Passive Wastewater Treatment of CCB Landfill Leachate

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INTRODUCTION

Allegheny Energy has found passive wetland treatment to be an efficient and cost-effective method of treating leachate from coal combustion byproduct (CCB) disposal areas, particularily where the facility was designed without provisions for water treatment and has been closed. Following early initiatives, Allegheny Energy has accumulated over 10 years of design, construction, operating, and regulatory experience with passive wetland treatment technologies. In keeping with it's Environmental Stewardship Policy, these environmentally-friendly systems are Allegheny Energy's preferred alternative for water treatment wherever site conditions are favorable to their inherent biological and geochemical contaminant removal processes.

To date, Allegheny Energy (AE) has installed passive wetland treatment systems to treat metals-bearing leachate at two of its closed CCB facilities. Work was initiated in 1988 with construction of a prototype treatment wetland at the Albright closed CCB landfill in northern West Virginia. With positive results from this system, in 1994 AE entered into a tailored collaboration with the Electric Power Research Institute (EPRI) to advance this technology. This jointly-funded project centered on a full-scale application of passive treatment at the Springdale closed CCB landfill in western Pennsylvania and included a major research and development component to evaluate existing and experimental technologies for the treatment of CCB leachate.

This paper provides an overview of Allegheny Energy's experience with wetland treatment systems at their Albright and Springdale CCB facilities and future systems under design and evaluation for other CCB sites. This review is followed by a brief discussion of the various passive treatment technologies available to the utility industry.

HISTORY OF PROJECTS

Albright System

In 1986, the West Virginia Department of Natural Resources (WVDNR) indicated that treatment of the metals-contaminated leachate from the Albright closed CCB landfill would be necessary. Conventional chemical treatment options were evaluated by AE, but were found not to be cost-effective due to the site's remote location, terrain constraints, and unmanned status. At the time, passive technologies were in their infancy, a promising approach to wastewater compliance, but with no hard design standards applicable to the treatment of CCB leachate. In search of a more cost-effective means of treating these waters, AE initiated efforts to investigate the viability of using wetland treatment for this site. The investigation and subsequent design led to approval from the WVDNR for construction of an R&D passive wetland treatment system at Albright.

The initial Albright system consisted of four small basins formed by dikes in an existing drainageway and vegetated with transplants from surrounding wetlands. Completed in 1988, this system proved successful in meeting NPDES limitations of 1.5 mg/L for iron, but not the 1.0 mg/L limit set for manganese. In the early 1990s, work by the US Bureau of Mines (US BoM) indicated that manganese removal rates are much lower than those for iron in wetland environments, and that removal rates for both parameters are largely a function of wetland surface area[1]. Two additional basins were added to the system during 1992 to provide additional surface area and, thereby, increase manganese removal capacity. While showing significant reductions in manganese discharge levels, the expanded system was still unable to meet compliance for that parameter. In 1993, pilot level modifications were made to evaluate preliminary data by others on the ability of limestone beds to remove manganese[2]. Based on these results and findings from the Springdale system after its construction, the Albright

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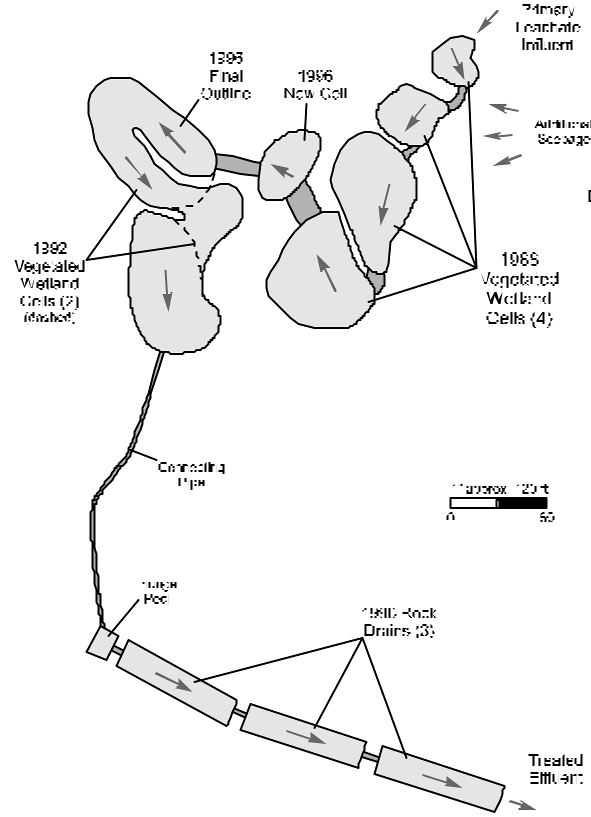


Figure 1. Albright System Layout

system was modified in 1996 to include three rock drains, reaching the final configuration shown by Figure 1. Following a brief 1-month period of self-inoculation for the manganese-oxidizing bacteria, almost total removal was achieved for manganese at Albright, and that system is now fully in compliance. Each major component of the Albright system has been continually monitored for influent and effluent water quality, and flow, for nearly 10 years.

