Constructed Wetlands: Passive Systems for Wastewater Treatment

Renee Lorion

Technology Status Report prepared for the US EPA Technology Innovation Office under a National Network of Environmental Management Studies Fellowship

Completed August 2001

Used primarily to treat wastewater, constructed wetlands also can be an attractive natural setting where wildlife builds habitat and humans visit. Above is the Hayfield Site at the Tres Rios demonstration constructed wetlands (Photo: Bing Brown, Phoenix Water Services)

Source: http://ag.arizona.edu/AZWATER/arroyo/assets/wetlnd1.gif

Notice

Foreword

Constructed wetlands are an innovative and inexpensive treatment approach that have the potential to treat organic and inorganic compounds in wastewater from a range of sources. EPA's Technology Innovation Office (TIO) provided a grant through the National Network for Environmental Management Studies (NNEMS) to prepare a technology assessment report on the use of constructed wetlands for applications other than municipal wastewater. This report was prepared by a first year graduate student from Washington State University during the summer of 2001. It has been reproduced to help provide federal agencies, states, consulting engineering firms, private industries, and technology developers with information on the current status of this technology.

About the National Network for Environmental Management Studies (NNEMS)

NNEMS is a comprehensive fellowship program managed by the Environmental Education Division of EPA. The purpose of the NNEMS Program is to provide students with practical research opportunities and experiences.

Each participating headquarters or regional office develops and sponsors projects for student research. The projects are narrow in scope to allow the student to complete the research by working full-time during the summer or part-time during the school year. Research fellowships are available in Environmental Policy, Regulations and Law; Environmental Management and Administration; Environmental Science; Public Relations and Communications; and Computer Programming and Development.

NNEMS fellows receive a stipend determined by the student's level of education and the duration of the research project. Fellowships are offered to undergraduate and graduate students. Students must meet certain eligibility criteria.

About this Report

This report summarizes the status of constructed wetlands to remove contaminants from wastewater, and profiles several sites where constructed wetlands have been implemented for treatment applications other than municipal wastewater. It contains information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts were made to independently confirm the resources used.

While the original report included color images, this copy is printed in one color. Readers are directed to the electronic version of this report to view the color images; it is located at **http://clu-in.org**.

Abstract

Constructed wetlands can mimic the filtration processes of natural wetlands, effectively removing contaminants from wastewater. Successful applications for the treatment of municipal wastewater have led to the exploration of the technology for the treatment of other wastewater, including industrial, agricultural, acid mine drainage, storm water, landfill leachate, and urban and airport runoff. This paper will summarize the state of the technology, and profile several sites where constructed wetlands have been implemented for treatment applications other than municipal wastewater.

Table of Contents

Introduction

As they are depleted and affected by development, the importance of natural wetlands in watershed systems becomes increasingly apparent. Efforts to restore and maintain wetlands have been crucial to water quality in many areas. A better understanding of the benefits that wetlands provide has led to the use of constructed wetlands to mimic the filtration processes that take place in the fragile ecosystem of a natural wetland. Constructed wetlands have great potential as a clean-up technology for a variety of wastewaters.

Constructed wetlands have proven to be a very effective method for the treatment of municipal wastewater. For a small community with limited funds for expanding or updating wastewater treatment plants, constructed wetlands are an attractive option. Rural municipalities have access to adequate inexpensive land, and wetlands blend into a natural landscape setting. Once the wetlands are designed and constructed, annual maintenance costs are low. In addition, wetlands add aesthetic value, and provide wildlife habitat and recreation opportunities.

The application of constructed wetlands for municipal wastewater treatment has led to the study of their use for other kinds of wastewater. Acid mine drainage, agricultural wastewater, industrial wastewater, stormwater runoff, landfill leachate and airport runoff are all good candidates for remediation using constructed wetlands. Site-specific designs that carefully consider factors such as hydrology, native plant species, and seasonal temperature fluctuation can lead to efficient removal of contaminants in wastewater. Demonstration projects have shown that wetlands are effective at removing both organic and inorganic contaminants. The relatively inexpensive nature of this type of treatment makes it a potentially cost-effective option for remediation.

Design

The design considerations for constructed wetlands systems are varied and site dependent[1]. Municipal wastewater treatment systems are most concerned with the reduction of suspended solids, organic matter, pathogens, phosphates, and ammonium and organic nitrogen. Other kinds of wastewater treatment wetlands may be concerned with these same contaminants in addition to other organic compounds, residual explosives, or metals. Some system designs anticipate exactly what kinds of contaminants the wetlands will receive, and at what levels, while others face variable and unpredictable wastewater flows. Some wetland systems treat specific substances, such as airplane deicer fluid. Other systems, such as a stormwater runoff system, may receive a mixture of contaminants, with levels of incoming water varying widely with season and year.

