Presented at the Water Reuse Symposium III,
August, 1984, San Diego, California

A PRACTICAL MODEL FOR WATER HYACINTH BASED WASTEWATER MANAGEMENT - DESIGN AND OPERATION

E. Allen Stewart, III, P.E.
Senior Vice President & Technical Director

David L. Haselow
Aquatic Scientist

Natalie McComis Wyse
Aquatic Scientist

Amasek, Inc.
400 High Point Drive
Cocoa, Florida 32926

INTRODUCTION

It is noteworthy that during the last decade, which has been characterized by an intense demand for new nutrient control technologies, that the Engineering Community has not seriously considered the autotrophs (green plants) as a logical agent for both removal and recovery of nutrients (primarily Nitrogen and Phosphorus) from wastewaters. Basically, the only use of autotrophic cultures for nutrient control which has been considered fundable by EPA has been the application of effluent upon inefficient, terrestrial crops, with these systems quite often being used more for effluent-disposal rather than nutrient control. Other more intense, autotrophic cultures, such as the use of the floating aquatic plant, the water hyacinth (Eichhornia crassipes), have, until recently, been restricted to small, limited research projects without being given serious consideration for application in full scale 201 programs. This attitude has understandably delayed the proper assessment, development and maturation of these technologies. Fortunately, however, it is finally becoming widely recognized that there is an inevitable biological relationship between heterotrophic and the autotrophic communities that is paramount to the sustenance of the stability associated within a quasi-steady state ecosystem, and that there is more than a philosophical implication that emulation of this relationship within a water pollution control management program may similarly offer greater stability for our own artificial systems and provide significant improvements in our ability to treat and recover "wastewater" and associated resources.

Water hyacinth based wastewater management systems are now receiving serious attention in at least three areas of the country. In California (1) their use as a means of economically preparing wastewater for renovation to drinking water quality is being investigated. In Texas (2) water hyacinth cultures have served as an energy efficient means of providing secondary treatment. It is in Florida (3) however that the focus is on extensive nutrient control, as cultural eutrophication of valuable surface waters is an ever-growing concern in this rapidly developing state whose economic integrity relies significantly upon water quality related amenities. Consequently, it is not unknown for nutrient discharge allocations imposed by The Florida Department of Environmental Regulations to call for Total Nitrogen levels of near 1.50 mg/l and Total Phosphorous levels of less than 0.20 mg/l (4). These demands have aroused interest in water hyacinths, and extensive efforts to demonstrate the extent of this plant's nutrient removal capabilities have been supported by several Florida municipalities, as well as various environmental regulatory agencies.

The study presented within this paper is the result of development work funded and conducted by Amasek, Inc. (based in Cocoa, Florida) in response to this need for effective, inexpensive nutrient control methods in Florida. The intent of this effort was to establish a simple, reliable model for purposes of accomodating the Engineering Community's need to identify and quantify critical design, cost and operational criteria. As with other biological processes, the basic Monod (5) equation was utilized as the foundation of the model. Data collected over a one year operational period gathered from the Amasek facility in Lake Helen, Florida (Volusia County), was utilized to establish ranges of the necessary constants. The resulting model offers the engineer the capability of establishing the areal extent of the growing lagoons, the harvest frequency and quantity, the evapotranspirational losses, and expected effluent quality during climatic extremes in terms of Nitrogen and Phosphorus from an input of influent nutrient loads, minimum and maximum temperatures and rainfall.

EXPERIMENTAL PROCEDURES

The Amasek development facility consisted of five clay sealed lagoons in series, fed from a volumetric chemical feed system which allowed close documentation of nutrient and salt inputs. The lagoon sizes and general system arrangement were as noted in figure 1.

A chemical feed formulation was designed to simulate domestic secondary effluent. This formulation as shown in Table 1, permitted regulation of influent quality within the range of about 20-50 mg/l Total Nitrogen, and about 3.0-10.0 mg/l Total Phosphorus. The flow rate was meter regulated at 7500 gpd. Shown in Table 2 is the general quality of the influent as noted from composite samples taken during the course of the study.

Fresh, wild hyacinths which were placed in the lagoon system quickly responded to the high nutrient content of the waters. By February, 1982 a satisfactory standing crop had been established and continuous testing initiated. The system was operated in a continuous mode through the first two ponds. From pond two, a batch flow was directed to pond three every third day. This batch was then quantified by measuring the water rise in pond three. Also, water quality samples were taken simultaneously from the batch. After three days detention this batch was again sampled, the change in water volume noted, and the batch diverted to Pond 4. Following an additional three day period, the batch, now in pond 4, was again similarly sampled and directed to pond 5. This batch approach permitted careful assessment of the dynamic relationships between nutrients, water movemements, and other environmental factors to crop growth.

Plant growth rate was assessed by areal sampling of the standing crop. Before each run, eight grids were randomly selected for sampling. From these a 1 ft^2 sample was taken and placed in mesh bags, where they were drained for a period of 30 minutes prior to weighing. From this information the standing crop and crop density were determined. During the course of the project the wet density was generally kept between 2.0 - 3.0 lb/ft^2, as this has been noted to be a near optimum density range for ensuring maximum yield (6). Harvesting was done by hand to maintain the standing crop at the desired density. Daily field sampling was also done for maximum and minimum air temperature, rainfall, water temperature, D.O. and pH.

RESULTS

Water quality results for influent and effluent as shown in Table 3, indicate significant nutrient removals from the system. Specific crop growth rate and harvest quantities, as shown in Table 3, indicate a discernible relationship between plant uptake and nutrient removal. Also noted is the impact of transpiration upon the overall water budget.

MODEL DEVELOPMENT

Data collected from each batch as it moved through Ponds 3 and 4 provided needed information regarding the dynamics of the nutrient removal process within a managed hyacinth culture. To describe this process, the basic principles of enzymatic reactions applied to the organism level, as originally described by Michaelis-Menton (7) and Monod (5), were utilized to initiate model development, the basic equation being:

$$U_s = U_{max} \frac{S}{K_s + S} \quad [1]$$

where U_s = specific growth rate; 1/day

U_{max} = maximum potential specific growth rate; 1/day

S = Limiting nutrient concentration; mg/l

K_s = half-rate concentration of limiting nutrient, mg/l.

