ECOLOGICAL ENGINEERING

Ecological Engineering 14 (2000) 199–206

www.elsevier.com/locate/ecoleng

An evaluation of a constructed wetland to treat wastewater from a dairy farm in Maryland, USA

Jennifer A. Schaafsma, Andrew H. Baldwin *, Christopher A. Streb

Department of Biological Resources Engineering, University of Maryland, College Park, MD 20742-5711, USA

Received 20 August 1997; received in revised form 4 December 1998; accepted 10 December 1998

Abstract

In the Chesapeake Bay drainage basin, wastewater from animal operations laden with nutrients, sediment, and biochemical oxygen demand (BOD) contributes to the degradation of surface water quality. A constructed wetland system was built to treat wastewater from a dairy farm in Frederick County, Maryland to evaluate the use of wetland technology as a best management practice for dairy waste. To assess treatment effects, we sampled water once a month at several sites through the system, which consists of two settling basins, two cells, and a vegetated filter strip. Samples were analyzed for total nitrogen, ammonia, nitrate/nitrite, total phosphorus, ortho-phosphate, total suspended solids, biochemical oxygen demand, dissolved oxygen, temperature, conductivity, and pH. Flow through the wetland system resulted in significant reductions in concentrations of all analytes except nitrate/nitrite. Relative to initial concentrations, total nitrogen was reduced 98%, ammonia 56%, total phosphorus 96%, ortho-phosphate 84%, suspended solids 96%, and biochemical oxygen demand 97%. Nitrate/nitrite increase by 82%, although mean concentrations were much lower than concentrations of ammonia or total nitrogen. The increase in nitrate/nitrite is probably due to the oxidation of ammonia via nitrification in the vegetated filter strip. Our results suggest that while reductions are large, further removal is necessary to meet design requirements. This may be possible through the addition of another anaerobic wetland cell downstream of the system or recirculation of wastewater through the wetland cells to promote denitrification and uptake of nutrients by plants.

Keywords: Constructed wetland; Wastewater treatment; Vegetated filter strip; Nutrients; Oxygen demand; Suspended solids; Dairy waste

1. Introduction

Wastewater from animal operations and run-off from agricultural lands contributes large quantities of nutrients, sediment, and biochemical oxygen demand (BOD) to the Chesapeake Bay through its network of tributaries. The Maryland Department of the Environment (1993) has identified 134 non-point source (NPS) priority watersheds of which the first and third most important are the Lower Monocacy and Upper Monocacy

* Corresponding author. Tel.: +1-301-4017855; fax: +1-301-3149023.

E-mail address: ab174@umail.umd.edu (A. H. Baldwin)

0925-8574/99/$ - see front matter
PII: S0925-8574(99)00029-4

watersheds, respectively. Designated as a Maryland Scenic River, the Monocacy watershed contains the greatest percentage of dairy cows (32%) and the highest animal manure production (11%) in the state (Brodie, 1988). In the Upper Potomac River Basin, which receives flow from the Monocacy, a study reported 43% of the nitrogen and 60% of the phosphorus that enter the basin come from animals. Animal waste and fertilizer provide twice the nitrogen and phosphorus as is required by the agricultural crops in the watershed (Jaworski et al., 1992). These nutrients feed algal blooms that deplete dissolved oxygen, damage habitat for fish nurseries and threaten recreation (Dunne and Leopold, 1978). Within these priority watersheds, emphasis is being placed on developing low cost solutions to abate the nutrient problem at its source.

One solution is to employ wetlands, which provide a chemical and biological environment suitable for improving water quality (Mitsch and Gosselink, 1993; Reddy and D'Angelo, 1994). The growing recognition of their attributes has spurred the legal protection of natural wetlands and the construction of wetlands for water quality improvement and wastewater treatment. Constructed wetlands have been used to improve the quality of river water (Mitsch et al., 1995), stormwater (Johengen and LaRock, 1993), coal mine drainage (Hedin and Nairn, 1993), and municipal sewage (Brix, 1994). Using wetlands for treating dairy and swine wastewaters, which are higher in nutrients, solids, and BOD than the above examples, is a relatively recent application of constructed wetland technology (Hammer et al., 1993; Cronk, 1996). In our study we wanted to evaluate the effectiveness of a constructed wetland system in treating water from a dairy operation in the Upper Monocacy watershed.

