USE OF A CONSTRUCTED WETLAND/VEGETATED STRIP SYSTEM FOR SWINE WASTEWATER TREATMENT

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INTRODUCTION

Use of constructed wetlands for the treatment of agricultural wastewaters has been, in the past, a subject of much discussion and little research. Constructed wetlands have been extensively used in the treatment of municipal wastewaters (Baker 1993). Typical agricultural waste streams exhibit, in many cases, constituent concentrations and variability which differ from municipal wastewaters (Baker 1993). A number of research projects have recently begun in an effort to assess the usefulness of constructed wetlands in the treatment of agricultural wastes and to develop and validate design criteria (McCaskey 1994; Reaves et al. 1994; Rice 1994; Skarda et al. 1994; Sikora 1994; Toor and Eddleman 1994).

A constructed wetland/vegetated strip system for the treatment of swine wastewaters has been in operation in Mississippi since 1991. The system (Figure 1) treats wastewater from an existing two stage lagoon system which receives waste from a farrowing house located at the Pontotoc/Flatwood Branch of the Mississippi Agricultural and Forestry Experiment Station (MAFES). The wetland/vegetated strip system was designed by Ross Ulmer of the USDA Soil Conservation Service and Don Hammer of the Tennessee Valley Authority. Day to day operation of the system, as well as data collection and analysis, has been conducted by personnel from MAFES, the Mississippi Cooperative Research Service, and Mississippi State University. The system is being operated to provide a "first look" at constructed wetlands performance in the treatment of swine wastewater. This paper will describe the physical system, its management, and results of the first 16 months of the evaluation.

METHODS AND MATERIALS

The constructed wetland system operating at the Pontotoc Ridge-Flatwoods Branch Experiment Station represents a cooperative effort by the Tennessee Valley Authority, the Mississippi Agricultural and Forestry Experiment Station, the Mississippi Cooperative Extension Service, Mississippi State University, and the USDA Soil Conservation Service to evaluate the efficacy of surface flow constructed wetlands for the treatment of wastewater from a swine production facility. The system consists of two parallel 0.04 ha surface flow constructed wetlands in series with two parallel 0.04 ha vegetated strips (Figure 1). The wetland cells are loaded from the second stage facultative lagoon used to treat wastewater from the station's farrowing house. Hydraulic, nitrogen, and BOD_5 loading rates are summarized in Table 1. Hydraulic retention time is approximately 12 days.

Each constructed wetland cell is 33 m long and 12 m wide. Each cell has a 15 m middle section that is 23 cm deeper than 9 m sections at the influent and effluent ends (Figure 2). The slope of the cells is less than 1 percent. Operating depth is 12 cm at the shallow sections and 35 cm at the deep section. The shallow sections were planted with cattail (*Typha latifolia*, L.) and water chestnut (*Trapa natans*, L.) in 1991. The deep section was left unplanted and the depth and turbidity is sufficiently great that the emergent plants have not encroached upon it.

Each vegetated strip is 46 m long and 9 m wide, with a slope of 2.5 % (Figure 3). Although the strips were originally planted with rye grass, natural succession has subsequently been allowed. Current vegetation in these strips is grasses, weeds, and woody bushes. There are two outlets in each vegetated strip cell. A shallow (20 cm) outlet allows discharge of water at the effluent end of the strips. A deeper (45 cm) outlet was placed below the surface of the clay soil which underlies the vegetated strip to act as an indicator of seepage through the sublayer.

PVC pipes are used to transport the wastewater between subsystems. There is an orifice at the influent end of each wetland cell. Flow rate is regulated by changing the size of the orifices. Water depth in the wetland cells is regulated using a PVC elbow attached to a swivel. Water from the two wetland cells is mixed prior to transfer to the vegetated strips. Flow to the vegetated strip is alternated daily 5 days per week.

On-site Measurements and Sample Collection

On-site measurements and sample collection reported here occurred during the period April 1992 through July 1993. Sampling interval was weekly during summer (May - August) and biweekly during the remainder of the year. On-site measurements included flow rate, dissolved oxygen content, and water temperature. Daily rainfall data was recorded at the station.

