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Effect Of Aquatic Macrophytes On Physico-Chemical Parameters Of Agricultural Drainage Water[1]

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ABSTRACT

Retention ponds and flooded fields are currently used as a possible treatment system to improve the quality of agricultural drainage water that has been discharged from organic soils planted to vegetable crops. The role of aquatic macrophytes cultured in these systems on physico-chemical characteristics of treated and untreated drainage water were monitored over a period of 27 months. Allowing drainage water to flow through a reservoir stocked with waterhyacinths (*Eichhornia crassipes* [Mart] Solms) decreased dissolved O_2, temperature, pH, conductivity (EC), turbidity, and HCO_3^- alkalinity, but increased the dissolved CO_2. Dissolved O_2 of water flowing through the reservoirs stocked with elodea (*Egeria densa* Planch) or cattails (*Typha latifolia* L) was increased, thus, creating an anaerobic environment in the water. Drainage water flowing through these systems was high in pH, temperature, CO_3^{-2} alkalinity and turbidity, but low in dissolved CO_2, HCO_3^- alkalinity, and EC compared to untreated water. Appreciable reduction in biological oxygen demand (BOD) and chemical oxygen demand (COD) was observed in the water flowing through the reservoir stocked with waterhyacinths, but little or no change was observed in water flowing through other treatment systems. Dissolved O_2, EC, pH, and temperature were increased in the water flowing over flooded fields, but dissolved CO_2, HCO_3^- alkalinity and turbidity were decreased as compared to untreated water.

INTRODUCTION

Lake Apopka (12,500 ha) located in Florida, U.S.A., is currently eutrophic. One of the causes of the lake's gradual decline was nutrient loading from the discharge of drainage water from adjacent organic soils (7,800 ha) planted with vegetable crops (EPA, 1979 a). Currently, retention reservoirs are used to detain excess organic soil drainage water in order to reduce nutrient loads to the lake. In recent years, several researchers (Wahlquist, 1972; Wooten and Dodd, 1976; Cornwell, et al. 1977; Reddy, et al. 1982) have used aquatic plants stocked in ponds and flooded fields to reduce nutrient levels of wastewaters. These systems, however, not only remove nutrients from the water, but also alter the physico-chemical characteristics of the water. Some of the characteristics of water that can be influenced by the presence of aquatic macrophytes and algae are dissolved O_2, biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), pH, dissolved CO_2, HCO_3^- and CO_2^{-2} alkalinity and turbidity. The objective of this study was to evaluate the seasonal variations in physico-chemical parameters of water as influenced by the floating, submersed, and emersed aquatic plants cultured in reservoirs and flooded fields.

MATERIALS AND METHODS

Experimental reservoirs and flooded fields were established at the Agricultural Experiment Station Research Farm, in the Zellwood Drainage District near Lake Apopka. Soil type (Lauderhill series) in this area is organic (Lithic Medisaprists, euic, hyperthermic) with a muck layer thickness of 20 to 120 cm underlain by about 25 cm thick calcareous rock and marl. These soils are planted with vegetable crops (carrots, sweet corn, raddish, celery) from September through May, and are flooded during June through August to control weeds and soil-borne pathogens. Mole drains are established in these fields at a depth of about 90 cm. During periods of excessive rainfall, organic soils are drained by lowering the water level in adjacent canals. Water from these canals is moved into larger canals and then pumped into the adjacent lake. Drainage water from one of the large canals was pumped into the experimental reservoirs.

Five flow-through reservoirs (Fig. 1) were constructed with 2.0 m high levees of organic soil and with bottoms composed of calcareous marl. Reservoir R1 (3720 m^2) was partitioned into equal areas by two chevron shaped chickenwire fences. The first section was stocked with waterhyacinths (*Eichhornia crassipes* [Mart] Solms), followed by elodea (*Egeria densa* Planch), and cattails (*Typha latifolia* L) in the second and third sections, respectively. Drainage water was pumped diagonally through the plant stands in the order of waterhyacinths, elodea, and cattails at a rate of 57 m^3/hr. Additional reservoirs, R2, R3, and R4, each with a surface area of 1240 m^2, were connected in series by riser panels and were stocked with waterhyacinths (R2), elodea (R3), and cattails (R4). Drainage water was pumped at a rate of 57 m^3/hr diagonally through R2 and was allowed to flow by gravity through R3 and R4. Water was also pumped (19 m^3/hr) into reservoir R5 (1240 m^2) which contained no cultivated aquatic macrophytes. Water depth was one m in R1, R2, R3, and R5, and 0.6 m in R4. Flooded field, F1 (3721 m^2), series of flooded fields, F2, F3, and F4 (each with a surface area of 1240 m^2) were stocked with