2. Methods

2.1. Site description

The constructed wetland system is located at a privately owned dairy farm in Frederick County, Maryland, (39°32′30″ N, 77°23′00″W). It was built in 1993 by the U.S. Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) according to NRCS technical guidelines (SCS, 1991). The NRCS is studying the system for the potential application of constructed wetlands as a best management practice (BMP) for reducing nutrient and sediment pollution.

The system was designed to provide treatment for 170 cows (455 kg each), to result in a 6-week hydraulic residence time in wetland cells, and to have no outflow except from storm events greater than a 25-year 24-h storm. It includes two settling basins (SB1 and SB2), two wetland cells (Cell 1 and Cell 2, each 0.055 ha in area and designed to maintain 0.15 m water depth), and a vegetated filter strip (VFS) 0.06 ha in area to catch any overflow (Fig. 1). During the majority of our study, standing water and saturated soils were observed in the VFS, suggesting that it is functioning as a third wetland. Originally, the cells were planted with *Typha latifolia* L. and *Schoenoplectus tabernaemontani* (K.C. Gmel.) Palla (most of plantings subsequently died, and the cells have been colonized by *Lemna minor* L., and *Echinochloa crus-galli* (L.) Beauv). One of the settling basins (SB1) collects water that drains from a 120-day capacity manure pit and flush water from the milking parlor (Fig. 1). The other settling basin (SB2) receives stormwater run-off from the barnyard (about 0.25 ha area), silo effluent, and occasional overflow from SB1. The stormwater that runs off the roofs and paved areas around the barns and outbuildings is di-

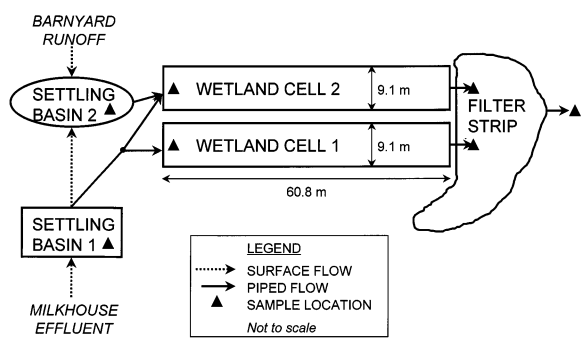

Fig. 1. Schematic of the constructed wetland system for treating dairy waste, Frederick, MD, USA.

Table 1
Change in concentration of wastewater constituents across the constructed wetlands system from settling basin 1 to the vegetated filter strip outflow[a]

Parameter	Concentration in settling basin 1 (mg/l)	Concentration change at vegetated filter strip outflow (%)
Ammonia	71.71 ± 13.28	−55.73% ($P = 0.0914$)
Nitrate/nitrite	5.51 ± 1.57	+81.82% ($P = 0.0122$)
Total Kjeldahl nitrogen	164.23 ± 74.64	−98.07% ($P = 0.0457$)
ortho-phosphate	56.65 ± 10.70	−84.33% ($P = 0.0009$)
Total phosphorus	52.59 ± 13.81	−95.86% ($P = 0.0022$)
Biochemical oxygen demand	1913.9 ± 291.5	−96.89% ($P < 0.0001$)
Total suspended solids	1644.7 ± 533.7	−96.07% ($P = 0.0147$)

[a] Concentration values for constituents in the settling basin are mean ± SE. Concentration change values are the percentage change in concentration between settling basin 1 and the outflow of the vegetated filter strip. P-values of two-tailed t-tests of settling basin versus filter strip outflow concentrations are given in parentheses.

verted around the cells to minimize the quantity of water treated. This diverted water normally percolates into the soil before it reaches the filter strip. The effluent from SB1 is split and flows equally into Cells 1 and 2 through underground pipes, while the effluent from SB2 flows into Cell 2 only.

The vegetated filter strip receives outflow from both cells (Fig. 1). The diverted stormwater, if any, also rejoins the flow in the filter strip. The VFS was not specifically planted but has been colonized by wetland plants such as *Typha latifolia* and *Polygonum punctatum* E11.

