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CONSTRUCTED WETLAND TREATMENT SYSTEMS FOR WATER QUALITY IMPROVEMENT

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Abstract. The Savannah River National Laboratory implemented a constructed wetland treatment system (CWTS) in 2000 to treat industrial discharge and stormwater from the Laboratory area. The industrial discharge volume is 3,030 m^3 per day with elevated toxicity and metals (copper, zinc and mercury). The CWTS was identified as the best treatment option based on performance, capital and continuing cost, and schedule. A key factor for this natural system approach was the long-term binding capacity of heavy metals (especially copper, lead, and zinc) in the organic matter and sediments. The design required that the wetland treat the average daily discharge volume and be able to handle 83,280 m^3 of stormwater runoff in a 24 hour period. The design allowed all water flow within the system to be driven entirely by gravity.

The CWTS for A-01 outfall is composed of eight one-acre wetland cells connected in pairs and planted with giant bulrush to provide continuous organic matter input to the system. The retention basin was designed to hold stormwater flow and to allow controlled discharge to the wetland. The system became operational in October of 2000 and is the first wetland treatment system permitted by South Carolina DHEC for removal of metals.

Because of the exceptional performance of the A-01 CWTS, the same strategy was used to improve water quality of the H-02 outfall that receives discharge and stormwater from the Tritium Area of SRS. The primary contaminants in this outfall were also copper and zinc. The design for this second system required that the wetland treat the average discharge volume of 415 m^3 per day, and be able to handle 9,690 m^3 of stormwater runoff in a 24 hour period. This allowed the building of a system much smaller than the A-01 CWTS. The system became operational in July 2007.

Metal removal has been excellent since water flow through the treatment systems began, and performance improved with the maturation of the vegetation during the first season of growth of each system. Sediment samples after the first and third years of operation indicated that copper was being bound in the sediments very rapidly after entering the treatment system. The design of the system encourages low redox and sulfide production in the sediments. The objective is to stabilize metals, including mercury, as sulfide compounds in the sediments.

Costs for maintenance and operation of the systems are minimal, consisting primarily of ensuring that the pipes are not clogged and that water is flowing through the system. The treatment cost per thousand gallons is many times less than conventional wastewater treatment facilities. Life expectancy and function of the biological system is based on the life of the engineering aspects and not the wetland ecology.

INTRODUCTION

The ability of natural wetlands to improve many aspects of water quality has been recognized for many years. This natural process has been utilized in many different forms and applications to use constructed treatment wetlands for the purpose of water quality improvement (Moshiri, 1993; Kadlec and Knight, 1996; Shutes, 2001; Kadlec and Wallace, 2009). One aspect of the natural wetland functions that has been capitalized on is the biogeochemical cycling and storage processes that occur in the systems. Heavy metal retention by constructed and natural wetlands has been effectively used in many applications including acid mine drainage, wastewater treatment and stormwater runoff (Scholes et al., 1998; Sobolewski, 1999; Mays and Edwards. 2001; Carleton et al., 2001; Walker and Hurl, 2002).

The A-01 NPDES outfall at the Savannah River Site (SRS) receives process wastewater discharges from the Savannah River National Laboratory (SRNL), Savannah

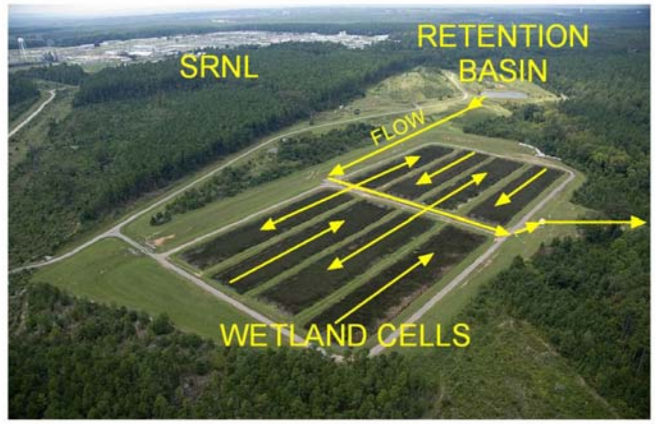
River Ecology Laboratory and other facilities in the area. Additionally, the outfall receives stormwater runoff from all of these areas. The South Carolina Department of Health and Environmental Control (SCDHEC) has established concentration limits for a variety of chemicals that could be contained in this water. Routine monitoring indicated that copper concentrations were regularly higher than the permit limit and the water routinely failed biomonitoring tests. Other chemicals (e.g. lead, mercury, etc) were occasionally higher than the anticipated permit limits. Overall, the largest problem appeared to be the elevated copper levels in the water. A series of studies revealed that the copper was coming from a wide variety of sources and was elevated in stormwater runoff. The end result of these analyses was that nearly one million gallons of water needed to be treated daily and during storms up to 20 million gallons would need to be treated.

