SYSTEM CHARACTERISTICS AND REMOVAL EFFICIENCIES OF A CONSTRUCTED WETLAND DESIGNED FOR TERTIARY TREATMENT OF BLEACH-KRAFT PULP MILL EFFLUENT

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INTRODUCTION

Georgia Pacific's Leaf River Pulp Operations in New Augusta, MS, instituted a pilot study in the spring of 1989 to determine the performance expectations for constructed wetlands treatment of pulp mill effluent. The project established three identically configured wetland cells with control over depth and flow rate. Phase I of this pilot study involved testing with Panicum repens, torpedo grass, and is reported elsewhere (Reaves et al. 1991). This presentation will report the findings of the Phase II pilot project begun in August of 1991.

PURPOSE

The purpose of this study is to measure changes in target parameters while maintaining a constant depth in each experimental wetland cells, altering only flow rate, to arrive at site specific design criteria that can be used in the development of a larger constructed wetlands for treatment of all or part of ≈ 20 million gallons of wastewater discharge per day.

LITERATURE REVIEW

Interest has increased during recent years over the use of constructed wetlands for treatment of many types of wastewater. Several studies have been conducted on domestic sewage (Watson et al. 1989) while only a limited number of investigations have focused on pulp mill effluent (Allender 1984; Hammer et al. 1993; Reaves et al. 1991; Thut 1989, 1990, and 1993; and Tettleton et al. 1993). Even fewer have designed their projects around a free water surface flow wetland (Hammer et al. 1993; Reaves et al. 1991; and Tettleton et al. 1993).

Historically, studies with constructed wetlands have attempted to enhance contact surface area by passing the wastewater through a bed of inert substrate such as gravel or marl (i.e., Submerged Flow Wetland). While this design provided abundant contact surface area, the systems also had increased construction (i.e., gravel or marl) and maintenance (i.e., occlusion of interstitial spaces of substrate) related cost. For this reason, our wetland cells were designed on the free water surface flow wetland design.

To optimize contact surface area for bacterial attachment, (Reed and Brown 1992) in Phase I of our study we selected torpedo grass, a plant that exhibits dense stem growth, as our principle wetland vegetation. Reaves et al. (1991) reported that this plant did not prove suitable. Typha latifolia, cattail, and Scirpus validus, soft-stem bulrush, were chosen for Phase II design based on recommendations made by Knight (1991).

METHODS

System Design

Phase II design criteria included two deep zones per wetland cell to enhance hydraulic retention capacity. Each cell is 1/3 acre (0.13 hectare) with an aspect ratio of approximately 3:1. A splitter box with vertical weirs was constructed to provide a measured flow to each wetland cell from one of the secondary clarifiers at the mill's wastewater treatment facility. Influent was piped from the overflow of the splitter box to a head pipe at each wetland equipped with six adjustable angle nozzles along its length. The adjustable nozzles help balance the flow along the length of the head pipe to provide even distribution across the cells.

Sampling Design

Testing began once vegetation in the cells attained 75% coverage of water surface area. Data included in this study were collected between 7 October 1991 and 3 January 1994. Hydraulic loading rates were as follows: Cell 1 -43 000 liters per day (lpd); Cell 2 - 95 000 lpd; Cell 2 (changed December 1992 to 21 500 lpd); Cell 3, 148 000 lpd.

Sample Collection and Frequency

On each visit, a sample was collected from one nozzle from each wetland. This provided one inlet sample per cell. Another sample was collected at the overflow from each wetland's exit weir. At least twice each week the samples were analyzed for temperature, dissolved oxygen, turbidity, conductivity, pH, total suspended solids, true color, and biochemical oxygen demand - 5 day. Once a week, samples were analyzed for nitrate, ammonia, total Kjeldahl nitrogen, and total phosphorus. All tests were conducted according to Standard Methods, modified and adapted to Hach Chemical Company procedures (Hach 1991).

Statistical Analysis

To determine whether the wetland cells had altered the wastewater as it passed through the system, a two sample Student's t test was performed on the average inlet and outlet concentrations for each parameter, from each cell, at its corresponding flow rate. The t-statistic was calculated with the aid of a microcomputer running Jandel's SigmaPlot v. 5.0 for DOS (Norby et al. 1992). The significance level was $\alpha = 0.05$ for all comparisons.