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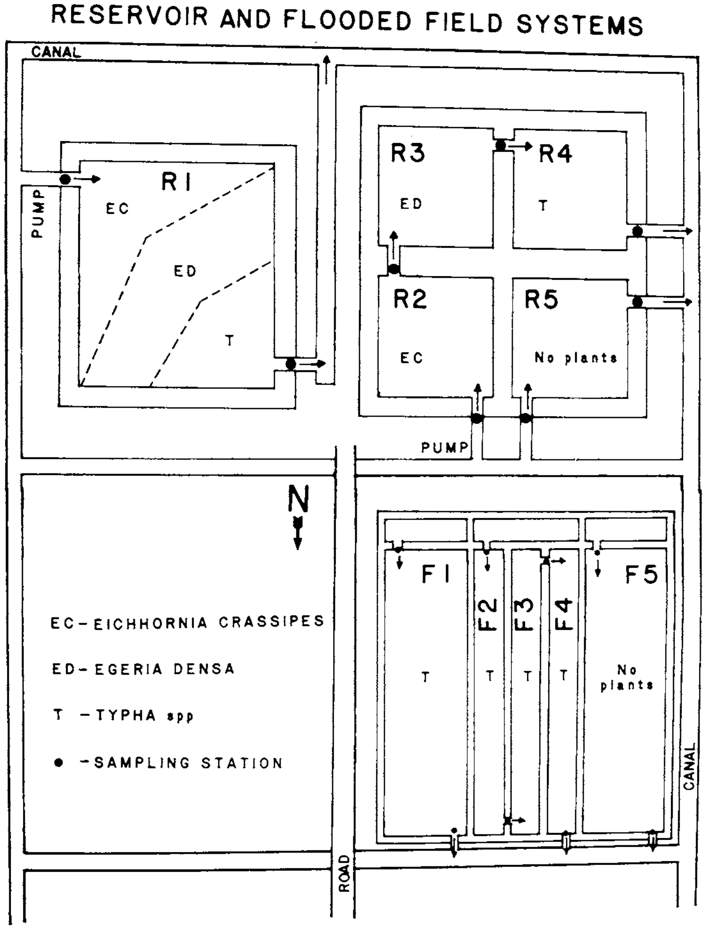

Figure 1. Schematic representation of the field layout of reservoirs and flooded fields.

cattails (Fig. 1). Flooded field, F5 (3720 m^2), was not stocked with plants. Drainage water was pumped into F1, F2, and F5 at 26 m^3/hr for 6 hrs each day, 6 days a week, to obtain a water column depth of 20 cm. Water was allowed to flow by gravity from F2 to F3 and F4. Once every 3 months, 50% of the area covered by waterhyacinths were removed from R1 and R2 reservoirs. Cattails were harvested once every 4 months. Elodea and *Chara* sp. were not harvested.

Water samples were obtained at the inlet and outlet of each reservoir and flooded field after 3 hrs of pumping. Between July 1977 and August 1978, water samples were obtained once a week, but during September 1978 to September 1979, frequency of water sampling was increased to 3 times a week. Water samples were collected between 10:30 and 11:00 A.M. on any given day.

Dissolved O_2 of the water was measured at the time of water sampling using a YSI oxygen meter. Dissolved CO_2, HCO_3^- and CO_3^{-2} alkalinity, pH, and conductivity were measured within one hour after collection of the water sample. Electrical conductivity and pH were measured using a conductivity meter and a pH meter. Dissolved CO_2, HCO_3^-, and CO_3^{-2} alkalinity were determined by titration (A.P.H.A., 1971). Turbidity was measured using a turbidity meter. Chemical oxygen demand was measured for only 4 months (June 1979 to September 1979) on water samples collected every Wednesday using a BOD apparatus (Hach Chemical Co.).

RESULTS AND DISCUSSION

Biomass Yields

Productivity of waterhyacinths in R1 and R2 was in the range of 10.4-45.8 g dry wt/m^2•day, while elodea and *Chara* sp. recorded a productivity of 1.4-4.6 and 0.3-2.5 g dry wt/m^2•day, respectively. Productivity of cattails were 3.0-11.9 g dry wt/m^2•day in reservoirs, and 9.5-40 g dry wt/m^2•day in flooded fields.