2.2. Field and lab methods

Between September 1995 and May 1997, water samples were collected monthly from the settling basins, cell inflow and outflow pipes, and the VFS outflow (Fig. 1). Dissolved oxygen, pH, conductivity, and temperature were measured in the field with portable meters. The samples were transported on ice to the lab where they were analyzed for total suspended solids (TSS), 5-day biochemical oxygen demand (BOD), total Kjeldahl nitrogen, ammonia, nitrate/nitrite (i.e. nitrate plus nitrite), total phosphorus, and ortho-phosphate according to APHA (1992).

To evaluate treatment effects, the percent change in year-round average concentrations of the analytes across the system and its components was calculated. Student's t-tests were performed to determine if the differences between influent and effluent concentrations were statistically significant.

3. Results

The system significantly reduced the levels of most wastewater constituents (Table 1). Nitrate/nitrite levels, however, increased significantly across the system. Levels of nutrients, BOD, and TSS generally decreased across the wetland cells (Figs. 2 and 3), although the reduction was statistically significant for only nitrate/nitrite, BOD, and TSS in Cell 1 (Table 2). The effluent of Cell 1 had higher mean concentrations of all constituents than that of Cell 2 except nitrate/nitrite (Figs. 2 and 3). In contrast with the wetland cells, there was a significant reduction in levels of most analytes across the VFS (Figs. 2 and 3; Table 2). Mean levels of ammonia decreased between the Cell 2 outflow and the VFS outflow, but not significantly so. Nitrate/nitrite increased significantly between the outflows of both Cells 1 and 2 and the VFS outflow. Ortho-phosphate was a large percentage of total phosphorus and appears to exceed total phosphorus at the VFS effluent when concentrations are very low. This may be

because samples for ortho-phosphate analysis were frozen and homogenized before analysis but samples for total phosphorus analysis were stored liquid; particulate phosphorus may have settled out before analysis.

Dissolved oxygen levels generally increased across the system, with the highest readings usually measured at the effluent from the VFS (Table 3). Conductivity generally decreased across the system, indicating a decrease in the concentrations of ions such as ammonium and phosphate. Mean pH and temperature varied little across the system, although both fluctuated considerably during the study.

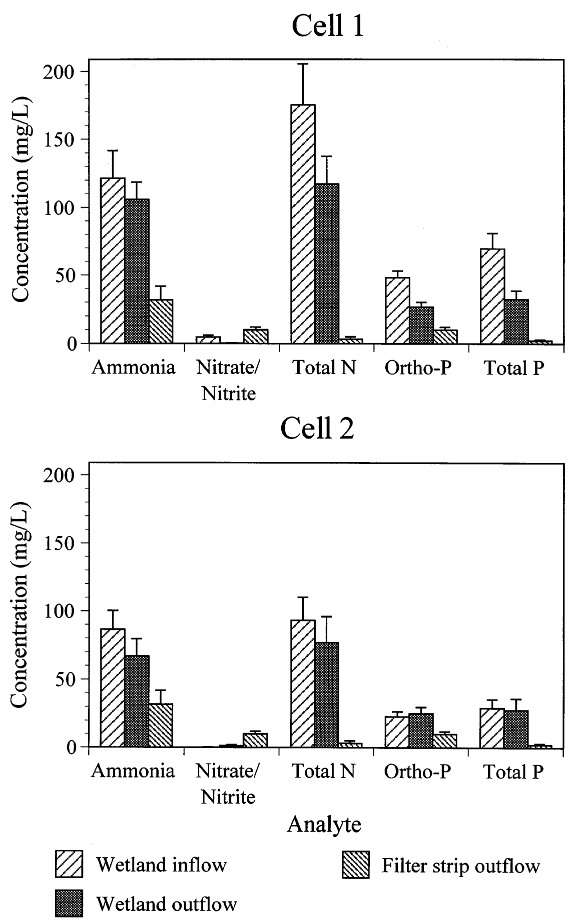

Fig. 2. Mean concentrations of nutrients entering and leaving the wetland cells and leaving the vegetated filter strip. Error bars indicate + 1 SE. Statistical comparisons of influent and effluent concentrations are presented in Table 2.

