# ADAPTIVE WATERSHED MANAGEMENT IN THE COPPER BASIN: EVALUATION OF EARLY SUCCESSES[1]

K.Y. Bell[2], C.L. Stokes, F. Miller, and K.L. Faulk

**Abstract:** The Copper Basin Mining District Site (Site) has been host to 150 years of copper mining, beneficiation and mineral processing, and sulfuric acid and other chemical production processes that have left a legacy of environmental degradation that has affected the Ocoee River. In order to improve the health of the Ocoee River, the US Environmental Protection Agency, Tennessee Department of Environment and Conservation, and Glenn Springs Holdings, Inc. a subsidiary of Occidental Petroleum Company, agreed to conduct a cooperative, voluntary environmental restoration and redevelopment of the Copper Basin. Part of this agreement was to develop and implement interim actions to alleviate contaminant loading to the Ocoee River so that short-term progress could be realized while long-term remedial actions were identified and implemented in upper parts of the watersheds.

Use of an adaptive management approach to watershed restoration has resulted in early identification of the most significant problems. The major benefit of this process has been early remediation of the worst problems in a complex set. This has allowed valuable resources traditionally utilized for full site characterizations to be applied toward remedial activities, which could potentially change the original character of the Site. Results of the early restoration successes in this hard-rock mining impacted watershed are presented along with long-term remedial actions being conducted in upper parts of the watersheds. Measurable success has been achieved in part because of the flexibility resulting from regulatory collaboration and stakeholder cooperation.

**Additional Key Words:** watershed restoration, in-pit water treatment, adaptive management, voluntary clean-up

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[2]Katherine Y. Bell (will present the paper, email: kybell@bwsc.net) and Carrie L. Stokes are Environmental Engineers and Kenneth L. Faulk is a Geologist with Barge, Waggoner, Sumner & Cannon, Inc. Nashville TN 37201; and Franklin Miller is a Vice President, Glenn Springs Holdings, 2480 Fortune Drive, Suite 300, Lexington, Kentucky 40509.

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## Introduction

The Copper Basin Mining District Site (Site) is located in southeastern Tennessee, near the North Carolina and Georgia borders and comprises an area of approximately 50 square miles adjacent to lands administered by the Cherokee National Forest. The Copper Basin, north of the Ocoee River, is drained by North Potato Creek and Davis Mill Creek, which empty into the Ocoee River. The Basin has been host to 150 years of copper mining, beneficiation and mineral processing, and sulfuric acid and other chemical production that have left a legacy of environmental degradation. In addition to mining and related operations, associated support infrastructure (railroads, equipment storage, salvage and disposal yards, and other waste processing facilities, and operations support offices) can be found throughout the Basin. Remnants of these mining practices remain scattered throughout portions of both North Potato Creek and Davis Mill Creek watersheds.

Recognizing the environmental impacts and having been identified as a potential responsible party, Occidental Petroleum Corporation through its wholly owned subsidiary Glenn Springs Holdings, Inc. (GSH), agreed to voluntarily remediate the Site. Through a Memorandum of Understanding, GSH, the Tennessee Department of Environment and Conservation (TDEC) and the US Environmental Protection Agency (USEPA) agreed to work together in a coordinated manner with the common goal of environmental remediation and redevelopment of the Site. The Site boundaries and major tributaries are shown in Fig. 1.

The objective of this paper is to provide a description of a unique adaptive management approach using regulatory collaboration that is succeeding in a timely fashion. This approach to remediation and redevelopment is a long-term, complicated undertaking and is demonstrating measurable success because of the flexibility in management resulting from stakeholder cooperation, resource sharing and interdisciplinary technical expertise. A summary of the administrative documents and the purpose of those documents are provided in Table 1.

## Immediate Interim Actions to Alleviate Contaminant Discharges to the Ocoee River

In the Memorandum of Understanding, GSH agreed to implement several specific interim actions in order to immediately alleviate contaminant discharge to the Ocoee River while studies proceed in upper parts of the affected watersheds. These activities, outlined in Administrative Orders on Consent (AOC) as described in Table 1, focused on treatment of the entire flow from streams draining the two watersheds that comprise the Site. In addition to treatment, the AOCs provided guidance for diverting water from un-impacted areas of the Site around waste materials and contaminated water to prevent mixing of clean water with contaminated water.

### Davis Mill Creek

An AOC for Removal Action at Davis Mill Creek required the refurbishment, operation and maintenance of the Cantrell Flats Wastewater Treatment Plant up to the original 1970s design capacity and diversion of Belltown Creek and the effluent from the Gypsum Pond to the Ocoee River so as to accommodate a 10-year/24 hour storm event. These removal actions were implemented to support the objective of alleviating contaminant discharge from Davis Mill Creek into the Ocoee River. These interim removal actions will remain in effect until the USEPA determines that the final remedy selected by USEPA in a Record of Decision and has been implemented and is operating effectively. The locations of the immediate interim Davis Mill Creek activities are shown in Fig. 2.

