14.9	2.6-17.5	8.6
Phosphorus, P	4.135-9.72	0.25-4.75	2.65
Boron, B	0.29-0.42	0.14-0.27	0.21
Calcium, Ca	20.2-35.6	23.1-27.8	25.2
Magnesium, Mg	10.4-19.8	9.1-15.1	12.9
Manganese, Mn	0.08-0.36	0.01-0.04	0.02
Potassium	13.5-20.6	--	--
Sodium	32.2-52.8	18.8-35.9	28.1
Methylene Blue Active Substances (detergent residue)	0.26-3.2	0.03-0.88	0.37

(a) Secondary Treatment - trickling filters (standard and high rate) and modified activated sludge chlorinated; service area - Pennsylvania State University and Borough of State College.

(b) Reference (3-13).

Summary

The composition of conventionally treated secondary effluents is dependent on numerous site-specific factors. Basically, secondary effluent characteristics are affected by: (1) the geographical location and nature of the sewage treatment plant service area, (2) design type and operation of the sewerage system, and (3) time. However, based on the information contained in this section, a "typical" secondary effluent can be defined by the following major parameters:

	Concentration (mg/l)	
Parameters	Mean	Range
Suspended Solids (SS)	30	(10-80)
Biochemical Oxygen Demand (BOD)	35.7	(10-80)
Total Nitrogen (T-N)	21	(10-40)
Total Phosphorus (T-P)	10.9	(5-15)

Treatment Requirements

Sewage treatment requirements are based on the established water quality criteria of the receiving waters. Federal effluent limitations on dischargers and state agencies have promulgated these standards for the maintenance of "desirable" conditions in the aquatic environment. The public water supply recommendations included in the first column of Table 3-4 are examples of generally higher quality requirements. However, recently proposed criteria, which are based on recreational development of certain waters, are even more protective of aquatic resources. As an example, the Environmental Protection Agency has proposed a total phosphorus criterion of 0.025 mg/l for certain lakes and reservoirs used for recreational purposes.(3-14)

Basis of Effluent Regulations

Wastewater treatment plants are required to have effluent wastewater discharge permits. Terms of the permits vary in response to site and situation specific factors. The minimum acceptable level for sewage treatment plants is established by Federal law as secondary treatment by July 1, 1977, and then "best available wastewater treatment technology" by July 1, 1983. EPA has defined secondary treatment under Title 40, Part 133 of the Code of Federal Regulations (CFR) essentially to be 85 percent removal of BOD and suspended solids; there are also fecal coliform and pH standards.(3-10)

In addition to Federal effluent limitations, which serve as the minimum level of acceptability, individual states have promulgated effluent requirements based on prescribed water quality standards for the various intra - and interstate river segments, lakes, and other water bodies. Each state must now classify all water bodies within its jurisdiction according to the best and highest use to be made of that particular aquatic segment. Ambient water quality standards are then assigned based on designated uses. Standards are to be met throughout the given body of water except within a limited mixing zone allowed downstream of each point source discharge.

By law the states must pay particular attention to stream segments and other water bodies where application of the Federal effluent limitations will not be sufficient to allow achievement of state water quality standards.

Special planning procedures and stricter permit terms are to be established for such areas. In general, more stringent effluent limitations are being imposed on dischargers located in these areas (known as "Water Quality Segments", in contrast to "Effluent Limited Segments" where the ambient standards will be achieved after imposition of the minimum Federal effluent limitations).

Special planning procedures invoked for Water Quality Segments are typically grounded in modeling of the stream segment and its various pollutant parameters. Background concentrations and actual discharges are taken into account. The objective of this approach is to enable state officials to determine the total pollutant load for various parameters in order that the water quality standards will be achieved along that segment. This process is then followed by an allocation procedure whereby the total load for a given pollutant is divided among the dischargers.

It must be emphasized that this process is very complex and highly stream-specific. For example, discharges can be required to abate to different levels on the same segment. Presumably, if the total modeled capacity has been allocated, new sources wishing to discharge will have to locate elsewhere or be faced with a zero-discharge limitation. In instances where a waste-water treatment facility is located on a Water Quality Segemnt, state or regional EPA officials must be consulted so that the specific planning and pollutant allocation details for that discharger can be determined.

Survey of State Requirements

During the conduct of this study the following states were contacted to collect pertinent water quality criteria and municipal wastewater effluent regulations.[3-15]

Alabama	Louisiana
Florida	Mississippi
Georgia	Texas.

With the exception of Florida the above states have minimum effluent requirements of 85 percent removal of suspended solids and biochemical oxygen demand. Florida requires a 90 percent removal efficiency. Furthermore, Florida has in certain cases required advanced wastewater treatment (definitely implying tertiary treatment), defining it as that which will provide an effluent containing not more than the following concentrations.(3-16)

Biochemical Oxygen Demand (BOD_5)	5 mg/l
Suspended Solids (SS)	5 mg/l
Total Nitrogen (N)	3 mg/l
Total Phosphorus (P)	1 mg/l.

None of the states of concern has established specific water quality criteria with respect to nutrients. However, the state "anti degradation" or "freedom" statements could be interpreted to provide a basis of restricting nutrient discharges. Briefly, these narrative statements assert, for example, that "wastes after discharge--shall not create conditions which adversely affect public health or use of the water for the following purposes: domestic or industrial water supply, propagation of aquatic life, agricultural water, recreation and other legitimate uses."

In regard to nutrients and specifically nitrogen species, the state ambient dissolved oxygen standards are indirectly used as a model basis for control of aquatic conditions.

Typically, the states of concern have established minimum dissolved oxygen concentrations for designated use segments which range from 4 to 5 mg/l. However, Texas requires a minimum of 6 mg/l in certain segments classified for contact recreation.(3-17) On the other hand, Louisiana will allow 2 mg/l in certain instances.(3-18)

As an example of the use of dissolved oxygen standards for control of nutrients, Mississippi's modeling practices have led officials to conclude that sewage treatment plants should incorporate maximum effluent limitations of 15 parts per million (ppm), Biological Oxygen Demand (BOD), 5 ppm Total Kjeldahl Nitrogen (TKN), and at least 5 ppm Dissolved Oxygen (DO). This 15-5-5 BOD-TKN-DO standard was used by state personnel for review of the plans and permit applications for both the Picayune and the Orange Grove treatment facilities. Table 3-6 reflects this logic.

Permitting the plan review for the Bay St. Louis plant took place somewhat differently (results also in Table 3-6). At the time when these procedures were being undertaken, Mississippi had not yet received official designation by EPA to operate the permit program, and the Atlanta Regional Office of EPA performed the necessary tasks. The modeling techniques used

TABLE 3-6. EPA/STATE SEWAGE DISCHARGE LIMITATIONS
(mg/1)

	*NSTL		**PICAYUNE		*ORANGE GROVE		*BAY ST. LOUIS	
	Monthly Average	Weekly Average	Monthly Average	Weekly Average	Monthly Average	Weekly Average	Monthly Average	Weekly Average
Biochemical Oxygen Demand (5 days)	30	45	18	27	15	30	10	15
Suspended Solids	30	45	30	45	30	45	30	45
Total Kjeldahl Nitrogen	N/A	N/A	7	11	6	12	N/A	N/A
Ammonia Nitrogen	N/A	N/A	N/A	N/A	N/A	N/A	3	4.5

Source: National Space Technology Laboratories Ref. No. AE580615

* Sewage Lagoons

** Sewage Plant

by EPA-Atlanta were not the same as now used by the state, and EPA arrived at effluent limitation of 10-2-6, in contrast with 15-5-5. Based on the 10-2-6 standard, EPA determined to apply a more stringent ammonia nitrogen limitation instead of one for TKN. BOD discharge concentrations are also significantly more restricted at Bay St. Louis than at either Picayune or Orange Grove. However, state officials have indicated that the 15-5-5 standard will be used at the next opportunity for review of the Bay St. Louis permit. The result is that effluent limitations will likely be relaxed at that time so that all 3 plants will be required to abate their discharges to similar levels.

Summary

As discussed in this section the establishment of municipal waste water effluent requirements is dependent on site ans situation specific factors which relate to background water quality, designated uses of the water body and Federal/State requirements. It is conceivable that zero discharge might be deemed necessary for certain pollutants. However, for the purpose of comparing possible treatment requirements with the design performance of alternative tertiary treatment processes and water hyacinth systems, Florida's definition of advanced treatment will be used. Florida's relatively stringent definition would require a final municipal waste water effluent to be in compliance with the following:

Biochemical Oxygen Demand (BOD_5)	5 mg/1
Suspended Solids (SS)	5 mg/1
Total Nitrogen (N)	3 mg/1
Total Phosphorus (P)	1 mg/1 .

Water Hyacinth System

The use of a water hyacinth system to control potentially deleterious pollutant concentrations is similar to wastewater treatment by land application. The uptake of constituents and subsequent harvesting of the plants is a major mechanism leading to the design reduction of secondary effluent throughput strength. However, inherent biological, chemical, and physical mechanisms of hyacinth systems influence the final discharge quality.

Review of Operating Experience

The most credible approach to determining removal efficiencies and final associated costs of a water hyacinth system is, of course, from data developed in actual field investigations. Preliminary operating experience is available from NSTL investigations and from work conducted at the University of Florida. Some basic information is also available from General Development Corporation.

NSTL "Zig-Zag" Lagoon and Bay St. Louis Investigations. The on site NSTL "zig-zag" lagoon is a chemical waste system primarily for photographic wastes. Most of the NSTL laboratory work concerning metals is believed to be centered around this system. Removals of carbon, nitrogen and phosphorus exceeding 95 percent have been shown by the available zig-zag lagoon data from NSTL.[3-19] This high removal efficiency appears associated with relatively low influent nutrient concentrations and a long retention time. Hyacinth growth was probably limited by nutrient availability during the high growth period of these preliminary investigations.

With respect to municipal waste treatment, the information developed from this lagoon research and associated laboratory investigations is of limited use. Two points are perhaps important: (1) the NSTL uptake data demonstrate that hyacinths have a high tolerance to heavy metals; and (2) hyacinth root growth responds inversely to nutrient availability.

The NSTL Bay St. Louis lagoon studies are intended basically for development of harvesting information. The waste stabilization lagoon is also used for propagation of water hyacinths needed for other NSTL investigations. The available influent/effluent data from NSTL and Burke Associates (consulting engineers) were judged as inappropriate in regard to estimating the effectiveness of a hyacinth system in providing tertiary polishing of a secondary effluent. However, observations of the healthy proliferation of water hyacinths in the Bay St. Louis lagoon indicate that: (1) hyacinths can grow well in highly polluted municipal waste waters (essentially raw sewage); and (2) hyacinth surface coverage does not exclude algal production.

Investigations at the University of Florida. During the conduct of this study a University of Florida Ph.D. thesis by R. M. Clock (1968) was obtained.[3-20] The following abstracted material concludes Clock's literature review:

"Furman and Gilcreas[a], studying the application of oxidation ponds to treatment of residential wastes in the vicinity of Tampa, Florida, grew water hyacinths in the third of a series of one-half acre, 3.5 feet deep lagoons. Water hyacinths covered the lagoon densely from the period August, 1964, to March, 1965, when they were removed because of mosquito breeding problems. With a five-day detention time and using BOD loadings of approximately 50 pounds per acre, the water hyacinth ecological system resulted in anaerobic conditions which eliminated nitrite and nitrate and removed organic and ammonia nitrogen. These latter forms of nitrogen were lowered 63.1 to 85.1 percent during the summer and fall months. During the winter months the decrease was 31.5 to 41.4 percent. These investigators concluded that the water hyacinth did not afford a practicable system for the removal of nitrogen in an oxidation pond treatment process.

"Sheffield[b] described a laboratory scale semi-continuous flow investigation wherein approximately 94 percent removal of nitrate and ammonia nitrogen was obtained with ten-day recirculated detention of an extended aeration effluent in contact with water hyacinths. Orthophosphate removal varied from a high of 77 percent to a low of 10

(a) Furman, T. Des. and Gilcreas, S. W., "The Application of Oxidation Ponds to Treatment of Residential Wastes", Phelps Laboratory, Department of Civil Engineering, University of Florida, Gainesville, Florida, unpublished (1965).

(b) Sheffield, C. W., "Removal of Nitrogen and Phosphorous After Secondary Sewage Treatment", unpublished Master of Science dissertation, University of Cincinnati. (1966).

> percent in the water hyacinth tank. However, chemical coagulation with lime increased the best removal of nitrate, ammonia, and phosphate to 99 percent. Sheffield's work was performed in Cincinnati, with the water hyacinth tank outdoors, during the time period May to July, 1966. Significant nitrate removal occurred only under anaerobic conditions in the water hyacinth tank, and this occurred in the period 4 July to 15 July."

A main objective of Clock's investigations involved the documentation of nitrogen removal by controlling the net denitrification in a lagoon environment covered with water hyacinths. Parallel plywood covered cells were used for control purposes during the investigations. The secondary effluent strength from the University's treatment facility varied significantly during the flow through investigations. However, raw sewage was bypassed to the investigation cells to maintain subsurface anaerobic conditions.

Briefly, Clock's field operation experiences, at Gainesville, Florida, demonstrate that high removals of nitrogen and phosphorus can be expected during high growth periods. Observed nitrogen removals by the hyacinth system were about 85 percent of the influent concentrations in August, 1967, and March, 1968. However, less than 50 percent of throughput nitrogen was removed in November, 1967. Throughput phosphate removal exceeded 50 percent in August, 1967, and April, 1968; however, during the February, 1968, investigations both the hyacinth and control throughput phosphate concentrations were greater than influent values.

Although the data in the thesis are rather limited, Clock's work indicates that: (1) enhancement of net denitrification is most important to an effectively designed/operated hyacinth system; (2) assuming an abundance of nitrates, carbon can be considered as limiting with respect to denitrification; and (3) the problems associated with low dissolved oxygen and highly soluble phosphorus concentrations in a hyacinth system effluent require further definition.

Orange Grove. Orange Grove Utilities, Inc., operates a waste treatment facility for approximately 6,000 residents. The estimated inflow averages 0.6 mgd (0.3 - 1.2 mgd) to the lagoon system. The lagoon system treats essentially 100 percent domestic wastes and consists of two aerated cells in parallel followed by settling cells.[3-21] NSTL personnel have stocked one of the final settling cells (research cell) with water hyacinths the first of July, 1975.[3-22] Another settling cell is considered as a control with respect to the research cell influent/effluent investigations.

NSTL personnel have developed baseline influent/effluent data prior to stocking the research cell (March - June) and continue to collect grab samples to document conditions since stocking with water hyacinths (July - to present). Unfortunately the Orange Grove system has been in a state of evolution during the initial baseline investigations (expansion and addition of mechanical aerators complete by June 20, 1975).[3-21] As a result of these construction alterations alone, NSTL's initial data cannot be considered as a definite reference of baseline conditions.

The present NSTL investigations include a parallel control. The operation parameters of the water hyacinth research cell and parallel control are summarized in Table 3-7. Information provided by the consulting engineers for Orange Grove, Brown & Russell, Inc., compares reasonably well.[3-21] As shown in the table, the estimates of retention times are about 4 and 10 days for the hyacinth and control cell, respectively. Even considering the differences in operation parameter estimations provided by NSTL and Brown & Russell, the ratio of retention times (hyacinth cell retention:control cell retention) is about 1:2. This difference in retention times severely limits the comparability of influent/effluent water quality evaluations. Influent/effluent water quality characterizations of the hyacinth and control cell throughputs (based on grab samples) are presently being developed by NSTL. Brown & Russell is also required to document the overall influent/effluent water quality of the Orange Grove system. Table 3-8 is intended as a summary of the available throughput data provided by these sources.

With respect to the purposes of this study, the data presented in this summary table must be considered as preliminary at this time. Close control of retention times and investigations of system conditions and performance during the winter will be required for the development of design information.

TABLE 3-7. ORANGE GROVE HYACINTH RESEARCH OPERATION PARAMETERS[3-21]

	Water Hyacinth Research Cell	Control Cell
Surface Area	0.295 hectares (0.73 acres)	0.99 hectares (0.40 acres)
Total Volume	4336 meters^3 (153.3 x 10^3 feet^3) (1.145 x 10^6 gallons)	2376 meters^3 (83.9 x 10^3 feet^3) (0.627 x 10^6 gallons)
Average Flow	1060 m^3/day (0.28 mgd)	236.5 m^3/day (0.0625 mgd)
Retention Time[a]	4.1 days	10 days

(a) Estimated from above.

TABLE 3-8. ORANGE GROVE AND WATER HYACINTHS INFLUENT/EFFLUENT CHARACTERISTICS

	Orange Grove[a] Sewage System		Water Hyacinth[b] Cell		Control Cell[b]	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Temperature	--	--	27	26	27	28
pH	--	--	7.5	6.5	6.9	7.1
Suspended Solids	450	29	32.7	6.8	21	32
Dissolved Solids	338	220	282	221	341	382
Dissolved Oxygen	--	--	5.6	2.0	5.2	3.1
Biochemical Oxygen Demand	153	27	27	11	33.2	77
Total Organic Carbon	--	--	30	22	23.6	30
Kjeldahl Nitrogen	34	6.9	2.17	1.15	4.31	3.82
Total Phosphorus	2.32	2.07[c]	5.23	4.24	6.75	6.63

(a) From Reference (3-21), average of four values to reflect July, 1975, conditions.
(b) From NSTL Reference Number AE580617, July average.
(c) Calculated from phosphate; Reference (3-21).

General Development Corporation. General Development Corporation (GDC) designs and builds total communities. One of their major problems is that of sewage treatment. Since "biological" removal systems have received such widespread acclaim in the news media, GDC has decided there may be some merit in investigating the possibilities. At present, they have plans to test two systems: (1) sand filter/bulrush system; and (2) water hyacinth system. Unfortunately, neither system is complete; thus, data applicable to this study were not available. However, a brief description of each system follows for further reference.[(3-23)]

General Development Corporation has designed a system for collecting waste materials from widely scattered home units. The system employs anaerobic stabilization prior to further treatment. The effluent from septic systems is pumped (low pressure) to a central collection station. At the station, the effluent is aerated and released to a small lagoon. GDC is investigating the possibilities of using a combination of sand filter (removes solids) and bulrushes (remove nutrients and water) as a tertiary treatment system. However, this system is currently "considered in the design phase".

GDC also operates a primary treatment facility for the city of Port Charlotte, Florida. Flow through the system is approximately 1.5 mgd (5.67×10^3 m^3/day). Secondary sewage treatment is realized with four one-acre lagoons operated in series. The system design includes the coverage of the third lagoon by water hyacinths. The surface cover provided by the water hyacinths was intended for the purpose of lowering the dissolved oxygen content of the effluent so that denitrification would be enhanced. Unfortunately, soon after the canopy closed, the aerial portion died. Death was attributed to the red spider mite (a recognized hyacinth pest); however, this question has not been resolved.

The most immediate observed benefit from the hyacinths was the reduction in suspended solids attributed to filtration by the hyacinth root mat. Unfortunately, GDC had no growth data and had not monitored consistently the throughput of the hyacinth lagoon cell. Also, the question of harvest had not been addressed.

Design Rationale

Because of limited operational experience with actual water hyacinth treatment systems, the empirical information available was judged inadequate for design purposes here. In the absence of key operation data, the hyacinth treatment system was analyzed in terms of factors/parameters/mechanisms identified in the literature that appeared to be significant technical and/or cost sensitive features. Thus, in order to provide a logical basis for estimating design requirements and associated costs, the pollutant removal mechanisms expected to predominate within a water hyacinth system were considered. From review of all available information it was concluded that the best approach to developing requirements and costs would be to design the hyacinth system for nitrogen removal. The resulting influences on throughput phosphorus, DO, BOD, and suspended solids were postulated. As developed previously, influent constituent concentrations (mg/ℓ) to the conceptual hyacinth system were assumed as follows:

	Range	Mean
Total Nitrogen	10-40	21
TKN	10-30	
NH_4-N	5-25	
NO_3/NO_2-N	0-7	
Total Phosphorus	5-15	10.9
Suspended Solids	10-80	30
BOD	10-80	

After a brief discussion of the throughput removal mechanisms considered, a seasonally-based hyacinth lagoon design is advanced. The expected optimum and adverse effluent quality is presented. The operation requirements for nitrogen and phosphorus removal are estimated. A final summary discusses key estimated requirements for a water hyacinth treatment system for water throughput levels of 1, 2, 5, 10 mgd (1.0 mgd = 3.8×10^3 m^3/day, $\simeq$ 10,000 people).

Nitrogen Removal Mechanisms. Throughput nitrogen can be reduced within a hyacinth system by net denitrification, harvested plant assimilation, and waste-solids settling. Denitrification can result in a net loss of N_2

gas to the atmosphere. Insolation, temperature, available nutrients and retention time are key factors controlling the growth/harvest assimilation of throughput constituents. A portion of the complexed nitrogen species which settles to the bottom will be removed from the lagoon throughput. Volatilization of ammonia is expected to be slight and therefore neglected.

In order to optimize a nitrogen-removal-based hyacinth system (i.e., minimize needed hyacinth surface requirements), denitrification (the reduction of nitrates and/or nitrites to nitrogen gas and/or N_2O by anaerobic bacteria) should be enhanced. Both pH of greater than 6.5 and anaerobic conditions must be maintained to promote denitrification. However, an aerobic surface layer must be present to ensure adequate hyacinth growth and nitrification (the oxidation of ammonium salts to nitrites and to nitrates by aerobic bacteria). The reaction rates are also highly dependent on temperature and carbon concentration. However, the predominant influence on the amount of nitrogen which can be removed is the concentration of available nitrates (NO_3^-).

The quantity of nitrate entering the hyacinth lagoon will depend on the preceding treatment step. A highly productive facultative lagoon (aerobic surface layers and anerobic bottom) can further enhance both plant assimilation and denitrification. The effects of pH and temperature of the nitrification rate are presented in Figures 3-2 and 3-3, respectively. Long retention times (several days) must be provided to enhance nitrification.[3-24] Dissolved oxygen levels above 2 mg/ℓ are required for the nitrification reactions to occur. The nitrifying organisms will be expected to concentrate in the upper aerobic inches of the facultative hyacinth lagoon. The upper root mass of the hyacinths provides a high surface area (substrate) for these nitrifying microbes. The complete oxidation of the expected median of 10 mg/ℓ of ammonia in the influent by nitrifying bacteria to nitrate imposes an oxygen demand of 45 mg/ℓ.[3-6,3-12]

Assuming highly productive facultative conditions are maintained, denitrification in a hyacinth lagoon system can be considered limited by available carbon.[3-25] Denitrifying bacteria require organic carbon as an energy source. In a conventional denitrification reaction, methanol is commonly employed as a supplemental carbon source.[3-27] The methanol induced to increase reaction rates can be calculated as follows[3-27, 3-29]:

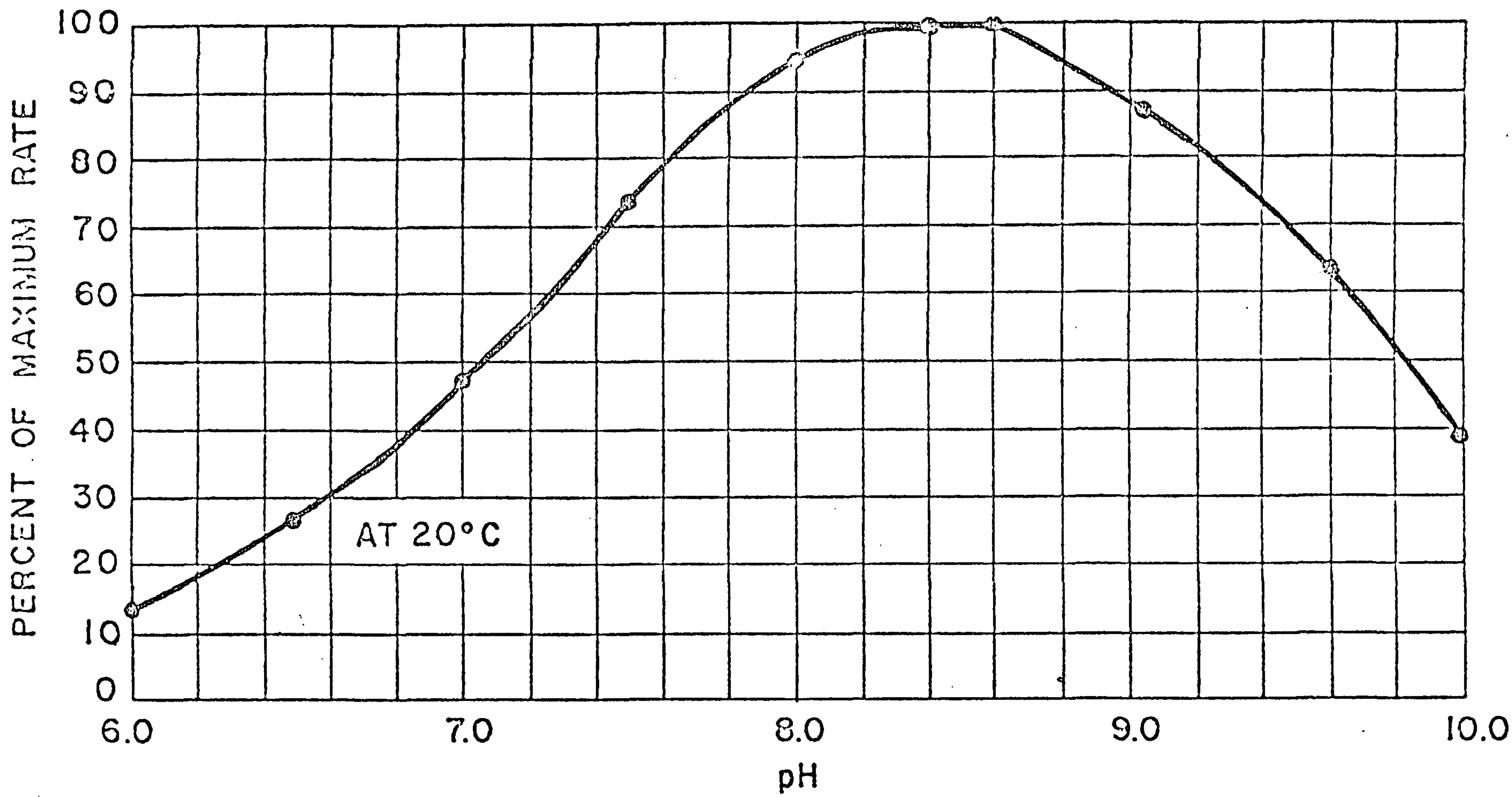


FIGURE 3-2. EFFECT OF pH ON NITRIFICATION RATE

Source: Reference 3-26.

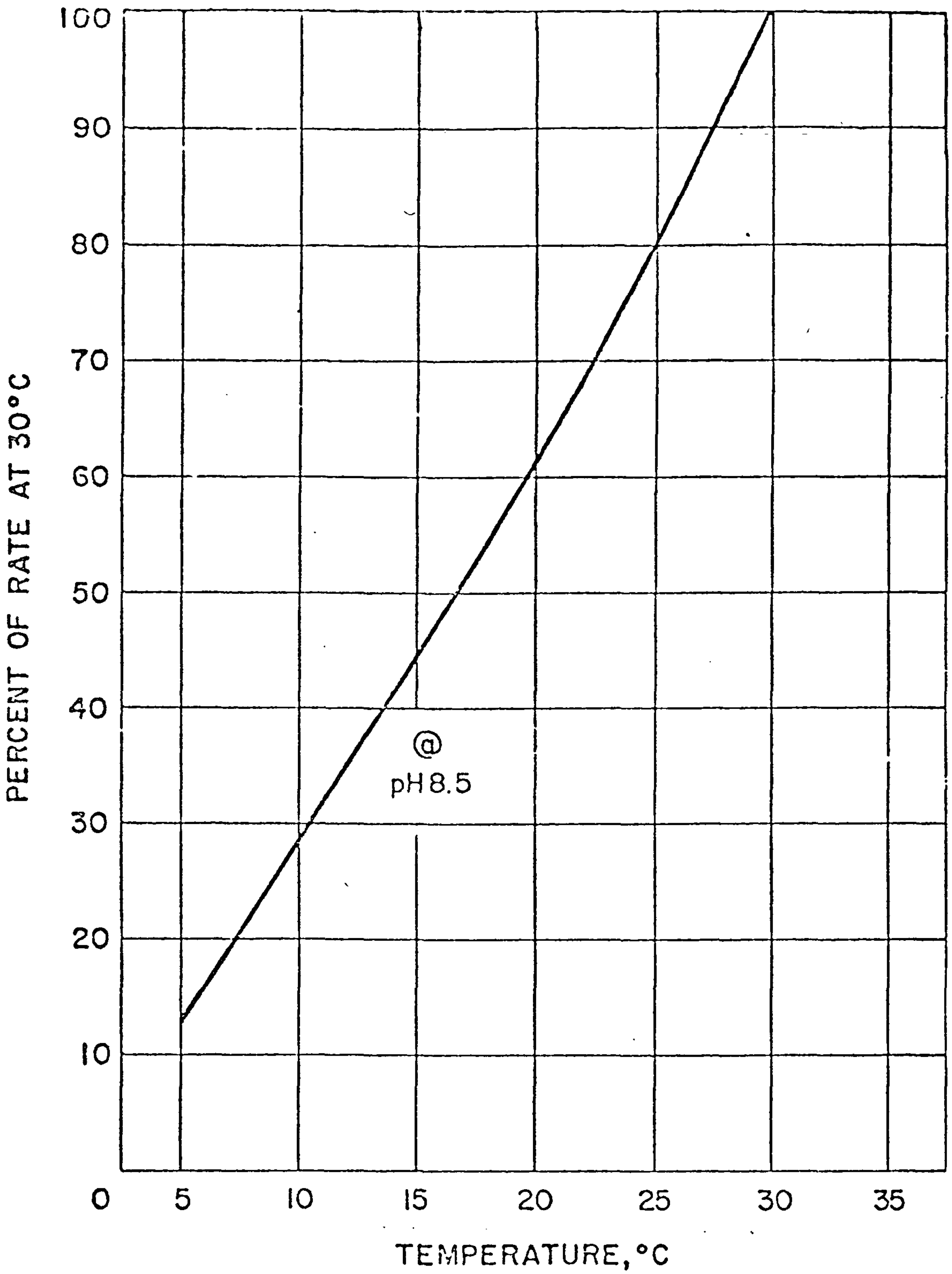


FIGURE 3-3. TEMPERATURE DEPENDENCE OF THE RATE OF NITRIFICATION

Source: Reference 3-26.

Methanol required = 2.47 x Nitrate Concentration + 1.53 x Nitrite Concentration + 0.87 x Dissolved Oxygen Concentration.

The concentration of denitrification organisms, temperature, pH and retention time are also important in regard to denitrification rates. As an example Figure 3-4 relates temperature to nitrate loadings and microbial populations (represented by mixed liquor volatile suspended solids). In a hyacinth lagoon the bottom and settling solids in the anaerobic zone act as the substrate for the denitrifiers. The lower root surface area could also provide additional substrate for the denitrifying organisms.

The majority of the throughput nitrogen which is not lost to atmosphere due to denitrification must be assimilated by the hyacinths and removed from the system by harvesting. Both NH_4+ and NO_3- are readily available for assimilation into plant tissue. A review of all available information suggests that growth/harvest removal of nitrogen can be realistically estimated by assuming that nitrogen amounts to 2.5 percent of the plant dry weight.[3-30] The dry weight of a hyacinth is assumed to be about 5 percent of the total weight.

