Project Number 05

PROJECT COMPLETION REPORT

Performance Evaluation of an Artificial Wetlands Filter Treating a Facultative Lagoon Effluent

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INTRODUCTION

Wastewater stabilization lagoons have been used for treating wastewater for over 3000 years, with the first recorded pond treatment plant constructed in the United States in 1901 (Reed et al., 1988). Virtually thousands of these systems exist, treating a wide range of industrial and municipal wastewaters (EPA 1983). Facultative lagoons, because of their low construction and operation costs, are the most common systems encountered. These lagoons are quite capable of reducing five day biological oxygen demand (BOD5) to acceptable discharge levels; however, total suspended solids (TSS) resulting from the natural occurrence of algae in the lagoons can greatly exceed permissible effluent limitations (Harris 1977).

Upgrading facultative lagoons to meet effluent standards for TSS has focused on processes to remove algal solids (Harris 1977; Nagavi and Malone 1986). A more direct approach uses aquatic plants to completely shade the water column and thus prevent light penetration and the growth of algae (Reed et al., 1988). Floating plants such as water hyacinth (Eicchornia crassipes) can be used to upgrade sewage lagoons (Wolverton, 1986), and though this is an effective treatment method, the water hyacinth is limited to warm climates or greenhouse use. In addition, high concentrations of chemical waste and brackish or salt water can inhibit the growth of this plant (Haller et al., 1974). To overcome the limitations of water hyacinths, other plant based systems have been developed using either floating plants such as duckweed, Lemna minor, or media-rooted emergent plants such as the European reed, Phragmites comunis (Wolverton 1984; Cooper and Boon, 1987). Artificial wetlands filters (AWF), using cold tolerant emergent plants in combination with a fixed film, rock media biofilter, offers a potentially effective treatment scheme for extended season use (Elkins et al., 1986; Reed et al., 1988).

The use of both artificial and natural wetlands for wastewater treatment is well documented (Spangler 1976; Laksman 1979; Wolverton 1983). Similar systems such as the root zone method, natural wetlands, Max Plank Institute Process, and the Lelystad Process have been used in Europe and England for a number of years to treat both domestic and industrial wastewaters (Cooper and Boon, 1987). Typically, an AWF system uses a combination of rock media with attached microbial growth and rooted emergent plants to reduce BOD5, nutrients, and TSS to acceptable standards. The media supports a mixed bacterial population capable of degrading a wide range of simple organic compounds. The actual mechanisms of bacterial degradation are unknown, but are considered to be a combination of aerobic and anaerobic processes. Solids associated with the wastewater are physically entrapped in the rock media and are biologically degraded over time. Nitrogen in the wastewater is removed via coupled nitrification/denitrification processes or by plant uptake (Laksman, 1979, Wolverton et al., 1983; Gersberg et al., 1986).

Gersberg et al (1986), in a pilot scale study using primary wastewater, compared the performance of bulrush, cattails, common reed and an unvegetated control. Using a hydraulic residence time of six days, mean BOD5 removal rates were 96, 81, 74, and 69 percent respectively, for bulrush, reed, cattails and unvegetated systems. The difference in these removal efficiencies appeared to be based on the degree of root penetration into the rock media.

Artificial wetland systems are being recommended and constructed to help small communities with facultative lagoons upgrade to meet more stringent effluent standards. In Louisiana, two municipal plants using AWF units for polishing lagoon effluent are in operation, while many other small communities are considering these systems. While some initial design criterion for filter depth, width and length have been specified for home treatment systems (Hughes and Deffes, 1987), the larger treatment plants were designed from data developed at NASA (Wolverton 1983). Little information is available for continuous flow systems addressing critical upper-end organic loading capacities, specific filter volume requirements, and nutrient requirements. More importantly for the operating plants in Louisiana, no specific AWF operational data is available for parameters relating to BOD5, TSS, algal solids, and other water quality parameters.

The objective of this study was to evaluate the performance of an existing AWF system used to polish effluent from a facultative wastewater stabilization lagoon. The site selected for this study was the treatment plant at the Gillis W. Long Hansen's Disease Control Center located in Carville, Louisiana.

SITE DESCRIPTION

The treatment plant facility used in this study was located at the United States Department of Public Health Gillis W. Long Hansen's Disease Center in Carville, Louisiana. This research hospital serves about 500 resident and non-resident patrons. In the past several years the existing treatment plant was upgraded from a conventional trickling filter with an anaerobic digestor to an aerated lagoon/facultative lagoon/AWF system.

The upgraded treatment system, shown in Figure 1, consists of an aerated lagoon, two facultative lagoons, AWF and a Ultraviolet (UV) disinfection system. Raw wastewater is collected and pumped from a wet well to a submerged discharge in the aerated lagoon. The water depth of the aerated lagoon is five feet with a surface area of 1.74 acres and a total volume of 384,250 ft^3. At the treatment plant design flow of 150,000 gpd, the resulting detention time in the aerated lagoon is 19.1 days. Four 3.0 h.p. floating aerators are available, but only two are operating at any one time. Wastewater from the aerated lagoon flows into two serially connected facultative stabilization lagoons. The first lagoon has a water depth of five feet, a surface area of 0.40 acres, and a volume 87,500 ft^3 giving a detention time at the design flow rate of 4.4 days. The second lagoon has depth of five feet, surface area of 0.60 acres, and a total volume of 132,500 ft^3, giving a detention time at design flow of 6.5 days. The discharge from the last facultative lagoon goes to the submerged header inlet in the AWF. Treated wastewater is discharged from the AWF through a V-notched weir. Disinfection of the final discharge is achieved by the UV unit. The process flow of the treatment train can be modified by the use of a bypass pipeline which allows the flow to go directly from the aerated lagoon to the AWF.

The AWF unit was designed to meet effluent standards of 10 mg/l BOD5, and 15 mg/l TSS and sized based on a flowrate of 150,000 gpd (104 gpm) and detention time of 24 hours (Wolverton 1983). A crossection of the Carville AWF is shown in Figure 2 with an influent treatment