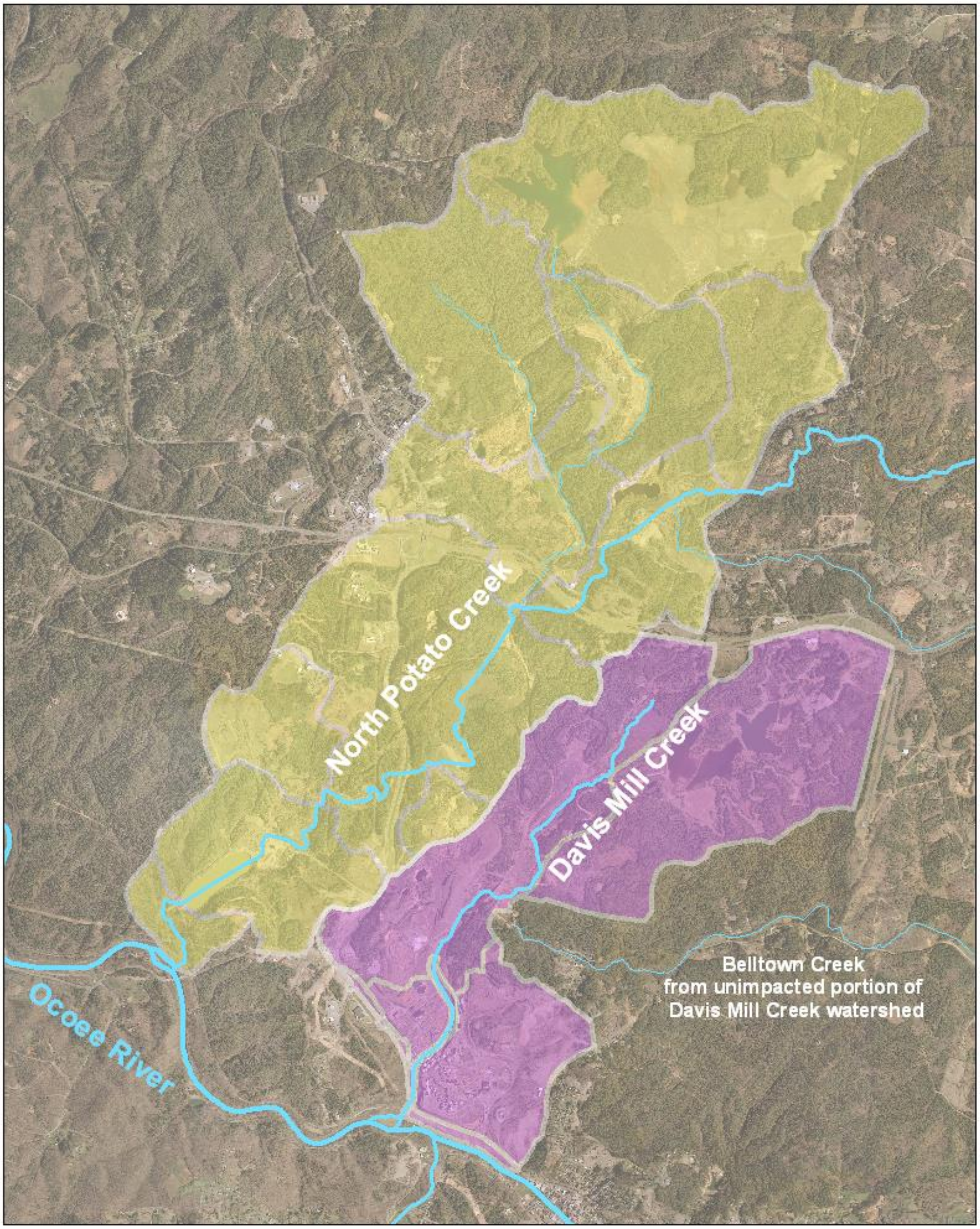


Figure 1. Site Boundaries and Major Tributaries in the Copper Basin

Table 1. Summary of Administrative Documents for Restoration of the Copper Basin

| Document | Agency | Date | Purpose | Term | Actions | Status |
|---|---|---|---|---|---|---|
| Memorandum of Understanding (MOU) | USEPA | January 2001 | The MOU provides an overall framework and establishes roles and responsibilities among USEPA, TDEC and OXY USA | Long-Term | The MOU outlines three AOCs and the TDEC Order, and provides assurance on the part of the federal government not to list or propose to list the site on the NPL as long as terms of the MOU are met. | Ongoing |
| North Potato Creek Administrative Order on Consent (AOC) | USEPA | January 2001 | The North Potato Creek AOC provides for temporary alleviation of contaminant discharge to the Ocoee River from North Potato Creek while long-term actions under the state Voluntary Cleanup Oversight and Assistance Program proceed | Interim | Conduct Engineering Evaluation/Cost Analysis to address contaminant discharge to the Ocoee River | Complete |
| | | | | Interim | Construction of in-pit water treatment plant near the mouth of creek at the South Mine Pit | Complete |
| Davis Mill Creek Administrative Order on Consent (AOC) | USEPA | January 2001 | The Davis Mill Creek AOC provides for temporary alleviation of contaminant discharge to the Ocoee River from Davis Mill Creek while long-term actions proceed | Interim | Refurbish the existing Cantrell Flats Water Treatment plant and divert Belltown Creek and Gypsum Pond water | Complete |
| Administrative Order on Consent for Partial Payment of Response Costs | USEPA | January 1, 2001 | The Partial Payment AOC defines the provisions for OXY USA to pay into the Copper Basin Special Account to fund a Remedial Investigation/Feasibility Study for Davis Mill Creek watershed | Interim | OXY USA has paid into the Copper Basin Special Account | Complete |
| TDEC Commissioner's Order (TDEC Order) | TDEC | January 2001 | The Order provides a framework for remediation of North Potato Creek watershed by establishing performance goals, interim remedial actions, public participation requirements, discharge limits for existing facilities, institutional controls, site inspection guidelines, redevelopment process guidelines, and operation and maintenance plan requirements | Interim | Conduct additional site characterization | Complete |
| | | | | | Eliminate or restrict access to physical hazards | Complete |
| | | | | | Implement required interim remedial actions including:<br>1. remove or isolate PCB and lead contamination<br>2. evaluate feasibility of subaqueous disposal of acid-generating wastes<br>3. construct additions to the passive treatment demonstration project | 1. Ongoing<br>2. Complete<br>3. Complete |
| | | | | Long-Term | Conduct work to meet performance goals | Ongoing |
| TDEC Additional Agreed Interim Actions (3) | TDEC | 1. March 2003<br>2. February 2005<br>3. July 2006 | Implement three additional agreed interim actions to improve conditions in North Potato Creek watershed | Interim | 1. cover slag to reduce risk to human health<br>2. remove and dispose of acid generating materials<br>3. in-stream removal and habitat enhancements | 1. Complete<br>2. Ongoing<br>3. Ongoing |
