Constructed Wetlands for the Treatment of Wastewater

Report No. 195

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by

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Performance Data from Model Constructed Wetlands for Wastewater Treatment

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Abstract

A study has been initiated to contribute to the development of process-based design approaches for constructed wetlands in cold climates. Eight bench-scale vegetated sub-surface bed wetland cells were placed in the climate-controlled environment of Montana State University's Plant Growth Center. Three each were planted with native cattail and bulrush, while two cells remained unplanted as a control treatment. Since April 1996 the cells have received a stream of synthetic wastewater at a rate of 30 ml/min, resulting in a hydraulic residence time of approximately 5 days. To date, the system has been operated at three separate influent concentrations and at various steady temperatures ranging from 4° C to 21° C. Samples drawn from influent and effluent once per residence time have been analyzed for the parameters COD, NH_4, PO_4, and SO_4. Concentration data are presented as a time series moving average for each water quality parameter. All treatments have displayed 80 to 90% COD removal efficiency at temperatures greater than 12° C. Emergent plants have had significant effects upon ammonia and phosphate removal efficiency. Only planted wetland cells exhibited significant long-term phosphate removal. Substantial sulfate removal was expressed in all treatment types at the higher wastewater strengths. Sulfate treatment efficiency was greatly reduced at the lower strength for planted treatments, attributed to increased oxygenation of the root zone. Due to significant water loss through evapo-transpiration, planted treatments generally display greatly improved removal efficiencies if measured on a mass rather than concentration basis.

Introduction

A long-term study has been initiated which will contribute to the development of process-based approaches for designing constructed wetlands

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(CW) for wastewater treatment in middle- and high-latitude regions with cold climates. Specific goals of the study are to: (a) provide additional information on the feasibility of using sub-surface flow (SSF) wetlands to treat wastewater in cold climates, (b) develop objective design and operational criteria for constructed SSF wetlands based on evaluation and modeling of key process controls, (c) document the quality of water emerging from model SSF wetlands.

The aim of this paper is to present priority parameters as a time series which can be compared to various operational changes and plant life cycle changes for three different plant treatments. Priority parameters routinely sampled (once per residence time t_H) in both influent and effluent include: COD as a measure of total organics, the nitrogen species NH_4, NO_3, NO_2, phosphate PO_4, and sulfate SO_4. Continuously monitored parameters include temperature (since project initiation) and effluent flow rate (recently). Other water quality parameters including total Kjeldahl nitrogen (TKN) and pH are less frequently sampled.

Methods

Eight constructed wetlands (CW cells) were constructed and placed in an environmentally controlled greenhouse. Each CW cell is 152 cm long, 76 cm wide, and 53 cm deep and filled with gravel (19 mm > size > 13 mm) to a depth of 46 cm. The average initial porosity was 0.40. Water temperature at a depth of 36 cm was measured in each cell by a differential thermocouple which records data every half hour. Greenhouse air temperature was also measured at the same frequency. Additional details are found in Biederman and Stein (1997).

Three cells each were planted with *Typha sp.* (broad-leaf cattail) and *Scirpus sp.* (hard-stem bulrush) on December 5, 1995, while two cells remained unplanted as treatment controls. The plants were recovered from a native wetland near Bozeman, MT. Root stocks were planted on 30-cm centers at a depth of 7 cm. Both species exhibited nearly 100% transplant success and rapid initial growth. At approximately nine months after planting, stable heights of 1 m for the bulrush and 2 m for the cattail were achieved. At this time, depth of root penetration below the gravel surface was 27 cm for the cattail and 46 cm (to cell bottom) for the bulrush. However, root density decreased as a function of depth for both species. Basal density of the cattails appeared to have stabilized at approximately one stalk per 10 cm^2 over the entire wetland surface, while bulrush density was more varied, as the original transplant plugs could still be distinguished after nine months. Both plant species were observed to enter a period of relative dormancy from December 1996 through May 1997, after which time vigorous regrowth began. Within a period of one month, both species achieved heights of 2 to 3 m and very dense basal coverage of their entire respective wetland cells. In early October 1997 the plants once again entered a period of relative dormancy.