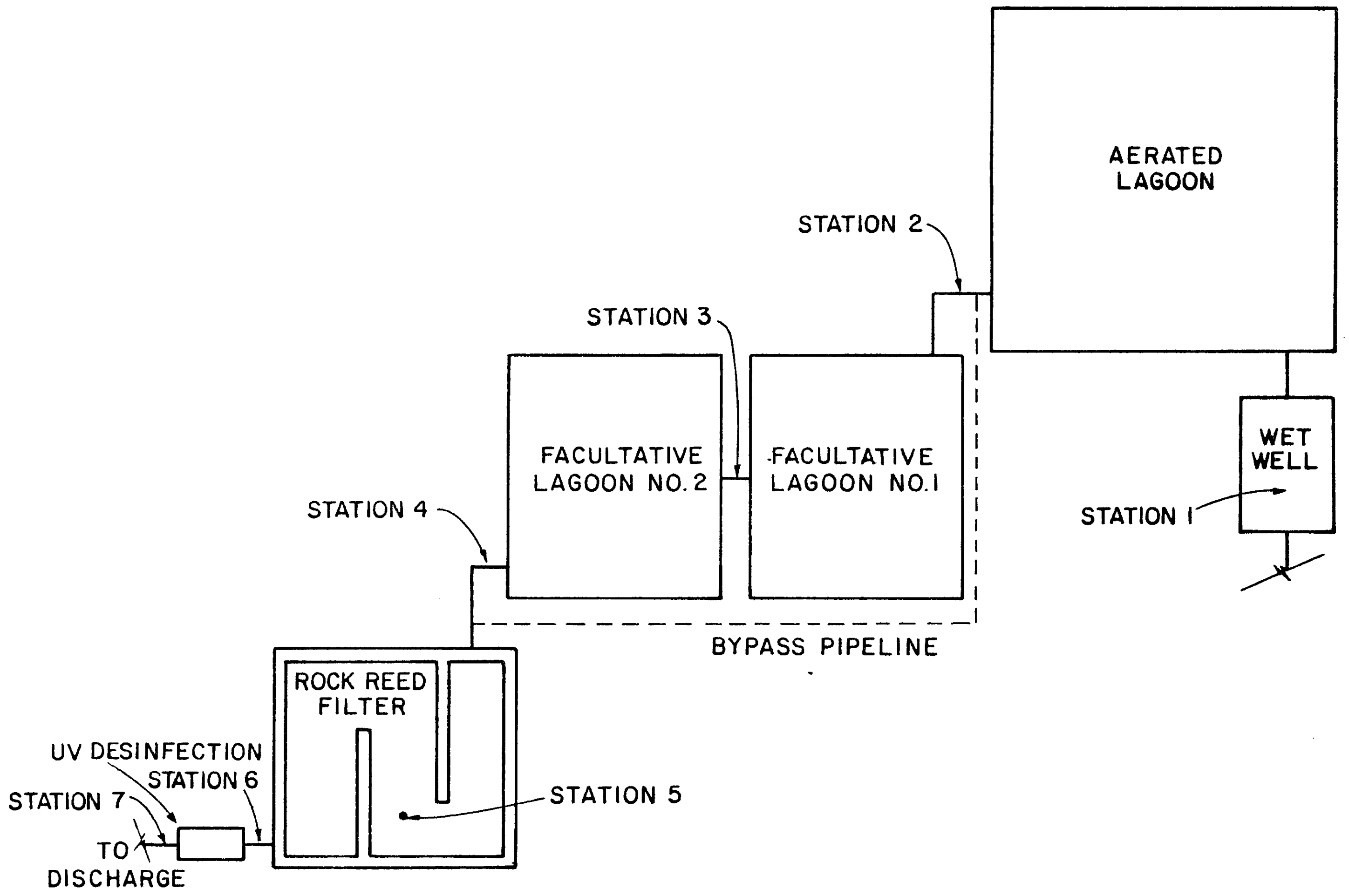

Figure 1. Layout of the wastewater treatment facility located at the U.S. Department of Public Health Gillis W. Long Hansen's Disease Center in Carville, Louisiana.

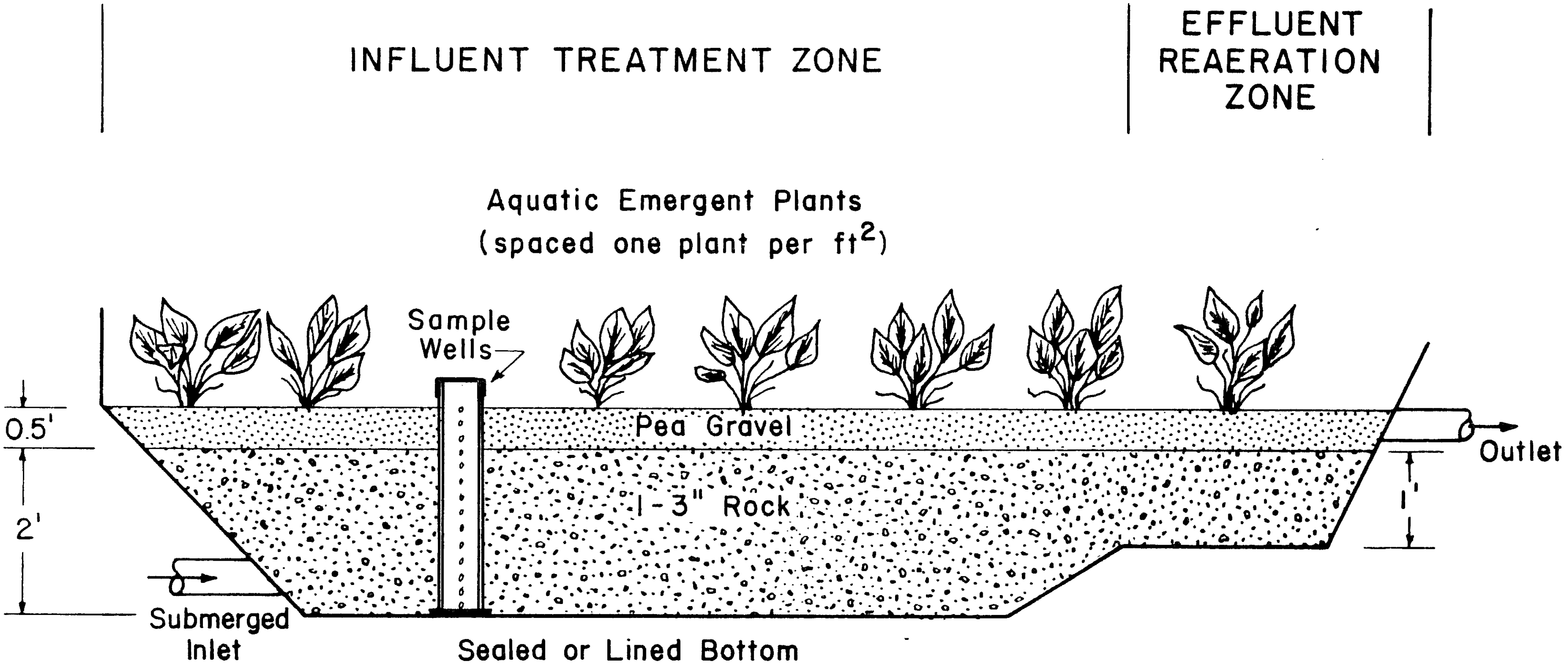

Figure 2. Crossection of the artificial wetlands filter (AWF) located at the Carville wastewater treatment facility.

zone (depth two ft) and effluent reaeration zone (depth one ft). The filter bed is composed of two feet of one to three inch limestone with a 0.5 foot cap of pea gravel. Sidewalls are 3.5 feet deep with a sideslope of one on two. The AWF has a center line length of 480 feet with a surface area of 0.51 acres. Four perforated sampling wells (6 inch diameter, 2.5 feet deep) are located at intervals of about 100 feet along the center line. Influent wastewater is distributed through an eight inch submerged header pipe and flows horizontally to an effluent weir. Water levels are maintained at a depth of about four inches below the surface of the pea gravel to control mosquitoes, filter flies, and algae. Arrowhead or Swamp Potato (_Sagittaria_ _latifola_) and Duck Potato (_Sagittaria_ _falcata_) were planted on one foot centers in the pea gravel over the surface of the filter.

MATERIALS AND METHODS

Evaluation of the performance of the treatment system at the Carville site was carried out over a five month period from February through June of 1988. Samples were collected about twice a week throughout this time period. Sample stations were established as shown in Figure 1 to evaluate the performance of each of the treatment components as well as the AWF.

Field samples were taken by the Environmental staff at the Carville site and samples were transported to the LSU Department of Civil Engineering laboratories for analysis. Flowrates, temperature and pH were measured in the field. Temperature and pH were measured directly with a Hach Mini pH meter. Flowrate data was taken from inplant flow recording equipment. Samples were stored at 4 deg C for no more than 24 hours until analyzed in the laboratory for BOD5, TSS, and VSS. All analyses were performed in accordance with Standard Methods (APHA 1980). Rainfall data for the Carville area was collected from the St. Gabriel weather station.