That portion of the nutrients removed through direct plant uptake within a system therefore can be described as follows

$$N = Z_o(e^{Ut} - 1)n \quad [2]$$

where N = Weight of nutrients incorporated into plant tissue

Z_o = Weight of standing crop

t = Time

n = Nutrient fraction of plant tissue.

Similarly then the total nutrient removal can be quantified through equation [3].

$$N_T = K_n N_T + Z_o(e^{Ut} - 1)n \quad [3]$$

where N_T = total nutrient removal

K_N = fraction of removed nutrients not attributable to direct plant uptake.

This approach was discussed by Musil and Breen (8) who based the development of Umax and Ks through a series of laboratory growth studies, using the methodology presented by Lineweaver and Burk (9). A comparison of the field results from the Amasek, Lake Helen study and the findings of Musil and Breen reveal the difference one might anticipate between a true net productivity, i.e. gross productivity minus plant respiration and animal grazing influences, and a laboratory productivity, i.e. gross productivity minus just plant respiration. This led to the consideration of utilizing a more practical specific field growth rate parameter, U_f, as opposed to an ideal laboratory specific growth rate, U_l. If a relatively short time period is considered (1-5 days) it is possible to approximate the influence of grazing pressures (animal respiration) upon the field crop production. As graphical shown in Figure 2, this actual field production can be expressed by

$$Z_f = Z_o e^{U_f (t-1)} e^{Ul} = Z_o e^{U_f (t-1) + Ul} \quad [4]$$

While this is an approximation, it permits a more realistic assessment of the role of the hyacinth crop for nutrient removal, as it brings attention to the importance of the role of the primary producer to nutrient dynamics and removal. This challenges, to some degree, the emphasis which has been placed upon incidental removal mechanisms such as denitrification and soil adsorption (10,11), although these are certainly significant contributors to the process.

Equation [3] can now be appropriately adjusted

$$N_T = K_n N_T + Z_o [e^{U_f (t-1) + U_1 - 1}] n \quad [5]$$

where N_T = total nutrient removal

K_n = fraction of removed nutrient not attributable to direct plant uptake.

In their studies, Musil and Breen (8) indicate that Nitrate Nitrogen is the limiting growth factor for hyacinth growth, implying that Ammonia Nitrogen is not directly available to the hyacinth plant. However, many field studies (12,13) indicate that Ammonia does promote plant growth, including the study at Lake Helen. A casual observation of the fate of Ammonia Nitrogen within a hyacinth lagoon indicates the presence of active nitrification, as Nitrate-Nitrogen invariably emerges as a significant percentage of the in-pond Nitrogen. It is hypothesized that Musil and Breen (8), working under laboratory conditions, may have eliminated a nitrifying population within the hyacinth root zone, thereby eliminating the ability of the plant to accommodate the conversion of Ammonia to Nitrate prior to uptake. In field conditions, however, nitrification invariably is quite active and does not appear to be involved in limiting the rate of Nitrogen uptake, even Ammonia Nitrogen. It is further suggested that there may be a symbiosis of sorts between this nitrifying population and the hyacinth, with the plant providing the needed oxygen source through its root system. This is, of course, a hypothesis that needs further investigation for confirmation.

In field conditions, when typical wastewater effluents are involved, it appears reasonable to utilize Total Nitrogen, rather than Nitrate Nitrogen, as the target (limiting) nutrient. This has significant economic implications, for it reduces the need to expend energy for aeration normally required to accomplish nitrification within conventional secondary wastewater treatment systems.

While Nitrogen is utilized as the limiting nutrient within this model, it is important to recognize the restraints of this condition. First of all, it has been the experience of the authors that Iron is usually the first nutrient to become depleted within hyacinth systems. However, since Iron at reasonable levels is not a controlled pollutant, a feed program can be easily implemented to sustain an adequate source of Iron. This also applies to other elements such as Potassium, Magnesium, Manganese, and Calcium. Secondly, because the Nitrogen to Phosphorus ratio in sewage effluent is often 3:1 to 5:1, it is reasonable to anticipate a depletion of Nitrogen prior to adequate Phosphorus removal. To adjust this balance, Nitrogen can be added to the system, as was done in Lake Helen, or some Phosphorus reduction can be done prior to entering the hyacinth system. When hyacinths are utilized to remove nutrients to very low levels, it is conceivable that Phosphorus could exert a growth-limiting influence. Some researchers (14) have suggested that 0.10 mg/l as Total

Phosphorus would limit hyacinth growth. However, growth of these plants in waters in the range of 0.02 mg/l has been observed (3,15). As the Phosphorus content of hyacinths varies noticeably with the Phosphorus content of the water (15), it may be suspected that luxury uptake may occur, or that physiological adjustments made by the plant reduce the metabolic Phosphorus demands. As hyacinths display polymorphism to some degree and respond quite obviously to environmental conditions, the latter case may be suspected. As a suggestion, it may be wise to be aware of the possibility of Phosphorus limitations. However, as a rule, it does appear that the other target nutrient, Nitrogen, is much more influential on the rate of growth. Nitrogen subsequently, regardless of form (Nitrate, Ammonia, organic or Nitrate) was the logical selection as Monod's limiting nutrient, S.

The next requirement in model development was to establish the relationship between temperature and growth rate. Because water temperature serves as a good representative of long term ambient temperature trends, it was utilized as the temperature parameter during this analysis (16).

The effect of temperature upon biological activity can be expressed by the van't Hoff-Arrhenius relationship.

$$\frac{U_2}{U_1} = \Theta^{T_2 - T_1}$$

where U_2 = specific growth rate at T , 1/day

U_1 = specific growth rate at T , 1/day

T_2, T_1 = temperatures, °K

Θ = constant, usually 1.01 to 1.10.

In identifying a Θ value for the Lake Helen conditions, a regression analysis was done with ln U on the y axis (empirically collected rates at similar Nitrogen concentrations) and $(T_2 - T_1)$ on the x axis. The resulting slope, therefore, is the negative of ln Θ. This relationship, as shown in Figure 2, indicates a reasonable Θ value of 1.07, when T_2 is set at 25°C, and $(T_2 - T_1)$ _ Θ.

In an effort to approximate the values of K (concentrations of Total Nitrogen where $U_f = 1/2\ U_{max}$) and U_{fmax} for field conditions, an attempt was made utilizing the method described by Lineweaver and Burk (9). This method, as noted, was also used by Musil and Breen (8) in their laboratory investigations.

