IMPROVEMENT OF WATER QUALITY BY LAND RECLAMATION AND PASSIVE SYSTEMS AT AN EASTERN U.S. COPPER MINE[1]

Ben B. Faulkner[2] and Franklin K. Miller

Abstract. The Copper Basin in southeast Tennessee was the site of extensive copper and sulfur mining activities. For more than 150 years, numerous companies and individuals were involved in mining, refining and manufacturing operations in the area. It is one of the most dramatically impacted mining areas in the eastern United States. As part of voluntary remediation efforts at the site, Glenn Springs Holdings performed a demonstration project that included land reclamation and installation of a 1 hectare (2 acre) anaerobic wetland in October, 1998. Those efforts have been used to test and evaluate the effectiveness of reclamation and passive systems to treat acidic surface waters and acid mine drainage. These activities have successfully reduced the concentrations of key metals, including iron, copper, zinc and aluminum from typical mg/l concentrations by one or more orders of magnitude. The demonstration passive system has also consistently neutralized the acidity of the entire targeted watershed with average influent flows of 1100 Liters per minute (300 gallons per minute) through sulfate reduction and limestone dissolution. It is anticipated that in the future, effective land reclamation and installation of innovative passive systems will be the key methods whereby this massive remediation project will continue to improve water quality to the Ocoee River.

Additional Key Words: Ducktown, acid mine drainage, Ocoee River, anaerobic wetland

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Introduction

The Tennessee Copper Basin is located where Tennessee, North Carolina, and Georgia meet and where the Ocoee River is formed (Figure 1). It is an area with a rich history rooted in copper mining (Daniels, undated). Copper was shipped out of the basin as early as 1847 and underground mining continued until 1987. The Basin's mines are the only deep shaft copper mines east of the Mississippi River. Limited surface mining was conducted within the Basin in the 1970's. Open roasting of the copper ore to remove impurities began prior to the Civil War, resulting in a denuded landscape as timber was cut for fuel for the roasting process and sulfuric acid rained down within a 9,000 hectare (35 square mile) area containing the fumes from the process. Severe erosion of the native soils gave the appearance of un-reclaimed surface mines, and the unique area is discernable from outer space. Reforestation efforts began in the1920s and concentrated efforts began in the 1940's which were carried out by the mining companies, academic institutions, and government agencies, particularly TVA. Others have documented both revegetation (Cook et al., 2000) and reforestation (Muncy, 1986) research on tailings and eroded soils. Sulfuric acid production replaced copper, zinc and iron mining as the primary industry in the 1980's, and the abandoned underground mines were inundated with acid water. Portions of the mines have collapsed to the surface or are in danger of collapse, further challenging successful land reclamation (Figure 2).

Figure 1. Location of CopperBasin

Figure 2. Collapsed underground mine

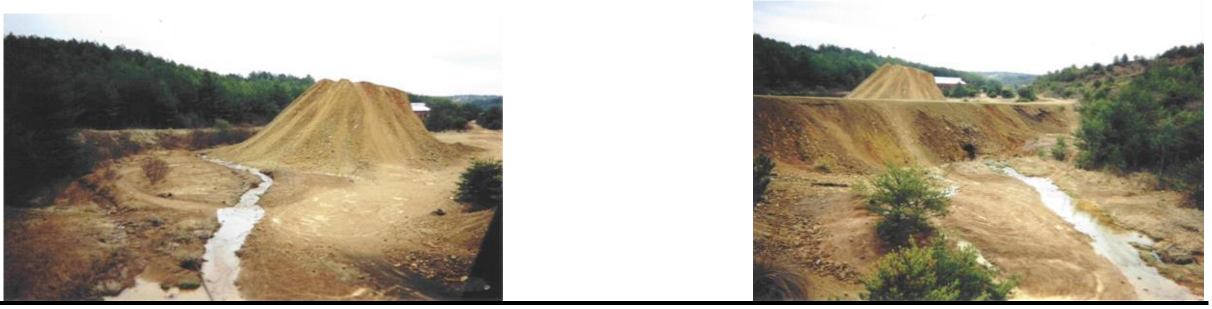
Acid drainage emanates from the ore wastes scattered within the two affected tributaries of the Ocoee River, North Potato Creek and Davis Mill Creek. Even the areas not directly affected by mining or waste disposal exhibit soil erosion and lightly buffered runoff from the forested, but acidic soils (BWSC Inc., 2000).