RESULTS

Treatment Plant Unit Operations

The measured flowrates through the treatment plant at the Carville site ranged from 30 - 160 gpm (43,200 - 230,000 gpd), with a mean flowrate of 84 gpm (120,960 gpd). The calculated high range, low range and mean detention times for the aerated lagoon, facultative lagoon No. 1, facultative lagoon No. 2, and the AWF are presented in Table 1. The mean flowrate resulted in detention times for each process that were 20 percent higher than the design flowrate of 104 gpm. For the high flow condition, detention times were decreased almost 48 percent from the design detention times. For the low flow condition, detention times increased 56 percent over design detention times.

The mean values for the raw wastewater characteristics are shown in Table 2. Comparison of the Carville data with typical values for domestic wastewater reported by Metcalf and Eddy (1981), indicates that the Carville wastewater is considered a weak wastewater. In addition, the ratio of TSS to BOD5 and VSS to TSS for the Carville wastewater is higher than values reported by Metcalf and Eddy.

The BOD5 measured at each of the 7 sample stations is shown in Figure 3 and the mean values presented in Table 2. The mean BOD5 values for sample stations 1-7 were 110.6, 19.1, 16.2, 13.5, 8.1, 5.2, and 4.9 mg/L, respectively. As indicated by the standard deviations, the variability of the BOD5 was higher in the raw wastewater samples than in

Table 1. Unit operation detention times based on high range,low range, mean,and design flowrates for the Carville, Louisiana Wastewater Treatment Facililty.

Unit Operation	Detention Time, days			
	Design	Mean	High Range	Low Range
Aerated Lagoon	19.1	23.8	12.4	66.4
Facultative Lagoon No.1	4.4	5.3	2.8	15.1
Facultative Lagoon No.2	6.5	7.8	4.3	22.8
Artificial Wetlands Filter	1.0	1.2	0.7	3.5
Total System	31.0	38.1	20.2	107.8

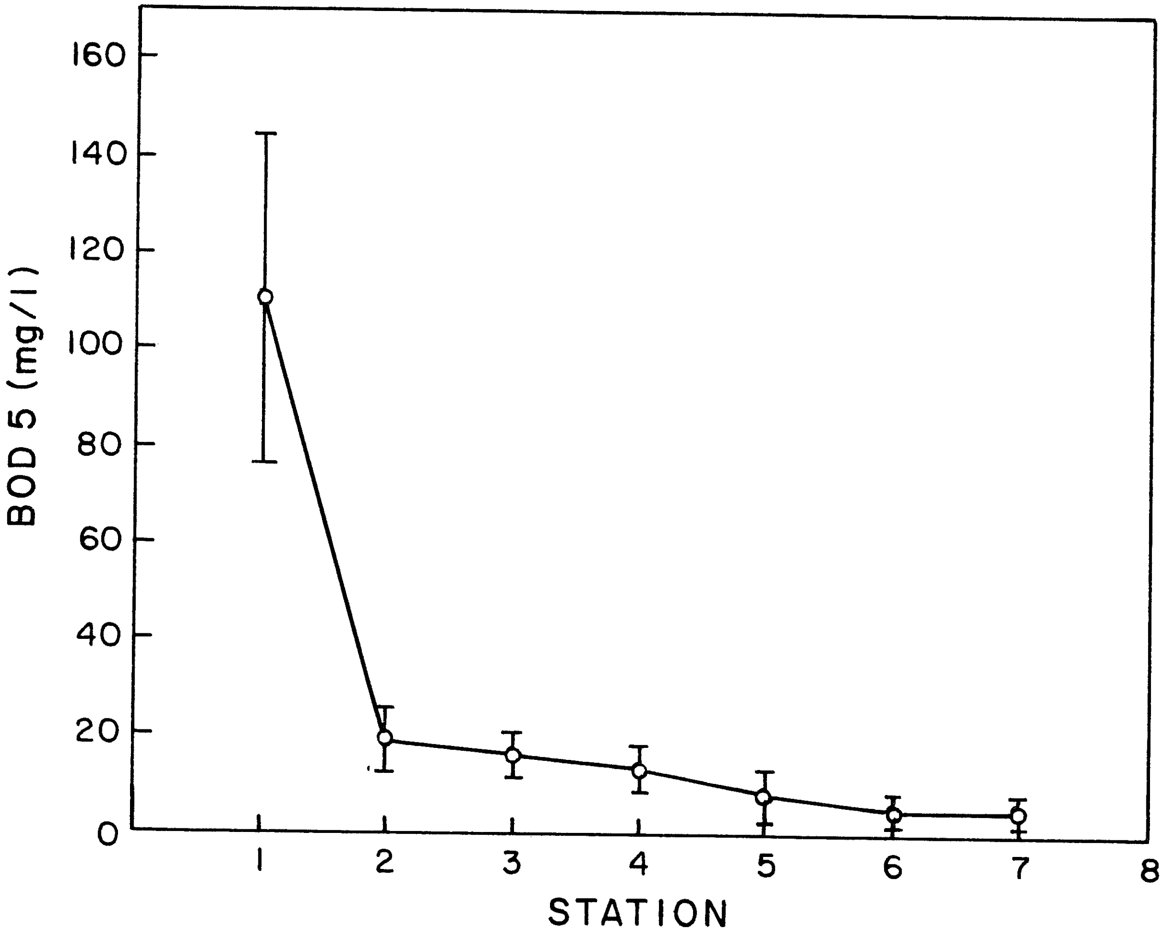

Figure 3. Mean biological oxygen demand (BOD5) for each unit operation at the Carville facility.

Table 2. Mean values for parameters measured for each unit operation at the Carville wastewater treatment facililty.*

Unit Operation	BOD5 mg/L	TSS mg/L	VSS mg/L	pH
Raw Influent (station 1)	110.6 (34.03) n = 24	119.9 (51.90) n = 25	103.3 (28.20) n = 18	8.1 (0.49) n = 26
Aerated Lagoon (station 2)	19.1 (6.46) n = 24	95.7 (25.25) n = 25	74.8 (11.99) n = 18	8.1 (0.33) n = 26
Facultative Lagoon No.1 (station 3)	16.2 (4.88) n = 24	57.2 (14.23) n = 26	56.9 (10.23) n = 19	8.6 (0.57) n = 26
Facultative Lagoon No.2 (station 4)	13.5 (4.69) n = 24	45.9 (14.34) n = 26	44.7 (9.90) n = 18	8.9 (0.58) n = 26
Artificial Wetlands Filter Sample Well (station 5)	8.1 (4.90) n = 26	17.7 (8.10) n = 26	16.0 (6.60) n = 18	7.8 (0.30) n = 26
Artificial Wetlands Filter Effluent (station 6)	5.2 (2.92) n = 22	10.8 (7.82) n = 25	8.9 (4.67) n = 18	7.7 (0.30) n = 26
Final Effluent (station 7)	4.9 (2.91) n = 21	11.0 (8.06) n = 24	10.0 (7.57) n = 17	7.7 (0.28) n = 26

* standard deviation shown in parenthesis

the other process discharges. Table 3 shows the relative removal efficiencies of each of the unit operations. The aerated lagoon removed most of the influent BOD5 (82.7 percent), with overall BOD5 removed by the treatment plant of 95.5 percent. The two facultative lagoons contributed little to BOD5 removal (less than 3 percent) in the system. The AWF removed about 7.5 percent of the total BOD5 through the system, which is significant considering that the filter followed the two facultative lagoons.

The mean TSS data (Figure 4) for sample stations 1-7 were 119.9, 95.7, 57.2, 45.9, 17.7 10.8, and 11.0 mg/L, respectively. As summarized in Table 3, the aerated lagoon and facultative lagoon No. 1 removed 20.2 and 32.1 percent of the TSS. The second facultative lagoon removed only a small percentage (9.4 percent) with the AWF removing 29.3 percent. Overall mean TSS removal by the upgraded treatment plant was 91.0 percent.