A small amount of the throughput nitrogen will be removed by waste solids settling. However, deamination and resulting resolubilization of a portion of the settled organically complexed nitrogen must be considered. For the purposes of this report, the feedback of nitrogen to the system is assumed as 50 percent of the settling organic nitrogen.[3-25]

Biochemical Oxygen Demand Removal Mechanisms. In this type of system the biochemical oxygen demand (BOD) can be considered removed by at least three mechanisms: (1) denitrification, (2) solids filtration and settling, and (3) plant assimilation. As previously discussed, complete microbial denitrification generally requires a supplemental carbon source. The Florida investigations illustrate that the soluble BOD is being utilized as a carbon source for the microbial reduction of nitrate[3-30] BOD: NO_3-Nitrogen $\simeq$ 3.91:1.0[3-25, 28, 29]

The hyacinth lagoon also acts as both a filter system and settling basin. These mechanisms will enable the removal of the BOD associated with the solids fraction. A release of approximately 50 percent of the soluble BOD from the settled solids can be realized due to anaerobic degradation in the sediment. There can be a further removal of soluble BOD by plant as-

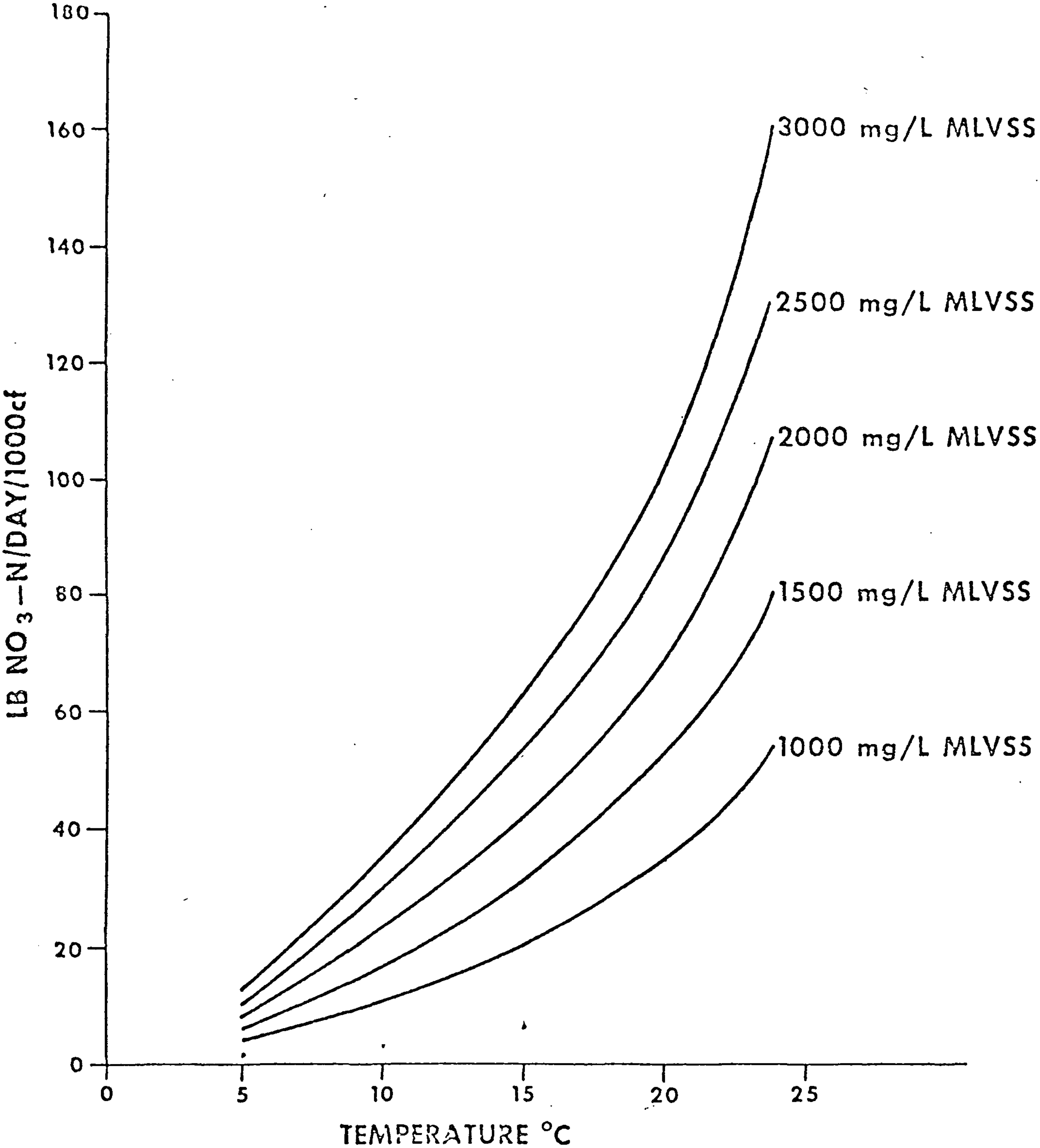


FIGURE 3-4. EFFECT OF TEMPERATURE AND MLVSS[a] ON DENITRIFICATION RATES

Source: Reference 3-26

(a) Mixed liquor volatile suspended solids.

assimilation. Thus, it appears that a well designed and operated hyacinth lagoon can be very effective in reducing the throughput BOD.

Phosphorus Removal Mechanisms. In a hyacinth lagoon, two mechanisms for phosphorus removal should be considered: (1) precipitation (physical, chemical or biological) and (2) plant assimilation. Phosphorus in the form of P_2O_5, is highly soluble. Thus, since conditions in the hyacinth lagoon bottom must be anaerobic for efficient nitrogen removal, throughput reduction of phosphorus due to complexation with precipitated solids is expected to be slight.

Plant assimilation can be considered as the dominant mechanism for phosphorus removal in a hyacinth system. As a conservatively high working estimate, the phosphorus concentration of a harvested water hyacinth can be assumed to equal 0.5 percent (dry weight basis).[3-30] Table 3-9 was generated as a representation of operation requirements for phosphorus removal. The construction of the table carries with it the following assumptions:

- Phosphorus (P) removal is the design objective.
- All of the P in secondary effluents is available for plant intake (appropriate species and sufficient retention time).
- Exchanges of Phosphorus to the atmosphere or lagoon bottom are in equilibrium and/or insignificant.
- The required supplemental nitrogen is supplied (Nitrogen is expected to be limiting due to the imbalance in influent and hyacinth assimilation N:P ratios[3-25, 30].
- Each hyacinth plant assimilates 0.437 percent P on a dry weight basis.[3-31] (It should be noted that assimilation rates of P are highly dependent on available phosphate concentrations (as discussed in Chapter 2).
- Havesting rate equals the growth rate.
- 100 gal (~ 380 liter) per capita day of secondary effluent.[3-12]

A typical total phosphorus concentration of a secondary effluent is about 10.9 mg/ℓ[3-6]. As shown in Table 3-9, a harvesting/growth rate of 40 dry tons per acre-year can provide for the removal of the "typical" phosphorus contributions from 105 people. This assumes a constant hyacinth production

TABLE 3-9. OPERATION REQUIREMENTS FOR PHOSPHORUS REMOVAL[(a)]

Growth/ Harvest Rate dry tons/ acre	Approximate Population Served per Acre of Water Hyacinths Phosphorus Removed (mg/ℓ)							
	2	4	6	8	10	10.9	12	15
10	144	72	48	36	29	26	24	19
14.7	212	106	71	53	42	39		28
20	287	144	96	72	57	53	48	38
30	431	215	144	108	86	79	72	57
40	574	287	191	144	115	105	96	77
50	718	359	239	179	144	132	120	96
60	862	431	287	215	172	158	144	115
66	948	475	316	237	190	(174)	157	126
97.5	1400	700	467	350	280	257	233	187

(a) Calculation basis: Hyacinth composition--0.4367 percent P (dry weight) rate of 3.3 dry tons per acre-month. Although conservatively high P assimilation value of 0.5 percent is used in this report, the operation requirements presented in Table 3-9 are considered more indicative of the expected median hyacinth lagoon P assimilation rates.

Removal Mechanisms for Suspended Solids. The solids can be removed from the hyacinth lagoon via two mechanisms: filtration and settling. Under appropriate design conditions, the hyacinth mats can function as a physical-biological filter and remove suspended solids. This approach is presently being utilized by General Development Corporation very effectively. The hyacinth basin can also act as a sedimentation basin. In this event the throughput of influent suspended solids, produced algae, and hyacinth fragments can be effectively controlled. If the lagoon is effectively covered by hyacinth mats and properly operated, the above mechanisms should effectively reduce suspended solids to below 10 mg/ℓ. But if the hyacinth mat coverage is not complete (say less than 50 percent), then a high loss of suspended solids could result. As a reference, the loss of suspended solids from a waste stabilization basin ranges from 30 to 50 mg/ℓ.[3-6, 25]

Dissolved Oxygen Influences. A hyacinth lagoon designed for nitrogen removal should be generally anaerobic below 10 centimeters in depth. This is aided by three major factors: (1) remaining biological oxygen demand; (2) the nitrogenous oxygen demand; and (3) reduced reaeration due to the hyacinth mats. There will be an oxygen depletion by the remaining soluble biological oxygen demand being utilized during denitrification. There will also be an oxygen depletion with microbial oxidation of ammonium to nitrate (or nitrogenous oxygen demand). The hyacinth mats will cover a major portion of the water surface; as a result, wind turbulence and subsequent reaeration will be effectively reduced in the hyacinth lagoon. The major oxygen inputs should be due to algal activity and influent organic addition.

Estimation of Hyacinth System Performance. The design of a hyacinth treatment system involves both site and situation specific considerations. These considerations include: loading rates, detention time, aerobic/anaerobic depth relationships, and harvesting doctrine. The operation requirements of hyacinth system will be a function of geographic/seasonal conditions. Consequently, applicable design rationale must also be based on site conditions (e.g., insolation/temperature). The following estimates are based on the conceptual performance of a water hyacinth treatment system for limiting conditions (winter) and optimum conditions (late summer).

Winter Design Estimations. Where ambient temperatures are below 10 C or 50 F, hyacinth growth is inhibited and only "maintenance" activity continues. Frost conditions will result in injury to the exposed portions of the plant at 0.6 C, and at temperatures below -2 C, the entire plant including root system is destroyed. When no net growth is experienced, the only expected nitrogen loss from the system will result from denitrification and solid deposition.

Studies by Clock have indicated that during the winter, denitrification can account for about a 25 percent decrease in soluble nitrogen from the system.[3-20] Observations from water hyacinth lagoons operating in Tampa, Florida, during the winter (minimum air temperatures averaged 10 to 16 C), show decreases in organic and ammonia nitrogen of approximately 32 and 41 percent respectively.[3-20]

As indicated by the following calculations (Table 3-10), carbon will be the limiting factor in determining denitrification efficiency. It was assumed that both nitrification and denitrification occurred over a period of five days as shown in the Florida[3-20] investigation. The solids were assumed to be between 10 and 40 mg/ℓ because the resulting cover of the hyacinth mat must be considered. The BOD removal was assumed to be by (1) filtration/settling of the solid portion of the BOD and (2) consumption/fixation as a carbon source for denitrification. The resulting effluent BOD was estimated as 4 mg/ℓ.

However, a solids release of 10 to 40 mg/ℓ should be anticipated. During such periods the BOD can be assumed as approximately 30 percent of the suspended solids. Thus, the total effluent BOD could range from 7 to 16 mg/ℓ. The nitrogen removed was assumed to be approximately 25 percent as shown in the previously discussed Florida study. The estimation of winter throughput characteristics is presented in Table 3-10. (The resulting effluent for winter conditions, expected in Louisiana, Texas, Mississippi, Alabama, South Carolina, Georgia, and northern Florida is summarized in Table 3-12.

Summer Design Estimations. In the summer the hyacinth growth will not be limited due to temperature unless the temperature rises above

TABLE 3-10. ESTIMATION OF WINTER THROUGHPUT CHARACTERISTICS OF HYACINTH SYSTEMS

A. Nitrogen Throughput Concentration
   1. The organic nitrogen settles to the bottom
      21 mg/ℓ - 6 mg/ℓ = 15 mg/ℓ soluble nitrogen
   2. There is a 25 percent removal of nitrogen by nitrification/denitrification[4]
      15 mg/ℓ of soluble Nitrogen x (1-0.25)
      = 11 mg/ℓ of soluble nitrogen
   3. Winter effluent of nitrogen
      Winter effluent = 11 mg/ℓ as nitrogen

B. Biochemical Oxygen Demand Throughput Concentration
   1. BOD removed by solids settling
      36 mg/ℓ of BOD_{total} - 16 mg/ℓ BOD with solids = 20 mg/ℓ soluble BOD
   2. BOD lost through denitrification
      4 mg/ℓ of Nitrogen removed $\left\{\frac{\text{3.91 BOD Removed}}{\text{Nitrogen Removed}}\right\}$ [3-20,25,27-29]
      = 16 mg/ℓ of BOD (soluble) removed by denitrification.
   3. BOD soluble remaining =
      20 mg/ℓ of BOD soluble - 16 mg/ℓ of BOD soluble = 4 mg/ℓ of BOD soluble
   4. Probable effluent BOD associated with typical solids loss
      10 mg/ℓ solids = 3 mg/ℓ of BOD (0.3 mg of BOD/mg of solids)
      40 mg/ℓ solids = 12 mg/ℓ of BOD (0.3 mg of BOD/mg of solids)
   5. Expected total BOD in effluent =
      $BOD_{soluble} + BOD_{solid}$
      lowest normal BOD in effluent = 4 mg/ℓ + 3 = 7 mg/ℓ
      Highest normal BOD in effluent = 4 mg/ℓ + 12 = 16 mg/ℓ

C. Phosphorus Throughput Concentration
   1. Phosphorus removed by solids settling
      Total phosphorus - Phosphorus in settled waste solids
      11 mg/ℓ - 1 mg/ℓ = 10 mg/ℓ of phosphorus
   2. Phosphorus in the effluent=soluble
      Phosphorus + Phosphorus in the solids
      = 10 mg/ℓ of P + 1 mg/ℓ of Phosphorus
      = 11 mg/ℓ of P

34.4 C for more than 4 or 5 weeks. For this portion of the investigation, the temperature was assumed to be less than 34.4 C, and therefore, hyacinth activity would not be inhibited. The controlling design parameter was assumed to be nitrogen. Phosphorus and carbon should not be limiting due to the high concentration of phosphorus in the influent and the fixation of atmospheric carbon dioxide by the hyacinths. For the summer conditions, nitrogen is considered removed by three mechanisms, denitrification, deposition of waste solids, and assimilation of nitrogen by the hyacinths. The soluble nitrogen will be the total nitrogen in the influent minus the nitrogen settled by waste solids and the nitrogen removed by denitrification plus the nitrogen added by the feedback from anaerobic digestion of nitrogen in the waste solids. The final effluent nitrogen concentration is expected to equal approximately 17.5 mg/ℓ as nitrogen (Table 3-11). For the design purposes of this study, the nitrogen was conservatively assumed to be reduced to approximately zero or approximately one milligram per liter nitrogen as nitrogen. The biological oxygen demand in the effluent was also estimated to be 1.5 mg/ℓ due to BOD reduction from solids settling and denitrification plus some BOD due to decomposition of trapped solids. The phosphorus is removed by two processes, the uptake by hyacinths and the settling of waste solids. The concentration of phosphorus was predicted to be approximately 8 mg/ℓ as phosphorus. Calculations of summer throughput characteristics are shown in Table 3-11 and the resulting summer performance (growth period) of the conceptual water hyacinth treatment system is included in Table 3-12.

Throughput and Land Use. As shown in Table 3-12, good removals of throughput Suspended Solids and BOD may be expected during hyacinth growth periods. Only a 25 percent reduction of influent phosphorus concentrations, 10.9 mg/ℓ, for this system designed for nitrogen control is anticipated. Nearly five times the active hyacinth surface area would seem required for complete removal of influent phosphorus. Furthermore, a hyacinth system for phosphorus removal should also be designed to minimize nitrogen loss due to net denitrification in order to reduce needed supplemental nitrogen and associated costs.

Wide ranges in SS and BOD are shown in Table 3-12 for applicable winter conditions (maintenance period). These ranges should not be reduced at this time since the required design information based on operation

TABLE 3-11. ESTIMATION OF SUMMER THROUGHPUT CHARACTERISTICS

A. Biological Oxygen Demand in Effluent

1. BOD removed by solids filtration and settling

$$BOD_{removed} = BOD_{solid} = 16 \text{ mg}/\ell$$

2. BOD feedback by solids anaerobic digestion in sediment

$$0.5\ BOD_{solids} = 8 \text{ mg}/\ell$$

3. Soluble BOD in basin before denitrification and hyacinth assimilation

$$\text{Soluble BOD} = BOD_{\text{soluble in influent}} + BOD_{feedback}$$
$$= 20 + 8 = 28 \text{ mg}/\ell$$

4. BOD removed by denitrification is soluble BOD

$$BOD_{soluble} = 0 \text{ (carbon limited)}$$

5. BOD effluent will equal BOD in the solids

$$BOD = (5 \text{ mg}/\ell \text{ of solid}) \frac{(0.3 \text{ mg of BOD})}{\text{mg of SS}}$$
$$= \underline{1.5 \text{ mg}/\ell}$$

B. The Nitrogen Concentrations in the Effluent

1. The nitrogen removed by filtration and settling

5 mg/ℓ of organic nitrogen = nitrogen deposited

2. The feedback nitrogen will be 50 percent of the trapped organic nitrogen

5 mg/ℓ (0.5) = 2.5 mg/ℓ of feedback nitrogen

3. The soluble nitrogen before denitrification

Soluble nitrogen = Soluble nitrogen in influent + feedback nitrogen
= 2.5 mg/ℓ + 15 mg/ℓ
= 17.5 mg/ℓ as Nitrogen

4. The soluble nitrogen after denitrification

a. Nitrogen removed by denitrification[3-20,25,27-29]

$$= \frac{\text{Soluble BOD in mg}/\ell}{\frac{3.91 \text{ mg of BOD}}{\text{mg of Nitrogen}}} = \frac{28}{3.91}$$
$$= 7.2 \text{ mg}/\ell \text{ as nitrogen}$$

b. Soluble Nitrogen after denitrification

Soluble Nitrogen = 17.5 - 7.2 = 10.3 mg/ℓ as Nitrogen

5. Assume all nitrogen not lost to the atmosphere is removed by Hyacinth Assimilation

The concentration of soluble nitrogen = <1 mg/ℓ as nitrogen

C. The Solids Concentration

1. Since filtration sedimentation should be enhanced, effluent Suspended Solids were assumed to be less than 5 mg/ℓ.

D. The Phosphorus Concentration

1. The phosphorus removed by solids entrapment

1 mg/ℓ of phosphorus

2. The soluble phosphorus

Soluble phosphorus = 11 mg/ℓ - 1 mg/ℓ
= 10 mg/ℓ

3. The quantity of phosphorus in effluent

a. The pounds of phosphorus assimilated by the hyacinths (15.6 acres) (1.1 lbs of Phosphors/acre-day) = 17.2 lbs of phosphorus/day by the hyacinths

b. The pounds of phosphorus available per day (10.0 mg/ℓ of phosphorus (8.34) (1 MGD) = 83.4 lbs of phosphorus/day

c. Quantity of phosphorus remaining in the effluent

$$= \frac{83.4 \text{ lbs/day} - 17.2 \text{ lbs/day}}{8.34}$$
$$= 8 \text{ mg}/\ell \text{ as phosphorus}$$

TABLE 3-12. ESTIMATES OF PERFORMANCE OF A CONCEPTUAL WATER HYACINTH TREATMENT SYSTEM (Nitrogen Removal Design Basis)

	Effluent Concentrations (mg/ℓ)			
	SS	BOD	N	P
Secondary Effluent	30	35.7	21	10.9
Range	(10-80)	(10-80)	(10-40)	(5-15)
Maintenance Period[a]	10-40	7-16	10-11	10-11
Growth Period[b]	<5	<1.5	<1	∿8
	Removal Efficiency (Percent)			
	SS	BOD	N	P
Maintenance Period	20-80[c]	55-80	∿50	∿0
Growth Period	∿90[c]	>95	>95	∿25

(a) Estimated November-March effluent concentrations for Texas, Louisiana, Mississippi, Alabama, Georgia, South Carolina, and northern Florida.
(b) Estimated April-October effluent concentrations for region specified in (a) above, plus the winter effluent for southern Florida.
(c) Based on influent concentration of 50 mg/ℓ.

TABLE 3-13. ESTIMATED LAGOON AREAS FOR REMOVAL OF NITROGEN

United States Regions	Hyacinth Growth/Harvest dry tons/acre-year (MT/ha-yr)	Required Lagoon Area, Acres (Hectares) Secondary Effluent Throughput (Flow) 1 mgd[a]	2 mgd	5 mgd	10 mgd
Except South Florida[b]	4 (8.0)	78.1 (31.6)	156.2 (63.2)	390 (158)	781 (316)
Except South Florida[b]	10 (22.4)	31.2 (12.6)	62.5 (25.3)	156 (63.2)	312 (126)
Except South Florida[b]	20 (44.8)	15.6 (6.32)	31.2 (12.6)	78.1 (31.6)	156 (63.2)
South Florida	20 (44.8)	31.2 (12.6)	62.5 (25.3)	156 (63.2)	312 (126)
South Florida	40 (89.6)	15.6 (6.32)	31.2 (12.6)	78.1 (31.6)	156 (63.2)

(a) 1 million gallons per day (3.8×10^3 m^3/day, ≈10,000 people)
(b) Year around growth not expected, 6 months assumed (see a & b above)

experience has not been developed. Nitrogen removal during maintenance periods is estimated to be about 50 percent. Phosphorus removal during the maintenance period is expected to be insignificant.

A hyacinth system should be very efficient for BOD polishing in both summer and winter. However, seasonally-related Suspended Solids losses typical of lagoon systems should be expected. Removals of nitrogen by net waste solids entrapment, denitrification, and/or hyacinth assimilation will also vary in response to climatic fluctuations. This problem is not expected to be as severe in southern Florida. Effluent concentrations of phosphorus will depend dominantly on influent concentrations and the anaerobic activity of the facultative hyacinth system. The nitrogen based design need of well established anaerobic conditions (to enhance denitrification and minimize required surface area/costs) may also pose an effluent dissolved oxygen problem. Effluent dissolved oxygen concentrations may be less than the generally required 4 mg/ℓ. However, this possible problem may not be realized since long retention times will be required for effective nitrogen removal.

Futhermore, other cognizant design/operation tradeoffs should also be available to mitigate dissolved oxygen-related problems. However, if high phosphorus removals are required, some form of additional treatment should be explored. The expected low effluent nitrogen and dissolved oxygen concentrations could aid in phosphorus removal if Barnard's concept[3-31] is employable.

Table 3-13 summarizes the estimated lagoon surface area required for nitrogen removal as related to selected site specific seasonal growth variables and situation specific sewage characteristics. It must be reemphasized that growth rates and throughput characteristics are highly variable in both time and space. The nitrogen-removal-based surface area requirements presented in the table are intended as working estimates required to focus on the economic feasibility of a water hyacinth system for municipal wastewater treatment.

As developed previously, both soluble nitrogen (N) and phosphorus (P) concentrations are estimated to range from 10 to 11 mg/ℓ in a hyacinth system receiving a secondary effluent. Thus for a 1.0 mgd (3.785×10^3 m^3/day or $\simeq$ 10,000 people) sewage treatment system, available N and P loadings in a hyacinth system throughput may be considered to range from 83.3 to 91.6 pounds per day, each. For an annual growth harvest rate of 20 tons/ac, a hyacinth system could be designed on a basis of 2.75 pounds of nitrogen and 0.55 pounds of phosphorus assimilation per acre-day (assumes N and P are 2.5 and 0.5 percent of dry weight). In the case where growth/harvest rate of 20 tons/ac occurs in 6 months (see table), design N and P assimilation rates for the applicable season(s) can double to 5.5 and 1.1 pounds/ac-day, respectively. The active hyacinth lagoon area required can be estimated by dividing the soluble loading rate (mass/time) requiring removal by the appropriate design assimilation flux (mass/area-time). Following this procedure, the surface area estimations needed for costing purposes were generated, as presented in Table 3-13.

As shown in the table, a surface area of about 78 acres (32 hectares) is the projected need for further treatment of a 1.0 mgd secondary throughput for a selected low growth/harvest of 4 tons (dry) per acre per six months. In southern Florida the same area would provide an equal level of treatment for five times the population assuming a 40 tons/acre-year growth/harvest. The associated estimates of performance and seasonal/locational assumptions have been included in Table 3-12, above.

The retention time through a lagoon system is equal to the throughput divided by the volume (surface area x depth). At a given depth, the retention time in a hyacinth system can be considered solely related (inversely) to the design growth/harvest rate. Assuming a depth of four feet, a hyacinth system designed for a growth/harvest rate of 40 ton/acre-year would result in a retention time of about 20 days. A hyacinth system designed on the basis of 4 tons/acre-year would have a retention time of 100 days. Since five times the active surface area has been estimated to be required for phosphorus removal, associated retention times would equal 100 and 500 days for systems designed on the basis of 40 and 4 tons/acre-year, respectively.

References For Chapter 3

3-1 Fair, G. M., Geyer, J. C., and Olkun, D. A., Water and Wastewater Engineering, 1, John Wiley and Sons, Inc., New York (1968). Water Supply and Wastewater Removal, 2, John Wiley and Sons, Inc., New York (1968). Water Purification, and Wastewater Treatment and Disposal, John Wiley and Sons, Inc., New York (1968).

3-2 Anderson, M. S., Comparative Analyses of Sewage Sludges. Sewage and Industrial Waste (1956) Chapter 28, pp 132-135.

3-3 Bertrand, G., and Benson, B., The Control of Zinc in the Principal Foods of Vegetable Origin. Bul.Coc.Hyg.Aliment.(1928) Chapter 16, pp 457-463, and Ann.Inst. Pasteur (1929) Chapter 43, pp 386-393, Abstract from Bibl Minor Elements, 4th ed. (1948) Chapter 1, p 938.

3-4 Hegsted, Mark D., McKibbin, John M., and Drinker, Cecil K., The Biological, Hygenic and Medical Properties of Zinc and Zinc Compounds. Supplement No. 179 Public Health Report, U. S. Public Health Service, Washington, D. C. (1945).

3-5 Rooney, R. C. (editor). Water Quality Criteria (1972). A Report of the Committee on Water Quality Criteria. EPA-R3-73-033. U.S. Environmental Protection Agency, Washington, D. C., USGPO, Washington, D. C. (1973), p 613.

3-6 Pound, C. E., and Crites, R. W., Characteristics of Municipal Effluents. In: Recycling Municipal Sludges and Effluents on Land, Proceedings of the Joint Conference, July 9-13, 1973, Champaign, Illinois, National Association of State Universities and Land-Grant Colleges, Washington, D. C. (1973), pp 49-61.

3-7 Metcalf and Eddy, Inc., Wastewater Engineering, Collection, Treatment, Disposal, McGraw-Hill Book Company, New York (1972).

3-8 Mytelka, A. I., Heavy Metals in Wastewater and Treatment Plant Effluents, Journal WPCF. Vol. 45, No. 9, pp 1859-1864, September, 1973.

3-9 Hunter, J. V., and Kotalik, T. A., Chemical and Biological Quality of Treated Sewage Effluents. Recycling Treated Municipal Wastewater and Sludge through Forest and Cropland, W. E. Sopper and L. T. Kardor, Pennsylvania State University, University Park, Pennsylvania (1973), pp 6-25.

3-10 Environmental Protection Agency Regulations on Secondary Treatment Information, 4DCRF 133.102; 38 FR 22298, August 17, 1973.

3-11 Wastewater Treatment Study--An Element of the Regional Water Resources Management Effort, prepared for Montgomery County, Maryland, CH_2M Hill Consultants, Reston, Virginia, November, 1972.

3-12 Eckenfelder, W. W., Jr., Water Quality Engineering for Practicing Engineers, Barnes and Noble, Inc., New York (1970).

3-13 Kardos, L. T., and W. E. Sopper, 1973, Renovation of Municipal Wastewater Through Land Disposal by Spray Irrigation, in Recycling Treated Municipal Westewater and Sludge Through Forest and Cropland, W. E. Sopper and L. T. Kardos, Editors, Pensylvania State University Press, University Park, Pennsylvania.

3-14 Environmental Protection Agency, Proposed Criteria for Water Quality--Volume I, U. S. Environmental Protection Agency, Washington, D. C., p 425 (October, 1973).

3-15 Personal communications (phone and mail) -- 1975

Alabama

Mr. Craig Kneisel
Alabama Water Improvement Commission
Montgomery, Alabama
(205) 277-3630

Florida

Dr. Frank Philipps
Water Quality Bureau
Florida Department of Environmental Regulation
Tallahassee, Florida
(904) 488-6221

Georgia

Mr. Tommy Furlow
Environmental Protection Division
Georgia Department of Natural Resources
Atlanta, Georgia
(404) 656-4708

Mississippi

Mr. Bill Barnett and Mr. Ralph Waters
Mississippi Air and Water Pollution Control Commission
Jackson, Mississippi
(601) 354-7661

Louisiana

Mr. David Bruce
Louisiana Stream Control Commission
Baton Rouge, Louisiana
(504) 389-5309

Texas

Mr. Larry Bailey
Texas Water Quality Board
Austin, Texas
(512) 475-3454

EPA-Atlanta

Mr. Rick Newson
U.S. Environmental Protection Agency
Atlanta, Georgia
(404) 526-5784

Mr. Ernesto Perez
U.S. Environmental Protection Agency
Atlanta, Georgia
(404) 526-5491

Mr. Mike Williams
U.S. Environmental Protection Agency
Atlanta, Georgia
(404) 526-3633

3-16 Rules of the Florida Department of Pollution Control, Pollution of Waters Supplement, No. 25, Chapter 17 - 3.04.

3-17 Water Quality Standards Texas Water Quality Board; Texas Water Code Chapter 21, Section 21.002, 60th Legislature, Chapter 313, Section 1,02, as amended. Approved October 25, 1973.

3-18 Louisiana Water Quality Criteria, Louisiana Stream Control Commission, L.R.S. 56:1433; Adopted August 14, 1973.

3-19 Personal communications with Wolverton, B. C., McDonald, R. C., and Barlow, R. M. (NSTL personnel), BCL trip in July, 1975.

3-20 Clock, R. M., "Nitrogen and Phosphorus Removal From a Secondary Sewage Treatment Effluent", unpublished Ph.D. dissertation, University of Florida (1968).

3-21 Personal communications with Donnie W. Berryhill, P.E., Brown & Russell, Inc., Consulting Engineers, Gulfport, Mississippi (phone and mail), September 10, 1975.

3-22 NSTL Reference Number AE580618.

3-23 Personal communications with Harold Smith, President of General Development Corporation (GDC) Utilities, Miami, Florida; and Mr. W. Wilcox, Vice President of GDC Environmental Quality Laboratory, Port Charlotte, Florida, September, 1975.

3-24 Wuhrmann, K., "Nitrogen Removal in Sewage Treatment Processes", Verhandl. Intern. Verein. Limnol., XV, 580-596 (1964).

3-25 Reimers, R. S. and Englande, A. J., personal communication, Tulane University, Belle Chasse, La. (Nov., 1975).

3-26 Culp, G. L., Wesner, G. M., Culp, R. L., and Benjes, H. H., "Advanced Wastewater Treatment Seminar Manual", Culp, Wesner, and Culp, El Porada Hills, California (Sept., 1975).

3-27 "Methanol Cleans up in Sewage", Chemical Week, p 35 (July 19, 1972).

3-28 "Nitrification and Denitrification Facilities - Wastewater Treatment", EPA, Technology Transfer (August, 1973).

3-29 St. Amant, P. P. and McCarth, P. L., "Treatment of High Nitrate Waters", J. Amer. Water Works Associat., p 659 (Dec., 1969).

3-30 Personal communications with NSTL, July, 1975.

3-31 Barnard, J. C., "Biological Nutrient Removal Without the Addition of Chemicals", Water Research, 19, 485-490 (1975).

CHAPTER 4

COST AND PERFORMANCE COMPARISONS

Cost Estimates - Hyacinth System

The costs of hyacinth treatment systems presented in this section have been estimated by adding the costs associated with conventional lagoon construction and operation to the costs related to harvesting water hyacinths. A range of surface areas required for nitrogen removal (summarized from those developed in the previous chapter were used as a basis for cost estimates. The annualized costs to effect nitrogen removal at 1, 2, 5, 10 mgd treatment facilities are developed. Annualized cost requirements for phosphorus reduction are also summarized.