Table 1. Loading Rates of the Wetland Cells

Parameters	Upper Cell Mean(±SD)	Lower Cell Mean(±SD)	Unit
Hydraulic	1.3±0.5	1.7±0.7	(cm/d)
BOD_5	6.1±3.5	6.5±3.0	(kg/ha/d)
NH_3-N	14.3±4.9	19.0±8.2	(kg/ha/d)
SS	11.9±7.7	11.9±7.0	(kg/ha/d)
O-PO_4 as PO_4	7.8±4.4	9.6±4.6	(kg/ha/d)

Volumetric flow rate was measured using a stopwatch and a graduated cylinder on each sampling date. Rate measurements were taken of influent and effluent water flow of the wetland cells. When effluent was present, flow rate measurements were also taken from the outlets of the vegetated strip cells. Dissolved oxygen content and temperature were measured with a YSI Model 58 Dissolved Oxygen Meter and a Model 5739 Sensor with a stirrer. The measurements were made at the influent, middle, and effluent sections of each wetland cell at a depth of about 7-8 cm.

Water samples were taken from the influent and effluent ends of the wetland cells and the shallow and deep outlets of the vegetated strips. Samples were collected in plastic bottles. Profile samples were also taken from the wetland cells on a quarterly basis, at distances of 9, 16, and 24 m from the influent points. The samples were transported approximately 100 km to the laboratory of the Agricultural and Biological Engineering Department. Samples were transported in an insulated container. Ice (about 1-1.5 kg) was placed in the container during hot days in order to inhibit biological or chemical changes in the samples.

Sample Analyses

Most sample analyses were conducted at the Water Quality Laboratory of the Agricultural and Biological Engineering Department, Mississippi State University. Parameters analyzed were biochemical oxygen demand (BOD_5), suspended solids (SS), ammonia nitrogen (NH_3-N), nitrate nitrogen (NO_3^--N), total Kjeldahl nitrogen (TKN), ortho phosphate (O-PO_4), total phosphate (T-PO_4), and fecal coliform bacteria. Fecal coliform bacteria concentration was tested at the State Chemical Laboratory at Mississippi State University.

Five day biochemical oxygen demand (BOD_5) was determined using a YSI Model 58 Dissolved Oxygen Meter and a Model 5730 Sensor and followed standard methods (APHA 1989). Suspended solids (nonfilterable residue) concentration was determined by filtration and gravimetrical method (APHA 1989) using Watman glass microfibre filters (1.2 micrometers pore size). Drying to constant weights was done with an oven at 103°C.

Ammonia nitrogen (NH_3-N) concentration was determined by nesslerization (APHA 1989) using reagents from Hach Company and then read using a Model 601 Spectronic Spectrophotometer at a wavelength of 450 nm. Total Kjeldahl nitrogen was determined by digestion with a Hach Model 23130-20 Digesdahl Digestion Apparatus, followed by the ammonia test. Total Kjeldahl nitrogen concentration was measured as NH_3-N concentration. Nitrate nitrogen (NO_3^--N) was determined by cadmium reduction (Hach Co. 1986) using reagents produced by Hach. Nitrate nitrogen (NO_3^--N) concentration was read with a color wheel.

Ortho-phosphate (O-PO_4) concentration was measured by using the ascorbic acid method (APHA 1989) with reagents produced by Hach Company. Concentration was read spectrophotometrically at a wavelength of 690 nm. Total phosphate (T-PO_4) concentration was determined by using persulfate digestion with a Model-7 Castle autoclave, followed by O-PO_4 analysis (APHA 1989).

RESULTS

Hydraulic Loss

Table 2 summarizes measured influent and effluent water flow rates for the constructed wetlands and the vegetated strips. Influent rates are reported with standard deviations. Effluent rates were non-normally distributed and are reported with their ranges. Mean effluent flow rates were approximately 11 percent less than influent rates in the wetlands. Effluent flow rates included rainfall. The measured effluent flow rate from the vegetated strips was only 18 percent of the influent rate (based on the wetland effluent). Vegetated strip effluent flow rate was zero on 60 of 78 observations (Figure 4). The occurrence of effluent flow in the vegetated strips appeared most frequently to coincide with rainfall. Overall hydraulic loss, based on system influent and effluent flow rates, was approximately 84 percent.