Savannah River Nuclear Solutions (SRNS) personnel explored numerous options to bring the outfall waters into compliance with the permit conditions. The analysis was complicated by the need to treat the large volume of stormwater that contained elevated copper concentrations. Conventional treatment systems for metal removal (e.g. ion exchange, chemical precipitation, etc.) proved to be very expensive for the volume of water that needed to be treated and the extremely low concentrations that must be achieved in the water before it was released to the stream. The search for more cost-effective alternatives resulted in constructed wetlands being considered as an alternative. Constructed wetlands are widely used to treat both domestic and industrial wastewater and have been effective in treating metal containing waters from acid mine drainage. Preliminary evaluations showed that a wetland system might achieve the required level of treatment at the lowest cost for construction and operation.

FACILITY DESIGN AND METHODS

The complete design provided for a stormwater retention basin to manage the volume of inflow to the wetland treatment cells. The basin moderates the effects of stormwater surges and provides additional water to keep the wetland flooded during dry periods. The design required that the wetland for A-01 treat the average discharge volume of 800,000 gallons (3,030 m^3) per day, and be able to handle 22 million gallons (83,280 m^3) of stormwater runoff in a 24 hour period. The design allowed all water flow within the system to be driven by gravity so no pumps were required.

The CWTS for A-01 outfall is composed of eight one-acre wetland cells connected in pairs as treatment units. They were planted with giant bulrush (*Schoenoplectus californicus*) to provide continuous organic matter input,



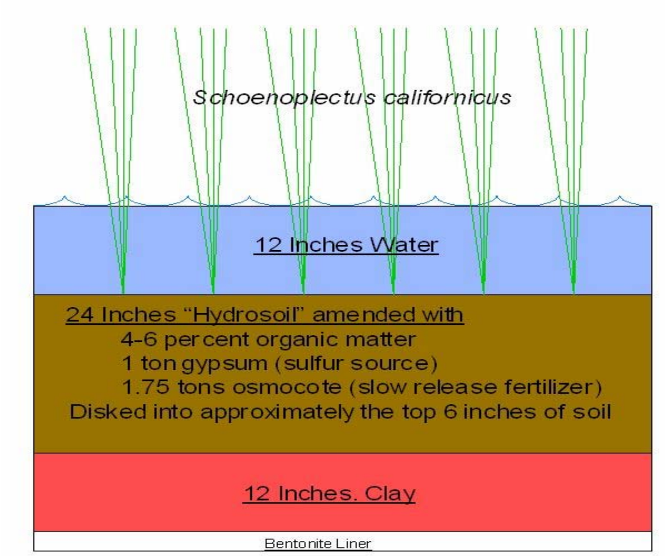
Layout and flow path through CWTS for A-01 outfall.

and provide resistance to water flow across the cell. A retention basin was designed to hold stormwater flow prior to entry into the wetlands and to allow control of water flow into the treatment system. The system became operational in October of 2000 and was the first wetland treatment system permitted by South Carolina DHEC.

Because of the exceptional performance of the A-01 CTWS, the same strategy was used to improve water quality of the H-02 outfall that receives discharge and stormwater from the Tritium Area of SRS. The primary contaminates in this outfall were also copper and zinc. The design for this second system required that the wetland treat the average discharge volume of 110,000 gallons (415 m^3) per day, and be able to handle 2.56 million gallons (9,690 m^3) of stormwater runoff in a 24 hour period. This allowed the building of a system much smaller than the A-01 CWTS. The system became operational in July 2007.

Routine monitoring samples for water quality are collected at a compositing sampler at the compliance point for monthly reporting. As part of the research effort, monthly grab samples are collected from numerous other locations from the inflow to the system through the discharge to the receiving stream. Water samples

Layout and flow path through CWTS for H-02 outfall.