Conventional Lagoon Cost Estimates

The estimates of capital and normal operation costs of a conventional lagoon system have been derived from the information presented by Patterson and Banker[4-1]. The basis of this cost estimation procedure is the required lagoon surface area. Following the development of surface area requirements in the previous chapter, eight acreages were considered as shown in Table 4-1.

Construction Costs. The estimates of construction and related costs include: the construction cost of the lagoon; the cost of the land for the lagoon site; engineering costs; legal, fiscal and administrative costs; and interest during construction. The Water Quality sewage treatment cost index[4-2] was used to update the lagoon construction costs to April, 1975.

A number of separate cells are normally employed in larger lagoon systems. Lagoon depths generally range from 3 to 5 feet (0.9 - 1.5 m). The estimated average costs also include construction at the lagoon site for an access road, outfall sewer, fencing, seeding of embankments, and other construction work, with the exception of pumping stations and

TABLE 4-1. CALCULATION OF CAPITAL COSTS[a] (Exclusive of Harvesting Equipment)

	Lagoon Surface Area - Hectares (Acres)							
	6.5 (16)	12.5 (31)	25.1 (62)	31.6 (78)	63.2 (156)	126 (312)	158 (390)	316 (781)
Pond Construction[b] (April, 1975)	169,800	277,900	447,700	524,900	849,100	1,389,400	1,698,200	2,624,500
Total Engineering	24,000	35,000	49,000	54,000	78,000	110,000	130,000	185,000
Land @ $1000/ac[c]	26,000	47,000	84,000	100,000	190,000	350,000	440,000	850,000
Subtotal	219,800	359,900	580,700	678,900	1,117,100	1,849,400	2,268,200	3,659,500
Legal, Fiscal, and Administration	5,500	7,500	10,300	11,000	15,000	20,000	22,500	28,500
Subtotal	225,300	367,400	591,000	689,900	1,132,100	1,869,400	2,290,700	3,688,000
Interest during[d] construction	4,200	8,200	15,900	19,700	46,900	72,300	95,200	171,300
Total	229,500	375,600	606,900	709,600	1,179,000	1,941,700	2,385,900	3,859,300
Annualized capital[e] costs	24,430	39,980	64,600	75,530	125,490	206,670	253,960	410,780

(a) From reference (4-1), Nonaerated ponds, 3 - 5 feet deep, embankment protection not considered.

(b) $\frac{\text{WQO-STP Cost Index for April, 1975}}{\text{WQO-STP Cost Index for January, 1971}} = \frac{232.5}{150.6} = 154.4$ percent

(c) Required land for construction is Land cost/1000

(d) Based on 6 percent X $\frac{\text{Interest Rate on Municipal Bonds, April, 1975}}{\text{Interest Rate on Municipal Bonds, January, 1971}} = \frac{6.46}{5.08} = 127.2$ percent

(e) 25 years @ 7.5 percent

embankment protection other than seeding. Larger cell areas and/or less attention to embankment stabilization may be possible for a hyacinth system. However, any costs saving would be expected to be negated by the probable greater costs incurred to insure dependable access for harvesting equipment.

Engineering Costs. Estimated engineering costs include basic services such as preliminary design reports, detailed design, and certain office and field engineering services during construction of the project. The estimates also reflect special service costs (i.e., comprehensive improvement studies, resident engineering soils investigations, land surveys, preparation of applications for government grants, operation and maintenance manuals). The engineering costs presented in the table will likely be shown to be a low estimate, since the hyacinth treatment system is in an early state of development.

Land Costs. The acquisition of land for construction of hyacinth lagoons in the region of concern is expected to require an investment ranging from $500 to $2,000 per acre for rural land and $15,000 to $25,000 per acre for urban land (1975)[4-3]. The additional land needed for construction of the required surface area should not be underestimated. Since $1000 per acre has been assumed, the influence of this additional land can be assessed by comparing the required pond surface area with land costs/1000 (increased land requirement).

Legal, Fiscal, Administration and Interest Costs During Construction. The costs estimated for legal, fiscal, administration and the interest during construction have also been included in the Table 4-1. The interest during construction was escalated from 6 percent, using the ratio of April '75/ January '71 reported average interest rates on municipal bonds[4-2].

TABLE 4-2. ANNUAL LABOR HOURS AND OPERATING COSTS[a] (Exclusive of Harvesting)

	Lagoon Surface Area - Hectares (Acres)							
	6.5 (16)	12.5 (31)	25.1 (62)	31.6 (78)	63.2 (156)	126 (312)	158 (390)	316 (781)
Operation Labor (hours)	250	380	590	690	1,100	1,900	2,200	3,800
Maintenance (hours)	260	340	460	500	690	940	1,100	1,600
Subtotal (hours)	510	720	1,050	1,190	1,790	2,840	3,300	5,400
Administration and other (10 percent, $)	51	72	105	119	179	284	330	540
Subtotal (hours)	561	792	1,155	1,309	1,969	3,124	3,630	5,940
Payroll costs[b] ($)	2,811	3,969	5,788	6,560	9,867	15,655	18,191	29,767
Indirect Labor costs (15 percent, $)	422	595	868	984	1,480	2,348	2,729	4,465
Subtotal ($)	3,233	4,564	6,656	7,544	11,347	18,003	20,920	34,232
Material and Supply[c] Costs ($)	907	1,225	1,815	1,966	2,949	4,084	4,537	6,655
Annual Operating Costs ($)	4,140	5,790	8,470	9,510	14,300	22,100	25,460	40,900

(a) From reference (4-1), Nonaerated Ponds, Warm Climates

(b) Mixed Personnel \$3.85/hr (January, 1971) X $\frac{\text{April, 1975}}{\text{January, 1975}}$ ratio of nonsupervisory employees, "Water, Steam and Sanitary Systems", SIC Code 494-7 = 3.85 $\frac{4.79}{3.68}$ = \$5.01/hr

(c) Times ratio of Wholesale Price Indexes for Industrial Commodities $\frac{\text{April, 1975}}{\text{January, 1971}} = \frac{169.7}{112.2}$ = 151.2 percent

Total and Annualized Capital Costs. As shown in Table 4-2 the estimated total capital costs (exclusive of harvesting equipment) range from about $230,000 to $3,860,000 for a surface area requirement of 16 acres and 1.22 square miles, respectively.

The annualized capital costs presented in the table were calculated assuming 25 years at 7.5 percent interest. The 25-year period corresponds to the period used by EPA in their estimates[4-4], and the interest rate is that for BBB municipal bonds, April, 1975[4-2]. This period and rate are consistent with values used in other parts of this report.

Annual Operating Costs. The annual operating cost estimates exclusive of harvesting were also developed using the format provided by Patterson and Banker[4-1]. The estimated operation costs shown in Table 4-2 are those expected for normal operation and maintenance of a lagoon system. The estimated costs of material and supplies needed in normal operation are also included.

The operation labor, maintenance and administration hours are presented along with payroll costs. Payroll costs were increased from January '71 mixed personnel rates of $3.85/hr to $5.01/hr as footnoted in the table. Material and supply costs were also inflated (Wholesale Price Indexes) to the April '75 estimation basis used in this report. Data used for updating came from the same EPA source[4-2].

As shown in the table, annual operating costs, exclusive of harvesting, range from about $4,000 to more than $40,000 for the surface areas considered. In comparison to the capital costs previously developed, normal operating costs range from 17 to 10 percent of the estimated annualized capital costs for the required pond surface areas considered (16 acres to 1.22 sq. mi., respectively).

Harvesting, Chopping, Hauling Hyacinth Costs

Most important to the total costs of a hyacinth sewage treatment system are the harvesting costs. Unfortunately, these costs are not well defined in the literature. A high degree of optimization is probable since documented cost estimates range by more than a factor of four. NSTL projects harvester costs, based on their investigations, at $30,000 (design capacity 15 wet tons/hour). A boat to push the hyacinth mats to the harvester and a conveyor system from the harvester must also be considered. Maintenance costs are also important and may amount to 25 percent of labor requirements.[4-5]

The estimation of harvesting costs used in this report is based primarily on reported costs for mechanical control (harvesting) of nuisance conditions caused by water hyacinths in southern waterways. The estimation procedure for harvesting, chopping and hauling hyacinths for final disposition is included in Table 4-3. Neither the selection of, nor costs for, final disposition have been included in the estimation procedure. Both capital and operations costs are assumed in the development. As shown, the major portion of the cost is associated with the operation and capital requirements of the harvester. Harvesting, chopping and hauling costs are expected to amount to about $1700 per acre for a growth/harvest rate of 20 tons (dry)/acre-year.

In comparison, the costs for harvesting less dense rooted aquatic plants, requiring more complex underwater cutting equipment, appear to be on the order of four times greater than the calculated hyacinth harvesting costs.[4-7]

Annualized Costs

The annualized costs of a hyacinth system designed for nitrogen removal is presented in Table 4-4. The surface area requirements for a nitrogen removal based system have been previously developed and summarized in Table 3-13. These area requirements were used in developing the annualized cost of a hyacinth system as presented in Table 4-4. As shown in the table the requirements of 1, 2, 5, and 10 mgd treatment plants were considered.

TABLE 4-3. HARVESTING, CHOPPING, HAULING HYACINTH COSTS (CAPITAL AND OPERATING, 1975)

Estimation Procedure

Assume 100 acres of pond (10 x 10 acres)

Assume 20 tons (dry) per acre/year = 2000 tons (dry)/year @ 95 percent water would be 40,000 wet tons/year to harvest

Assume harvest 1/2 of crop, 4 times/year = 10,000 wet tons/harvest

Harvester, 10-ft wide (Incl. one man) (29 tons (wet)/hr) (29 tons (wet)/hr) = 43 days (50 days at 85% avail)	
$2.13/wet ton (1971)* =	ca $3.30/wet ton (1975)
Chopper: $0.035/wet ton (1972)* =	ca $0.051/wet ton (1975)
Boat pusher 1 man, $4.79/29 tons (wet) =	$0.17/wet ton (BCL estimate)
Boat, fuel, trailer	0.05/wet ton
Conveyor, belt, 24" wide, 10' long	0.05/wet ton (BCL estimate)
Trucks, dump, 3-ton (2)	0.25/wet ton (BCL estimate)
Gasoline (180 mi/da, 8 mpg)	0.06/wet ton
Drivers (2) @ $4.79/hr	0.33/wet ton
	4.26/ton (wet)

For this system Annual Operating Costs = 4.26 (40,000) = $170,400

Unitized Costs

At a harvesting rate of 20 tons (dry)/acre-year
harvesting, chopping and hauling costs = $1704/acre ≃ $4200/ha

* Source: From Reference (4-6)

TABLE 4-4. ANNUALIZED COSTS OF A HYACINTH SYSTEM DESIGNED FOR NITROGEN REMOVAL

	1 MGD	2 MGD	5 MGD	10 MGD
Southern Florida				
20 ton/acre-year				
Normal Operation	5,790	8,470	14,300	22,090
Debt Service	39,980	64,600	125,490	206,670
Harvesting	53,160	106,330	265,820	531,650
Total ($/year)	98,930	179,400	405,610	760,410
(¢/1000 gal.)	(27.10)	(24.58)	(22.22)	(20.83)
40 ton/acre-year				
Normal Operation	4,140	5,790	9,510	14,300
Debt Service	24,430	39,980	75,530	125,490
Harvesting	53,160	106,330	265,820	531,650
Total ($/year)	81,730	152,100	350,860	671,440
(¢/1000 gal.)	(22.39)	(20.84)	(19.23)	(18.40)
Other Areas				
4 ton/acre-year				
Normal Operation	9,510	14,300	25,460	40,890
Debt Service	75,530	125,490	253,960	410,780
Harvesting	26,580	53,160	132,910	265,820
Total ($/year)	111,620	192,950	412,330	717,490
(¢/1000 gal.)	(30.58)	(26.43)	(22.59)	(19.66)
10 ton/acre-year				
Normal Operation	5,790	8,470	14,300	22,090
Debt Service	39,980	64,600	125,490	206,670
Harvesting	26,580	53,160	132,910	265,820
Total ($/year)	72,360	126,230	272,700	494,580
(¢/1000 gal.)	(19.82)	(17.29)	(14.94)	(13.55)
20 ton/acre-year				
Normal Operation	4,140	5,790	9,510	14,300
Debt Service	24,430	39,980	75,530	125,490
Harvesting	26,580	53,160	132,910	265,820
Total ($/year)	55,150	98,930	215,950	405,610
(¢/1000 gal.)	(15.11)	(13.55)	(11.83)	(11.11)

Cost associated with year around growth/harvest rates of 20 and 40 tons/acre-year for southern Florida are presented. Costs estimates for other areas at growth/harvesting rates of 4, 10 and 20 tons/acre-year are also included.

Normal operation costs, debt service (annualized capital costs) and harvesting costs are presented and totaled in the table. Total treatment costs are also presented as ¢/1000 gals for comparison purposes. From the table average costs of a hyacinth treatment system can be expected to range from 30 to 10¢/1000 gal treated depending on the throughput. Site and situation specific conditions will also influence this cost.

It is important to note that these costs have been developed under the assumption that the median hyacinth influent nitrogen concentration of 21 mg/ℓ is to be reduced to essentially zero during growth/harvest season(s). During less active growth periods, nitrogen removal efficiencies will decrease. Where only maintenance growth can be sustained through the winter, expected removal of nitrogen will be due solely to net denitrification and net solids entrapment. The expected winter and summer effluent characteristics have been summarized in Table 3-12.

Summary of Operation Requirements and Costs for Phosphorous Removal

Table 4-5 summarizes the operation requirements and annualized costs for a hyacinth system designed for phosphorus removal. Lagoon surface area requirements for phosphorus removal were estimated to be on the order of five times the requirements for nitrogen removal. The total costs also include required additional nitrogen costs assumed to be supplemented by the addition of NH_4NO_3 at $186/ton (April, 1975).[4-8] As will be discussed in a later section, the treatment costs for phosphorus removal shown in this table are more than an order of magnitude greater than required for a lime clarification approach. In contrast to a hyacinth system, lime clarification would also be effective in reducing phosphorus throughput concentration in the winter.

TABLE 4-5. SUMMARY OF OPERATION REQUIREMENTS AND ANNUALIZED COSTS FOR HYACINTH SYSTEM DESIGNED FOR PHOSPHORUS REMOVAL

	1 MGD	2 MGD	5 MGD	10 MGD
Southern Florida				
20 ton/acre-year				
Area (acres)	156.2	312.4	781.0	1562.0
Total Cost ($/year)	443,970	837,130	1,974,280	
(¢/1000 gal)	(121.64)	(114.68)	(108.18)	
40 ton/acre-year				
Area (acres)	78.1	156.2	390.5	781.0
Total Cost ($/year)	389,220	748,160	1,802,030	3,496,900
(¢/1000 gal)	(106.64)	(102.49)	(98.74)	(95.81)
Other Areas				
4 ton/acre-year				
Area (acres)	390.5	781.0	1952.5	3905.0
Total Cost ($/year)	450,690	794,210		
(¢/1000 gal)	(123.48)	(108.80)		
10 ton/acre-year				
Area (acres)	156.2	312.4	781.0	1562.0
Total Cost ($/year)	311,060	571,300	1,308,870	
(¢/1000 gal)	(85.22)	(78.26)	(71.72)	
20 ton/acre-year				
Area (acres)	78.1	156.2	890.5	781.0
Total Cost ($/year)	254,310	482,330	1,136,620	2,166,070
(¢/1000 gal)	(69.67)	(66.08)	(62.08)	(59.34)

Cost Estimates - Alternative Tertiary Systems

In this section, tertiary treatment systems which provide an alternative to hyacinth systems are described, and their performance and cost are estimated. The major source of information for this was the work and publications of the Advanced Waste Treatment Group, Environmental Protection Agency, Cincinnati, Ohio. Specific publications are referenced in the following report section but acknowledgement must also be made to the personal assistance provided by Dr. Robert Smith and Dr. Harry Bostian.

Tertiary Treatment Methods

There are a number of viable tertiary treatment methods which have been used singly or in combination. Each process has different characteristics and, in general, removes a different impurity. However, there is some duplication in impurity removal capabilities and some overlap in capabilities. In other words, these processes are not completely specific or unique for the removal of a particular pollutant.

In the context of this study, the particular pollutants of interest are:

- Suspended solids (SS)
- Biochemical oxygen demand (BOD)
- Nitrogen (N)
- Phosphorus (P)

Performance and efficiency of the various tertiary treatment processes will be measured in terms of their removal of these pollutants.

Sufficient information is available for several tertiary treatment processes to permit performance and cost estimates to be provided. These are:

- Filtration - Both microscreening and multimedia filtration
- Granular carbon adsorption
- Lime clarification
- Ammonia stripping.

In addition, several other tertiary treatment processes can be discussed and compared qualitatively with the above listed processes. Among the processes which will be qualitatively discussed are:

- Nitrification-denitrification
- Breakpoint chlorination
- Ion exchange.

Filtration and Microscreening

As a tertiary treatment process, filtration can be utilized as a roughing filter following the secondary treatment equipment; for this application, filtration and microscreening are competitive. Filtration is also used downstream of the lime clarification tertiary treatment process as a polishing filter.

Smith and McMichael[4-4] report that the roughing filter has been investigated by Truesdale and Birkbeck in England and by the Metropolitan Sanitary District of Greater Chicago. In England, the roughing filter removed about 60 percent of the suspended solids from a secondary effluent containing 17 mg/ℓ of suspended solids. The same performance was obtained from microscreening equipment.

At the Metropolitan District of Greater Chicago, microscreening removed 70 percent of the suspended solids in secondary effluent containing about 11 mg/ℓ. Removal was 75 percent for the sand filter.

Microscreening of secondary effluent was also investigated by the Department of Water and Power of Los Angeles. With an average suspended solids concentration in the secondary effluent of 21 mg/ℓ, about 65 percent of the suspended solids was removed by the microscreen.

At Lebanon, Ohio, suspended solids removal was investigated with a fine mesh screen and with a coarser screen. With an influent suspended solids concentration of 17 mg/ℓ, 89 percent was removed by the fine screen; 73 percent of 27 mg/ℓ was removed by the coarser screen. BOD reduction averaged 61 percent for the coarse screen and 81 percent for the fine screen.

According to Smith and McMichael[4-4], about 60 percent of the 5-day BOD is in the form of particulates. Therefore, microscreening or rapid sand filtration should remove about 42 percent of the 5-day BOD.

Multimedia polishing filters which will remove essentially all of the suspended solids from water are equally useful downstream of activated sludge or lime clarification processes. Filters of this type, both with and without the addition of alum or polyelectrolytes, have been used at the South Tahoe Public Utility District and have been tested at Lebanon, Ohio, and at the Blue Plains Plant in Washington, D.C. No chemicals are needed when the filter is used downstream of the lime clarification process. The multimedia polishing filter is necessary for the removal of turbidity when a high quality effluent is required.

Granular Carbon Adsorption

As reported by Smith and McMichael[4-4], practical operating experience with the granular carbon adsorption process for treating secondary effluent has been obtained at the Pomona, California, pilot plant. This pilot plant, which has a design flow of 288,000 gpd, consists of five downflow pressure contractors. Four of these contractors are normally in operation. The contact time is 36 to 40 minutes.

Performance is such that the suspended solids concentration in the effluent stream is normally less than 1 mg/ℓ. About 80 percent of the organic species (COD, TOC) are normally removed.

Lime Clarification

The lime clarification process is useful for removing phosphorus and suspended organic material. An additional benefit is that the increased pH resulting from lime addition makes ammonia nitrogen available for removal by air stripping.

Equipment used for this process consists of one or two upflow clarifiers. Lime sludge is recirculated. For hard water applications, one upflow clarifier is sufficient; for soft water, two upflow clarifiers in series would be used with the ammonia stripping column followed by a recarbonation unit between the two clarifiers.

Results obtained on a 75 gpm unit at Lebanon, Ohio, indicate that phosphate levels can be reduced from 30 mg/ℓ to 2.2 mg/ℓ. Removal of BOD averaged 86 percent, and the removal of TOC and COD averaged 58 percent.

A second lime clarification plant has been operated at the Blue Plains pilot plant at Washington, D.C. Phosphate concentrations are reduced by 93 percent, giving an effluent concentration of about 1.5 mg/ℓ. BOD is reduced from 45 to 15 mg/ℓ and a 50 to 60 percent reduction in TOC has been achieved.

Ammonia Stripping

Moderate costs are involved if an ammonia stripping column is used in conjunction with the lime clarification process. Equipment for this process generally consists of a suitably sized packed tray tower equipped with an air blower. This is probably the best process for removing ammonia nitrogen from wastewater but the process performance is strongly dependent on air and water temperature. For example, use of the process may not be feasible in temperate climates during the winter months when the temperature of ambient air is below 32°F. However, during summer months and in warmer climates, the efficiency of stripping should be sufficiently high so that 90 percent removal of ammonia nitrogen can be achieved.

Pilot scale and larger operations at Lake Tahoe have confirmed these results, according to Smith and McMichael.[(4-4)]

Nitrification-Denitrification

This process is an alternative to ammonia stripping and can be achieved through modification of the secondary activated sludge process.

Nitrification is the bacterial oxidation of ammonia nitrogen in two steps, first to nitrite and then to nitrate. According to Eckenfelder,[4-9] the pH range for the oxidation of ammonia to nitrite is 7.5 to 9.0, and the range for the oxidation of nitrite to nitrate is 8.0 to 9.0. Dissolved oxygen levels in excess of 2.0 mg/ℓ are desirable to maintain maximum conversion rates. A hydraulic retention time of 3.5 hr at 15 C has been suggested as leading to a suitable design.

Denitrification[4-10] is achieved by biological digestion under anaerobic conditions. A source of carbon must be provided if carbon concentration is inadequate. Under these conditions, the nitrate is reduced to nitrogen gas and some nitrous oxide. Methanol can be used as a carbon source and 25 to 35 percent excess is required to satisfy the organism's growth and energy requirements. A dentention time of 10 days in deep ponds is a common treatment period; use of a closed tank, however, would appear to require holding times of slightly more than 2 hours[4-9].

Costs have been investigated by Smith[4-11] for columnar and dispersed flow reactors for performing the denitrification step of this process; these costs were found to be roughly comparable. Comparison of the costs of this single step with those for ammonia stripping indicate total treatment costs will be at least 50 percent higher for nitrification-denitrification. This aspect, coupled with additional complexity and need for close control, served to eliminate the nitrification-denitrification process from further consideration as an alternative for present purposes.

Breakpoint Chlorination

Breakpoint chlorination is another alternative tertiary process for the removal of ammonia nitrogen from wastewaters.[4-12,13] In this process, chlorine gas is added to the wastewater stream until the chlorine residual concentration reaches a minimum point. For chlorine additions below the breakpoint value combined chlorine residuals predominate and their concentration increases to a maximum with increasing chlorine dosages and then decreases to a minimum value at the so-called breakpoint. Above the breakpoint, the free chlorine residual predominates and its concentration increases with increasing chlorine dosage.

Stoichiometrically, a weight ratio of 7.6:1 of chlorine to ammonia nitrogen is required to oxidize ammonia to nitrogen gas. In tests on actual waste streams performed at the Blue Plains plant in Washington, D.C., 95 to 99 percent of the ammonia was converted to nitrogen gas and no significant amount of nitrous oxide was formed. The quantity of chlorine required for breakpoint chlorination of raw wastewater was found to be 10:1. For secondary effluent, this ratio decreased to 9:1 and to 8:1 for lime-clarified and filtered secondary effluent.

The breakpoint chlorination process has the advantages of low capital cost, a high degree of efficiency and reliability, insensitivity to cold weather, and the release of nitrogen as nitrogen gas. It has the disadvantage of adding a substantial quantity of dissolved solids to the effluent and a total processing cost which is about twice that for ammonia stripping. Because of these disadvantages, breakpoint chlorination has not been considered a viable alternative.

Ion Exchange

Anionic phosphorus and nitrogen compounds may be removed using an anion exchanger with efficiencies in the range of 80 to 90 percent, according to Eliassen and Tchobanoglous.[(4-10)] To accomplish this, an ion exchange resin is placed in a bed and the waste to be treated is passed through it. When the exchange capacity of the bed has been depleted, the feed is stopped and a regenerating solution passed through the bed.

The chloride ion in common salt is an inexpensive regenerant for these anionic resins. Sodium hydroxide,hydrochloric acid, methanol, and bentonite materials have been used successfully in removing organic materials fouling the resins. Wastes from the ion exchange process will consist of backwash water, rinse water, and spent brine containing small amounts of exchanged ions.

The ion exchange process has the advantage of high efficiency and insensitivity to temperature, but process control and operation are relatively complex. Other disadvantages include a total removal cost about 2.5 times that of ammonia stripping and need for a means of disposing of the spent brine. Because of the high cost, this method will not be considered further as an alternative.

Other Alternative Tertiary Processes

A number of other alternative tertiary treatment processes have been studied [4-10] in an effort to evaluate their potential for the removal of unwanted constituents, primarily nutrients, in wastewaters. Among these processes are:

- Algae harvesting
- Electrochemical treatment
- Electrodialysis
- Reverse osmosis
- Distillation
- Land application
- Sorption.

None of these processes has been considered a viable alternative for present purposes either because insufficient information could be found on performance or costs, because application would be difficult, impractical, complex, or unwise, because performance would be inadequate, or because costs or other requirements would be much greater than the processes used in this evaluation of alternatives.

Estimates of Performance

Estimates of performance for three tertiary treatment processes when used singly and three combinations of processes are given in Table 4-6. The processes are those described previously in some detail.

In Table 4-6, the first row of values specifies the concentration of various contaminants that might be expected in the effluent stream of a reasonably well designed and operated (secondary treatment) activated sludge plant. These values are representative ones selected from the values in Table 3-4.

TABLE 4-6. ESTIMATES OF PERFORMANCE OF SELECTED TERTIARY TREATMENT PROCESSES AND SELECTED COMBINATIONS OF PROCESSES

Process or Process Combinations	Effluent Concentrations SS, mg/ℓ	BOD, mg/ℓ	N, mg/ℓ	P, mg/ℓ
0. Secondary Effluent	30	35.7	21	10.9
1. Microscreening or Rapid Sand Filtration	9	20.8	21	10.9
2. Granular Carbon Adsorption	3	5.0	21	10.9
3. Lime Clarification	3	16.4	21	0.8
4. Lime Clarification + Multimedia Filtration	0.3	14.5	21	0.8
5. Lime Clarification + Ammonia Stripping	3	16.4	2.1	0.8
6. Lime Clarification + Ammonia Stripping + Granular Carbon Adsorption	0.3	1.6	2.1	0.8

The remaining values in Table 4-6 were computed on the basis of representative performance of the stated processes and combinations of processes. The degree of removals which should be achievable are tabulated in Table 4-7 and briefly discussed in the following paragraphs.

Process 1 - Microscreening or Rapid Sand Filtration

As previously discussed and based on Smith and McMichael,[(4-4)] microscreening or rapid sand filtration has been demonstrated to achieve at least 70 percent removal of suspended solids. Since 60 percent of the BOD is contained in the suspended solids, a 42 percent reduction (0.6 x 0.7) of BOD can be achieved by application of these techniques.

Process 2 - Granular Carbon Adsorption

A granular carbon bed, according to Smith and McMichael,[(4-4)] removes contaminants both by adsorption and by a filtering action. About 90 percent of the suspended solids are removed and about 80 percent of the dissolved organics are removed. Thus, the total BOD removal would be expected to be 54 percent (0.90 x 0.60) in the suspended solids plus 32 percent (0.80 x 0.40) dissolved or 86 percent overall.

Process 3 - Lime Clarification

The lime clarification process removes suspended solids as well as phosphorus by precipitation of the phosphate. Smith and McMichael[(4-4)] report that 90 percent removal of suspended solids can be achieved. This also means 54 percent (0.9 x 0.6) removal of BOD. Ninety-three percent removal of phosphorus has been consistently demonstrated.

TABLE 4-7. SUMMARY OF PERFORMANCE OF SELECTED TERTIARY TREATMENT PROCESSES AND SELECTED COMBINATIONS OF PROCESSES

Process or Process Combinations	Removal Efficiency, percent			
	SS, mg/ℓ	BOD, mg/ℓ	N, mg/ℓ	P, mg/ℓ
1. Microscreening or Rapid Sand Filtration	70	42	0	0
2. Granular Carbon Adsorption	90	86	0	0
3. Lime Clarification	90	54	0	93
4. Lime Clarification + Multimedia Filtration	99	59.4	0	93
5. Lime Clarification + Ammonia Stripping	90	54	90	93
6. Lime Clarification + Ammonia Stripping + Granular Carbon Adsorption	99	95.4	90	93

Process 4 - Lime Clarification Plus Multimedia Filtration

Lime clarification followed by multimedia filtration, according to Smith and McMichael,[4-4] will result in 99 percent removal of suspended solids. BOD removal would be 59.4 percent (0.99 x 0.6). No additional phosphate removal would be achieved.

Process 5 - Lime Clarification Plus Ammonia Stripping

Ammonia stripping as a supplement to lime clarification will remove 90 percent of the nitrogen, as reported by Smith and McMichael,[4-4] Removal of suspended solids, BOD, and phosphorus by lime clarification will not be enhanced by the ammonia stripping process.

Process 6 - Lime Clarification Plus Ammonia Stripping Plus Granular Carbon Adsorption

The addition of granular carbon adsorption to lime clarification results in substantial enhancement of suspended solids and BOD removal. According to Smith and McMichael,[4-4] 99 percent removal of suspended solids can be achieved. BOD removal will be 99 percent of that contained in the suspended solids (or 59.4 percent) plus 90 percent of that which is dissolved (or 36 percent). The total BOD removal would be 95.4 percent as indicated in Table 4-7 Nitrogen and phosphorus levels would be the same as previously discussed.

Estimates of Cost

Estimates of cost for the processes and process combinations as defined previously in Tables 4-6 and 4-7 have been derived from the information presented by Smith and McMichael.[4-4] Appropriate adjustments have been made in the costs which they reported to allow for increases in capital costs, operating costs, and interest rates.

Capital Costs

Capital costs associated with the six tertiary treatment processes and process combinations as a function of size are listed in Table 4-8. These costs were derived from graphical information presented by Smith and McMichael[4-4] with adjustments made for differences in capital cost between March, 1969, and April, 1975.

The capital cost index[4-2] for sewage treatment facilities was 232.5 in April, 1975, and 129.84 in March, 1969, (the time of the Smith and McMichael work.[4-4] Thus, their capital cost values have been multiplied by 1.791, (i.e., 232.5/129.84) to adjust them to current (April, 1975) values.

Unit Treatment Costs

Unit costs for tertiary treatment, also derived from the work of Smith and McMichael,[4-4] are shown in Table 4-9. Adjustments have been made in debt service costs and in operating and maintenance costs.

Debt service costs were adjusted both for the increase in capital cost, as previously discussed, and for increases in interest rates. Since March, 1969 (to April, 1975), bond interest charges have increased from 4-1/2 percent to 7-1/2 percent.[4-2] Thus, based on bond repayment schedules, this increase in interest results in an increase in payment rates by a factor of 1.330. Coupled with the increase in capital cost by a factor of 1.791, debt service costs will be 2.382 times those given by Smith and McMichael.

Operating and maintenance costs have been assumed to vary as the labor cost index. The labor cost index[4-2] was 3.14 in March, 1969, and 4.79 in April, 1975. Therefore, an adjustment factor of 1.53 was used with the Smith and McMichael[4-4] values. For comparison, the consumer price index increase factor for the same time period was 1.47. Thus, little error has been introduced by assuming that operating and maintenance costs were all labor rather than partially labor and partially materials.

