REVIEW OF OPERATIONS AND PERFORMANCE DATA ON FIVE WATER HYACINTH BASED TREATMENT SYSTEMS IN FLORIDA

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ABSTRACT

Operational data are reviewed from five water hyacinth [Eichhornia crassipes (Mart) Solms] based wastewater treatment systems in Florida. Discussions are also presented regarding the impact of crop growth and viability upon system performance. A model developed around the Monod relationship provides performance projections which are compared to actual values. Model projections are sufficiently conservative for operational dependability, with N removal in particular being much more dependent upon removal mechanisms not associated with direct plant uptake. Information regarding system management as related to system performance, harvesting needs and pest/pathogen control is presented.

Keywords: Nutrient removal mechanisms, plant uptake, simulation model, wastewater, system management, harvesting.

INTRODUCTION

While the concept of using aquatic vegetation, particularly the water hyacinth [Eichhornia crassipes (Mart) Solms], for wastewater treatment has been extensively investigated and reviewed for nearly 20 years, there still remains little information regarding the operational needs associated with large scale applications. Work by Amasek, Inc., in Florida has been directed principally towards the commercial application of this technology for domestic wastewater treatment, a need which is most critical in Florida's regulation and management of surface waters. The purpose of this paper was: 1) to describe the model for predicting nutrient removal; 2) review operational data from five water hyacinth-based wastewater treatment systems; and 3) compare model predictions with operational data.

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MODEL DESCRIPTION

In developing an operations and design approach to meet these practical demands, a model was developed from field studies (Stewart et al., 1984) in which nutrient removal was considered to be accomplished by two basic means; direct plant uptake and all other processes. The direct plant uptake fraction was expressed using the Monod relationship:

$$Uf = Ufmax\ [S/(Ks+S)] \qquad [1]$$

where Uf = specific field growth rate, d^{-1}; S = concentration of limiting factor mg L^{-1}; Ks = concentration of limiting factor when Uf = Ufmax; Ufmax = maximum potential field growth rate, d^{-1}.

This relationship was adjusted in accordance with the V'ant Hoff Arrhenius relationship:

$$U_2/U_1 = \theta\ T_2 - T_1 \qquad [2]$$

where U_1, U_2 = specific field growth rate at temperatures T_1, T_2; T_1, T_2 = air temperatures in K°; θ = constant (1.04 - 1.09).

While other researchers (Musil and Breen, 1977), have evaluated hyacinth growth dynamics on a small scale finding U to approach 0.15 d^{-1}, it was felt that measurements from large scale operations would give a more practical value. Using the Lineweaver-Burke (1934) approach, it was determined (Stewart et al., 1984) that Ufmax of 0.06 d^{-1} was an appropriate value for field conditions, with total N serving as the limiting nutrient, at Ks = 5 mg L^{-1}.

In completing the model, a final nutrient concentration was expressed as a function of flow out, loads in and removal by direct uptake and other processes.

$$Cn = (QICi - Nu - NI)/Qo \qquad [3]$$

where, Cn = effluent nutrient concentration; Ci = influent nutrient concentration; QI = daily flow in; Qo = daily flow out; Nu = daily mass nutrient removal by plant uptake; NI = daily mass nutrient removal by incidental processes.

In final form the developed equation becomes:

$$Cn = \frac{(1-Km)\ Qf\ CI - Pw\ Pn\ Z\ [\exp\ (UfTaf) - 1]}{(1-Km)\ Qo} \qquad [4]$$

where Km = fraction of total nutrient removed not attributable to direct plant uptake; Pw = solids fraction of the crop; Pn = fraction of nutrients in dry weight of crop; Z = standing crop; Taf = temperature adjustment factor; Taf = $1/_{\theta}\ 298 - T_1$.

TESTING MODEL RELIABILITY

Amasek operated five hyacinth based systems in Florida and collected pertinent water quality and flow data for a one year period. Operational practices exercised during this period included maintenance through harvesting, control of pests and pathogens and to maintain a desired crop density maintenance between 12 to 19 kg (fresh wt) m^{-2} (Ryther et al., 1979) and addition of necessary macro and micronutrients (particularly Fe). Standing crop was measured weekly in each system, and plant nutrient content monitored regularly to permit a reasonable assessment of direct plant uptake.