Dissolved Oxygen (DO)

Dissolved O_2 concentration of the treated water increased by an average of 122% in the large single reservoir, R1, compared to an increase of 149% in the water flowing through series of small reservoirs, R2, R3, and R4 (Table 1). Control reservoir, R5, increased DO values of the incoming water by 35%. In the small reservoir series, DO concentration of the water flowing through R2 decreased by 23%, due to dense plant cover above the water column and high O_2 demand in the water column. Oxygen levels in this pond were in the range 0-6 $\mu g/ml$ (Fig. 2). High levels during certain times of the year were observed when the pond surface was covered partially by waterhyacinths. Depletion of O_2 was probably due to the dead root fragments from the hyacinths and leaking of soluble organic compounds from the roots. However, DO increased by 257% in the presence of submerged elodea plants (R3). Dissolved O_2 of the water leaving the R3 reservoir was in the range of 8-14 $\mu g/ml$. Directing water flow through an additional small reservoir, R4, resulted in a decrease in DO, but DO levels were about 2.5 times higher than in untreated water. Dissolved O_2 also increased (53 to 100%)

TABLE 1. PERCENT REDUCTION OR INCREASE IN THE CONCENTRATION OF SEVERAL PHYSICO-CHEMICAL PARAMETERS OF THE TREATED DRAINAGE WATER.[a]

Reservoir system	DO	Temp	EC	pH	DCO_2	HCO_3	Turbidity
R1	−121.7 b	−4.7 a	−0.2 a	−2.5 b	27.3 c	−0.9 b	11.3 ab
R2	22.5 c	4.4 c	0.5 a	2.6 a	−65.3 d	1.6 b	30.0 a
R2 → R3	−257.4 a	−4.4 a	7.5 b	−9.4 c	83.5 a	32.5 a	0.6 b
R2 → R3 → R4	−148.9 b	−5.9 a	11.5 c	−9.1 c	83.9 a	32.1 a	−6.1 bc
R5	−35.4 c	−1.7 b	6.9 b	−10.9 c	58.8 b	38.2 a	−21.5 c

[a] Percent reduction or increase in the physico-chemical parameter = [(I-O)/I] x 100 where; I = values of the inflow drainage water; O = values of the outflow drainage water; Negative sign indicates the increase in the physico-chemical parameter of the drainage water. For each parameter, values with same letter are not statistically significant at the 0.05 level of probability, using Duncan's Multiple Range Test.