Municipal wastewater destined for wetlands treatment often travels through a treatment train, although in some cases wastewater is released directly into a wetland system. The initial step is usually passage through a traditional wastewater treatment plant, where excess ammonia is removed, followed by a sedimentation chamber where

[1] For further information on wetland design considerations, see the USDA-NRCS, EPA Region III document: *A Handbook of Constructed Wetlands: Volume 1 General Considerations.*
Also see the NFESC document: *Constructed Wetland Technology Application Guide, Inception through Implementation.*

any remaining suspended material is removed. Depending on the levels of fecal coliforms and the requirements for effluent contaminant levels, the water may be disinfected with chlorine before release into the constructed wetland system. If the water is to be discharged into a waterway, the minimum contaminant criteria may be different than a system in which the wetlands are the final destination for the water.

Engineered wetlands for other kinds of wastewater may also consist of a series of treatment steps that have been built according to the expected flow and loading rates. In general, the heavier the load a system receives, the larger the wetlands system will need to be to effectively remove contaminants. The heavier load could be a large volume of water discharged into the system, or volumes with higher concentrations of contaminants. A series of lined settling and aeration ponds, or lagoons, may be the initial step in treatment, followed by release into the actual wetland. The wetland designs can vary from more traditional systems, with populations of native plants, to aerobic systems that function without aquatic plants and treat waste primarily with added bacteria. An aerobic system may use aquatic plants in a final polishing step.

Wetlands are constructed as either surface flow or subsurface flow systems. Surface flow systems require more land, but generally are easier to design, construct and maintain. They consist of shallow basins with emergent and submergent wetland plants that tolerate saturated soil and aerobic conditions. Water flows in one end of the basin, moves slowly through, and is released at the other end. These systems provide habitat and public access. Subsurface flow systems consist of an underground flow of wastewater through some kind of substrate such as gravel. These systems demonstrate higher rates of contaminant removal than surface flow wetlands. The earth provides insulation for subsurface flow wetlands in cold climates. Subsurface flow systems limit human and animal exposure, and do not provide habitat for birds, which may be a desirable characteristic for a site such as an airport.

Mechanisms for Removal

Contaminants are removed from wastewater through several mechanisms. Processes of sedimentation, microbial degradation, precipitation and plant uptake remove most contaminants[2]. Heavy metals in a wetland system may be sorbed to wetland soil or sediment, or may be chelated or complexed with organic matter. Metals can precipitate out as sulfides and carbonates, or get taken up by plants. Compounds in sediment, such as iron oxides, show preference for certain metals. This behavior can affect how efficiently a metal is adsorbed in a wetland. A system that has reached the limits of its adsorption capacity can exhibit a reduction in contaminant removal rates. After a system has reached its capacity for metal sorption, metal sulfide formation becomes the main method of metal removal. Sulfate-reducing bacteria oxidize organic matter and reduce sulfate to form hydrogen sulfide. Hydrogen sulfide reacts with metals to form metal sulfides, which precipitate. Compared to sediments, plants do not take up much metal,

[2] For further information on fates of contaminants, see Chapter 3 of *Constructed Wetlands Treatment of Municipal Wastewater*, EPA/625/R-99-010. See also the NFESC document *Constructed Wetland Technology Application Guide*. A good discussion of the fate of metals is found in Dunbabin and Bowmer, 1992. A good discussion of sulfide and carbonate precipitation can be found in Gusek, et al. (1998).

but they are involved in oxygenation and microbiological processes that contribute to the ability of the wetland to remove metals.

Organic compounds can be broken down for consumption by microorganisms in a wetland system. This biodegradation removes the organic compounds from water as they provide energy for the organisms. Organics can also be degraded when taken up by plants. They can also sorb to surfaces in the wetland, usually to plant debris. Organic compounds containing nitrogen sorb to surfaces in the wetland, and organic nitrogen is converted to ammonia. Ammonia can volatilize, be exchanged with other cations in the sediment, or be nitrified if oxygen is present. Nitrate is the form of N taken up by plants, so emergent plants use it during the growing season. Excess nitrate in an anaerobic system is reduced to N_2 and N_2O gases as a result of denitrification, the main mechanism of nitrate removal.

Some wastewaters contain phosphates from cleaning products. Storm water and agricultural wastewater may contain fertilizer runoff containing phosphates. Phosphates can sorb to surface plants and floating plant litter, as well as to sediment surfaces. They may precipitate out of solution with metals at more alkaline pH levels. Soluble inorganic phosphate is taken up by plants, and cycled through their growth and decomposition. Most phosphate is removed from wastewater through sediment retention. Phosphates sorb to sediment surfaces through bonds to positively charged clay particles and by substituting for silicate in clay structures.

It is not completely understood how explosives are removed in a wetland system. Wastewaters contaminated with compounds such as RDX[3] have been successfully treated by constructed wetlands. It is suspected that several processes working in conjunction contribute to their degradation. Enzymes reduce nitro groups to amino groups in some explosives, such as TNT. Nitro groups in RDX are reduced to nitroso groups by enzymes. These compounds are broken down further by ring cleavage. Degradation also occurs in plants that take up the compounds.

Limitations and Considerations

Many factors affect the ability of a constructed wetland to effectively remove contaminants. Temperature and fluctuations in flow affect wetland function and can cause a wetland to display inconsistent contaminant removal rates. Colder conditions slow the rate at which the wetland is able break down contaminants. A heavy flow of incoming water can overload the removal mechanisms in a wetland, while a dry spell can damage plants and severely limit wetland function. Using designs that consider these factors, wetlands have been successfully implemented in a variety of climates.