As suspected, field data is more scattered than laboratory data. Subsequently, firm linear relationships were more difficult to establish. However, as shown in Figure 3, there was a discernible relationship established from the Lake Helen work between the inverse of the field growth rate and the inverse of Total Nitrogen concentration. From this a maximum field growth rate (U_{fmax}) of 0.03 - 0.06/day, and K_s of 7.50 - 8.00 mg/l Total Nitrogen can be identified as a reasonable design range.

In an attempt to obtain maximum yield from the crop, it is desirable to maintain the crop within a certain density. Ryther et al (6), as noted, indicated from field studies that the optimum wet density is about 2.0 - 3.0 lb/ft². This correlates well with Amasek's experience that both intraspecific and grazing pressures can interfere with productivity when excessive crop density is allowed. The logical theme then is to develop a harvest stabilized, quasi-steady state system, or pulse-stabilized per Odum (17). Therefore, within a certain grazing space, A:

$$D_tA - D_\circ A = D_\circ A(e^{U_f(t-1)} + U_{1-1}) \qquad [6]$$

or

$$D_t - D_\circ = D_\circ(e^{U_f(t-1)} + U_{1-1}) \qquad [7]$$

where D_t = maximum desired wet crop density (D_{max})

$D_\circ$ = wet crop density at time zero (minimum allowable density or D_{min}).

The time factor in this case, therefore, would be the time between harvesting, and would be determined by equation [8]

$$t_h = \ln\left(\frac{Dmax}{Dmin}\right)/U_f \qquad [8]$$

With the relationships developed within equations [4],[5] and ' [8], it becomes practical to express the Nitrogen removal effiency through equation [9].

$$R_n = \frac{K_n Q C_n t_h + WND_\circ A\ (e^{U_f(t_h - 1)} + U_{1-1})}{Q C_n t_h} \qquad [9]$$

where R_n = fraction removal of Nitrogen

Q = daily flow

A = growing area

C_n = Total Nitrogen concentration.

WN = Nutrient fraction of wet plants

Finally, the Nitrogen effluent concentration (C_{en}), can be expressed by:

$$C_{en} = \frac{Q C_n t_h - K_n Q C_n t_h - WND_\circ A_\circ (e^{U_f(t_h - 1)} + U_{1-1})}{Q t_h - K_w D_\circ A_\circ (e^{U_f t_{n-1}}) + r_{th} A} \qquad [10]$$

where K_w = evapotranspiration constant expressed as volume of water loss per unit net growth

r_{th} = rainfall during period t_h.

The constants, K_n, K_w, and K_p (Phosphorus loss coeefficient) were considered during the Lake Helen study and are summarized in Table 4. Indications from these values are that over fity percent of the Nitrogen loss is from incidental phenomenon. It is suspected that the major contributor to secondary Nitrogen removal would be denitrification. This has been indicated by Debusk et al (10), as well as several other researchers. Other mechanisms, however, such as ecosystem recycling and uptake, emmigration (through larval emergence and predation), adsorption and even Ammonia stripping may be significant contributors as well. It is suggested that the hyacinth crop, as the primary producer, offers significantly to the support of these processes, and subsequently is paramount to the efficiency of even these indirect Nitrogen losses.

Incidental Phosphorus losses are less reliable to predict, with indications that during certain periods some additional Phosphorus loads may be imposed upon the water column through intermittent release from stores. It is likely that adsorption/desorption phenomenon within the submerged soils plays a significant role in Phosphorus dynamics within the lagoons, although larval emergence should also be suspected. The soil/water exchange is one reason why separation of lagoons should be considered during process design, with the final lagoons being protected from the capricious behavior of the Phosphorus-laden sediments of the receiving lagoons. Actual selection of high Phosphorus affinity soils may also be considered, if extensive Phosphorus removal is desired.

Values for the evapotranspiration loss coefficient (Kw) are generally consistent with other findings (18). As a rule, highly productive hyacinth systems can be expected to transpirate 150 - 200 inches/year. This offers significant benefit to the wastewater manager in cases where both hydraulic and nutrient loading limits are expressed within a discharge allocation. Utilizing the obvious relationship between growth rate and transpiration was considered an appropriate method of projecting water losses.

Upon development of these basic equations, they were incorporated into a practical computer program design model [HYADEM - HYAcinth DEsign Model] which is intended to assist the engineer in quickly projecting system performance in terms of nutrient removal, and in establishing areal requirements, evapotranspirational losses and harvesting needs from simple inputs of flow, temperature, rainfall, nutrient concentrations and the "constants" Θ, K_s, K_w, K_p, K_n, U_1, U_f, and D_{max}.

MODEL VERIFICATION

The model (HYADEM) was utilized to establish design criteria for a small pilot facility funded by the City of Orlando. This study not only served to determine the predictive reliability of this model but also to permit objective assessment of the overall applicability of a hyacinth system for providing the City with needed additional nutrient removal capability. The printout as shown as Figure 6 indicates a total winter time (T=12°C) areal requirement of about 2000 ft². Values used in this run were as listed below.

U_1 - - - - - - - - - - - - - - - - 0.15/day

U_2 - - - - - - - - - - - - - - - - 0.06/day

K_s - - - - - - - - - - - - - - - - - - 5 mg/l TN

Monthly Rainfall	4.5 inches
Maximum Crop density	3.0 lb/ft² (wet)
Summer Temperature	25°C
Winter Temperature	12°C
Influent Nutrient values	6.0 mg/l TN 1.0 mg/l TP
Desired Effluent Nutrient Values	1.5 mg/l TN 0.5 mg/l TP.

This pilot study was constructed as a series of five lagoons, each providing about 400 ft^2 of growing area. By facilitating assessment of process performance, the study also presented a valuable opportunity to determine the effectiveness of hyacinths to consistently reduce nutrients to well below AWT levels.

For a period of several months, 24-hour composite influent and effluent samples were collected daily and tested from this system. The design model was adopted to serve as a HYAcinth Monitoring and Operational Model [HYAMOM] computer program to track the performance of the process and the reliability of the model. As noted in Figure 7, the system responded as projected, with both Nitrogen and Phosphorus being removed to or below the desired levels. The model simulated this performance quite well. In many cases when the model predicted a phosphorus deficiency, effluent levels would be removed to well below 0.10 mg/l, TP. Nitrogen projections fit well even when levels fell below 1.0 mg/l TN.