Applied empirical parameter values were as follows: Kn for N 0.3 - 0.6; Kp for P 0 - 0.6; $\theta = 1.06$; Ufmax = 0.04 d^{-1} to 0.06 d^{-1}; Pn for N 0.025 - 0.04; Pp for P 0.005 - 0.008; and Pw = 0.05.

SITES OF INVESTIGATION

The five operating projects all varied in size and performance requirements (Table 1). Of the five systems, the City of Orlando and the Loxahatchee lagoons were sealed with a clay admix to prevent interface with the ground water. The Naval Training Center (NTC) facility and City of Kissimmee facility contained natural clay seals. The City of Melbourne system was constructed with underdrains. However, they were not used as part of this operation. Both the Melbourne and Kissimmee systems which had been previously used as wastewater polishing ponds were characterized by a highly organic sediment. The NTC facility lagoons occasionally received some solids from the contributing secondary systems. These solids were comprised largely of alum floc and organic material. Accumulation of this material was noted in the receiving area of the lagoons. Both the Iron Bridge and Loxahatchee lagoon sediments were largely inorganic, as they received a highly treated low solids effluent.

RESULTS AND DISCUSSION

System performance in terms of N and P influent and effluent concentration are noted in Figures 1 and 2. Desired effluent N and P goals were met at each system. In general, the model sufficiently tracked performance for operational purposes. A comparison of actual and model projected effluent values for N and P are presented in Table 2.

Kissimmee

Model projections for Kissimmee were notably optimistic for both N and P for the period of March 1985 through December 1985, even when relatively conservative values are used for Ufmax (0.04 d^{-1}) and the incidental loss coefficients (Kn = 0.3, Kp = 0). A more detailed review of the nutrient budget during this time period by Amasek (1986) revealed that large amounts of unmonitored nutrients were being contributed to the system from an extraneous source. Indications were that the underlying organic sediments served as an autochthonous nutrient source, although N_2 fixation may also have been a contributor. It was determined that nearly

TABLE 1. Description of five systems investigated.

Name	Flow	Influent BOD_5, TSS, TN, TP	Lagoon size and description	Effluent goals BOD_5, TSS, TN, TP	Comments
	$m^3\ d^{-1}$	---mg L^{-1}---		----mg L^{-1}----	
Orlando, NTC McCoy	3,024-4,536	10-20,10-20, 10-20,1-3	0.61 ha, detention time less than 24 h	0-10,0-5, 5-10,0.5-1	Lagoons added to increase permitted capacity
Orlando, Iron Bridge	30,240	2-6,2-6, 12-16,0.2-1	12.15 ha, detention time 3-5 d, 2 lagoons in paralled	2.5,2.5, 10.5-14.5,0.5	Require 45.4 kg-N removed per day. Lagoons added to increase permitted capacity.
Melbourne, David B. Lee	9,450-13,230	20-40,20-40, 20-60,2-6	4.86 ha, detention time 3 d or less 4 lagoons, 2 in series set as 2 parallel systems	20,20, 14-25,2-5	Require 62 kg-N removed per day. Lagoons are old perc ponds converted to hyacinth lagoons to increase permitted capacity.
Loxahatchee River Environmental Control District Jupiter, FL	7,560-11,340	1-6,1-6 1-3,0.5-1.5	3.44 ha, detention time 5-7 d. One lagoon	0-5,0-5, 3,1	Hyacinth originally introduced to control N during upset periods and control suspended solids prior to spray irrigation.
Kissimmee, Martin Street	588	6,20, 15,1.5	1.49 ha, detention time over 20 d, 2 lagoons in series	5,5, 2.5,0.5	Funded by State of Fla. to determine treatment capabilities of hyacinths.

