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SITE Technology Capsule

Anaerobic Compost Constructed Wetlands Technology

Abstract

As part of the Superfund Innovative Technology Evaluation (SITE) Program, the U.S. Environmental Protection Agency (EPA) evaluated constructed wetlands systems (CWS) for removing high concentrations of zinc from mine drainage at the Burleigh Tunnel in Silver Plume, Colorado.

Exploration geologists have known for many years that metals, most commonly copper, iron, manganese, uranium, and zinc, frequently accumulate in swamps and bogs located in mineralized areas. This understanding forms the basis for the design of CWS—essentially excavated pits filled with organic matter—that have been developed and constructed over the past 15 years to treat drainage from abandoned coal mines in the eastern United States. Mine drainage is routed through the organic material, where metals are removed through a combination of physical, chemical, and biological processes.

In fall 1994, anaerobic compost wetlands in both upflow and downflow configurations were constructed adjacent to and received drainage from the Burleigh Tunnel, which forms part of the Clear Creek/Central City Superfund site. The systems were operated over a 3-year period. The effectiveness of treatment by the CWS was evaluated by comparing the concentration of zinc and other metals from corresponding influent and effluent analyses. By far the dominant toxic metal present in the drainage was zinc. The upflow CWS removed an average of 93 percent of the zinc during the first year of operation, and 49 and 43 percent during the second and third years. The downflow CWS removed an average of 77 percent of zinc during the first year and 70 percent during the second year. (Flow was discontinued to the downflow system in the third year.) Complete data were published in the innovative technology evaluation report (ITER) for the evaluation and are available from EPA.

Introduction

The SITE Program was established in 1986 to accelerate the development, evaluation, and use of innovative technologies that offer permanent cleanup alternatives for hazardous waste sites. One component of the SITE Program is the Demonstration Program, that develops engineering, performance, and cost data for innovative treatment technologies. Data developed under the SITE Demonstration Program enable potential users to evaluate each technology's applicability to specific waste sites. The Colorado Department of Public Health and Environment (CDPHE) identified passive treatment by wetlands as the preferred remedial alternative for drainage from the Burleigh Tunnel. CDPHE is

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responsible for remediating the site and worked with EPA's National Risk Management Research Laboratory (NRMRL) to construct the demonstration systems and to design the evaluation.

The primary objectives of the SITE Program's evaluation of the CWS were to (1) measure the reduction of zinc (the dominant toxic metal) in Burleigh Tunnel drainage that resulted from CWS treatment with respect to cell configuration and seasonal variation (temperature); (2) assess the toxicity of the Burleigh Tunnel drainage; (3) characterize the reduction in toxicity that resulted from treatment of the drainage by the CWS; and (4) estimate the reductions in toxicity in the stream (Clear Creek) that receives the Burleigh Tunnel drainage. Reductions in the concentrations of other metals were also measured as a secondary objective and are reported in the ITER.

Design of Constructed Wetlands System

For this evaluation, wetlands were designed and constructed to treat mine drainage through a combination of sorption, precipitation, and biological sulfate reduction. The evaluation was conducted on both upflow and downflow CWS cells.

Both cells consisted of an 0.05-acre cell (pit) filled 4 feet deep with a mixture of an organic-rich compost (96 percent) and alfalfa hay (4 percent). The cells were installed below grade to reduce freezing of the cells during winter. The earthen sidewalls of both cells were bermed. The base of each cell was made up of a gravel subgrade, a 16-ounce geofabric, a sand layer, a clay liner, and a high-density polyethylene liner. The base was separated from the influent or effluent piping by a geonet. A 7-ounce geofabric separated the perforated polyvinyl chloride (PVC) piping from the compost. The compost was held in place with a combination of 7-ounce geofabric and a geogrid in the upflow cell. The perforated effluent piping was also supported by the geogrid in the upflow cell. Up to 6 inches of dry substrate material was located above the perforated piping. The geonet and perforated piping ensured even distribution of the influent water into the treatment cells and prevented short-circuiting of water through the cells. Short-circuting causes a decrease in residence time and often can impair performance. Influent and effluent distribution piping were also staggered horizontally as an added precaution against short circuiting.

The flow to the CWS cells was regulated by a series of concrete v-notch weirs, one for the influent and one for the effluent of each cell. The effluent weir controlled the flow and the hydraulic residence time of the mine drainage through both CWS cells. Mine drainage entered the upflow cell under pressure at the base of the compost and discharged out the top, whereas flow entered the downflow cell from the top and flowed by gravity to the bottom for discharge. Each cell was designed for a flow of 7 gallons per minute (gpm), but loss of permeability in the downflow cell blocked flow. The remaining flow from the drainage was diverted to Clear Creek (untreated) via the influent weir. A drainage collection structure was constructed within the Burleigh Tunnel to build sufficient hydraulic head to drive the flow through the two CWS.