The mean VSS data shown in Figure 5 for sample stations 1-7 was 103.3, 74.8, 56.9, 44.7, 16.0, 8.9, and 10.0 mg/L, respectively. The efficiency of each unit operation (Table 3) indicated that the aerated lagoon removed 27.6 percent of the VSS followed by the artificial wetlands filter with 34.7 percent. The first facultative lagoon removed a higher percentage (17.3) than the second lagoon (11.8) with overall treatment plant removal efficiency for VSS of 91.4 percent.

The mean pH values for each of the sample stations is shown in Figure 6. The mean pH for sample stations 1-7 was 8.1, 8.1, 8.6, 8.9, 7.8, 7.7, and 7.7, respectively. The pH of the raw wastewater and the discharge from the aerated lagoon remained about the same; however, the pH increased dramatically from algal respiration in both the first and

Table 3. Performance of each unit operation for the Carville wastewater treatment facililty.

Unit Operation	percent removal*		
	BOD5	TSS	VSS
Aerated Lagoon	82.7	20.2	27.6
Facultative Lagoon No.1	2.6	32.1	17.3
Facultative Lagoon No.2	2.5	9.4	11.8
Artificial Wetlands Filter	7.5	29.3	34.7
U/V Disinfection	0.2	<0.1	<0.01
Total System Performance	95.5	91.0	91.4

* percent removal based on percent of total

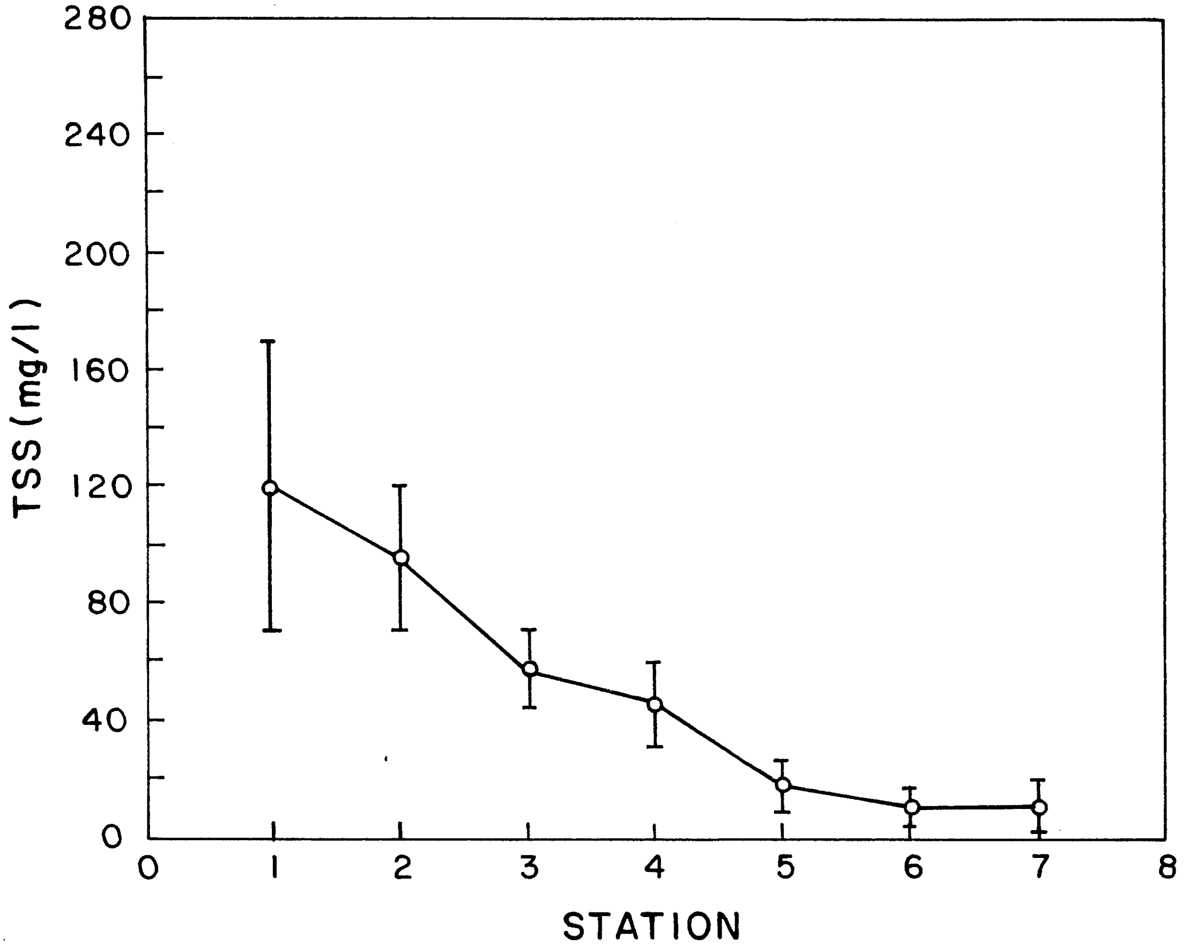

Figure 4. Mean total suspended solids (TSS) for each unit operation at the Carville facility.

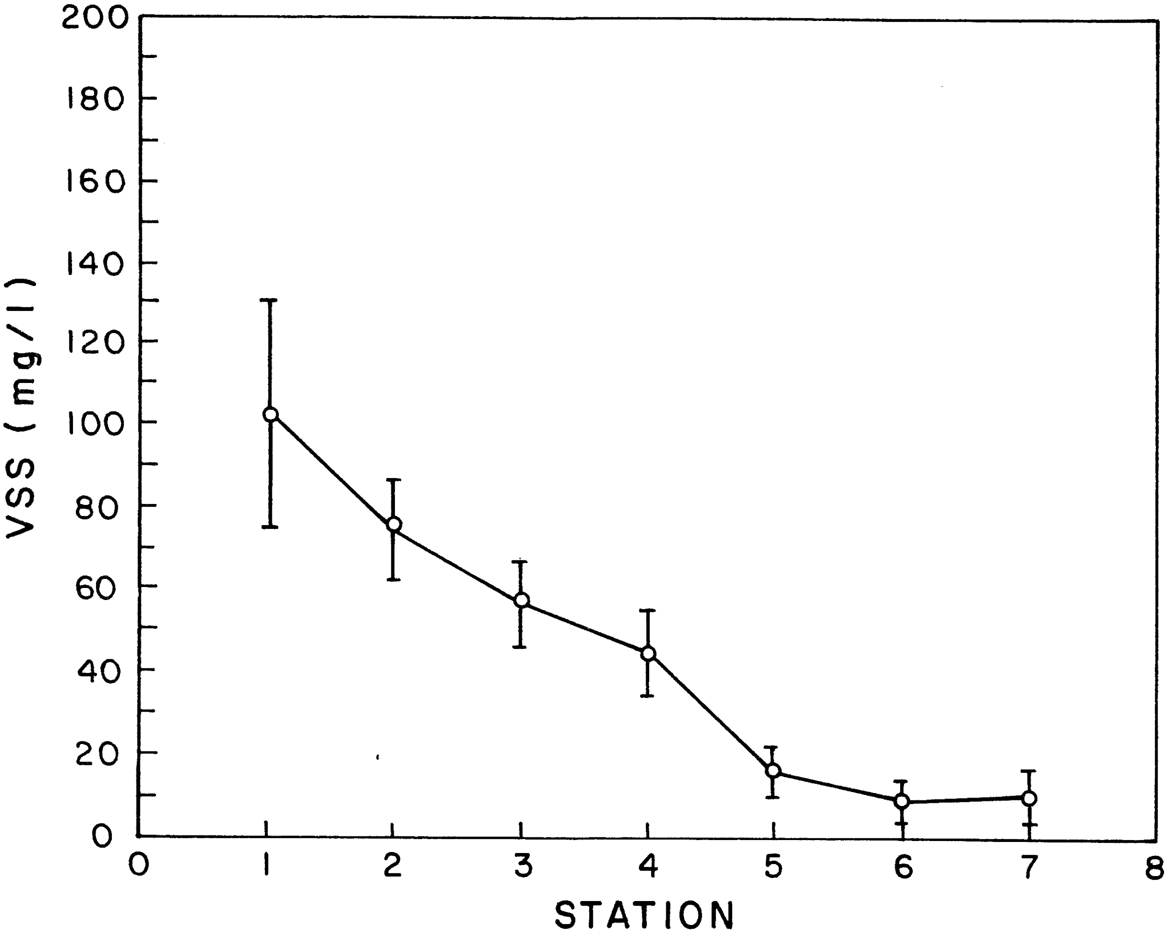

Figure 5. Mean volatile suspended solids SS for each unit operation at the Carville facility.