The McPherson Branch Demonstration Site

Glenn Springs Holdings, Inc. (a subsidiary of Occidental Petroleum) entered into a Voluntary Cleanup Oversight and Assistance Program (VOAP) in January, 2001 with Tennessee Division of Environment and Commerce Superfund's office with the consent of the Region 4 office of the US Environmental Protection Agency. The stated objective of that agreement is the restoration of biologic integrity in the severely impacted watersheds. One such watershed was chosen as a demonstration site to explore the potential for reclamation technologies to improve water quality. McPherson Branch is a small (165 hectare / 410 acre) first-order watershed with a monoculture of pine growing on the eroded soils. Near its confluence with North Potato Creek, this stream exhibited low pH, moderate acidity, and elevated metals concentrations in a study period from 1996 to 1998. Additionally, stream remediation was challenged by the high sediment load from the eroded areas upstream. Even paved roadways located well above the creek channel were subject to regular inundation with sandy silt from the barren areas (Figure 3).

Figure 3. Silt from eroded areas at wetland construction site (well above flood plain).

A small refuse pile (7600 cubic meter /10,000 cubic yard), typical of that randomly scattered in the basin was located near McPherson Branch and caused an increase in the metals concentrations of the stream as it flowed through the disposal area (Figures 4 and 5).



Figures 4. and 5. Refuse Pile near McPherson Branch caused water quality impact (see Table 1).

The relatively low concentrations of metals and acidity indicated the drainage was a good candidate for passive treatment. Anecdotal evidence of very high flows and obvious high sediment loads required an innovative approach to implementing passive treatment.

A concrete diversion dam was constructed in 1998 in McPherson Branch, creating a stilling basin for separation of settleable solids (Marshall Miller, 1998). A sluice gate for flushing silt and a sediment trap for the inlet to the passive system were incorporated into the design. In this way, baseline and limited storm water with low TSS could be introduced into the passive system, constructed outside the flood plain. McPherson Branch had been channelized many years prior, and acidic native rock had been used for the stream bank and parallel roadway. To prevent seepage through the roadway, a Fabriform® blanket was installed on the west bank of the creek for approximately 70 meters (200 feet) upstream of the dam.

Figure 6. Concrete Diversion Dam.

The design of the system is a variation on the hundreds of anaerobic wetland systems implemented to ameliorate problematic coal and hard rock drainages (Skousen et al., 1996, 1998). The system was installed in late 1998 and covers 0.8 hectares (2 acres) using a GCL liner overlain with 0.7 meter (2 feet) agricultural lime enriched soil, 0.7 meter (2 feet) of crushed 2.5 cm (1 inch) limestone of minimum 75% $CaCO_3$ content, hay bales, and 0.15 meter (6 inches) spent mushroom compost (Figure 7). Cattails (*Typha latifola and augustifola sp*.) with at least 0.02 cubic meter (one cubic foot) of root mass and soil were transplanted from a nearby borrow area with similar quality acidic drainage. Bare rootstock from an Atlanta nursery was also planted in a pattern so the performance of each could be evaluated.