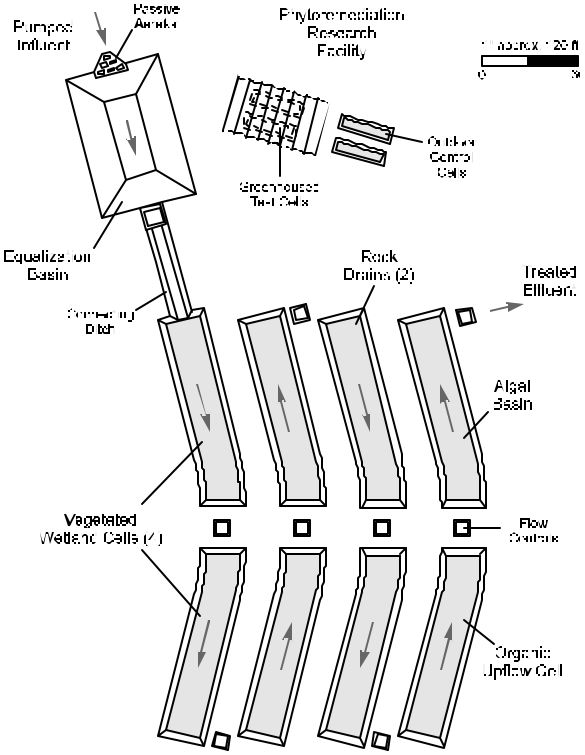
Springdale System

Leachate from the Springdale landfill underdrain had been discharging since the site was closed in 1975. In 1994, the Pennsylvania Department of Environmental Protection (PADEP) indicated that the existing NPDES permit for this discharge would soon be revised to require more stringent effluent limits on iron and manganese. Based on the success at Albright, AE entered into a Consent Order and Agreement with the PADEP to meet the expected effluent criteria using passive wetland treatment.

The new NPDES permit also included future compliance with a number of other trace metals for which no passive design standards were available at the time. In response to this need, the AE/EPRI tailored collaboration project was designed with dual purposes of: (1) using proven passive wetland technologies to comply with existing NPDES limits for iron and manganese and (2) designing and evaluating emerging and experimental technologies aimed at achieving eventual compliance with the additional parameters.

At Springdale, insufficient land area was available below the discharge to construct a system to receive gravity flow, necessitating a pumping facility to convey the leachate to a more suitable site uphill. Based on the leachate chemistry, it was determined that compliance with existing dissolved iron limitations of 7 mg/L could be met by use of a simple oxidation/precipitation basin, which would also equalize the intermittent flow from the pumps before entering a wetland system. These facilities were constructed in 1994 and achieved immediate compliance for dissolved iron. In 1995, eight additional treatment cells were added to the system in advance of issuance of the new NPDES permit, creating the final system layout shown by Figure 2.

Figure 2. Springdale System Layout



These cells included four vegetated wetland basins for iron polishing, two rock drains to culture manganese-oxidizing bacteria, an organic upflow cell to promote sulfide mineral formation, and an algal growth basin for vegetative uptake of trace metals. The completed system was immediately successful in meeting compliance for all parameters except boron, which continues to be the focus of additional efforts by AE to identify an effective passive treatment mechanism for its removal.