Dissolved Oxygen

The dissolved oxygen records of the 2 wetland cells are summarized in Table 3. The DO concentrations at the midpoint were consistently greater than those at either end. Dissolved oxygen concentrations, frequently in excess of saturation, indicated that primary production by phytoplankton occurred and was an important component of the elevated oxygen levels. The DO concentrations at the effluent end were somewhat greater than at the influent end. The magnitude of the differences between the center section and the ends was not uniform over time. In both cells, during the period late June through early September 1992, mid-section DO was depressed. Mean DO concentrations during this time are summarized in Table 4.

Much of the reduction in center section DO during summer 1992 was probably caused by partial occlusion of the water surface by an algal mat (species unknown) that was observed covering a varying percentage of the "free" surface. The fraction covered varied from approximately 1/4 to over 3/4 of the middle section. The DO content of the open sections of the wetlands, when not occluded, probably followed a diurnal cycle similar to that experienced in other water bodies. Measurement of DO was generally between 10:00 a.m. and 1:00 p.m. so that, on average, neither minimum nor maximum concentrations were recorded.

The frequent occurrence of super-saturated dissolved oxygen concentrations in the open center sections indicates that much of the reaeration was a byproduct of primary production by phytoplankton. The BOD_5 profiles of the wetland cells suggest that the phytoplankton caused a measurable increase in the organic content of the wastewater (Table 5).

Table 2. Hydraulic Loss in the wetland/vegetated strip system. Outflow rates had non-normal distributions. Ranges are reported.

Location	Inflow Rate (l/m±SD)	Outflow Rate (l/m, Range)
Upper Cell	3.5±1.3	2.7 (11.0-0)
Lower Cell	4.6±2.1	4.5 (14.4-0)
Vegetated Strips	7.2	1.3 (8.9-0)
Overall	8.1±2.1	1.3 (8.9-0)

Table 3. Mean dissolved oxygen concentrations for influent, middle, and effluent sections in each wetland cell during the period April 1992 - July 1993.

	CELL 1 (mg/l, Range)	CELL 2 (mg/l, Range)
Influent	2.6 (0.4-12.8)	4.2 (0.2-15.0)
Middle	9.2 (0.2-19.5)	8.9 (0.4-19.0)
Effluent	5.5 (0.5-15.3)	4.7 (0.9-13.8)

Table 4. Mean dissolved oxygen concentrations for influent, middle, and effluent sections in each wetland cell during the period late June - early September 1992.

	CELL 1 (mg/l)	CELL 2 (mg/l)
Influent	0.8	2.1
Middle	2.4	3.5
Effluent	1.3	1.8

Table 5. Wetland biochemical oxygen demand along a profile from the influent to effluent ends. Middle 1 and Middle 2 were measured at the influent and effluent ends of the open section. Based on 7 observations.

	BOD_5 (mg/l, ±SD)
Influent	31.2 (±7.1)
Middle 1	40.2 (±15.6)
Middle 2	38.4 (±17.6)
Effluent	15.4 (±10.9)

Waste Treatment

Reductions in the concentration of BOD_5, ammonia, phosphate, and suspended solids in the wetland cells and the vegetated strips are summarized in Table 6. Data are presented on both a concentration and mass basis. The mass reductions incorporate the impact of measured hydraulic loss on system waste treatment. Implicit in their use is the assumption that the measured rates truly reflect effluent flow from the vegetated strips. Percent removals, using both concentration and mass bases, are summarized in Table 7. Reductions in concentration and mass removal are similar in the constructed wetlands. Removal rates were approximately 40 percent for total phosphorus, 52 percent for BOD_5, 65 percent for suspended solids, and 70 percent for ammonia nitrogen. The total Kjeldahl nitrogen record, although incomplete, suggests that organic nitrogen represented a relatively small fraction of the influent and effluent nitrogen content. Nitrate nitrogen, virtually absent in the wetland influent, had a mean concentration less than 1 mg/l in the wetland effluent, suggesting effective linking of nitrification-denitrification in the system.