DISCUSSION

With the establishment of a reliable and practical method for projecting extensive nutrient removals from wastewater through the use of water hyacinth lagoons, it is now possible for the wastewater manager and the design engineer to provide a renovated water which can be returned to hydrologically depressed areas without the threat of culturally induced hypereutrophication.

In Florida, and presumably in many other states, fresh water resources and critical wetlands have been seriously jeopardized by past poor management practices, such as extensive drainage, over-pumping of groundwaters, and clearing of wetlands. River basins, such as the upper St. John's in Florida, have been reduced to a fraction of their past areal expanse. The impacts have been noticeable through reduced wildlife and fish resources, deteriorating water quality, destructive fluctuations in flow patterns, expansive aquatic weed growths, and a general attenuation of aesthetic value. Return of highly treated effluents to these basins is now becoming recognized as a possible method of assisting in restoration of these critical areas. This approach is already being considered by several local Florida governmental entities, and support is being seriously reviewed by the Florida Department of Environmental Regulations and the St. John's River Water Management District, as well as several active, environmentally concerned private groups.

The model presented provides a mechanism from which this (hyacinth) and similar autotroph-based nutrient removal technologies can be evaluated by the practicing engineer. Hopefully, as operating data is gathered and compiled, the model will be further refined, and confidence in process reliability strengthened. There is now reason to believe that the hyacinth concept is ready to leave the arena of pure research and enter into the reality of practical application. In doing so, there is the potential of expanding our capabilities to consistently provide higher levels of pollutant removal at a reasonable demand of both energy and financial resources.

REFERENCES

1. Conn, W.M., Catenary Treatment of Municipal Wastewater To Produce A Potable Water Source, Water Utilities Department, City of San Diego, California.

2. Dinges, Ray, "Development of Hyacinth Wastewater Treatment Systems in Texas", Aquaculture Systems for Wastewater Treatment, Seminar Proceedings and Engineering Assessment, United States Environmental Protection Agency, MCD-67, Sacramento, California, September, 1979, p. 193.

3. Amasek, Inc., Assessment of Iron Bridge Water Hyacinth Pilot Study, P. O. Box 3767, Cocoa, Florida 32924, March, 1984.

4. Amasek, Inc., Review, Evaluation and Recommendations for Effluent Dispersal into the Reedy Creek Drainage Basin, P. O. Box 3767, Cocoa, Florida 32924, June, 1984

5. Monod, J., Recherches sur la Croissance des Cultures Bacteriennes, Jermann Press, Paris, 1942, 210 p.

6. Ryther, John H., "Treated Sewage Effluent as a Nutrient Source for Marine Polyculture", Seminar Proceedings and Engineering Assessment, United States Environmental Protection Agency, MCD-67, Sacramento, California, September, 1979, p. 351.

7. Michaelis, L. and Menten, M.L., "Die Kinetiek der Inverteinwirkung", Biochem. Z., Vol. 49, 1913, p. 333.

8. Musil, C. F. and Breen, C.M., "The Application of Growth Kinetics to the Control of Eichhornia crassipes (Mart.) Solms. through Nutrient Removal by Mechanical Harvesting", Hydrobiologia, Vol 53, No. 2, 1977, p. 165.

9. Lineweaver, H. and Burk, D., "The Determination of Enzyme Dissociation Constants", J. Am. Chem. Soc., Vol. 56, 1934, p. 658.

10. DeBusk, T.A., Williams, L.D., and Ryther, J.H., "Removal of Nitrogen and Phosphorus from Waste Water in a Waterhyacinth-Based Treatment System", J. Environ. Qual., Vol. 12, no. 2, 1983, p. 257

11. Swett, Dan, "A Water Hyacinth Advanced Wastewater Treatment System", Seminar Proceedings and Engineering Assessments, United States Environmental Protection Agency, MCD-67, Sacramento, California, September 1979, p. 233.

12. Stewart, E. Allen, III, "Utilization of Water Hyacinths for Control of Nutrients in Domestic Wastewater", Seminar Proceedings and Engineering Assessment, United States Environmental Protection Agency, MCD-67, Sacramento, California, September 1979, p. 273.

13. Mitsch, William J., "Ecosystem Modeling of Lake Eutrophication with Special Reference to Aquatic Weed Management", Department of Environmental Engineering Sciences, University of Florida, Gainesville.

14. Haller, W. T., et al, "Phosphorus Absorption by and Distribution in Waterhyacinths", Proceedings of the Crop and Soil Science Soceity Florida, 1970, V. 30, p. 64.

15. Musil, C. F. and Breen, C. M., "The Influence of Site and Position in the Plant Community on the Nutrient Distribution In, and Content of _Eichhornia crassipes_ (Mort.) Solms.", _Hydrobiologia_, Vol. 53, No. 1, 1977, p. 67.

16. Kruzic, Andrew P., "Water Hyacinth Wastewater Treatment System at Disney World", Seminar Proceedings and Engineering Assessment, United States Environmental Protection Agency, MCD-67, Sacramento, California, September, 1979, p. 257.

17. Odum, Howard T., _Environment, Power, and Society_, Wiley - Interscience, New York, 1971, p. 261.

18. Lee, C. and McKim, T. "Water Hyacinth Treatment System", Interim report for the Reedy Creek Utilities, Lake Buena Vista, Florida, 1980.

TABLE 1. CHEMICAL FEED FORMULATION FOR SIMULATED WASTEWATER*

Additive	gm/day
Sodium Chloride	4,645
Milorganite	376
Ferrous Sulfate Iron (II) sulfate	59
Urea	535
Potassium Nitrate	1,746
DiAmmonium Phosphate	349
TOTAL	7,710

681.30 gm N per day

28.58 gm Fe per day

73.48 gm P per day

* Intentionally varied slightly during course of project.

TABLE 2. INFLUENT WATER QUALITY*

MONTH	BOD_5	CHLORIDES	NITRATE-N	TKN	TN	TP	TDS	TSS	Fe	K
2/26/82	9	281	23.6	30.9	54.5	15.3	911	17	0.16	58.5
4/2/82	5	143	13.9	16.4	27.3	7.81	604	3	0.19	38.2
5/4/82	9	222	16.5	18.9	35.4	11.8	3,134	2	3.05	36.3
5/28/82	12	139	14.7	19.3	34.0	11.5	3,310	2	1.85	42.2
6/30/82	5	365	17.5	29.6	47.1	20.0	3,764	3	6.43	60.3
7/30/82	3	140	16.9	13.7	30.6	3.65	624	4	0.06	49.1
9/2/82		93	8.2	12.8	21.0	3.19	466	5	0.60	21.6
9/30/82	6	153	10.4	15.8	26.2	4.87	601	5	0.03	31.3
10/28/82	5	260	12.3	27.7	30.0	8.42	786	13	0.04	37.7
AVERAGE	6.75	199.56	14.9	20.6	35.5	9.62	157.78	6	1.38	41.64

* All Parameters in mg/l, as measured by laboratory analysis of composite samples (weekly).

