MULTI-YEAR RESEARCH ON THE USE OF CONSTRUCTED WETLANDS FOR ADVANCED WASTEWATER TREATMENT

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Abstract. The use of constructed wetlands for tertiary wastewater treatment is emerging as a cost-effective wastewater treatment technology. Constructed wetlands are theoretically designed and operated so that the target constituents have ample time to interact with wetland substrates and microbiota to effect constituent removal necessary to achieve water quality discharge limits. Unfortunately, engineering natural systems is complicated and operational criteria are poorly defined. Long-term research is needed that compares design configurations as well as performance since each constructed wetland system is subjected to a variety of stochastic events (i.e. wind speed and direction, sedimentation due to pulsed rain events, plant dispersal and plant succession).

The 650-acre constructed wetland system in Augusta, Georgia was developed in three phases, beginning with a 60-acre pilot study that evaluated use of the technology for ammonia and BOD removal. The pilot study was operated from 1997 – 1999. Design changes resulting from the pilot study were incorporated into Phases 2 and 3, which were completed in 2000 and 2002 respectively. During 2003-2004, an innovative optimization study was conducted to compare performance criteria between wetland cells of different design configurations, age, planting schemes, and operational criteria such as depth and flow. The cells were monitored using multiprobe HydroLab® technology. Water quality analyses included BOD, TSS, nitrate+nitrite, TKN, ammonia, ortho- and total phosphate. Continuous weather data were also collected using a GroWeather® monitoring station.

Results of this research indicated that wetland cell performance was similar regardless of design, age, planting scheme, flow rates and various operational manipulations. The study suggested cell orientation to prevailing winds and duckweed cover may have impacted treatment efficiency. Nitrogen removal may also have been compromised by nitrogen import from large colonies of roosting redwing blackbirds as well as blue-green algae blooms. There is also evidence that suggests preferential flow patterns and stagnant zones within the cells may be potentially decreasing efficiency and overall removal performance. A tracer study is planned to evaluate aboveground and belowground processes that may alter the theoretical homogenous flow design of constructed wetland systems.

Introduction

One of the largest constructed wetlands for tertiary wastewater treatment is located in Augusta, GA. The system was designed in 1997 for ammonia and BOD reduction, based on a loading rate of 3.0 kg/ha/day for NH_3-N with an average daily flow of 28MGD at an average concentration of 2.25mg/L NH_3-N. Dr. Donald Hammer was senior design consultant for the original design, which specified construction of 12 surface-flow wetland cells of approximately 30-acres each with an aspect ratio (length:width) of 4:1). The cells were designed in a marsh-pond-marsh configuration, with cell area being 40% marsh and 60% pond. The concept of long narrow cells was to provide adequate length to initiate nitrification after most of the BOD_5 and TSS load has been removed in the front marshes (Hammer and Knight, 1992).

The first phase of the project was a pilot or proof of principle project which included construction of an equalization basin with a retention time of 3 days, an above-ground distribution canal system, an effluent collection system and two 30-acre wetland cells (Figure 1). The cells were designed for an operating level of 6-80 in. in the marshes and 3 ft. in the ponds. Marshes were planted in various configurations on 5ft. center. Plants utilized were *Typha latifolia*, *Typha angustifolia*, *Typha domingensis*, *Scirpus validus*, *Scirpus californicus* (USDA hybrid), *Scirpus pungens/americanus*, *Juncus effusus*, and *Zizaniopsis miliacea* (native cutgrass). One marsh was not planted to evaluate natural recruitment.

During the first year of operations, the wetland project experienced most potential problems for surface-flow wetlands (Kadlec and Knight, 1996), including 100-year flood stage, excessive secondary solids loading, and extensive insect and waterfowl impacts on vegetation. Replanting of the front marshes was required during the first six months due to excessive solids smothering the vegetation, however the resilience of wetland vegetation was well demonstrated. Data collected in the first year was significantly compromised due to ongoing problems but did indicate considerable water quality improvement. Most promising results were obtained for whole effluent toxicity testing and priority pollutant removal.

During Year 2 of the pilot study, flow and influent water quality were consistent with design parameters, wetland coverage was good to excellent, and performance met design expectations resulting in an effluent averaging 1ppm NH_3-N, 10-15ppm BOD_5, and <20ppm TSS. Whole effluent toxicity results were 100% No Observed Effects Concentration (NOEC) for both *Ceriodaphnia dubia* and fathead minnow, as compared to pre-wetland values of 12.5 – 25%. There were no priority pollutants detected. Plant evaluations indicated *Typha* sp., cutgrass, and *Scirpus* sp. were most robust in the pilot cells.