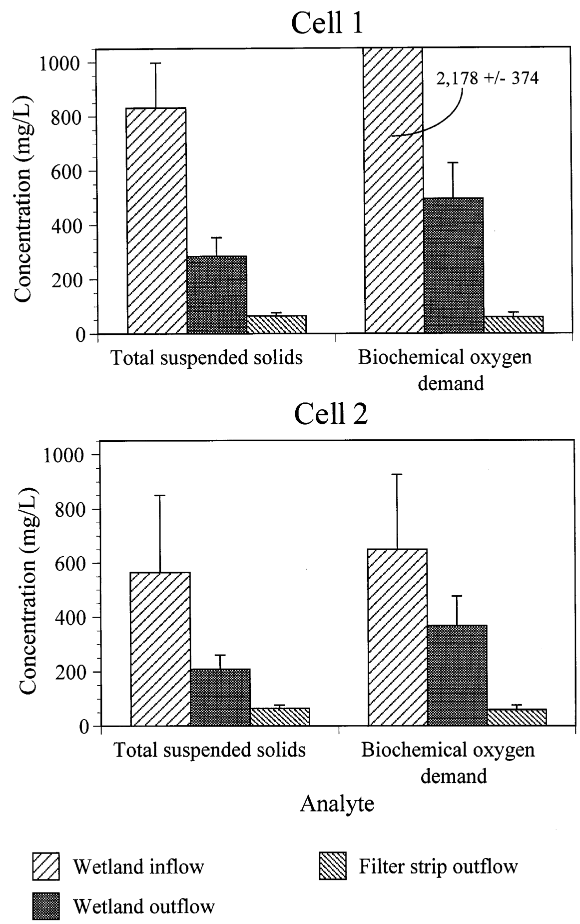

Fig. 3. Mean concentrations of total suspended solids (TSS) and biochemical oxygen demand (BOD) entering and leaving the wetland cells and leaving the vegetated filter strip. Error bars indicate + 1 SE. Statistical comparisons of influent and effluent concentrations are presented in Table 2.

4. Discussion

We observed significant reductions in concentrations of most wastewater constituents across the wetland treatment system. Average effluent concentrations from the vegetated filter strip were only slightly above the design requirements of < 30 mg/l BOD, < 30 mg/l suspended solids and < 10 mg/l ammonia (SCS, 1991). Of the various components of the system, the VFS appeared to be the most important contributor to the changes in analyte concentrations observed.

Our results differ from those of a similar study conducted by Cronk (1995) at the same site between August 1994 and April 1995. This earlier study showed removal of wastewater constituents in the wetland cells, but their effluent concentrations nonetheless greatly exceeded the design requirements listed above; dilution was suggested as a means of improving treatment (Cronk, 1995). The VFS outflow was not sampled during Cronk's study, but was probably flowing infrequently; effluent was flowing from Cell 1 or Cell 2 on only a minority of their sample events. Rainfall during the Cronk study was average for the area (CMREC, 1995, 1996). The majority of our study, in contrast, was conducted during 1996, the wettest of the previous eleven water years (CMREC, 1997). We observed that the percent change in concentration in the cells was similar or lower for most analytes than occurred in Cronk's study. However, because we usually observed and sampled water flowing from the VFS, our overall reduction in concentrations was higher.

Comparisons to studies at other locations are difficult because of differences in climate, latitude, altitude, and design and scale of operation. A study in Ireland (Costello, 1989) investigated a dairy farm with almost as many animals, but having a larger area of vegetated wetland (12 ha vs. 0.11 ha at our site). They found reductions in concentrations of BOD to be 99%, ammonia and nitrate 95%, and orthophosphate 91%. Levels of analytes in effluent were lower than was achieved in our study site, possibly because of the greater extent of vegetated wetland or because the effluent was more thoroughly cleaned of solids before it entered the wetland. A system in Oregon (Skarda et al., 1994) separated solids and then diluted the effluent with treated wastewater to maintain a recommended maximum of 100 mg NH_3/l. They found reductions of total phosphorus and total Kjeldahl nitrogen to be 50–55%, and orthophosphate, BOD, suspended solids, and ammonia to be 40–50%. Our data show greater removal percentages but recirculation of treated water in their system eliminates discharge of nutrients into surface waters. A study in New Zealand (Tanner et al., 1995a,b) varied plantings and loading rates and used shorter retention times (2–7 days) than our system. They found BOD was reduced by 80%, suspended solids 75–80%, total nitrogen 75%, and total phosphorus 74% in planted wetlands. These studies are indicative of the wide range of treatment effectiveness observed for constructed wetlands receiving dairy waste.