Percent mass removal, as computed from the vegetated strip influent and effluent flow rates and concentrations, was greater than concentration reduction in the vegetated strips. This is a reflection of the large hydraulic loss which appeared to occur in the vegetated strips. On a concentration basis, BOD_5 and total phosphate reduction was approximately 50 percent. Suspended solids reduction was 35 percent. Ammonia nitrogen removal was 83 percent. On a mass basis, however, removal of all constituents exceeded 90 percent. When vegetated strip effluent flow occurred, mean nitrate nitrogen concentration was approximately 3.5 mg/l. This represents approximately 50 percent of the vegetated strip effluent ammonia concentration. The method used to estimate nitrate nitrogen (Hach colorwheel) was relatively coarse, so these data must be regarded as first approximations.

Table 6. Wetland, vegetated strip, and overall removal in the Pontotoc system on both a concentration (mg/l) and mass (g/d) basis. Mean values for the period April 1992 through July 1993 are reported with ±Standard Deviation or (Range).

	Influent	Effluent
BOD_5		
Wetland Cell 1:		
Conc. (mg/l)	47.0 (87.1-19.7)	20.5 (73.9-0.9)
Mass (g/d)	242.0 (632.3-81.4)	89.1 (577.4-0)
Wetland Cell 2:		
Conc. (mg/l)	45.5 (104.7-13.6)	24.5 (79.8-2.5)
Mass (g/d)	261.2 (518.5-23.4)	146.0 (511.4-0)
Veg.Strips:		
Conc.(mg/l)	23.5 (63.1-2.6)	10.9 (54.2-0.1)
Mass (g/d)	235.1 (1019.1-0)	19.8 (229.8-0)
Overall:		
Conc.(mg/l)	46.2 (104.7-13.6)	10.9 (54.2-0.1)
Mass (g/d)	503.2 (684.7-127.4)	19.8 (229.8-0)
NH_3-N		
Upper Cell:		
Conc. (mg/l)	111.9 ±13.7	36.3 ±13.7
Mass (g/d)	570.4 ±195.2	135.3 (484.4-0)
Lower Cell:		
Conc. (mg/l)	112.2 ±13.2	40.6 ±11.3
Mass (g/d)	760.2 ±327.7	265.5 (642.8-0)
Veg. Strips:		
Conc. (mg/l)	39.0 ±10.6	6.7 (13.8-2.5)
Mass (g/d)	400.8 (1194.2-0)	12.3 (96.1-0)
Overall:		
Conc. (mg/l)	112.0 ±13.4	6.70 (13.8-2.5)
Mass (g/d)	1330.6 ±328.1	12.3 (96.1-0)

Table 6. (continued)

	Influent	Effluent
T-PO₄		
Upper Cell:		
Conc. (mg/l as P)	27.9 ±6.8	17.7 ±5.3
Mass (g/d as P)	140.8 (249.5-52.0)	71.7 (221.4-0)
Lower Cell:		
Conc. (mg/l as P)	27.4 ±6.5	16.5 ±3.5
Mass (g/d as P)	163.4 (364.0-24.2)	102.0 (445.9-0)
Veg. Strips:		
Conc. (mg/l as P)	17.1 ±4.07	8.0 (14.9-3.6)
Mass (g/d as P)	173.7 (667.3-0)	15.3 (117.4-0)
Overall:		
Conc. (mg/l as P)	27.6 ±6.6	8.0 (14.9-3.6)
Mass (g/d as P)	304.2 (503.7-115.2)	15.3 (117.2-0)
SS		
Upper Cell:		
Conc. (mg/l)	94.5 ±39.0	30.9 ±21.0
Mass (g/d)	477.2 ±308.3	111.2 (403.2-0)
Lower Cell:		
Conc. (mg/l)	87.8 ±44.5	35.9 (156.0-1)
Mass (g/d)	475.2 ±280.4	189.0 (633.3-0)
Veg.Strips:		
Conc. (mg/l)	32.5 (101.6-1)	21.2 (66.4-3.1)
Mass (g/d)	300.2 (942.6-0)	25.8 (277.3-0)
Overall:		
Conc. (mg/l)	91.0 ±41.7	21.2 (66.4-3.1)
Mass (g/d)	952.4 ±431.0	25.8 (277.3-0)

Table 7. Percent reductions of waste components on both a concentration (mg/l) and mass basis (g/d). Vegetated strip reductions are based upon effluent from the constructed wetlands.

