Proceedings of the Second International Conference on Wetlands and Remediation
5-6 September 2001 (Burlington, Vermont)

ON-SITE REMEDIATION OF PETROLEUM CONTACT WASTES USING SUBSURFACE FLOW WETLANDS

Scott D. Wallace, P.E., North American Wetland Engineering,
Forest Lake, Minnesota, USA.

ABSTRACT

Williams Pipeline Company operates a terminal facility in Watertown, South Dakota. The facility generates large quantities of petroleum contact waste in the spring and summer months. Petroleum contact waste is characterized as storm water runoff, hydrostatic test water, or other water sources that have come in direct contact with petroleum products. The combined petroleum/water waste is routed through an oil-water separator and stored onsite.

The waste has characteristically high levels of BTEX as well as elevated concentrations of $CBOD_5$ and Ammonia. The high $CBOD_5$ and Ammonia concentrations impeded the performance of an existing physical/chemical treatment works, resulting in permit noncompliance. Several biological treatment processes were tested at the pilot scale, but none proved feasible due to short residence times and the high oxygen demand of the influent waste.

In July 1998, a subsurface flow constructed wetland was installed onsite. The 16,000 square foot (1,486 square meter) wetland was designed to process a flow-equalized input of approximately 400 gallons per day (1.5 cubic meters per day) on a seasonal (May - October) basis. To provide adequate oxygen transfer, a Forced Bed Aeration™ system (US Patent 6,200,469) was built into the wetland bed. The system was initially planted with *Phragmites communis* and over-seeded with *Phalaris arundinacea*.

Average influent $CBOD_5$ (at 20% of the bed length) was approximately 10,000 mg/L (as high as 16,000 mg/L) with effluent concentrations (at 80% of the bed length) averaging approximately 6 mg/L. Influent ammonia concentrations (at 20% of the bed length) averaged approximately 100 mg/L (as high as 230 mg/L) with effluent concentrations (at 80% of the bed length) averaging approximately 0.5 mg/L.

Numerous transect samples were collected during 1998 and 2000. In most cases, BTEX was removed in the first 40% of the bed length. BTEX removal is believed to be largely a function of enhanced volatilization as a result of the aeration system. $CBOD_5$ and Ammonia removal appears to follow a first-order exponential decay pattern, in most cases reaching non-detect levels at 80% of the bed length.

Due to the water vapor loss induced by the aeration system and the high evapotranspiration conditions of a South Dakota summer, the wetland has operated as a zero-discharge system since startup. Because the processing capability of the wetland has exceeded initial design expectations, wastes from other facilities in North and South Dakota are now brought to the Watertown wetland for treatment.

This case study demonstrates that subsurface flow constructed wetlands can be designed to process high-strength petroleum contact wastes, provided that adequate oxygen transfer is designed into the wetland reactor. In high evapotranspiration environments, constructed wetlands can be designed as zero-discharge systems.

INTRODUCTION

Petroleum wastes are documented to naturally degrade in natural wetland environments (Wemple & Hendricks, 2000). The microbial community associated with the plant rhizosphere creates an environment conducive to degradation of many volatile organic compounds (Schnoor et. al., 1995; Pardue et. al., 2000). Both surface flow and subsurface flow constructed wetlands have been used to treat petroleum wastewaters (Knight et. al., 1999).

Surface flow constructed wetlands have been used to treat petroleum wastewaters from Amoco's Mandan, North Dakota facility since the early 1970's (Litchfield & Schatz, 1989; Litchfield, 1993). Similarly, Chevron has used surface flow wetlands to polish wastewater from the Richmond, California refinery (Duda, 1992). For higher strength wastes, surface flow wetlands have been used in conjunction with mechanical treatment systems (Lakatos, 2000).

Due to the higher surface area present in a gravel bed, subsurface flow wetlands can achieve more biological treatment in a given unit area (USEPA, 1988). Initial work on the use of subsurface flow wetlands to treat industrial organic compounds was completed in Germany (Seidel, 1973). Tenneco, Inc. has used a rock-reed wetland for treatment of oil & grease (Honig, 1988). Subsurface flow wetlands have also been used to treat coke plant wastewaters (Jardiner et. al, 2000).

A subsurface flow wetland was used at the Gulf Strachan Gas Plant, approximately 200 km northwest of Calgary, Alberta to treat hydrocarbon-contaminated groundwater (Moore et. al., 2000). This study is significant because it demonstrated successful treatment of hydrocarbon waste under winter conditions. Also, an aeration system was used during the winter months, which resulted in improved removal of TPH and BTEX.