A constructed wetland treating wastewater that contains contaminants such as metals or residual explosives must be monitored for contaminant buildup. Some wetland systems for acid mine drainage treatment use a compost or peat lining. Metal precipitates can build up in the compost, peat, or sediment, causing these layers to become non-permeable. It may be necessary to dredge the contaminated substrate after it has reached saturation. In some aerobic systems that utilize added bacteria, alcohol is added to feed the microorganisms rather than organic compost. This method avoids contaminant build up problems in the sediment.

[3] Royal demolition explosive or research department explosive, hexahydro-1,3,5-trinitro-1,3,5-triazine

Testing effluent water from a wetland system is necessary, as the goal of the design is to remove contaminants. Water cannot be discharged into waterways if it does not meet standards. In some cases, the constructed wetlands act as holding ponds for storm water overflow, preventing floods. The water is then discharged into the natural watershed over time. Wetlands are often constructed adjacent to an existing stream or creek, some of which are heavily polluted from years of receiving contaminated water. Clean discharge into these waterways is a crucial component to their restoration. Other constructed wetlands may be the final destination of wastewater, which will either evaporate or seep into the groundwater.

Other considerations that may affect the feasibility of a constructed wetland application include the availability of suitable land. In sites with steep slopes, it may not be economically practical to excavate an area and reinforce it with retaining walls. Soil type, vegetation, and high contamination levels in soil or water may make a site unsuitable for wetland construction. Issues such as mosquitoes and odor can arise, but can be avoided with careful planning. The long-term effects of contaminant exposure on wildlife and vegetation are not fully understood. Studies of ecological risk and bioaccumulation are still needed[4].

Conclusions

Constructed wetlands have a great potential for contaminated wastewater treatment. With careful design and planning, a constructed wetland can efficiently remove a variety of contaminants. The cost for design, construction and implementation can be considerably lower than other wastewater treatment options. The following set of case studies demonstrates the range of sites where this technology has been successfully applied.

[4] See Canfield, et. al., an ecological risk study in progress.

CASE STUDIES

Ariel view of the Apache Nitrogen Products Wetland Project. http://www.hargis.com/awp/indexawp.htm

Constructed Wetlands at Milan Army Ammunition Plant, Milan, Tennessee

Wastewater: Explosive residues in groundwater, TNT, RDX, HMX, 2ADNT, 4ADNT

Implementation Date:
1996-1998

Status:
Demonstration complete

Contact:
Darlene Bader
(410) 436-6861
dfbader@aec.apgea.
army.mil

CERCLA Site EPA ID:
TN0210020582

Groundwater contaminated with residual explosives was treated using constructed wetlands. A subsurface flow wetland and a surface flow wetland were constructed and compared. The subsurface wetland demonstrated a higher proficiency for contaminant removal.

Site History

Milan Army Ammunition Plant was constructed during World War II. The plant produced, stored, transported and packed ammunition. The wastewater from production facilities was discharged into open ditches that drained into nearby streams until 1981. Contaminants from discharged water in the drainage ditches leached into the groundwater. Water sampling of nearby residential and public water supply wells indicated the presence of contaminants

Wetland Application

Two demonstration wetlands were constructed, a surface flow, or lagoon, wetland and a subsurface flow or gravel-based wetland. The subsurface flow wetland consisted of two cells in series, four feet deep and populated by emergent plants. A carbon source was added to the first cell to maintain anaerobic conditions. The second cell was maintained at aerobic conditions. Water was retained in the 0.088-acre anaerobic cell for eight days, and in the 0.030-acre aerobic cell for two days. The anaerobic cell was designed to degrade the explosives, while the aerobic cell was designed to treat by-products of degradation, biological oxygen demand, nutrients, and total suspended solids. The surface flow wetland was comprised of two lagoons in series. These wetlands were two feet deep and populated by submergent plants.

Results

The subsurface flow wetland met demonstration goals of < 50 ppb of total nitrobodies except during periods of very low temperature. Further study indicates that a full-scale system with greater retention times would perform even during winter months. Goals of < 2 ppb of TNT were also met for most of the demonstration, except for a short period when data was not collected to due to equipment failure. The surface flow wetland was unable to meet the total nitrobody-removal goals, and met the TNT removal goal for only the first 50 days of the demonstration. The surface flow wetland experienced a tadpole infestation that damaged plants in the initial stages of the demonstration, and adequate plant growth was not reestablished. A hailstorm later damaged the remaining plants. The surface flow wetland was not evaluated in a cost-performance study. The subsurface flow wetland was found to be a cost effective and efficient system for the remediation of explosives.

Site References:

ESTCP. 1999. *The Use of Constructed Wetlands to Phytoremediate Explosives-Contaminated Groundwater at the Milan Army Ammunition Plant, Milan, Tennesee.*

Federal Remediation Technologies Roundtable online report: http://bigisland.ttclients.com/frtr/00000154.html

Constructed Wetlands at Westover Air Force Reserve Base, Chicopee, MA

Wastewater: Aircraft deicing fluid runoff. Fluid contains primarily propylene glycol, as well as and ethylene glycol, wetting agents, and anti-corrosion agents (Methylbenzotriazole).