FIGURE 1

INFLUENT and EFFLUENT TOTAL NITROGEN CONCENTRATIONS

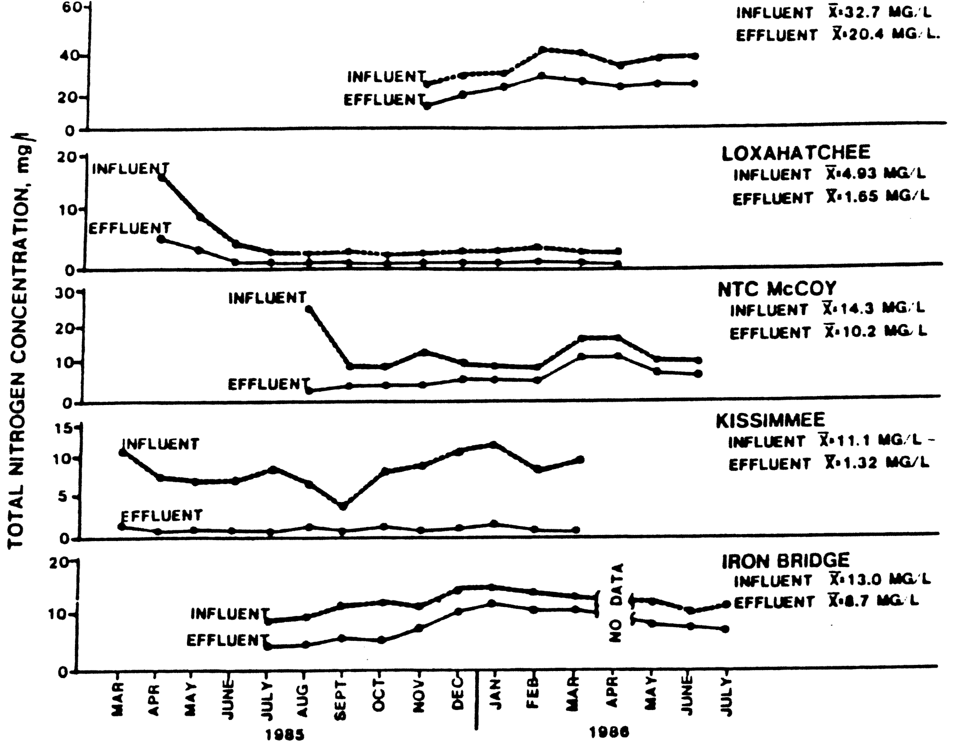
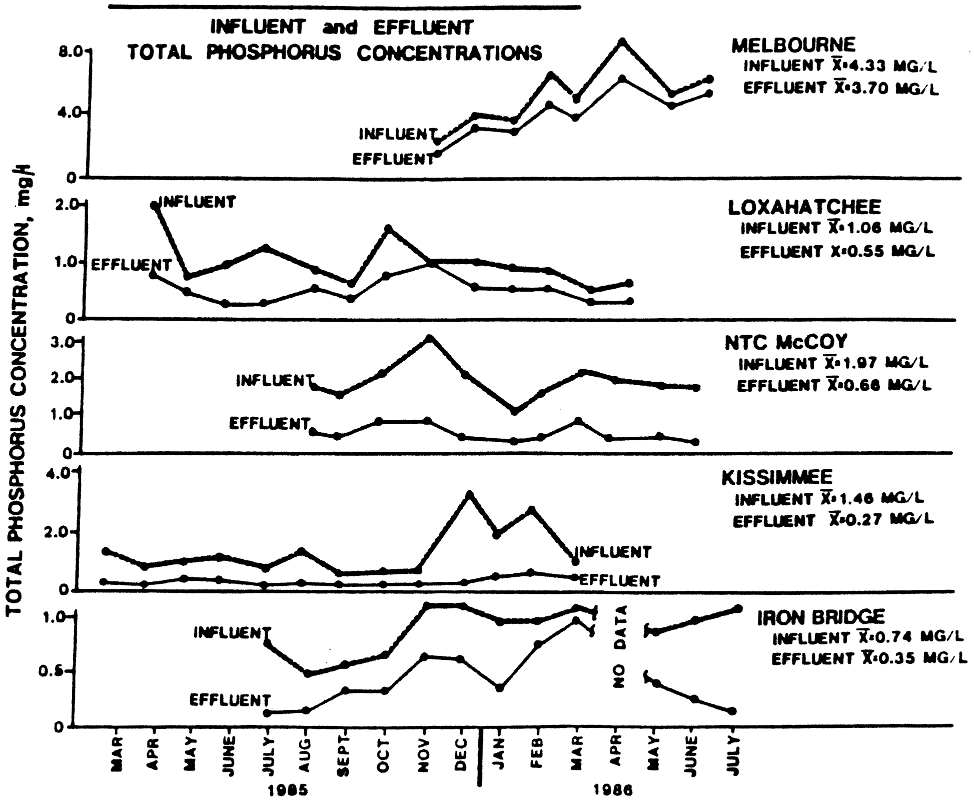