SYSTEM DESIGN

The wetland system was designed to process "facility contact water", which is a blend of hydrostatic test water, stormwater runoff from containment areas, spills, and leaks. Based on monitoring data from a variety of Williams' pipeline terminals, it was apparent that, in addition to BTEX, the contact water also contains very high levels of $CBOD_5$ (up to 16,000 mg/L) and Ammonia (up to 230 mg/L), which is attributable to the variety of materials the pipelines have transported in the past. Facility contact water is run through an oil/water separator and stored in an existing storage tank.

The wetland system was originally designed to process a flow-equalized input of 400 gallons per day (1.5 cubic meters per day). A timer-controlled transfer pump is used to meter facility contact water into the wetland treatment cell. Because the tank is frozen in the winter (and generation of facility contact water during the winter is minimal), the wetland is only used from May through October.

A 16,000 square foot (1,486 square meter) horizontal subsurface flow wetland was designed for onsite processing of the facility contact water. The wetland is covered by a 3-inch (7.5 cm) mulch layer for odor control. The hydraulic loading on the wetland is 0.025 gallons per day per square foot (1 millimeter per day). The wetland has a surface water discharge permitted by the State of South Dakota (SDDENR 1998). However, due to the low hydraulic loading rate the facility has operated without discharging since operation began in August 1998.

Because of the high strength nature of the waste, the wetland was designed with a Forced Bed Aeration™ system (Wallace, 2001). Eight thousand four hundred linear feet (2,560 meters) of aeration tubing with turbulent flow emitters spaced every 24 inches (610 mm) was installed. A 1.5-HP (1.1 kW) blower is used to pressurize the aeration system. The blower is programmed to run 24 hours per day. A schematic of the aeration system is shown in Figure 1.

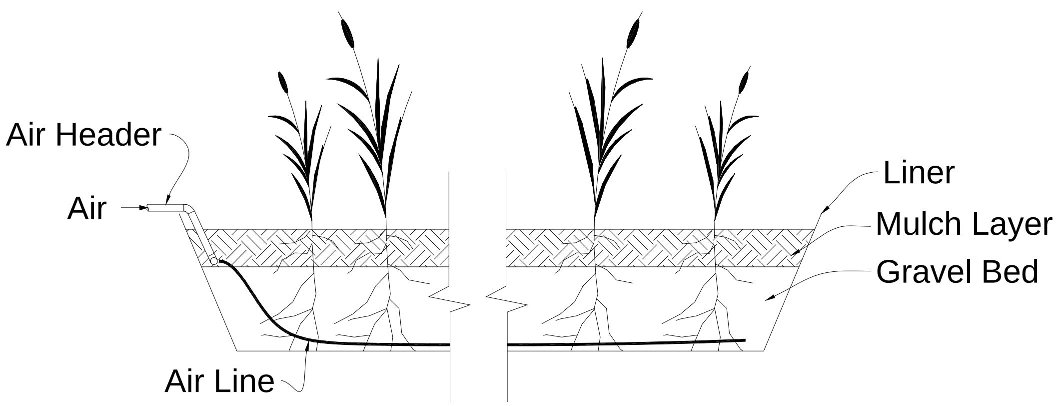

FIGURE 1. Forced Bed Aeration™ process schematic (Wallace, 2001).

SYSTEM PERFORMANCE

Initial monitoring was begun in August 1998 immediately after construction of the facility. Samples are collected from internal sample ports located 20%, 40%, 60% and 80% along the length of the wetland cell. Analytical results are summarized in Figures 2, 3, 4, and 5.