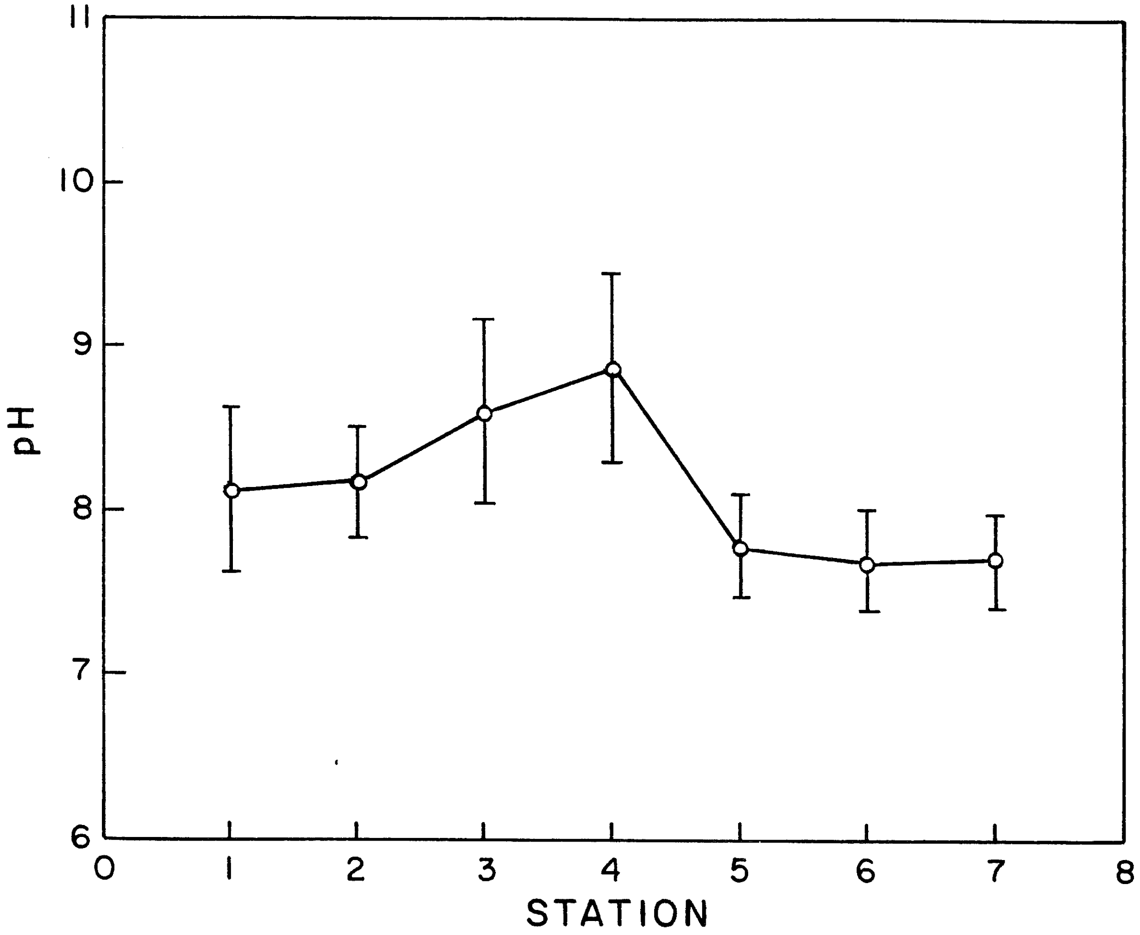

Figure 6. Mean hydrogen ion concentration (pH) for each of the unit operations at the Carville facility.

second facultative lagoons. The pH was reduced through the artificial wetlands filter to more acceptable levels for discharge.

Artificial Wetlands Filter

Excessive and sudden hydraulic loading can affect the performance of an AWF unit through decreased detention times and increased interstitial space velocities. The period of study for this project covered the highly variable transition between spring and summer conditions in southern Louisiana. Rainfall records and flowrate data for the Carville site (Figure 7) indicate that rainfall events occurring over the course of the study had a dramatic effect on treatment plant flowrates. For example, the event of days 41-45, resulted in an increase in flowrate of almost 42 percent. Several rainfall events, days 17-19 and 62-63, produced over 4 inches over a 48 hour period. The overall downward trend in flowrates (Figure 7), particularly after day 60, can be attributed to record low stage readings in the nearby Mississippi River and the onsite of drought conditions which continued through much of the spring and summer of 1988.

The results of the hydraulic data shown in Figure 7 and summarized in Table 1, indicate that the Carville facility is strongly influenced by rainfall and the variations in flow, at times, reduced the actual detention time through the filter to just 14.4 hours and increased estimated interstitial velocities by over 35 percent. The increase in velocities can be critical in the reaeration zone where the cross sectional area of the rock media bed is only a foot deep. Clogging of the Carville AWF in the reaeration zone has been indicated as an operational problem.