TABLE 2. Comparison of nutrient effluent values to projected values.

System	Influent		Actual effluent		Projected effluent		Model parameters		
	N	P	N	P	N	P	Ufmax	Kn	Kp
	---------------mg L^{-1}						d^{-1}		
Kissimmee	11.1	1.46	1.32	0.27	-3.6	-0.65	0.04	0.3	0
Iron Bridge	13.0	0.74	8.7	0.35	9.1	0.41	0.04	0.3	0
NTC McCoy	14.3	1.97	10.2	0.66	12.4	0.69	0.04	0.6	0.5
Loxahatchee	4.93	1.06	1.65	0.55	1.81	0.71	0.04	0.3	0
Melbourne	32.7	4.33	20.4	3.70	25.6	3.57	0.06	0.6	0

20% of the removed N and 23% of the removed P came from autochthonous sources. Of the removed N, 56% was accountable through direct plant uptake while 44% was attributed to incidental mechanisms (Kn = 0.44). Similarly, nearly 65% of the P removed

FIGURE 2



was accountable through direct plant uptake, while 35% was attributed to incidental mechanisms (Kp = 0.35)--in this case probably sedimentation within the receiving lagoon. The Kissimmee study clearly indicated the importance of sediment dynamics when low effluent concentrations are required. Subsequently, it is suggested that during design, considerations should be given to careful selection of pond sediments.

Iron Bridge

Performance at Iron Bridge followed the model projections rather closely, particularly for N, with Ufmax at 0.04 d^{-1}, Kn = 0.3 and Kp = 0.0. This system is of interest because of an upset condition that occurred between November 1985 and May 1986. The upset was characterized by a loss of standing crop due to infestation by the hyacinth weevil, encroaching aquatic vegetation, possible toxic influences and a following debilitating opportunistic infection by the water mold Pythium sp. The correlation between mass removal and standing crop which is shown in Figure 3, indicates that N removal, regardless of the mechanisms involved, is dependent upon standing crop viability and mass. At the Iron Bridge facility, the actual Kn value for the study period was about 0.6 with Kp being approximately 0.3. Accordingly, field growth was somewhat lower than projected, particularly during the upset period. Using the more conservative values of Kn = 0.3 and Kp = 0, however, provides the operation the necessary degree of safety for ensuring system performance.

NTC McCoy

The facility at NTC McCoy is characterized by a high hydraulic and nutrient loading rate. Incidental mechanisms played an important role in nutrient removal, with the model showing reasonable projections at Kn = 0.6 and Kp = 0.5. Phosphorus loss is largely due to precipitation as aluminum phosphate, which is carried over from the secondary clarifiers.