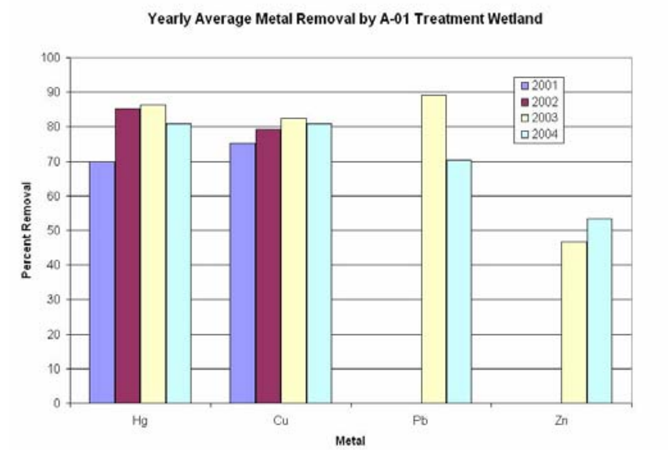
Typical cross section of wetland treatment system.

collected from A-01 included the old compliance point, at the entrance into the wetland cells (after the retention basin), after passage through each of the first wetland cells (A cells), after passage through each of the second wetland cells (B cells), and at the discharge to the stream. Samples from H-02 were collected at the retention basin, the entrance and exit of the wetland cells, and near the compliance location. Samples were analyzed for copper by method #220.1 and for mercury by the new EPA method 1630 for low level detection of total mercury.

RESULTS AND DISCUSSION

The treatment systems were designed to reduce copper concentration in the effluent and to allow the effluent to pass toxicity tests. Copper removal has been excellent since water flow through the treatment systems began, and this improved with the maturation of the vegetation during the first season of growth of each system. Water sampled at the inflow to the CWTS continued to be routinely above the permit limit. After passage through the treatment cells, the copper concentration is well below permit limits, and often below detection limits of the test procedure (10 µg/L). Sediment samples after the first year of operation indicated that copper was being bound in the sediments very rapidly after entering the treatment system. Subsequent sampling indicated that the primary increase of copper in the sediments remained in the initial section of the wetland cells (Knox et al., 2006).

Mercury content in the water of the A-01 outfall was also monitored using the ultra-low detection methodology that is now available. Because the design of the system encourages a low redox status of the sediments in the treatment cell, it was anticipated that mercury would also



be removed from the water column. Mercury removal improved with maturation of the vegetation and the sediments, and averaged greater than 80% removal of total mercury during the second year of operation.

The wetland cells are very anaerobic and the sediments have negative redox potentials. As a result, manganese and iron mineral phases in the sediments have been reduced to soluble forms and increase in the water during passage through the wetland system. Average effluent concentration of iron was 476 µg /L and of manganese was 123 µg /L. Solubilization of iron and manganese from soils under anaerobic conditions in wetlands is not uncommon (Goulet and Pick, 2001). The discharges are seasonal in nature, with higher levels present in the effluent during the warmer months. These metals are rapidly oxidized and deposited on the rock discharge from the wetland cells, as indicated by analysis of the periphyton at the discharge to the receiving stream.

Vegetation development within the treatment wetland cells has been excellent. Most cells were near optimal maximum densities of bulrush shoots reported for natural systems. Growth rates of the shoots have been very impressive, averaging over 6 centimeters per day during the maximum elongation phase of growth. Biomass production has also been excellent and provides the organic matter that the system utilizes for continuing functionality.

Water discharges at SRS are typically very soft, with low hardness and buffering capacity. Total organic carbon in the water is also increased by the wetland system due to the high additions of organic matter to the system and the normal decompositional processes. Levels of total organic carbon generally doubled during passage through the wetlands. This natural wetland process and the reduction of metal bioavailability were documented for surface waster discharges at SRS (Specht, 2005). High organic ligand levels in the water reduce the toxicity of some metals resulting in a three-fold increase in the regulatory copper limit through application of a Water Effects Ratio (WER). This high organic material concentration is also responsible for the ability of the effluent to pass acute toxicity testing using the U.S. Environmental Protections Agency methodology on all sample dates.

CONCLUSIONS

The wetland treatment systems have been very effective in reducing the heavy metal concentrations in the effluent at the A-01 and H-02 outfalls to within permit limits. The single treatment system has brought both metals of concern to within permit limits, and removed toxicity of the discharge. The continuing cost of operation for the facility has been very low, since the systems are entirely passive and only require periodic observation to assure that there is no resistance to normal gravity flow of the water. The wetlands are a self-maintaining system through the annual production of organic matter that will renew binding sites for metals and maintain redox conditions for sediment chemistry to continue. This solution has provided a low cost construction option and low cost maintenance program for the effective treatment of large volumes of permitted water discharges from an industrial area. Additional research is being conducted to understand the sediment chemistry and sulfur metabolism, the metal loading and fate within the system, the vegetative cycle of organic matter production and decomposition, and seasonal variations in water quality parameters and chemistry.

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