TABLE 2. INFLUENT WATER QUALITY*

MONTH	BOD_5	CHLORIDES	NITRATE-N	TKN	TN	TP	TDS	TSS	Fe	K
2/26/82	9	281	23.6	30.9	54.5	15.3	911	17	0.16	58.5
4/2/82	5	143	13.9	16.4	27.3	7.81	604	3	0.19	38.2
5/4/82	9	222	16.5	18.9	35.4	11.8	3,134	2	3.05	36.3
5/28/82	12	139	14.7	19.3	34.0	11.5	3,310	2	1.85	42.2
6/30/82	5	365	17.5	29.6	47.1	20.0	3,764	3	6.43	60.3
7/30/82	3	140	16.9	13.7	30.6	3.65	624	4	0.06	49.1
9/2/82		93	8.2	12.8	21.0	3.19	466	5	0.60	21.6
9/30/82	6	153	10.4	15.8	26.2	4.87	601	5	0.03	31.3
10/28/82	5	260	12.3	27.7	30.0	8.42	786	13	0.04	37.7
AVERAGE	6.75	199.56	14.9	20.6	35.5	9.62	157.78	6	1.38	41.64

* All Parameters in mg/l, as measured by laboratory analysis of composite samples (weekly).

TABLE 3. SUMMARY OF GROWTH RELATED FACTORS

Month	Z	Δ Z	U_f	R	T	Q_i	ET LOSS	f	N In lb	N In mg/l	N added lb	N added mg/l	N Out lb	N Out mg/l	P In lb	P In mg/l	P Out lb	P Out mg/l
Feb 1982	9,050	1,847	-0-	1,200	17.0	3,839	1,826	-0-	45.97	51.27	4.17	4.65	1.94	2.59	7.47	8.33	1.96	2.61
Mar 1982	14,175	9,327	0.029	2,747	18.0	7,460	3,656	6,600	56.83	30.44	0.92	0.50	2.26	1.38	9.23	4.94	1.64	1.00
Apr 1982	19,100	20,459	0.024	4,460	20.5	7,460	2,937	15,550	51.08	27.37	16.46	8.82	2.27	1.01	8.30	4.44	1.80	0.80
May 1982	17,608	20,954	0.034	2,373	20.0	7,341	4,573	15,100	47.89	25.23	9.73	5.13	1.79	1.37	7.78	4.10	2.13	1.63
Jun 1982	17,178	33,559	0.051	4,460	25.0	6,948	2,958	22,000	35.76	20.57	17.20	9.90	3.64	1.72	5.81	3.34	2.41	1.14
Jul 1982	16,229	34,796	0.043	3,594	26.6	7,519	2,581	23,600	45.33	23.32	18.18	9.35	3.62	1.64	7.36	3.79	3.20	1.45
Aug 1982	15,127	17,301	0.022	2,445	26.7	7,257	1,557	12,000	45.33	24.16	17.87	9.52	3.58	1.70	7.36	3.92	2.23	1.04
Sep 1982	14,461	39,052	0.049	4,529	25.4	7,351	4,993	29,000	29.37	15.45	15.19	8.00	3.40	1.91	4.77	2.81	0.77	0.43
Oct 1982	12,149	16,319	0.037	1,935	21.0	7,341	-0-	12,000	41.50	21.87	21.07	11.10	5.97	2.38	6.74	3.55	0.80	0.32
Nov 1982	17,807	17,829	0.020	956	22.75	7,998	1,853	14,500	51.72	25.84	16.55	8.27	2.64	1.48	8.40	4.20	0.49	0.27
Dec 1982	17,145	16,439	0.021	2,042	18.65	8,725	3,055	14,500	40.15	17.80	18.27	8.10	6.56	3.29	6.52	2.89	0.98	0.49
Jan 1983	20,340	12,130	0.015	1,757	12.20	7,381	2,130	10,500	74.14	38.86	10.28	5.39	12.07	6.67	12.04	6.31	1.38	0.76
Feb 1983	20,298	10,101	0.012	4,778	12.50	5,032	3,846	9,000	30.65	26.08	10.28	8.75	9.83	7.06	4.98	4.24	1.80	1.29

SYMBOLS

- Z = Standing wet hyacinth crop in pounds
- Δ Z = Gross change in standing wet hyacinth crop in pounds
- U_f = Field growth rate - 1/day
- T = Average water temperature - °C
- Q_i = Average daily flow in gpd, from feed system (excludes rainfall)
- ET LOSS = Net water loss due to evapotranspiration in gpd
- f = Quantity of wet hyacinths harvested - total in pounds
- N In = Nitrogen in through chemical feeder, calculated by input/flow
- N added = Fertilizer Nitrogen added
- R = Rainfall contribution averaged in gpd
- N out = Effluent total Nitrogen from laboratory analysis
- P in = Total Phosphorus, calculated by input/flow
- P out = Effluent total Phosphorus, from laboratory analysis

TABLE 4

Nitrogen, Phosphorus, and Evapotranspiration loss coefficients developed

at

LAKE HELEN, FLORIDA

DATE	K_n	K_p	K_w (gallons/ wet pound produced)
2/82	0.94	0.93	9.43
3/82	0.82	0.71	11.80
4/82	0.64	0.19	4.30
5/82	0.59	0.10	6.77
6/82	0.33	-1.19	2.64
7/82	0.41	-0.92	2.30
8/82	0.70	0.21	2.79
9/82	-0.06	-1.41	3.96
10/82	0.66	0.32	0.00
11/82	0.69	0.41	3.12
12/82	0.61	0.16	2.91
1/83	0.80	0.68	5.46
2/83	0.59	0.09	10.67
Mean	0.595	0.022	5.09
Standard Deviation	0.244	0.498	3.44

