CONSTRUCTED WETLANDS FOR ACID DRAINAGE CONTROL IN THE TENNESSEE VALLEY

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Abstract--Constructed wetlands are often a preferred alternative to conventional methods of treating acid drainage at mine sites, coal preparation facilities, and coal-fired power plants. The Tennessee Valley Authority (TVA) has designed and constructed wetlands in Alabama and Tennessee to treat acid discharges from these sources. Between June 1985 and August 1987, seven wetlands were constructed to treat acid drainage at an inactive coal preparation plant and adjacent mined area and four wetlands were constructed at TVA coal-fired power plants. Although site-specific characteristics often restricted use of standardized methods, generic design, construction, and operation guidelines have been developed. Treatment efficiencies have ranged from 82% - 99% removal for total iron and 9%- 98% removal for total manganese. Preliminary design guidelines for required treatment area were: ph < 5.5 s.u., 2.0 m^2/mg Fe, 7.0 m^2/mg Mn; pH > 5.5 s.u., 0.75 m^2/mg Fe, 2.0 m^2/mg Mn. Wetlands systems costs from design to operation averaged $12.18/$m^2$ of treatment area.

INTRODUCTION

Acid mine drainage is generated by the oxidation of iron sulfides in mine spoil, producing water that is acidic, with high concentrations of iron (Fe), sulfate, and other objectionable constituents, including manganese (Mn), aluminum, suspended and dissolved solids, color, and hardness (EPA 1971; Caruccio and Giedel 1985). Although stoichiometry may be somewhat different, acid drainage from ash ponds at coal-fired power plants is similar to acid mine drainage.

Though effective, conventional acid drainage control techniques, such as chemical treatment or land reforming, are costly and generally require long-term maintenance. Constructed wetlands appear to offer an inexpensive, self-maintaining, long-term solution to treating acid drainage of moderate flows and chemical concentrations. The ability of wetlands to remove pollutants from acid drainage has been demonstrated by several investigators (Wieder et al. 1984; Guertin et al. 1985; Brodie et al. 1987). Various researchers have explored design and operational

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parameters of constructed wetlands for treating acid drainage (Hammer and Kadlec 1983; Pesavento 1984; Huntsman et al. 1985; Girts and Kleinman 1986; Wieder and Lang 1986).

The Tennessee Valley Authority's (TVA) first constructed wetland for acid drainage treatment, known as Impoundment 1, was located at a reclaimed coal preparation plant site in northeast Alabama (Brodie et al. 1987). Success of this wetland at meeting permit effluent limitations has led to the construction of 11 wetland treatment systems at TVA coal facilities and coal-fired power plants, and to an extensive research program on constructed wetlands. This paper summarizes TVA's constructed wetlands treatment systems and offers preliminary design guidelines based on results to date.

TECHNIQUES

Site characteristics often restricted use of standardized methods; therefore, wetlands were designed for specific conditions. A generic description of pre-design investigations through wetlands operation follows.

Pre-design

State regulators generally met onsite with TVA officials to review alternative sites and treatment options. Wetlands systems were approved as long as all effluent discharge limitations were to be met (i.e., total Fe < 3.0 mg/L, total Mn < 2.0 mg/L, pH = 6.0 - 9.0 s.u., and nonfilterable residue < 35.0 mg/L). Therefore system designs ocassionally included a final cell to provide for chemical treatment if necessary.

Wastewater characterization and site hydrology were the two most important pre-design data needs. Pre-construction water quality sampling was conducted for all flows to be treated and any streams that would be affected by the wetlands. Analyses included pH, Eh, total and dissolved Fe and Mn, nonfilterable residues (NFR) and total dissolved solids, sulfate, aluminum, dissolved oxygen, manganese, zinc, selenium, mercury, and cadmium. Flow monitoring was incorporated into baseline site monitoring and compared to existing flow data and hydrologic modeling. Baseline population estimates of aquatic biota in receiving streams were estimated to provide a means of documenting stream recovery.

Often it was necessary to locate the wetland off the immediate area or leased/owned surface, thus negotiations with landowners for initial access and long-term future control were conducted. TVA owned or purchased many of the wetland sites but also pursued other surface control arrangements including long-term leases and permanent easements.