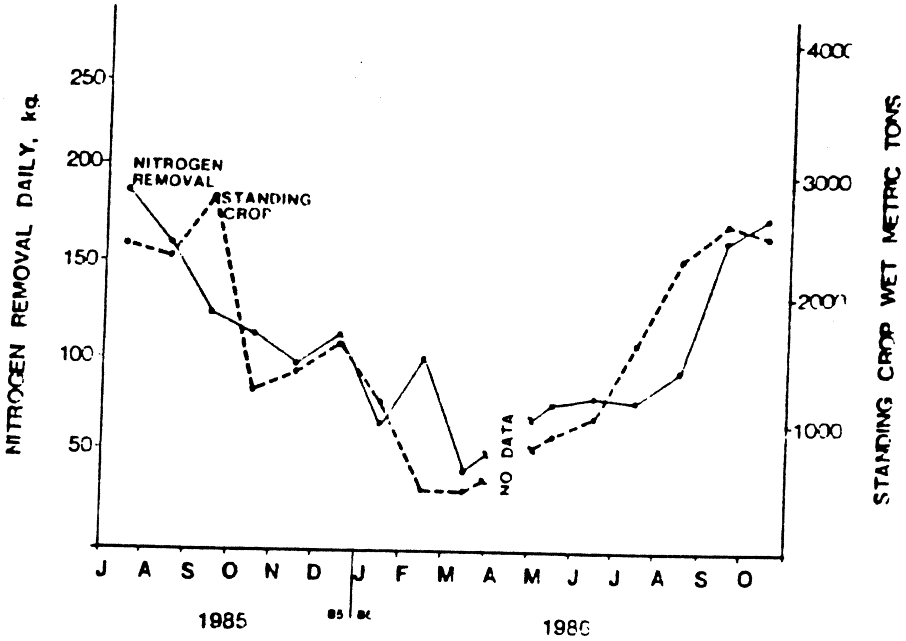


FIGURE 3. Standing crop and system N removal performance at Iron Bridge.

Loxahatchee

This system's response was adequately simulated by the model, even at lower concentrations of N (1.5 mg L^{-1}).

Melbourne

Incidental losses of N, as with NTC McCoy, were very influential at Melbourne. Even with Kn = 0.6 and Ufmax at 0.06 d^{-1}, projections were conservative. The actual average Kn value for the system over the study period was calculated at 0.90 with Kp averaging near zero. Some drop in system performance and growth rate was noted from March to May 1986, at a time in which encroachment by other aquatic species (principally, alligator weed, Alternanthera sp.), was most extensive. This problem was eliminated during June 1986. Observed growth rates were generally near those projected during most of the study period.

In establishing initial design criteria and operational parameters, the model as presented is appropriate, providing sufficient safety margin to ensure performance. It was observed that growth rate and plant uptake is a more predictable parameter, with other removal mechanisms showing wide variations, depending upon water quality, crop health, temperature, etc. Therefore, while it is tempting to suggest that system design and operation can be established upon processes other than direct plant uptake (DeBusk and Ryther, 1984; Weber and Tchobanoglous, 1985), until these processes can be properly identified, and their dynamics predicted, it may be precarious to depart from the more conservative uptake model. Using the values of Ufmax at 0.04 d^{-1} and a Kn at 0.3 and Kp at 0.0, can result in a safe design and operation. As research and development progresses, the impact of incidental processes should become more predictable. Significant work regarding the influences of nitrification and denitrification have already been conducted by Reddy (1984) and Weber and Tchobanoglous (1986) in hyacinth cultures. Other processes which need research attention are sediment influences, internal ecological influences, and the role of larval emergence and external predation.

One significant observation, as previously noted, is the importance of crop viability to overall performance. This suggests that the hyacinth crop itself directly facilitates the major nutrient removal processes. This has been suggested by Reddy (1984) and Weber and Tchobanoglous (1986), who noted that nitrification is probably supported within the root zone by active pumping of O_2 through the plant's vascular system to the nitrifying population.

In managing large-scale systems, while the concept of non-harvesting/non-management has some obvious appeal, it is not a practical approach to maintaining crop viability where heavy grazing by pests, such as the hyacinth weevil (Neochetina eichhorniae) is prevalent, or successional pressures from other aquatic plants are likely to occur. Consequently, some method of effective crop harvesting must be incorporated into design and operational programming. While it may not be needed to harvest at a level to optimize crop yield, sufficient plant material should be removed to maintain crop viability and control pest populations.