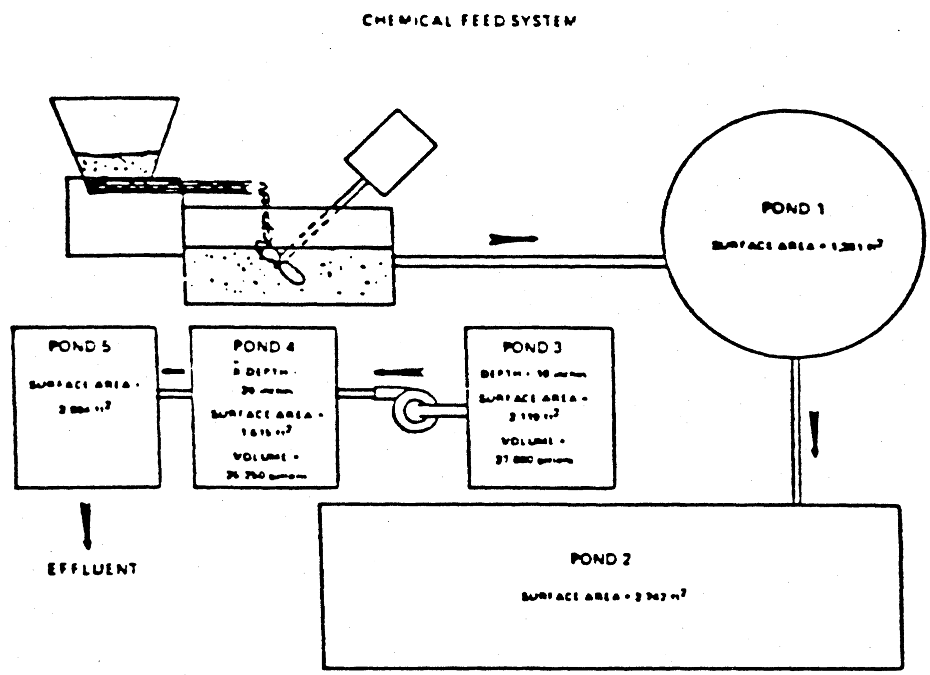

FIGURE 1.
FLOW SCHEMATIC
AND
POND CONFIGURATION AT LAKE HELEN

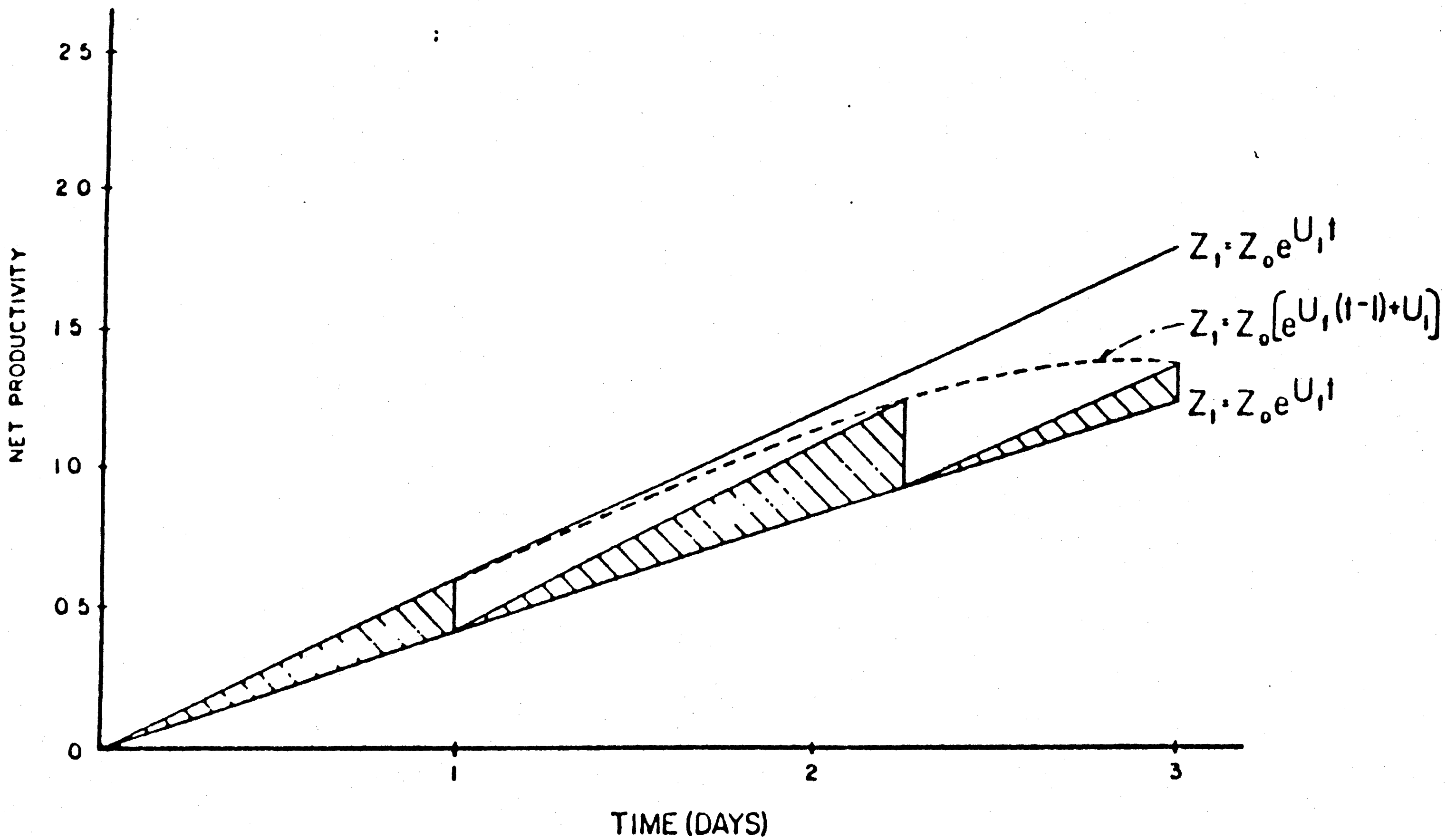

FIGURE 2. METHOD FOR APPROXIMATION OF NET PRODUCTION

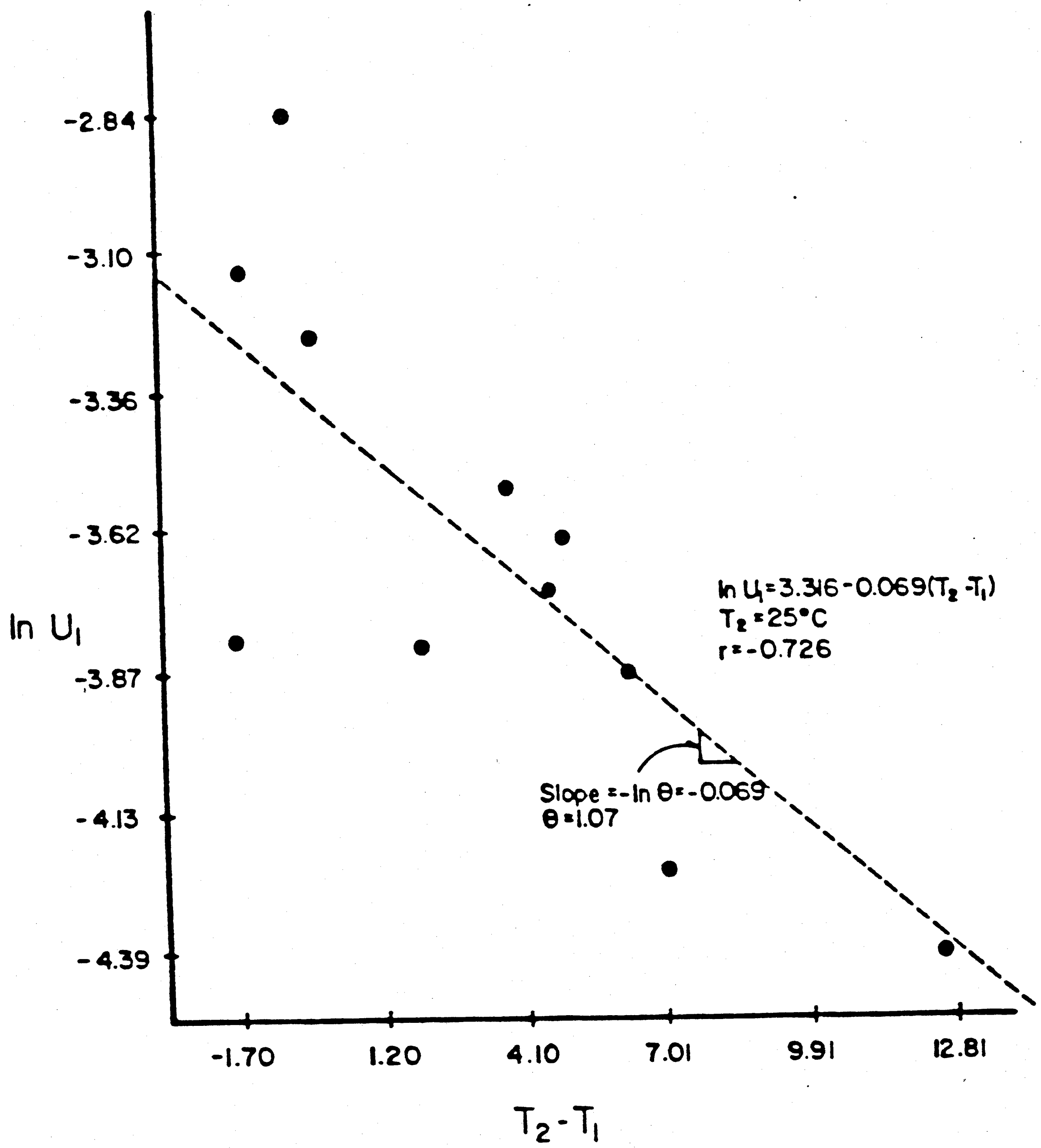