A continuous flow of synthetic wastewater has been delivered by a peristaltic pump system at a rate of 30 ml/min/cell ±5% (t_H = 5 days) since April 5, 1996. Sampling of influent and effluent every fifth day (once per t_H) has occurred continuously since June 1996. All samples are analyzed for concentrations of nitrate, phosphate and sulfate by ion chromatography.

Chemical oxygen demand (COD) is measured by colorimetric determination following digestion. Ammonium is measured in all samples colorimetrically, and total Kjeldahl nitrogen TKN is determined whenever a control parameter is varied. From April 5 to August 16, 1996, approximate average influent concentrations were 200, 80, 8, and 8 mg/L for COD, NH_4, PO_4-P, and SO_4-S, respectively. From August 17, 1996 through October 19, 1997 all concentrations were halved. Virtually all influent nitrogen was in ammonia form. Since October 20, 1997 approximate influent concentrations have been 450, 25, 45, 8, 8 mg/L for COD, NH_4, TKN, PO_4-P, and SO_4-S, respectively At all times appropriately scaled smaller concentrations of micro-nutrients have been maintained. Details can be found in Stein et al., 1998.

Results and Discussion

After construction of the wetland cells, but prior to planting, the baseline hydrodynamics of all cells were analyzed using a conservative tracer (KBr with bromide measured colorimetrically). The system demonstrates less than ideal plug-flow as bromide appeared in the effluent before one t_H; and remained for at least 4 t_H. Repetition of tracer tests at 18 months after planting showed little change in hydrodynamics for all cells (Stein et al., 1998).

Significant evapo-transpiration (ET) loss has been observed during summer months from all treatments. Using a crude technique, initial estimates of July ET are Cattail = 15.1 ml/min, Bulrush = 7.1 ml/min, Control = 3.9 ml/min. The significance of these initial ET estimates demonstrated the need for continuous monitoring of effluent rate. A system designed to meet this objective has recently been implemented and should greatly enhance our understanding of wetland evapo-transpiration and its influence on water quality.

Approximately 1550 water quality samples have been drawn and analyzed since project initiation. Mean values for measured concentrations of COD, ionized ammonia (NH_4), phosphate, and sulfate from each plant treatment type are shown in a time series format in Figs. 1-4, respectively.

Chemical Oxygen Demand (COD) concentration data are presented as a five point moving average in Fig. 1. Note the correlation between influent and effluent concentration variation offset by approximately one residence time and the increase in variance at the higher influent concentration. Differences in effluent concentration between treatments are confounded by different effluent flow rates. During periods of active plant growth, and therefore significant ET, effluent concentration is greatest for cattail, followed by control and bulrush. During relative plant dormancy, control treatments had the greatest COD effluent concentration but the differences are very small.

Ammonium concentration data are shown as a five point moving average in Fig. 2. Nitrate and nitrite have not been detected in either influent or effluent. Occasional measurement of total nitrogen using TKN analysis showed that ammonium constitutes more than 95% of the total nitrogen load through the