| Davis Mill Creek Operating Unit 3-D Administrative Order on Consent (OU 3-D AOC) | USEPA | August 2003 | The OU 3-D AOC provides for implementation of the selected alternative presented in the Final Focused Feasibility Study of Potential Interim Actions in Davis Mill Creek OU 3-D | Interim | 1. Increase the detention of stormwater by raising the elevation of sediment dams<br>2. Modify dam outfalls to increase stormwater detention<br>3. Remove sediments from existing ponds to increase stormwater detention<br>4. Construct retention structure and pumping system on the West Drainage Channel | 1. Complete<br>2. Complete<br>3. Complete<br>4. Deferred |
| Davis Mill Creek Administrative Order on Consent Amendment (AOC Amendment) | USEPA | August 2003 | The Davis Mill Creek AOC Amendment provides for a monitoring study to determine if routing the clean Belltown Creek and Gypsum Pond water from downstream of Dam 3 to the Ocoee River will prevent it being contaminated by Davis Mill Creek in route to the Ocoee River. If the evaluation shows that the water quality is degraded, then provisions for extension of the diversion pipe to the Ocoee River are included | Interim | 1. Conduct Davis Mill Creek monitoring study and evaluate water quality changes<br>2. Develop agreement to install diversion extension from Dam 3 to the Ocoee River | 1. Complete<br>2. Ongoing |
| Davis Mill Creek Administrative Settlement Agreement and Order on Consent (Settlement and AOC) | USEPA | September 2005 | The Davis Mill Creel Settlement and AOC provides for investigation to determine the nature and extent of contamination and any threat to the public health, welfare or the environment caused by the release or threatened release of hazardous substances, pollutants or contaminants at or from the Davis Mill Creek watershed | Interim | Conduct a Remedial Investigation/Feasibility Study in the Davis Mill Creek watershed | Ongoing |

Cantrell Flats Wastewater Treatment Plant. The Cantrell Flats Wastewater Treatment Plant was constructed in the mid-1970s for the purpose of treating waste streams from several industrial processes at the Intertrade Holdings Company's plant site. The plant began treating Davis Mill Creek in 1988, and storm water treatment began in 1993. The plant is owned and operated by Intertrade Holdings and agreements between Intertrade Holdings and GSH were made to provide access and ongoing operation and maintenance of the treatment plant.

In order to comply with the Davis Mill Creek AOC, the plant was refurbished in late 2002 to increase the plants original hydraulic design capacity of 2200 gpm to 4200 gpm, and treat Davis Mill Creek water that is pumped to the 2.1 million gallon surge pond used for equalization (BWSC, September 2005). The action was taken to minimize metals loading from Davis Mill Creek. In addition to treating storm- and base-flow from Davis Mill Creek, influent to Cantrell Flats includes storm-water runoff, industrial process water and pretreated groundwater from the Intertrade Plant, and mine water from Mary Mine. Key components of the plant include:

◦ The Davis Mill Creek pump station immediately upstream of Silt Dam 3;
◦ A 2.1 million gallon surge pond used for equalization;
◦ A lime silo, lime slakers and slurry tanks for lime feed;
◦ A 20,000 gallon rapid mix tank for mixing lime slurry with surge pond influent;
◦ A 100,000 gallon reactor tank for aeration; and,
◦ Two clarifiers, each 160 feet in diameter with a capacity of 1.5 million gallons, operating in parallel for hydroxide precipitation of metals.

The refurbished plant has been in operation since November 2002 and has removed over 12 million pounds of metals and over 22 million pounds of acidity. A summary of plant performance is shown in Table 2. Underflow from the plant is disposed on-site in underground mine workings.