TABLE 4-8. CAPITAL COSTS OF TERTIARY TREATMENT FACILITIES
(Adjusted to April, 1975)

Alternative	Total Capital Cost, millions of dollars			
	1 MGD	2 MGD	5 MGD	10 MGD
1. Microscreening	0.06	0.11	0.25	0.45
2. Granular Carbon Adsorption	6.81	10.39	17.91	28.66
3. Lime Clarification	0.23	0.39	0.79	1.25
4. Lime Clarification + Multi-media Filtration	2.02	3.08	5.80	9.13
5. Lime Clarification + Ammonia Stripping	1.93	3.44	7.95	14.69
6. Lime Clarification + Ammonia Stripping + Granular Carbon Adsorption	8.74	13.83	25.86	43.34

TABLE 4-9. UNIT COSTS FOR TERTIARY TREATMENT

Alternative	Cost, cents/1000 gallons 1 MGD	2 MGD	5 MGD	10 MGD
Microscreening				
Debt service	1.43	1.29	1.19	1.10
Operating and maintenance	0.89	0.86	0.84	0.81
Total	2.32	2.15	2.03	1.91
Granular Carbon Adsorption				
Debt service	19.06	15.24	10.48	8.10
Operating and maintenance	35.19	24.48	15.30	10.71
Total	54.25	39.72	25.78	18.81
Lime Clarification				
Debt service	5.96	5.00	3.81	3.22
Operating and maintenance	11.48	8.57	5.66	4.13
Chemical cost	5.83	5.83	5.83	5.83
Total	23.27	19.40	15.30	13.18
Lime Clarification + Multimedia Filtration				
Lime clarification total	23.27	19.40	15.30	13.18
Debt service (multimedia filtration)	4.29	3.33	2.38	1.91
Operating and maintenance (multimedia filtration)	6.89	5.36	3.83	3.06
Total	34.45	28.09	21.51	18.15
Lime Clarification + Ammonia Stripping				
Lime clarification total	23.27	19.40	15.30	13.18
Debt service (ammonia stripping)	4.05	3.81	3.57	3.33
Operating and maintenance (ammonia stripping)	7.19	5.81	4.28	3.37
Total	34.51	29.02	23.15	19.88
Lime Clarification + Ammonia Stripping + Granular Carbon Adsorption				
Lime clarification total	23.27	19.40	15.30	13.18
Ammonia stripping total	11.24	9.62	7.85	6.70
Granular carbon adsorption total	54.25	39.72	25.78	18.81
Total	88.76	68.74	48.93	38.39

The total unit treatment costs shown in Table 4-9 are the sums of the appropriate component costs as described. These unit costs should be suitable for comparison among these various processes and process combinations and with other competing processes which have been similarly costed.

Comparison of Hyacinth and Other Processing Systems

The comparison of hyacinth-based tertiary treatment systems with conventional methods is not simple. Both types of systems can be designed to produce different levels of performance capability at different levels of cost. Table 4-10 contains a summary of hyacinth system characteristics developed in Chapters 3 and 4. The cost data refer to a 1 mgd design, while the performance figures are independent of throughput rate. Table 4-11 presents analogous information for the competitive systems.

Since both cost and performance are involved, and since there are four parameters relating to performance, direct comparison of these two tables is not possible. It is necessary to either: (1) fix performance requirements and compare costs to meet the requirements; or (2) fix cost and compare performance. The first option will be taken here, as it appears to be more representative of the usual design process. Still, it is clear that the cost comparison will depend on what performance requirements are selected.

To illustrate the comparison process, the following requirements have been selected.

- year-around operation
- 5 mg/ℓ suspended solids
- 5 mg/ℓ BOD
- 3 mg/ℓ nitrogen
- 1 mg/ℓ phosphorus

These standards are based on the Florida requirements as discussed in Chapter 3.

From Table 4-10 and 4-11, it may be seen that only one hyacinth system (phosphorus design, south Florida) and only one of the competitive

TABLE 4-10. PERFORMANCE AND COSTS OF HYACINTH TERTIARY TREATMENT SYSTEMS (1 mgd capacity)

Area[a], Period[b], Design[c]	Performance: Suspended Solids (mg/l)	Performance: BOD (mg/l)	Performance: Nitrogen (mg/l)	Performance: Phosphorus (mg/l)	Annualized Cost (¢/1000 gal)
S. Florida Nitrogen Removal	5	1.5	1	8	27.1
Other Areas, Growth Period, Nitrogen Removal	5	1.5	1	8	19.8
Other Areas, Maintenance Period, Nitrogen Removal	30	14	11	11	19.8[d]
S. Florida Phosphorus Removal	5	1.5	1	1	121.6
Other Areas, Growth Period, Phosphorus Removal	5	1.5	1	1	85.2
Other Areas, Maintenance Period, Phosphorus Removal	30	14	11	11	85.2[d]

(a) Two regions are considered: (1) south Florida; and (2) "other", defined as north Florida plus a strip 100 miles wide along the Gulf Coast.

(b) In south Florida it is assumed the growth is year-around and 20 tons/acre-year are harvested. In the other areas, it is assumed that growth occurs only from April through October and 10 tons/acre-year are harvested. The remainder of the year is the "maintenance period".

(c) Two design processes were employed: one aimed at removing all nitrogen, the other of removing all nitrogen and phosphorus. The former is called the "nitrogen" design, the latter the "phosphorus" design.

(d) In the other areas, cost per 1000 gal is computed on an annual basis. Costs are therefore shown as being the same during growth and maintenance periods, even though the costs are not uniformly distributed through the year.

TABLE 4-11. PERFORMANCE AND COSTS OF COMPETITIVE SYSTEMS

	Suspended Solids (mg/ℓ)	BOD (mg/ℓ)	Nitrogen (mg/ℓ)	Phosphorus (mg/ℓ)	Cost (¢/1000 gal)
Microscreeming or Rapid Sand Filtration	9	20.8	21	10.9	2.32
Granular Carbon Adsorption	3	5.0	21	10.9	54.25
Lime Clarification	3	16.4	21	0.8	23.27
Lime Clarification and Multimedia Filtration	0.3	14.5	21	0.8	34.45
Lime Clarification and Ammonia Stripping	0.3	16.4	2.1	0.8	34.51
Lime Clarification and Ammonia Stripping and Granular Carbon Adsorption	0.3	1.6	2.1	0.8	88.76

systems (lime clarification + ammonia stripping + granular carbon adsorption) meet the requirements. The hyacinth cost is 121.6 ¢/1000 gal, while the other is 88.8 ¢/1000 gal. The hyacinth cost is higher, but in view of the general accuracy of the cost estimation process, not significantly higher.

If other standards had been selected, the results would have been somewhat different, but it does not seem that in any realistic case, the hyacinth system would show a dramatic cost advantage. Of course, there are situations in which a treatment facility operator might find that hyacinth systems are much cheaper because land is already available, (or very low-cost), or labor can be obtained at modest incremental cost. Another case would be one in which the phosporus content of the secondary effluent is low. However, in general, costs for the two types of systems seem to be comparable.

As noted above, the costs in Tables 4-10 and 4-11 are based on 1 mgd throughput. Hyacinth system unit costs decrease somewhat with increasing throughput, as shown in Table 4-5, but the competitive systems offer much sharper unit cost reductions, as shown in Table 4-9. Unit costs of the 10 mgd system are less than half those of the 1 mgd system. Water hyacinth systems would probably not be competitive in the larger sizes. On the other hand, for smaller size systems (of which there are substantial numbers) the same trend suggests that water hyacinth systems might offer cost advantages. This, however, was not analyzed in detail in this study.

A Hybrid System

In examining the phosphorus-design hyacinth system of the preceeding section, it is apparent that the cost of dealing with the phosphorus is quite high. From Table 3-12, it can be seen that the nitrogen design meets the Florida standards with the exception of the phosphorus. The cost of the nitrogen design (south Florida, 1 mgd) is 27.1 ¢/1000 gal from Table 4-4. The phosphorus design for the same case is 121.64 ¢/1000 gal from Table 4-5. Using hyacinths, then, it costs some 94.54 ¢/1000 gal to remove the one additional component. This suggests the desirability of alternative methods for removing the phosphorus.

From Table 4-6, it can be seen that lime clarification alone would meet the phosphorus standard (and also the suspended solids standard). Table 4-9 shows that the cost of lime clarification alone would be 23.27 ¢/1000 gal, which is one-fourth that of the hyacinth system cost for removing phosphorus.

Performance and Cost

This suggests that the best way of meeting the Florida standards might be to feed the secondary effluent into a nitrogen-design hyacinth system, followed by lime clarification. The cost would then be of the order of 27.1 + 23.27 = 50.37 ¢/1000 gal. This is well below the 121.6 ¢/1000 gal figure for the phosphorus-design hyacinth system, and appreciably below the 88.67 figure for lime clarification + ammonia stripping + granular carbon adsorption system. Table 4-12 shows the estimated performance of the hybrid system. The hybrid meets the standards fully during the growth period, but falls somewhat short in nitrogen and BOD during the maintenance period. It is considerably superior in performance to the hyacinth phosphorus design during the maintenance period. In fact, the hybrid system has real potential for the Gulf Coast region if somewhat relaxed standards are applied.

Because of the apparent advantages of this hybrid system over the phosphorus-design, all-hyacinth system, the hybrid has been selected as the primary basis for comparing hyacinth systems with conventional (non-hyacinth) systems. In the following subsections, additional aspects of the hybrid design are explored; primarily, its sensitivity to changes in requirements and uncertainties in hyacinth parameters.

Effect of Throughput Rate

The costs of the preceeding subsection were developed on the basis of a 1 mgd throughput. To illustrate the effect of other rates, the cost

TABLE 4-12. PERFORMANCE COMPARISONS FOR THE HYBRID SYSTEM

	Suspended Solids (mg/ℓ)	BOD (mg/ℓ)	Nitrogen (mg/ℓ)	Phosphorus (mg/ℓ)
Florida Standards	5	5	3	1
Hybrid (maintenance period)	3	7-16	10-11	0.8
Hybrid (growth period)	3	1.5	1	0.8
Hyacinth-Phosphorus Design (maintenance period)	30	7-16	10-11	11

data for the hyacinth system (nitrogen design) were taken from Table 4-4, and added to comparable data for the lime clarification process from Table 4-13. As would be expected, the sensitivity to throughput lies between the sensitivity shown by the pure hyacinth system and the pure non-hyacinth system. Increasing the throughput tenfold reduces the unit cost by about 30%.

Effect of Hyacinth Yield per Acre

As stated in Chapter 2, the actual harvestable yield per year is not well-known at this time. A value of 20 dry tons per acre-year has been selected for design purposes, but it is of interest to inquire what the effect would be if this assumption is in error. To estimate this effect, the same computations required for Table 4-13 were made except that a yield of 40 tons/acre year was assumed. The unit costs for this case are compared with the unit costs in the 20 tons/acre-year case in Table 4-14. It is indicated that a two-fold change in yield per acre produces only about a 10 percent change in unit cost. Considering that a two-fold reduction in lagoon area is involved, it is perhaps surprising that the change in cost is not larger.

Some idea of the reasons behind this result can be obtained from Table 4-15, which shows the percentage cost breakdown for the 1 mgd, 20 tons/acre-year, south Florida case. If the yield is changed by any factor, the total tonnage of hyacinths to be harvested remains the same, for a given throughput. There is a certain amount of nutrient to be absorbed, and approximately the same plant weight will be required to do this, for any yield. Therefore, the harvesting cost will be about the same, regardless of the yield. However, in Table 4-15, the only acreage-sensitive elements are the hyacinth maintenance and operation (3%) and the hyacinth debt service (21%). Thus, only 24% of the total cost is related to yield at all. Even these yield-sensitive costs, however, are less than proportional. This is to say doubling the acreage results in less than a doubling of these costs. The reason for this can be seen from Table 4-1, which is a breakdown of the hyacinth capital costs for different lagoon areas.

TABLE 4-13. EFFECT OF THROUGHPUT RATE ON ANNUAL COST[a]

	1 MGD	2 MGD	5 MGD	10 MGD
Total Cost ($/year)	182,930	320,900	684,600	1,240,410
(¢/1000 gal)	50	44	38	34

(a) Based on south Florida system, yield 20 tons/acre-year.

TABLE 4-14. EFFECT OF THROUGHPUT AND YIELD ON UNIT COST (¢/1000 gal)

	1 MGD	2 MGD	5 MGD	10 MGD
20 Tons/Acre-year	50	44	38	34
40 Tons/Acre-year	45	41	35	32

TABLE 4-15. COST BREAKDOWN - HYBRID SYSTEM[a]

Cost Element	% of Total
Operation and Maintenance (hyacinth)	3
Operation and Maintenance (lime clarification)	23
Debt Service (hyacinth)	21
Debt Service (lime clarification)	12
Chemical Cost (lime clarification)	12
Harvesting (hyacinth)	29
TOTAL	100

(a) Based on a 20 tons/acre yield, 1 mgd, south Florida design.

Effect of Relaxed Standards

In the foregoing analyses, the rather severe standards of Table 1-1 have been used for the purposes of system comparisons. If other, less stringent requirements are to be imposed, the costs of the hyacinth system, and the comparison with non-hyacinth systems would be altered. There are, of course, many combinations of relaxed standards, but only a few can be considered here.

For example, if there is no phosphorus requirement, as in the case of the example standards of Table 3-6, it would be possible to eliminate the lime stripping portion of the hybrid design entirely, which would cut the cost approximately in half. The nitrogen-design hyacinth-only system should be entirely adequate in south Florida, and possibly satisfactory in the other areas as well, if the standards of Table 3-6 are typical.

Taking the south Florida case, the unit cost would be of the order of 27 ¢/1000 gal. If there is no nitrogen standard either, then microscreening alone might be adequate, at a cost of 2.32 ¢/1000 gallons. If there is a nitrogen standard, then the competition might come from lime clarification + ammonia stripping, at a cost of 34 ¢/1000 gallons.

If there is a relaxation only in the nitrogen standard, so that smaller lagoon areas and smaller quantities of harvested plants would be required, the effect on cost of the hybrid system would be appreciable. If, for example, it is desired to remove only about half the nitrogen, down to the order of 10 mg/ℓ, the lagoon area could be cut in half, as could the harvesting costs. Based on the breakdown of Table 4-15, a cost reduction of the order of 20% might be expected.

Further examples could be analyzed, but it should be clear that the attractiveness of hyacinth systems will be markedly influenced by the effluent standards which are imposed.

Uncertainties and Research Needs

In preparing the foregoing estimates, it was necessary to make a number of assumptions about plant behavior, nutrient uptake and risks. A substantial amount of effort has gone into hyacinth research, but many needed facts are still not known. In this section, some of these problems are reviewed, and some indications are given as to directions for future investigations. Some of the more significant facts and questions are the following.

1. The ecology of the water hyacinth is not adequately understood at this time. Growth is seasonal; growth rate and growing season are temperature dependent - thus, location specific. In addition, chemical tolerance limits and reaction (growth) rates, based on sewage characteristics and percent cover, are not available in the hyacinth literature.

2. The potential for hyacinth lagoon/public health interactions has not been addressed in the literature.

3. The legality of introducing hyacinths into noninfested areas has not been addressed in the literature. Water hyacinths have been classified as a noxious weed by the Federal Government.[4-14] Thus, even though technical feasibility may be demonstrated, legal constraints may preclude actual use.

4. Nitrogen can be removed from the waste stream by three main processes: plant assimilation, solids settling, and denitrification.

    <u>Plant Assimilation</u>. Water hyacinth growth is seasonal and limited by several factors, i.e., temperature, nutrient availability, percent cover, etc. Literature data are sparse and mostly limited to projections based on optimum conditions. As a result, projections of nitrogen removal due to plant assimilation have been based on estimated ranges of hyacinth production per growing season. In most areas in the United States where hyacinth occurs, plant assimilation of nitrogen will only occur approximately 6 to 8 months per year.

    <u>Solids Settling</u>. A percentage of the organic nitrogen (nitrogen complexed in organic materials) will be removed by solids settling. The amount will depend on the percent cover of hyacinth (filtering effort), sewage throughput characteristics, and system design/operation techniques. A portion of the trapped throughput nitrogen must be considered as a feedback

due to decomposition. Although estimated in this report, a more accurate quantification of the relationships between the aforementioned variables requires further operation investigations.

Denitrification. Denitrification should be enhanced as it can result in a net loss of N_2 gas to the atmosphere and thereby reduce active hyacinth surface area requirements for nitrogen removal. Denitrification in a facultative hyacinth system depends on throughput characteristics and particularly on the rate of nitrification which is expected to occur in the top several inches (aerobic) of the lagoon. The major factors controlling nitrification are temperature of the water and/or amount of substrate for the nitrifying organisms; the hyacinth root mat (substrate for organisms) probably plays a large role in determining population levels of nitrifying organisms. Temperature and pH strongly control denitrification rates in the lower zone (anaerobic) of a facultative hyacinth system. Organic carbon, as an energy source for denitrifying bacteria, should be considered limiting in summer. If the hyacinth root mat extends into the anaerobic zone of the lagoon, it may beneficially increase the amount of substrate for the denitrifying organisms. This question has not been resolved. Furthermore, quality controlled site and situation specific investigations are also required to substantiate the nitrification/denitrification relationship estimated for the purposes of this report.

5. In the hyacinth system, phosphorus is removed by plant assimilation and precipitation (physical, chemical, biological); hyacinth uptake is the dominant removal mechanism. Due to the expected high throughput concentration of phosphorus, large areas are required to effect significant removals even during active growing seasons. With phosphorus removal as a primary design objective, denitrification probably should be minimized. Supplemental nitrogen and/or other process changes may also be required. In comparison with lime

clarification, a dependable year around process, phosphorus removal using water hyacinths does not appear cost effective. Additional treatment measures could be employed to economically control phosphorus. One approach which takes advantage of low nitrogen and dissolved oxygen concentrations without addition of chemicals, is reported by Barnard.[4-15] However, the available data was considered inadequate for the purposes of this report.

6. Suspended solids are considered removed from the hyacinth system by two mechanisms: filtration and settling. The hyacinth root mat should be an effective filter; settling is primarily a function of the loading rate and retention time. Sound operation experience must be gained in order to more adequately quantify the entrapment and subsequent decomposition of suspended matter estimated in this report.

7. Low discharge dissolved oxygen concentrations (<4 mg/ℓ) may be a problem. Effluent dissolved oxygen concentrations are projected to be highly dependent on system design and operation. Thus, field investigations should also be directed to identify the available options which can lead to the development of cognizant design/operation criteria.

8. Due to insufficient data on removal mechanisms for suspended solids, biochemical oxygen demand, nitrogen and phosphorus, and on hyacinth ecology, realistic design/operation criteria for a hyacinth treatment system cannot be established. However, in the absence of key operation data, the hyacinth treatment system was overviewed in terms of factors/parameters/mechanisms identified in the literature that appeared to be significant technical and/or cost sensitive features. The resulting projections developed in this report are believed to provide reasonable working estimates of the potential feasibility of using water hyacinths for municipal sewage treatment.

In order to resolve these questions, a substantial amount of additional research is required. These research needs are summarized in Table 4-16.

TABLE 4-16. RESEARCH NEEDS

Parameter	Mechanism(s)	Rationale/Comments
1. Ecology of the hyacinth	(a) growth rate/nutrient/location/season	The hyacinth/lagoon interaction is based on nutrient removal efficiency. Unless temporal and spatial efficiency curves can be established, design criteria cannot be evaluated.
	(b) growth rate/percent cover/harvest rate/location/season	This information must be acquired before alterative disposition schemes (disposal/use schemes) can be costed.
	(c) sexual reproduction potential[1]	Due to the legal restrictions and questions pertaining to transport and use of hyacinths, the potential for seeds escaping and germinating must be established.
	(d) genetic manipulation	A major limitation to hyacinth growth is temperature. A research program to establish temperature tolerance would offer the possibilities of increasing the range of hyacinth use as well as increasing productivity within established ranges.
2. Public health considerations	(a) potential for the transmission of pests to the general public	The creation of shallow lagoons may result in breeding places for human pests (e.g., mosquitoes).
	(b) cost of pest control (hyacinth and man)	If there is a possibility for pests, control costs must be established.

TABLE 4-16. RESEARCH NEEDS
(Continued)

Parameter	Mechanism(s)	Rationale/Comments
3. Legal investigation of water hyacinth status.	Legal opinion of how Federal and State noxious weed laws will effect municipalities use of hyacinth.(1)	Since the hyacinth has been declared a noxious weed, users may be libel for removal or control cost if hyacinths are introduced into noninfested areas.
4. Treatment efficiency mechanisms.	SS: loading rate; Filtration/Sedimentation/Feedback; Productivity/Harvest Scheme - percent cover/Location/Season BOD: (same as above) N: (same as above); NITRIFICATION - DENITRIFICATION P: (same as above)	These relationships must be established before cost-effective design criteria can be calculated. At present, we can only give estimates.
5. Phosphorus	Additional treatment mechanism(s)	Phosphorus removal does not appear to be cost-effective. Additional treatment may be required.
6. Dissolved Oxygen	Additional treatment mechanism(s)	DO levels in the effluent stream may be below allowable standards. Some additional treatment may be necessary.
7. Lagoon Design	Loading rate; detention time; aerobic/anaerobic depth relationships; rooting depth (microbial substrate); <u>harvesting regime</u> (summarized from 4 above)	System effectiveness is a function of the mechanisms listed for 4 above. Treatment costs can be optimized by lagoon design.
8. Post-harvest use of hyacinth	Materials, oils, chemicals, energy, etc.	Could reduce operating cost.
9. Quality Control for Ongoing Research		The existing design does not seem adequate for SS, BOD, N, P, and DO mechanism clarification.

References for Chapter 4

4-1 Patterson, W. L. and Banker, R. F., "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities", Black & Veatch Consulting Engineers (1971).

4-2 Bostian, Harry G., personal communication, Advanced Waste Treatment Laboratory, Environmental Protection Agency, Cincinnati, Ohio, October 24, 1975.

4-3 Personal communications with Hal Gorman, 10/31/75, BCL Louisiana Regional Center, New Orleans.

4-4 Smith, Robert and McMichael, Walter F., "Cost and Performance Estimates for Tertiary Wastewater Treating Processes", Report No. TWRC-9, Robert A. Taft Water Research Center, Cincinnati, Ohio, June, 1969.

4-5 Personal communications with Wolverton, B. C., McDonald, R. C., and Barlow, R. M. (NSTL personnel), BCL July trip in July, 1975.

4-6 Bagnall, L. O., et al., "Aquatic Weed Utilization--Harvesting and Processing", University of Florida (February, 1973).

4-7 Bryant, C. B., "Aquatic Weed Harvesting Costs and Equipment--1972", Hyacinth Control Journal, Vol. 12 (May, 1974).

4-8 Agricultural Prices (April '75), United States Department of Agriculture, Statistical Reporting Service, Crop Reporting Board, Washington, D.C. 20250.

4-9 Eckenfelder, W. Wesley, Jr., "Nitrification and Denitrification", Vanderbilt University, Nashville, Tennessee.

4-10 Eliassen, Rolf and Tchobanoglous, George, "Removal of Nitrogen and Phosphorus from Wastewater", Environmental Science and Technology, 3, 536-541 (June, 1969).

4-11 Smith, Robert, "The Cost of Columnar Denitrification for Removal of Nitrogen from Wastewater", U.S. Environmental Protection Agency, Cincinnati, Ohio, January, 1972.

4-12 Dean, R. B. and Convery, J. J., "Wastewater Treatment Technology for Potable Reuse", presented at Municipal Wastewater Reuse Research Needs Workshop, Boulder, Colorado, March 18, 1975.

4-13 "Physical-Chemical Wastewater Treatment Plant Design", U.S. Environmental Protection Agency, Technology Transfer, Rev. January, 1974.

REFERENCES FOR CHAPTER 4

(Continued)

4-14 Public Law 93-629. Federal Noxious Weed Act of 1970. U.S. Congr. Adm. News. 93rd Congress. Leg. Hist:7660-7668.

4-15 Barnard, J. L. 1975. Biological nutrient removal without the addition of chemicals. Water Research 9:485-490.

CHAPTER 5

POSSIBLE USES FOR HARVESTED WATER HYACINTHS

In the previous chapter, it was indicated that water hyacinth systems appear to offer appreciable cost advantages over competitive systems in terms of water processing itself. In addition, the hyacinth systems produce substantial amounts of a by-product, the harvested water hyacinth plants themselves. If a profit can be realized from this by-product, the cost comparison might be substantially changed. The purpose of this chapter is to examine this possibility.

If the major objective is to study the effect of by-product utilization on the relative cost of hyacinth water treatment, the water treatment costs themselves provide a yardstick for assessing the magnitude of the profit required. If the profit is small compared to the treatment cost, it will not alter the comparison between hyacinth and other systems.

For example, the hybrid (hyacinth plus lime clarification) system discussed in Chapter 4 was designed on the basis of harvesting 20 dry tons per acre-year. The required lagoon area is 31.2 acres for a 1 mgd system, so 624 dry tons would be produced per year. The total annual operating cost of this configuration would be \$182,500. This means a cost of about \$300 per dry ton of harvested hyacinth. If a profit of \$300 per ton could be realized, then the hybrid system would no doubt penetrate the market completely and quickly. A profit which was half this large would cut the effective cost of water treatment in half, which would substantially improve market penetration. Profits much below \$75 per ton (one quarter of the total processing cost) would probably not assist greatly in market penetration, as they would not materially change the effective cost of treatment.

Of course, if a hyacinth system is already in being, and if it is possible to realize even a small profit from the harvested plants, it would be advantageous to do so. Also, there might be non-economic reasons for making use of the harvested plants. The objective here, however, is to assess probable market response to new hyacinth systems. Profits much less than \$75 per ton would not have a large effect on this response.

In the following sections, a number of possible uses for the harvested plants are considered: extraction of various chemicals, production of fuels, production of fertilizers and soil conditioners, and use as a cattle feed. In each of these applications, the $75/dry ton yardstick will be used to evaluate the potential.

Potential Utilization for Chemicals and Fuel

Processes that have been demonstrated for converting a large variety of biomass materials to chemicals and fuels include:

	Process	Chemical/Fuel
1.	Hydrolysis and Fermentation	Ethanol
2.	Fermentation	Ethanol
3.	Enzyme Reduction	Ethanol, Hydrogen
4.	Chemical Reduction	Oils
5.	Hydrogasification	Solid Fuel & Methane
6.	Catalytic gasification	Methane
7.	Pyrolysis	Solid Fuel, Oil, Alcohol
8.	Drying, shredding, incineration	Solid Fuel
9.	Anaerobic Fermentation	Methane.

Ethanol

The high cost of drying water hyacinths (estimates range from $20 to $180 per dry ton) will eliminate all those processes (5,6,7 and 8) that require a relatively dry substrate for further processing or use. An examination of water hyacinth composition in Table 2-9 shows that dried water hyacinth is relatively low in cellulose (20 to 25%). This level of potential ethanol precursors is probably too low to consider one of the ethanol processes (1,2 and 3) as a feasible utilization concept for water hyacinth biomass. Alternate or competitive biomass materials such as municipal solid refuse, bagasse, wood byproducts, sugar cane and cattle manure all have higher cellulose and hemicellulose contents (usually well over 50%). For these reasons all of the potential processes listed above can be eliminated as being economically unfeasible except for chemical reduction or hydrogenation to oils and anaerobic fermentation to methane.

Fuels

Processes 4 through 9 relate in one way or another to fuels. It can be noted that, assuming 17% ash, a ton of dry hyacinths would be equivalent to about 10 million BTU, at best. At a price of $2.00 per million BTU, the value of hyacinths as a source of fuel (or replacement of petroleum as a fuel stock) would be about $20, at current energy prices. Hence, no conversion process which yields energy or replaces energy or another fuel could have a value of greater than $20 per ton of hyacinths.

Of the fuel processes listed, methane production through anaerobic fermentation has received the most attention, and seems to be the most promising for hyacinth systems. The anaerobic digestion of biomass materials requires an aqueous slurry of only 3 to 20% solids for efficient operation. The lower limit of this range can probably be achieved with chopped water hyacinths. Also this operation is run at atmospheric pressure with only slow agitation required. There are therefore no inherent economic reasons for discounting the feasibility of using bioconversion technology to convert harvested water hyacinths to methane.

The conversion of organic wastes to methane is not new. It has been practiced to some extent since 1905, when methane gas from a city-sized septic tank in Exeter, England was collected and used for street lighting in the vicinity of the plant. A number of universities and other institutions are actively researching bioconversion of various organic wastes at the present time (see Table 5-1).

Work at NSTL has already demonstrated that bio-gas containing 69 to 91% methane can be produced from harvested water hyacinths. This has

TABLE 5-1. INSTITUTIONS RESEARCHING THE BIOCONVERSION OF ORGANIC WASTES

Institution	Primary Investigator
University of Massachusetts	Short W.
University of California, Berkeley	Oswald, W., Golueke, C.
Dynatech. Corporation	Wise, D.
University of Illinois	Pfeffer, J.
University of Pennsylvania	Zandi, I., Wolf, M.
Case Western Reserve University	Krampitz, L.
United Aircraft Research Labs.	Christopher, G.
U.S. Department of Interior, Bureau of Mines	Sauner, W., Appell, H.
Stanford University	Henry, J., McCarty, P.
University of Florida	Smith, P.
Clemson University	Andrews, J.
University of Texas	Speece, R.
Curran Associates	Meier, P.
Massachusetts Institute of Technology	Cooney, C.
Hamilton Standard Corporation	Turk, M.
University of Tennessee	Hollaender, A.

demonstrated technical feasibility of the concept, but the production rates are quite low. These experiments required time periods on the order of three months. It would be highly desirable to increase the rate appreciably.

Thermophilic Versus Mesophilic Digestion. Considerable work has been done recently on the use of thermophilic versus mesophilic bacteria for the production of methane from a variety of organic substrates. Mesophilic bacteria are those that show optimum growth at about 36 C and thermophilic bacteria show optimum growth (and methane production) at about 65 C. A very recent review article and laboratory report has been written by C. C. Cooney and D. L. Wise[5-1].

Cooney and Wise point out that the advantages of thermophilic over mesophilic digestion are:

1. higher rates of digestion
2. greater conversion of waste organics to gas
3. decreased fluid viscosity
4. faster solid-liquid separation, and
5. minimization of bacterial and viral pathogen accumulation.

Although this approach has the disadvantage that additional heat has to be supplied to maintain the elevated temperature, the retention time in the digester is minimized. The above authors state that their and other results (cited in their paper) "show maximum productivities of thermophilic systems to be less than 10 day retention times".

It should be pointed out that the development of a thermophilic anaerobic digestion system was obtained by a simultaneous selection and acclimation of microorganisms to thermophilic temperatures. The selection process was made by preincubating potential sources of the desired organisms (e.g., compost, rumen juice, sewage sludge, etc.) in digesters at various temperatures. The digesters were then acclimated by raising the temperature about 3 C every three weeks until 65 C was reached. During this process the laboratory digesters were fed solid waste and raw sewage sludge every other day. By this process different populations of bacteria were produced that were best suited for either mesophilic or thermophilic operation but not both.

Plant Size. Unlike the chemical reduction of biomasses to produce oils, a plant for anaerobic fermentation to produce methane is not economically size sensitive. In fact the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) has a program in which the feasibility of biomass-generated energy production and utilization by single farms and small communities is being assessed.

The simplest and probably least expensive type of anaerobic digestor is an underground tank. Systems of this type have been heated by circulating some of the reactor contents through a long clear plastic tube during daylight hours.

Possible Contribution to Profit. Wolverton, McDonald and Gordon[5-2] have demonstrated that 13.9 ml of methane gas can be produced per gram of wet plant material. This is equivalent to 4.45 standard cubic feet (SCF) of methane per pound of dry water hyacinths. This number is in excellent agreement with the quantity of methane produced from a variety of other types of biomasses reported in the literature: values which generally fall between 4.5 and 5 SCF of methane per pound of dry biomass material. This yield converts to 8.9 thousand SCF per ton of dry material. At the current (unregulated) market price of the order of $1.50 per thousand SCF[5-16], the market value of the methane from a ton of hyacinth would be about $13.15.

In recent years the total U.S. annual consumption of natural gas has been about 21×10^{12} SCF, so there is no market size limitation for methane.