Based on favorable pilot study results, several recommendations were presented for Phase 2 and 3: modify the 40% marsh:60% pond area to 75% marsh:25% pond area, primarily to minimize open water that was attracting waterfowl; change the pond area to a series of ditches resulting in a marsh:ditch configuration; install a baffle curtain in the equalization basin to redistribute flow and enhance solids removal; plant the marshes with alternating rows of cattails, cutgrass, and bulrush on 3ft. centers to achieve coverage and

Figure 1. Pilot wetland cell configuration showing equalization basin, distribution canal, and wetland cells in marsh:pond:marsh configuration.

compliance within six months; maintain a wet, but not flooded, marsh for a minimum of six weeks so plants can acclimate and establish; and flood marshes gradually, reaching an operational depth of 8 – 10 in.

Phase 2 of the wetland complex was completed in 2000, adding 7 additional wetland cells. Phase 3 was completed in 2002, adding 3 wetland cells. The final complex consists of four wetland cells in a marsh:pond configuration and eight wetland cells in a marsh:ditch configuration (Figure 2).

A twelve month study was conducted from November 2003 through October 2004 to evaluate treatment performance for ammonia and BOD removal within the wetland complex, comparing treatment performance of wetland cells of varying age and configuration. A major change in operations of the Augusta facility occurred in 1999 when the City of Augusta, Georgia privatized the operation of the J.B. Messerly Wastewater Treatment Plant to OMI, Inc. Numerous operational changes made between 2000 – 2003 resulted in lowering NH_3-N and BOD_5 loading into the wetlands complex. There was a shift in nitrogen loading from NH_3-N to NO_3-N due to enhanced nitrification within the treatment process.

Materials and Methods

All readings within wetland cells were datalogged with HydroLab DataSondes equipped with a SCUFA® Fluorometer for chlorophyll. For marsh:pond configured cells, readings were taken in the rear marsh at a depth of approximately 0.5ft; for marsh:ditch configured cells, readings were taken at a depth of 2 ft. Readings were taken every 10 minutes for a minimum of 48 hours, recording temperature, specific conductivity, salinity, TDS, DO, pH, ORP, and chlorophyll by fluorometry.

Figure 2. Aerial view of Augusta, GA constructed wetland complex, Phases 1-3, December 2003.

Grab samples for chemical analyses were taken each month at effluent weirs at the rear of wetland cells and submitted to a private laboratory for analysis of BOD_5, TSS, TKN, NO_3-N + NO_2-N, NH_3-N, TSS, Total Phosphate, Ortho-Phosphate, As, Cd, Cu, Pb, Ni, Zn, and Hg. Canal samples were only taken from April and October 2004. OMI, Inc. provided wastewater plant and final wetland discharge data for NH_3-N, BOD_5, flow, COD, pH, DO, and temperature.

Results

Ammonia and BOD data from the secondary wastewater treatment effluent and tertiary wetland treatment effluent are presented graphically in Figures 3 and 4. The daily secondary wastewater effluent NH_3-N ranged from 0 to a maximum of 16.5 ppm, with an annual average of 0.31 ppm for the study period. The daily secondary wastewater effluent BOD5 ranged from 1.8 to 14.2 mg/L during the study period, with an annual average of 4.8 ppm for the study period (Figure 4).

The monthly effluent averages for both NH3-N and BOD5 from the wetland complex were consistently below the NDPES permit limits of 1.5ppm and 10ppm, respectively, throughout the study period (Figures 3 and 4).

Data collected within the wetland complex during study period are presented in Table 1. The plant effluent data reflects the secondary discharge from the wastewater treatment plant that constitutes the wetland complex influent. The wetland effluent data reflects the official NPDES monitoring discharge point from the entire wetlands complex. Wetland cells 1 and 5, are marsh:pond:marsh design and cells 8, 12, 6, and 7 are marsh:ditch:marsh:ditch design. Cells 1:5, cells 1:8, and cells 6:7 were paired throughout the study. Due to a difference in retention time for the two wetland cell designs, results are only compared between wetland cells of the same design and between paired cells and the final wetland complex effluent. Data collected within the pilot wetland in 1998 – 1999 and secondary effluents from the wastewater plant from 2000 – 2003 are also presented in Table 1 for comparison.