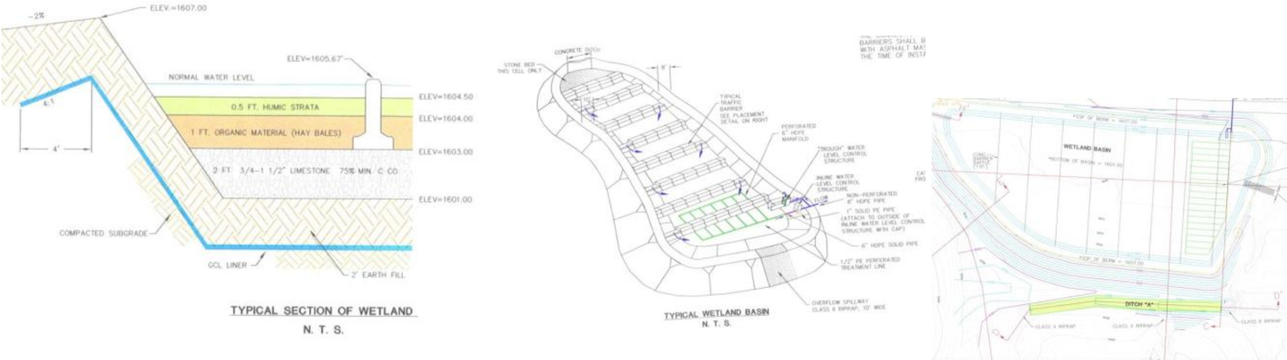


Figure 7. Cross-section, skew, and plan views of McPherson Br. Demonstration Anaerobic Wetland.

Another challenge to the design was the need to protect against vandalism. At the time of design, the area was not secure, and it has been the scene of substantial destruction. Rather than earthen or wooden barriers between cells, concrete traffic barriers were chosen.

It has been proven by laboratory and field scale research that maintaining a sub-surface flow through a limestone bed under an organic rich substrate will effectively introduce alkalinity through both limestone dissolution and sulfate reduction (Skousen and Ziemkiewicz, 1996). Rather than encouraging aerobic processes (producing voluminous metal oxyhydroxides), designers seek to encourage subsurface flow and anaerobic processes which produce much more dense metal sulfides (Hedin et al., 1994). Hydraulic appurtenances to ensure this deep subsurface flow pattern, rather than across the surface of the system are challenging. Much attention has been focused on the subsurface flow patterns of anaerobic passive treatment systems (Peart and Cooper, 2000) with and without pipe manifold systems. Many systems rely on valves with constant monitoring and adjustment to maintain desired water levels, and periodic flushing to keep the limestone bed free of precipitates and flocculates (Kepler and McCleary, 1997). An innovative pre-fabricated structure was employed as a water level regulator at the effluent of our system. An Agridrain® flow control unit was fitted to the 15 cm (6 inch) HDPE perforated pipe manifold system in the last two cells of the anaerobic system (Figure 8). The pre-fabricated plastic unit allows for a deliverable surface water level by drawing variable flow from the bottom of the system, forcing subsurface (anaerobic) flow. Levels are determined by removable gates in a track. The only modification to the manufactured product was the replacement of the steel access door with a corrosion proof polymer or stainless steel, providing durable, secure access. A 2.5 cm (1 inch) perforated polyethylene pipe network was laid beside the effluent manifold network for sampling, inoculation, or backwash potential.

