PERFORMANCE OF A CONSTRUCTED WETLAND IN SWINE WASTEWATER TREATMENT

By

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The performance of constructed wetland and vegetated strip systems for swine wastewater treatment at Pontotoc/Flatwood Branch Experiment Station was monitored for 16 months, weekly during summer and biweekly in other seasons. A laboratory analysis of wastewater constituents was performed. Constituent removal efficiencies were determined on both a concentration and a mass basis. Removal efficiencies varied among constituents. Overall concentration removals of BOD_5, SS, NH_3-N, O-PO_4 ranged from about 63% to 94%. Overall mass removals of all constituents were more than 90%. Fecal coliform removal was variable. Overall hydraulic loss of 83% was achieved. The open water segment of the wetland cells enhanced dissolved oxygen (D.O.) concentration.

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CHAPTER I

INTRODUCTION

The concept of using wetlands to treat wastewaters has received increasing attention in recent years (Finlayson and Chick, 1983). It has been suggested that the use of wetlands may be a simple and energy-efficient means of removing pollutants from wastewaters (Nichols, 1983). Wetlands remove nutrients and aquatic pollutants using a complex variety of biological, physical, and chemical processes (Hammer, 1993). Use of natural wetlands for wastewater treatment is not acceptable since wildlife habitats may be adversely affected. Currently, discharging untreated wastewaters into natural bodies of waters is illegal in the United States (EPA, 1988). Therefore, attention has shifted to the use of constructed wetlands as wastewater treatment facilities.

Considerable effort has been devoted to studies on the role of constructed wetlands for wastewater treatment. Most of the studies, however, were conducted on constructed wetlands treating municipal and industrial wastewaters (Wieder *et al.*, 1990). Knowledge of the technology, performance, and utility of constructed wetlands for agricultural/animal wastewater treatment is still very limited (Krider and Boyd, 1992). Attempts to establish design criteria for constructed wetlands for agricultural wastewater treatment are still underway (Cooper *et al.*, 1992). More information, either from laboratory studies or field studies is required.

This research was conducted at the swine unit of the Pontotoc/Flatwood Branch Experiment Station-MAFES, Mississippi State University. The system treats wastewater from the swine operation. The system consist of a two-stage lagoon in series with two parallel constructed wetlands. The wetlands are followed by two parallel vegetated strips to provide final polishing. This research focused on the two constructed wetland cells and the two vegetated strip cells. A novel feature of the constructed wetland design was the use of open water segments to enhance dissolved oxygen (D.O.) concentration (Hammer, 1991). Low D.O. has been experienced at other constructed wetlands used to treat agricultural wastewater (Davis *et al.*, 1992).

The objectives of this research were:

1. To monitor the performance of the constructed wetlands and vegetated strips in the treatment of wastewater from the second stage lagoon;
2. To estimate the reduction in hydraulic flow rate through the wetlands and vegetated strips;
3. To monitor the effect of the open water section on constructed wetland dissolved oxygen.

CHAPTER III

MATERIALS AND METHODS

System Description

This research was conducted at the Pontotoc/Flatwood Branch Experiment Station, MAFES Mississippi State University. The overall system consisted of an anaerobic lagoon in series with an aerobic lagoon, two parallel constructed wetlands, and two parallel vegetated strips (Figure 5). This system is currently treating wastewater from a swine operation (about 250 hogs).

The anaerobic lagoon is loaded with the raw waste and washing water of 50 m^3/d. Most of the solids settle out in this lagoon. The effluent from the anaerobic lagoon flows into the aerobic lagoon. The constructed wetland cells are then loaded with a portion of the effluent from the aerobic lagoon. Finally, effluent from the wetland cells flows into the vegetated strips as a final treatment. The water flowing into the vegetated strips was alternated every weekday.

The wetland cells are FWS systems. Each cell is 33 m long and 12 m wide (0.04 ha). The slope of the cells is less than 1 percent. Each cell has a deep section in the middle and shallow sections in the influent and effluent ends (Figure 3).