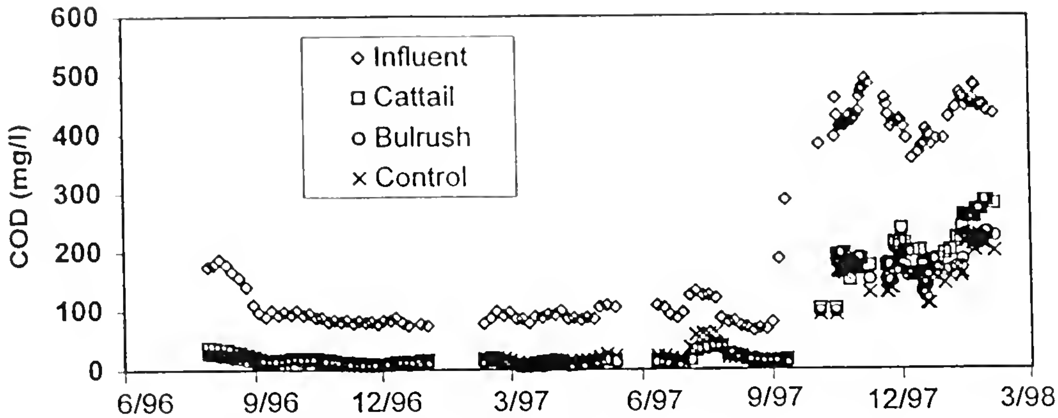

Figure 1. Chemical Oxygen Demand Concentration as a Function of Time

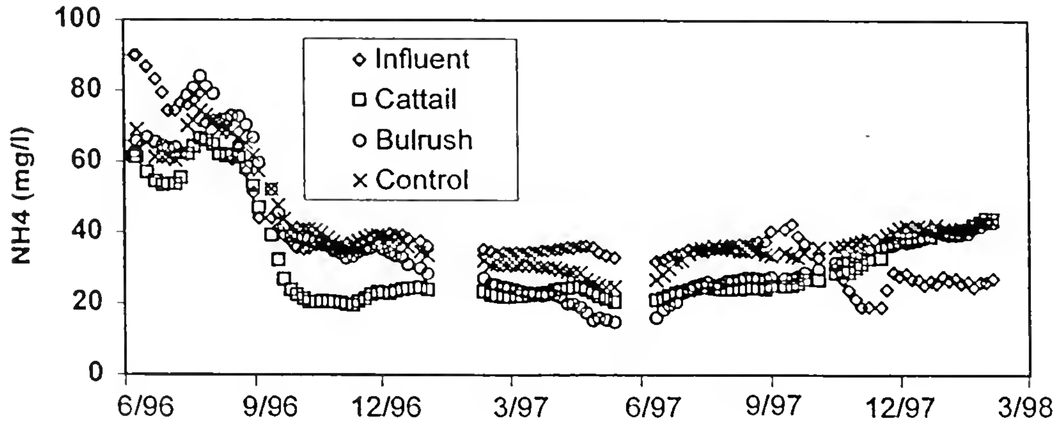

Figure 2. Ammonium Concentration as a Function of Time

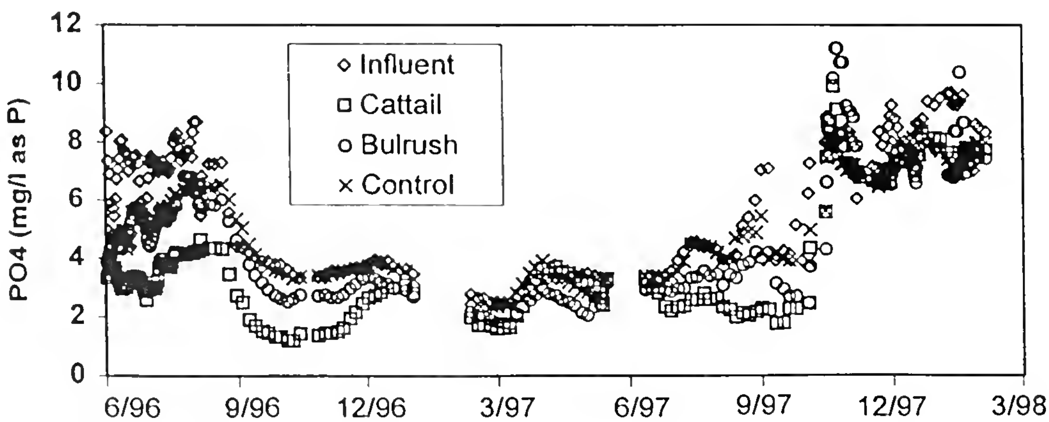

Figure 3. Phosphate (as P) Concentration as a Function of Time

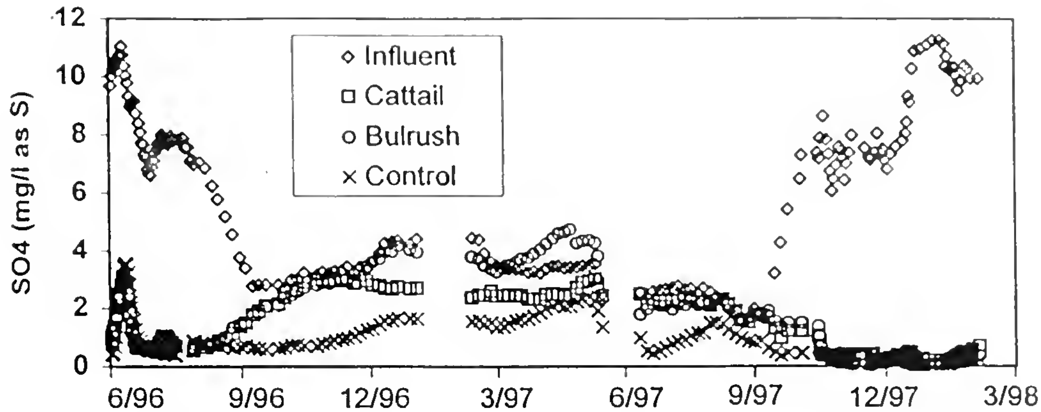

Figure 4. Sulfate (as S) Concentration as a Function of Time

system prior to October 1997. The straight line after October 1997 represents the approximate total nitrogen inflow as a greater proportion of organic N was added to the influent. Although all cells expressed some reduction in NH_4 prior to August 1996, only planted treatments have exhibited appreciable long-term ammonia removal.

Measured phosphate concentration data are presented as a nine point moving average in Fig. 3. Overall removal efficiency clearly varies by treatment and season. By August 1996, four months after the start of wastewater application, the control treatment's removal efficiency had decreased from approximately 40% to virtually zero, and has remained there since. Both cattail and bulrush were dormant between December 1996 and June 1997, and after October 1997. During the 1997 growing season, cattail growth was more vigorous than bulrush. During this active plant growth phase, phosphate removal efficiency increased, especially for cattail. It is suspected that uptake by macrophytic plants exhibiting vegetative growth is a significant mechanism of phosphate removal.

Sulfate concentration data are shown as a nine point moving average in Fig. 4. Higher influent concentrations prior to August 1996 and after October 1997 correlate to lower effluent concentrations, especially for the planted treatments. Note that influent COD concentrations vary in a manner similar to sulfate. An odor of H_2S from the wetlands during higher influent concentrations suggests the reduction of SO_4 by sulfur-reducing bacteria (SRB's). SRB activity implies the existence of anoxic regions within the wetlands during this time. It is believed that the reduced oxygen demand during the period August 1996–October 1997 led to a slight increase in dissolved oxygen content (though this was not directly measured), resulting in inhibition of