CONCLUSIONS

The importance of processes other than direct plant uptake for nutrient removal varied with the five systems studied. The direct correlation between the rate of areal loading and areal removal as noted in Figure 4, indicates that at least in the case of N that nutrient availability influences the rate of nutrient removal, and that direct plant uptake dominates at lower loading rates. In the case of P, this correlation is not so obvious. Except for the condition presented by the NTC data, areal removal rates do not appear to be influenced by influent loading rates. Based upon the data and findings presented, a need can be clearly seen to expand our ability to identify all of the nutrient removal

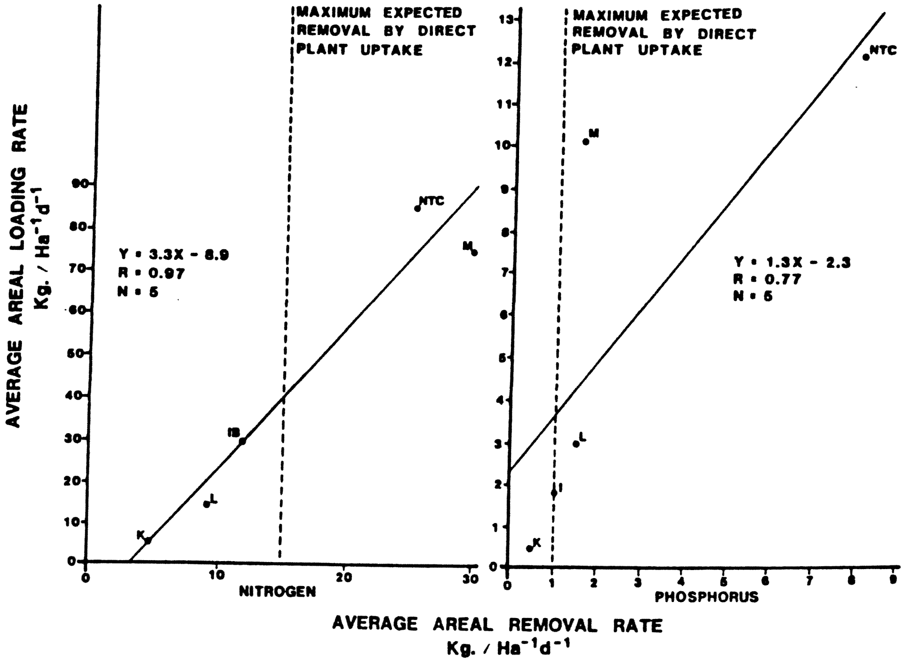


FIGURE 4. Relationship of areal loading and removal rates for N and P.

processes involved in hyacinth systems. At this time, establishing design and operations around direct plant uptake appears legitimate and adequately conservative to ensure system performance.

REFERENCES

Amasek, Inc. 1986. Assessment of OPERATIONS, Water Hyacinth Nutrient Removal Treatment Process Pilot Plant: City of Kissimmee. Florida Department of Environmental Regulation. FEID #59-6000348. Prepared for Briley Wild and Associates, Inc., Ormond Beach, FL.

DeBusk, T. A., and J. H. Ryther. 1984. Nutrient removal from domestic wastewater by water hyacinths. The importance of plant growth, detritus production, and denitrification. Future of Water Reuse. Proceedings: Water Reuse Symposium III. San Diego, CA. p. 713-723.

Lineweaver, H., and D. Burk. 1934. The determination of enzyme dissociation constants. J. Am. Chem. Soc. 56:658.

Musil, C. F., and C. M. Breen. 1977. The application of growth kinetics to the control of Eichhornia crassipes (Mart) Solms. through nutrient removal by mechanical harvesting. Hydrobiologia 53:165.

Reddy, K. R.. 1984. Nutrient transformations in aquatic macrophyte filters used for water purification. Future of Water Reuse Proceedings: Water Reuse Symposium III. San Diego, CA. p. 660-678.

Ryther, J. H., D. W. LaVergne, M. D. Banisak, and T. A. DeBusk. 1979. Biomass production by marine and fresh water plants. Proceedings Third Annual Biomass Energy Systems Conference. SERI/TP-33-285.

Stewart, E. A., D. L. Haselow, and N. M. Wyse. 1984. A practical model for water hyacinth based wastewater management. Design and Operation. Future of Water Reuse. Proceedings: Water Reuse Symposium III. San Diego, CA. p. 679-702.

Weber, A. A., and G. Tchobanoglous. 1985. Rational design parameters for ammonia conversion in water hyacinth treatment systems. J. Water Pollut. Control Fed. 57:316-323.

Weber, A. A., and G. Tchobanoglous. 1986. Prediction of nitrification in water hyacinth systems. J. Water Pollut. Control Fed. 58:376-380.