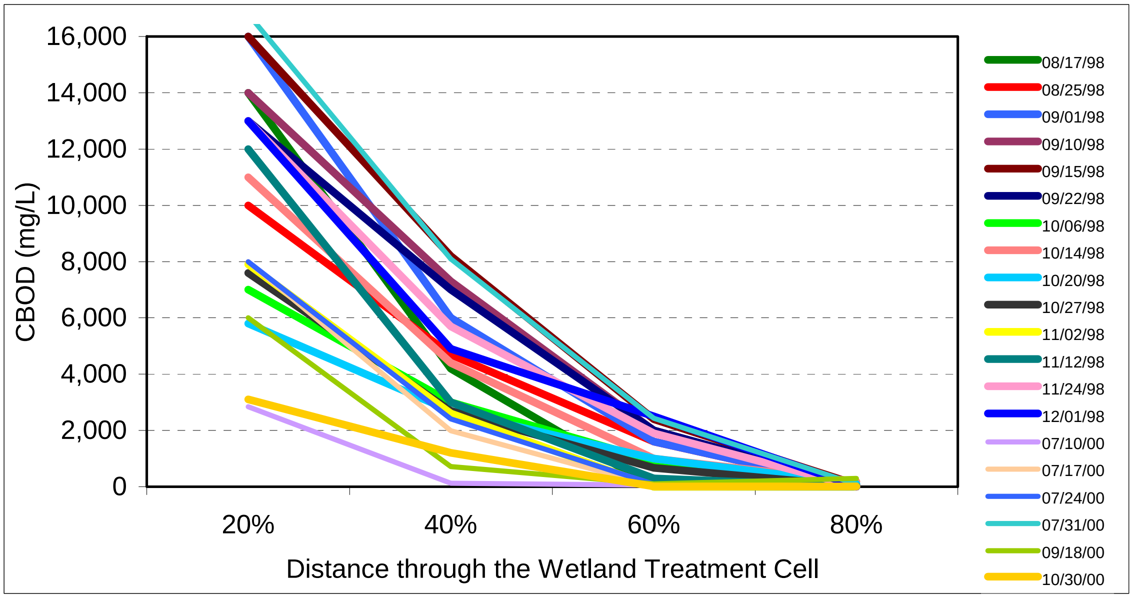

FIGURE 2. $CBOD_5$ removal within the wetland treatment cell.

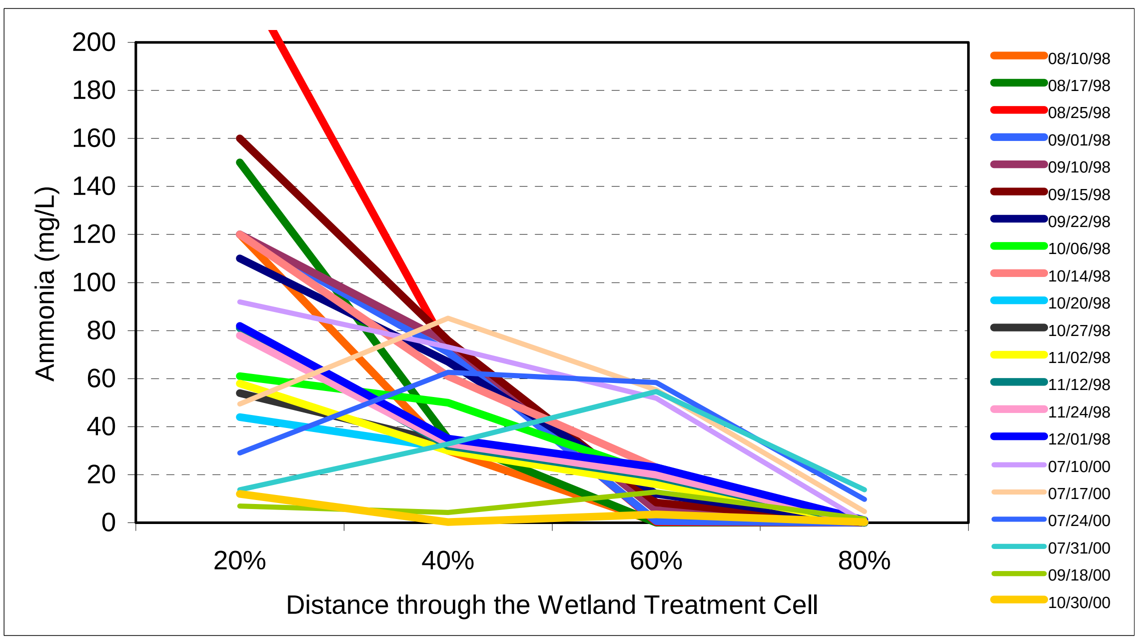

FIGURE 3. Ammonia removal within the wetland treatment cell.