The changes in concentrations of nutrients and solids across the wetland system are attributable to a number of removal mechanisms. Plant uptake has been found to be an important contributor to nutrient removal in other wetlands (Peterson and Teal, 1996; Tanner, 1996). Ammo-

Table 2
Results of *t*-tests of concentrations of water quality parameters in influent and effluent wastewater for components of the constructed wetlands system[a]

Parameter	Cell 1 inflow vs. cell 1 outflow	Cell 1 outflow vs. filter strip outflow	Cell 2 inflow vs. cell 2 outflow	Cell 2 outflow vs. filter strip outflow
Ammonia	0.5229 (−)	0.0013 (−)	0.3092 (−)	0.1612 (−)
Nitrate/nitrite	0.0088 (−)	0.0034 (+)	0.1619 (+)	0.0089 (+)
Total Kjeldahl nitrogen	0.4055 (−)	0.0001 (−)	0.5316 (−)	0.0016 (−)
ortho-phosphate	0.0794 (−)	0.0004 (−)	0.5479 (+)	0.0031 (−)
Total phosphorus	0.0576 (−)	0.0002 (−)	0.9802 (−)	0.0080 (−)
Biochemical oxygen demand	0.0015 (−)	0.0034 (−)	0.3920 (−)	0.0131 (−)
Total suspended solids	0.0092 (−)	0.0094 (−)	0.2394 (−)	0.0145 (−)

[a] Values are *P*-levels from two-tailed *t*-tests. Direction of change indicated as positive (+) or negative (−).

Table 3
Summary of field parameters measured at various locations in the constructed wetland system for treating dairy waste[a]

Location	Parameter			
	Dissolved oxygen (mg/l)	Conductivity (mS/cm)	pH	Temperature (°C)
Settling basin 1	2.08 ± 0.47 (0.35–6.35)	2.54 ± 0.32 (0.3–5.58)	6.9 ± 0.28 (5.5–10.05)	15.1 ± 1.6 (4.2–25.2)
Settling basin 2	1.22 ± 0.28 (0.25–5.14)	1.94 ± 0.22 (0.76–3.56)	6.77 ± 0.07 (6.32–7.28)	13.9 ± 1.6 (2.3–25.2)
Cell 1 inflow	3.23 ± 0.53 (0.35–7.21)	3.75 ± 0.5 (1.22–8.53)	6.87 ± 0.17 (5.36–8.23)	14.5 ± 1.6 (4.6–24.6)
Cell 1 outflow	2.25 ± 0.51 (0.28–9.76)	2.68 ± 0.23 (1.38–4.68)	7.51 ± 0.09 (6.98–8.37)	14.1 ± 1.7 (3.1–27.8)
Cell 2 inflow	2.89 ± 0.42 (0.32–6.79)	2.36 ± 0.33 (0.81–7.1)	7.13 ± 0.12 (6.38–8.2)	13.8 ± 1.5 (2.3–24.4)
Cell 2 outflow	3 ± 0.38 (0.038–7.32)	1.99 ± 0.17 (0.89–3.29)	7.35 ± 0.08 (6.45–7.81)	13.8 ± 1.6 (3.4–26.5)
Filter strip outflow	3.97 ± 0.43 (2.08–6.25)	1.29 ± 0.34 (0.71–4.3)	6.79 ± 0.1 (6.3–7.44)	15.2 ± 1.6 (8.4–21.6)

[a] Values are mean ± SE of monthly measurements between October 1995 and May 1997; range given in parentheses.

nia reduction is also achieved by volatilization at the surface and, in aerobic zones, oxidation to nitrate via nitrification (Brix, 1993; Mitsch and Gosselink, 1993). Oxidation is probably limited in the wetland cells based on the low dissolved oxygen concentrations we observed, but the increase in nitrate/nitrite we observed in the filter strip parallels an increase in dissolved oxygen levels there. Sediment, BOD, and nutrients are removed more completely in the VFS than in the cells, possibly due to greater density of vegetation in the VFS. Stems interrupt the flow diffusing the kinetic energy required to carry solids and prevent the resuspension of solids by wind (Dunne and Leopold, 1978). Particulate nitrogen, phosphorus, and BOD are also reduced as solids settle. Phosphorus compounds are further removed by sorption to soils and by plant uptake (Brix, 1993).