Ammonia Plant Size. Another possibility that could be considered is the production of ammonia for fertilizer from the methane produced from the water hyacinth - anaerobic digestor plant. It is generally conceded that a minimum-sized ammonia plant, to be economically competitive, should have the capacity to produce 600 tons of ammonia per day. One ton of ammonia requires about 35,000 SCF of natural gas or methane, so the amount of methane produced from the water hyacinths from an average city of 20,000 population would make up less than 0.3% of an economically sized ammonia plants requirements. In fact, to supply all of the methane requirements for a minimum-sized ammonia plant, water hyacinths would have to be processed from a city of about 7.2 million people.

Paper Production

As part of an over-all investigation of possible salable products from water hyacinths harvested from the lakes and streams of Florida, Nolan and Kirmse evaluated the papermaking properties of this plant material.[5-3]

This work involved four different chemical pulping processes with a careful examination of the important variables. The investigators concluded from their comprehensive study that commercially acceptable paper pulps cannot be made from water hyacinths. The major problems that were uncovered from their investigation are:

(1) The freeness values (drainage rates) after beating (to develop fiber strength) were in the commercially unacceptable range of 25 to 40 ml compared to freeness of 450 to 600 ml for pine kraft pulp.

(2) Tensile strength and bursting strength values of the water hyacinth pulps were erratic and unacceptably low for most applications.

(3) Yields of pulp from water hyacinths were very low (13 to 15% of dm)

(4) Only 18% as much water hyacinth could be charged to the digesters in contrast to 100% for wood chips (due to the very bulky nature of water hyacinth fibers).

(5) Two to three times as much cooking liquor per gram of fiber was required for water hyacinths compared to wood pulping, due to the high absorbency of W. H. fibers.

Problems 4 and 5 indicate that water hyacinth fibers are: (1) very bulky in nature; and (2) very absorbent.

This may indicate that, although, water hyacinth fibers are not suitable for making paper, they may be very useful as an absorbent wadding for sanitary napkins or disposable diapers; however, no research in this area has been found.

Ether Extract

Most chemical analyses of water hyacinths report on ether extract of about 3.5 percent of dry matter. This ether extract is probably a mixture of unsaturated fatty acid lipids. Although this type of material has economic value in many commercial applications its low concentration in fresh water hyacinths (less than 2/10ths of 1 percent) would make it uneconomical to recover.

Recovery of Metals

BCL believes that the recovery of most metals from whole fresh water hyacinths would be uneconomical. However, if water hyacinths were utilized as a fuel, recovery of metals from the resulting ash could then be a viable process. Also, if water hyacinths were utilized for anaerobic fermentation to produce methane, it may be possible to economically recover metals from the sludge. This sludge would have to be readily filterable and the cake dryable. The resulting dry cake could then be burned as a fuel and metals could be recovered from the resulting ash. However, based on the concentrations shown in Table 2-12, the quantities which could be recovered are of the order of a few pounds per dry ton of hyacinth. Appreciable economic returns do not seem probable.

Potential Agricultural Uses

This section briefly examines three potential agricultural applications--soil mulches or compost, fertilizer, and livestock feed. Several points are covered. These include the "technical suitability" of harvested water hyacinths in various agricultural applications, an assessment of harvesting and processing costs, an examination of the economies of usage (including costs of competitive materials), and an assessment of the market potential relative to the potential production of water hyacinths in the southeastern United States.

Compost

Good compost materials are those in which the tissues decompose and a reasonably high percentage of nitrogen in the tissues is easily converted to nitrates by soil microorganisms. Aquatic weed tissues vary tremendously with regard to the ease of nitrogen conversion to nitrates. Some plant tissues not only nitrify poorly themselves, but may inhibit or prevent conversion of nitrogen already present in the soil from other sources.

Composition. An important factor to consider when adding an organic residue to the soil is the carbon-nitrogen ratio, which averages about 23:1 in water hyacinths. This value is within the carbon-nitrogen ratios of 20:1 to 30:1 found in legumes and much lower than the 90:1 ratio to most straws. The addition of organic matter to normal soil evokes an immediate response from the soil microbes which eventually degrade the organic material into its basic components and leave a more or less stable residue--soil humus. During this biological process, the carbon-nitrogen ratio tends to equalize at the same level as present in the soil itself, which averages about 11:1 in normal mineral soils. The soil microorganisms require nitrogen for their metabolism with the simultaneous evolution of carbon dioxide. This nitrogen is obtained from the added organic material when the carbon-nitrogen ratio is small, such as less than 30:1, or from the soil where the carbon-nitrogen ratio is large. Where the carbon-nitrogen ratio is large, there is a temporary depletion of available nitrogen with detrimental effects on plants growing in the soil.

The elemental content of organic material is an important aspect to consider before its use as a soil amendment or plant nutrient source. The presence of undesirable elements, toxic to plants, may prevent the use of organic materials in these types of applications. Table 2-12 indicates the concentration of aluminum and heavy metals in samples of water taken from various Florida locations by researchers at the University of Florida.

Aluminum content was relatively high in all but a few samples of water hyacinths, and this could pose a problem if large amounts of water hyacinths were applied to soil in which aluminum-sensitive plants were growing. The iron content was also relatively high, which could be an asset. The zinc and manganese contents also may add to water hyacinths' potential value. The small amount of lead in water hyacinths does not pose a threat as to subsequent uptake in edible plant tissue. All of these elements appear to be highly water insoluble, especially aluminum and iron.

A compost material may be formed by piling whole or chopped hyacinths and allowing them to decompose aerobically. If sufficient time and space are available, a composted produce can be made from whole water hyacinths with no further processing. However, chopping or reduction increases the bulk density and improves the handling characteristics of the plant, which aids in processing, transportation, and storage. Chopping also increases biological activity in composting and reduces the time required to produce a composted product. Whole plants require about 6 months and chopped plants 3 months to compost adequately for commercial use. The composts are then dried, ground, and mixed with mineral constituents. This material has been used for potting ornamentals and as an additive to municipal park flower beds.

Price. Composted hyacinths have sold for $12.00 per cu yd. At a bulk density ranging from 20 to 53 lb per cu ft, this results in a price of $16.76 to $30.65 per ton. Preliminary tests showed the hyacinth compost to have excellent water retention. Indications are that it can constitute no more than 25 percent of a sand-compost mixture without harm to plants.

By comparison, peat moss reportedly sells for $8.00 to $10.00 per bale, or $12.00 to $20.00 per cu yd in loose form[5-4].

Markets. There are no readily available data concerning the volume of sales or consumer expenditures for compost and mulches. BCL checked with a number of sources, including the American Association of

Nurserymen, The Ohio State University, the U.S. Department of Agriculture, and the editor of Home and Garden Supply Merchandiser to try to obtain market information. Although no specific data were obtained, it was reported that the compost and mulch market is presumably growing at a fairly rapid rate as a result of increased interest in home gardening and landscaping. Apparently little information is exchanged among nurseries and garden supply stores merchandising these products.

One method of developing a gross estimate of the market for composts and mulches is based upon Census data, along with data from a University of Tennessee study. In 1972 the Bureau of the Census reported total U.S. sales of retail nurseries and lawn and garden supply stores of \$829.5 million. Sales in the Southern region of the United States amounted to \$211.5 million (from Texas eastward to the Atlantic Coast). A study conducted by agricultural economists at the University of Tennessee[5-15], covering several counties in Tennessee, indicated that homeowner expenditures for "maintenance items" accounted for 12.4 percent of total homeowner expenditures for landscape plants, lawn materials, and related supplies. "Maintenance items" were defined to include fertilizer, lime, mulches, and pesticides. If it is arbitrarily assumed that mulches account for approximately one-quarter of all expenditures for "maintenance items", the mulches would comprise about 3.1 percent of total retail nursery sales. Multiplying this percentage by \$211.5 million results in an estimated <u>retail market</u> for mulches (or compost materials) of some \$6.5 million in the 14 states comprising the Southern region. The <u>wholesale market</u> is conservatively estimated at least equal to the retail market, making the total market potential around \$13.0 million. If one further assumes that the compost would only be sold in those southernmost areas where water hyacinths grow for 12 months throughout the year, the market potential might only be 20-30 percent of the estimated \$13.0 million, or about \$2.6 to \$3.9 million annually. This estimate is very crude, and it should be noted that it is unknown at this time what level of market penetration, or market percentage, might be achieved by composted water hyacinths.

Transportation costs for composted hyacinths might be comparable to costs incurred by commercial feedlot operations manure disposal. In a 1973 study conducted by Battelle's Columbus Laboratories, manure trucking costs of \$1.25 per ton, plus \$0.05 per ton-mile, were reported. These rates presumably have increased in the past 2 years; assuming inflation of 35 percent, present handling costs are estimated at approximately \$1.70 per ton plus \$0.0675 per ton-mile. If these costs are presumed to be representative of compost transportation, it would cost approximately \$23.75 to transport 10 tons of compost a distance of 10 miles, resulting in a cost per ton of \$2.38.

The market for various products is price competitive. Various types and grades of materials are available, depending upon the quality and price demands of the consumer. Certainly any compost material containing water hyacinths would have to be priced reasonable close to existing compost in the given market, unless superior beneficial effects could definitely be demonstrated. At the very least, users would have to be assured that there would be no danger of seed dispersal and germination from the use of composted water hyacinths.

Fertilizer

Research by Parra and Hortensteine[5-5] indicates that dried water hyacinths may have utility as a soil amendment and nutrient source in crop production. The amounts of available plant nutrients and the rate of nutrient release are important factors to consider in the use of water hyacinths as a soil amendment. Nutrient content of water hyacinths varies with location, season of the year, and water quality. On a dry weight basis, this study indicated that water hyacinths contained an average of 1.61 percent nitrogen, 0.31 percent phosphorus (0.71 percent P_2O_5) and 3.81 percent potassium (4.59 percent K_2O).[a] These three nutrients are considered the major fertilizer elements. The percentage content of other macro-nutrients such as calcium, magnesium, and sodium were 1.66 percent, 0.56 percent, and 0.56 percent, respectively.[5-8]

In considering the use of water hyacinths as a <u>fertilizer</u> material, the primary nutrient content (N, P_2O_5, and K_2O) is an important factor. Table 5-2 indicates the average primary nutrient content of commercial fertilizer mixtures in five southeastern states for 1974. There are many

(a) Data supplied by NSTL indicated a composition of 2.5% N, 1.0% P_2O_5, and 5.3% K_2O.

TABLE 5-2. AVERAGE PRIMARY NUTRIENT CONTENT OF FERTILIZER MIXTURES IN FIVE SOUTHEASTERN STATES, U.S.A., YEAR ENDED JUNE 30, 1974
(Percent)

State	N	P_2O_5	K_2O	Total
Alabama	8.3	13.9	14.9	37.1
Florida	9.6	6.1	12.9	28.6
Georgia	5.9	10.3	15.7	31.9
Louisiana	11.4	15.3	13.7	40.4
Mississippi	9.8	16.0	16.2	42.0
Average	9.0	12.3	14.7	36.0
Composition of dried water hyacinth	1.6	0.7	4.6	6.9

Source: Reference (5-6).

different analyses of mixed fertilizers, for example, 5-20-20, 6-24-24, 8-32-16, 3-9-9, 4-12-12, etc. For the five states the average nutrient content was 9 percent N, 12.3 percent P_2O_5, and 14.7 percent K_2O. This analysis is much higher than the composition of dried water hyacinths, which is 1.6 percent N, 0.7 percent P_2O_5, and 4.6 percent K_2O. Naturally, the composition of dried water hyacinths will vary somewhat according to the water source in which they grow. However, even if the composition of the three primary nutrients were increased by 50 percent over these levels, their usage as a fertilizer material would appear to be limited, simply due to the low percentage of primary nutrients.

In September, 1974, the approximate farm prices of the three primary fertilizer nutrients were as follows: nitrogen = \$0.25 per lb; P_2O_5 = \$0.20 per lb; K_2O = \$0.08 per lb. 1975 price information is not readily available at this time. Prices in the spring were higher than in September, 1974, but since the spring have receded to somewhat lower levels. Generally, fertilizer prices have risen sharply over the past several years. At the present time, however, nitrogen is the only one of the three primary nutrients that appears to be in short supply, with the prospect of further higher prices. The supply/demand relationships for P_2O_5 and K_2O are generally satisfactory, with further price increases not expected at this time.

Based on the above prices for the primary fertilizer nutrients, a hypothetical price of a 1.6-0.7-4.6 analysis fertilizer material, similar to the composition of dried water hyacinths, can be estimated. The estimating equation is

$$\text{Hypothetical fertilizer price per ton} = (2{,}000 \times 0.016 \times 0.25) + (2{,}000 \times 0.007 \times 0.20) + (2{,}000 \times 0.046 \times 0.08) = \$18.16$$

No account of the value of other nutrients such as calcium, manganese, zinc, etc., has been taken into account in this estimation. On the other hand, it is assumed that the three primary nutrients are soluble and available for assimilation by plants. Both of these factors would need to be considered in a more detailed analysis of the potential value of dried water hyacinths as a fertilizer material. The \$18.16 per ton figure simple presents a benchmark estimate of potential fertilizer value.

Feed

Water hyacinths have reportedly been fed to swine in Asia and have been grazed by cattle in the tropics. There are also reports indicating water hyacinths have been hand harvested during drought periods to use as fodder for ruminants. This section summarizes some of the studies conducted at the University of Florida relative to the feed value of water hyacinths.

With the exception of one study, all of the studies dealt with the use of water hyacinths as a cattle feed ingredient. Being ruminants, cattle are most likely to be able to utilize water hyacinths of all forms of commercial livestock. Water hyacinths may have applications in fish feeding; however, there is no readily available literature on this type of feed application.

Water hyacinths have been considered both as a dry feed ingredient and as a silage material.

Dried Water Hyacinths. Research on the nutritional value of aquatic plants for livestock was initiated at the University of Florida in 1968. Water hyacinths were harvested from various freshwater sites and processed by chopping, pressing of the chopped material, and dehydration of the pressed residue. This crude method of processing resulted in a low quality press residue because a large portion of the nutrients were in the pressed juice.

The steps involved in harvesting and processing water hyacinths for feed use are shown in Figure 5-1.

Easley and Shirley[(5-7)] studied concentrations on ten nutrient elements used in livestock feeds in several species of aquatic plants, including water hyacinths. Their results for water hyacinths are shown in Table 5-3.

The data in Table 5-3 are expressed on a dry weight basis. Calcium concentration in water hyacinths was lower and varied less throughout the year than for any other element. The concentration of approximately 2 percent calcium is similar to that found in legumes. A calcium/phosphorus

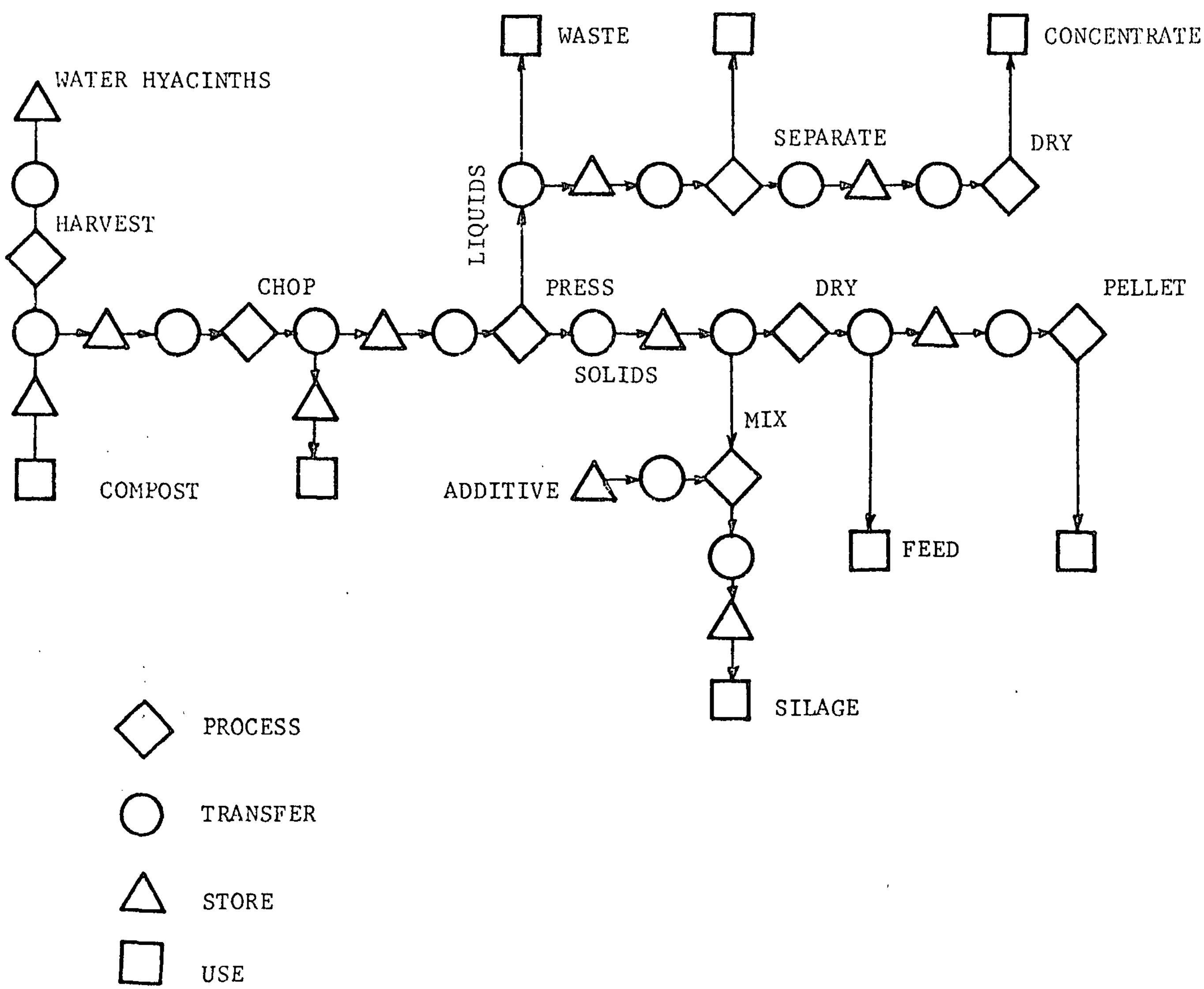


FIGURE 5-1. WATER HYACINTH HARVESTING -- PROCESSING SYSTEM FOR LIVESTOCK FEED

TABLE 5-3. CONCENTRATION OF MINERAL FEED NUTRIENT ELEMENTS IN WATER HYACINTH SAMPLES TAKEN FROM LAKE APOPKA, FLORIDA

Element	Average	High	Low
	Percent, dry basis		
Calcium	2.2	2.7	2.0
Phosphorus	0.50	0.66	0.17
Potassium	4.1	6.4	1.0
Magnesium	0.59	0.64	0.52
Sodium	0.94	1.20	0.62
	mg/kg, dry basis		
Iron	1,701	3,183	522
Copper	12	30	7
Zinc	43	71	30
Manganese	142	227	106
Chromium	3.2	10.6	-0-

Source: Reference (5-7).

ratio of approximately 2:1 is desirable but ratios as high as 7:1 may be satisfacory for cattle. The calcium/phosphorus for water hyacinths was approximately 4.4:1.

Average potassium values were in the range of most land forages found in the United States, i.e., 1 to 3 percent. Magnesium content of water hyacinths were approximately 0.6 percent is also comparable to land forages.

The average sodium content of water hyacinths was found to be 0.94 percent, much higher than most land forages, which range generally from 0.01 to 0.14 percent. Land forages are almost always low in sodium with regard to livestock dietary requirements.

The iron concentration of water hyacinths was also high relative to forage crops, averaging 1,700 mg per kg of dry weight. This high iron content may be detrimental, since it was found that steer calves fed rations containing 1,600 parts of iron per million iron as ferrous sulfate resulted in depressed daily feed intake and daily weight gains.

Copper, zinc, and manganese concentrations of water hyacinths were found to be in the range of most land forages.

Chromium, a dietary requirement of rats, is associated with carbohydrate metabolism. Average chromium concentrations in water hyacinths were approximately 3 mg/kg dry weight.

The average percentage of daily requirements of nutrient elements for steers found in 1 kg of dried water hyacinths is shown in Table 5-4. These requirements are from the National Research Council's recommendations for a 300-kg steer fed to gain 1.1 kg per day. It is important to note that these data only indicate the nutrient to be metabolized by the animal.

Other research has indicated that the protein content of dried water hyacinths ranges from 12 to 18 percent on a dry weight basis. Crude fiber content has been measured between 13 and 20 percent, but on an ash free dry weight basis would be equivalent to the land forage values of 25 to 30 percent. The ash content has been shown to be extremely variable, ranging from 10 to 30 percent or above, compared to land forage values ranging from 5 to 8 percent. This fraction of the plant needs further consideration and the proper utilization of water hyacinths in livestock diets.

TABLE 5-4. AVERAGE PERCENTAGE OF DAILY REQUIREMENT OF SELECTED NUTRIENT ELEMENTS PER KILOGRAM OF DRIED WATER HYACINTH, FOR 300-KG STEER

Element	Percent
Calcium	85
Phosphorus	25
Potassium	82
Magnesium	98
Sodium	134
Iron	170
Copper	21
Zinc	31
Manganese	133

Source: Reference (5-7).

Calcium, phosphorus, potassium, magnesium, and sodium, are major nutrient elements in animal feeds. Shirley's research indicated that approximately 3 kg of dried water hyacinths would provide an excess of these elements for a 450-kg steer. As previously indicated, the calcium/phosphorus ratio of slightly in excess of 4:1 is slightly higher than the optimal level for cattle, but may not be detrimental.

Copper, zinc, iron, and manganese are minor nutrient elements of livestock feeds. The amounts of these nutrients supplied by 1 kg of dried hyacinths has already been shown in Table 5-4.

The above data concerning the relatively high concentration of nutrient minerals in water hyacinths indicate that care must be taken to prevent mineral imbalances if they are to be used in livestock feed rations.

Another question relates to the palatability of dried water hyacinths in livestock feed diets. Experiments have been performed in which cattle were offered diets containing processed water hyacinths as the sole diet and in mixed diets with molasses or molasses and oilseed meal added. Hentges reports that voluntary feed intake did not exceed 1 percent of live body weight per day until the product was found and blended with sugarcane molasses (30 percent by weight). At this level of intake the cattle were losing weight. On the other hand, similar cattle offered Bermuda grass mature hay maintained their weight by voluntarily consuming a quantity equal to 2 percent of their live body weight per day.

Pelletization of the ground pressed residue increased its daily intake by cattle to about 1.5 percent of live body weight. At this point, various levels of water hyacinths pressed residue were tested in blends with other feed ingredients. It was concluded that with the low quality, experimentally processed water hyacinth pressed residue available, an expected intake by yearling cattle of at least 2.8 percent of live body weight would not be obtained with more than 25 percent water hyacinth in the balanced diet. On the other hand, dried water hyacinths were deemed acceptable at a low level in cattle diets. The University of Florida has also conducted toxicity tests on cattle fed water hyacinths. In numerous short-term experiments, no signs of toxicity were observed in cattle or sheep. One group of six yearling cattle were offered dried water hyacinths at a maximum tolerance level in their diets for 9 months without apparent toxic effects or digestive disturbances as judged by live performance and postmortem examination of organs and tissues.

All of the preliminary animal feeding experiments indicated the need for a high level of supplemental protein to the diets containing pressed water hyacinths. It was previously indicated that a substantial fraction protein was lost in the pressed juice. Other research found protein to be extremely difficult to extract from pressed residue of whole, medium-sized water hyacinth plants. The high ash content of dried water hyacinths apparently reduces voluntary feed intake of dry matter and crude protein.

The above research also indicated that digestive coefficients for dry organic matter were lowest in diets containing water hyacinths. This was also true regarding the digestion coefficient for crude protein. It was concluded that the organic plant materials provided none of the digestible protein, substantiating the belief that the pressed juice contained most of the useful protein.

To determine the market value of water hyacinth dried pressed residue as a cattle feed component, a feeding trial was conducted with individually fed steers to compare the water hyacinth product with two popular competitive products--cottonseed hulls and sugarcane bagasse pellets, as the only source of bulky large particles in a high concentrate cattle finishing diet. The results showed water hyacinths pressed residue to have a replacement value at least equal to these competitive products. This indicates that the market value of low quality experimentally processed water hyacinths dried pressed residue might be based on its use as a replacement for cottonseed hulls and sugarcane bagasse pellets in cattle diets.

Contacts with cottonseed hull and bagasse pellets suppliers indicated that cottonseed hulls are currently priced at approximately $40.00 per ton for bulk delivery. Bagasse pellets are priced at $50.00 per ton. Therefore, based on current market conditions, it appears that dried hyacinths pressed residue would have to sell in this price range to be competitive.

Water Hyacinths Silage. Previously it has been noted that animal feeding experiments using dried pressed water hyacinths encountered problems with voluntary feed intake and palatability of the processed plant products. Also, a commercially economical drying system has not been developed. Another possible method of feed utilization of these plants is as silage for ruminants.

Early attempts to ensile unprocessed fresh water hyacinths, chopped pressed water hyacinths, and chopped pressed water hyacinths with molasses were unsuccessful due to excessive spoilage and inadequate fermentation. A subsequent study at the University of Florida evaluated water hyacinths ensiled with various preservatives.[5-9] Preservative treatments utilized dried citrus pulp (DCP) as an absorbent and source of fermentable carbohydrates, standard cane molasses (SCM), yellow dent corn (YDC), and dried water hyacinth pressed residue (DWH).

The study results showed favorable fermentation of water hyacinth in preservatives was achieved in silage at desired levels of acidity, aroma, and texture. Cattle acceptability of most silage treatments was immediate. Although the plants ensiled in each of five different experiments were harvested at different times of the year, different stages of growth, and at different locations, the results of preservative comparisons on chemical composition and cattle acceptability were consistent in all experiments. The most acceptable silages received a preservative level of 4 kg dried citrus pulp and 1 kg of standard cane molasses per 100 kg of pressed plant residue.

The most acceptable silage treatments were at the highest level of preservatives, lowest pH, highest percentage organic matter, and lowest percentage ash--upon removal from the barrel silos. As the acceptability of a silage treatment increased, there is an increase in preservative level and a decrease in acidity and ash.

Experimental cattle used in the above experiment ranged in age from 2-3 years and in weight from 230-370 kg.

Another study by Baldwin[5-10] compared pangolagrass silage with water hyacinths silage in diets for sheep. Silages were evaluated according to chemical composition, voluntary feed intake, and nutrient digestibility.

Water hyacinths were harvested from a freshwater lake, chopped, and pressed to remove moisture, and ensiled in a tower pilot silo. 4 kg of dried citrus pulp and 0.5 kg sugarcane molasses per 100 kg of plant material were added as the silos were filled.

Changes in acidity and temperature of the silages indicated that fermentation occurred with both water hyacinths and pangolagrass. A decrease in the ash and crude protein content of water hyacinths as a percentage of dry matter was noted between the chopping and pressing stages. This indicated that soluble minerals and protein were being lost in the press effluent. Chemical composition of water hyacinth silage (WHS) was similar to that of pangolagrass silage (PGH), except for ash and crude protein, which were higher in the water hyacinth silage.

The results indicated that dry matter intake of PGS was larger than for WHS. Digestibility of dry matter, organic matter, and crude protein was also higher for PGS. Voluntary intake of both PGS and WHS was inadequate to meet the dry matter, crude protein, and digestible protein requirements of sheep averaging 34 kg in weight. Additionally, WHS failed to provide the required digestible energy, phosphorus, and magnesium.

The lower dry matter and inorganic matter digestibility for water hyacinths silage is believed to result from excessive loss of the more soluble factions of these constituents in the effluent resulting from pressing.

It was concluded that improved methods of reducing the moisture content of plants to be ensiled with minimal nutrient loss are needed. Also, mineral imbalances in water hyacinths silage observed in this study, especially the calcium/phosphorus ratio (8.4:1) and high potassium level (3.3 percent of dry matter) need to be corrected.

Cattle Feed Market Potential. Since water hyacinths are not at present a commercial feed ingredient, there are naturally no market data available. In order to estimate the total market potential of harvested water hyacinths as a feed ingredient, Battelle followed the procedure outlined in Table 5-5.

This analysis assumed:(1) that water hyacinths would be used only as a cattle feed ingredient, and not in any other type of livestock feed; (2) water hyacinths would only be utilized in those areas where they can potentially be used in wastewater treatment (Figure 5-2); and (3) water hyacinths would be a potential feed substitute for existing commercial by-products feeds such as wheat and rice mill feeds, seeds, skim milk, hominy, and other by-products feeds. It would also be a potential substitute for harvested forages other than hay--including straw, silage,and bagasse pellets.

The first column in Table 5-5 indicates the total roughage-consuming animal units for cattle in seven southeastern states.* The second column shows the estimated percentage of roughage-consuming animal units in each state where water hyacinths are believed to grow for a major fraction of the year. Basically, this percentage includes all areas south of Baton Rouge, Louisiana, with the exception of several counties along the coast of eastern Georgia and the southern most portion of South Carolina. The third column shows

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* An animal unit is a standard unit for comparing actual animal numbers for all types of livestock and poultry. An animal unit is based on a dry weight quantity of the feed consumed by the average milk cow during a day's period. A set of factors is developed for each type of livestock and poultry by relating feed consumption for each type of livestock to the feed consumed by the average milk cow. A roughage-consuming animal unit pertains to livestock and poultry numbers weighted by the roughage-consumption factor per roughage feeds including pasture.

TABLE 5-5. ESTIMATED TOTAL CATTLE FEED MARKET POTENTIAL OF HARVESTED WATER HYACINTHS IN AREAS OF PRODUCTION, UNITED STATES

State	State Total--Roughage-Consuming Animal Units, Cattle	x	Estimated Percentage in Major Water Hyacinth Region	=	Total Units in Major Water Hyacinth Region
Alabama	1,093,000		10		109,300
Florida	1,341,000		100		134,100
Georgia	1,395,000		10		139,500
Louisiana	997,000		50		99,700
Mississippi	740,000		10		74,000
South Carolina	516,000		10		51,600
Texas	9,035,000		20		1,807,000
Total	15,117,000				2,415,200

Total roughage-consuming animal units by cattle, USA, 1971 = 82,350,000

$$\frac{2,415,200}{82,350,000} = 2.93\%$$ in water hyacinth area

Total by-product feeds consumed by cattle, USA, 1971 = 7,708,000 tons

Total harvested forage, other than hay, consumed by cattle, USA, 1971 = 136,161,000 tons

7,708,000 x 0.0293 = 226,000 tons
136,161,000 x 0.0293 = 3,990,000 "

4,216,000 tons estimated total consumption of by-product feeds and harvested forage (other than hay) in areas where water hyacinths grow throughout the year[(a)].

Source: Reference (5-11) and Battelle Computations.

(a) Includes wheat and rice millfeeds, seeds, skim milk, hominy, other by-product feeds, straw, silage, and beet pulp.

The total estimated roughage-consuming animal units in the major water hyacinths production region. This total of approximately 2.4 million animal units is slightly less than 3 percent of the total roughage consuming animal units for cattle in the entire U.S. in 1971. This percentage was then multiplied by the total consumption of by-product feeds consumed by cattle and harvested forages (other than hay) consumed by cattle in the United States in 1971. The summation of these two products resulted in an approximate estimated total market potential of 4.2 million tons of harvested water hyacinths.

It is emphasized that the 4.2 million tons pertains to estimated total market potential, not an estimate of actual consumption. For example, if water hyacinths could substitute for 10 percent of this total market, their consumption on a dry weight basis would be approximately 420,000 tons per year; similarly, if they could substitute for 25 percent of the total market, annual consumption would be slightly in excess of 1 million tons per year. The actual market penetration will of course depend upon water hyacinths' proven effectiveness as a feed ingredient, along with their price relative to existing commercial feed products.

At an average selling price of $40 per ton, the maximum potential feed market value would be approximately $168 million, or about $42 million, if a 25 percent level of market penetration were achieved.