RESULTS AND DISCUSSION

Vegetation Performance

Vegetation coverage of the wetlands progressed rapidly. By the end of the second growing season, their coverage had reached better that eighty-five percent for cattails and ninety-five percent for bulrush. The plants were healthy and there was no apparent failure to thrive introduced by the wastewater or any of the design criteria (i.e., depth, flow rate, etc.). Dense plant matter appeared to decompose normally and did not pose a maintenance problem by accumulation.

Physical - Chemical Water Parameters

Table 1 provides percentage reduction and indicates whether the change was an increase or decrease for the given parameter and flow rate. Table 2 summarizes descriptive sample statistics of each test parameter collected at a corresponding flow rate.

With the exception of turbidity in Cell 2 (21 500 lpd) which increased, pH in Cell 3 and conductivity in Cell 2 (21 500 lpd) which did not change significantly, all physical - chemical parameters measured in this study decreased in concentration.

Conductivity and pH. Conductivity only decreased 5% or less and pH only decreased 3% or less. No reason can be offered for these reductions except to speculate that they could be related to water balance and that an accurate correction for rain fall may remove their significance.

Temperature. The wastewater supplied from the clarifier has a temperature of 35° - 40° C or greater as it enters the wetlands. The retention time through the wetland cell allows adequate time for the temperature to reach ambient conditions (e.g., reductions of > 27%).

Dissolved Oxygen. While the secondary clarification of the wastewater has reduced the organic load to well below typical permit limits prior to being applied to the wetland, there remains enough organic material in the wastewater for bacterial metabolism to significantly deplete (e.g., 40 - 78%) the available dissolved oxygen in the span of each wetland cell's retention time. Oxygen depletion is further affected during the warmer times of the year when oxygen saturation levels are low.

Turbidity. Turbidity in water is frequently associated with bacterial growth, algal growth, and suspended particles. The wastewater entering the wetlands has measurable levels of total suspended solids. Significant decreases in turbidity occur (42 - 46%) in the wetlands and appear to be linked to decreases in suspended solids. The increase in turbidity (+45%) that occurred in the slower flow rate study (21 500 lpd) of Cell 2 (Table 1 and 2) may be related to disturbance of sediments during sampling or more probably due to algal or bacterial growth during the summer sampling period.

Organic Parameters

Changes in concentration of Total suspended solids, true color, BOD(5), ammonia, nitrate, TKN, and total phosphorus are summarized in Table 3. Table 4 summarizes descriptive sample statistics of each test parameter collected at a corresponding flow rate.

Total Suspended Solids. Total suspended solids (TSS) are primarily associated with the presence of wood particulates and lignins left over from the wood pulping process. These solids are filtered by the vegetation and settled over the length of the retention time through the wetlands. Under all flow rates, TSS showed significant decreases ranging from 51 to 66%.

True Color. As with TSS, true color of the wastewater is known to be directly related to the tree pulping process and is comprised of very small wood particles with high molecular weights that are in a colloidal suspension in the wastewater. The particles' colloidal nature, size and weight prevents them from being filtered or settling in the wetlands. True color is not expected to be significantly affected by wetlands treatment. In fact, all flow rates showed no significant change between inlet and outlet concentrations with the exception of the 43 000 lpd (Cell 1) flow rate which exhibited a statistically significant decrease of 11%. This reduction may be the result of dilution from rainfall.

Biochemical Oxygen Demand - 5 Day. Biochemical oxygen demand - 5 day, [BOD(5)], is significantly reduced during normal oxidation and clarification in the paper mill's wastewater treatment plant. However, measurable levels do enter each wetland cell. BOD(5) consistently decreased 25 - 54% from inlet to outlet across the cells. Even with inlet values as low as 9 mg/l we typically measure decreases of 50%.

Nutrient Parameters

Ammonia. With the exception of Cell 2 (21 500 lpd), all flow rates showed consistent reductions in ammonia (e.g., 14 - 31%). These reductions may be related to nitrification. While dissolved oxygen levels at the outlets was low, there was certainly enough available dissolved oxygen to facilitate this process. Additional losses could be related to volatilization.