Regulations neither specifically addressed nor gave guidance on constructing treatment wetlands. Permits and approvals for wetlands construction required from State and Federal regulators included a National Environmental Policy Act review, floodplains (Executive Order No. 11988) review, National Pollutant Discharge Elimination System permit, surface mining permit, and a water engineering report.

Topography was determined in sufficient detail to plan the number and location of cells to minimize cut and fill requirements dictated by a particular gradient. Because site regrading was usually an early step in wetlands construction, topography was completely altered, and detailed (e.g., 2-foot contour interval) topographic surveys were not warranted.

Geology was evaluated to determine if the site overlay shallow bedrock or lacked suitable growth media. If necessary, sources of borrow and adequate growth media were identified. Flow patterns and depth of groundwater were determined to identify inflows or outflows that could affect water quality or hydrologic balance.

Preferred sources of emergent vegetation for transplantation were nearby natural wetlands developed in similar quality water to avoid stress from abrupt changes in edaphic conditions. Cattail (Typha), followed by Scirpus, Eleocharis, and Carex were the most tolerant, readily available species for transplantation. A rush Juncus was used with less success. Preliminary research results (S. R. Copeland, unpubl. data) suggested that Typha latifolia and Eleocharis quadrangulata provided higher radial oxygen loss than other common species, thereby enhancing substrate redox conditions to bind insoluble forms of metal precipitates in the substrate.

Design and Construction

Size of wetlands, number of cells, spillways, and dike specifications were designed for 10-year, 24-hour storm event estimated from site flow monitoring or various methodologies (Lyle 1987). Erosion and sedimentation control structure design and construction (EPA, 1976; USDA, 1982), along with best engineering estimates and practices were used for those components having no design guidelines.

TVA's constructed wetlands ranged in size from 3.5 m^2 (38 ft^2) to 113.0 m^2 (1216 ft^2) per average flowing liter per minute, and 2.0 m^2 (22 ft^2) to 41.0 m^2 (441 ft^2) per maximum flowing liter per minute. Design sizes were dependent on water quality characteristics, storm flow hydrology, and land availability. Wetlands were designed to accommodate stormflow, then increased in size if very poor quality water was to be treated. Increasing the size of a wetland up to twice the stormflow design area only modestly increased costs and provided adequate treatment area.

Wetlands shapes varied because of existing topography, geology, or land availability. Irregular shapes for wetlands cells enhanced natural appearance and provided hydraulic discontinuity. Configurations that increased velocities causing channelization, scouring, bank erosion, etc. were avoided.

Number of cells for constructed wetlands was determined by site topography and hydrology. Level sites were amenable to large cells hydraulically chambered with rock or earthen finger dikes, large logs, vegetated hummocks, or other baffles. Steeper gradients required more grading or a system of several cells terraced down slope.

Water depth and bottom slope were dependent on plant species, pollutant concentrations, freeze potential, and desired longevity of the system. Typha latifolia has been the preferred species in TVA constructed wetlands. Other plants used in shallow water include Scirpus, Juncus, Carex, Eleocharis, and Equisetum. Excessive water depths not only inhibited desirable species development, but promoted anoxic, reducing conditions in the water column seriously affecting the oxidation of iron and manganese. Shallow water depths which are subject to freezing in more northern climates are suitable in the Tennessee Valley. The primary advantages of shallow water is to enhance oxygenation and increase plant production. Potential disadvantages are reduced storage capacity and retention time. Average water depth in TVA's wetlands ranged from 15-30 cm (6-12 in) with some shallower and some deeper areas to provide for species diversification. A few deep pockets of one meter or greater were included in many cells to provide recharge zones and aquatic fauna refuge in drought events.

Most wetlands were completed in early summer, although successful installations were completed as late as October. Wetlands construction began with clearing the site, followed by grading and dike construction, and importing suitable materials as necessary to meet design specifications. Brush was burned or pushed along the site perimeter to provide wildlife habitat. Spillways were either rock-lined or covered with non-biodegradable erosion control matting and planted with Scirpus, Carex, or grasses. Water level control or flow monitoring devices were incorporated into the spillway design and construction.