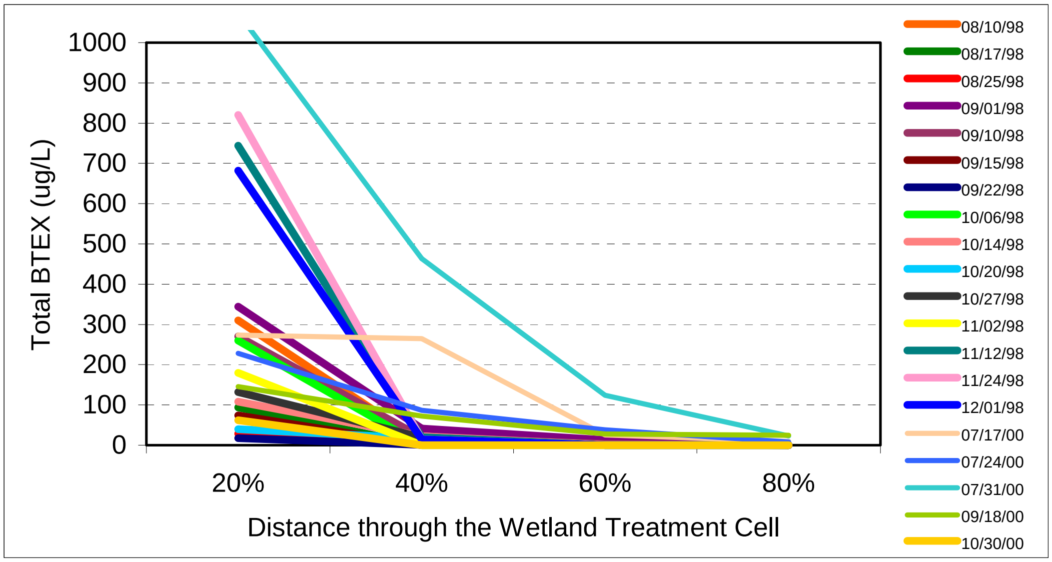

FIGURE 4. BTEX removal within the wetland treatment cell.

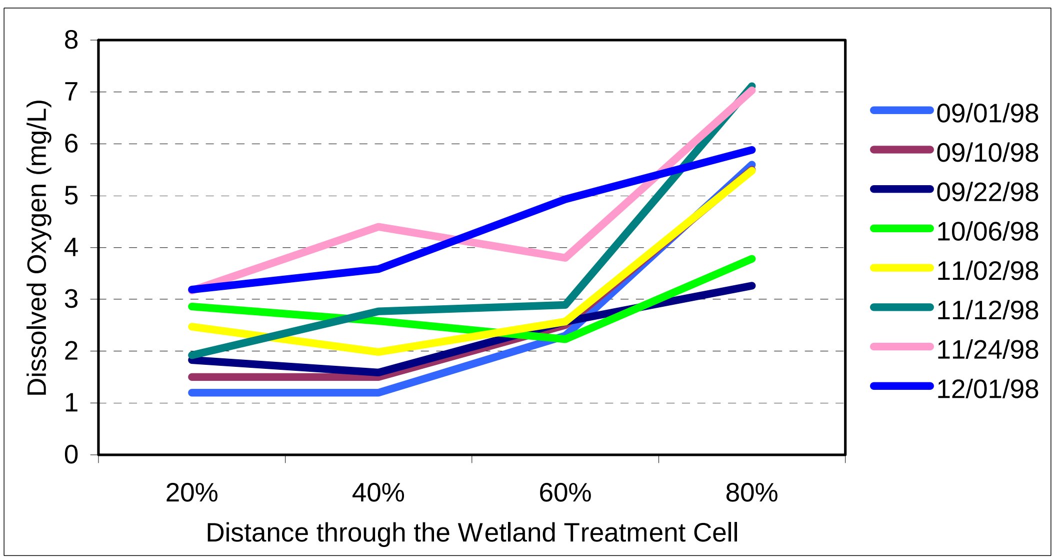

FIGURE 4. Dissolved Oxygen concentrations within the wetland treatment cell.

CONCLUSIONS

Numerous longitudinal transect samples were collected during 1998 and 2000. $CBOD_5$ and Ammonia removal appear to follow a first-order exponential decay pattern, in most cases reaching non-detect levels at 80% of the bed length. Average removal rates were 99% for $CBOD_5$ and 98% for Ammonia. There were no significant differences in treatment efficiency during the operating season.

In most cases, BTEX was removed in the first 40% of the bed length. BTEX removal is believed to be largely a function of enhanced volatilization as a result of the aeration system. However, some of this BTEX may be captured and degraded in the mulch layer. Volatilization would be consistent with the off-gas measurements conducted at Gulf Strachan, which indicated that approximately 50% of the BTEX mass was volatilized in the first 6m of the wetland (Moore et. al., 2000), although the BTEX levels at the Watertown system are much lower.

The oxygen demand exerted on the wetland system has averaged 0.003 pounds O_2 per square foot (16 grams O_2 per square meter per day) since August 1998. Assuming that in the absence of aeration, atmospheric diffusion and wetland plants could jointly transfer up to 7.2 grams O_2 per square meter per day (Gersberg et. al., 1989), the aeration system is making up the balance of the oxygen transfer requirement. This is consistent with the increasing dissolved oxygen levels that are observed as the water progresses down the length of the wetland cell.

Due to the water vapor loss induced by the aeration system and the high evapotranspiration conditions of a South Dakota summer, the wetland has operated as a zero-discharge system since startup. Because the processing capability of the wetland has exceeded initial design expectations, wastes from other facilities in North and South Dakota are now brought to the Watertown wetland for treatment.