Diversion of Clean Belltown Creek and Gypsum Pond tributary flow from Davis Mill Creek. The Belltown Creek watershed covers 1,972 acres, which represents 65% of the Davis Mill Creek watershed. The Gypsum Pond watershed covers 436 acres, which represents 14% the Davis Mill Creek watershed; the remaining portion of the watershed is 715 acres. Flow from the Belltown Creek and Gypsum Pond watersheds constitutes over 75% of the flow in Davis Mill Creek. The quality of the water in both the Belltown Creek and Gypsum Pond tributaries is significantly better than the quality of water in Davis Mill Creek. However, when good quality water from Gypsum Pond and Belltown Creek mixes with poor quality water in Davis Mill Creek, all the water becomes poor quality and must be treated at the Cantrell Flats Wastewater Treatment Plant.

The Davis Mill Creek AOC required the design and construction of a diversion system to divert clean Belltown Creek and Gypsum Pond water around Davis Mill Creek to the Ocoee River. The action was taken to prevent the relatively clean water from Belltown Creek and the Gypsum Pond from requiring treatment at Cantrell Flats Wastewater Treatment Plant.

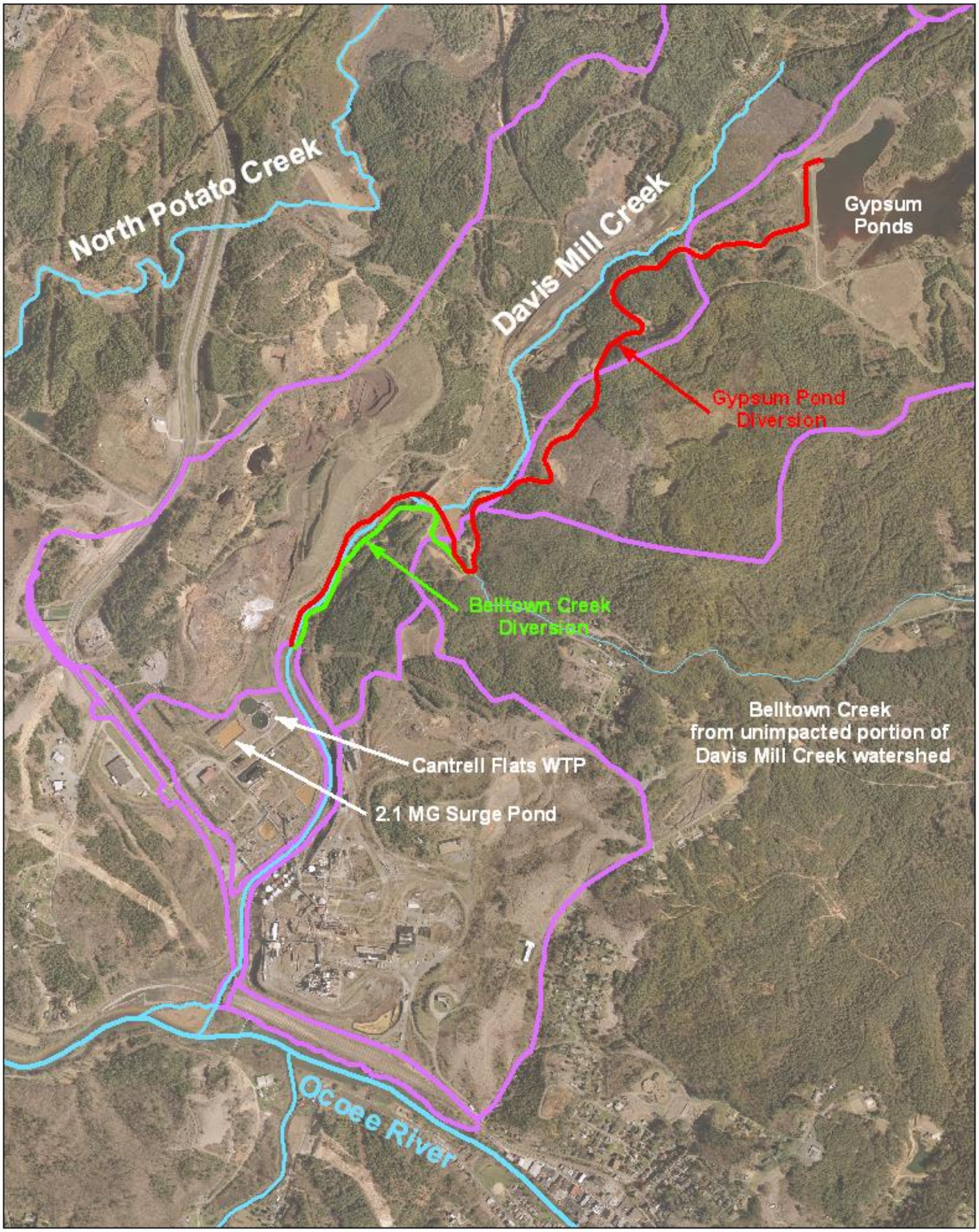


Figure 2. Davis Mill Creek and Locations of Major Interim Actions

Table 2. Performance of the Refurbished Cantrell Flats Water Treatment Plant from November 2002 through November 2006 for an Average Daily Flow of 2.26 MGD.