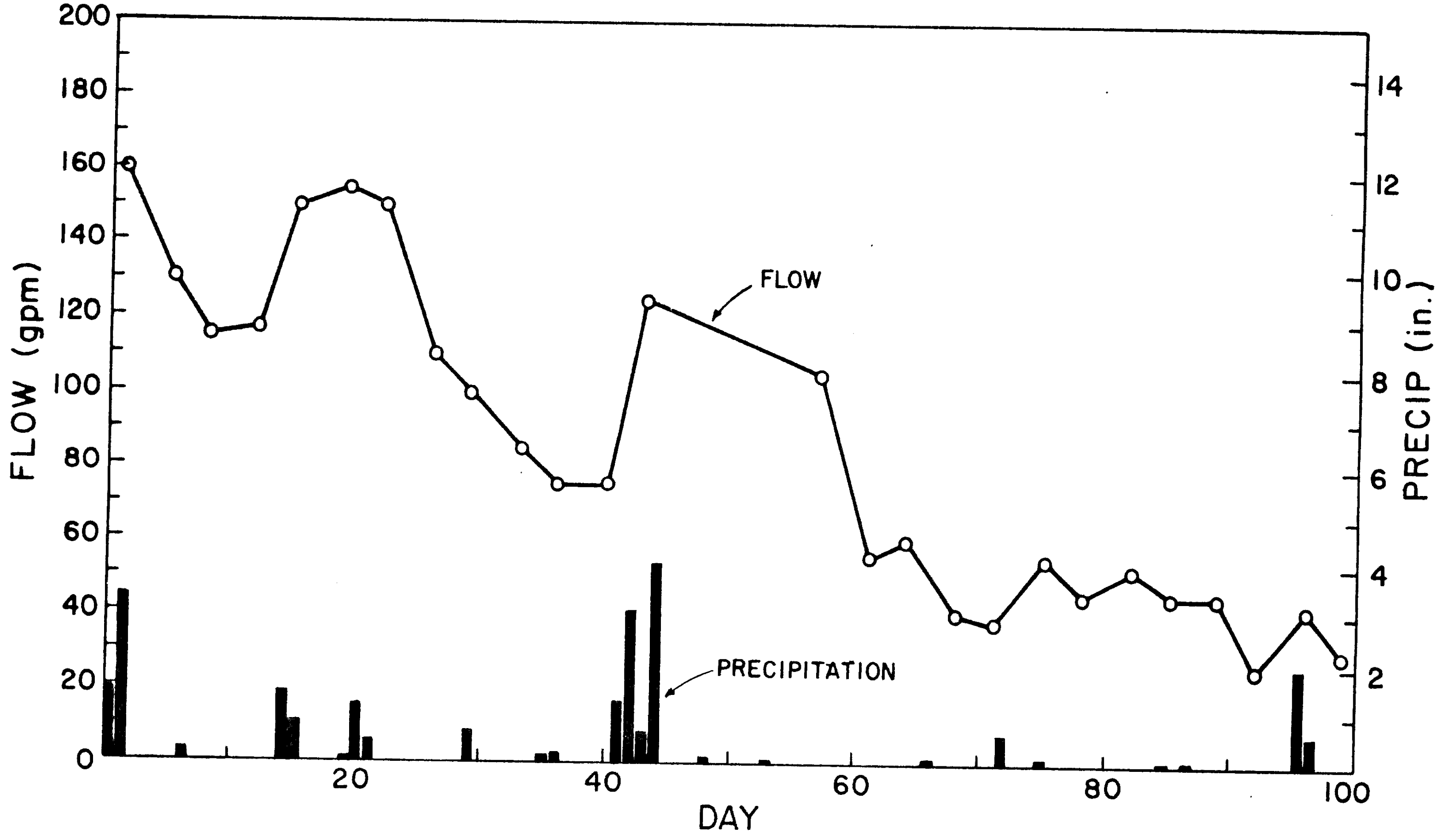

Figure 7. Precipitation and wastewater flowrate data (February - June 1988) for the Carville facility.

The effect of occasional hydraulic overloading can produce mixed results. Increased flowrates increase the washout of trapped inert and degrading solids, thus, cleansing the filter and providing more sites for further entrapment. However, valuable bacterial solids involved in the degradation of the entrapped solids can also be washed out of the filter by the same process. Thus, entrapment may be enhanced after an increased hydraulic load, but degradation is inhibited until bacterial populations recover. The net overall affect may not be noticed in the actual operation of the filter if sufficient filter volume is provided. In addition, for the Carville site where the filter acts mostly to entrap solids rather than degrade BOD5, short term hydraulic washout of solids may be an advantage. For other more heavily organically loaded AWF units, hydraulic overload may seriously limit BOD5 reductions through the system. Sizing of this zone could be critical to the operation of the AWF depending on the loading of TSS or BOD5. High TSS loading indicating the need for greater entrapment volume and a smaller reaeration zone. High BOD5 loading indicating the need for less entrapment volume and more sites for BOD5 reduction and larger reaeration zone. The use of these AWF subunits needs to be reviewed critically and further design refinements developed.

The time trace data for BOD5 measured in the influent and effluent to the AWF is shown in Figure 8 and the mean values presented in Table 2. The influent to the filter was the discharge from facultative lagoon No. 2. The influent BOD5 ranged from about 8 mg/L to 25 mg/L with a mean value of 13.5 mg/L. The BOD5 effluent from the filter ranges from about 2.0 mg/L to 15.0 mg/L with a mean value 5.2 mg/L. This mean BOD5 value is well below the design BOD5 effluent concentra-

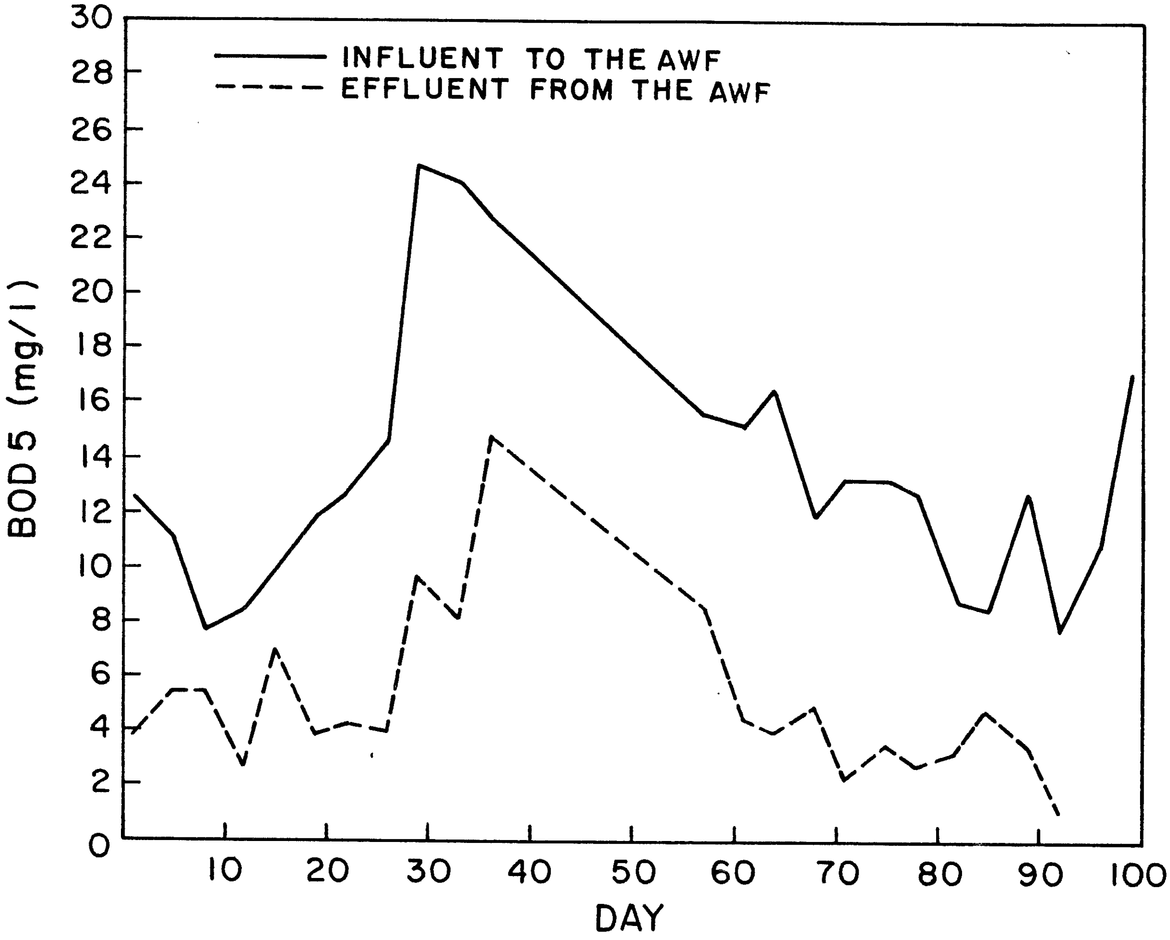

Figure 8. Biological oxygen demand (BOD5) time trace data for the influent to and effluent from the artificial wetlands filter (AWF).

tion of 10 mg/L. The BOD5 may not be a good measure of the ultimate BOD exerted on the filter as algal solids trapped in the filter can exert a latent BOD load because of slow decay rates. Thus, the influent loading indicated may be much higher if ultimate BOD were used as the measure.