Implementation Date:
Construction planned for fall of 2001

Status:
Contracting stage

Contact:
Jeff Karrh, P.I.
NFESC, ESC411
(850) 982-1272
karrhjd@nfesc.navy.mil

The Westover Air Force Reserve Base is in the process of building a demonstration sub-surface flow wetland to treat aircraft deicing fluid runoff. The wetland will serve as a study in design, construction and implementation to establish a model for future DoD applications.

Site History

The base is an active Air Force Reserve base, opened in 1940. At that time it was the largest air force base in the United States. It housed many different divisions of the Air Force until 1974, when jurisdiction of the base was transferred to the Air Force Reserve. It is home to the 439th Airlift Wing, as well as to tenant organizations such as the US Marine Corps Reserves and the Massachusetts Army National Guard. Two active runways exist on the base. Deicing activities for aircraft and runways occur every winter. The amount of deicing fluid used varies with the severity of winter weather. Precautions are taken to reduce the amount of fluid that is released into the environment, but some release is inevitable. Deicing fluid that enters the storm sewer system can cause adjacent surface waters to become contaminated. Other US airports have experienced problems with this contamination resulting in fish kills downstream.

Wetland Application

A horizontal subsurface flow wetland will be constructed to treat aircraft deicing fluid. The subsurface model was chosen to eliminate odors, to efficiently treat contaminants in a small area, and to prevent an increase in bird air strikes. This type of wetland does not provide habitat for birds, which are undesirable near a runway. The proposal is to build one or two subsurface flow cells, with a total area between 0.5 and 1 acre. The runoff from deicing operations on the East ramp is piped into an oil/water separator, and flow from the separator will be piped to the wetland cells. Water will be released through an outfall into Cooley Brook, which flows to the Chicopee Reservoir and River.

Results

The purpose of the project is to demonstrate how constructed wetlands might be implemented at other DoD sites to treat deicing fluid runoff. Extensive initial sampling is still taking place to establish accurate baseline levels of contaminants in surface water in the area. Goals for the wetland include reduction in biochemical oxygen demand levels, which increase with additions of propylene glycol. Monitoring for BOD_5 will allow for evaluation of wetland efficiency at removing propylene glycol. The goal will be to achieve average levels of BOD_5 < 30 mg/L. Other goals of this wetland project include implementing a low cost, low maintenance method of deicing fluid runoff treatment that will improve deicing logistics and flight scheduling, without creating odors or increasing bird air strikes.

Site References:

ESTCP Website Summary:
www.estcp.org/projects/compliance/200007o.cfm

Karrh, J., Knight, R., Cancilla, D., Hernandez, M. ESTCP. 2001. *Demonstration Plan: Westover Air Reserve Base, Chicopee, MA*. Revised Draft-Final Document.

Constructed Wetlands at Iowa Army Ammunition Plant, Middletown, Iowa

Wastewater: Surface and groundwater with residual explosives, RDX (Royal Demolition Explosive, Hexahydro-1,3,5-trinitro-1,3,5-triazine)

Implementation Date:
1998

Status:
Ongoing

Contact:
Donald D. Moses
USACE Omaha District
(402) 221-3077
Donald.d.moses@
Usace.army.mil

CERCLA Site EPA ID:
IA7213820445

The Iowa Army Ammunition Plant in Middletown, Iowa treated surface and groundwater contaminated with explosives using full-scale constructed wetlands. The wetlands reduced RDX concentrations in wastewater to non-detectable levels throughout the first two years of operation.

Site History

The plant has been in operation since 1941, loading, assembling and packing ammunition. Discharge from these activities caused nearby Brush Creek to flow red with explosives and explosive by-products. A lagoon, the Line 800 Pinkwater Lagoon, was constructed in 1943 to hold contaminated wastewater. An earthen embankment called the Line 1 Pinkwater Impoundment was constructed to impound wastewater in 1948. These two areas were the greatest sources of contamination, with drainage directly into Brush Creek.

Wetland Application

Soils from both the lagoon and the impoundment were excavated and transferred to a landfill. The excavated areas became the sites for the engineered wetlands, which were designed to treat residual explosives in the soil and contaminated groundwater. The 5.5-acre lagoon wetland was lined with sediment from a nearby lake for a seedbank, and filled with water from surface runoff and groundwater infiltration. The 3-acre impoundment site wetland was lined with sediment from the upper reaches of the impoundment area as well as with sediment from the lake to establish emergent and submergent plant species. Both wetlands have pipe structures to regulate the water level. The impoundment wetland has an upper hydraulic control structure that can be used to divert Brush Creek into the impoundment.

Results
During the 1998 and 1999 growing seasons, surface water, sediments and plant tissues were carefully monitored. The transferred seedbed was a successful means of establishing a diverse community of local plant species. Plant tissue sampling at three times during the growing season showed non-detectable levels of explosives. Sediment sampling in both wetlands showed that remediation goals had been met, explosive levels were reduced to below 1.3ppm for RDX in all but one area. Surface water was monitored monthly. A great reduction in RDX levels was seen during the first growing season, with a slight increase occurring during the winter. The second growing season showed further reduction, to almost non-detectable levels, with another slight increase over the cold season. Projections are that reductions will continue until levels are non-detectable year round. Overall ecological monitoring will continue, to assess the contaminant buildup risk to plant and animal populations.