Based on the estimates of Chapter 3, it would require about 1400 hyacinth facilities, each serving a city of 10,000, to provide a million tons of dry hyacinth material per year. If the market penetration were 25 percent, then some 350 such installations would be required to produce the hyacinths. It will be seen in the next chapter, that it is relatively unlikely that this many facilities will be built in the region of interest. It seems, therefore, that major penetration of this particular market is not probable, because of limitations in the hyacinth supply. Converesly, however, it appears that this market could absorb all the hyacinths which would probably be produced, if hyacinth costs can be kept low enough to permit sale at a competitive price.

Harvesting and Processing Costs

If water hyacinths are ever to be utilized in agricultural and/ or other end uses, the first step is mechanical harvesting. There are several problems related to mechanical harvesting, including removal of the plants from the water, removal of the plants from the harvest site, and disposal of the plants.

Removal from the water consists of severing the plant from the bottom, if necessary, and lifting it from the water along with entrained water, wildlife, and trash. Removal from the site consists of transportation of the bulky, heavy, and low value plants to a disposal location. Since water hyacinths consist of 95 percent water, this process is quite costly and often reduces system capacity. It is most likely to benefit from some type of intermediate processing.

Criteria used to evaluate a mechanical system are effectiveness, capacity, efficiency, reliability, and economy. Effectiveness is the ability to perform the intended function, for example, removal of water hyacinths from the water or water from the plants. Capacity is the rate at which the function is performed, e.g., acres per day or tons per hour. Efficiency is a ratio of input energy to unit of performed function, e.g., horsepower-hours per ton. Reliability is the ability of the system to function predictably and continuously with minimum maintenance, for exampel, portion of total working hours actually available for system operation. Economy is the total cost of operation for each functional unit, for example, dollars per dried ton of water hyacinths.

A total harvesting processing system consists of a harvesting unit, a reduction unit, a fractionation unit, a separation unit, a drying unit, and a packaging unit. These units may be arranged as previously shown in Figure 5-1. Potentially useful products or raw materials are available at the discharge of each unit. The process materials balance is shown in Figure 5-2. The harvesting rate and condition of harvested plants affects subsequent operations. Given sufficient time and space, a composted product can be made with no further processing. However, chopping or reduction of the water hyacinth increases its bulk density

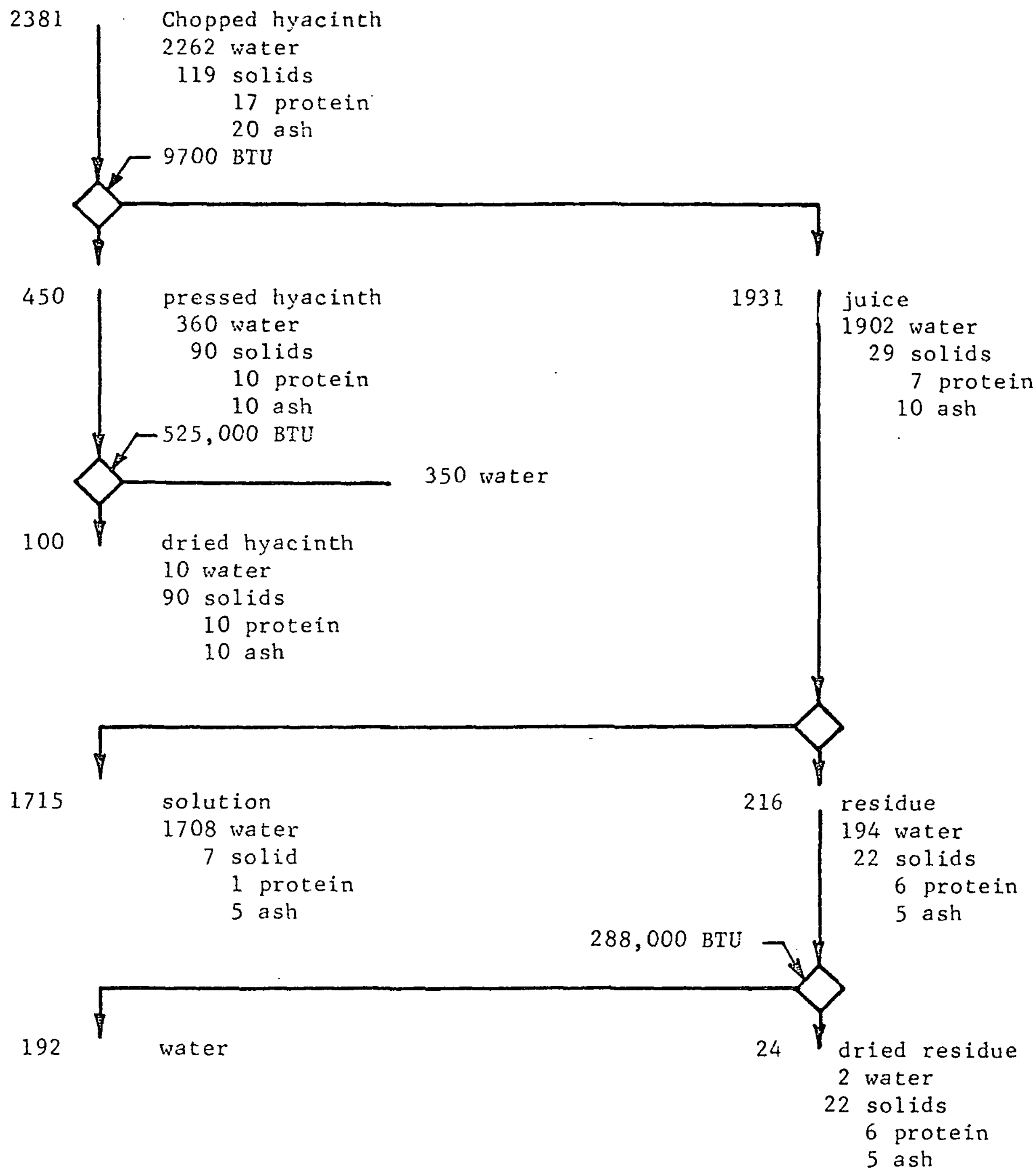

FIGURE 5-2. HYACINTH PROCESS MATERIAL BALANCE

and improves the handling characteristics, which helps processing, transportation, and storage. Chopping also increases biological activity in composting and reduces the time required to produce a composted product. Pressing, or fractionation, separates the plant into a drier, fibrous fraction and a nutritious liquid fraction. The fibrous fraction can be dried or mixed with carbohydrates and ensiled. Separating the suspended nutrients from the pressed liquor produces a waste liquor and a cake which is high in useful nutrients and low in fiber. Drying produces a feed that is easier to store and transport, being lighter and less biologically active. Pelleting increases the density, reduces dust losses, and improves the palatability of either the pure plant feed or the mixed feed.

Most harvesters in use or in development use an inclined conveyor to lift the plants from the water and, if necessary, a cutter to sever the plants below the water. Other devices being investigated as hyacinth harvestors are crimpers and pumps. In one test, one 10-ft wide flat wire belt conveyor harvested an average of 29 tons per hour during 55 operating hours, with a peak of 44 tons per hour (wet weight). The harvester was available for work 85 percent of total working hours. It was expected that improved engineering and additional field testing would improve machine availability. Harvesting costs on the contract under which this test was performed was \$2.13 per ton of raw hyacinth, or \$42.60 per dry ton.

This particle size of water hyacinths may be reduced to increase bulk density and improve handling characteristics by processing the plant in various types of shoppers, shredders, crimpers, or crushers. One type of processor, the sheer-bar forage chopper, cuts cleanly and uniformly, and depending on blade design and speed, throws the plant particles downward or up a spout. Wet chopped hyacinths adhere to the spout wall and occasionally build up sufficiently to stop the flow. A downward discharge into a conveyor is more satisfactory. In one study, a small forage chopper (16 inches throat width) chopped 26 tons of hyacinths per hour into 1-inch lengths. By modifying the feeding geometry, the capacity of this chopped approached 60 tons per hour. The cost of chopping was estimated at 3-1/2 cents per raw ton and 68 cents per dry ton of material (Table 5-6).

Since water hyacinths contain more water than can be economically removed by thermal processes, mechanical fractionation is used to rapidly and inexpensively remove much of the water. Screw presses are most commonly used, but roller presses and variations on roller presses have been used experimentally.

The continuous screw press consists of an auger in a perforated housing which conveys the material to be pressed against a resistance, decreasing its volume and forcing fluid free of the material and causing it to flow out of the housing. The pressed cake leaves the housing past the restricter in a separate stream. It has been found that destruction of the plant tissues and cells, such as is accomplished in a screw press, aids fractionation.

A 12-inch diameter screw press operating at 38 rpm removed 71 percent of the water from 13 tons of chopped hyacinth per hour. In other tests at lower feed rates, up to 80 percent of the water was removed in a single pass. Estimated costs of screw press fractionation of water hyacinth have been placed at 35 cents per raw ton and at $9.31 per dry ton of material (Table 5-7).

The pressed water hyacinths are quite uniform, with a moisture content between 80 and 90 percent. A silage product can be made with the addition of suitable carbohydrates. Solids can be recovered from the liquid fraction of the pressed juice by filters, centrifuges, and if time and space permit, settling basins or tanks. Chemical or thermal coagulation may aid in efficiency and speed of recovery.

No economically practical way of recovering the solids from hyacinth press juice has yet been determined. However, the product recovered from the juice is relatively fiber free and high in protein and other valuable nutrients. It can be dried and may be useful as a high value feed supplement. Recovered juice products could easily be equal in value to the press cake as a feed material.

TABLE 5-6. ESTIMATED COST OF CHOPPING WATER HYACINTH

	\$/Raw Ton	\$/Dry Ton
Machine \$5,100 cost; 25% per year for depreciation, interest, repair; 150 days/year, 6 hours/day, 100 tons/hour, 80% available	0.018	0.35
Energy 0.46 HPhr/ton, 12 HPhr/gal, 20¢/gal	0.008	0.15
Labor 0.3 man-hour/hour, \$3.00/man-hour, 100 tons/hour	0.009	0.18
Total	0.035	0.68

Source: Reference (5-12).

TABLE 5-7. ESTIMATED COST OF SCREW PRESS FRACTIONATION OF WATER HYACINTH

	\$/Raw Ton	\$/Dry Ton
Machine \$80,000 cost; 25% per year for depreciation, interest, repair; 150 days/year, 6 hours/day, 100 tons/hour, 80% available	0.278	7.34
Energy 4 HPhr/ton, 12 HPhr/gal, 20¢/gal	0.053	1.41
Labor 0.7 man-hour/hour, \$3.00/man-hour, 100 tons/hour	0.021	0.56
Total	0.352	9.31

Source: Reference (5-12).

Pressed water hyacinths may be dried in a rotary dehydrator, a fixed or traveling bed dryer, or possibly in an air-agitated dryer. The dried product is more suitable than silage for simple storage and transportation.

Rotary dehydrators have been used extensively for drying forage and other fibrous products. The single-pass dehydrator is one in which the product moves directly from an inlet at one end to discharge at the opposite end. In the triple-pass dehydrator, the product reverses direction twice in passing from inlet to discharge. Triple-pass dryers are usually more efficient in terms of material, space, and fuel. Bagnall dried 6,800 pounds of water hyacinth per hour from 88 percent moisture content to 22 percent moisture content in a 6,000-lb per hour dehydrator.[5-13] Discharge moisture content was too high for safe storage because operating conditions were not stable and inlet moisture and feed rate were too high. However, these problems presumably would not occur in an established system. Fuel consumption ranged from 1,400 to 1,600 Btu per pound of water evaporated, which is similar for other vegetative materials in this type of dryer. The estimated drying costs were 81 cents per raw ton and $21.23 per dry ton of water hyacinths (as shown in Table 5-8). Bagnall found that coarse shredded hyacinth dried 2-1/2 times as fast as whole plants. Fine shredded material dried only 40 percent faster than whole plants. An excessive reduction in particle size results in agglomeration of particles. This results in larger particles instead of smaller particles being exposed to the air stream, consequently, a reduced drying rate. Also, it was found that drying rate was proportional or less-than-proportional to the heat input. The lower than proportional rate may be caused by hardening of the hyacinth particles, which interferes with the diffusion of moisture throughout the material.

Agricultural engineers at the University of Florida have performed preliminary tests on solar drying of various types of crops and agricultural products. These crops included soybeans, water hyacinth, and pressed citrus pulp. Small-scale (1 bu) dryers were tested using three types of solar

TABLE 5-8. ESTIMATED COST OF DRYING WATER HYACINTH

	$/Raw Ton	$/Dry Ton
Machine $135,000 cost; 25% per year for depreciation, interest, repair; 150 days/year, 6 hours/day, 100 raw tons per hour, 80% availability (80% m feed, 10% m product)	0.469	12.33
Energy 100 lb water evaporated/gal, 11¢/gal	0.323	8.51
Labor 0.5 man-hour/hour, $3.00/man-hour, 100 raw ton/hr	0.015	0.39
Total	0.807	21.23

Source: Reference (5-12).

collectors: heated air, heated water, and direct insolation. The direct insolation system produced the best results and it was recommended that further investigation be made on the feasibility of direct insolation drying systems for high-moisture products. Researchers concluded that solar crop drying can be satisfactorily conducted in high or low moisture products during any season of the year in Florida.[5-14]

Solar drying systems for Florida would be competitive with conventional oil and gas systems if they could be purchased for $1.00 per sq ft of collection area, and the system was used continuously for at least 2 months per year and had a useful life of 5 years.

Dried water hyacinths were pelleted after drying to determine pelleting characteristics and procedures to be followed. Dried hyacinths were fed directly into a hammermill equipped with a 1/8-inch screen. The hyacinths were pelleted through a die having a 3/8-inch diameter by 2-1/2-inch long holes. The only additive used in pelleting was steam and water.

A preliminary test was made for hyacinths to determine the optimum size grind by grinding through a 1/8 or 1/4-inch screen, and using no screen. The raw dried product appeared to crumble easily and was very dusty. The moisture content of the hyacinths was optimum for processing and the moisture content of 8.4 percent in the cool pellets is satisfactory for storage. A very dense pellet was formed, with a weight of 51.6 lb per cu ft.

The production rate of pelleted water hyacinths was found to be low, with excessive power requirements. However, when hyacinths were combined into a ration with feeds of higher lubricity, production rates and power requirements for pelleting were found to be satisfactory. It was concluded that a wet pelleting process may be more satisfactory for forming pure aquatic plant pellets.

Costs of Complete Experimental Processing Systems. Various experimental processing systems for aquatic plants have been tested. These include a complete mobile processor, a mobile press-stationary dehydrator, a and a silage system. Some of the previous cost component analyses were drawn from these systems.

Mobile Processor. A schematic diagram of the mobile processor is shown in Figure 5-3. This processor removed 91 percent of the water from water hyacinths, producing a product with a 73 percent moisture content. Losses of hyacinth dry matter were approximately 35 percent. Additional drying was necessary before this product could be stored.

The average hourly consumption of hyacinths was 1.3 tons, with an hourly dry matter production of 86 pounds.

The estimated harvesting and processing costs for this unit are shown in Table 5-9. The total cost, $16.73 per raw ton or $393.35 per dried ton of water hyacinths, is much higher than would be economically feasible. However, if it were possible to change some of the assumptions regarding machine and labor costs, total cost per ton could be reduced substantially. For example, if depreciation, interest, and repairs were charged at a rate of 20 percent of the machine costs instead of 25 percent, the machine operated for 250 days per year, 8 hours per day, with a 75 percent availability, total machine costs would amount to $2.92 per raw ton and $68.70 per dried ton. Also, if it were possible to operate with two men instead of three, labor costs would be reduced by 33 percent. Under these assumptions, total processing costs would be $7.65 per raw ton and $179.99 per dried ton. Even though this represents a reduction of more than 50 percent, the cost still would be substantially greater than the agricultural value of the product, whether used for compost or as an animal feed ingredient.

Mobile Press-Stationary Dehydrator. Water hyacinths were processed in the mobil press-stationary dehydrator system shown schematically in Figure 5-4. This system removed 99 percent of the water, reducing product moisture content to 22 percent. This is still slightly higher than required for storage. 33 percent of the hyacinths dry matter was lost in this process. The estimated raw plant consumption rate was 12.8 tons per hour with 807 lb dry matter produced per hour.

The estimated costs associated with this system are shown in Table 5-10 and amount to $4.92 per raw ton and $155.81 per dried ton. These costs are still high but might be reduced substantially given improvements in the system, coupled with operation on a commercial scale.

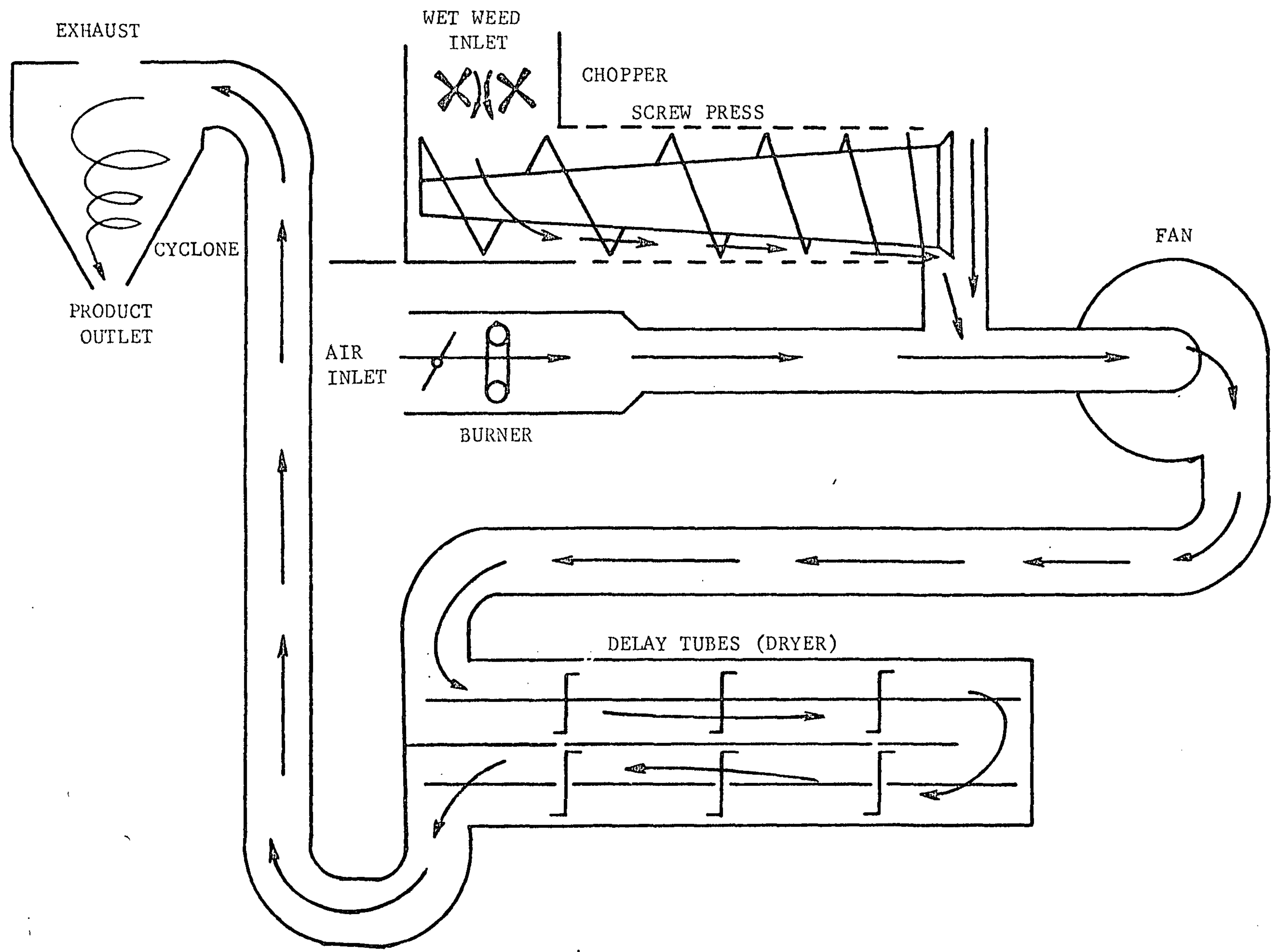

FIGURE 5-3. MOBILE AQUATIC WEED PROCESSOR SCHEMATIC

TABLE 5-9. ESTIMATED HARVESTING-PROCESSING COST WITH MOBILE PROCESSOR

	$/Raw Ton	$/Dry Ton
Machine		
$35,000 cost; 25% per year for depreciation, interest, repairs; 150 days/year, 6 hours/day, 60% available, 1.6 raw tons/hour	10.13	238.29
Energy		
26 HPhr/raw ton, 12 HPhr/gal, 20¢/gal, 450,000 BTU/raw ton, 140,000 BTU/gal, 17¢/gal	0.98	23.05
Labor		
3 men, $3.00/hour, 1.6 tons/hour	5.62	132.35
Total	16.73	393.35

Source: Reference (5-8).

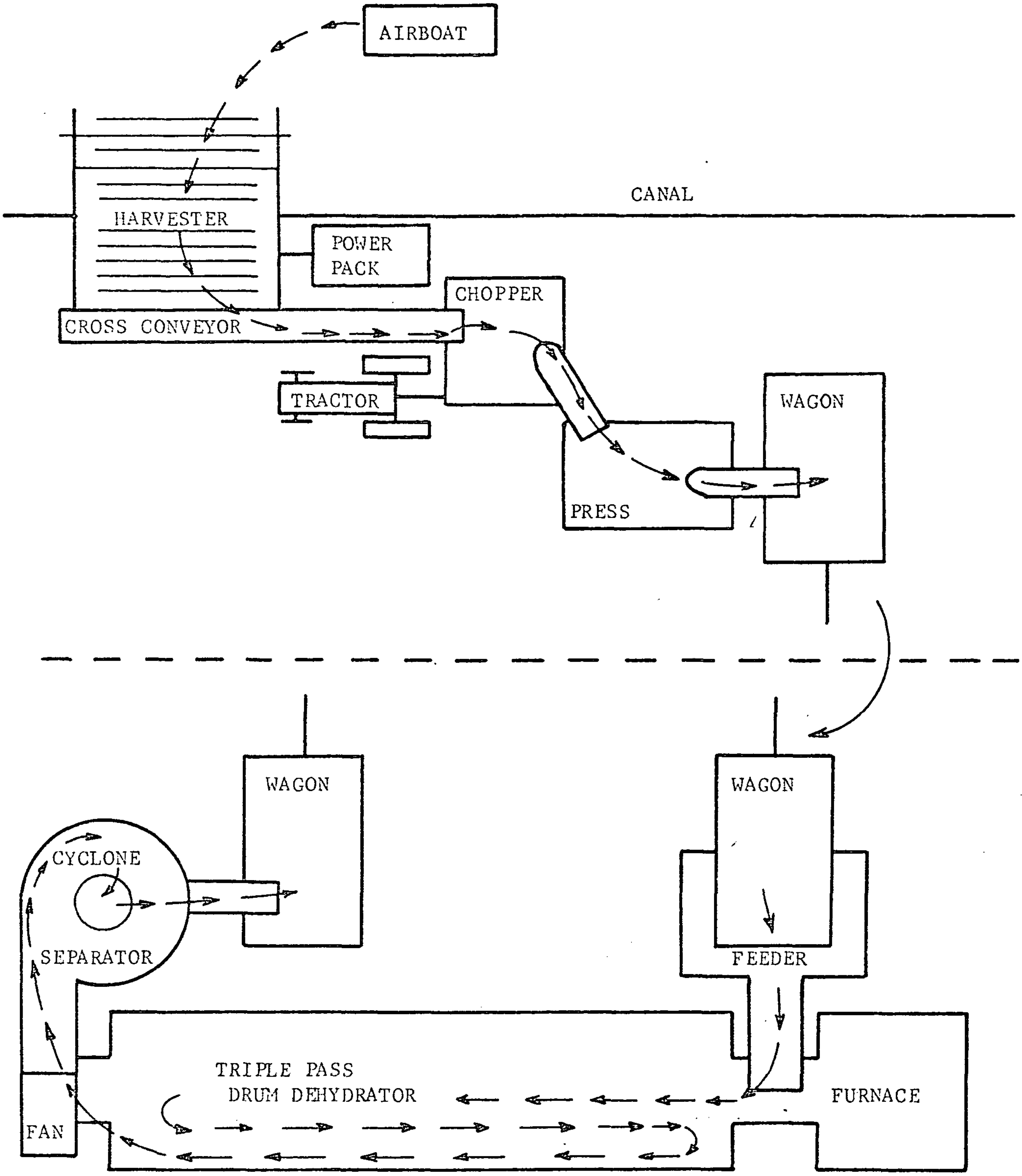

FIGURE 5-4. MOBILE PRESS -- STATIONARY DEHYDRATOR PROCESS

TABLE 5-10. ESTIMATED HARVESTING-PROCESSING COSTS OF MOBILE PRESS-STATIONARY DEHYDRATOR SYSTEM

	\$/Raw Ton	\$/Dry Ton
Machine \$100,000 machine; 25% per year for depreciation, interest, repairs; 150 days/year, 6 hours/day, 12.8 raw tons/hour, 80% available	2.71	85.86
Energy 6.2 HPhr/ton, 12 HPhr/gal, 20¢/gal, 770,000 BTU/ton, 140,000 BTU/gal, 17¢/gal	1.04	32.86
Labor 5 men, \$3.00/hour, 12.8 tons/hour	1.17	37.09
Total	4.92	155.81

Source: Reference (5-8).

Silage Costs. Water hyacinths were processed in a harvesting-pressing system to prepare them for ensiling. The press removed 72 percent of the water, reducing product moisture content to 85 percent. Dry matter losses amounted to 14 percent. Consumption of raw hyacinth was 4.3 tons per hour, with production of 1.3 tons of ensilable pressed cake produced per hour.

Costs of producing silage under this system are shown in Table 5-11 and amount to $7.70 per raw ton or $148.23 per dried ton.

Summary. Estimated operating costs of all three experimental harvesting/processing systems for water hyacinths place the cost of the product at an unreasonably high level. This is partly due to the small experimental scale of operations. Conditions were those observed and not necessarily the best obtainable for the same equipment. Bagnall notes that there were some discrepancies in capacities of individual devices and in every case one device limited the performance of the entire system.

As previously noted, refinements in a hyacinth harvesting and processing system along with operation of the system under large-scale commercial conditions, could reduce costs considerably. However, there are no known data to verify this hypothesis. Bagnall suggests that an optimum size harvesting and processing operation would require approximately 1,000 acres of water hyacinths to provide the necessary material to achieve required economics of scale. The maximum city population in which water hyacinths might economically serve as a tertiary water treatment system is 100,000 people. If a lagoon area of 3 acres per 100 population is assumed, it would result in a maximum lagoon size of 300 acres. Therefore, the question arises as to whether investment and operating costs at even this size would justify a harvesting and processing operation. The answer presumably is "no"; however, a more thorough analysis is required before definite conclusions can be made.

Another area that requires additional study concerns the handling, packaging, and transportation costs of processed water hyacinths, i.e., from the processing discharge point to the ultimate consumer.

TABLE 5-11. ESTIMATED COST OF PRODUCING SILAGE

	$/Raw Ton	$/Dry Ton
Machine $40,000 machine; 25% per year for depreciation, interest, repairs; 150 days/year, 6 hours/day, 4.5 tons/hour, 80% available	3.09	61.73
Energy 7 HPhr/ton, 12 HPhr/gal, 20¢/gal	0.12	2.33
Labor 5 men, $3.00/hr, 4.3 tons/hour	3.49	69.77
Additives	1.00	14.40
Total	7.70	148.23

Source: Reference (5-8).

Summary and Conclusions

A summary of major points relating to use of water hyacinths is given below. This is followed by a Table 5-12 which compares the principal utilization possibilities in terms of their potential for affecting the relative attractiveness of hyacinth system.

Chemicals and Fuels

- The value of water hyacinths as a fuel or source of combined carbon does not exceed \$20 per dry ton.
- Other waste products, such as municipal solid refuse, wood wastes, manure, etc., are equally or more acceptable as raw materials for producing chemicals and fuels.

Fertilizer and Compost

- Water hyacinths contain a low percentage of the primary fertilizer nutrients--nitrogen, phosphate, and potash--relative to commercial fertilizer materials.
- Water hyacinths probably would not be suitable as a fertilizer material; their potential value is probably less than \$20 per ton on basis of nutrient content.
- Water hyacinths have a favorable carbon/nitrogen ratio for compost--about 23:1.
- The concentration of metals, e.g., aluminum, could be toxic to some plants.
- The high pH of water hyacinths may be beneficial on sandy, acidic soils.
- Whole hyacinths can be composted; however, chopping improves the plant's handling characteristics and increases biological activity necessary for composting.
- Composted hyacinths have sold for \$12 per cu yd, or about \$17-\$30 per ton, depending upon the bulk and density. Transportation costs are roughly estimated at \$1.70 per ton plus \$0.0675 per ton-mile.

- Water hyacinths may comprise up to 25 percent of a sand-compost mixture.
- The total compost market in the southernmost portion of the United States where the water hyacinths grow actively is roughly estimated currently at 200,000-300,000 tons per year, but could amount to many times this amount if composts are added to soils where large acreages of commercial crops are gorwn, such as sugarcane.

Feed

- No evidence of toxicity was found in samples of Florida water hyacinths fed to cattle and sheep.
- Even though toxicity was not evident, mineral imbalances could result from the high mineral nutrient content of water hyacinths; for example, the high iron content could be detrimental to livestock production efficiency. Extreme caution would need to be taken if plants were grown in waters containing excessive amounts of heavy metals.
- Water hyacinths have a high ash content relative to land forages; this needs to be investigated further, since the high ash content appears to reduce the animal's feed intake.
- Dried water hyacinths must be blended with molasses to be palatable as a livestock feed.
- The crude protein content of water hyacinths on a dry weight basis ranges from 12 to 18 percent. However, it is extremely difficult to extract the protein from the pressed residue.
- Many nutrients are contained in the juice pressed from water hyacinths. However, a commercially feasible method of drying the juice residue needs to be developed.

- The digestibility of diets containing water hyacinths is lower than diets containing conventional land forages.
- Dried hyacinth press residue would most likely technically compete with cottonseed hulls or bagasse pellets as a feed ingredient. These ingredients currently sell for $40 to $50 per ton.
- An acceptable silage can be made by combining water hyacinth with dried citrus pulp and molasses. However, some mineral impalances need to be corrected.
- The cattle feed market potential in the areas where water hyacinths grew vigorously is roughly estimated at 4.2 million tons. However, water hyacinths could be expected to achieve only some fraction of this total market potential.
- Harvesting and processing cost estimates range from $148 per dry ton for silage up to $393 per dry ton for a product produced from a mobile processing unit based on experimental results. Under optimum conditions, these costs could be significantly reduced. At this time, the costs of producing a livestock feed ingredient appear to be three to eight times greater than the estimated product value based on competitive prices.

TABLE 5-12. POTENTIAL IMPACT OF HYACINTH UTILIZATION

Use	Selling Price[a] ($)	Production Cost[a] ($)	Market Size Limit	% Reduction in Sewage Treatment Cost[b]
Methane	$13.15	NA[c]	None	6
Mulch	$30.00	20	Possible	10
Fertilizer	$18.16	20-80	None	6
Cattle Feed	$50.00	20-80	None	17
Silage	$40.00	150	None	13

(a) For the amount produced per dry ton of harvested hyacinths

(b) Based on $300/ton (1 mgd, hybrid design, south Florida) and assuming zero production cost.

(c) Not available

References for Chapter 5

5-1. Cooney, Charles L., and Wise, Donald L., "Thermophilic Anaerobic Digestion of Solid Waste for Fuel Gas Production", Biotechnology and Bioengineering, 17 (8), pp 1119-1135 (August 1975).

5-2. Wolverton, B.C., McDonald, R.C., and Gordon, J., "Bio-Conversion of Water Hyacinths into Methane Gas: Part I", NASA Technical Memorandum TM-X-72725, July 1975.