Nitrate. Our results for nitrate have been inconsistent with published data from prior studies. Cell 1 and Cell 2 (95 000 lpd) (Tables 3 and 4) did not significantly change in concentration. Cell 2 (21 500 lpd) and Cell 3 (Tables 3 and 4) showed 60% and 21% reductions, respectively. Quality assurance/quality control methods conducted during the 1993 year revealed a potential problem with our nitrate data. The evidence indicates that our data may be higher than measurements provided by an analytical testing laboratory.

Total Kjeldahl Nitrogen (TKN). The combination of deep anaerobic zones and shallow aerobic zones in the wetlands was expected to make conditions favorable for reductions in TKN. With the exception of Cell 2 (21 500 lpd), all flow rates indicated decrease in TKN ranging from 13% to 25%.

Total Phosphorus. Adsorption of phosphorus to sediments is one of the principal means of phosphorus removal. The wetlands have shown that they can significantly remove phosphorus for as long as two to three growing seasons. Reductions ranged from 8% to 20% across all flow rates with the exception of Cell 2 (21 500 lpd) which did not significantly change.

CONCLUSIONS

Reductions in Target Parameters. Free water surface flow wetland treatment of secondary treated bleach kraft pulp mill effluent represents a viable alternative to conventional methods. Reductions in target parameters such as BOD(5), TSS, and nutrients often approached levels for advanced waste treatment ($\leq$ 10 mg/l). Corrections for nitrate analysis procedures and continued study of the slower flow rate of 21 500 lpd may yield additional information leading to concrete design criteria.

Performance of Vegetation. At present, projections for larger scale wetlands would include a combination of cattails and bulrushes in the design. Both of these plants thrived in the wetlands. Additionally, the bulrushes remained lush and green during the cold temperature periods that the cattails were dormant. A blend of these two would provide for standing live material throughout the year. These species appear to coexist without competitive exclusion.

Deep Zones. The deep zones were originally intended to provide nonvegetated areas that would be aerated through wind action. Duckweed quickly inhabited the wetlands and covered all available open water. However, the deep zones did provide volume for larger hydraulic retention capacity. The deep zones can provide increased hydraulic retention capacity in instances where available land is limited. Their value as an anaerobic zone has not been quantified.

Flow Rate. Optimal flow rate has not been determined yet. Assuredly there will be a point of diminishing return. Additional testing of our slowest flow rate of 21 500 lpd may help to conclude this point.

ACKNOWLEDGEMENTS

We would like to thank Acker Smith, Manager of Environmental Affairs, who provided the initial concept for this project and Warren Richardson, Mill Manager of Georgia Pacific's Leaf River Pulp Operations in New Augusta, MS, for their generous support of our efforts. Additional thanks go to Robert L. Knight, Ph.D., Senior Environmental Scientist (Gainesville), and Jim Bays, Environmental Scientist (Tampa), of CH2MHill for their expert guidance.

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Table 1. Summary of comparison between inlet and outlet of each wetland Cell and direction of significant change for each parameter tested.

Parameter	Flow:	Cell 1 43 000 lpd	Cell 2 95 000 lpd	Cell 2 21 500 lpd	Cell 3 148 000 lpd
Water Temperature		30% ↓	31% ↓	28% ↓	27% ↓
Turbidity		42% ↓	44% ↓	45% ↑	46% ↓
pH		2% ↓	1% ↓	3% ↓	NC
D.O.		50% ↓	40% ↓	78% ↓	51% ↓
Conductivity		5% ↓	5% ↓	NC	3% ↓

↓ : Outflow concentration or level significantly less than inflow ($p < 0.05$).
↑ : Outflow concentration or level significantly greater than inflow ($p < 0.05$).
NC: Outflow concentration or level showing no significant change from inflow ($p < 0.05$).