A limitation of our study is that the design of the system resulted in complex hydrologic conditions that prevented us from quantifying mass removal rates. The system was originally designed such that flow rates into the cells would be equal, creating two replicate wetland cells. During our study, the higher-than-normal precipitation overloaded SB1 and flowed into SB2, resulting in different flow rates into Cell 1 and Cell 2. Also, dilution from ground water seepage or stormwater diverted to the VFS may account for some of the analyte reduction we observed. However, we were unable to detect any ground or surface water inputs based on measurements of inflow rates to the VFS from Cells 1 and 2 and outflow rates from the VFS. In fact, our measurements indicated that more water was entering the VFS from the cells than was leaving via surface flow, suggesting a minimal input of water from groundwater or stormwater and a high evapotranspiration rate. Finally, the hydrology of the system currently appears to differ substantially from that for which it was initially designed. The original design was supposed to result in a hydraulic residence time of 47 days, the length of time estimated to achieve the design requirement for BOD of 30 mg/l (field test method; SCS, 1991; Kodmur et al., 1994). Using the actual BOD

values measured at inflow and outflow locations for this period yields a calculated residence time of only 7 days. Factors that may have reduced residence time include siltation by excessive solids input from the settling basins and development of channelized flow patterns through the wetland cells.

Possible changes to improve the treatment capacity of the system include increasing the density of vegetation in the cells and modifying the design of the system. Recent plantings of *Typha latifolia* and *Phragmites australis* (Cav.) Trin. Ex Steud are currently being evaluated and show promise of establishing a greater density of vegetation in the wetland cells. Possible design modifications include recirculation during periods of elevated precipitation and increasing residence time (e.g. by reducing channelization through the use of influent dispersal units or adding cells). Recirculation or adding an anaerobic cell downstream of the filter strip would provide an anaerobic environment promoting denitrification of nitrate and nitrite generated in the filter strip. Finally, a roof over the manure pit, the largest source of wastewater, would decrease the hydraulic and waste loading rates to the wetland cells and filter strip, probably increasing the effectiveness of the system.

5. Conclusions

The constructed wetland system reduced concentrations of most constituents present in dairy farm wastewater. An exception is nitrate/nitrite, which increased in concentration as water flowed through the vegetated filter strip, presumably due to oxidation of ammonia. The filter strip, which is essentially a third wetland, appears to be more effective in treating wastewater than the wetland cells, possibly because it is more densely vegetated. Addition of an anaerobic cell after the filter strip or recirculation of filter strip effluent through the wetland cells would promote nitrogen removal via denitrification. Our research underscores the need for understanding the hydrology of constructed wetlands, especially the responses of wetland-based systems to above-normal precipitation events.

Acknowledgements

Thanks to Ellen DeRico, who conducted the nutrient analyses, and to Pat Kangas and Adel Shirmohammadi for their insightful comments on the manuscript. This research was supported by a U.S. Environmental Protection Agency Clean Water Act Section 319 grant administered through the State of Maryland Department of Natural Resources.

References

APHA, 1992. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, New York, 1268 pp.

Brix, H., 1993. Wastewater treatment in constructed wetlands: system design, removal processes, and treatment performance. In: Moshiri, G.A. (Ed.), Constructed Wetlands for Water Quality Improvement. Lewis, Boca Raton, FL, pp. 9–22.

Brix, H., 1994. Constructed wetlands for municipal wastewater treatment in Europe. In: Mitsch, W.J. (Ed.), Global Wetlands: Old World and New. Elsevier, Amsterdam, pp. 325–333.

Brodie, H.L., 1988. Estimated distribution of farm animals and their manure nutrient production in Maryland by watershed, 1988. Agricultural Engineering Department, University of Maryland, College Park, MD.

CMREC, 1995. Precipitation data for 1995 collected at the Central Maryland Research and Education Center, University of Maryland, Clarksville, MD.

CMREC, 1996. Precipitation data for 1996 collected at the Central Maryland Research and Education Center, University of Maryland, Clarksville, MD.

CMREC, 1997. Precipitation data for 1997 collected at the Central Maryland Research and Education Center, University of Maryland, Clarksville, MD.

