A DESIGN APPROACH FOR CONSTRUCTED WETLANDS FOR STORM WATER AND POINT-SOURCE WASTEWATER TREATMENT

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Abstract. Constructed wetlands can mitigate ecological risks to aquatic receiving systems by decreasing concentrations and toxicity of contaminants associated with storm water and point-source wastewater. This paper describes an approach to constructed wetland design for treatment of copper and biochemical oxygen demand (BOD). In constructed wetland microcosm systems, total copper was decreased from 46 μg/L to 12 μg/L (73% removal). Five-day BOD decreased by >50% (approximately 20 mg/L to <10 mg/L) in secondary treated wastewater. This design approach was successful in treating wastewaters to meet regulatory discharge limits.

INTRODUCTION

Constructed wetlands are a viable alternative for treating contaminated waters from a variety of sources, including municipalities, agricultural operations, and industrial sites (Moshiri, 1993; Kent, 1994). Materials often included on National Pollution Discharge Elimination System (NPDES) permits such as solids, biochemical oxygen demand (BOD), and metals (e.g., copper, lead) can be effectively decreased using constructed wetlands, thereby mitigating potential for adverse impacts on receiving waters (Brix, 1993; Hawkins et al., 1994; Huddleston et al., 2000). The biological, chemical, and physical processes inherent to wetlands can function to transfer or transform materials from aqueous phase to forms less bioavailable and less toxic to receiving water organisms (Mitsch and Gosselink, 1993; Moshiri, 1993). However, these inherent wetland processes are not always taken into account or utilized effectively in constructed wetland design. One approach to constructed wetland design is to integrate the various processes and contributions associated with wetland vegetation, hydrosoil, and hydraulic retention time to achieve the overall water treatment objective(s). This paper describes two constructed wetland treatment systems designed using this integrated process.

MATERIALS AND METHODS

Study Sites

Savannah River Site, Aiken, SC. The A-01 outfall collects storm water and wastewater from technical facilities at the Savannah River Site (SRS) nuclear facility. Average daily flow from the 77-ha watershed is approximately 1 mgd. The outfall periodically exceeded the site-specific total copper limit of 22 μg/L and failed to meet the narrative criterion of “no toxicity”.

National Starch and Chemical Company, Enoree, SC. The National Starch and Chemical Company produces cabinetry glues and a variety of adhesives for the pharmaceutical and food packaging industry. The facility operates a wastewater treatment plant and discharges approximately 80,000 gpd of secondary treated effluent to the Enoree River. Treated effluent from the facility occasionally exceeded 5-day BOD limits during winter months.

Design Approach

The constructed wetland systems were designed using an integrated approach, whereby principles of wetland biogeochemistry and influences from wetland vegetation, hydrosoil characteristics, and hydraulic properties (macrofeatures) were synthesized to promote transfers and transformations of the targeted wastewater constituents. The integrated process involves theoretical modeling, review of pertinent scientific literature, and physical modeling to establish design characteristics for the full-scale constructed wetland system.

Macrofeature criteria. Selection criteria for wetland vegetation include: (1) potential effects on hydrosoil pH and redox potential; (2) compatibility with hydrosoil; (3) compatibility with local climate; (4) ability to tolerate hydraulic fluctuations; (5) resistance to herbivory; (6) cost and availability; and (7) non-exotic species. Considerations for hydrosoil selection included (1) compatibility with vegetation, (2) organic carbon content,

(3) particle size distribution, (4) nutrient availability, and (4) location and availability.

Based on discharge flow rates and availability of land for wetland construction, a hydroperiod must be established that facilitates the desired transfers and transformations of targeted wastewater constituents, as well as meets the hydraulic requirements of the selected wetland vegetation.

Conceptual design. Information from theoretical modeling and published literature was synthesized to form the conceptual designs of the constructed wetlands, and to provide design guidelines for physical models. The physical models were used to confirm the design characteristics by evaluating wetland function and performance, allowing modifications, if necessary, to incorporate into the final design.