Site References:

Kiker, J.H., Larson, S., Moses, D.D., Sellers, R. 2001. *Use of Engineered Wetlands to Phytoremediate Explosives Contaminated Surface Water at the Iowa Army Ammunition Plant, Middletown, Iowa*. Proceedings of the 2001 International Containment and Remediation Technology Conference and Exhibition.

Fulton Creek Regional Storm Water Management Facility, Edmonton, Alberta

Wastewater: Storm water runoff

Implementation Date:
1997

Status:
Ongoing

Contact:
H.Kuehne
780-451-7666
kuehneh@edmonton.
associated-eng.com

The need for a storm water management system was recognized, as was the need for fill for an adjacent freeway expansion. The excavation area was utilized as a constructed wetland, creating a storm water holding facility that would reduce flooding downstream and improve storm water runoff quality while attracting wildlife and recreation.

Site History
The city of Edmonton, expecting continued growth in the area around Whitemud Drive between 34 Street and Highway 14, wanted to expand Whitemud Drive from four lanes to six. This action required a large amount of fill. In addition to the freeway runoff, it was expected that the watershed in this area would be affected by increasing residential and industrial development. It was desirable to find a solution for storm water management that was cost efficient and would prevent Fulton Creek from flooding downstream. Creating a wetland in the area excavated to provide the highway fill met these needs. It would provide sufficient storm water storage capacity, as well as higher quality runoff and wildlife habitat. Expansion of the area was considered in the planning stages, and the facility was designed to handle the impacts of runoff from future development.

Wetland Application
A 55-acre wetland was created adjacent to the highway. Computer modeling was used to anticipate storm water loads based on historical storm frequency and severity. The system was equipped with a piping system with receiving and outlet structures to control rates of release downstream. Rapid drawdown capability was included in the design to prevent downstream flooding due to severe storms or the occurrence of storms in rapid succession. The goal was to create

an area that was not uniform to attract diverse plants and wildlife. Vegetation was strategically planted at different levels along the shoreline to reflect potential flooding and expected water level fluctuation. Low and high marsh areas were created, to promote a variety of submerged plants. Islands were formed for waterfowl nesting areas away from humans and predators. A terrace for wildlife viewing was included.

Results

The installation of an effluent water quality monitoring program is planned. The data from this program will allow for evaluation of the effectiveness of the wetland based on baseline contaminant levels. The object was to develop a facility that would meet a number of needs, and this was accomplished at an estimated $3 million savings to the City of Edmonton. A storm water storage facility was created, providing fill for a highway expansion. Additional benefits of the system include reduced downstream flooding, improved runoff quality, and created habitat for wildlife.

Site References:

Kuehne, H., Cairns, J. *An Innovative Approach to Development of a Regional Storm Water Management Facility.* Associated Engineering, City of Edmonton Transportation Department. www.ae.ca/about/papers/fulton.html

Constructed Wetlands at Burleigh Tunnel, Silver Plume, Colorado

Wastewater: Acid Mine Drainage, containing primarily Zinc

Implementation Date:
1994

Status:
Decommissioned

Contact:
Edward Bates
USEPA
National Risk Management Research Laboratory
(513) 569-7774
bates.edward@epa.gov

CERCLA site EPA ID:
COD980717557

The Burleigh Tunnel is part of the Central City/Clear Creek Superfund site. Two wetland cells were constructed adjacent to the tunnel as a technology demonstration to treat acid mine drainage. The wetlands were in operation for four years.

Site History
The Burleigh Tunnel site is downstream from a group of silver mines. The mines were in their height of production in the late 19th century, with an increase in activity during World Wars I and II. The Tunnel discharges into Clear Creek at significant flow rates. Elevated levels of zinc were found in the discharge. The effect of contaminants on the fisheries of Clear Creek led to the inclusion of the Burleigh Tunnel in the Clear Creek/Central City Superfund site.

Wetland Application
Two wetland cells were constructed, each with an area of 0.05 acres and a depth of four feet. Both cells were lined with a geofabric layer, followed by a sand layer, a clay liner and a polyethylene liner to prevent seepage. An organic-rich compost and hay mixture was used as a substrate. One wetland was a downflow design, and the other an upflow design. Water enters a downflow system at the top and moves with gravity towards the discharge weir. In the upflow system, water enters at the bottom is forced to the top of the cell for release. V-notch weirs were used at either end of the cells to control flow rates.

Results
The downflow cell experienced flow problems in the first few years of the demonstration. The flow dropped significantly in the third year, and influent to the cell was cut off. Reduction in the permeability of the substrate was attributed to precipitation of metal oxides, hydroxides and

carbonates, sedimentation, and compaction of the substrate. The cell did remove significant amounts of zinc from the water, averaging 77 percent removal during the first year and 70 percent removal during the second year. Removal rates increased in the third year, as reduced flow rates resulted in increased residence time for wastewater. The upflow cell had removal rates of over 90 percent during the initial phase of the demonstration. Heavy spring runoff in the spring of 1995 sent flows through the cell that were three times greater than the flow the cell was designed to treat. After the overloading, the removal rates dropped to 50 to 60 percent. It is suspected that the heavy flows caused aerobic conditions and a reduction in sulfate-reducing bacteria. Removal during the initial phase is attributed to absorption and biological sulfate reduction, while removal after the overloading was probably the result of chemical precipitation. The system demonstrated that anaerobic compost constructed wetlands can be effective at treating mine waste, and fluctuations in flow rates can affect performance.