| Dissolved Parameter | Average Influent | Average Effluent | Percent Removal | Load Reduction | Total Load Reduction |
|---|---|---|---|---|---|
| | mg/L | mg/L | % | pounds/day | pounds |
| Cadmium | 0.08 | 0.01 | 85.5 | 1.3 | 1,854 |
| Copper | 0.59 | 0.02 | 96.3 | 10.8 | 15,770 |
| Iron | 356 | 0.60 | 99.8 | 6683 | 9,770,973 |
| Lead | 0.10 | 0.06 | 38.5 | 0.7 | 1,041 |
| Manganese | 36.4 | 2.81 | 92.3 | 632 | 924,546 |
| Zinc | 54.3 | 0.18 | 99.7 | 1,018 | 1,488,728 |
| Total Metals | | | | 8,347 | 12,202,912 |
| Acidity | 838 | 10.2 | 98.8 | 15,578 | 22,775,376 |

The system included increased storm-water detention capacity and diversion of effluent from the Gypsum Pond, combined with the Belltown Diversion up to a 10-year/24-hour precipitation event. The two diversion pipes were designed to divert up to 170,000 gpm (BWSC, September 2005). Project planning activities included work plan preparation and completion of detailed engineering design. Final construction drawings and specifications were submitted August 2003 and included:

- 3,019 feet of 63" diameter HDPE pipe to divert Belltown Creek;
- 4,403 LF of 20" diameter and 2,750 LF of 18" diameter HDPE pipe to divert discharge from Gypsum Pond to Belltown Creek;
- Modifications to Belltown Dam and Davis Mill Creek Silt Dams;
- Modification to the Gypsum Pond Dam Spillway; and,
- Sediment removal from detention ponds behind Silt Dams 1, 2, and 3.

GSH began work on the Gypsum Pond diversion in late 2003; the project was completed in March 2004. The Belltown diversion project construction began in May of 2004 and was completed in December of 2004. The 63" diameter pipe was brought to the site by train, and installed as shown in Fig. 3A, 3B and 3C.

Figure 3A. Transport of the 63” diameter HDPE pipe to the Site.

Figures 3B and 3C. Installation of 63” Diameter HDPE Pipe to Divert Belltown Creek.

North Potato Creek

North Potato Creek flows in a southwesterly direction, draining 9,700 acres before discharging into the Ocoee River approximately 2.25 miles downstream of the city of Copperhill, Tennessee. The creek flows through the South Mine Pit, which is located 0.4 mile above its confluence with the Ocoee River. The South Mine Pit is an abandoned surface mine with a surface area of approximately 20 acres that was opened in the late 1970’s. By order of USEPA, North Potato Creek was routed through the South Mine Pit in 1991 to act as a sediment trap prior to discharge to the Ocoee River. A detailed map of the North Potato Creek watershed is shown in Fig. 4.

An AOC required an engineering evaluation/cost assessment to evaluate temporary response action alternatives in support of selection of a Non-Time Critical Removal Action for North Potato Creek. The objective was to address and alleviate contaminant discharge from North Potato Creek into the Ocoee River while long-term work and study proceeds upstream in the North Potato Creek watershed. Characterization efforts were completed to obtain information concerning factors influencing the South Mine Pit and North Potato Creek to support evaluation of a range of removal action alternatives. Data obtained for the South Mine Pit was used to develop a hydrologic and chemical mass balance model and a limnologic model. Incorporation of the South Mine Pit in the removal action was proposed to provide for flow equalization, high iron, deep pit water to support enhanced metal precipitation, and settling of precipitated solids (BWSC, et al., February 2003). Laboratory and field treatability studies were conducted to evaluate akalinization of deep pit water, sludge settling in the pit, and sludge stability.

Nine removal action alternatives were considered, including no action, in-pit treatment, conventional lime treatment, and six other passive and active treatment technologies. The selected alternative was an in-pit water treatment system designed with a dual lime feed system to treat both base and storm flows, up to and including the 10-yr/24-hr storm event; a critical component of this system is an upstream diversion dam system reduces the maximum storm event flow to 436,000 gpm. Other major components of the plant included:

- North Potato Creek, deep pit, and recycle pump stations;
- Lime silo and feed system;
- Rapid mix tank; and,
- Diversion structure and diversion channel.

Operation of the North Potato Creek Water Treatment Plant began on January 10, 2005 (BWSC, August 2005). Dissolved iron has been measured daily at the pit discharge since plant operations began; the full analytical suite is also analyzed at two week intervals. Removal rates (Table 3) of the treatment system are sufficient to treat North Potato Creek to concentrations below the Tennessee Water Quality Criteria for its designated uses. The largest North Potato Creek storm flow treated to date by the plant was 48,000 gpm.