5-3. Nolan, W. J., and Kirmse, D. W., "The Papermaking Properties of Water Hyacinth", Hyacinth Control J. 12, pp 90-97 (1974).

5-4. Agricultural Prices, USDA Statistical Reporting Service (September 1974).

5-5. Parra, J. V., and Hortensteine, C. C., "Plant Nutritional Content of Some Florida Water Hyacinths and Response by Pearl Millet to Incorporation of Water Hyacinths in Three Soil Types", Hyacinth Control J. (May 1974).

5-6. Commercial Fertilizers - Consumption in the U.S., Year Ended June 30, 1974, USDA Statistical Reporting Service (May 1975).

5-7. Easley, J.F., and Shirley, R. F., "Nutrient Elements for Livestock in Aquatic Plants", Hyacinth Control Journal, 12; May 1974.

5-8. Bagnall, L. O., Shirley, R. L, and Hentges, J. R., "Processing, Chemical Composition, and Nutritive Value of Aquatic Weeds", Publication No. 25, Florida Water Resources Research Center; November 1973.

5-9. Baldwin, J. A., Hentges, J. R., and Bagnall, L. O., "Preservation and Cattle Acceptability of Water Hyacinth Silage", Hyacinth Control Journal; 12; May 1974.

5-10. Baldwin, J.A., Hentges, J. F., Bagnall, L. O., and Shirley, R. L., "Comparison of Pangolagrass in Water Hyacinth Silages as Diets for Sheep", Journal of Animal Science, 40, 5; 1975.

5-11. Allen, G. C., and Hodges, E. F., Livestock-Feed Relationships, National and State, Statistical Bulletin No. 530, Economic Research Service, U. S. Department of Agriculture; June 1974.

5-12. Bagnall, L. O., Hentges, J. R., and Shirley, R. L., "Aquatic Weed Utilization -- Harvesting and Processing", presentation to Weed Science Society of America, Atlanta, Georgia; February 1973.

REFERENCES
(Continued)

5-13. Bagnall, L. O., "Drying Characterisitcs of Aquatic Forages", presentation to American Society of Agricultural Engineers, undated.

5-14. Baird, C. D., and Bagnall, L. O., "Solar Crop Drying in the Sunshine State", paper number 75-3004 at meeting of American Society of Agricultural Engineers, University of California; June 1975.

5-15. Badenhop, M. B., and Trail, M. Dewayne, "Expenditure Patterns for Landscape Plants, Lawn Materials, and Related Supplies by Homeowners in Metropolitan Areas in Tennessee", Bulletin 524, University of Tennessee Agricultural Experiment Station (January 1974).

5-16. Chemical Engineering News, p 7, January 5, 1976.

CHAPTER 6

CHARACTERISTICS OF THE MARKET FOR WASTE TREATMENT FACILITIES

The final major task of this study was to examine the market and the marketing environment for hyacinth-based wastewater treatment facilities. This was done by (1) examination of various statistical sources and (2) interviewing a number of people concerned with waste treatment in the southeastern United States. The information was synthesised for presentation here. Also, a list is included of those interviewed, as is a copy of the questionnaire which was used to structure the interview process.

The Waste Treatment Facility Acquisition Process

Waste treatment plants are capital facilities acquired by for the purpose of complying with the water pollution discharge requirements of PL 92-500[6-1] and/or appropriate state laws regulating wastewater discharges. Treatment facilities are required to meet specific discharge standards by 1977, 1983, and 1985, as specified by PL 92-500. State water pollution control laws, in a few instances, exceed federal discharge standards, but most treatment facility design and acquisition considerations can be discussed within the context of PL 92-500 standards.

The heart of PL 92-500 is a permit system which seeks to regulate the discharge of every point source polluter in the country. The permit system utilizes a two-tiered standard for industry, and one interim and one long-term standard for muncipalities.

Municipal treatment facilities must be designed to meet "secondary treatment" standards by 1977, and these facilities must achieve most practicable waste treatment technology by 1983, which implies the use of advanced treatment for many facilities discharging into water quality limited streams.

The acquisition of municipal waste treatment facilities occurs over an extended time period and involves three or more levels of government approval. The general sequence of events involved in acquiring a municipal waste treatment facility is identified in Figure 6-1. The acquisition process

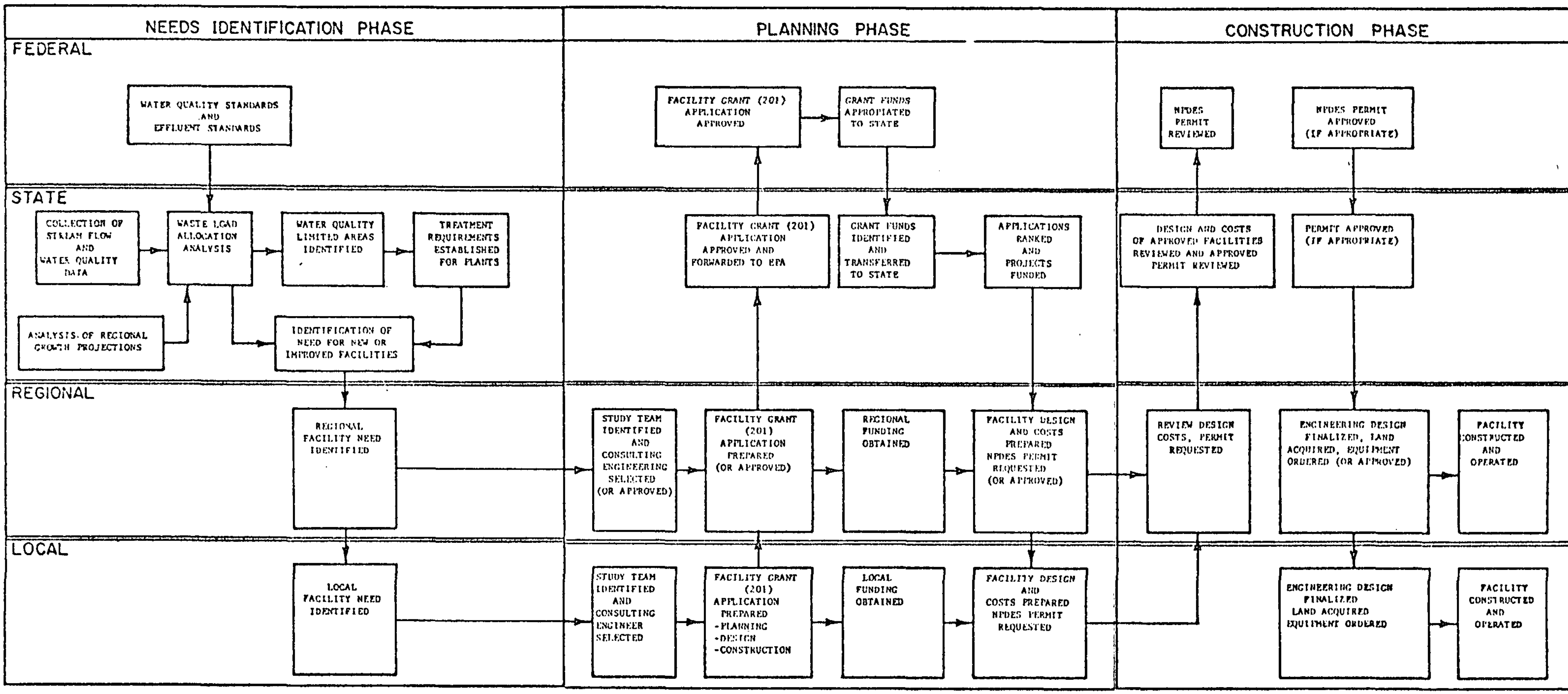

FIGURE 6-1. GENERALIZED MUNICIPAL WASTE TREATMENT FACILITY ACQUISITION PROCESS

is best understood when viewed as a four-level, three-phased process: federal, state, regional, and local levels; and needs identification, planning, and construction phases. The process, as diagramed in Figure 6-1, has been generalized to provide an overview of the actual acquisition process existing in six Southern states. The overview is based on interviews conducted in Texas, Louisiana, Mississippi, Alabama, Georgia, and Florida, the states most likely to utilize a vascular aquatic plant waste treatment system.

The governmental levels involved in the acquisition process reflect the need for federal specification of pollution control guidelines and standards and the existence of federal grants; the state regulation and enforcement of standards and guidelines; the regional coordination (or funding) of facilities; and the local funding and construction of facilities. The phases of acquisition are chronological. First, a need for waste treatment facilities must be identified, then facilities must be planned, including acquiring financing, and finally constructed. Within this rather abbreviated process overview lies many complex technical and administrative procedures. These procedures, described below, constitute the framework of the institutional setting within which a new waste treatment technology or process, such as vascular aquatic plants, will be evaluated, approved, and implemented.

The impetus for all water pollution control today rests with the federal government's implementation of PL 92-500. The establishment and enforcement of water quality standards, and effluent guidelines is the initiating action in the facility-acquisition process. All state, regional, and local activities, by governments or industries, are motivated by these standards.

In the six states examined in this study, the needs-identification phase of the acquisition process utilizes the federal EPA standards and guidelines as the principal basis for analyzing waste loads and water quality. Two states interviewed had standards more stringent than EPA effluent standards; but these were partial exceptions, and overall, the federal EPA standards prevailed as the baseline for initiating action in identifying facility needs.

The role of state government is very important in identifying facility needs. Every state interviewed provided a mechanism for identifying "needs". The mechanism was usually centered about one or two agencies and existed in varying degrees of formality and structure. The principal state agencies responsible for providing the "needs" identification are:

State	Agency
Texas	Texas Water Quality Board, Department of Health
Louisiana	Louisiana State Stream Control Commission, Bureau of Environmental Health
Mississippi	Mississippi Area Water Pollution Control Commission
Alabama	Alabama Water Improvement Commission
Georgia	Georgia Department of Natural Resources
Florida	Florida Department of Environmental Regulation.

The role of each of these agencies is to identify the water quality conditions of the states' waterbodies, and to determine the need for waste treatment plants located along these waterbodies. The identification procedure is usually accomplished through the collection and analysis of stream flow data, water quality data, and selected regional-growth data within the framework of a waste-load allocation model. The identification of a need for new or expanded treatment facilities is usually the responsibility of the state.

After a facility need is identified by the state, the responsibility for acquiring that needed facility is assigned to either a regional or local government agency.* Once the responsibility for acquiring a facility is assigned by the state, and accepted by a substate agency, then the planning phase of the acquisition process begins. The planning phase is the most intense phase of the acquisition process because it includes the identification, review, and approval of facility technical specifications, facility costs, sources of funding, and permit requirements. The primary responsibility for all these activities rests with a local (or regional) government agency.

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* The role of regional government agencies in the states examined in this study is weak, but implementation of Section 208--Areawide Waste Treatment Management--of PL 92-500 may strengthen the role of regional agencies in acquiring and managing waste treatment facilities. A move in this this direction has already started in Texas where the State Water Quality Board has issued a policy of recommending funding of regional treatment facilities over local facilities.

This agency usually retains the services of a consulting engineering firm to assist it in some, or all, of the following tasks:

- Preparing a grant application to EPA for a facility grant as authorized under Section 201 of PL 92-500. This section provides funds from EPA through a three-step procedure for planning, design and construction of waste treatment facilities. The grant is a 3:1-matching type requiring 25 percent funding by the local (and/or a state) agency.
- Preparing a set of technical specifications for a waste treatment facility which examines alternative technologies and seeks the most cost-effective design of a facility.
- Preparing the necessary documents for obtaining local funds through bond authorization or other means.
- Preparing a request for an NPDES permit from the state-authorizing agency or EPA if the state has not assumed authority for issuing permits.

The role of the state during the planning phase is essentially (1) to provide assistance, where needed, to local agencies; (2) review and approve 201 applications, facility designs, local funding arrangements, and NPDES permits; and (3) award Section 201 grants on a priority basis to local agencies. The actual procedures involved at the state level during the Planning Phase are extremely intricate and vary from state to state. This phase of the acquisition process is pivotal in the promotion and application of a new waste treatment technology, such as vascular aquatic plants, because it is during this phase that facility-design engineers and state pollution-control engineers must examine and accept the treatment techniques which will be incorporated in the final plant design.

The final phase of the facility-acquisition process is the construction phase. From a technology-applications viewpoint this phase of the acquisition process would be unimportant except that once construction is completed, data can be collected on the performance of new technology. With a relatively untested treatment process such as vascular aquatic plants, it is important to provide for extensive collection of operational data so that operational problems can be corrected as soon as possible, and design changes made where necessary.

The municipal waste treatment-acquisition process is complex and time-consuming as presently structured. The opportunity for introducing new technologies, such as vascular aquatic plants, must occur on three governmental levels: local, (or regional), state, and federal. But more *importantly, it must be introduced to the engineering profession* which provides the technical support for the government agencies responsible for acquiring waste treatment facilities.

The Waste Treatment Facility Marketing Environment

Recent interest within the National Aeronautics and Space Administration in "technology applications" raises questions about the issue of markets for specific technology applications. When does a technology application become developed enough to be considered a "product"? Who owns the technology-application "product"? Who sells the technology-application "product"? Who is a potential user of the technology-application "product"? How many of these potential users exist? What are their needs? Their purchasing power? Their buying habits? What other technology might affect the new technology-application "product"? What public policy actions or major economic trends could affect the use of the technology-application "product"?

These types of questions are not normally raised by government agencies; but they should be. In the seemingly endless search for new technology to support an agency's mission, many promising technologies are identified which have a potential for application in private industry or in other government agencies. One such technology is wastewater treatment using vascular aquatic plants. Although this technology is still in the development stage, now is the appropriate time to examine its potential application. An appraisal of the potential applications of this technology should help to identify the need for continued development, the potential returns to society as a result of its application, and the possible impacts of this technology on society.

To better understand the probable costs and benefits and the likely impacts of a technology on society, it is necessary to be able to describe with some precision the potential "product" resulting from the application of an emerging technology. Although it is impossible to completely specify a "product" based only on development technology, performance parameters of sufficient detail can usually be identified which help in defining a technology-application "product", and the potential market for the "product". The remainder of this section will focus on (1) the most likely "product" or application which appears to be emerging from vascular aquatic plant technology, and (2) the marketing environment in which this "product" must compete.

The Technology Application "Product"

The concept of using vascular aquatic plants for wastewater treatment involves several technology applications. The principal and controlling application is that of advanced wastewater treatment. This includes treatment of suspended solids, BOD, nitrogen, and phosphorus. Other potential applications involve the utilization of harvested plants as a feed-stock for energy and food production. The main by-products of the waste treatment process include:

- Protein supplements (cattle feed and chicken feed)
- Compost
- Fertilizer
- Synthetic gas
- Paper stock
- Other bio-mass conversion applications.

The view of waste treatment as the prime or controlling "product" is derived from the economics of processing vascular aquatic plants. Many types of water-based plants, including water hyacinths, exist today in nature, often in large quantities, but commercial uses of these plants do not exist. Under the waste treatment concept the vascular aquatic plant would increase in value because it would serve two purposes: (1) a media for removing certain pollution constituents from wastewater, and (2) a feed stock for energy or food products.

This analysis of the potential for applying vascular aquatic plant technology concentrates on the key issue of waste treatment because a significant need for improved wastewater treatment processes appears to exist. Furthermore, based on current technology, the economic feasibility of harvested aquatic plant by-products appears dependent upon the successful use of aquatic plants in the waste treatment process. Several potential aquatic plant by-product applications are discussed in Chapter 5. These applications represent a summary of the state-of-the-art based on a literature survey and are independent of plant use in the wastewater treatment process.

Identification of a specific waste treatment product using aquatic plants is difficult to define because the technology and regulation of waste treatment is constantly changing. The most likely waste treatment "product" to emerge from aquatic plant technology will probably be supplementary secondary treatment and/or tertiary (advanced) treatment in communities smaller than 50,000 in population. The constituents treated and the estimated cost of treatment are listed in Tables 4-10 and 4-12. The "product" use will be limited to small treatment plants (<5 MGD) located in suburban or rural communities located within 100 miles of the Gulf of Mexico. Initially, treatment facilities using aquatic plants will land-fill the harvested plants. Eventually, economic uses of the harvested plants are expected which will result in a cost savings, though these savings may not be large when compared with water treatment costs.

The Marketing Environment

The concept of a marketing environment is concerned with the "totality of forces and entities that surround and potentially affect the marketing of a particular product.[(6-2)] This definition is also useful in assessing the potential for applying an emerging technology. A technology-application "product" as defined above will emerge in the market one day. It is, therefore, necessary to understand the factors which are likely to affect the "product".

Three major levels of envoronmental activity affect a product: (1) the organization environment, (2) the market environment, and (3) the macro-environment.* These environments shape a product from within and from outside. The policies, missions, goals, and objectives of an organization determine how and if a product is to be marketed. The needs, size, and characteristics of the user market shape the demand for the product. Finally, larger scale influences such as public policy, economic trends, business cycles, technology developments, and institutional behavior shape the markets for a product. Each of these environments are discussed below as they affect an aquatic plant waste treatment facility.

The Organization Environment

This level of the marketing environment is the most difficult to comprehend and analyze because it involves the key policy issues of when and how does a government agency transfer public technology to the private sector or to other units of government. A discussion of these issues is obviously beyond the scope of this analysis, but the success or failure of a technology application will hinge upon the interpretation of these policy issues since every "product" needs an advocate or promoter.

The possible roles of a government agency in this environment vary greatly. Some agencies are assigned a very strong "applications" mission. They are funded to achieve a specified level of technology applications in a specific area. Probably the most important agency in the "applications" role is the Energy Research and Development Administration, and the former Atomic Energy Commission. The Atomic Energy Commission specifically was assigned the task of developing, regulating, and applying nuclear technology. In this capacity, it has influenced the marketing environment for energy probably more than any other institution.

The role which NASA eventually selects in applying and "marketing" the aquatic plant waste treatment technology will be shaped by many factors including:

(1) Its perceived mission as a technical agency.

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* Kotler[(6-2)] discusses these three environments plus a fourth which he terms, "extra-environment" or a "sero-relevance" environment.

(2) Its relationship with, and understanding of, environmental agencies and organizations.

(3) Its staff's capability to identify, analyze, and develop an environmental technology.

(4) Its staff's willingness and ability to develop a program for applying a new technology in a very diverse and segmented market.

(5) Its perceived threats from other agencies, organizations, and institutions.

(6) Its assessment of the opportunity presented by applying a specific technology to limited geographic areas.

These factors should be evaluated before an agency commitment to apply a new technology is made. If a decision is made to develop a technology-applications program, then the issue of program scope--the how, where, and when--of technology application can be evaluated in light of financial, legal, and political constraints.

The Market Environment

A crucial factor in assessing the return or benefits to society from applying a new technology is the estimate of potential demand for the technology application. Measuring the potential demand for aquatic plant waste treatment can be accomplished as follows:

- Define potential users of the technology
- Define purchase or acquisition process
- Define geographic areas where aquatic plant treatment can be applied
- Identify, for a given time period, the number and size of municipalities likely to use aquatic plant treatment technology.

The "product" user for an aquatic plant waste treatment facility are municipalities and industrial plants. Because of the diversity of waste-treatment requirements, a quantitative estimate of the industrial market cannot be made within the scope of this study. The major potential industrial users of aquatic plant technology, however, based on water pollution constituent parameters, are the paper and pulp industry, and the chemical industry. Both industries have extensive operations along the Gulf Coast, the primary geographic area for aquatic plant applications.

Potential municipal users of an aquatic plant treatment technology include all communities with a population of less than 50,000 which require advanced waste treatment or supplementary capability to secondary treatment facilities. The prime users of this technology are those small sewage systems (<5 MGD) which presently use a lagoon or stabilization pond. These types of treatment systems are the predominant sewage treatment system in the country today. A recent survey revealed that over 80 percent of the sewage systems (8182 of 9891) in the United States (Federal Regions 2, 3, 4, 5, and 9) in 1968 had a capacity of 1 MGD or less.[6-3]

The "product" acquired is a custom-engineered facility. The administrative mechanics of acquiring such a custom-engineered facility were described previously. (See Figure 6-1). The technical specifications of a waste treatment facility must be tailored to the particular needs of a specific sewage district, and are based on industry standards for various techniques, processes, equipment, and systems. These standards are identified in the professional literature and equipment catalogs of civil and sanitary engineers. Because engineering standards are the key to plant design the introduction of a new technology such as aquatic plant waste treatment should occur within the professional engineering literature.

Although treatment facilities are acquired by public agencies, the technical specifications for the facilities are almost always defined by private consulting engineers retained by municipalities. The role of consulting engineers is especially important in smaller municipalities which do not usually maintain technical staffs. Since over 80 percent of all sewage systems in the country are less than 1 MGD, it is apparent that the civil engineering-design community will significantly influence the successful application and implementation of aquatic plant waste treatment technology.

Vascular aquatic plants, such as water hyacinths, can grow only in tropical and semi-tropical climates. An initial survey of plant-growing areas indicated that the upper range for year-round growth of water hyacinths was at a latitude of about 100 miles north of the Gulf of Mexico.[6-4]

Subsequent data were identified which modified this observation by differentiating between "active growth" and "maintenance activity". Active growth of hyacinths was determined to occur year-round only in southern Florida. The remainder of the hyacinth-growth area experienced active growth only in the warm months. During the colder months the hyacinths were characterized by maintenance activity. A year-round application of a totally hyacinth-based waste treatment system is thus limited to South Florida. The remaining area cannot utilize year-round waste treatment facilities based only on hyacinths. The analysis of a potential market for an aquatic plant waste treatment facility has been modified to reflect this temperature constraint.

An estimate of the potential size of the market for aquatic plant waste treatment is based on the number of communities with a population of 50,000 or less located within 100 miles of the Gulf of Mexico. The market is further modified to reflect the year-round market in South Florida (Table 6-1)

TABLE 6-1. POTENTIAL MARKET FOR AQUATIC PLANT WASTE TREATMENT FACILITIES[(a)]

State	Number of Communities Under 50,000	Population of Communities
Texas	210	3,396,979
Louisiana	61	898,564
Mississippi	26	377,248
Alabama	32	345,870
Georgia	25	222,236
Florida	289	3,270,213
Total	643	8,511,110
South Florida	167	1,890,000

(a) Based on counties located within approximately 100 miles from the Gulf Coast.

Source: U.S. Census of Population, 1970, and Battelle Columbus Laboratories.

The population identified above is served by approximately 700 separate sewage systems in the 1 MGD to 5 MDG range based on the national distribution of treatment facility sizes. If all these systems are to meet 1977 EPA standards for secondary treatment and 1983 standards for advanced treatment, then additional expenditures will be required over the next 2 to 8 years to upgrade these facilities. In addition to upgrading existing facilities, new facilities will be required to serve the expected population expansion in the market area in communities of less than 50,000 population. Projections of population growth in the potential market area are listed in Table 6-2.

TABLE 6-2. POPULATION PROJECTIONS IN THE POTENTIAL MARKET AREA FOR AQUATIC PLANT TREATMENT FACILITIES

	1980	1990	2000
Total Area	9,908,754	11,485,286	12,706,898
South Florida	2,610,000	3,285,000	3,915,000

Source: OBERS Projections of BEA Economic Areas, Series E Population, 1972 U.S. Water Resources Council, Washington, D. C., and Battelle Columbus Laboratories.

This projected growth rate will require the construction of additional facilities in the potential market area. (See Table 6-3).

TABLE 6-3. ESTIMATED NEW MUNICIPAL TREATMENT FACILITIES REQUIRED BY POPULATION GROWTH

Facility Size[a]	1980	1990	2000	Total
1 MGD	97	111	86	294
5 MGD	8	10	7	25

(a) Based on a shift to 70-30 mix from the 80-20 mix of 1 MGD to 5 MGD.

Source: Battelle Columbus Laboratories.

The costs of upgrading existing treatment facilities and construction of new treatment facilities are enormous. Investment operational costs data for aquatic plant treatment facilities are developed in Chapter 3 and 4, and it was shown that hyacinth systems have a potential cost advantage of the order of 2:1. However, an estimate of the potential cost for new facilities based on 1975 cost estimates* for traditional technology plants were applied to the projected facilities. These values are listed below (Table 6-4).

TABLE 6-4. ESTIMATED INVESTMENT REQUIRED FOR NEW TREATMENT FACILITIES

($ Millions)

Facility Size/Year	19 1980	1990	2000	Total
1 MGD	77.6 - 116.4	88.8 - 133.2	68.8 - 103.2	235.2 - 352.8
5 MGD	32 - 48	40 - 60	28 - 42	100 - 150
Total	109.6 - 164.4	128.8 - 193.2	96.8 - 145.2	335.2 - 502.8

Source: Battelle Columbus Laboratories

Thus the potential market for waste treatment facilities in the Gulf Coast market area is approximately $500 millions. If the use of water hyacinths can effect a cost savings of only 10 percent over conventional treatment systems, then a savings of $50 million in facility investments can be realized.

The potential investment required for upgrading existing facilities to handle advanced treatment would be even greater than that required for new

* Battelle Columbus Laboratories interviews with government officials and engineering consulting firms indicated that new primary and secondary treatment plants cost between $.80 to $1.20 per gallon/person/day or approximately $1 million for a 1 MGD plant. Upgrading costs ranged between $.40 to $1.00 per gallon/person/day depending upon the level of existing treatment.

facilities. Based on upgrading costs of \$.40 to \$1.00/gallon/person/day of treated effluent, the costs of upgrading existing treatment facilities would range between \$340 and \$851 million. Thus the total costs for upgrading existing treatment facilities and building new facilities in the potential market area could approach \$1.3 billion (measured in 1975 dollars). Because South Florida is now the only portion of this potential market which can utilize the present state-of-the-art of aquatic plant technology, only about \$330 million in upgraded and new facilities are candidates for applying aquatic plant technology. This is a substantial market in terms of population served and dollar investment, but it represents only about 25 percent of the potential market if a "winter crop" is developed to replace hyacinths in the area outside of South Florida.

In addition to assessing the size and value of the potential market, an assessment of the market environment should consider several additional factors. Among these are institutional, legal, and safety factors. Each of these are described briefly as they influence the application of aquatic plant waste treatment technology.

The most pervasive of all nonquantifiable factors affecting any market in the seventies is the institutional factor. The institutional factor encompasses the many official and unofficial, formal, and informal organizations which can influence, either actively or passively, the potential market for aquatic plant waste treatment. The most common type of institutional concern involves the activities of government agencies directly involved with approving and regulating the use of a product or technology. This is a serious concern for aquatic plant technology, but it is not the only institutional factor. The major institutions and their possible influences on the successful application of aquatic plant technology are discussed below.

NASA	The prime interest of NASA, to date, is the development of aquatic plant waste treatment technology. NASA could influence the development and application of aquatic plant technology by taking on the institutional role of promoter or marketing agency. Since aquatic plants are available in nature, there is no incentive for a private firm to "manufacture" hyacinths and realize a profit from the sale of waste treatment hyacinths. Thus the traditional marketing incentive for applying a new technology is absent in this case, and the lowly hyacinth may be without an advocate unless NASA accepts that role.

EPA

The principle mission of this agency which influences the proposed technology is establishment of water quality standards and effluent guidelines for waste water discharge within the constraints of PL 92-500. EPA also sponsors research in advanced wastewater treatment. It may, therefore, view the NASA development technology as a competitor to other technologies currently being investigated under EPA sponsorship. On balance, however, if the aquatic plant technology meets effluent guidelines and is operationally reliable, EPA will probably endorse the NASA-sponsored technology.

EPA has another important function, facility grant authority under Sections 201 and 202 of PL 92-500. This function, as presently structured, discourages the development of aquatic plant treatment facilities because the formula for federal grants excludes land as a facility cost. Since EPA can award a grant equivalent to 75 percent of the facility cost, exclusive of land, it may be more cost-effective from a community's viewpoint to minimize the land requirements for a treatment plant. The specific advantage or disadvantage depends upon the relative cost of land in a community. One final function of EPA which affects plant design is the enforcement of violations under PL 92-500. A maximum fine of $25,000 can be assessed for negligently discharging effluents. If poor design is considered negligence, then designers will tend to be conservative and use only traditional treatment processes.

U.S. Army Corps of Engineers

As the principal agency assigned the responsibility of maintaining the Nation's navigable waterways, the Corps for many years has funded research to eradicate noxious weeds such as water hyacinths. Substantial hyacinth-eradication programs exists at the Corps of Engineers District level throughout the Gulf Coast region. The Corps would be pleased to cooperate in any useful technical application involving water hyacinths, especially if some marketable product is identified for harvested hyacinths.

State and Local State Pollution Control Agencies	These agencies vary in responsibility on a state-by-state basis, but essentially, they are assigned the state responsibility for implementing PL 92-500. The typical tasks assigned these agencies includes (1) waste-load analysis of receiving waterbodies; (2) river-basin planning, Section 303(e), PL 92-500; (3) issuing state wastewater discharge permits or NPDES permits if applicable; and (4) reviewing and approving Municipal and industrial waste treatment facility plans. This agency usually influences a state's policy and regulatory position regarding pollution discharges into waterbodies. In industrial development-oriented states, these agencies are usually under considerable pressure to be lenient in interpreting industrial effluent discharge standards. These agencies are also caught up in the present debate over the necessity for imposing advanced waste treatment standards on every small municipality. This issue is important because sufficient political support may develop which would force Congress to rewrite portions of PL 92-500 to modify advanced treatment in small communities. If this action should occur, then the projected need for a treatment process such as aquatic plants offer may cease to exist.
Departments of Health	Both at the state and local level (if appropriate), these agencies are involved in evaluating the public health aspects of any waste treatment technology. In the case of lagoon systems utilizing water hyacinths, a potential mosquito problem might develop. In view of 1975's encephalitis epidemic, support may be growing to eliminate lagoons in the South.
Water Districts, Municipal Engineering Departments, Public Works Departments, or Planning Agencies	These agencies are usually assigned all or part of the responsibility for planning and constructing new waste treatment facilities. They vary widely in size and technical competence. Most of these agencies rely on private consulting engineering firms, to design waste treatment facilities. Recent changes have occurred in some states which discourages the construction of small local facilities in favor of larger regional facilities. As this trend grows, local agencies might oppose abdicating their traditional authority to a "regional council", but they will probably not reverse the trend. The impact of this move toward regionalization could adversely affect the market environment for aquatic plant treatment because larger aquatic plant treat-

ment facilities are not likely to be competitive with other less land-intensive technologies.

The Water Hyacinth Control Society

This professional association is an international organization dedicated to research and investigation of means to eradicate water hyacinths. The Society is also concerned about other noxious aquatic weeds and plants. Members of the Society, including the past president, have been interviewed regarding the proposed aquatic plant treatment technology. The general attitude of these members was receptive. They are eager to review research, development, and engineering studies when available, and will probably evaluate such studies in their professional journal. Their major concern is with uncontrolled growth of hyacinths.

The Professional Engineering Community

Grouped within the institutional organization are many professional associations, private consulting firms, research institutes, and university facilities. The most important subelement of this "institution" is the private civil engineering firm because it is the private consulting firm which is responsible for selecting waste treatment technologies and designing treatment plants.

The Waste Treatment Equipment Industry

An assortment of equipment manufacturers has a strong interest in promoting the mechanical and chemical treatment of waste. They no doubt will point out every deficiency of an aquatic plant treatment system, especially when that deficiency makes their equipment appear more attractive. This industry is behaving in a natural way under the private-enterprise system. The industry must seek to protect its investment and attract new sales. The proposed aquatic plant system could pose a severe threat to certain manufacturers in the industry. These firms will likely try to influence design-engineering firms to continue in the direction of mechanical-physical and chemical treatment. They have a strong advantage in that they have long-term and strong relations with the engineering community. If a marketing campaign were mounted to promote aquatic plants, the most difficult anti-plant influence to overcome would probably be that of threatened equipment manufacturers.

The Environmental Movemnet	This "institutional" organization represents the various national, regional, and local environmental preservation groups which have grown in influence and size over the past several years. The influence which this institution exerts on the aquatic plant technology is likely to be positive since the aquatic plant technology does not introduce chemicals into the treatment process, but rather allows nature to treat wastewater in a biological-cycle process.