Physical model. The physical models, or wetland microcosm systems, were used to confirm the conceptual design, make modifications if necessary, and provide design parameters for the full-scale constructed wetlands. These systems were constructed outdoors, either on site where the actual wastewater and soils were utilized, or off-site under more generic conditions (e.g., simulated wastewater, formulated soils). Wetland cells were constructed using 100 or 150 gallon Rubbermaid® utility tanks, arranged to represent hydraulic conditions of the conceptual design (Fig. 1). Gravity flow was utilized whenever possible, or flows were regulated using piston pumps, giving the desired hydraulic retention time. Vegetation was planted in realistic field densities. Hydrosoil (consisting of upland soils collected from the site) was amended to promote desired transfers and transformations of the targeted wastewater constituents. Plant shoots were placed on 6" centers, allowing approximate field density to be achieved in one growth season.

RESULTS

Design Characteristics

Design characteristics for the constructed wetland systems (Table 1) were determined by integrating principles of wetland biogeochemistry and influences from wetland vegetation, hydrosoil characteristics, and hydrology (macrofeatures) were synthesized to promote transfers and transformations of the targeted wastewater constituents.

Physical Models

Savannah River Site. This study was conducted for one year, from May 1999 through April 2000. Acid soluble copper in the inflows of the constructed wetland physical model averaged 46 (±9) μg/L (range: 27 to 68μg/L) (Fig. 2).

(a)

(b)

Fig. 1. Wetland microcosm systems (physical models) used to confirm constructed wetland design characteristics for the Savannah River Site (a) and National Starch and Chemical Company (b).

Outflow concentrations averaged 12 (±7) μg/L (range: 3 to 29 μg/L). On average, copper removal by the model wetland system was 73% (±14).

Survival and reproduction of *Ceriodaphnia dubia* (water flea) in 7-d exposures to inflow and outflow waters were also used to measure performance of the model constructed wetland system. Mortality in inflow water ranged from 40 to 100% and from 0 to 20% in outflow water. With the exception of the initial toxicity test performed in June 1999, no significant difference (α=0.05) in reproduction was observed in test organisms exposed to control and outflow water. Thus, *C. dubia* toxicity was not detected in outflow water from the model wetland system.

National Starch. This study was initiated in mid-December 2002 and will continue for through spring 2003. Preliminary results at the National Starch facility indicate that approximately 50% of BOD_5 is being removed by the constructed wetland system, although influent BOD_5 has not exceeded 20 mg/L to date (permitted average discharge limit of 24 mg/L). BOD_5 in the wetland effluent has ranged from 5 to 10 mg/L, which is within the range for most natural waters.

Table 1. Design characteristics for constructed wetland systems at Savannah River Site and National Starch and Chemical Company

Design Characteristic	Savannah River Site	National Starch
Vegetation	*Schoenoplectus californicus*	*Typha latifolia*
Hydrosoil	85% sand 15% silt and clay amendments: $CaCO_3$, $CaSO_4$, organic matter, time-release fertilizer	80% sand 20% silt/clay amended with time-release fertilizer
Hydroperiod	48 h	96 h
Flow rate (full-scale)	0.96 MGD	80,000 gpd
Target Conc.	22 μg/L Ttl. Cu	24 mg/L BOD_5

DISCUSSION

The constructed wetland system at SRS was designed under the premise that altering the form of copper in the outfall would mitigate risks to receiving-water organisms. The primary objective was to transfer and transform copper into species with limited bioavailability. Copper speciation in aquatic systems is dependent on ambient conditions, including pH, redox potential, temperature, ionic strength, and concentrations of potential ligands (Leckie and Davis, 1979). Metal toxicity to aquatic organisms generally decreases with decreasing solubility of the metal species (Rand, 1995). Divalent copper ions and some copper hydroxyl species have been correlated with toxicity in aquatic organisms (Deaver and Rodgers, 1996). However, copper bound as carbonate ($CuHCO_3^+$, $CuCO_3$, $Cu(CO_3)_2^{-2}$) and sulfide (CuS, Cu_2S) minerals are less bioavailable (Berry et al., 1996). This constructed wetland design targeted conditions for copper sulfide precipitation and sorption to organic matter and hydrosoil particles. The full-scale constructed wetland system based on this design is now fully operable at SRS. Performance data from March 2001 to April 2002 indicated that copper in the A-01 outfall decreased from 31 (±10) μg/L (wetland inflow) to 6 (±3) μg/L (wetland outflow), consistently meeting the discharge limit of 22 μg/L.