Vegetation was hand-dug to obtain complete root balls/rhizomes. Transplantation was completed on the same day as digging, and plants were not subjected to extreme temperatures, drying, or wind during transport. Typha was set into the substrate at about nine plants /m^2 and stems broken over above the water level to prevent windfall and to stimulate new growth from the rhizomes. Bulrush clumps were simply placed in the desired location.

Wetlands were fertilized with a phosphorous-potassium fertilizer such as 0-12-12 at 400 kg/ha (353 lb/ac). Mosquito fish (Gambusia affinis) were stocked for insect pest control.

Operation and Maintenance

Post-construction activities included effluent monitoring, fertilization, and maintenance of dikes, spillways or other control structures and pest control. Effluent monitoring was performed several meters downstream of the final spillway so that any leakage was included in the sample. Monitoring requirements included pH, total Fe and Mn, and NFR. Additional water chemistry and biological monitoring were used to quantify wetlands treatment efficiencies and wetlands habitat benefits. After the first year, fertilization was done only if vegetation showed signs of nutrient depletion. Dike repair due to muskrate burrowing was required at one wetland. Army worm (Simyra henrici) infestations at another required control measures to prevent eradication of cattail.

RESULTS

A summary of characteristics and water quality parameters for TVA's 11 constructed wetlands is presented in Table 1. Dates of initiated operation are based on the first time effluent monitoring began (i.e., usually within one week of initial dischange). Areas are given as surveyed inundated area. Influent water chemistry, in most cases, is based on at least one year of seasonal sampling of contributing seeps. Effluent monitoring, including flow, is generally based on twice monthly discharge permit sampling results from the date on which the wetland system began operating.

TABLE I

TVA ACID DRAINAGE WETLANDS TREATMENT SUMMARY

Wetlands System	Date Initiated Operation	Area m^2	Number Cells	Influent Water Parameters (mg/L) pH	Fe	Mn	NFR	Effluent Water Parameters (mg/L or L/min) pH	Fe	Mn	NFR	Flow Ave	Flow Max	Treatment area m^2/mg/min Fe	Mn
W C 018	6-86	4800	3	5.6	150.0	6.8		3.9	6.4	6.2		70	1495	0.2	4.2
King 006	10-87	9300	3	4.2	153.0	4.9	40.0					379	2271	0.2	5.0
Imp 4	11-85	2000	3	4.9	135.0	24.0	42.0	4.6	3.0	4.0	6.0	42	49	0.4	2.0
950 NE	9-87	2500	2	6.0	11.0	9.0	19.0	6.6	0.5	0.2	49.0[1]	348	1673	0.7	0.8
R T - 2	9-87	7300	3	5.7	45.2	13.4		6.7	0.8	0.2	2.0	238	681	0.7	2.3
Imp 2	6-86	11000	5	3.1	40.0	13.0	9.0[2]	3.1	3.4	14.0	0.8[2]	400	2200	0.7	2.1
Imp 3	10-86	1200	3	6.3	13.0	5.0	28.0	6.8	0.8	1.9	4.7	87	379	1.1	2.8
W C 019	6-86	25000	3	5.6	17.9	6.9		4.3	3.3	5.9		492	6360	2.8	7.4
950-1 & 2	1976	3400	3	5.7	12.0	8.0	20.0	6.5	1.1	1.6	5.4	83	341	3.4	5.1
Imp 1	5-85	5700	4	6.3	30.0	9.1	57.0[3]	6.5	0.9	2.1	2.8	53	227	3.6	11.8
Col 013	10-87	9200	5	5.7	0.7	5.3		6.7	0.7	13.5		288	408	45.6	6.0

1 - one effluent sample to date
2 - one sample, July 1987
3 - from preconstruction instream sample

Impoundment 1 was TVA's first constructed wetland, treating acid seepage from a coal slurry pond dike at the reclaimed Fabius Coal Preparation Plant in Jackson County, Alabama. Dominant vegetation is *Typha*, with *Scirpus*, *Leersia*, *Juncus*, *Eleocharis*, *Utricularia*, and *Sparganium* among a total of 41 species present two years after construction. Since construction, Impoundment 1 has produced compliance quality effluent.