	Wetland		Vegetated Strip		Overall	
	Conc.	Mass	Conc.	Mass[1]	Conc.	Mass[1]
BOD_5	51	54	54	92	76	96
NH_3-N	66	71	83	97	94	99
T-PO_4	39	44	53	91	71	95
SS	63	69	35	91	77	97

[1]These should be regarded as upper limits. Actual mass removal rates may have been lower. See Discussion.

DISCUSSION

The dissolved oxygen record provides convincing evidence that the use of open water sections in marsh-pond-marsh constructed wetlands does indeed increase the dissolved oxygen content in the center of the cell. It also appears that occlusion of the water surface by filamentous algae or floating plants (e.g., duckweed) may inhibit reaeration and/or oxygen production by phytoplankton (Table 4). Supersaturated dissolved oxygen concentrations indicate that much of the elevated oxygen content is due to oxygen production by phytoplankton. It should be noted that oxygen production by phytoplankton follows a diurnal cycle, with maximum and minimum concentrations occurring, on average, late in the afternoon and before dawn, respectively. Sampling, as mentioned, was performed between 11:00 a.m.

and 1:00 p.m. The mean center section dissolved oxygen reported is probably a reasonable average for the system. Promotion of primary production by phytoplankters necessarily increases the biochemical oxygen demand of the wastewater (Table 5). In the Pontotoc wetland cells, reduction of BOD_5 was quite variable, as indicated by the large standard deviations in Table 6. By contrast, ammonia reduction was extremely consistent, as shown by the relatively small standard deviations in the same table. It may be that the wetlands, as designed, are more appropriate for systems in which nitrogen removal is the primary consideration (which was the case at Pontotoc). It may also be true that BOD_5 removal may have been enhanced had the planted section at the effluent end of the cells been extended.

Presentation of the waste removal data on a mass (kg/d) basis is meaningful if it is assumed that, ultimately, a system such as the one at Pontotoc will be a part of a zero discharge waste management strategy. If meeting discharge criteria is the ultimate goal of a system, then the concentration of waste material which accompanies hydraulic loss in a system is not useful. If land application or recycling is the desired end, then presenting reduction data on a mass basis is a less ambiguous measure of system performance.

Having stated the above, it should be pointed out that the actual mass removal of the Pontotoc system may have been less than indicated by Table 7. If mean vegetated strip effluent flow exceeded 1.3 l/m, then percent mass reductions have been overestimated. Hydraulic loading of the vegetated strips was approximately 13 mm/d. Based on station records, average daily rainfall was 2.8 mm/d. Vegetated strip effluent was 2.5 mm/d. Estimated deep percolation for a heavy clay soil is approximately 0.3 mm/d (Pringle 1994). Evapotranspiration would have to have been approximately 13 mm/d for the water balance to hold. Although evapotranspiration rates of this magnitude have been reported for actively growing plants (Rosenberg et al. 1983), it is unlikely that this rate could have been maintained continuously. It is possible that significant periods of effluent flow from the vegetated strips may have been missed. This would have been particularly likely in colder months when sampling was conducted biweekly. In this light, it is reasonable to conclude that the mass removal rates of Table 7 represent upper limits.

Table 8 summarizes the estimated mass of each constituent removed by the constructed wetlands and vegetated strips. It is interesting to note that, although removal percentages were, in general, greater for the vegetated strips than for the constructed wetlands, the actual mass of the constituents removed was generally greater in the wetlands. Total phosphorus was the only constituent which may have had a greater mass removal in the vegetated strip.

Table 8. Mass removal (estimated range) by each component of the system at Pontotoc, MS.

Constituent	Wetland	Vegetated Strip
BOD_5	257-272 g/d	127-216 g/d
NH_3-N	878-945 "	333-389 "
T-PO_4	119-134 "	92-158 "
SS	600-657 "	105-273 "