Site References:

Anaerobic Compost Constructed Wetlands System (CWS) Technology: Innovative Technology Evaluation Report. 2001. National Risk Management Research Laboratory, Office of Research and Development, USEPA.

Bioreactor System at West Fork Mine, Missouri

Wastewater: Acid mine drainage containing lead and zinc

Implementation Date:
1996

Status:
Ongoing

Contact:
James Gusek
Knight Piesold LLC,
Denver, CO
(303) 629-8788
jimg@kpco.com

Wastewater containing lead and zinc from an underground lead mine is treated by a five-cell bioreactor system. The system has met goals for effluent contaminant levels in its first four years of operation.

Site History

The West Fork Mine is an active lead mine that discharges water into the West Fork of the Black River in central Missouri. The wastewater has a pH of 8.0. Lead levels range from 0.4 to 0.6 mg/L, and zinc levels are around 0.36 mg/L. The mine wastewater contributes about 10% of the total flow of the West Fork.

Wetland Application

Following bench-scale testing and water quality modeling, a pilot-scale field test was constructed. It was in operation for 2 years, during which lead levels were reduced to less than 0.02ppm. The full-scale design incorporated the successful aspects of the pilot-scale field test. A 50 percent safety factor was included in the design to accommodate possible future increases in contaminant loads. The system consists of five fully lined cells. Mine drainage is pumped from the underground mine to the settling pond, and flows through the remaining four cells by gravity. The first cell is a settling pond for solids removal. The water then flows into two anaerobic cells in parallel. These cells contain a substrate made of composted manure, sawdust, inert limestone, and alfafa that lies between two layers of geotextile lining. Sulfide production in these cells is the primary mechanism for lead removal. The fourth cell is an algae-filled rock filter cell for removal of BOD, manganese, and sulfide. Dissolved oxygen is increased in this cell. The final polishing step is an aeration pond to further remove BOD. The water is then released into the West Fork via an outfall.

Results
One problem that arose was a sulfide gas lock situation in the anaerobic cells. Sulfide gas that was generated by the sulfate-reducing bacteria was becoming trapped in the substrate and preventing full flow through the substrate. This problem was remedied by ripping up the geotextile lining that lay on top of the substrate, and replacing the substrate. It was projected that the system would require very little maintenance, however it was found that periodic rototilling and backflushing of the cells was necessary to prevent clogging. Water sampling shows that the anaerobic cells produce sulfide at sufficient levels even during the coldest months. The rock filter cell has developed populations of native flora and fauna, and removes excess sulfide as well as lead. The system successfully reduced lead in the wastewater from average concentrations of 0.40 mg/L to between 0.027 and 0.050 mg/L. Levels of zinc, cadmium, and copper were also reduced to acceptable levels.

Site References:

Gusek, J., Wildeman, T., Mann, C., Murphy, D. 2000. Operational results of a 1,200-gpm passive bioreactor for metal mine drainage, West Fork, Missouri. In: *Tailings and Mine Waste*. Balkema, Rotterdam, pp.549-555.

Gusek, J., Wildeman, T., Miller, A., Fricke, J. 1998. The challenges of designing, permitting and building a 1,200-gpm passive bioreactor for metal mine drainage, West Fork, Missouri. In: *Proceedings of 15th Annual Meeting of American Society for Surface Mining and Reclamation*, pp. 203-212.

Wetland Remediation System at Elmendorf Air Force Base, Alaska

Wastewater: Groundwater containing BTEX and PAH's

Implementation Date: 1996

Status: Ongoing

Contact:
Kevin Oates
USEPA Anchorage, AK
(907) 271-6323
Oates.Kevin@epa.gov

CERCLA Site EPA ID: AK8570028649

A multi-celled wetland remediation system is used to treat groundwater contaminated by spilled fuel. Several years of operation have shown that the system is successfully removing BTEX and PAH's before discharge into a local stream.

Site History

Elmendorf Air Force Base, located in Alaska, is home to the 3rd Wing. Along the south boundary is an area called Operable Unit 5, which is the main receptor for groundwater and surface water flow from the base. Aircraft fueling activities and leaking fuel pipelines have caused the groundwater to become contaminated with petroleum, oil, and related compounds. Groundwater from the Operable Unit 5 area surfaces nearby and drains into the Ship Creek floodplain.

Wetland Application

The wetland remediation system consists of an overland flow cell, and a polishing wetland cell. A seep collection system for four groundwater seeps feeds three pump stations. Groundwater from the three pump stations is pumped into the inclined, gravel-lined overland flow cell. Volatilization of aromatic hydrocarbons and oxygenation occurs in the overland flow cell. Water moves by gravity into the wetland cell where remaining contaminants are removed. The wetland cell discharges treated water into Ship Creek. Average residence time in the wetland cell is about 8 days. This system treats an average of 51.2 gallons of water per minute.