Impoundment 4, also at the Fabius plant site, was built to treat acid seepage emanating from process water recirculation ponds. These ponds (pH = 3.5 s.u.) were reclaimed in 1986 and the inflow to Impoundment 4 has been limited. Dominant plants are *Typha* and *Scirpus*. The original planting of Impoundment 4 took place in November 1986. Few plants survived in spring and the wetland was replanted the following July. A sodium hydroxide (NaOH) treatment system was installed to augment the wetland treatment because of the extremely low pH of the seepage.

950-1 and 2 was a two-cell sedimentation basin receiving mine acid drainage from the reclaimed TVA Fabius 950 coal mine in Jackson County. A *Typha* marsh has naturally developed in the upstream cell with expansion into the lower cell. Treatment with NaOH, required from 1976 to 1984, has been discontinued. The discharge was released from NPDES permit monitoring requirements in 1987.

Impoundment 2 is a series of constructed wetlands intermediate in a 138 ha (341 ac) drainage basin receiving acid drainage from non-TVA abandoned mine land and the coarse refuse disposal area at the Fabius plant site. Effluent from the wetlands is treated with sodium hydroxide and discharged. Vegetation in the wetlands is predominantly *Typha*.

Widows Creek 018, located at TVA's Widows Creek Fossil Plant in Jackson County, receives seepage from an abandoned ash disposal area. The wetland was adjacent to a leaking coal pile runoff pond (pH = 2.8 s.u.) that has caused adverse effects on water quality and vegetative development. Dominant vegetation is *Typha*. An NaOH treatment system was installed at this wetland for pH increase.

Widows Creek 019 also receives acid seepage from abandoned ash disposal areas. Widows Creek Fossil Plant's operational needs at this site have resulted in plans to flood the wetland

and install a facility to pump water to an existing treatment system. Effluent data may reflect additional seepage within the wetlands system and should be viewed with caution.

Impoundment 3 is located at the TVA 950 coal mine and receives acid mine drainage. It was constructed to replace a chemical treatment system which operated from 1976 to 1986 and has produced compliance quality effluents since construction. Dominant vegetation is Typha.

Rocky Top 2 is located at TVA's reclaimed Fabius Rocky Top coal mine in Jackson County. Inflow is acid mine drainage and dominant vegetation is Typha.

950 NE is located adjacent to the TVA 950 coal mine and receives acid mine drainage from about 32 ha (79 ac) of reclaimed area. Dominant vegetation is Typha; only minor discharge has occurred since construction.

Kingston 006 is located at TVA's Kingston Fossil Plant in Roane County, Tennessee. It was constructed to treat acid seepage and runoff from active ash disposal areas. Dominant vegetation is Typha. About 20 cm (8 in) of high-calcium, minus 16 mesh limestone covered with about 30 cm (12 in) of spent mushroom compost for vegetative substrate was included in the final cell of the wetland system (B. G. Pesavento, pers. comm.).

Colbert 013 is located at TVA's Colbert Fossil Plant in Colbert County, Alabama. It receives acid drainage from an indefinite source near an active ash disposal area. This wetland is still under development and is dominated by Typha and Scirpus.

Water quality improvement has occurred at all of the operating constructed wetlands. Five systems have produced dramatic results and have apparently mitigated some of TVA's most stubborn pollution problems. Where regulatory limits were not entirely achieved, cost savings were realized in a reduction in chemicals needed for further metals precipitation or pH adjustment.

Total costs for construction of nine wetlands treatment systems are shown in Table 2. Overall average cost was $\$12.18/m^2$ ($\$1.13/ft^2$) of treatment area. Costs for 9 wetlands are best exemplified by the Impoundment 3 project, which cost $40,000. Total cost consisted of about 20 percent for design and project management, 35 percent for equipment and supplies, and 45 percent for labor. Because TVA was annually spending $12,000 to $15,000 for chemicals and $10,000 for pond maintenance that failed to maintain complying discharges, the wetland system, with an annual operation and maintenance cost of $1,000, has proven cost-beneficial within one year.