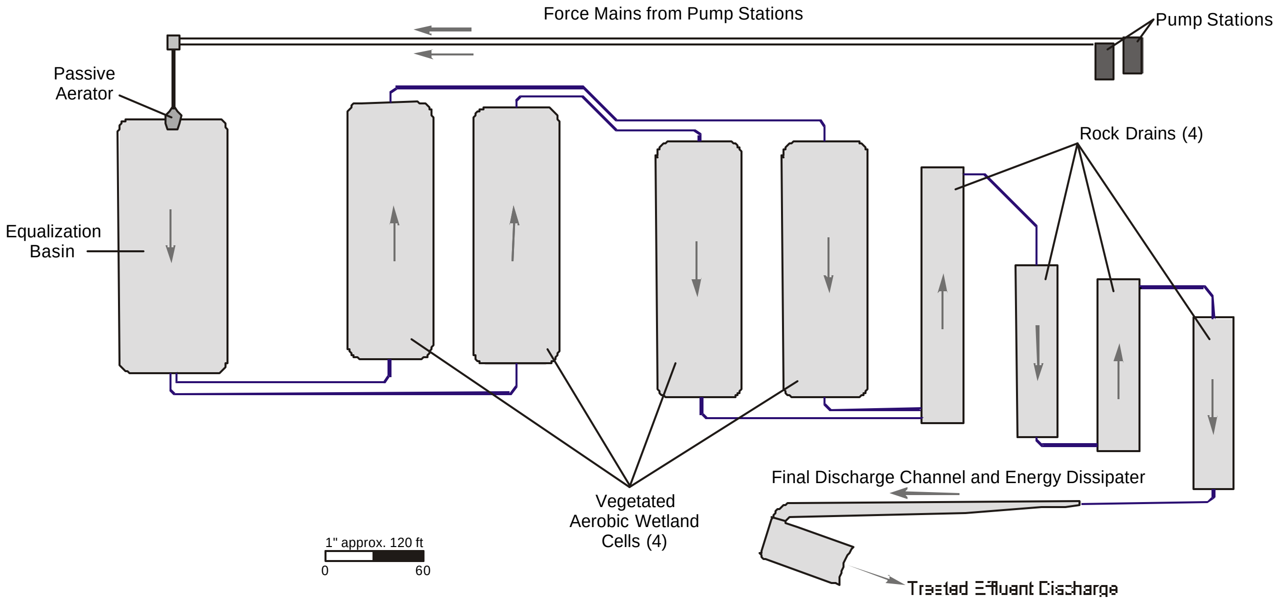
Influent and effluent loadings were monitored at ten points within the system for a period of two years following construction to evaluate the treatment effectiveness of the major components and technologies for a broad spectrum of parameters. Of particular interest was development of design criteria from the manganese-oxidizing rock drains, which were later applied to achieve manganese compliance at the Albright site. Additional experiments in phytoremediation are continuing in the on-site research facility, which has both greenhouse-enclosed and exposed test cells to evaluate the influence of climate on plant uptake rates.

Hatfield Design in Progress

At Allegheny Energy's Hatfield Power Station in Green County, PA, leachate currently discharges from underdrains at two adjacent CCB disposal areas, one closed and one active, and co-mingles in a sedimentation pond constructed below the toe of the fills. Current NPDES criteria apply to the sedimentation pond discharge. Both underdrains show elevated aluminum, iron, and manganese at circumneutral pH, and these waters are currently receiving chemical treatment with a caustic soda drip-feed system using the sedimentation pond as a primary settling basin for metal sludges formed by the neutralization process. To avoid long-term compliance and maintenance problems, AE decided to design and construct a passive wetland treatment system to eliminate chemical usage and provide a more permanent treatment solution on this site.

As shown by Figure 3, the underdrain waters will be collected and pumped to a treatment location adjacent to the CCB piles. Based on Phased Element Removal Technology[3], the design employs three passive technologies to sequentially remove aluminum, iron, and manganese. Pumped leachate will be aerated in a flow combination box and passive aerator prior to entering a flow equalization basin, where the majority of the aluminum and iron will oxidize and precipitate. Discharge from the equalization basin will be split between two sets of vegetated aerobic wetland cells operating in parallel to remove residual iron and initiate manganese removal.

Figure 3. Hatfield System Layout



Final manganese removal will occur in a series of manganese-oxidizing rock drains. The treatment system components have been designed for maintenance access on intermediate berms. The only regular maintenance anticipated to be necessary is cleaning of accumulated iron sludge from the equalization basin and first set of wetland cells. Construction of the Hatfield system is scheduled for the summer of 2000.

AVAILABLE PASSIVE TECHNOLOGIES

The passive technologies employed at Albright and Springdale have proven very effective for removing trace metals and other contaminants. Performance results are summarized by Table 1, which shows average influent and effluent concentrations and percent removals for major constituents. Using these data and design criteria developed from the existing systems, projections of performance are included for the Hatfield system. The following provides a brief summary of these technologies and guidelines for their application.