Results

In addition to PAH's and BTEX, water was tested for nitrate/nitrite and total phosphorus. Dissolved oxygen and temperature were also monitored. Water sampling at seven sites showed that the system is effectively removing PAH's and BTEX from the groundwater. Initial concentrations of contaminants in the groundwater varied widely between the different seeps. Significant contaminant reduction takes place in the seeps and pump stations as volatile contaminants are released. The overland flow cell removes remaining contaminants, and increases dissolved oxygen levels. Contaminant concentrations were found to be below detection levels in water entering the wetland cell. Nitrate/nitrite and total phosphorus levels increase as water leaves the seeps and travels to the overland flow cell, and decrease as water travels through the wetland cell. Sediment from the wetland cell was found to contain some BTEX, but no PAH's were detected in wetland sediment.

Site References:

United States Air Force Elmendorf Air Force Base, AK Environmental Restoration Program. 2001. *Annual Technical Report for Operable Unit 5 Wetland Remediation System*.

United States Air Force Elmendorf Air Force Base, AK Environmental Restoration Program. 2001. *Operations and Maintenance Manual Operable Unit 5 Wetland Remediation System.*

Constructed Wetlands for Perdido Municipal Landfill Leachate, Florida

Wastewater: Landfill leachate

Implementation Date: 1991

Status: Ongoing

Contact:
William F. DeBusk
Soil and Water Science Dept.
University of Florida
PO Box 110510
Gainesville, FL 32611

Landfill leachate was treated in a constructed wetland system near Pensacola. A treatment lagoon and ten wetland cells in series effectively reduced BOD, nitrates, suspended solids, phosphorus, and iron in leachate. The system is an effective, low cost alternative for treating landfill leachate.

Site History

The Perdido Landfill is located in Escambia County, Florida. It is the primary landfill for the greater Pensacola area. It receives approximately 600 tons of municipal solid waste each day. Waste consists of paper and paperboard, yard wastes, textiles, food wastes, glass, plastics, metals, and miscellaneous items. The landfill is lined, and a drainage system collects all leachate.

Wetland Application

The system consists of a treatment lagoon and 10 wetland cells in series. Raw leachate is collected in the primary treatment lagoon. Rainwater and surface runoff in this lagoon serve to dilute the leachate. An aeration system and a population of water hyacinths in the lagoon serve to pretreat leachate. It is then pumped uphill to the top of the wetland cells. The 2.4-acre area of the wetland cells is lined with a natural clay layer. Each cell was also lined with soil before planting. Leachate travels down through the slightly graded cells in a sepentine fashion. Each cell is slightly sloped towards the outflow end. Wetland cells were planted with a diverse set of emergent macrophytes. Plants tolerant of high ionic strength wastewater and high metal concentrations were chosen. A final pond is an open water holding pond. Treated water from the holding pond is pumped to a percolation pond for groundwater recharge.

Results

Sampling of surface water is done at several points in the system. Raw leachate is sampled, as is water in the primary treatment lagoon and at each wetland cell outflow. Monitoring and water testing show that the system is effectively removing nutrients in the landfill leachate. Samples are tested for total suspended solids, BOD_5, total organic carbon, total nitrogen, total phosphorus, iron, manganese, lead, cadmium and chloride. The leachate did not have high initial concentrations of heavy metals. Levels of nitrogen, phosphorus, organic carbon, iron and other contaminants were substantially reduced. On average, BOD_5 was reduced by 96%. Total suspended solids, iron, and total nitrogen levels were decreased by 98%. The system has proven to be a successful low-cost method of treating landfill leachate.

Site References:

DeBusk, W.F. 1999. Evaluation of a Constructed Wetland for Treatment of Leachate at a Municipal Landfill in Northwest Florida, in *Constructed Wetlands for the Treatment of Landfill Leachates*, Lewis Publishers, Boca Raton, FL, pp.175-186.

Constructed Wetlands at Apache Powder Superfund Site, Arizona

Wastewater: Groundwater containing nitrogen from industrial discharge

Implementation Date:
1997

Status:
Ongoing

Contact:
Andria Benner
USEPA Region 9
Benner.Andria@epa.gov
(415) 744-2361

CERCLA Site EPA ID:
AZD008399263

Groundwater with high levels of nitrogen from the production of nitroglycerin and other nitrogen compounds is treated in a series of wetlands. The system has proven to effectively remove excess nitrates from groundwater.

Site History

The site has been the home of Apace Nitrogen Products since 1922. Originally, the primary compound manufactured was nitroglycerin. Nitric acid, ammonium nitrate and nitrogenous fertilizer solutions were also produced. Wastewater from manufacturing was discharged through a drain system into unlined ditches. In 1971, water was diverted to an evaporation pond that was also unlined. The site was investigated in the 1987. Area soils showed high levels of heavy metals and arsenic. Sampling of groundwater and the nearby San Pedro River showed high nitrate concentrations. As a result, the site was placed on the National Priorities List in 1990.