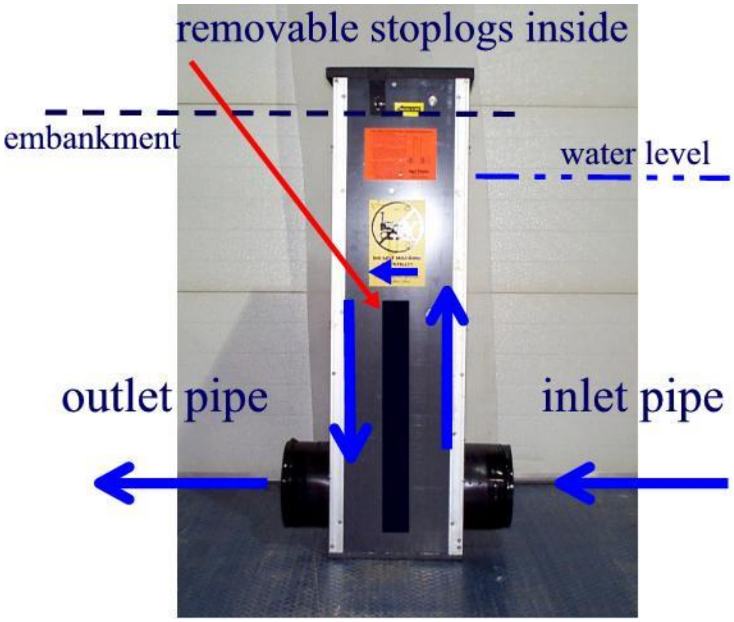


Figure 8. Agridrain flow control unit http://agridrain.com

The overflow outlet was provided by a contemporary weir located within a stainless steel box to discourage vandalism.

Effects of Land Reclamation

McPherson Branch was sampled upstream (#400) and downstream (#401) of the refuse pile, and again at the concrete diversion dam (#402 - where the flow was diverted to the passive system) 8 times during the period 10/1997 to 05/1998 (Figure 9 and Table 1).

Table 1. Mean pH and total metals concentrations for McPherson Branch sample sites.

Sample Location	Avg. pH	Acidity	Alk.	Total Fe	Total Mn	Total Cu	Total Zn	Total Al
Site 400 Upstream of refuse pile	4.6	18	<1	2.85	1.12	0.07	0.50	1.42
Site 401 Downstream of refuse pile	4.0	44	<1	6.83	1.22	0.32	1.33	4.29
Site 402 Dam site before removal of refuse	4.2	51	<1	5.13	1.50	0.57	1.68	4.16
Site 402 Dam site after removal of refuse	4.1	33	1	1.14	1.50	0.35	1.13	2.54

All units except pH (standard units) unless otherwise noted are in mg/L (ppm).

This simple sampling program indicated that reclaiming this single half hectare (one acre) pile of refuse material (less than 1% of the drainage area) reduced acidity, aluminum, copper, iron and zinc, but did not appear to decrease manganese concentrations. No measure of settleable solids was conducted, but the wetland inlet has appeared clear and relatively sediment free during daily observations in the three years since construction. No cleaning of the impoundment behind the diversion dam or the sediment trap within the dam has been necessary.

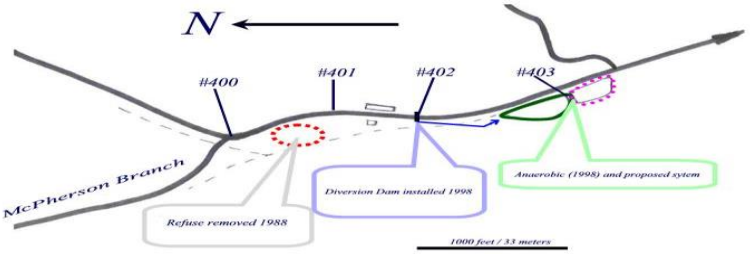


Figure 9. sketch of McPherson Branch Demonstration Project sampling sites

Passive System Performance

The passive system was sized as a demonstration with a variable inlet (valved at the dam) to introduce all or a portion of McPherson Branch. The inlet is limited by pipe size (20 cm. / 8 inch i.d.) to approximately 1500 lpm (400 gpm) as measured by graduated vessel and stopwatch at the pipe outlet.

Sampling of the influent and effluent of the demonstration anaerobic wetland system began in late October 1998 following start-up of the system and has continued on a weekly basis. The current weekly monitoring program includes analysis of influent and effluent samples to evaluate flow, field pH, and concentrations of alkalinity, acidity, iron, manganese, copper, zinc, aluminum, sulfate, hardness and COD. Initially, metals determinations were limited to total concentrations. The monitoring program was subsequently expanded to include dissolved metals concentrations as well. There were no remarkable differences in dissolved and total concentrations.