Oxidation/Precipitation Basins

Oxidation/precipitation (O/P) basins are open water impoundments designed to provide aeration for precipitation of aqueous metals, detention time to settle precipitates, and storage volume for accumulating precipitate sludge. They are most effective for removing large-volume sludge formers and are a key component in passive systems where iron is present in quantity. Results from Springdale indicate that arsenic, aluminum, and zinc will also tend to co-precipitate with iron. Iron sludge consists primarily of the amorphous oxyhydroxide *limonite* ($FeOOH\blacklozenge nH_2O$), formed by the process given below. In the aeration step, oxygen is introduced passively by means such as a splash plate or corrugated trough. Limonite sludge forms quickly thereafter, but settles very slowly. A detention time of at least 24 hours is recommended to produce a clear water discharge, with additional storage capacity for accumulated sludge usually maintaining the design detention time at 40% of the total volume occupied.

$$2\ Fe^{2+} + \tfrac{1}{2}\ O_2 + n\ H_2O\ = FeOOH\blacklozenge nH_2O + 4H^+$$

O/P basins function best in the circumneutral pH range of 6 to 9 SU. A single passive aeration device can only introduce enough oxygen to precipitate about 50 mg/L of iron[4]. For higher loadings, a series of basins and aerators can be employed. Oxidation of aqueous iron results in the generation of acidity (H^+), decreasing the pH of the wastewater. When significant amounts of iron are being removed, measures may be necessary to neutralize excess acidity with downstream components. The rate of iron precipitation also begins to diminish at a pH below 6 SU, with higher concentrations of iron becoming stable despite the presence of oxygen.

Table 1. Performance of CCB Treatment Systems Under Average Flows and Concentrations

	Albright			Springdale			Hatfield		
Parameter	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Projected Effluent	Projected % Removal
Flow	20gpm			40gpm			72gpm		
TSS	61	1	**98**	25	8	**68**	26	0.5	**98**
TDS	2464	1164	**53**	1818	1828	**	*		
pH	6.70	7.46	**(+11%)**	7.04	7.61	**(+8%)**	6.60	7.00	**(+6%)**
Acidity	106	1	**99**	23	14	**39**	*		
Alkalinity	137	72	**47**	106	121	**(+15)**	*		
Arsenic	*			0.061	0.005	**92**	*		
Aluminum	1.000	0.089	**91**	0.891	0.260	**71**	2.100	0.500	**76**
Boron	*			15.92	14.03	**12**	*		
Iron (total)	45.00	0.33	**99**	12.46	0.27	**98**	20.76	1.00	**95**
Iron (dissolved)	*			6.09	0.10	**98**	*		
Manganese	13.00	0.083	**99**	2.71	0.21	**92**	12.49	0.16	**99**

*Not a regulated NPDES parameter on this site **No significant change Concentrations in mg/L, pH in standard units

Vegetated Wetlands

Vegetated wetlands used for treatment are typically constructed as shallow basins with 1 to 2 feet of organic-rich planting substrate. For optimum plant development, a substrate meeting the classification of clay loam with at least 12% organic content has been found to best duplicate conditions found in natural wetlands[5]. The substrate is planted with species selected as appropriate for the local climate. Cattails are generally the hardiest plants for applications with high metals concentrations or potential for sludge accumulation[6]. Flow within the basins is best regulated at a depth of 0.1 foot or less[7].

Vegetated wetlands function as both physical filters and sites of biogeochemical activity to alter or fix contaminants in place, and are effective against a broad spectrum of parameters. Surface air contact creates an oxygen-rich, *aerobic* environment, which promotes the oxidation and precipitation of aqueous metals. Below the surface, the organic planting substrate consumes oxygen, creating an *anaerobic* environment that promotes sulfide mineral formation. Results from Albright and Springdale show that vegetated wetlands are effective for the removal of aluminum, arsenic, copper, iron, manganese, nickel, and zinc. Other studies indicate vegetated wetlands to be effective against cadmium[8], cobalt[9], and lead[8], and those at Springdale show some effect on beryllium and molybdenum as well. Most other trace metals can be considered candidates for removal in vegetated wetlands, but confirming research is sparse. Boron, commonly associated with CCB leachate, does not show significant removal in vegetated wetlands. Compliance sizing criteria for vegetated wetlands are available from the US BoM[1] for iron, manganese, and acidity based on surface area, as follows:

Iron	10 grams/(meter^2 - day)
Manganese	0.5 grams/(meter^2 - day)
Acidity	3.5 grams/(meter^2 - day)

These values are additive, so a vegetated wetland should be designed with sufficient area to remove each contaminant separately. Preliminary findings from Albright indicate that these criteria may not be sufficient for treatment of iron and manganese to levels approaching 1 mg/L[6]. Vegetated wetlands are limited in their capacity to accommodate large volumes of iron sludge and should be placed after an O/P basin to limit iron loading. Their biological processes will also diminish below a pH of 4 SU. Periodic maintenance is necessary to eliminate flow path short circuits, remove accumulated sludge, and replace spent substrates. Control of internal flow velocities is important for avoiding short-circuits or particle transport. As a general rule, a minimum substrate surface width of 1 foot is recommended for each gallon per minute of influent flow.

Manganese-Oxidizing Rock Drains

"Rock drains" are basins filled with loose stone or gravel that provide substrates for the growth of bacteria which oxidize aqueous manganese (Mn^{2+}) as energy for their life processes. These bacteria combine manganese and oxygen to form the mineral *pyrolusite* (MnO_2), the "black slime" coating commonly found on river rocks. Manganese will not normally precipitate below a pH of 9.5 SU[10] in chemical treatment, but in the presence of bacteria it can be effectively removed in waters with a pH as low as 6 SU and possibly as low as 5 SU[11]. The basic chemical reaction for this can be summarized as follows:

$$Mn^{2+} + H_2O + ½\ O_2 = MnO_2 + 2H^+$$

Detailed design criteria have not been published for rock drains. However, both the Albright and Springdale systems show good performance with basins having a total detention volume of approximately 48 hours. The bacteria grow only on the surface of the stones, so treatment efficiency is believed to also be a function of stone surface area. Rock diameters of 1 to 6 inches appear to produce a good ratio of surface growth area to void space. Water levels within the basins are generally maintained near the surface of the bed, and bacterial growth can occur throughout the water column in the substrate. Multiple basins with intermediate cascade aeration points have been found to introduce the oxygen necessary for the bacterial activity. Manganese-oxidizing bacteria are generally ubiquitous in the environment and will normally colonize a completed rock drain by natural growth within several months of construction.

Rock drains can be very effective against aqueous manganese, showing almost total removal under ideal conditions. They do not appear to function well with an influent iron concentration of greater than 1 mg/L[12], but the Albright application does achieve very low iron and manganese discharge concentrations with an average influent iron of 1.2 mg/L. When treating wastewater containing both iron and manganese, O/P basins and/or vegetated wetlands should be employed to remove iron upstream of a rock drain. At Springdale, the rock drains show some associative reduction of boron, molybdenum, and strontium, while those at Albright show significant reductions in aluminum, arsenic, copper, and nickel at low concentrations.

Organic Reduction Environments

A second bacterially-mediated process with potential for removal of trace metals is sulfate reduction. Anaerobic bacteria decompose organic matter in the presence of sulfates to generate sulfide, a powerful reducing agent. Sulfide is capable of joining with most aqueous metals to form sulfide minerals, with M^{2+} representing the metal in the following reaction:

$$\begin{gathered} M^{2+} + 4CH_2O + 2SO_4^{2-} = \\ MS_2 + H_2 + 2HCO_3^{-} + 2CO^{2} + 2H^{2}O \end{gathered}$$

Organic reduction environments can be created in many forms. One type used for acidity removal is a Sustained Alkalinity Producing System (SAPS), which functions by downflow of water through a layer of compost followed by a layer of limestone. Horizontal migration of water through organic-rich planting substrates will also result in sulfide generation in vegetated wetlands. For the Springdale project, an experimental cell was constructed using upflow through limestone and compost. Although sulfide was produced in abundance by this method, there were insufficient aqueous metals remaining at that point in the system for any significant removal to occur. In fact, some influent metals concentrations were so low that additional amounts were leached from the compost. It is concluded that this method of treatment would be more effective against higher concentrations of trace metals, and may not be able to achieve extremely low effluent concentrations.

Phytoremediation

Growing plants must take in nutrients and minerals, including small quantities of trace metals, from their surroundings to produce new tissue. Once incorporated in plant tissue, trace metals tend to be less mobile and are essentially removed from the environment until the plant decays, or possibly longer.