Table 2. **Statistical summary describing physical - chemical parameters measured in samples collected at corresponding cell and flow rate.**

		Cell 1			Cell 2			Cell 2			Cell 3		
	Flow:	43 000 lpd			95 000 lpd			21 500 lpd			148 000 lpd		
Parameter		AVG	N	SE	AVG	N	SE	AVG	N	SE	AVG	N	SE
Water Temperature	IN	27.35	288	0.23	27.16	184	0.24	26.95	104	0.49	26.99	288	0.23
	OUT	19.09	288	0.29	18.63	184	0.36	19.38	104	0.49	21.60	288	0.28
Turbidity	IN	51.76	270	6.14	69.61	181	8.61	17.62	89	3.90	52.91	270	6.43
	OUT	29.89	270	1.60	31.29	181	2.84	32.48	89	2.48	28.16	270	2.93
pH	IN	7.42	276	0.02	7.41	182	0.03	7.53	94	0.02	7.41	276	0.03
	OUT	7.23	276	0.02	7.36	182	0.03	7.29	94	0.02	7.39	276	0.02
D.O.	IN	3.43	285	0.08	3.75	281	0.10	2.76	101	0.14	3.32	268	0.09
	OUT	1.69	284	0.11	2.25	281	0.14	0.61	101	0.09	1.61	268	0.10
Conductivity	IN	3385	260	37.38	3501	180	47.26	3178	80	48.47	3428	260	36.56
	OUT	3200	260	35.73	3345	180	41.33	3037	80	74.44	3324	260	32.83

AVG = average, N = number of samples, SE = standard error, IN = sample collected at inlet of cell, OUT = sample collected at outlet of cell

Table 3. **Summary of comparison between inlet and outlet of each wetland Cell and direction of significant change for each parameter tested.**

Parameter	Flow:	Cell 1 43 000 lpd	Cell 2 95 000 lpd	Cell 2 21 500 lpd	Cell 3 148 000 lpd
TSS		66% ↓	55% ↓	60% ↓	51% ↓
True Color		11% ↓	NC	NC	NC
BOD(5)		25% ↓	36% ↓	12% ↓	54% ↓
Ammonia		31% ↓	27% ↓	NC	14% ↓
Nitrate		NC	NC	60% ↓	21% ↓
TKN		25% ↓	25% ↓	NC	13% ↓
Phosphorus		20% ↓	20% ↓	NC	8% ↓

↓ : Outflow concentration or level significantly less than inflow ($p < 0.05$).
↑ : Outflow concentration or level significantly greater than inflow ($p < 0.05$).
NC: Outflow concentration or level showing no significant change from inflow ($p < 0.05$).

Table 4. **Statistical summary describing organic and nutrient parameters measured in samples collected at corresponding cell and flow rate.**

Parameter	Flow:	Cell 1 43 000 lpd			Cell 2 95 000 lpd			Cell 2 21 500 lpd			Cell 3 148 000 lpd		
		AVG	N	SE	AVG	N	SE	AVG	N	SE	AVG	N	SE
TSS	IN	64.48	269	7.19	80.30	180	10.03	30.68	89	4.24	64.36	269	7.23
	OUT	22.01	269	1.84	35.92	180	6.24	12.44	89	0.57	31.46	269	3.57
True Color	IN	2357	262	56	2204	178	63.98	2299	84	88.83	2230	262	52.97
	OUT	2098	262	43	2116	178	56.11	2189	84	69.20	2192	262	50.32
BOD(5)	IN	17.59	167	1.37	19.20	105	2.08	15.64	64	2.12	18.30	166	1.74
	OUT	13.19	175	0.60	12.25	105	1.12	13.70	64	0.85	12.68	164	0.96
Ammonia	IN	8.93	96	0.77	10.43	68	0.76	3.95	28	1.66	8.36	96	0.79
	OUT	6.08	96	0.39	7.65	68	0.48	2.72	28	0.49	7.13	96	0.55
Nitrate	IN	11.59	78	1.60	15.43	57	2.25	13.81	26	3.40	16.89	87	2.10
	OUT	8.19	66	1.05	13.71	53	2.08	5.46	16	1.03	13.64	78	1.74
TKN	IN	16.88	95	0.98	15.49	68	0.86	13.19	27	1.47	14.54	95	0.80
	OUT	12.64	95	0.65	11.50	68	0.62	10.89	27	0.81	12.68	94	0.65
Phosphorus	IN	2.45	98	0.10	2.60	68	0.13	2.21	20	0.18	2.45	98	0.10
	OUT	1.97	98	0.09	2.08	68	0.10	2.38	19	0.18	2.25	97	0.09

AVG = average, N = number of samples, SE = standard error, IN = sample collected at inlet of cell, OUT = sample collected at outlet of cell