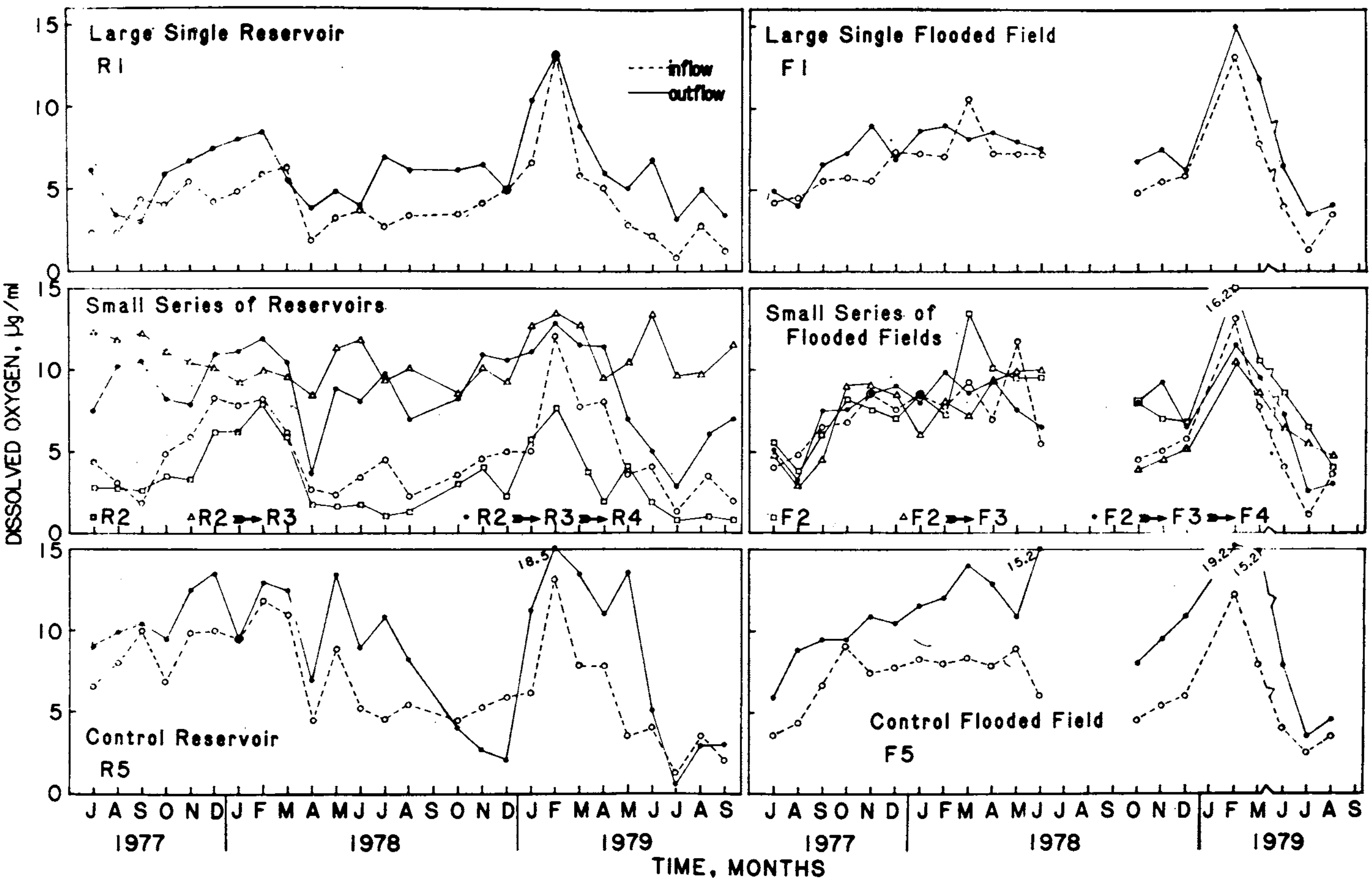

Figure 2. Dissolved oxygen concentration of the drainage water at the inflow and outflow of each treatment system.

when water was allowed to flow over flooded fields containing cattails (Table 2). Increased DO values of the water in the control reservoir and flooded fields were due to the photosynthetic activity of the algal blooms that were observed.

Temperature

No significant differences were observed between the temperature of water flowing through a large single reservoir stocked with three plant stands in series or 3 independent reservoirs in series (Table 1 and 2). Temperature of outflow drainage water in flooded fields was increased by 4 to 9%. Water flowing through cattail plant stands were cooler compared to the water flowing through the flooded field containing no plants.

Conductivity (EC)

Maximum reduction of 11.5% in the EC was observed for water flowing through three small independent reservoirs, R2, R3, and R4 (Table 1), whereas, very little or no change was observed in the EC values of the water flowing through reservoir R1. EC was reduced by 7% in the flowing through the control reservoir. Reduction in EC was due to uptake of ions by plants and precipitation to insoluble compounds. Conductivity of water flowing over flooded fields increased slightly (Table 2). This was

Table 2. Percent reduction or increase in the physico-chemical parameters of the treated drainage water flowing through the various flooded fields.[a]

Flooded fields	DO	Temp	EC	pH	DCO_2	HCO_3	Turbidity
F1	−67.2 ab	−5.0 b	−0.9 a	−5.9 b	40.1 b	3.2 a	26.0 a
F2	106.5 b	−5.4 b	−0.8 a	−4.1 c	30.5 b	1.5 a	19.0 a
F2 → F3	−81.1 ab	−4.1 b	−9.1 a	−4.3 c	29.9 b	1.3 a	24.5 a
F2 → F3 → F4	−52.8 a	−6.2 b	−2.1 a	−3.9 c	28.7 b	2.8 a	20.1 a
F5	−108.3 b	−9.4 a	−0.1 a	−8.9 a	74.0 a	9.0 b	−3.7 b

[a] Percent reduction or increase in the physico-chemical parameter = [(I-O)/I] x 100 where; I = values of the inflow drainage water; O = values of the outflow drainage water; Negative sign indicates the increase in the physico-chemical parameter of the drainage water. For each parameter, values with the same letter are not statistically significant at the 0.05 level of probability, using Duncan's Multiple Range Test.

probably due to the release of soluble ions from the underlying anaerobic organic soil to the overlying aerobic water column.

pH

pH of the outflow water was increased by 3 to 11% in the RI reservoir or 3 small reserviors in series, R2, R3, R4, or control reservoir, R5 (Tables 1 and 2). However, the pH of the water flowing through the reservoir, R2, was decreased by 3%. The decrease in pH was due to accumulation of CO_2 in the water beneath the waterhyacinth plant stands. In flooded fields, pH of the water was increased by 4 to 9%.

Dissolved Carbon Dioxide (DCO_2), Bicarbonate (HCO_3^-), and Carbonate (CO_3^{-2}) Alkalinity

Dissolved CO_2 of the outflow water decreased by an average of 27% in the large single reservoir (R1) compared to 84% in the series of small reservoirs (R2, R3, and R4 and 59% reduction in the control reservoir (R5) (Table 1, Fig. 3). In the reservoirs in series, DCO_2 concentration of the water flowing through R2 was increased by 65%. Dissolved CO_2 concentration of the water leaving waterhyacinths and flowing through submerged elodea plant stands was decreased by 84%. This was probably due to assimilation of CO_2 by elodea during photosynthesis. Directing the water through an additional reservoir, R4, resulted in no further decrease in DCO_2. Dissolved CO_2 of water in flooded fields was also decreased by 28 to 40% in the fields with cattails and by 74% in the control field (Table 3).