The mean value for BOD5 from samples taken at sample station 5 was 8.1 mg/L. Based on the influent concentration, the first 1/3 of filter volume removed 40 percent of the BOD5 while overall BOD5 removal was 62 percent. Field observations indicate that plant growth was not uniform throughout the bed, but tended to be higher in the first 100 feet of the filter. More efficient use of the filter volume may be gained by introducing the wastewater flows at several points along the length of the filter bed. This concept requires further investigation to fully optimize the AWF operation.

The time trace data shown in Figure 9 for the filter influent TSS ranged from 15.0 mg/L to almost 80.0 mg/L with a mean concentration of 45.9 mg/L. The effluent concentrations ranged from less than 1.0 mg/L to 31.0 mg/L with a mean concentration of 10.8 mg/L. While this range of TSS values occasionally exceeded the design effluent concentration of 15 mg/L, the mean value was well below this limit. Thus the AWF was highly effective for controlling facultative lagoon TSS concentrations to levels near 10.0 mg/L. This AWF had been operating for less than a year at the time of this study. Plant roots were not established to the full depth of the bed, and therefore lower TSS effluent concentrations can be expected as the filter bed matures.

The mean values for TSS (Table 2) indicate that 61.4 percent of the influent solids were removed in the first 1/3 of the filter bed. This again indicates that the flow arrangement used at the Carville site may

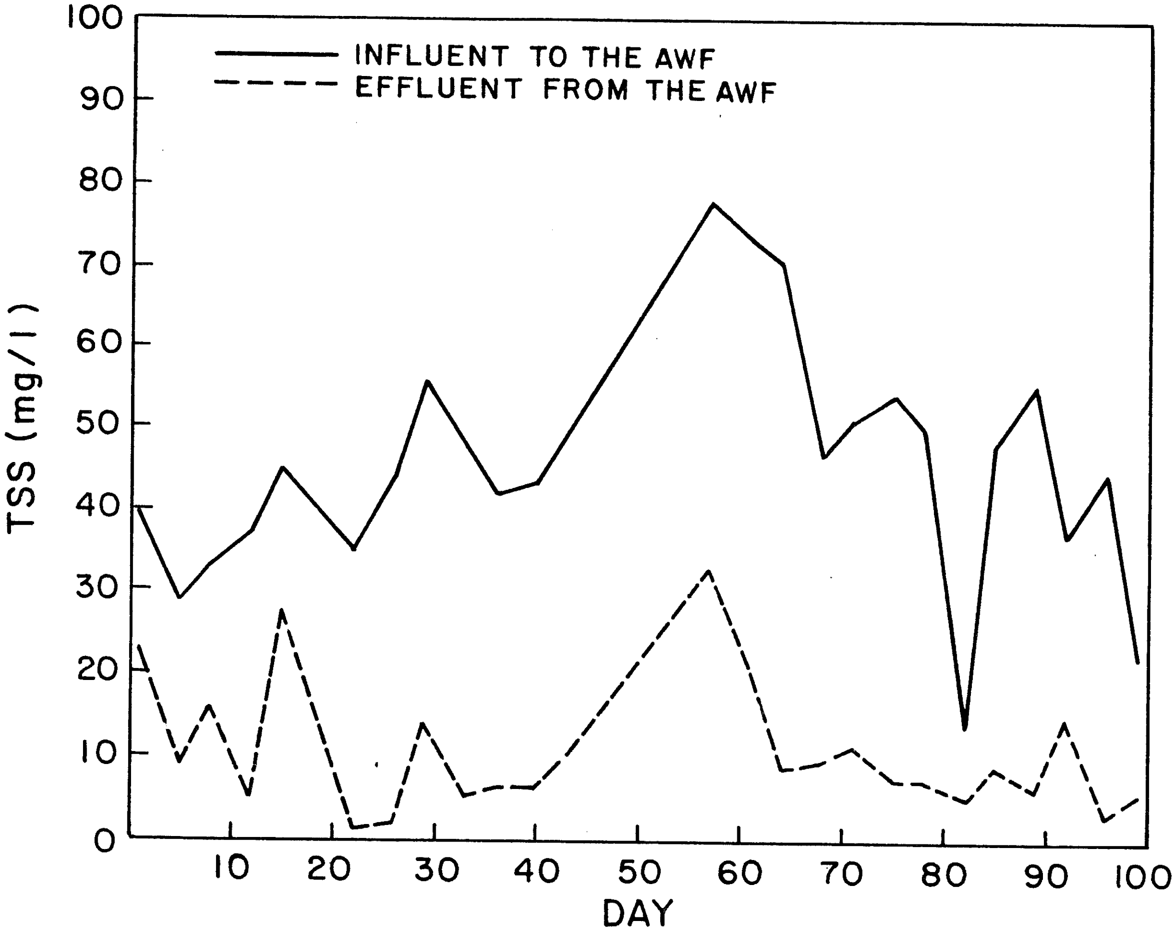

Figure 9. Total suspended solids (TSS) time trace data for the influent to and effluent from the artificial wetlands filter (AWF).

underutilizes the filter volume and stepping the flow to the filter could improve filter performance. Overall the filter removed 76.5 percent of the influent TSS.

The time trace data for influent VSS, shown in Figure 10, ranged from 22.0 mg/L to 63.7 mg/L with a mean concentration of 44.7 mg/L. The calculated VSS percentage of the TSS is 97.4, reflecting that most solids in the influent to the filter are composed of algae cells with very little inorganic solid material. The VSS data measured at Sample Station 5 ranged from 1.0 to 28.0 mg/L with a mean concentration of 16.0 mg/L. Based on this data, the first 1/3 of the filter removed 64.0 percent of the influent VSS. The percentage of VSS to TSS decreased to 90.4 indicating an increase in inorganic solids and decrease in organic solids. The filter effluent concentrations ranged from 2.3 to 21.3 mg/L with a mean concentration of 8.9 mg/L, resulting in an overall filter removal efficiency of 82.7 percent. Examination of the VSS to TSS ratio (82.4 percent) in the effluent indicates a decrease in the organic fraction and a further increase in the inorganic fraction.

The pH time trace data shown in Figure 11 indicates that influent pH values ranged from 7.9 to 9.9 with a mean value of 8.9. The effluent pH ranged from 6.8 to 8.1 with a mean value of 7.7. The AWF was very effective at reducing high pH resulting from algal respiration. Rapid decline in pH over the first 1/3 of the filter was evidenced by the mean pH at sample station 5 of 7.8. Thus, effective pH control was achieved in the first 1/3 of the AWF.

SUMMARY

The artificial wetlands filter (AWF) examined in this study was effective at controlling facultative lagoon effluent BOD5 and TSS to