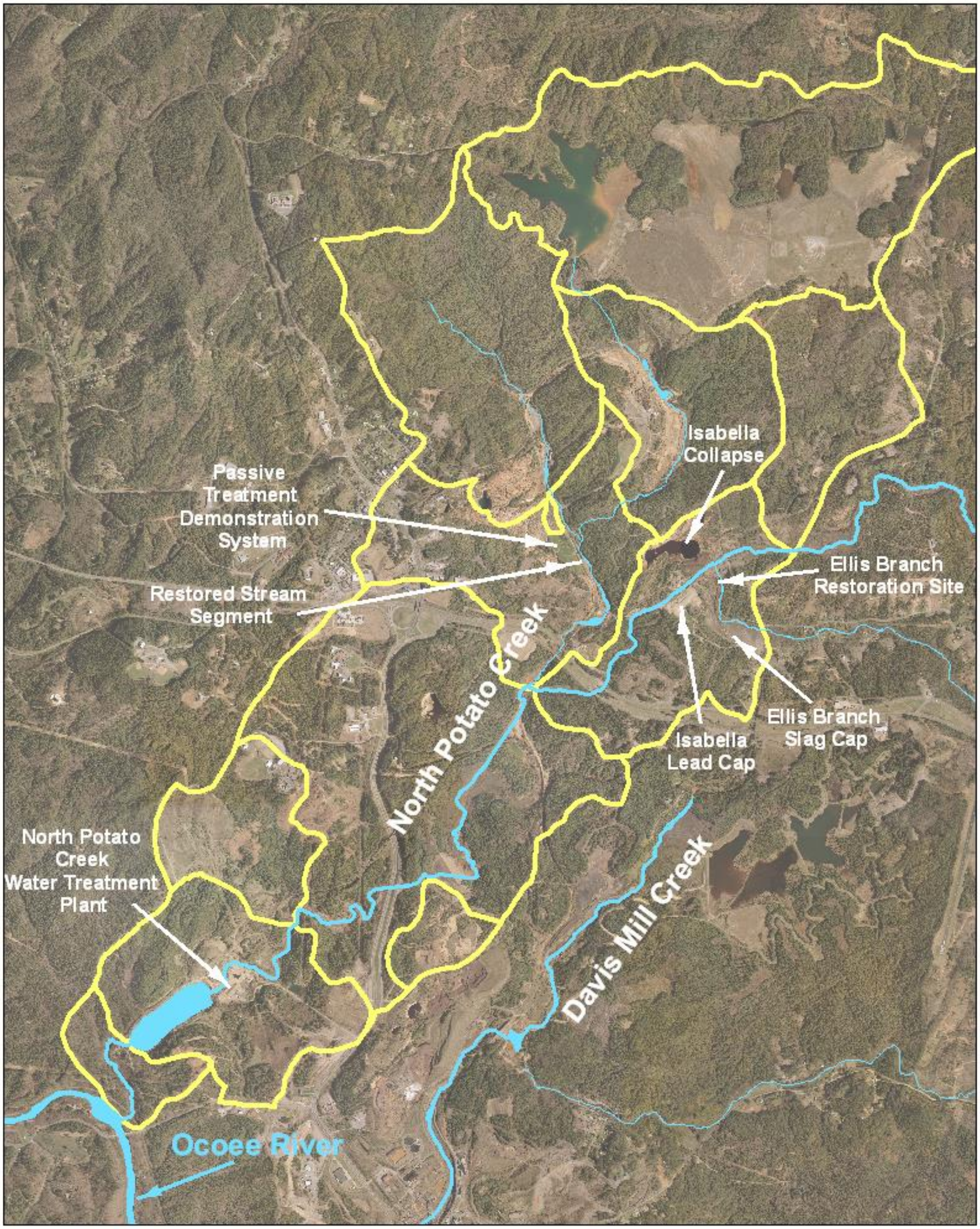


Figure 4. North Potato Creek and Locations of Major Actions

Table 3. Metals Concentrations in North Potato Creek at the Outlet of the South Mine Pit at Average Flow of 8160 gpm.

| Dissolved Parameter | Average Concentration During EE/CA | Average Concentration After Start-Up | Percent Removal |
|---|---|---|---|
| | mg/L | mg/L | % |
| Aluminum | 1.10 | 0.074 | 93 |
| Copper | 0.110 | 0.001 | 99 |
| Iron | 3.500 | 0.043 | 99 |
| Zinc | 0.580 | 0.026 | 96 |
| Cadmium | 0.070 | 0.0008 | 89 |
| Manganese | 2.500 | 1.200 | 53 |
| Lead | 0.0057 | 0.00006 | 99 |
| Cobalt | 0.024 | 0.0055 | 77 |

The in-pit treatment system utilized at the North Potato Creek site has proven to be a cost effective alternative to conventional lime treatment for treatment of large and highly variable acid mine drainage flows. The treatment system accomplishes a high level of treatment for large acid mine drainage flows without construction of the large infrastructure typically necessary to treat such large flows. The construction cost, operation and maintenance cost, and the treatment cost per 1000 gallons for the plant are provided in Table 4. The estimated cost for a conventional water treatment plant to accomplish comparable treatment of North Potato Creek as determined in the engineering evaluation/cost assessment (BWSC, February 2003) is also provided.