A treatment method known as *phytoremediation* uses this basic life process as a tool for removing contaminants from wastewater. Plants do not uptake trace metals as a sufficient percentage of their body mass to make this form of treatment practical for high-concentration parameters, such as iron and manganese. Even if a plant accumulates 1% of its mass in a given metal, that still generates 100 pounds of plant matter for every pound of metal removed. Instead, research is focused on identifying *hyperaccumulators*, those plants that can store exceptionally large amounts of trace metals in their tissues without ill effect. These plants may be a practical treatment method for removing low concentrations of trace metals, and it is suspected that at least some of the trace metal removal occurring at Albright and Springdale is a result of this process.

Research is also focusing on the emerging field of *transmigratory phytoremediation*, where plants modify a contaminant to a benign form and pass it back to the environment, rather than accumulating it in their tissues. This eliminates the potential problem of disposing of large volumes of plant matter. EPRI-supported research is being conducted in conjunction with the Springdale project to examine plant species that can volatilize selenium, continuously removing that contaminant out of wastewater and releasing it to the atmosphere as an innocuous methyl compound[13].

PHASED ELEMENT REMOVAL TECHNOLOGY DESIGN

One of the most important developments to come from the AE research has been the recognition that each wastewater contaminant has a preferred environment of removal. Passive systems treating for multiple parameters may require more than one internal treatment method, necessitating some form of ordering protocol. To aid in the design of multi-environment passive systems, developed a set of guidelines known as Phased Element Removal Technology (PERT™)[3] has been developed, the tenants of which are as follows:

- Generally target contaminants in decreasing order of concentration, as the parameter with the greatest loading often controls the treatment efficiency of lesser constituents

- Sequence treatment environments in order of increasing sensitivity to chemical or physical loading.

- Eliminate high-volume sludge formers as early as possible in the system and provide sufficient storage volume for the accumulated sludge.

- Use narrow, elongated treatment cells to increase the potential for separation of individual removal processes within multiple-parameter treatment environments.

- Identify limiting reagents and provide mechanisms for their introduction.

- Size components for flow capacity as well as chemical loading capacity to avoid hydraulic overloads and transport of incompatible contaminants to sensitive downstream components.

- Maximize influent contact with the effective treatment substrate through close hydraulic control to prevent flow path short-circuits.

- Allow for ready access to treatment components and for system maintenance, adjustment, and repair.

ECONOMIC ANALYSIS

An extensive cost analysis was performed for the Springdale passive treatment system[14], and the methodology later applied to the Albright system[6]. In these studies, comparisons were made to applicable chemical treatment alternatives based on capital construction costs and the present values of projected operation and maintenance (O&M) costs.

The largest capital cost factor for either passive or chemical treatment is basin construction. The relative requirements for basin construction between passive and chemical alternatives are approximately equal. Passive systems most often require a larger land surface area to construct than chemical alternatives, and for this reason may not be suited to applications where construction space is severely limited. The opposite, however, can also be true, as the Albright system achieved compliance on a site where a chemical alternative would be extremely difficult to construct. Construction space evaluations and cost estimates should be prepared from conceptual design layouts prior to committing to a given treatment alternative.

Passive wetland treatment systems derive their greatest economic advantage from their inherently low O&M requirements. No water management facility is totally maintenance free; however, passive systems have only minor operator involvement, usually weekly inspections, no mechanical maintenance except for pumping stations, if required, and no consumption of chemicals. Additional savings are realized by eliminating the costs of chemical storage, reporting, and safety training. Accumuated sludge removal is the primary maintenance cost associated with passive systems, as it is with chemical systems. Operational experience at the Allegheny Energy systems and others show that the frequency of sludge removal in the absence of chemical addition is infrequent and in the order of 10 to 15 years for a properly designed system without affecting performance. Longer term projections of O&M costs indicate that passive systems represent the least expensive alternative as the costs for capital replacement of mechanical chemical system components become a consideration.

CONCLUSIONS

Passive treatment has proven to be a reliable and cost-effective alternative to chemical treatment for the Albright and Springdale CCB sites and is planned for use on additional CCB facilities. Results from completed projects have led to significant advances in the understanding of passive removal processes and the development of improved design standards. The technologies employed are readily adaptable to other metals-bearing wastewaters found within the utility industry, provided attention is given to the individual limitations of each treatment method. The cost savings observed for the AE projects are inherent in the nature of passive treatment, and similar savings can be expected with its appropriate use.

As a result of these experiences, passive wetland treatment is now a major component of Allegheny Energy’s Environmental Management System for CCB facilities.

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