Bicarbonate concentration of the water flowing through R2 decreased by 1.6% and allowing the water to flow through the R3 reservoir decreased HCO_3^- concentration by 32.5% (Table 1, Fig. 4). Directing the water flow through an additional reservoir, R4, resulted in no further decrease in HCO_3^- concentration. Bicarbonate concentration of the water decreased by 38.2% in the control reservoir, R5. Similar response was not observed in the water flowing through the large single reservoir. Bicarbonate concentration of the water flowing over flooded fields also decreased by 1.3 to 3.2% in the fields planted to cattails and by 9.0% in the control field (Table 2). Large reduction in HCO_3^- concentration was due to increased pH, which resulted in CO_3^{-2} formation (Fig. 5).

Maximum concentration of DCO_2 was observed in the drainage water with pH less than 7.0. Dissolved CO_2 concentration of the water decreased with increase in pH, and approached zero at a pH of 8.3. Maximum HCO_3^- concentration was observed at a pH of 7 to 7.5 and decreased with increase in pH. Carbonate level in the drainage water

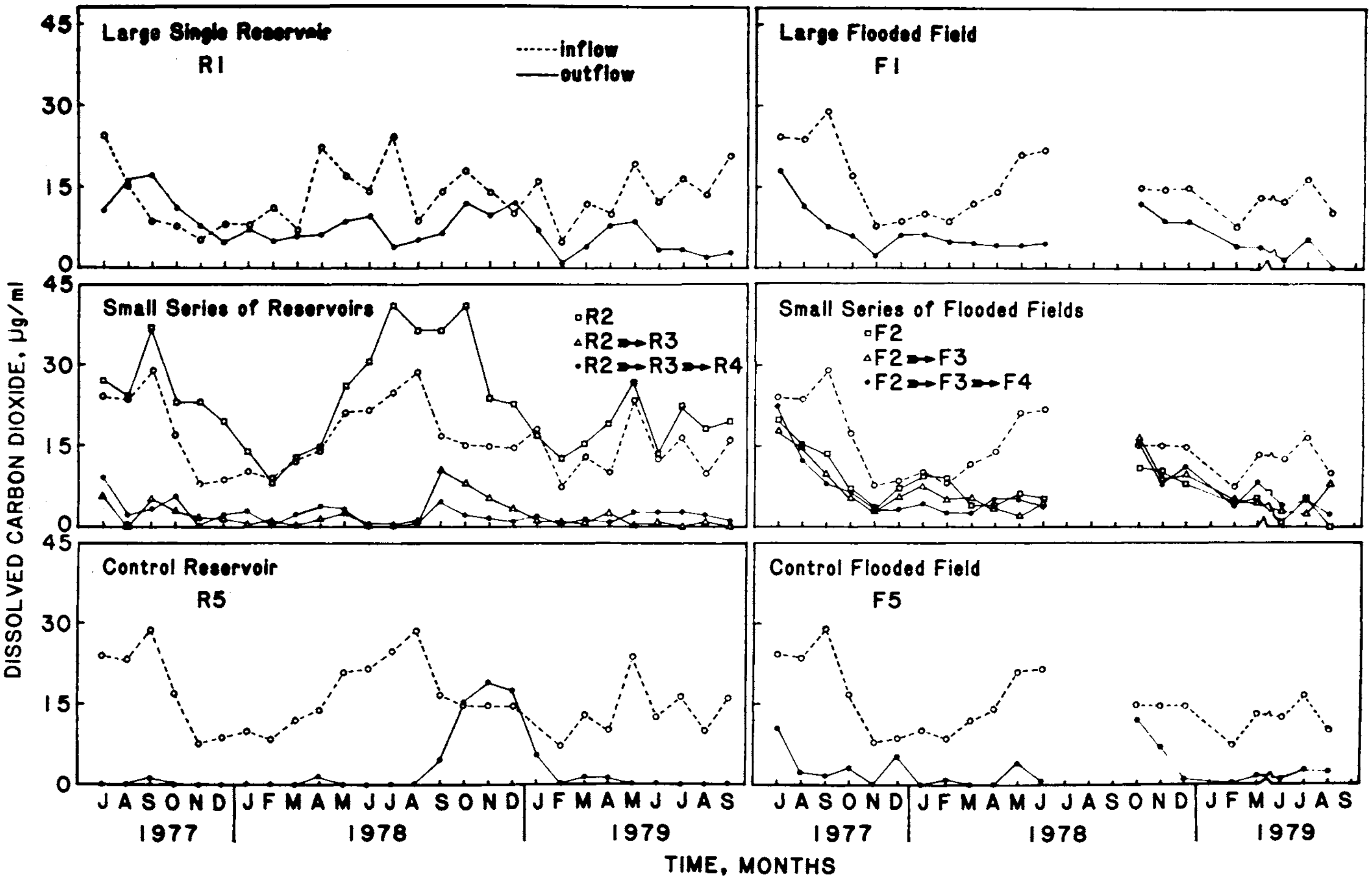

Figure 3. Dissolved CO_2 concentration of the drainage water at the inflow and outflow of each treatment system.