Table 4. Construction, Operation and Maintenance Costs

| | North Potato Creek WTP and Infrastructure | Conventional Treatment |
|---|---|---|
| Construction Cost (including engineering costs) | $4,000,000 | $25,000,000 |
| Annual Operation and Maintenance Costs | $400,000 | $1,300,000 |
| Treatment Cost Per 1000 Gallons | $0.085 | $0.24 |

<u>Summary of Results of Early Actions</u>

Implementation of early actions has yielded significant results. The combined result of interim actions, including treatment of Davis Mill Creek, diversion of Belltown Creek and the Gypsum Pond Tributary, and treatment of North Potato Creek, is the removal of over 10,000 pounds per day of metals that would have flowed into the Ocoee River. The advantage of early identification and remediation of the most significant problems that impact water quality at the Site is that the worst problems in a complex set are addressed immediately. This has allowed valuable resources traditionally utilized for full site characterization to be applied toward remedial activities, which potentially change the original character of the site. A summary of the results of early actions since 2002 are shown in Fig. 5.

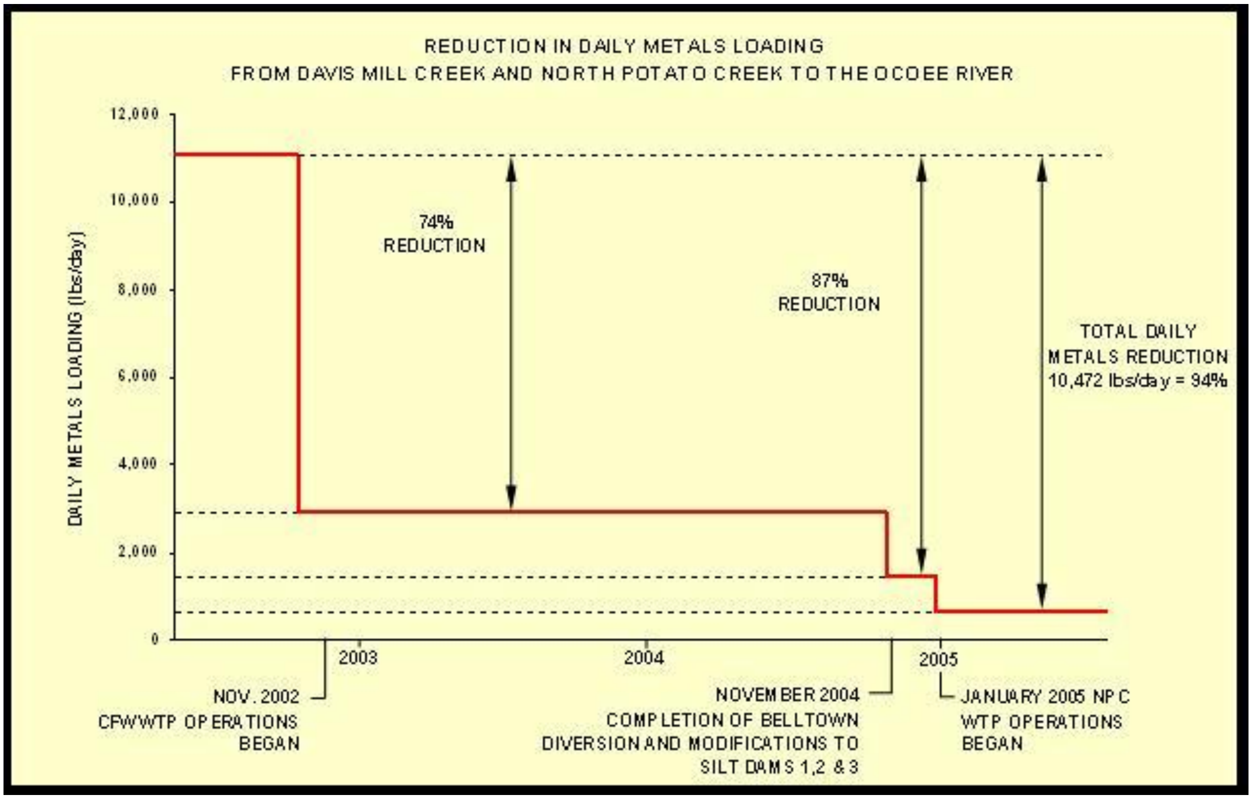


Figure 5. Summary of Results of Early Interim Actions in Davis Mill Creek and North Potato Creek Watersheds.

## Long-Term Remedial Actions in Davis Mill Creek

An AOC required a Remedial Investigation/Feasibility Study. The Remedial Investigation Report will describe site conditions, nature and extent of contamination, risks to human health and the environment and any treatability testing necessary to evaluate the potential performance and cost of treatment technologies being considered for the Feasibility Study. The Feasibility Study will evaluate alternatives for remedial action to prevent, mitigate or otherwise respond to or remedy the release or threatened release of hazardous substances, pollutants, or contaminants at or from Davis Mill Creek to the Ocoee River. The Remedial Investigation is currently ongoing; the Feasibility Study will be conducted following the completion of the Remedial

Investigation to determine the final remedial remedy which should enable the Ocoee River to meet the Tennessee Water Quality Criteria for its designated uses.

## **Long-Term Remedial Actions in North Potato Creek**

The TDEC Commissioner's Order, administered under the Voluntary Cleanup Oversight and Assistance Program, establishes interim actions that must be completed and long-term performance goals that must be met in the North Potato Creek watershed. Specific interim actions that must be implemented include addressing safety issues, conducting further characterization of the Site, and implementing interim remedial actions. The Order also provides for implementation of additional agreed interim actions if consistent with the final remedy to achieving performance goals. The performance goals for the watershed include:

- Sustain biological integrity;
- Eliminate or restrict access to physical hazards;
- Remediate areas that pose or may pose a human health risk; and,
- Avoid adverse effects during remedial actions.