Results of Evaluation

This section summarizes the laboratory analytical data from field sampling and in-field observations as they relate to the primary objectives of the evaluation. Definitive removal efficiencies and other relevant data are published in the ITER, available from EPA.

Removal Efficiencies

Results from this SITE demonstration and additional tests of the CWS technology suggest that it is capable of reducing the toxicity of contaminated mine drainage by removing metals such as zinc, cadmium, iron, lead, nickel, and silver. Data indicate that both systems initially removed significant percentages of zinc and other metals and that removal efficiency decreased over time. Trends in the data and results for efficiency are discussed in this subsection by treatment cell.

Downflow Cell

In general, the downflow cell was effective in removing zinc during the first year of operation. Zinc removal by this cell ranged from 69 to 96 percent with a mean removal efficiency of 77 percent. During the second year of operation, zinc removal ranged from 62 to 79 percent with a mean removal efficiency of 70 percent.

During the final 6 months of operation, loss of permeability caused by precipitation of metal oxides, hydroxides, and carbonates, and subsequent settling of fine materials in the cell, combined with compaction of the substrate material, reduced flow through the downflow cell, thereby increasing the residence time of the mine drainage in the cell. The increased residence time improved zinc removal. Zinc removal during this period ranged from 67 to 93 percent with a mean of 82 percent.

Aqueous geochemical modeling, observations of cell compost, results of the sulfate-reducing bacteria count, and acid volatile sulfide data suggest that biological sulfate reduction is not the primary removal mechanism for zinc within this cell. Instead, the primary removal mechanism is thought to be precipitation of zinc oxides, hydroxides, and carbonates in aerobic sections of the downflow cell.

Upflow Cell

During the first 6 months of operation, effluent samples from the upflow cell contained low (less than 1 milligrams per liter [mg/L]) concentrations of zinc. However, during the later part of 1994 and into 1995, zinc concentrations in effluent from the upflow cell began to increase. The concentrations of zinc ranged from 0.13 mg/L in early 1994 to 60.1 mg/L in May 1997.

In the spring of 1995, heavy runoff overwhelmed the CWS, channeling 20 gpm of aerobic water (nearly three times the design flow) through the upflow cell. This high runoff also apparently mobilized more zinc from the mine workings or mine waters and substantially increased the concentration of zinc in the mine drainage. The large flows created aerobic conditions, and the increased zinc loading had a detrimental effect on the upflow cell. These new conditions apparently initiated a change in the cell's microbial ecology. After the high flow event, the upflow cell removed only 43 to 49 percent of the zinc in the mine drainage. Before the high flow event, the upflow cell removed more than 90 percent of the zinc (mean removal in year 1 was 93 percent).

The loss of hydraulic conductivity in the substrate also affected the upflow CWS. During the demonstration, the height of the influent weir was periodically raised to increase the hydraulic pressure to maintain flow through the upflow CWS. The water level was raised approximately 1 foot over the 4-year demonstration. In 1997, this cell developed a visibly obvious preferential pathway in the southeast corner, adjacent to the bermed sidewall. This preferential pathway was eliminated by terminating flow to this section of the wetland by excavating the wetland substrate to allow installation of a cap on the influent line.

The high initial rates of zinc removal in the upflow cell were likely the result of adsorption and absorption of metals along with biological sulfate reduction. The decline in metal removal by the upflow cell after the high flow event is likely related to the decline in sulfate reducing bacteria in this cell. There are several possible reasons for the decline of the sulfate-reducing bacteria, including toxicity to the bacteria produced by high zinc concentrations, prolonged exposure to aerobic conditions that allowed other wetland bacteria to outcompete the sulfate-reducing bacteria, or the consumption of all the most readily metabolized growth materials by the sulfate reducing bacteria, leading to lower activity and eventually lower populations. Ultimately, the primary mechanism for metals removal over the last several years of the demonstration was likely chemical precipitation.

Toxicity of the Burleigh Tunnel Mine Drainage

Water samples from the Burleigh Tunnel were evaluated by EPA's National Exposure Research Laboratory for aquatic toxicity to Ceriodaphnia dubia (water fleas) and Pimephalus promelas (fathead minnows). The water was found to be toxic to both organisms at low concentrations. The concentrations of mine drainage resulting in death of 50 percent of the test organisms (LC50) ranged from 0.10 to 1.0 percent for the water fleas and from 0.62 percent to 1.6 percent for the fathead minnows over the course of the evaluation.

Reduction in Toxicity from CWS Treatment

Effluent waters from the treatment cells were also evaluated for aquatic toxicity using the same test organisms previously mentioned. Effluents from both treatment cells were not toxic to either test organism during the first 8 months of the demonstration. Nonetheless, although both systems were able to significantly reduce toxicity to the test organisms, this reduction declined over the first 2 years of operation. The reduction in toxicity correlated well with increasing zinc concentrations observed during this time frame.