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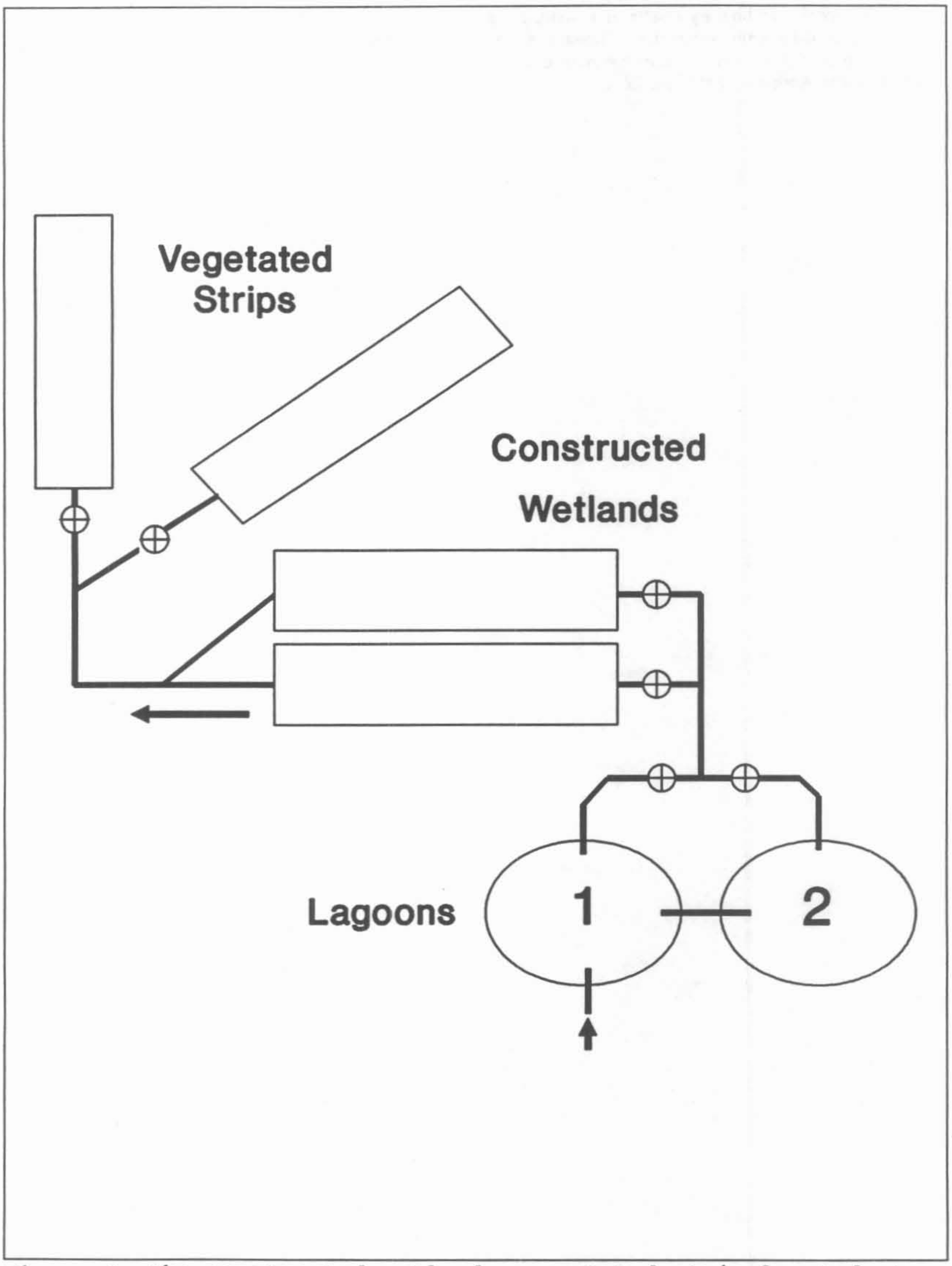

Figure 1. The constructed wetland - vegetated strip located at Pontotoc, MS.

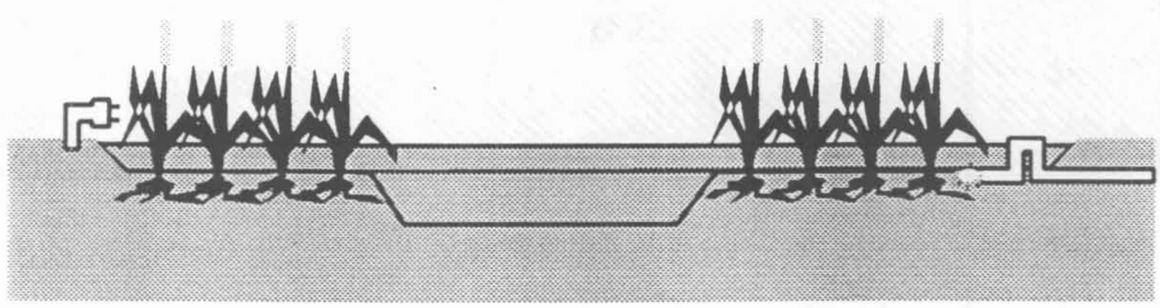

Figure 2. Marsh-pond-marsh constructed wetland in use to treat swine wastes at Pontotoc.