Wetland Application

A multi-celled wetland system is used to treat the excess nitrates in the groundwater. The level of nitrate in the groundwater is approximately 250 ppm. Groundwater is pumped from a shallow aquifer and piped to the first wetland cell. The first three wetland cells are 1.5 to 2 feet deep and are planted with cattails. Nitrate is removed in these cells by denitrification. The water flows through by gravity. The fourth cell is a 4 to 6 foot deep pond that contains underwater plants including pond weed. The higher dissolved oxygen content in this pond converts any ammonia that was generated back to nitrate. A final polishing cell removes any remaining nitrate. The nitrate levels upon leaving the fifth cell are less than 10 ppm, and the water is piped to a dry wash where it is discharged.

Results
The wetland system can treat 200 gallons of water per minute. Water has a residence time of about five days in the system. It has proved to be a successful project. Nitrate levels are consistently reduced to less than 10 ppm. The low long-term operations costs, low energy demands, and wildlife habitat creation contribute to the success of this project. The cost savings in implementing the wetland system over other technologies is estimated to be $15 million.

Site References:

Hargis and Associates, Inc. Hydrogeology and Engineering Consultants website. www.hargis.com

USEPA NPL Site Narrative Listing website. www.epa.gov/superfund/sites/npl/nar903.htm

USEPA Region 9 website. www.epa.gov/region9/waste/index.html

References

Canfield, T.J., Jorgensen, E.E., Burden, D.S., Kemble, N.E. 1997. *Constructed Wetlands: Contaminant Filters, Transformers, Or Sinks: Evaluating The Fate Of Contaminants In Sediments And Biota Of Wetlands Constructed For Wastewater Treatment.*

DeBusk, W.F. 1999. Evaluation of a Constructed Wetland for Treatment of Leachate at a Municipal Landfill in Northwest Florida, in *Constructed Wetlands for the Treatment of Landfill Leachates*, Lewis Publishers, Boca Raton, FL, pp.175-186.

Dunbabin, J.S., Bowmer, K.H. 1992. *Potential use of constructed wetlands for treatment of industrial wastewaters containing metals*. The Science of the Total Environment, 111 151-168.

ESTCP Cost and Performance Report. 1999. *The Use of Constructed Wetlands to Phytoremediate Explosives-Contaminated Groundwater at the Milan Army Ammunition Plant, Milan, Tennesee.*

Gusek, J., Wildeman, T., Mann, C., Murphy, D. 2000. Operational results of a 1,200-gpm passive bioreactor for metal mine drainage, West Fork, Missouri. In: *Tailings and Mine Waste*. Balkema, Rotterdam, pp.549-555.

Gusek, J., Wildeman, T., Miller, A., Fricke, J. 1998. The challenges of designing, permitting and building a 1,200-gpm passive bioreactor for metal mine drainage, West Fork, Missouri. In: *Proceedings of 15th Annual Meeting of American Society for Surface Mining and Reclamation*, pp. 203-212.

Kadlec, R.H. and Knight, R.L. 1996. *Treatment Wetlands*, Lewis Publishers, Boca Raton, FL.

Karrh, J., Knight, R., Cancilla, D., Hernandez, M. ESTCP. 2001. *Demonstration Plan: Westover Air Reserve Base, Chicopee, MA*. Revised Draft-Final Document.

Kiker, J.H., Moses, D.D., Larson, S., Sellers, R. 2001. *Use of Engineered wetlands to phytoremediate explosives contaminated surface water at the Iowa Army Ammunition Plant, Middletown, Iowa.* Proceedings of the 2001 International Containment and Remediation Technology Conference and Exhibition.

Kuehne, H., Cairns, J. *An innovative approach to development of a regional storm water management facility.* http://www.ae.ca/about/papers/fulton.html.

National Risk Management Research Laboratory, Office of Research and Development, USEPA. 2001. *Anaerobic Compost Constructed Wetlands System (CWS) Technology: Innovative Technology Evaluation Report*. Draft.

Naval Facilities Engineering Service Center. 2001. *Draft: Constructed Wetland Technology Application Guide, Inception through Implementation.*

United States Air Force Elmendorf Air Force Base, AK Environmental Restoration Program. 2001. *Annual Technical Report for Operable Unit 5 Wetland Remediation System*.

United States Air Force Elmendorf Air Force Base, AK Environmental Restoration Program. 2001. *Operations and Maintenance Manual Operable Unit 5 Wetland Remediation System.*

USDA-NRCS, EPA Region III. *A Handbook of Constructed Wetlands: Volume 1 General Considerations.*

USEPA National Risk Management Research Laboratory. 2000. *Constructed Wetlands Treatment of Municipal Wastewaters*. EPA/625/R-99/010.

USEPA Office of Emergency and Remedial Response. 1996. Engineering Bulletin: Constructed Wetlands Treatment. EPA/540/S-96/501.

USEPA Office of Water. 1993. *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat: 17 Case Studies*. EPA/832/R-93/005.

USEPA Office of Wetlands, Oceans and Watersheds. 2000. *Guiding Principles for Constructed Treatment Wetlands: Providing for Water Quality and Wildlife Habitat*. EPA/843/B-00/003.