SRB activity in planted cells. Continued sulfate reduction by the control treatment suggests that unplanted cells may have lower dissolved oxygen contents. Thus, the sulfate data presents circumstantial evidence of the positive influence of macrophytic plants on oxidation of the root zone, at least for conditions of relatively low oxygen demand in the water.

Further Research Efforts

Research is continuing with the established wetland system. Presented data represents several different operating temperatures. Data will be analyzed for the development of temperature-dependent kinetic modeling. Research will also focus on the development or application of models for evapotranspiration, as ET has significant effects upon parameter concentrations and volume of wetland effluent. Greater attention will additionally be paid to the study of the root zone microcosm, including redox potential and oxygen transfer from plant roots to biofilms.

Summary and Conclusions

Substantial reduction in COD has been observed from all three constructed wetland treatments at two unique influent concentrations (Fig. 1). Nitrogen removal has been far less dramatic and appears to be positively affected by the presence of two plant species (*Typha sp.* and *Scirpus sp.*) (Fig. 2). Phosphate removal is also positively affected by macrophytic plant species, especially during active growth (Fig 3). Chemical reduction of sulfate to hydrogen sulfide appears to be the primary transformation of oxygenated sulfur-containing compounds in the wetland system. Influent COD concentrations of >150 mg/L appear to facilitate this transformation in all treatments (Figs. 1 and 4). This transformation did not take place in planted treatments when influent COD concentrations were approximately 100 mg/L. Apparently the plants provide sufficient oxygen to inhibit this reaction which provides evidence for the plant-mediated oxygenation of the wetland environment. In general, plant effects appear to be correlated to the season and growth status of the plant. These effects are thought to be correlated to plant uptake of nutrients, oxygen transport into the root zone and to other plant-microbial biofilm interactions.

Acknowledgments

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