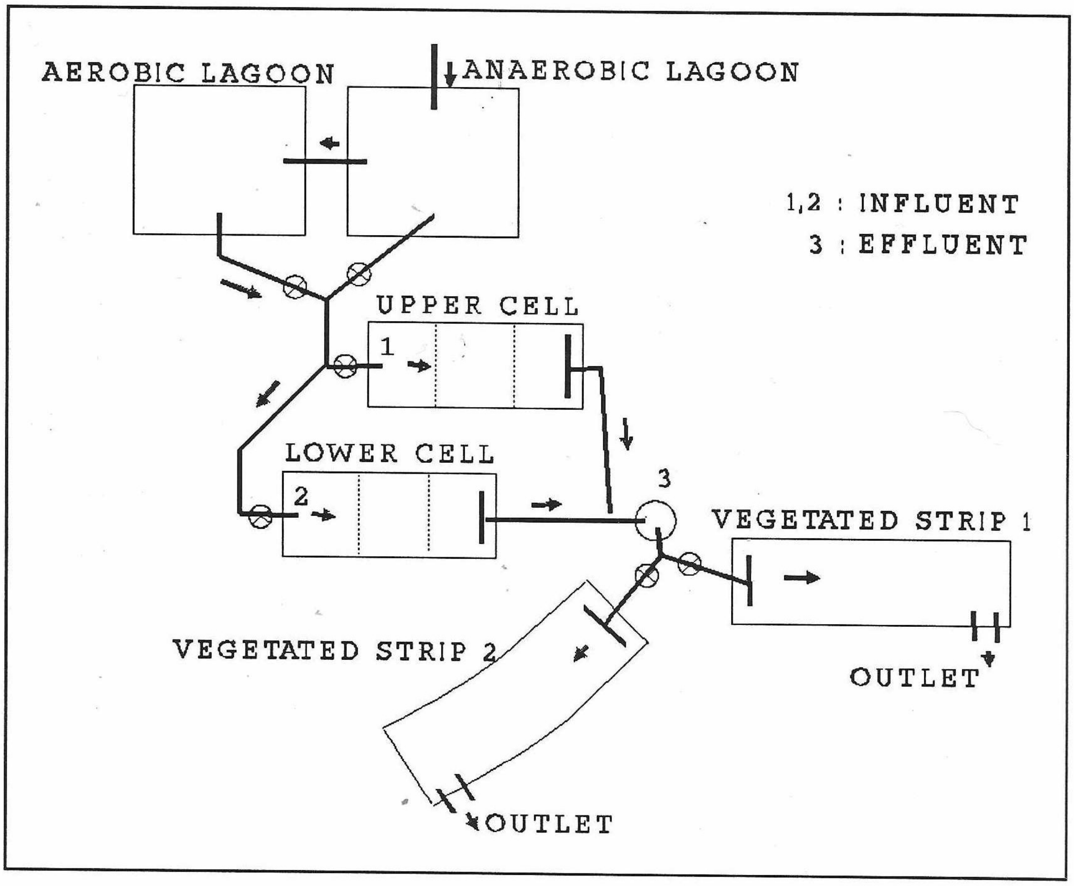

Figure 5. Layout of the Treatment Systems

The design depth is 43 cm for the deep section (15 m long) and 20 cm for the shallow sections (each 9 m long). Emergent plants used in this system are cattail (*Typha latifolia L.*) and water chestnut (*Trapa natans L.*). The emergent plants are grown in the shallow sections of the cells, with no emergent vegetation in the middle of the cells. The middle of the cells is left open to promote phytoplankton growth and gas exchange with the atmosphere. Through photosynthesis, phytoplankton are able to increase DO in the water. Phytoplankton then settle out during passage through the vegetated section at the effluent end of the cells.

Each vegetated strip is 46 m long and 9 m wide (0.04 ha), with a slope of 2.5 % (Figure 4). 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. As wastewater passes through the vegetated strips, contaminants are expected to be accumulated, decomposed, or incorporated into plant biomass. Water is expected to be removed via evapotranspiration. It was hoped that a near zero discharge could be achieved. There are two outlets in each vegetated strip cell, shallow (20 cm) and deep (45 cm), where any remaining water is discharged from the systems.

PVC pipes are used to channel the wastewater from one system to the others. There is an orifice at the influent end of each wetland cell. Flow rate was regulated by changing the size of the orifices. Water depth in the wetland cells was regulated by using a PVC elbow attached to a swivel. Water from the two wetland cells was mixed prior to transfer to the vegetated strips.

On-site Measurements and Sample collection

On-site measurements and sample collection were conducted 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.

Flow rate was measured by using a stopwatch, a graduated cylinder, and a bucket. 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.

Wastewater samples were taken from the influent and effluent ends of the wetland cells and the shallow and deep outlets of 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 put 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 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 were tested at the State Chemical Laboratory.

Biochemical oxygen demand (BOD_5) concentration was determined by measuring dissolved oxygen concentration with a YSI Model 58 Dissolved Oxygen Meter and a Model 5730 Sensor. Black bottles (300 ml) were used in the 5-day incubation at 20°C. Dissolved oxygen concentration was measured before and after the incubation (APHA, 1989).