Costello, C.J., 1989. Wetlands treatment of dairy animal wastes in Irish drumlin landscape. In: Hammer, D.A. (Ed.), Constructed Wetlands for Wastewater treatment, Municipal, Industrial and Agricultural. Lewis, MI, Chelsea, pp. 702–709.

Cronk, J.K., 1995. Wetlands as a best management practice on a dairy farm. In: Campbell, K.J. (Ed.), Versatility of Wetlands in the agricultural landscape. American Society of Agricultural Engineers, Tampa, FL, pp. 263–271.

Cronk, J.K., 1996. Constructed wetlands to treat wastewater from dairy and swine operations: a review. Agric. Ecosyst. Environ. 58, 97–114.

Dunne, T., Leopold, L.B., 1978. Water in Environmental Planning. W.H. Freeman, New York, 818 pp.

Hammer, D.A., Pullen, B.P., McCaskey, T.A., Eason, J., Payne, V.W.E., 1993. Treating livestock wastewaters with constructed wetlands. In: Moshiri, G.A. (Ed.), Constructed Wetlands for Water Quality Improvement. Lewis, Boca Raton, FL, pp. 343–347.

Hedin, R.S., Nairn, R.W., 1993. Contaminant removal capabilities of wetlands to treat coal mine drainage. In: Moshiri, G.A. (Ed.), Constructed Wetlands for Water Quality Improvement. Lewis, Boca Raton, FL, pp. 187–195.

Jaworski, N.A., Groffman, P.M., Keller, A.A., Prager, J.C., 1992. A watershed nitrogen and phosphorus balance: the Upper Potomac River Basin. Estuaries 15, 83–95.

Johengen, T.H., LaRock, P.A., 1993. Quantifying nutrient removal processes within a constructed wetland designed to treat urban stormwater runoff. Ecol. Eng. 2, 347–366.

Kodmur, V., Cronk, J.K., Shirmohammadi, A., 1994. Design criteria for constructed wetlands to treat animal waste based on biochemical oxygen demand and on nitrogen loadings. Paper 94-2601, Annual Meeting of the American Society of Agricultural Engineers, 13–16 December 1994, Atlanta, GA.

Maryland Department of the Environment, 1993. Maryland's Section 319 Non-point Source Nutrient Control Priority Watershed List. NPS Assessment and Policy Development Program, Annapolis, MD.

Mitsch, W.J., Gosselink, J.G., 1993. Wetlands. 2nd Edition. Van Nostrand Reinhold, New York, 722 p.

Mitsch, W.J., Cronk, J.K., Wu, X., Nairn, R.W., 1995. Phosphorus retention in constructed freshwater riparian marshes. Ecol. Appl. 5, 830–845.

Peterson, S.B., Teal, J.M., 1996. The role of plants in ecologically engineered wastewater treatment systems. Ecol. Eng. 6, 137–148.

Reddy, K.R., D'Angelo, E.M., 1994. Soil processes regulating water quality in wetlands. In: Mitsch, W.J. (Ed.), Global Wetlands: Old World and New. Elsevier, Amsterdan, pp. 309–333.

SCS, 1991. Constructed Wetlands for Agricultural Wastewater Treatment—Technical Requirements. Soil Conservation Service, Washington, D.C.

Skarda, S.M., Moore, J.A., Niswander, J.F., Gamroth, M.J., 1994. Preliminary results of wetland for treatment of dairy farm wastewater. In: DuBowy, P.J., Reaves, R.P. (Eds.), Proc. Workshop on Constructed Wetlands for Animal Waste Management, 4–6 April 1994, Lafayette, IN, pp. 34–42.

Tanner, C.C., 1996. Plants for constructed wetland treatment systems—a comparison of the growth and nutrient uptake of eight emergent species. Ecol. Eng. 7, 59–83.

Tanner, C.C., Clayton, J.S., Upsdell, M.P., 1995a. Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands. 1. Removal of oxygen demand, suspended solids and faecal coliforms. Water Res. 29, 17–26.

Tanner, C.C., Clayton, J.S., Upsdell, M.P., 1995b. Effect of loading rate and planting on treatment of dairy farm wastewaters in constructed wetlands. 2. Removal of nitrogen and phosphorus. Water Res. 29, 27–34.