During the first six months of operation, the anaerobic wetland system received only the base flow from McPherson Branch (#402). During this period, the average influent copper concentration was reduced from 0.43 mg/L to less than 0.025 mg/L in the effluent. Other metals, including aluminum, zinc and dissolved iron, were reduced by 85% or more. The pH increased after flowing through the treatment system from an average of 4 to 6.8. Acidity was eliminated and the alkalinity greatly increased.

Beginning in late April of 1999, at the request of EPA Region IV, mine water from the McPherson Mine shaft was routed to the wetland to evaluate the ability of the anaerobic wetland system to accommodate higher acidity and dissolved metals loadings. During the initial three weeks of modified operation, the mine water comprised the only source of flow to the anaerobic wetland system. A brief upset of the anaerobic process occurred in May, apparently due to this shock loading. Large volumes of gas were produced in the wetland and hay bales began floating to the surface.

In late May of 1999 until early September of 1999, the base flow from McPherson Branch was redirected back to the anaerobic wetland system in conjunction with the mine water from McPherson shaft. The combined McPherson Branch base flow with the mine water from McPherson shaft (which ranged from 100 to 200 lpm or 20 gpm to 50 gpm) resulted in an influent that ranged from 850 to 1700 lpm (225 gpm to 448 gpm). The average combined influent concentrations directed to the anaerobic wetland system for this period are presented in Table 2.

Table 2. Influent Conditions into the McPherson Branch Demonstration Wetland 6/9/99 to 9/8/99.

Influent Stream	Avg. Flow (gpm)	Avg. pH	Acidity	Alk.	Total Fe	Total Mn	Total Cu	Total Zn	Total Al	Sulfate	Hard.	COD
McPherson Branch Base Flow	348	3.79	33	<1	1.75	1.63	0.36	1.17	2.79	115	102	0
McPherson Shaft Mine Water	42	4.08	869	<1	305	14.23	0.12	12.13	39.29	1265	660	58
Composite Flow (weighted)	390	3.82	123	<1	34	2.98	0.33	2.35	6.72	238	162	6

All units unless otherwise noted are in mg/L (ppm) rounded to significant digits.

Following a period of acclimation, the anaerobic wetland system operation stabilized and produced a consistent effluent quality treating the combined base flow and mine water. During this time period, the mine water component of the influent flow had been increased from the initial 100 to 200 lpm (25 gpm to 50 gpm). From June 6, 1999 to Sept. 8, 1999, the acidity was reduced 100% and the alkalinity was increased from 0 mg/L to an average of approximately 160 mg/L.

Table 3. Mean effluent from the McPherson Branch Demonstration Wetland 6/9/99 to 9/8/99.

	Avg. Flow (gpm)	Avg. pH	Acidity	Alk.	Total Fe	Total Mn	Total Cu	Total Zn	Total Al	Sulfate	Hard.	COD
Composite flow		6.5	<1	160	1.00	2.83	0.00	0.02	0.15	145	328	52

All units unless otherwise noted are in mg/L (ppm) rounded to significant digits.

Mine water flow from McPherson Shaft was terminated to the anaerobic wetland system in September of 1999 as a permanent solution for the watershed is being planned by the construction of a horizontal shaft to de-water the Burra-Burra Collapse to the demonstration wetland before it can recharge the McPherson Mine pool. Since that time, only the base flow from McPherson Branch has been routed into the anaerobic wetland for treatment. Data follows in Table 4.

Table 4. Influent/Effluent Characteristics for McPherson Branch Wetland from 9/8/99 to 1/1/2002.

Sample Location	**Avg. Flow (gpm)**	**Avg. pH**	**Acidity**	**Alk.**	**Total Fe**	**Total Mn**	**Total Cu**	**Total Zn**	**Total Al**	**Sulfate**	**Hard.**	**COD**
Inlet	262	4.2	31	<1	1.07	1.52	0.311	1.094	2.351	142	104	5
Outlet		7.1	<1	73	0.353	1.64	0.008	0.045	0.073	128	192	13

All units unless otherwise noted are in mg/L (ppm) rounded to significant digits.