There are currently 17 subsurface flow constructed wetlands using Forced Bed Aeration™ for treatment of domestic and industrial wastes. In addition, a number of vertical flow wetlands have also been installed with Forced Bed Aeration™.

Due to their simplicity of operation, low maintenance needs and high treatment efficiencies, aerated wetland systems would be suitable for onsite remediation at other petroleum facilities.

REFERENCES

Duda P. J. II. 1992. *Chevron's Richmond Refinery Water Enhancement Wetland*. Report to the Regional Water Quality Board, Oakland CA.

Gersberg, R. M., S. R. Lyon, R. Brenner and B. V. Elkins. 1989. "Integrated Wastewater Treatment Using Artificial Wetlands: A Gravel Marsh Case Study" In D.A. Hammer (Ed.), *Constructed Wetlands For Wastewater Treatment; Municipal, Industrial and Agricultural*, pp 145-152. Lewis Publishers, Chelsea MI.

Honig R. 1988. "Tenneco's Use of Rock Reed Filter at a Natural Gas Pipeline Compressor Station". Poster Paper at the International Conference on Constructed Wetlands for Wastewater Treatment, Chattanooga TN.

Jardiner N., G. Blake, A. Mauchamp and G. Merlin. 2000. "Design and Performance of Experimental Constructed Wetlands Treating Coke Plant

Effluents". In *Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control*, pp 1325-1332. International Water Association, Colchester UK.

Kadlec R. H. and R. L. Knight. 1996. *Treatment Wetlands*. CRC Press Boca Raton FL.

Knight R. L., R. H. Kadlec and H. M. Ohlendorf. 1999. "The Use of Treatment Wetlands for Petroleum Industry Effluents". *Environmental Science and Technology*. 33 (7), 973-980.

Lakatos, G. 2000. "Optimization of Constructed Wetlands for Treatment of Petrochemical Waste Waters in Hungary". In *Proceedings of the 7th International Conference on Wetland Systems for Water Pollution Control,* pp 1279-1285. International Water Association, Colchester UK.

Litchfield D. K. and D. D. Schatz. 1989. "Constructed Wetlands for Wastewater Treatment at Amoco Oil Company's Mandan, North Dakota Refinery". In D.A. Hammer (Ed.) *Constructed Wetlands for Wastewater Treatment; Municipal, Industrial and Agricultural*, pp. 233-237. Lewis Publishers, Chelsea MI.

Litchfield D. K. 1993. "Constructed Wetlands for Wastewater Treatment at Amoco Oil Company's Mandan, North Dakota Refinery". In G.A. Moshiri (Ed.) *Constructed Wetlands for Water Quality Improvement*, pp. 485-490. CRC Press, Boca Raton, FL.

Moore B. J., S. D Ross, D. Gibson, and L. Callow. 2000. "Constructed Wetlands for Treatment of Dissolved Phase Hydrocarbons in Cold Climates". In J. L. Means and R. E. Hinchee (Eds.) *Wetlands & Remediation: An International Conference*, pp 333-340. Battelle Press, Columbus OH.

Pardue, J. H., G. Kassenga and W. S. Shin. 2000. "Design Approaches for Chlorinated VOC Treatment Wetlands". In J. L. Means and R. E. Hinchee (Eds.) *Wetlands & Remediation: An International Conference*, pp 301-308. Battelle Press, Columbus OH.

Schnoor J. L., L. A. Licht, S. C. McCutcheon, N. L. Wolfe and L. H. Carreira. 1995. "Phytoremediation of Organic and Nutrient Contaminants". *Environmental Science and Technology*. 318A-323A.

SDDENR (South Dakota Department of Environment and Natural Resources) 1998. Surface Water Discharge Permit No. SD-0026786. South Dakota Department of Environment and Natural Resources, Pierre, South Dakota.

Seidel K. 1973. "United States Patent 3,770,623". United States Patent Office, Washington DC.

USEPA (United States Environmental Protection Agency). 1988. *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment*. EPA/625/1-88/022. United States Environmental Protection Agency Office of Research and Development, Washington DC.

Wallace S. 2001. “United States Patent 6,200,469 B1”. United States Patent Office, Washington DC.

Wemple C., and L. Hendricks. 2000. “Documenting the Recovery of Hydrocarbon-Impacted Wetlands – A Multi-Disciplinary Approach”. In J. L Means and R. E. Hinchee (Eds.) *Wetlands & Remediation: An International Conference*, pp 73-78. Battelle Press, Columbus OH.