FIGURE 3. DETERMINATION OF VAN'T HOFF-ARRHENIUS CONSTANT, θ

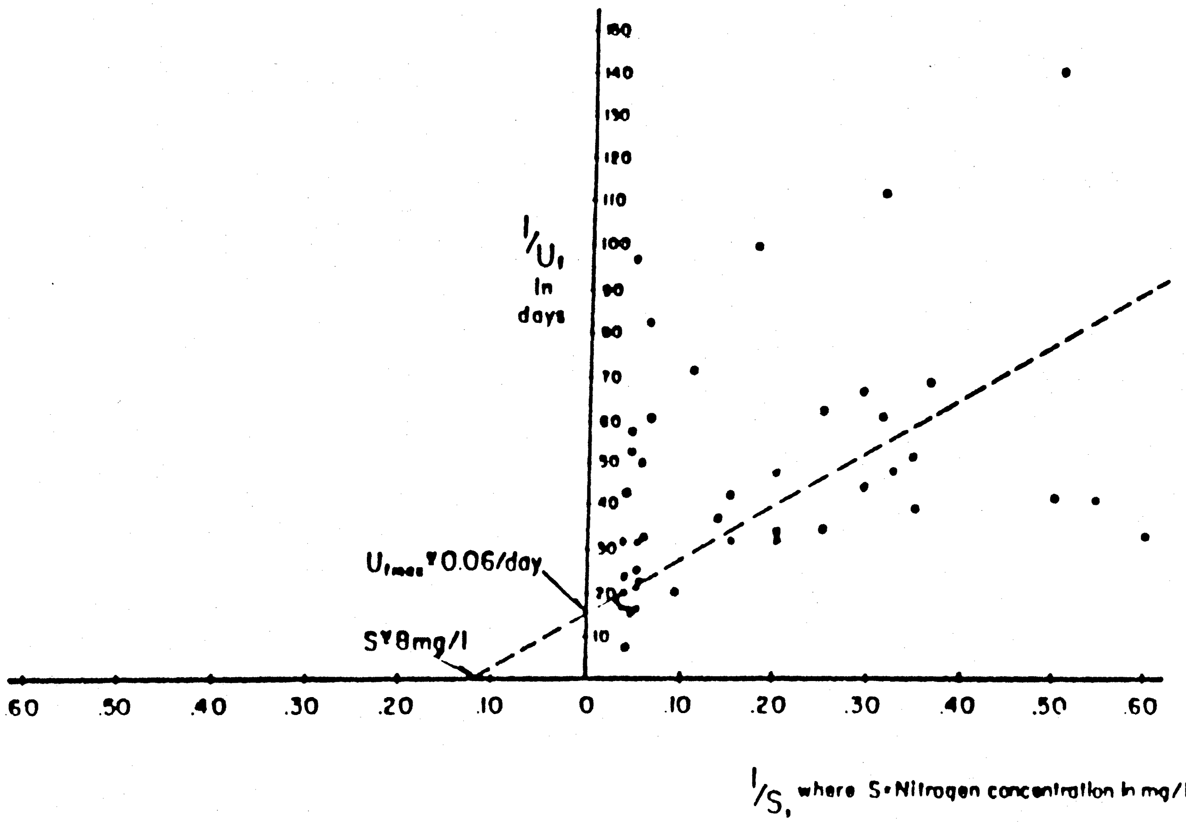

FIGURE 4. LINEWEAVER-BURK DETERMINATION OF MAXIMUM GROWTH RATE (U_{max}) AND HALF RATE CONCENTRATION (K_s) FOR FIELD CONDITIONS.