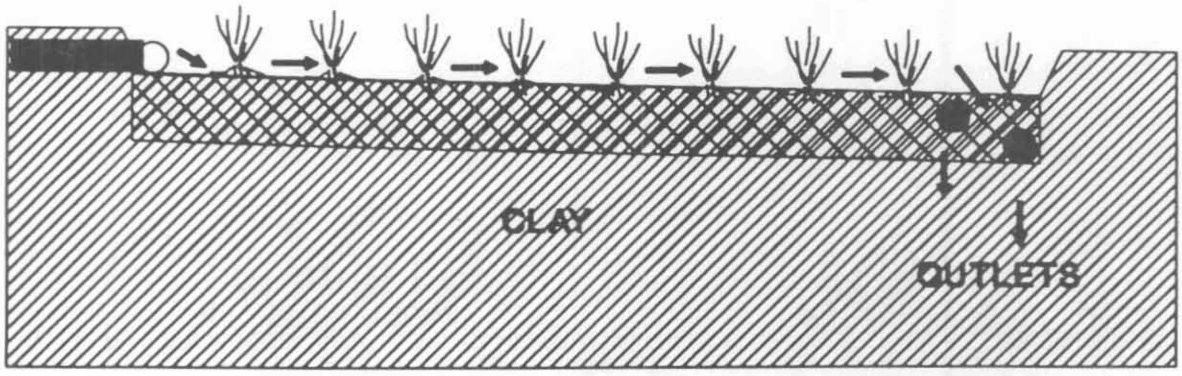

Figure 3. Vegetated Strips in use in the system at Pontotoc.

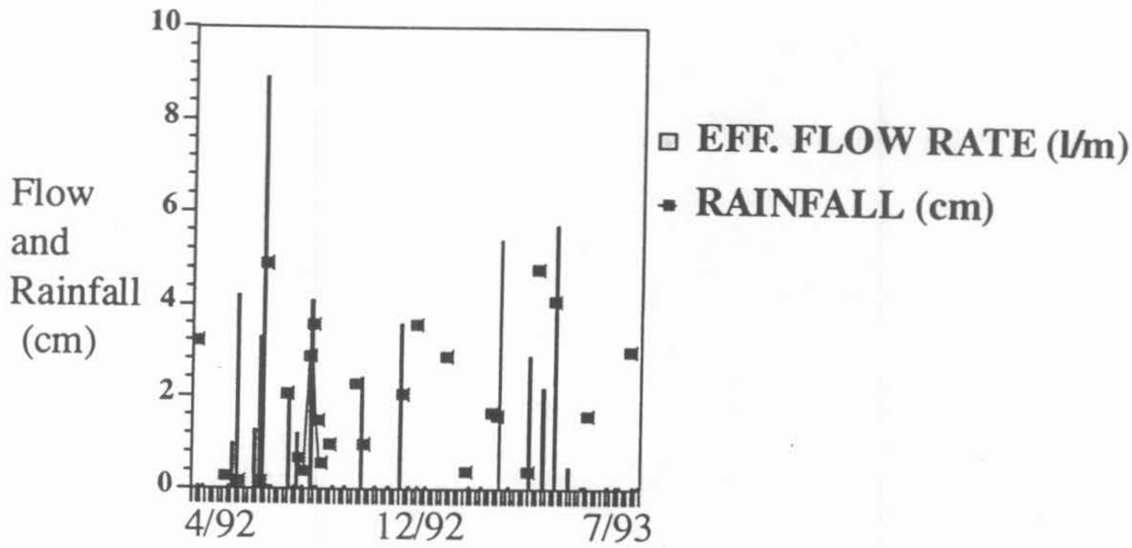

Figure 4. Effluent flow rate from the vegetated strips and rainfall recorded at the Pontotoc Branch Experiment Station.