Table 3. Average concentration of COD and BOD of the untreated and treated drainage water in the reservoirs.

Reservoir system	Chemical oxygen demand μg/ml				Biological oxygen demand μg/ml			
	Mean[a]	Min	Max	CV (%)	Mean[a]	Min	Max	CV (%)
Large single reservoir (R1)								
Inflow	154	39	385	61	22	6	40	44
Outflow	167	39	409	67	17	11	25	33
Small reservoirs in series								
Inflow	163	77	604	85	20	6	30	39
Outflow								
R2	121	31	262	57	11	6	18	35
R2 → R3	135	50	277	49	17	11	32	40
R2 → R3 → R4	166	58	492	77	16	5	22	35
Control reservoir (R5)								
Inflow	163	77	604	85	20	6	30	39
Outflow	157	50	377	71	13	4	26	52

[a]Based on time average (June 1979 to September 1979).

was observed at a pH of 7.5 to 8.0 and increased with increase in pH.

Oxygen Demand Parameters

Chemical O_2 demand of untreated drainage water ranged from 39 to 604 μg/ml (Tables 3 and 4). Reduction in COD was observed in the water flowing through waterhyacinth (R2) plant stands. Very little or no reduction was observed in COD of the water flowing through the remaining treatment system.

Appreciable reduction in BOD (15 to 45%) was observed in the water flowing through the reservoir systems (Table 3). Maximum reduction (45%) in BOD was observed in reservoir R2. It is interesting to note that both COD and BOD reduction was in the water flowing through waterhyacinth (R2) plant stands, where the environment was anaerobic, as indicated by low DO levels. Also, dense