Suspended solids (nonfilterable residue) concentration was determined by filtration and gravimetrical method (APHA, 1989). Whatman glass microfibre filters (1.2 micrometers pore size) and a Model HL 52 Mettler balance were used. Drying to constant weights was done with an oven at 103°C.

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

Ortho phosphate (O-PO_4) concentration was measured by using the ascorbic acid method (APHA, 1989) with reagents produced by Hach Co. Concentration was read using a Model 601 Spectrophotometer 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. Total phosphate concentration was measured as ortho phosphate concentration.

CHAPTER V

CONCLUSIONS

Performance of the constructed wetland at Pontotoc/Flatwood Branch Experiment Station has been monitored. A primary problem found in the system was the fluctuating loading rate due to orifice plugging. This problem was exacerbated in the upper cell due to the relatively low pressure head available. Loading rates in the lower cell were higher than in the upper cell. The low loading rates used required small orifice diameters, which were more frequently plugged. Fluctuating effluent flow rates were also due to rainfall. Maximum discharge levels, both concentration and mass for most of constituents, also occurred after rainfall events. The overall hydraulic loss was 83%.

The use of open water segment in the middle of wetland cells was able to enhance DO concentration (about 10 mg/l). During summer, however, DO concentrations in the middle section were depressed (to about 3 mg/l) due to an algal film covering the open water surface.

Treatment efficiency varied among constituents. Removal efficiency of BOD_5 in the wetland cells was about 51% (concentration basis) and 54% (mass basis). In the vegetated strips, BOD_5 removal efficiency was 49% (concentration basis) and 91% (mass basis). The overall BOD_5 removal efficiency was 76% (concentration basis) and 94% (mass basis).

Removal efficiency of SS in the wetland cells was 62% (concentration basis) and 69% (mass basis). In the vegetated strips, SS removal efficiency was 35% (concentration basis) and 91% (mass basis). The overall SS removal efficiency was 77% (concentration basis) and 97% (mass basis).

Ammonia nitrogen (NH_3-N) comprised the major fraction of TKN. Removal efficiency of NH_3-N in the wetland cells was 66% (concentration basis) and 71% (mass basis). In the vegetated strips, NH_3-N removal efficiency was 83% (concentration basis) and 97% (mass basis). The overall NH_3-N removal efficiency was 94% (concentration basis) and 99% (mass basis).

Nitrate nitrogen (NO_3^--N) concentrations increased after passing through the wetland cells and vegetated strips. The wetland effluent NO_3^--N concentrations ranged from 0.0 mg/l to 2.0 mg/l. In the vegetated strips, discharge NO_3^--N concentrations ranged from 0.0 mg/l to 10 mg/l.

Ortho phosphate (O-PO_4) comprised the major fraction of total phosphate (T-PO_4). Removal of O-PO_4 in the wetland cells was about 25% (concentration basis) and 28% (mass Basis). In the vegetated strips, O-PO_4 removal was 50% (concentration basis) and 93% (mass basis). The overall O-PO_4 removal was 63% (concentration basis) and 93% (mass basis).

REFERENCES

APHA, 1989. Standard Methods for the Examination of Water and Wastewater. Seventeenth edition. APHA, Washington D.C.

Bastian, R.K., P.E. Shanaghan, and B.P. Thomson, 1990. pp. 265-278. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Auburn University, Alabama.

Brodie, G.A., 1990. Selection and Evaluation of Sites for Constructed Wastewater Treatment Wetlands, pp. 307-317. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Cole, G.A., 1988. Textbook of Limnology. Third Edition. Waveland Press Inc., Illinois.

Cooper, C.M., S. Testa III, and S.S. Knight, 1992. Evaluation of ARS and SCS Constructed Wetland/Animal Waste Treatment Project at Hernando, Mississippi. Technology Application Project Report No. 17.

Costello, C.J., 1990. Wetlands Treatment of Dairy Animal Waste in Irish Drumlin Landscape, pp. 702-709. In: D.A. Hammer (Ed.). Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Davis, S.H., R. Ulmer, L. Strong, T.P. Cathcart, J.W. Pote, and W.Brock, 1992. Constructed Wetlands for Dairy Wastewater Treatment. Paper no. 92-4525, Presented at the 1992 International Meeting in Nashville, TN. ASAE, Michigan.

EPA, 1988. Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. EPA/625/1-88/022, Washington D.C.

Finlayson, C.M. and A.J. Chick, 1983. Testing the Potential of Aquatic Plants to Treat Abattoir Effluent. Water Research, 17(4): 415-422.

Gersberg, R.M., B.V. Elkins, and C.R. Goldman, 1983. Nitrogen Removal in Artificial Wetlands. Water Research, 17(9): 1009-1014.