FIGURE 6

PROJECTION FOR CITY OF ORLANDO

ENGINEER'S PROJECT NUMBER JEBP-PB1-83

NOVEMBER, 1 , 1983

Design flow .... 6E-03 mgpd
Design Nitrogen Removal .... 76.6667 %
Design Phosphorous Removal..... 60 %
Total Influent Nitrogen........ 5.99521 mg/l
Total Influent Phosphorous..... .999201 mg/l

	NITROGEN(MG/L) IN	NITROGEN(MG/L) OUT	PHOSPHOROUS(MG/L) IN	PHOSPHOROUS(MG/L) OUT
POND 1	6.00	1.46	1.00	0.42

NIT(LB/DAY) IN	NIT(LB/DAY) OUT	PHOS(LB/DAY) IN	PHOS(LB/DAY) OUT
0.30	0.07	0.05	0.02

SUMMER	POND 1	WINTER	POND 1
Ul(1/day)	.0738279	Ul(1/day)	.0240611
Uf(1/day)	.0295312	Uf(1/day)	.0138454
H (days)	6.17387	H (days)	13.1664
dZ(tons)	.046	dZ(tons)	.046
Z (tons)	1.11656	Z (tons)	2.85264
V (gpd)	322	V (gpd)	322
F (tons)	.223312	F (tons)	.570529
A (acres)	.0170885	A (acres)	.0436585
QI(mgpd)	6E-03	QI(mgpd)	6E-03
QO(mgpd)	5.74761E-03	QO(mgpd)	5.85584E-03
Removal N	76.6667	Removal N	76.6667
Removal P	60	Removal P	60

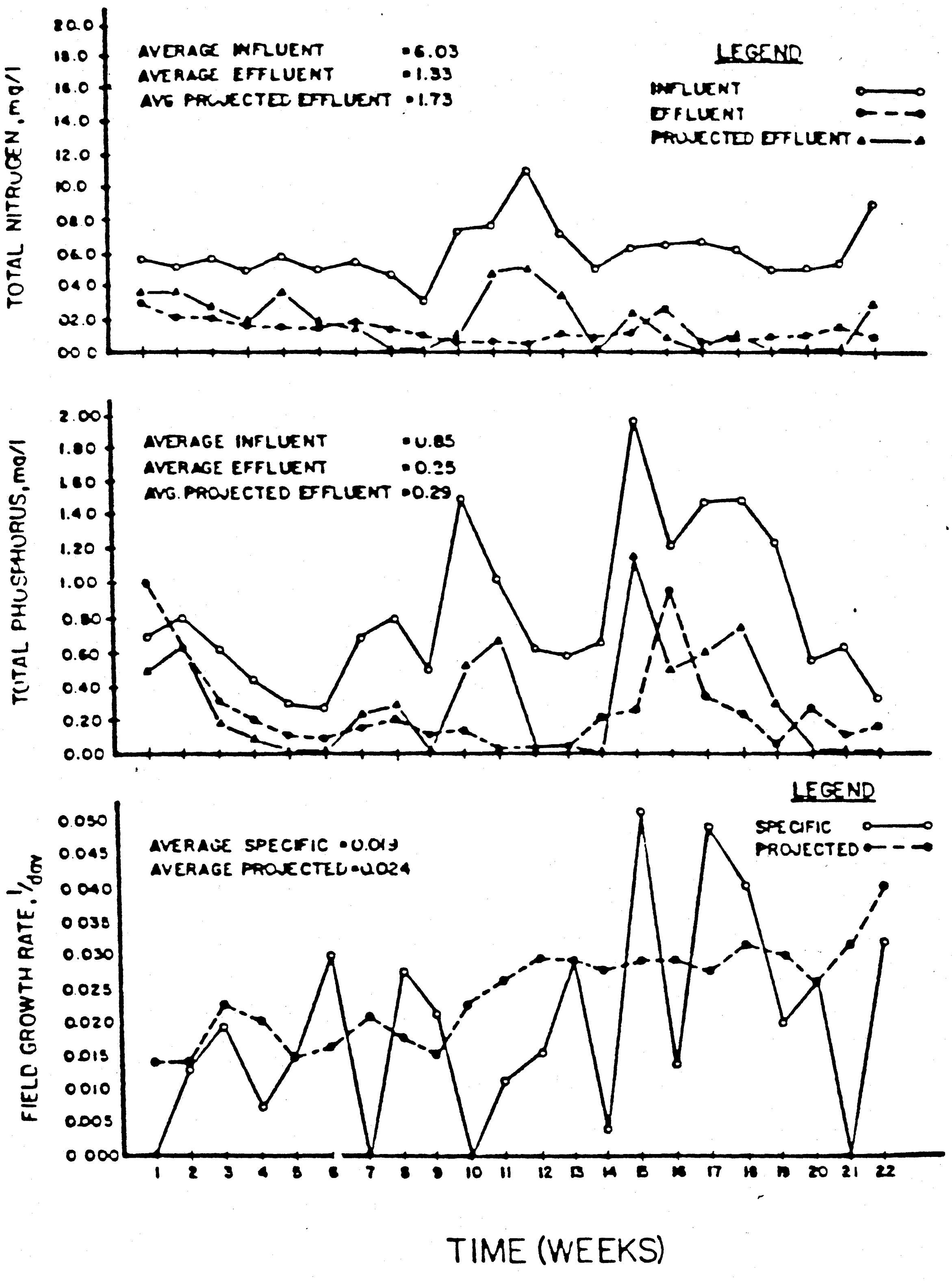

FIGURE 6. MODEL PREDICTED VALUES COMPARED TO ACTUAL VALUES FOR CITY OF ORLANDO PILOT STUDY