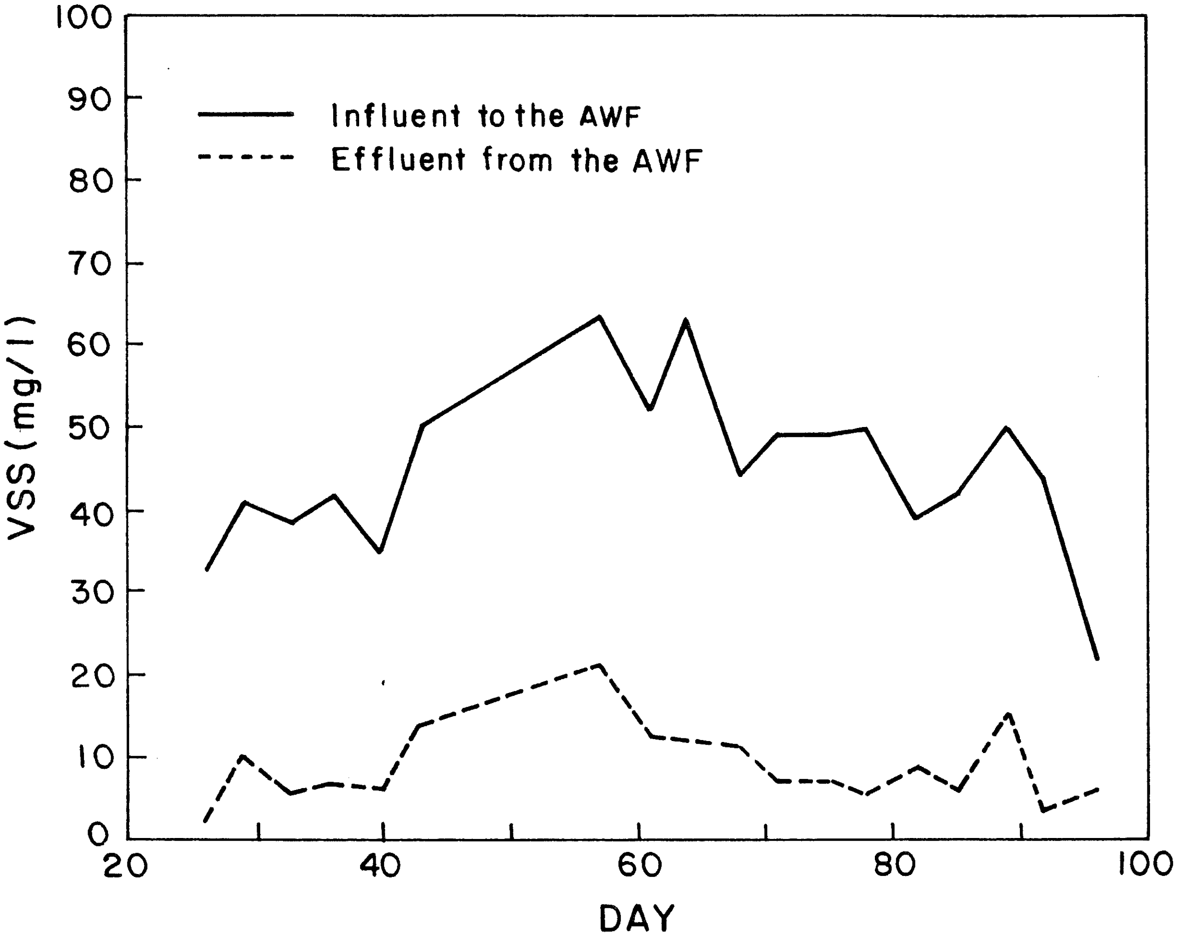

Figure 10. Volatile suspended solids (VSS) time trace data for the influent and and effluent from the artificial wetlands filter (AWF).

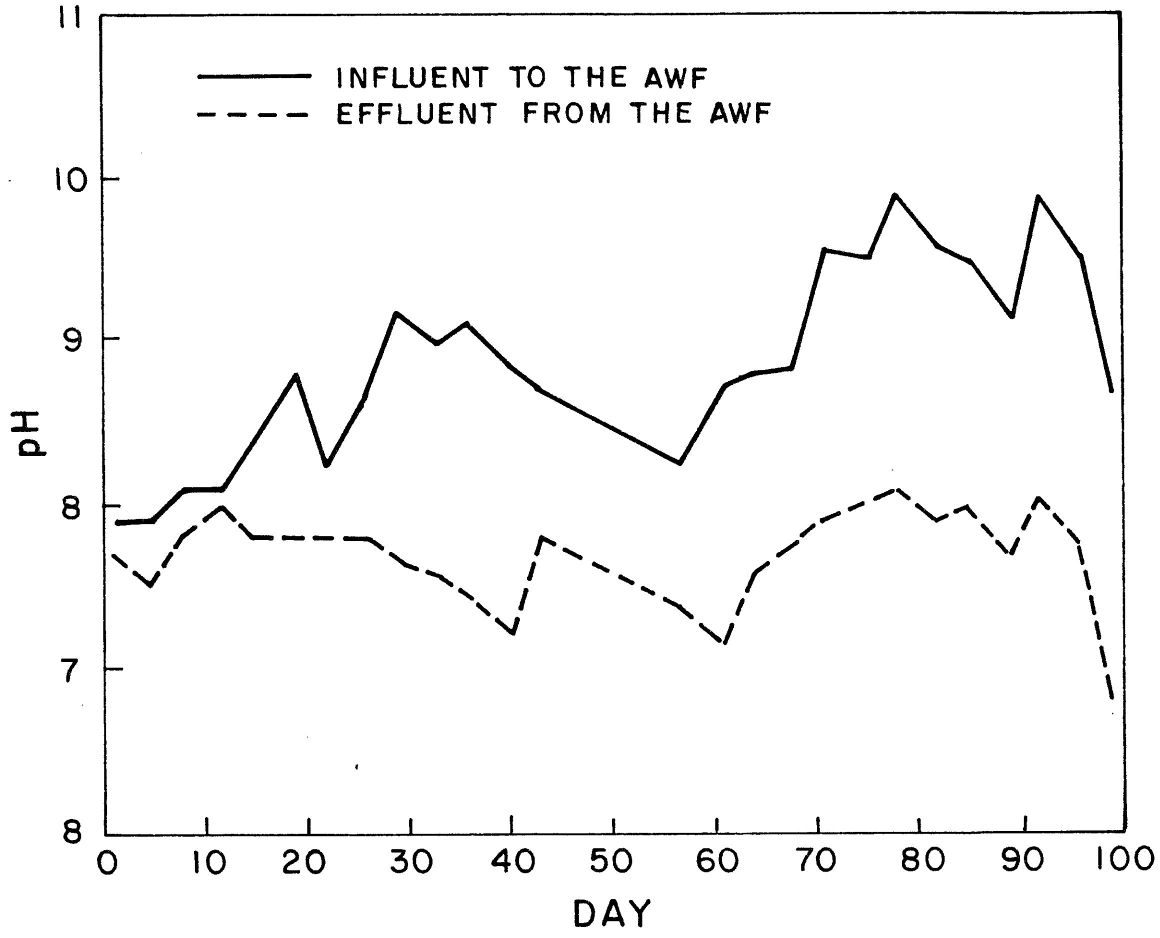

Figure 11. Hydrogen ion concentration (pH) time trace data for the influent to and effluent from the artificial wetlands filter (AWF).

concentrations below 10 and 15 mg/L, respectively. In addition, high pH resulting from algal respiration was effectively reduced through the filter. The AWF showed remarkable treatment efficiency under extreme (over 55 percent decrease in detention time) conditions of hydraulic loading.

For all measured parameters (BOD5, TSS, VSS and pH), at least a 40 to 50 percent reduction was achieved in the first 1/3 of the filter volume. Plants were observed to be nutrient limited and robust plant growth was achieved only in the front end of the filter. Splitting the influent to the filter into several separate flows, introduced at measured intervals along the filter bed, could improve overall filter performance and produce more uniform plant growth and root penetration into the filter bed. This could be a useful tool to enhance AWF unit start-up and for maintenance during low flow conditions.

Overall treatment plant performance was excellent with removal efficiencies for BOD5, TSS, and VSS of 95.5, 91.0, and 91.4 percent, respectively. Some redundancy of unit operations are indicated, particularly for Facultative Lagoon No. 2 which removed only 2.5, 8.3, and 10.5 percent of the total BOD5, TSS, and VSS input to the plant. Under the conditions of this study, it does appear that this unit could be taken out of line and the volume used to dampen hydraulic shock loads. The resulting wastewater would only increase BOD5, TSS, and VSS loading to the AWF by 20, 19.7, and 21.1 percent, respectively.

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