CONCLUSIONS

Constructed wetlands offer a preferred alternative to conventional methods of treating acid drainage from certain coal-related sources. TVA has constructed 11 wetlands for treating acid drainage and has developed guidelines for design, construction, and operation of the systems. Six of these constructed wetlands allowed TVA to discontinue chemical treatment for Mn and Fe removal and pH adjustment. Two systems were under development but were expected to produce compliance quality effluents by mid 1988. The remaining wetland systems, although not treating water to compliance levels, removed significant amounts of metals from the influent, reducing chemical treatment costs. As more wetlands are constructed for acid drainage treatment, and as research results become available, design criteria will no doubt be improved.

However, numerous wetlands treatment systems are planned or under construction in the coal and utility industries. Our experience suggests the following preliminary general guidelines for Fe and Mn treatment area requirements for desired discharge levels of Fe = 3 mg/L or less and Mn = 2 mg/L or less

Fe: $2\ m^2/mg < pH\ 5.5 > 0.75\ m^2/mg$
$(21\ ft^2/ppm < ph\ 5.5 > 8\ ft^2/mg)$

Mn: $7\ m^2/mg < pH\ 5.5 > 2\ m^2/mg$
$(75\ ft^2/ppm < pH\ 5.5 > 21\ ft^2/ppm)$

For pH levels of less than 5.5 s.u., suggested treatment area for Fe would be $2\ m^2/mg/min$ ($21\ ft^2/ppm$) and for Mn $7\ m^2/mg/min$ ($75\ ft^2/ppm$). For pH levels above 5.5 s.u., suggested treatment area for Fe would be $0.75\ m^2/mg/min$ ($8\ ft^2/ppm$) and Mn $2\ m^2/mg/min$ ($21\ ft^2/ppm$). For example, a seep with 50 mg/L Fe, 15 mg/L Mn, pH 5.6 s.u., and an average flow of 113 L/min (30 gal/min) would require:

For Fe, the rate factor is $.75\ m^2/mg/min$.

Area of treatment =
$0.75\ m^2/mg/min)(113\ L/min)(50\ mg/L) = 4237.5\ m^2$

For Mn, area =
$2\ m^2/mg/min)(113\ L/min)(15\ mg/L) = 3390\ m^2$

and the wetlands treatment system area should approximate $4200\ m^2$ ($45,200\ ft^2$ i.e., about 1 acre).

TABLE 2

WETLANDS SYSTEM CONSTRUCTION COSTS

Wetlands System	Area ha	% Equip	% Labor	% Overh	Total ($000's)	$/m^2	$/ft^2
R T - 2	0.7	32.6	53.4	14.0	26.4	3.58	0.33
Imp 2	1.1	70.2	12.3	17.5	57.0	5.25	0.49
W C 018 & 019	2.9	-	-	-	209.0	6.98	0.65
Imp 1	0.5	19.0	49.6	31.4	42.9	7.46	0.69
950 NE	0.3	38.1	46.0	15.9	35.2	13.80	1.28
Imp 4	0.2	28.2	26.8	45.0	28.0	14.12	1.32
King 006	0.9	28.6	43.3	28.1	131.7	14.21	1.32
Imp 3	0.1	34.8	43.5	21.7	40.2	32.03	2.98

average cost = $12.18/m^2 = $1.13/ft^2

These treatment area estimations do not include storm flow hydrology and size of constructed wetlands must be increased, if necessary, to accommodate storm events and prevent dike or spillway damage.

Obviously all of the above generalize numerous factors, i.e., temperature dependent rate constants, hydraulic loading, retention time, surface area for microbial growth, length, width, depth and slope of system, etc., for which we have limited information. Incorporation of these factors and development of an expression relating influent values for Fe, Mn, pH, and flow to desired effluent values and recommended treatment area, hydraulic loading, and retention time is underway and will be reported later.

Although our results are encouraging and we suspect that properly designed and constructed wetlands treatment systems will function for long time periods, better documentation is obviously needed. TVA has initiated research addressing basic design questions, including optimum substrates and vegetation, hydraulic and contaminant loading rates, treatment system capacity and longevity, storm event and ground water monitoring, and limestone bed design (Brodie et al. 1988).

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