Reduction in Toxicity of Clear Creek

Stream samples were evaluated for aquatic toxicity using the same test organisms previously mentioned. None of the samples were toxic to the test organisms, so toxicity reduction could not be ascertained using this method.

Comparison to Superfund Feasibility Study Evaluation Criteria

Table 1 summarizes the CWS performance compared with the Superfund feasibility study (FS) evaluation criteria. This table is provided to assist Superfund decision makers in considering these technologies for remediation at hazardous waste sites.

Status of Technology

Several hundred constructed and natural wetlands are treating coal mine drainage in the eastern United States. In addition, many constructed wetlands designed to treat metals-contaminated mine drainage have been constructed and tested, or are being tested, by EPA, various state agencies, and industry. The references below can be used to obtain more information about the technology.

Hedin, R.S., Narin, R.W., and Kleinmann, R.L.P. 1994. Passive Treatment of Coal Mine Drainage. United States Bureau of Mines Information Circular 9389.

Kadlec, R.H., and Knight, R.L., 1996. Treatment Wetlands. CRC Press. Lewis Publishers. Boca Raton, Florida.

Moshiri, G.A. 1993. Constructed Wetlands for Water Quality Improvement. Lewis Publishers. Boca Raton, Florida.

United States Bureau of Mines. 1994. Proceedings of the International Land Reclamation and Mine Drainage Conference on the Abatement of Acidic Drainage. Pittsburgh, Pennsylvania, April 24-29, 1994, Bureau of Mines Special Publication SP 066-4.

Technology Applicability

Constructed wetlands have been demonstrated to be effective in removing organic, metal, and nutrient elements including nitrogen and phosphorus from municipal wastewater, mine drainage, industrial effluents and agricultural runoff. The technology is waste-stream specific, and requires characterization of all organic and inorganic constituents. CWS designs vary considerably, and can be simple, single-cell systems, or complex multicell or multicomponent systems of varying depths.

The CWS designs used in this evaluation may be applicable as a long-term remedial technology at Superfund sites where acidic mine drainage is a problem, as the technology is capable of treating a range of contaminated waters that contain heavy metals. Influent waters must be characterized, however, because the effectiveness of a CWS can be reduced in waters with high pH, as precipitates form and clog the system prematurely. Low pH mine drainage can also be a problem because sulfate-reducing bacteria cannot survive in low pH environments.

Limitations

Land required for CWS is typically extensive compared with conventional treatment systems. Thus, in areas with high land values, a CWS treatment system may not be appropriate. Availability of land relatively close to the source of the contaminated water is preferred to avoid extended transport.

Climate at potential CWS sites can also be a limiting factor. Extended periods of severe cold, extreme heat, arid conditions, and frequent severe storms resulting in high flows or flooding can result in performance problems. Contaminant levels in treated and discharged water can vary in response to variations of influent volumes and chemistry. This variation may also be a limiting factor if there is no tolerance in discharge requirements for contaminant levels.

Table 1. Evaluation of CWS Treatment Compared to Feasibility Study Criteria

Criterion	Discussion
1. Overall Protection of Human Health and the Environment	As tested, the constructed wetlands system (CWS) provides only short-term effectiveness. In different circumstances, the CWS may provide short- and long-term protection by removing mine drainage contaminants. Substrate is a recycled product, not mined or manufactured.
2. Compliance with Applicable or Relevant and Appropriate Requirements (ARAR)	Wetland effluent discharge may require compliance with Clean Water Act regulations. Substrate disposal may require compliance with Resource Conservation and Recovery Act regulations.
3. Long-term Effectiveness and Permanence	CWS treatment removes contamination from mine drainage but may not meet discharge requirements. Use of CWS treatment with other technologies may be effective in meeting low-level discharge requirements.
4. Short-term Effectiveness	Presents few short-term risks to workers, community, and wildlife. Minimal personal protective equipment required for operators.
5. Reduction of Toxicity, Mobility, or Volume Through Treatment	CWS treatment reduces contaminant mobility, toxicity, and volume.
6. Implementability	Generally a passive treatment system, but can be active. Construction uses standard materials and practices within the industry.
7. Cost	Construction cost of a full-scale system (50 gallons per minute) is estimated at approximately $290,000. Operation and maintenance of a full-scale CWS is estimated to be $57,000 per year.
8. Community Acceptance	The public usually views the technology as a natural approach to treatment; therefore, the public generally accepts this technology.
9. State Acceptance	The Colorado Department of Public Health and the Environment (CDPHE) found the technology shows promise for treating acid mine drainage. Based on the cold climate and proximity to town, however, CDPHE recommended not implementing a full-scale permanent system at the Burleigh location. The Colorado Division of Minerals has built several CWSs to treat mine drainage.

Sources of Further Information

Definitive data from the evaluation are published in the ITER.

Further details regarding CWS are available in the literature and from the EPA NRMRL work assignment manager:

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