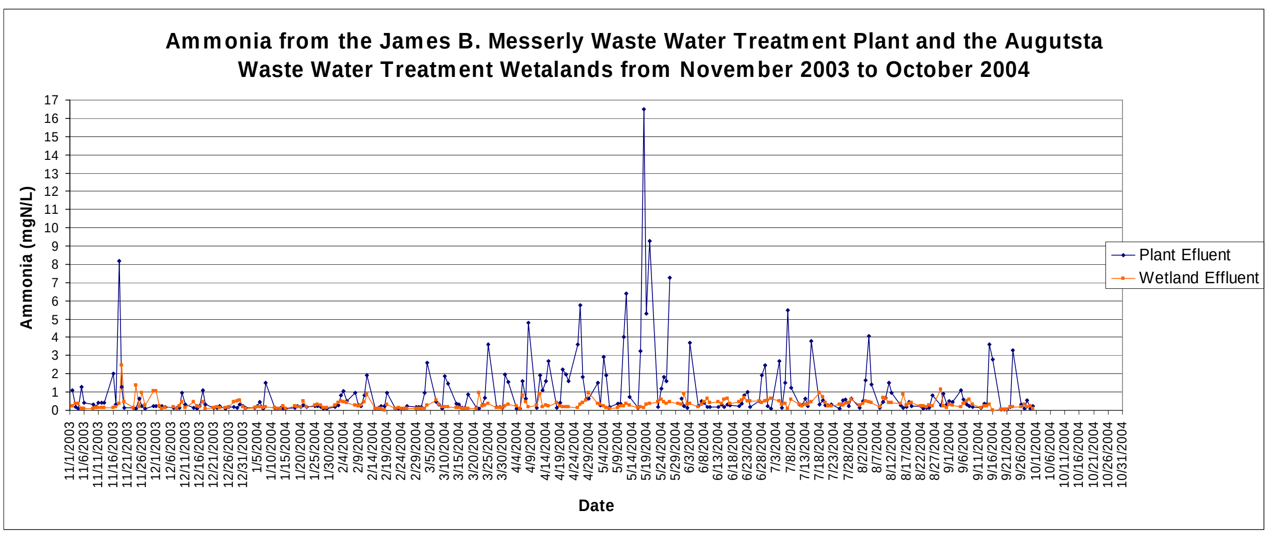

Figure 3. NH3-N from secondary treatment plant and final wetland effluent, November 2003 – October 2004.

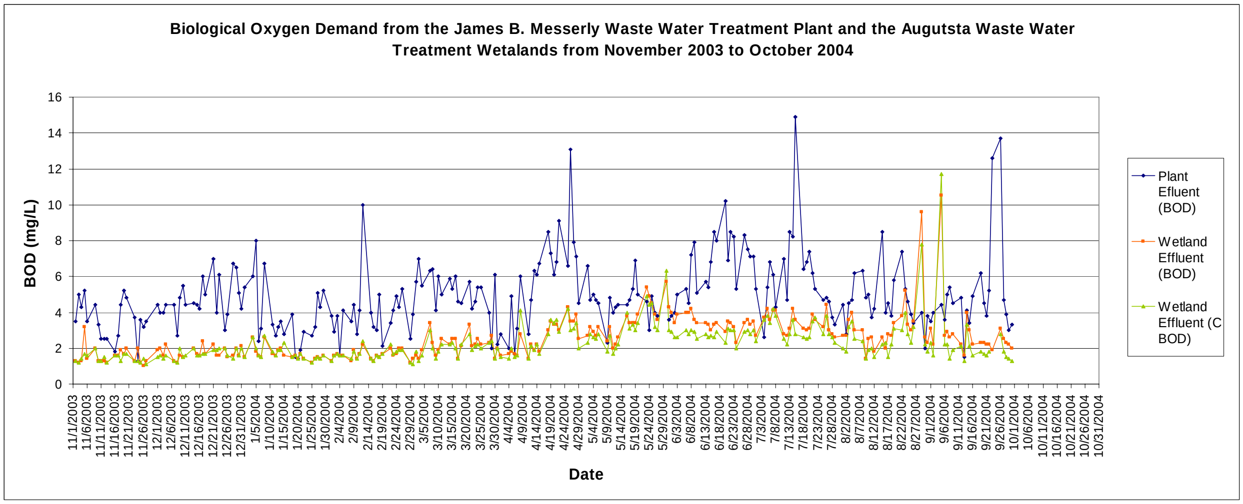

Figure 4. BOD_5 from secondary treatment plant and final wetland effluent, November 2003 – October 2004. Carbonaceous and nitrogenous wetland effluent BOD shown.

Table 1. Averaged Effluent Data from Multiphase Wetland Complex (Shaded cells indicate paired wetland observations). The year wetland units were brought on-line are noted.