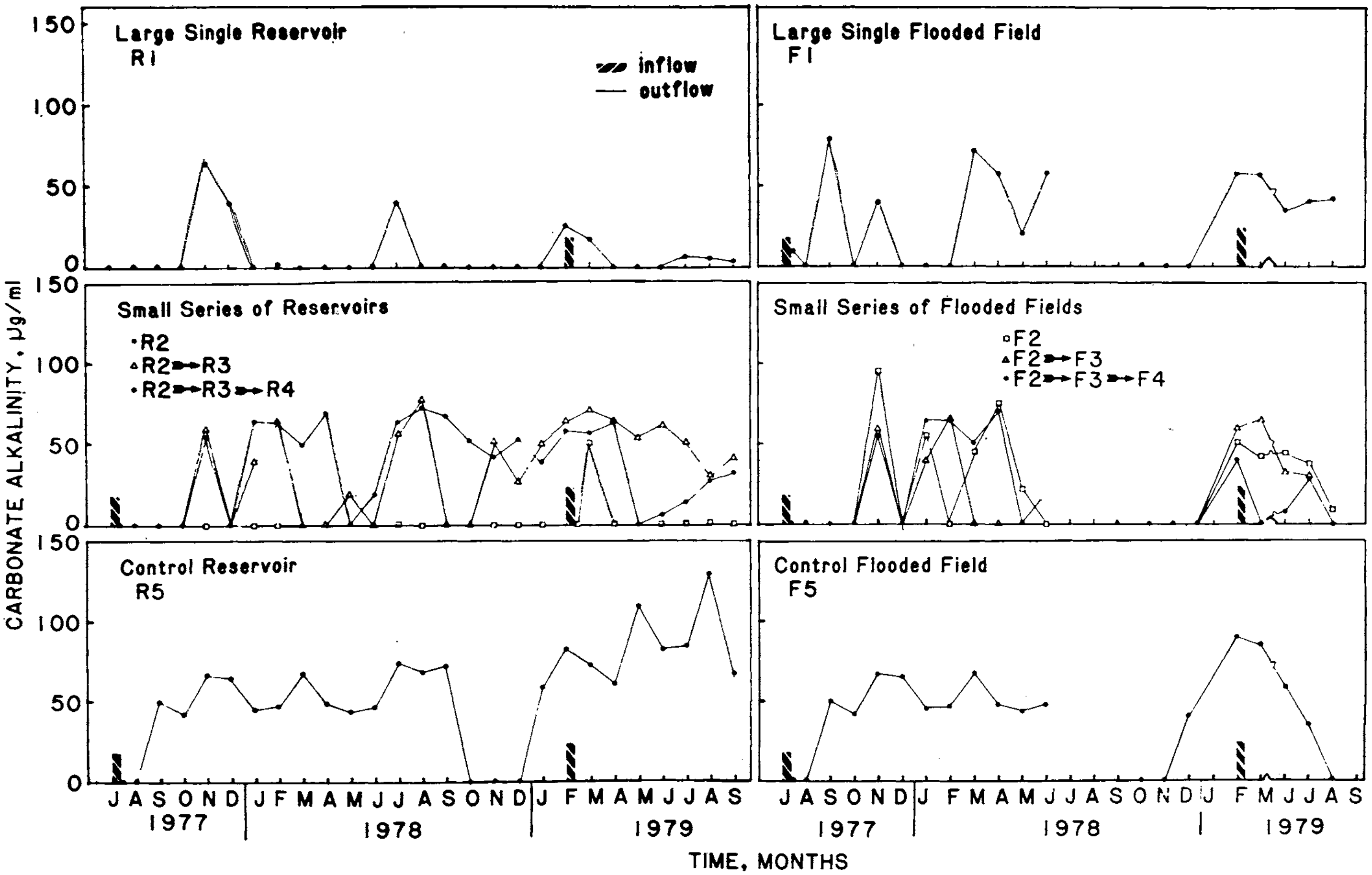

Figure 4. Bicarbonate alkalinity of the drainage water at the inflow and outflow of each treatment system.

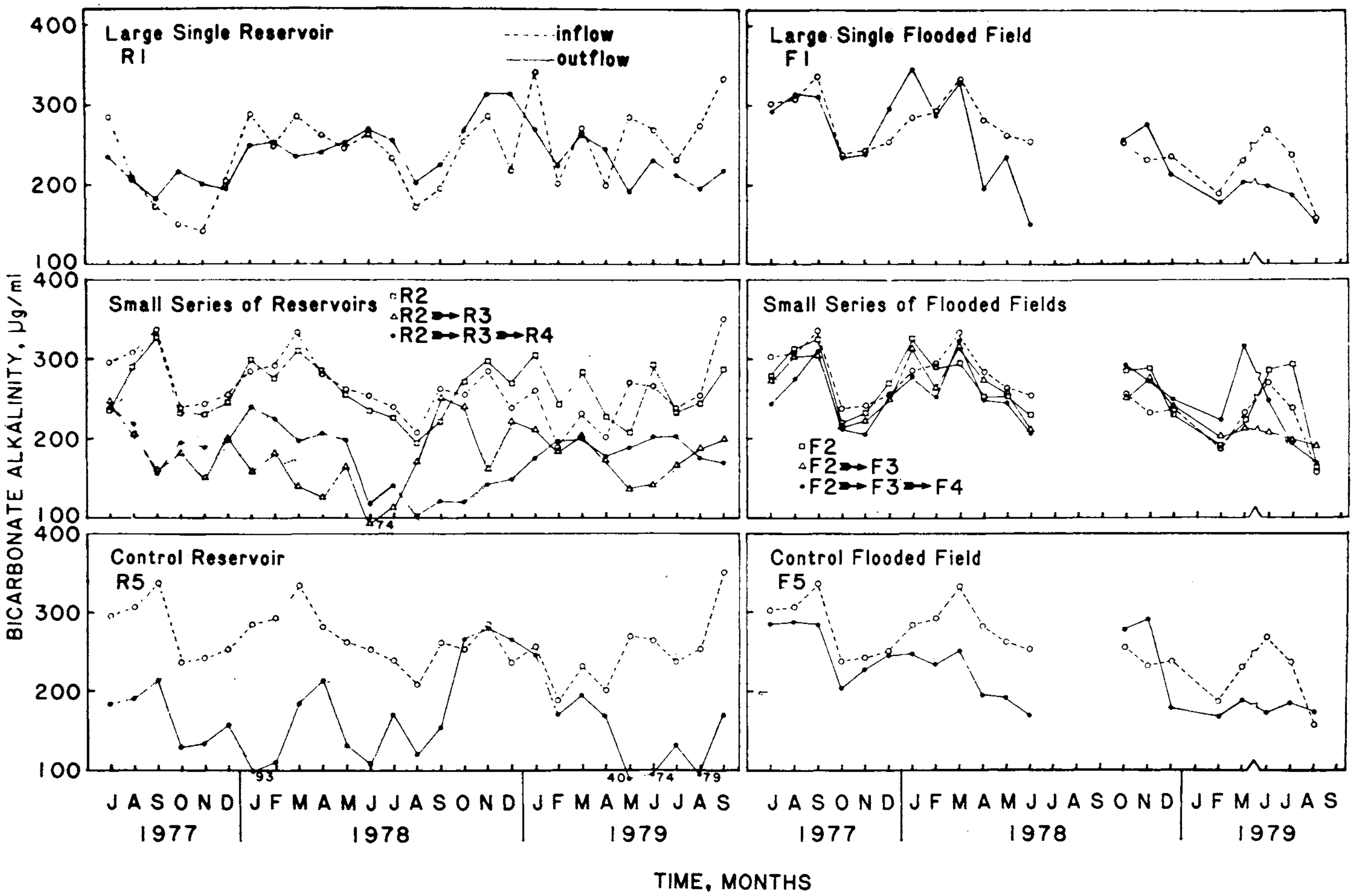

Figure 5. Carbonate alkalinity of the drainage water at the inflow and outflow of each treatment system.

waterhyacinth root systems provided a filtration effect, thus, decreasing the turbidity of the water. Decrease in turbidity means a reduction in suspended carbonaceous particles, thus, resulting in a reduction in both BOD and COD.