Guntenspergen, G.R., F. Stearns, and J.A. Kadlec, 1990. Wetland Vegetation, pp. 73-88. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Hach Co., 1986. Low Range Test Kit. Hach Co., Colorado.

Hammer, D.A., 1991. Constructed Wetlands Can Replace Conventional WW Treatment. Water & Wastewater, 6(5): 17-22.

Hammer, D.A., 1993. Designing Constructed Wetlands Systems to Treat Agricultural Nonpoint Source Pollution, pp. 71-111. In: R.K. Olson (Ed.), Created and Natural Wetlands for Controlling Nonpoint Source Pollution. C.K. Smoley, Florida.

Hammer, D.A., and R.K. Bastian, 1990. Wetlands Ecosystems: Natural Water Purifiers ?, pp. 5-19. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Hodson, P.H., 1973. the Role of Phosphorus in Bacteria and Viruses . In: E.J. Griffith, A. Beenton, J.M. Spencer, and D.T. Mitchell (Ed.), Environmental Phosphorus Handbook. John Wiley & Sons, New York.

Holmes, B.J., L.R. Massie, and G.D. Bubenzer. 1992. Design and Construction of a Wetland to Treat Milkhouse Wastewater. Paper no. 924524, Presented at the 1992 International Meeting in Nashville, TN. ASAE, Michigan.

Kadlec, R.H., 1990. Hydrologic Factors, pp. 21-38. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Kadlec, R.H., D.E. Hammer, In-Sik Nam, and J.O. Wilkes, 1981. The Hydrology of Overland Flow in Wetlands. Chemical Engineering Community, 9:331-344.

Krider, J.N. and W.H. Boyd. 1992. SCS Technical Requirements for Constructed Wetlands for Agricultural Wastewater Treatment. Paper, no. 924523, Presented at the 1992 International Winter Meeting. ASAE, Michigan.

Manahan, S.E. 1991. Environmental Chemistry. Fifth Edition. Lewis Publishers Inc., Michigan.

Metcalf and Eddy Inc., 1991. Wastewater Engineering: Treatment, Disposal, and reuse. Third Edition. McGraw-Hill Inc., New York.

Nichols, D.S., 1983. Capacity of Natural Wetlands to Remove Nutrients from wastewater. Journal of Water Pollution Control Federation, 55(5):495-505.

Reddy, K.R., E.M. D'Angelo, and T.A. DeBusk, 1990. Oxygen Transport Through Aquatic Macrophytes: The Role in Wastewater Treatment. Journal of Environmental Quality, 19: 261-267.

Riemsdijk, W.H.V., F.A. Weststrate, and J. Beek, 1977. Phosphates in Soils Treated with Sewage Water: III. Kinetic Studies on the Reaction of Phosphate with Aluminum Compounds. Journal of Environmental Quality, 6(1): 27-29.

Sawhney, B.L., 1977. Predicting Phosphate Movement through Soil Columns. Journal of Environmental Quality, 6(1): 86-89.

Sawhney, B.L. and D.E. Hill, 1975. Phosphate Sorption Characteristics of Soils Treated with Domestic Waste Water. Journal of Environmental Quality, 4(3): 342-346.

Sawyer, C.N. and P.L. McCarty. 1978. Chemistry for Environmental Engineering. McGraw-Hill Co., New York.

Syers, J.K., R.F. Harris, and D.E. Armstrong, 1973. Phosphate Chemistry in Lake Sediments. Journal of Environmental Quality, 2(1): 1-13.

Teal, J.M. and J.W. Kanwisher, 1966. Gas Transport in the Marsh Grass, Spartina alterniflora. Journal of Experimental Botany, 17(51): 355-361.

Tortora, G.J., B.R. Funke, and C.L. Case, 1992. Microbiology. Fourth Edition. the Benjamin/Cummings Publishing Company Inc., California.

Ulmer, R., L. Strong, T.P. Cathcart, J.W. Pote, 1992. Constructed Wetland Site Design and Installation. Paper no. 92-4528, Presented at the 1992 International Meeting in Nashville, TN. ASAE, Michigan.

Wieder, R.K., G. Tchobanoglous, and R.W. Tutle. 1990. Preliminary Considerations Regarding Constructed Wetlands for Wastewater Treatment, pp. 297-305. In: D.A. Hammer (Ed.), Constructed Wetlands for Wastewater Treatment: Municipal, Industrial, and Agricultural. Lewis Publishers Inc., Michigan.

Viessman, Jr.W. and M.J. Hammer, 1993. Water Supply and Pollution Control. Fifth Edition. Harper Collins College Publishers, New York.