Limestone dissolution in the anaerobic zone of a passive system increases hardness in the effluent primarily due to an increase in dissolved calcium. Sulfate reduction processes produce a decrease in sulfate concentrations in the effluent. Both processes consume acidity and increase alkalinity. Effluent alkalinity is plotted against the hardness increase and sulfate reduction for a select data period (when only creek water was entering the system) in Figure 10.

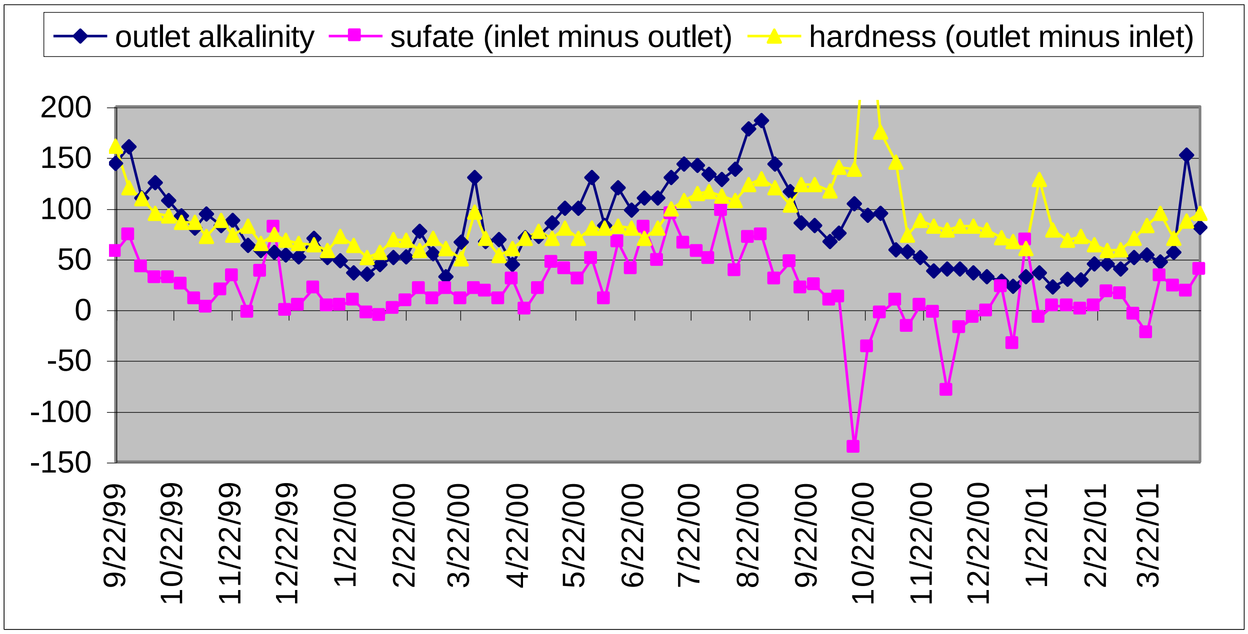


Figure 10. Graph of key parameters in McPherson Branch during creek water inlet conditions.

It is clear that alkalinity from the system is a function of both anaerobic biological sulfate reduction and limestone dissolution. The presence of copious quantities of malodorous black and white precipitates (Gusek, 1998), and no dissolved oxygen at the anaerobic system effluent confirms the flow path is subsurface and is undergoing sulfate reduction (Robbins et al., 1999). Planned additions to the existing anaerobic wetland demonstration system include construction and operation of an aerobic wetland unit (for increasing dissolved oxygen and reducing COD in the effluent), a rock filter bed for manganese removal (Sikora et al., 2000) and a restored stream segment. The stream segment will be inoculated with a benthic community to assess the performance of the system. Continued monitoring of these efforts will benefit the tailoring of future land reclamation and implementation of passive systems within the watershed in what is perhaps the largest current land reclamation project in the eastern United States.

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