Turbidity

For the reservoirs with aquatic plants, –6 to 30% reduction in turbidity of the outflow was observed (Table 1). In the control reservoir, R5, turbidity was increased by 22%. Turbidity was decreased by 30% in the water flowing through the R2 reservoir. Flooded fields with plants decreased turbidity by 19 to 22%, whereas, the control field with no plants increased turbidity by 4% (Table 2).

In conclusion, this study has shown that certain physico-chemical characteristics of the water can be altered by utilizing aquatic macrophytes. Changes in DO, EC, DCO_2, HCO_3^-, CO_3^-, and temperature of the water leaving the treatment system are probably transitory in nature. These changes would not be expected to be long term, detrimental, or beneficial to the treated water or to the receiving water body.

TABLE 4. AVERAGE CONCENTRATION OF CHEMICAL OXYGEN DEMAND ON THE UNTREATED AND TREATED DRAINAGE WATER IN FLOODED FIELDS.

Flooded field	Chemical oxygen demand, μg/ml Mean	Min	Max	CV (%)
Large flooded field (F1)				
Inflow	163	77	604	85
Outflow	219	69	423	62
Small flooded fields in series				
Inflow	163	77	604	85
Outflow				
F2	130	66	200	34
F8 → F3	214	54	423	61
F2 → F3 → F4	173	54	365	53
Control flooded field (F5)				
Inflow	163	77	604	85
Outflow	168	77	346	53

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LITERATURE CITED

1. A.P.H.A. 1971. Standard methods for the examination of water and wastewater. Amer. Publ. Health Assoc., 13th Ed., Washington, D.C.
2. Boyd, C. E. 1969. Vascular aquatic plants for mineral nutrient removal from polluted waters. Econ. Botany 23:95-103.
3. Boyt, F. L., S. E. Bayley, and Zolte, Jr. 1977. Removal of nutrients from treated municipal wastewater by wetland vegetation. J. Water

Pollut. Control. Fed. 49:789-799.

4. Buscemis, P. S. 1958. Littoral oxygen depletion produced by a cover of *Elodea canadensis*. Oikos 9:239-245.
5. Cornwell, D. A., J. Zoltek, Jr., C. D. Patrinely, T. des Furman, J. I. Kim. 1977. Nutrient removal by waterhyacinths. J. Water Pollut. Control Fed. 49:57-65.
6. E.P.A. 1979a. Environmental impact statement. Lake Apopka Restoration Project. Lake and Orange Counties, Florida. E.P.A. 904/9-79-043. 200 pp.
7. E.P.A. 1979b. Methods for chemical analysis. U. S. Environmental Protection Agency. E.P.A. 600/4-79-020. Cincinnati, Ohio. 430 pp.
8. Fetter, C. W., Jr., W. E. Sloey, and F. L. Spangler. 1978. Biogeochemical studies of a polluted Wisconsin marsh. J. Water Pollut. Control Fed. 50:290-307.
9. Penfound, W. T. 1956. Primary production of vascular aquatic plants. Limnol. Oceanogr. 1:92-101.
10. Rai, D. N., and Hayashree Datta Munshi. 1979. The influence of thick floating vegetation (waterhyacinth-*Eichhornia crassipes*) on the physico-chemical environment of a fresh water wetland. Hydrobiologia 62:65-69.
11. Reddy, K. R., P. D. Sacco, D. A. Graetz, K. L. Campbell, and L. R. Sinclair. 1982. Water treatment by an aquatic system: Nutrient removal by reservoirs and flooded fields. Environ. Mangmt. 6:261-271.
12. Tilton, D. L., and R. H. Kadlec. 1979. The utilization of a freshwater wetland for nutrient removal from secondarily treated wastewater effluent. J. Environ. Qual. 8:328-334.
13. Turner, R. E., J. W. Day, M. Meo, P. M. Payonk, T. B. Ford, and W. G. Smith. 1976. Aspects of land treated waste application in Louisiana wetlands. p. 145-167. *In* D. L. Tilton, R. H. Kadlec, and C. J. Richardson (eds.). Freshwater Wetlands and Sewage Effluent Disposal. Univ. of Mich., Ann Arbor, MI.
14. Wahlquist, H. 1972. Production of waterhyacinths and resulting water quality in earthen ponds. Hyacinth Control J. 10:9-12.
15. Wooten, J. W., and J. D. Dodd. 1976. Growth of waterhyacinths in treated sewage effluent. Econ. Bot. 30:29-39.