The only legal issue which was identified as having a potential influence on the application of aquatic plant technology was PL 874, the Grass and Plants Interstate Shipment Act, Ammendment to Chapter 3, Title 18, USC. This law prohibits the interstate transport or sale of water hyacinths, alligator grass, water chestnuts, and the seeds of such grass or plants. The penalty for violation of the act is $500. The Act apparently is not enforced strictly at this time. If aquatic plant technology were developed to an operational level, it would be necessary to amend this Act so that treatment plant owners could legally acquire plants when needed.

Safety may be a factor in operating an aquatic plant treatment facility. One safety issue likely to emerge would be a safety evaluation of the harvesting procedure to assure compliance with OSHA standards. This safety issue will not likely be a serious factor affecting the viability of the treatment process. Another safety issue which may prove more detrimental is the public health concern about pest control, especially of mosquitos. As previously mentioned, 1975's encephalitis epidemic has frightened many local and state health departments. Stricter standards affecting mosquito control are anticipated as a result of the 1975 experience. It remains to be seen whether such control would affect the cost and/or operation of aquatic plant lagoons.

The Macro-Environment

Several major factors compose the macro-envrionment influence on a product. The major factors are the economy, technology, and public policy. These will be reviewed briefly.

The economy's influence on the need for advanced waste treatment systems using aquatic plant technology is primarily one of capital investment capacity. The capital crisis is now emerging as a successor to the energy crisis in the United States. The rate of capital formation has declined and with it the reserve of capital needed for expanded and improved facilities--both private and public. In addition to an overall capital shortage, the apparant bankruptcy of New York City has had a negative influence on voter's attitudes toward more government spending at both the local and federal level. New bond issues are being rejected across the nation. These trends have reduced many local government's abilities to raise matching funds needed to obtain EPA construction grants for new and improved treatment facilities. This trend is continuing and could affect a significant portion of the potential water hyacinth market identified above.

Technology is always changing and influencing our lives. The waste treatment industry, however, has not been noted for rapid and dramatic technical innovation. Many of the standard treatment technologies have been around for over 50 years. The recent flurry of activity in the area of advanced waste treatment may result in some technological breakthroughs, but nothing dramatic is expected at this time which would significantly affect the technology required by the 1977 and 1983 guidelines of PL 92-500. The aquatic plant process is not very radical and has been used for many years in some experimental treatment plants. The continued development of aquatic plant technology appears to be one of the more promising of several advanced waste treatment technologies.

Public policy may have a greater effect on the continued development of aquatic plant technology than any other factor. Much unrest exists within the water quality and waste treatment industry. Many smaller communities are opposed to the anticipated stringent 1983 guidelines for municipal treatment plants. Many smaller communities feel they will be burdened with unusually large and unnecessary capital investments. If these sentiments prevail and work their way through the political system, it is highly probable that Congress may rewrite portions of PL 92-500. Another policy factor likely to hasten a rewrite of PL 92-500 is the delay experienced in drafting industry-effluent guidelines, and the delays EPA has experienced in funding new and improved municipal waste treatment facilities. Everyone close to the waste treatment program now believes that the 1977 secondary treatment standards for municipalities will be extended several years by Congress because physically and administratively, the country has been unable to meet the five schedules imposed by Congress.

The mood of Congress and the electorate, and the condition of the economy at the time PL 92-500 is amended, will strongly influence the future role of wastewater treatment. This amending action will probably occur in 1976. At that time a better assessment of the role of advanced waste treatment can be made.

The Industrial Treatment Facility Acquisition Process

The acqusition process for design, construction, and financing of industrial waste treatment facilities is similar to the acqusition of other components of industrial plants. The wastewater created by a plant's manufacturing or processing activities is analyzed to determine the type and degree of treatment required. A waste treatment facility must be capable of treating several different pollutants, and usually incorporates many alternative treatment techniques, each with a distinctive cost-effectiveness characteristic. The treatment facility is usually designed as a constrained optimization process. The acquisition of a biological system of vascular aquatic plants will occur in industry only if vascular aquatic plants are considered technically and economically feasible during the design trade-off stage.

The acquisition of waste treatment facilities by industry falls into two categories: (1) retrofit of existing industrial plants in order to obtain an NPDES permit, and (2) design of treatment facilities as an integral part of new industrial plants. The selection of waste treatment systems, in either situation, rests with a firm's engineering staff, or a consulting engineering firm retained by the plant owner to design treatment facilities. The cost of the water treatment facility is usually borne by the polluter; however, some states have offered assistance in financing pollution control systems.

An attractive alternative to obtaining an NPDES permit for discharging industrial pollution into a receiving water body is being encouraged by EPA under Section 208 of PL 92-500--Areawide Waste Treatment Management Planning. Under Section 208, industry is encouraged to pretreat its wastewater to certain standards then deliver it to areawide waste treatment facilities where, for a fee, the municipal treatment facility will process the industrial waste. The advantage of this approach is the savings in the capital investment otherwise required for a private treatment facility.

The predominant requirement of industrial treatment systems is the removal of total solids, BOD, and heavy metals. An illustration of the magnitude of the industrial waste pollution is seen from the figures appearing in Table 6-5, which appeared in the Fourth Annual Report on Environmental Quality. This table is based on industries located in the southeast United States, the prime area likely to utilize vascular aquatic plant treatments. From the statistics, it is clear that BOD and heavy metals are the major industrial pollutants. BOD pollution is a problem which requires massive treatment facilities at certain large plants, as seen from the statistics in Table 6-6. The use of water hyacinth or other vascular aquatic plants for pollution control offers only limited opportunities for treating the waste of large industrial plants.

Interviews with industry officials in the chemical, and paper and pulp industries in four Southern states indicated that industry is receptive to the concept of a vascular aquatic plant system for waste treatment; but many reservations exist about the ability of an aquatic plant system to cost effectively handle the high pollution concentrations and flow rates of many larger industrial plants. Eventual acceptance of aquatic plant treatment of industry's wastewater will depend upon the results of a significant research and engineering development program addressing specific industry pollution problems.

TABLE 6-5. INDUSTRIAL EFFLUENTS, EPA REGION IV
(In pounds per day)

SIC code[1]	BOD[2]	Total Phosphorous[3]	Nitrate[4]	Total Heavy Metals[5]	Total Solids
20-Food and kindred products	226,118	4,593	2,722	6,802	1,877,297
22-Textile and mill products	293,159	39,504	23,347	21,828	3,000,175
26-Paper and allied products	2,835,019	18,677	21,202	25,673	48,776,871
28-Chemical and allied products	933,316	74,063	70,961	145,934	83,795,063
32-Stone, clay, and glass	15,077	684	1,238	10,482	2,715,498
33-Primary metal industries	65,524	2,115	5,241	12,496	2,268,854
347-Coating, engraving, & allied services	3,335	1,395	788	3,830	477
35-Machinery	771	1,236	1,032	1,766	26,663
37-Transportation equipment	3,951	3,015	668	206	70,707
Total for these SIC codes[6]	4,210,567	143,494	121,243	221,384	131,020,201
Total for all permit applications in Region IV	4,777,222	1,013,680	208,951	821,292	1,234,551,055

1 Standard Industrial Classification Code, as defined by the Department of Commerce.
2 Biochemical oxygen demand.
3 As P
4 As NO_3
5 Includes antimony, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, silver, thallium, tin, and zinc.
6 Totals are less than sum of the columns because of elimination of double-counting.

Source: Environmental Protection Agency

TABLE 6-6. QUANTITY OF BOD DISCHARGE

BOD Discharge (Pounds per day)	Number of Facilities
0-500	1,574
500-1000	111
1000-10,000	174
10,000-25,000	45
25,000-50,000	21
50,000-100,000	5
100,000-250,000	8
250,000-500,000	1
500,000 and over	1

The acquisition of waste treatment facilities by industry has been a rather straightforward process, but it is becoming more complicated, according to industry officials interviewed in the Southeast. The plant owner's engineering staff, or a consulting engineering firm retained to design waste treatment facilities, has been responsible for analyzing the plant's wastewater discharge, then specifying the type of treatment needed to meet EPA effluent guidelines for a particular industrial process. The recommended treatment design was then submitted for state and/or EPA review in order to obtain an NPDES permit. Unless the proposed discharge was into a water quality limited stream, permits have usually been granted for facilities meeting industry effluent guidelines.

As the 1977 and 1983 deadlines outlined in PL 92-500 approach, the granting of industrial waste treatment permits will become much more complex. The identification of the "best practicable control technology currently available" for 1977, and the "best available technology economically achievable" which will result in "reasonable further progress" by 1983, will be difficult tasks. The EPA will most likely issue guidelines identifying these technologies only after consultation with industry, the engineering profession, representatives of environmental-oriented organizations, and other appropriate groups.

The identification of technology guidelines for 1977 and 1983 will be a very difficult task and probably a very complex administrative problem; but it is the key event which will determine whether or not a biological process for waste treatment using vascular aquatic plants will be acceptable by EPA for specific industry applications. These guidelines will be influenced strongly by the professional advice of pollution control specialists in government, industry, consulting firms, and public-interest groups. The initial criteria for screening potential technologies will be technical and operational feasibility and reliability. Cost advantages will not influence the decision on these guidelines until adequate engineering data are provided to justify the use of a new technology. Such data do not now exist for the vascular aquatic plant process.

The Industrial Treatment Facility Market Environment

Treatment Requirements

The EPA has established effluent guidelines for various categories of industrial pollution. Under PL 92-500, only 27 industrial pollution categories were listed as requiring effluent guidelines; however, by 1974 the EPA had identified approximately 180 industrial subcategories, and 45 additional variances as requiring distinct effluent standards based on careful analysis of control technology for each. In addition to these standards in 1973, EPA also published a list of 12 toxic pollutants and established effluent limitations for them. Industrial treatment processes must meet all published EPA standards, as well as yet-to-be-published standards, as required to meet the 1977 and 1983 goals of PL 92-500.

Industrial Applicability of Hyacinths

The applicability of a water hyacinth system for industrial waste treatment is limited spatially/temporally, and also by numerous other limiting factors which compositely define the ecological niche of the water hyacinth. As addressed earlier in this report, for optimum growth, the spatial/temporal limits of the hyacinth niche seem dominantly controlled by the insolation/temperature constraints of the subtropical earth biome. Within the United States applicable areas include much of the near Gulf coastal plains. Optimum U. S. growth conditions were forecasted as naturally present in southern Florida. In this area continued growth is probably throughout most of the year at a harvestable rate ranging from near 15 to more than 30 dry tons per acre-year. Even in this region, however, the direct application of a water hyacinth system to certain industrial waste streams can be expected to be restricted by constituents present at toxic concentrations or present at concentrations deficient for hyacinth growth. As an example, water hyacinth cannot tolerate 11,000-mg/l chloride solutions. A proper balance of nutrients in a subject waste stream is also needed for optimum growth/assimilation conditions.

In southern Florida major industrial pursuits include phosphate rock production, citrus and vegetable canneries, breweries, meat packing, dairy products and pulp and paper production. Plating wastes from various electrical and other fabrication processes employing a coating step during manufacture may also be candidates for the application of an industrial water hyacinth treatment system.[6-5,6-6] Aqueous wastes containing phenols or other biocides could also be of concern in this area.

Phosphate Production Wastes. A review of the mineral mining and processing section of the recent National Commission on Water Quality Report[6-7] indicates that phosphorus development waste problems are unimportant. The study attention, however, was limited to turbidity, dissolved oxygen/biochemical oxygen demand, alkalinity, and escapes of toxic flotation chemicals. Except during short storm conditions the latter three are irrelevant. The first parameter, turbidity, also relates predominantly to temporal suspended solid losses from the waste slimes and sand retention impoundments. Although the Commission report underestimates turbidity/suspended solids effects, associated impacts on the Peace and Alafia rivers are well known.[6-8] Even based on the data within the Commission report, suspended solids losses can result in concentrations exceeding 6000 mg/l. Under quiescent conditions the solids transported should quickly settle and dominate the character of receiving aquatic system sediments. Burial and exclusion of benthic habits in affected areas would seem most probable. Perhaps of more importance, however, is the continuous high dissolved solids seepage from the proliferating waste impoundments. In fact more than 400 square miles of groundwater in the Florida mining area are estimated to exceed drinking water standards for radium-226 (<3.0 pci/liter).[6-8]

The use of a water hyacinth treatment system for control of pollutants from the phosphate rock development industry should be explored. Suspended Solids (SS) can be controlled to varying degrees. As RA-226 is known to be highly associated via adsorption on other transportable constituents[(6-9)], control of SS could also reduce this problem. The filtration and/or uptake of RA-226 and/or host constituents requires further study.[(6-10)] Thus, the determination of the applicability of a hyacinth treatment system to the phosphate development waste emissions must logically await conduct of further study.

Food Processing Wastes. The application of a water hyacinth treatment system for reduction of cannery, brewery, meat packing and dairy waste water loads also has merit in this region. Untreated aqueous wastes from these industrial operations are high in Biochemical Oxygen Demand (BOD) and SS. As an example, cannery waste strengths can range from 1000 to 6000 m/l and 200 to 2000 mg/l for BOD and SS, respectively; with the wastes from vegetables processing being the stronger.[(6-11)] Although food processing wastes are not unlike municipal waste characteristics, the direct application of hyacinth treatment to these waste systems would not be without difficulty.

The use of a hyacinth system is similar in approach to land application. In many areas of the U.S. land application of food product waste waters has been practiced with exceptional success. As is the case for land application and also for the more conventional biological waste treatment processes, the direct application of a hyacinth treatment system to these wastes would require supplemental additions of nitrogen and/or phosphorus. The extremely high BOD loading may also result in near total anaerobic lagoon conditions which could prove fatal to water hyacinths (surface water D.O. must be >2.0 mg/l). A minimum measure would require addition of sodium nitrate for control of the resulting odor problems and provide needed nitrogen.

Most food processing operations pretreat wastewaters and discharge to municipal sewerage systems. Due to this inclusion with other municipal wastes the previously developed conventional and hyacinth treatment cost comparisons remain basically applicable. Perhaps a more appropriate BOD and SS hyacinth treatment based design would indicate a smaller area requirement than the ~1.0 ac/mgd N based design. However, BOD and SS reductions in municipal sewage throughputs with high percentages of food processing wastes would also be subject to numerous design/operation variables. Further field investigations would be required to allow a realistic definition of the removal efficiency and associated costs of hyacinth treatment system.

Plating Wastes. Plating wastes should only be a minor problem in southern Florida.[6-5] Plating wastewaters contain acids, alkaline cleaners, grease/oil cyanides and heavy metals (Cr, Zn, Cu, Ni, Sr, etc.). NASA/NSTL Bay St. Louis researchers have conducted laboratory water hyacinth removal studies with Cd, Ni, Pb, Hg, Ag, Co, and Sr.[6-12] These studies are preliminary in nature yet indicate that hyacinth have a high tolerance for heavy metals. Several of the NASA technical memorandum reports contain estimations suggesting hyacinth acreage requirements for selected heavy metal "removals". Preliminary field test data from the NSTL zig-zag chemical waste hyacinth treatment lagoon generally support the laboratory finding for silver "removal". These field studies also demonstrate excellent control of chromium and cyanides. Much of this work has been reported earlier in this report (see Chapter 2, Review of Hyacinth Characteristics).

Without further study concerning heavy metal cycling within the hyacinth/lagoon/sediment system leading to appropriate design/operation criteria, no basis for realistic projections of the applicability and thus the marketability of a water hyacinth treatment system for heavy metal control should be forecast. It seems most probable, however, that physical/chemical tertiary treatment processes for control of undesirable metal concentrations at their source would be shown to be superior to a hyacinth system due both to reasons of high effluent quality dependability yearly and costs.

Biocide Wastes. NASA/NSTL has conducted laboratory investigations concerning phenol uptake by water hyacinths.[6-13] Other aquatic plants have also been studied in regard to assimilation of mevinphos (an insecticide).[6-14] Promise is indicated by these basic investigations. However, again insufficient information has yet been developed to forecast the marketability of a water hyacinth system for control of these industrial/agricultural toxic compounds.

Size of the Industrial Market

As was the case for municipal systems, the market estimate depends on two factors: (1) the total amount to be spent on upgraded wastewater treatment of all types, and (2) the fraction of this expenditure in which water hyacinth systems would prove to be more attractive than the alternatives.

In this study it was not possible to address the second question to any useful depth. Industrial wastewater treatment problems are very different from one industry to another, and differ substantially from one plant to another within a given industry. Accordingly, it is very difficult to reach general conclusions about market penetration.

The overall industry expenditures on wastewater treatment can, however, be estimated from available sources. The capital cost to Florida industry for achieving 1983 water quality standards is estimated to be $1,556 million (1975 dollars). For south Florida, the cost is estimated to be $785 million (1975 dollars). The derivation of those estimates is outlined below.

The capital requirement for achieving 1983 standards was determined by an industry group from the 1973 National Commission on Water Quality staff draft report. The requirement included (1) expenditures to achieve 1977 standards in existing plants, (2) incremental requirements to achieve 1983 standards, and (3) capital required for new industrial treatment plants which will meet New Source Pollution Standards (NSPS), to replace those closed as uneconomical to upgrade. These data are presented in Table 6-7. The industries were then grouped and classified into standard industrial codes which matched the industry group. Table 6-7 presents the total 1975 dollar expenditures in the total U.S. by the standard SIC codes.

The employment in Florida within each of the given industries was then ratioed with respect to the employment in the total U.S. These ratios are shown in Table 6-8. The ratios were then applied to the total U.S. capital costs for meeting 1983 standards, to estimated by industry the capital cost for achieving 1983 standards in Florida.

TABLE 6-7. CAPITAL COSTS TO U.S. INDUSTRY TO ACHIEVE WATER QUALITY STANDARDS
($ BILLION [1975])

Industry	Existing Plants to 1977 Standard[(a)]	Existing Plants to 1983 Standard[(b)]	New Plants[(b)]	Total	SIC Code[(c)]	Total
Iron and Steel	2.08	0.55	0.65	3.28	33	3.28
Organic Chemicals	4.29	3.64	2.25	10.18		
Inorganic Chemicals	0.81	0.26	0.35	1.42	28	12.19
Plastics and Synthetics	0.21	0.29	0.09	0.59		
Petroleum Refining	0.83	1.18	0.29	2.30	29	2.30
Pulp and Paper	2.33	0.76	0.73	3.82	26	3.82
Metal Finishing	9.13	8.25	3.97	21.35	34	21.35
Fruits and Vegetables	0.16	0.11	0.05	0.32	20	1.67
Feed Lots	0.90	0.22	0.23	1.35		
Textiles	0.54	0.30	0.28	1.12	22	1.12
Steam Electric Power	4.09	1.28	0.99	6.36	49	6.36
All Other Manufacturing	11.28	6.17	10.11	27.56	All other	27.56
Total Manufacturing	36.65	23.01	19.99	79.65		79.65

(a) National Commission on Water Quality staff draft report, November 1975, page I-19, "Capital Expenditures for 1977".
(b) Ibid, page I-35, "Added Expenditures for 1983 Requirements".
(c) OMB Standard Industrial Classification Manual, 1972, Executive Office of the President, Office of Management and Budget.

TABLE 6-8. CAPITAL COSTS TO FLORIDA TO ACHIEVE 1983 STANDARDS

SIC Code	1973 Employment Total U.S.[a] (Thousands)	1973 Employment Florida[b] (Thousands)	Ratio Florida/ U.S.	U.S. Capital Costs ($ Millions)	Florida Capital Costs ($ Thousands)
33	1,315	4.7	0.0036	3,280	11,808
28	1,030	20.8	0.0202	12,190	246,238
29	187	0	0	2,300	0
26	718	17.2	0.0240	3,820	91,680
34	1,453	27.9	0.0192	21,350	409,920
20	1,736	48.0	0.0276	1,670	46,092
22	1,024	0	0	1,120	0
49	740	23.4	0.0316	6,360	200,976
All Other Manufacturing	11,617	232.0	0.0200	27,560	551,200
Total Manufacturing	19,820	374.0		79,650	1,557,914
TOTAL					(1.96%)

(a) Statistical Abstract of the United States 1974, U.S. Department of Commerce, Social and Economics Statistics Administration, Table 556, pages 347-349, "Non-Agricultural Industries - Number of Employees 1960 thru 1973".

(b) Employment and Earnings, States and Areas 1939-1974, U.S. Department of Labor, Bureau of Labor Statistics, 1975, "Florida Statewide Data By Industry", pages 155-162.

The industrial employment within the southern portion of Florida was ratioed against total Florida employment for each industry. This ratio was then applied to the total Florida capital expenditures to derive by industry the capital requirements for the southern Florida area only. The data are presented in Table 6-9.

It can be seen, then, that the total capital expenditures by industry in the southern Florida region is about twice that for municipal systems. However, it is estimated, based on present knowledge, that market penetration in the industrial applications will be substantially less than in muncipal applications. This conclusion is, however, highly tentative, and based only on a general review of the more significant industrial treatment problems.

Conclusions and Recommendations

The major conclusions which can be drawn from this review are:

- The waste treatment industry is composed of thousands of individual industrial plants and municipal sewage districts throughout the United States.
- Over 80 percent of the sewage districts in the United States are extremely small having a capacity of 1 MGD or less. This size facility capacity is capable of serving only 10,000 municipal residents.
- The acquisition of new waste treatment facilities and the upgrading of existing facilities is accomplished at the local sewage district level.
- Government funding approval and regulation of waste treatment facilities is controlled at the federal level by the EPA, at the state level by Pollution Control or Water Improvement agencies, and at the local level by sewage districts or an equivalent agency. The mandate for upgrading existing and new facilities is based on the NPDES permit system and other provisions contained in PL-92-500, The Water Pollution Control Act Amendments of 1972.

TABLE 6-9. CAPITAL COSTS TO SOUTHERN FLORIDA TO ACHIEVE 1983 STANDARDS

SIC Code	Employment Florida Statewide (Thousands)	Employment Southern Florida[a] (Thousands)	Ratio Southern Florida/ Florida	Florida Capital Costs ($ Thousands)	Southern Florida Capital Costs ($ Thousands)
33	4.7	-	0	11,808	0
28	20.8	3.0	0.14	246,238	34,473
26	17.2	-	0	91,680	0
34	27.9	16.8	0.60	409,920	245,952
20	48.0	21.2	0.44	46,092	20,280
49	23.4	13.6	0.58	200,976	116,560
All Other Manufacturing	232.0	154.9	0.67	551,200	369,304
Total Manufacturing	374.0	209.5		1,557,914	786,575

(a) Including Tampa, West Palm Beach, Fort Lauderdale, Miami, and surrounding areas, "Employment and Earnings, States and Areas, 1939-1974", U.S. Department of Labor, Bureau of Labor Statistics, 1975, Florida, pages 162-182.

- The municipal waste treatment facility design decision is made at the local sewage district level, but usually by a consulting engineering firm retained to provide design services. Industrial plant design decisions are made at the corporate engineering staff level, however, local engineering firms are often consulted.
- The estimated population of the potential market for aquatic plant waste treatment, based on applications in communities smaller than 50,000, was approximately 8,500,000 in 1970. By the year 2000 this market will increase by 4,200,000.
- The number of individual municipal facilities requiring upgrading in this market area is approximately 700. The number of new facilities by the year 2000 is projected to be 319 and includes 294 facilities in 1 MGD-capacity range, and 25 facilities in the 5 MGD-capacity range.
- The estimated value of these upgraded and new munciipal facilities could approach $1.3 billion based on 1975 facility costs in the Gulf South region. Of this amount, only about $320 million of new and upgraded facilities will be located in southern Florida, the only part of the market area now capable of utilizing aquatic plant technology on a year-round basis. The remainder of the market can utilize aquatic plants only if a "winter crop" is found to replace water hyacinths, or standards are relaxed.
- The potential benefit to society of applying aquatic plant waste treatment technology can, at best, only be estimated in terms of the potential savings in facility investment and operating costs. These potential costs-savings could amount to $165 million to south Florida if aquatic plants are half as expensive as other processing technologies in municipal applications. For the entire Gulf South region, assuming a year-round aquatic plant system can be developed, the potential cost-savings from using aquatic plants could approach $650 million if a 50 percent savings is achieved. These estimates are preliminary and cannot be substantiated until operational cost data are collected.

- There are possibly substantial additional benefits from improvements in industrial wastewater treatment, but substantial further work would be required to estimate market shares for hyacinth systems for each of the major industries in the region.
- The most important impact of the aquatic plant technology on society will be an improved environment. No significant impacts are anticipated based on the current level of technology.
- The major institutional constraints which could influence aquatic plant technology are government regulations and grants, industry opposition, resistance to innovation, the capital crisis, and a possible amendment to PL 92-500.

Persons Interviewed

Baker, Ralph, Florida Department of Environmental Regulation

Bankston, Dr. P. T., Governor's Office of Science and Technology, Jackson, Mississippi

Bayley, Donald, Water Quality Section, Jacksonville Department of Health, Welfare and Bio-Environmental Services

Barnett, William, Mississippi Area Water Pollution Control Commission, Jackson, Mississippi

Berry, Robert, Mississippi Area Water Pollution Control Commission, Jackson, Mississippi

Bond, Ron, City Engineer, for City of Valdosta, Georgia

Brady, Don, South Alabama Regional Planning Commission, Mobile, Alabama

Buchholz, William F., URS Company, Metairie, Louisiana

Clark, Carmen, Bernard Johnson, Inc., Houston, Texas

Cleverdon, J. Union Carbide, Mobile, Alabama

Coerver, James, Department of Engironmental Health, State of Louisiana, New Orleans, Louisiana

Duncan, Joseph, South Alabama Regional Planning Commission, Mobile Alabama

Emery, Mr., St. Regis Paper Company, Jacksonville, Florida

Ferguson, Donald, St. Regis Paper Company, Jacksonville, Florida

Glass, Peggy, Chief of Planning, Texas Water Quality Board, Austin, Texas

Guerrh, Lou, Texas Parks & Wildlife Department, San Antonio, Texas

Hallmark, David, Construction Grants, Texas Water Quality Board, Austin Texas

Harding, A., Environmental Engineer, Mays, Sudderth and Etheridge

Hoffitt, R., Environmental Engineer, Brunswich Pulp and Paper Company

Holdman, Dave, Mississippi Research and Development Center, Jackson, Mississippi

Holly, Ron, Municipal Waste Control, Alabama Water Improvement Commission, Montgomery, Alabama

Horn, Charles, Industrial Waste Control, Alabama Water Improvement Commission, Montgomery, Alabama

Jones, Garner, Permits Section, Texas Water Quality Board, Austin, Texas

Kappus, Uli, Environmental Engineer, Dames and Moore

Kneisel, Craig, Municipal Waste Control, Alabama Water Improvement Commission, Montgomery, Alabama

LaFleur, Robert, Louisiana State Stream Control Commission, Baton Rouge, Louisiana

Lang, Dr., Biologist, Georgia Department of Agriculture

Manning, Bill, Gulf Coast Waste Disposal Authority, Houston, Texas

Martindale, Rick, Municipal Waste Control, Alabama Water Improvement Commission, Montgomery, Alabama

McKeigney, Al, Manpower Department, Jackson, Mississippi

Nelson, Don, Permits Section, Texas Water Quality Board, Austin, Texas

Poret, Ory, State Land Office, Baton Rouge, Louisiana

Proctor, Phyllis, Texas Industrial Commission, Austin, Texas

Pruitt, Richard D., South Alabama Regional Planning Commission, Mobile, Alabama

Reheis, Harold, Section Chief, Environmental Protection Division, Georgia Department of Natural Resources

Rose, Gen. James M., Director, Division of Planning Coordination, Office of the Governor, Austin, Texas

Rose, Melton, Construction Grants, Texas Water Quality Board, Austin, Texas

Shah, Dilip, Lower St. Johns River Sub-District, Florida Department of Environmental Regulation

St. Amant, Jay, URS Company, Metairie, Louisiana

Steimle, Stephen E., Steimle, Smalley & Associates, Metairie, Louisiana

Teller, Joe, Gulf Coast Waste Disposal Authority, Houston, Texas

Trost, Charles, Houston-Galveston Area Council, Houston, Texas

Watkins, Frank, Lower St. Johns River Sub-District, Florida Department of Environmental Regulation

Welsh, Gene, Chief, Environmental Protection Division, Georgia Department of Natural Resources

Williams, C. D., Crown Zellenbach, Gulfport, Mississippi.

Questionnaire

1. What is the current process in this state (or city) for identifying the need for new or improved municipal sewage and industrial waste treatment facilities?

2. Once a need is identified what actions are required to obtain a permit, prepare plans, design, construct, and finance a treatment facility?

3. Who issues the NPDES discharge permit? State or EPA?

4. Are state discharge standards more restrictive than federal standards? If so, what type of additional technical information is needed to meet state standards?

5. Which agencies, organizations, or individuals do you perceive exert the most influence in the treatment facility design process?

6. Are these influential groups or individuals receptive to new technology?

7. Are these groups or individuals concerned more with technological feasibility, engineering feasibility, economic feasibility, or institutional feasibility? Please elaborate.

8. If an innovative waste treatment process, such as water hyacinth treatment, is to be successfully utilized, what problems or shortcomings in the process, if any, do you perceive might delay its acceptance by municipalities and industrial plants?

9. Is the local government or population concerned about controlling the propagation of water hyacinth? Is this concern considered a serious problem in this area? Are you aware of any noxious plant laws which might prohibit the use of water hyacinth? If so, do you feel changes to these laws could be effected if water hyacinth treatment facilities prove popular and successful elsewhere?

10. Do you feel that by-product utilization of harvested hyacinths is essential to the feasibility of the treatment process?

11. Which type of by-product utilization of spent hyacinths do you feel would be most advantageous in this area? Compost? Fertilizer? Food additive? Other (specify)?

12. Are there other factors, not mentioned above, which you consider important to the successful application of a new technology such as water hyacinth waste treatment?

References for Chapter 6

6-1. PL 92-500, Stat. 816 (1972).

6-2. Philip Kolter, Marketing Management, Prentice-Hall, Englewood Cliffs, New Jersey.

6-3. Review of Landspreading of Liquid Municipal Sewage Sludge, Battelle Columbus Laboratories, June 1975, EPA Report No. 670/2-75-049.

6-4. Battelle Columbus Laboratories field interviews.

6-5. Directory of Florida Industries, Florida State Chamber of Commerce, Jacksonville, Florida (1973).

6-6. "1972 Census of Manufacturers, Area Series, Florida", U.S. Department of Commerce, Bureau of the Census (March, 1975).

6-7. Final Report to National Commission on Water Quality, "Cost of Implementation and Capabilities of Available Technology to Comply with P.L. 92-500", Volume I, from Battelle's Columbus Laboratories (July 3, 1975).

6-8. "Radiochemical Pollution from Phosphate Rock Mining and Milling", Water Resources Association Symposium of the Colorado School of Mines, Golden, Colorado (July 1-2, 1974).

6-9. Shearer, S. D., Jr., and Lee, G. F., "Leachability of Radium-226 from Uranium Mill Solids and River Sediments; Health Physics, Vol. 1D, pp 217-227; 1964.

6-10. Report to Exxon, "Environmental Analysis Concerning Exploration for Uranium and Possible Resultant Mining and Milling Operations on the Navajo Indian Reservation, San Juan County, New Mexico", Battelle's Columbus Laboratories (April, 1975).

6-11. Eckenfelder, W. W., Jr., Water Quality Engineering for Practicing Engineers, Barnes and Noble, Inc., New York (1970).

6-12. Wolverton, B. C., "Water Hyacinths for Removel of Cadmium and Nickel from Polluted Waters", NASA Technical Memorandum TM-X-72721, National Space Technology Laboratories (February, 1975).

6-13. Wolverton, B. C., "Water Hyacinths for Removal of Phenols from Polluted Waters", NASA Technical Memorandum TM-X-72722, National Space Technology Laboratories (February 5, 1975).

6-14. Wolverton, B. C., "Aquatic Plants for Removal of Mevinphos from the Aquatic Environment", NASA Technical Memorandum TM-X-72720, National Space Technology Laboratories (February, 1975).