Unit (Year wetland unit brought on-line)	Flow from plant MGD	BOD5 mg/l	TSS mg/L	NO3-N plus NO2-N mgN/L	TKN mgN/L	NH3-N mgN/L	Total Phosphorus mgP/L	Ortho-Phosphorus mgP/L
NPDES Monthly Limits	46	10	20	-	-	1.5	-	-
Plant 1999		13.8	31	5.4	5.6	1.7	25.8	8.0
Pilot wetlands 1999 (1998)		10.1	42.5	1.6	3.6	0.5	25.2	8.2
Plant 2002	27.2	10.4	18.3	NA	NA	2.6	NA	NA
Plant 2003	33.9	9.5	17.8	NA	NA	2.1	NA	NA
Plant 11/03-10/04	26.7	4.8	11.1	NA	NA	0.9	NA	NA
Wetlands 11/03 – 10/04	NA	2.5		NA	NA	0.3	NA	NA
Cell 1 (2000)		3.6	15.2	8.6	2.1	0.4	7.5	7.7
Cell 5 (2000)		3.4	9.0	5.5	1.9	0.6	7.5	7.6
Cell 8 (2000)		2.1	2.7	4.8	1.3	0.1	7.6	7.8
Cell 12 (2000)		2.4	4.0	5.5	1.8	0.2	7.4	7.7
Cell 6 (2002)		1.7	3.6	9.0	1.7	0.4	8.3	8.1
Cell 7 (2002)		2.7	7.9	14.2	1.6	0.5	7.7	7.9
Canal 4/04-10/04 (1998)		3.7	3.3	13.5	1.9	1.00	9.6	9.8

Discussion

A 60-acre constructed wetland pilot study, conducted during 1998-1999, indicated that surface flow constructed wetlands would provide sufficient tertiary treatment to the wastewater effluent to meet stringent NPDES permit limits for NH3-N and BOD5. The study indicated that BOD5 would be reduced to approximately 10 - 15 ppm, with 10 ppm being considered the theoretical limit for these surface flow wetlands (Hammer, personal communication). NH3-N reduction in the pilot study resulted in a wetland effluent below the then pending NPDES permit limit of 1.0 ppm. Based on favorable pilot data, Phases 2 and 3 of the constructed wetlands complex were brought on-line in 2000 and 2002. The wetland were planted with the specified plants, however, the cells were flooded immediately resulting in significant losses of bulrush and cattails. The marshes were also not planted as specified in alternating equal bands and were heavily planted with native cutgrass which accounts for 50 – 85% coverage within Phase 2 and 3 wetland cells. The pilot cell vegetation, however, retains its diverse plant assemblage after six years. Wetland cells brought on-line in 2000 and 2002 consistently meet the monthly averaged NPDES permit levels for both NH3-N and BOD_5 of 1.5 and 10 ppm, respectively. The wastewater discharge into the wetlands varies throughout the day for both flow and concentration of constituents. Daily spikes, noted in Figures 3 and 4, and the rather consistent effluent discharged from the wetlands illustrate the value of the constructed wetlands in providing tertiary treatment. Residence times within the two wetland designs vary significantly due to differing marsh and pond areas and volumes, therefore they could not be directly paired in this study. The study does indicate, however, that all cells regardless of plant community, age, or wetland design produce an effluent that meets design criteria for the wetland complex. Paired wetland cells of the same design that are simultaneously receiving the same theoretical volume of wastewater produce comparable results for NH3-N and BOD5. A major part of the optimization study involved continuous monitoring of the effluent discharge from the wetland cells using HydroLab® technology coupled with fluorometry. Results of the continuous monitoring indicated that wetland cells of the marsh:pond:marsh design had more pronounced daily fluctuations in temperature; as well as dissolved oxygen and pH, which is attributable to the algal community within the large ponds. Specific conductivity readings were comparable among cells. ORP in all cells remained above 500 from November 2003 – April 2004, then dropped below -200 in the marsh:ditch cells from late May 2004 until late September. NO3-N data during these months indicate significant reductions approaching laboratory detection limits. Turbidity and chlorophyll values were typically higher and more variable in the marsh:pond:marsh cells throughout the monitoring period, attributable to algae.

The ponds and ditches were profiled using HydroLabs to determine if the ditches and ponds were stratifying and impacting the mixing and redistribution function of the open water. Temperature and dissolved oxygen profiles taken in ditches within selected cells in November 2003 and February and June of 2004 indicated stratification of wastewater. Dissolved oxygen levels were highest near the bottom of the 3 ft. ditches, the area that also had the highest chlorophyll readings. This data indicates that there is some level of short-circuiting occurring within the ditches which could impact the redistribution function of the ditches and overall treatment performance.

From October until early March, extensive flocks of redwing blackbirds utilize the wetlands for roosting. The birds leave the wetlands in mass at dawn and return at dusk. The current estimate of 4.5 million blackbirds roosting in the wetlands results in an importation of nitrogen and phosphates from fecal matter. Based on estimates of nitrogen and phosphorus loading by birds (Andersen et al, 2003), the flock adds 690 lbs of nitrogen and 94 lbs of phosphates to the wetlands each day. The birds are distributed throughout the 650-acre complex, and to date no detectable spike of nutrients has been detected in the routine monitoring during this period.

References

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