Removal of BOD in wetlands is primarily accomplished by microbial metabolism of soluble organic matter and sedimentation/filtration processes (Watson et al., 1989). Soluble organic compounds are primarily degraded by aerobic bacteria attached to plant and sediment surfaces, although anaerobic bacterial degradation can also be significant (Brix, 1993). A significant portion of the oxygen necessary to support the aerobic processes in wetland hydrosoils can be supplied by aquatic macrophytes via translocation of oxygen from the atmosphere to the rhizosphere (Michaud and Richardson, 1989; Stengel, 1993). Wetland vegetation used in the National Starch system was *Typha latifolia* (common cattail). From the water treatment perspective, this emergent macrophyte actively aerates its root zone, enhancing microbial activity responsible for BOD degradation. Growth rate of *T. latifolia* is relatively rapid and decay of detritus is relatively slow ($t_{½}$≈6 mo.), thus having minimal influence on BOD due to decomposition (Rodgers et al., 1983). Construction of the full-scale treatment wetland at National Starch is anticipated for 2003.

This integrated approach to constructed wetland design can be applied to a variety of situations, wastewater constituents, and sources. Constructed wetlands can improve water quality in Georgia and throughout the southeast. Sites or facilities unable to meet wastewater permit standards or with interest in improving the quality of discharge water should consider constructed wetlands for decreasing environmental risks.

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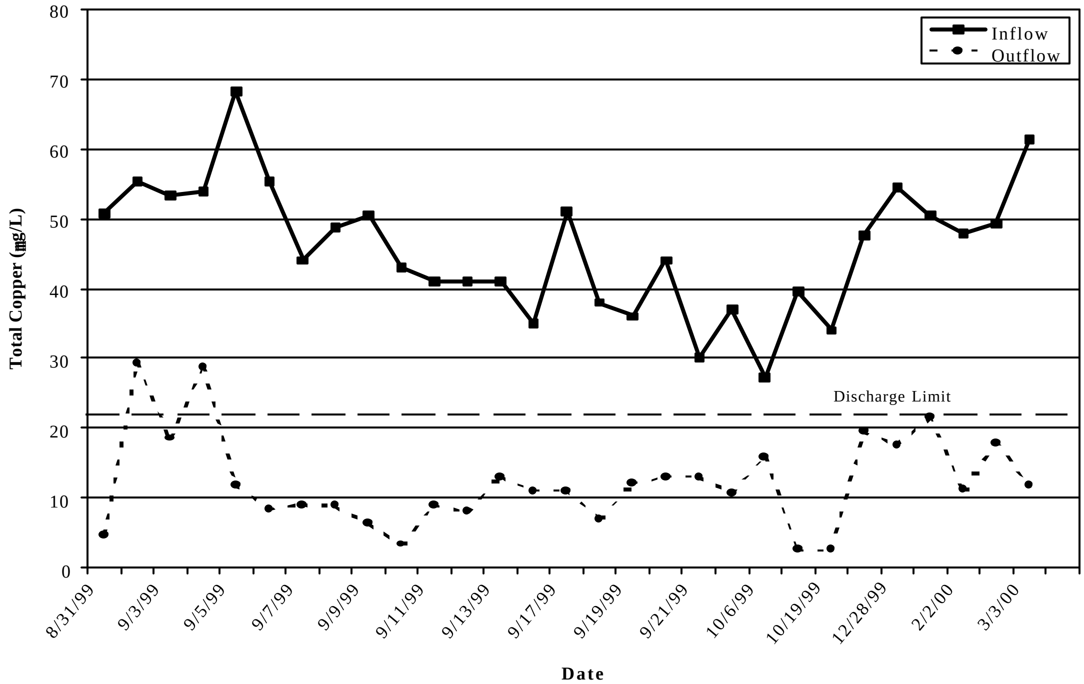

Fig. 2. Total recoverable copper in inflow and outflow water from a physical model constructed wetland system.

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