Although the Order establishes the long-term performance goals for the watershed, it does not define a specific technical approach to achieve and maintain those goals. Because of flexibility within the Voluntary Cleanup Oversight and Assistance Program, remedial actions are being implemented in the North Potato Creek watershed in a phased approach. This phased approach allows evaluation of the success of completed interim actions required by the Order and additional remedial actions performed by GSH. Results of completed actions are used to determine what additional measures should be taken to meet the long-term performance goals. Implementation of a phased approach supports selection of appropriate remedial actions in a cost-effective manner.

All interim actions specified in the Order to address safety, conduct further site characterization, and implement remedial actions have been completed by GSH. Three additional agreed interim actions related to waste removal and isolation were also performed by GSH.

Safety Actions

The Basin includes a number of abandoned and collapsing mine works and other deteriorating facilities and waste piles which may have posed a risk to public safety. The performance goal set forth in the Order specified that physical hazards were to be either eliminated or access to these hazards should be restricted. In order to address this safety goal, subsidence studies were performed to identify potential collapse areas and a subsidence monitoring program was implemented. Voids where subsidence was not an issue were filled with clean material; six miles of cyclone fencing and signage were installed around physical hazards.

Additional Site Characterization

Portions of North Potato Creek watershed have been degraded by mining and processing wastes that generate acid-rock drainage and elevated concentrations of metals. The exposed mining and process wastes may also pose risks to human heath through direct contact. To address the problems in North Potato Creek that were not dealt with as interim actions, the Order also specified that additional site characterization would be performed to identify additional areas of concern and contaminants of concern. Studies that have been conducted include the following:

- Operational history and identification of additional areas of concern
- South Mine Pit Studies
  - Limnological investigation
  - Flow and water quality monitoring
  - Storm water monitoring
- Isabella Pit Studies
  - Bathymetry and chemical study
  - Suitability study for material disposal
- Waste Inventory
- Focused surface water and storm water monitoring
- Annual biological surveys

Interim Remedial Actions in North Potato Creek

Interim remedial actions were specified in the Order to address three primary issues: 1) removal or isolation of PCBs and lead contamination to reduce risks to human health, 2) evaluation of the feasibility of placing acid-generating materials into a surface mine collapse for a waste disposal solution, and 3) construction of additions to an existing passive treatment demonstration project.

Removal of PCB-Contaminated Oil, Equipment, and Soils. After closure of mining and processing facilities, inactive electrical equipment remained on the Site. GSH performed a review of historical maps, interviewed former employees, and conducted a reconnaissance of the operational areas of the North Potato Creek watershed to inventory potential PCB-contaminated equipment (BWSC, February 2002). Forty-three pieces of inactive electrical equipment and the oil remaining within the equipment were removed for disposal and recycling in October 2001. Equipment was decontaminated and recycled via smelting. Oil with PCB concentrations less than 50 ppm was burned in a permitted energy recovery boiler while oil with PCB concentrations greater than 50 ppm was incinerated.

Fifty surface soil samples were collected from inactive electrical equipment locations after removal in 2001. Biased samples were collected from soils adjacent to former fill ports and beneath the equipment and from stained soils. In October 2005, additional sampling activities were performed to evaluate concrete and paved areas where PCB-contaminated electrical equipment was previously located and soils identified during previous investigations to have PCB concentrations exceeding 1 mg/kg. Ninety-eight additional concrete and soil samples were collected.

Remediation was based on a cleanup standard of 25 mg/kg for a low occupancy area as defined in 40 CFR 761.3. One area within the watershed, the former Isabella Pump and Power

Station, required remediation. Grid sampling was used to delineate the horizontal and vertical extent of PCB-contamination in the surface and subsurface soils. Samples were collected on 1.5-meter grid spacing in accordance with the Toxic Substance Control Act (TSCA) requirements to provide appropriate documentation for disposal. Results for PCBs ranged from non-detect to 320 mg/kg in the 90 samples collected during the delineation effort.

Removal activities at the former Pump and Power Station were completed in December 2004. Five hundred and eight tons of soil with PCB concentrations greater than 50 mg/kg were excavated and sent to a TSCA landfill for disposal. Ninety-five tons of soil with PCB concentrations less than 50 mg/kg were excavated and sent to a Subtitle D landfill for disposal. Excavated areas were backfilled and vegetated and a perimeter security fence was installed to restrict access.

Isolation of Lead Contamination. In the early 1900s, a lead chamber acid plant was constructed in the North Potato Creek watershed to capture sulfur dioxide gas generated during ore processing to produce sulfuric acid. The Isabella lead chamber building, located on a hill, was approximately 400 feet long and 140 feet wide. Approximately 1,400 tons of lead was used in construction of the building because of its resistance to attack by wet acid. The building, shown in Figure 6A, was dismantled; however, foundations and debris from the structure remained.

Investigations were conducted to delineate the extent of lead contamination (concentrations exceeding 400 mg/kg) within the former building footprint and adjacent area. Surface and subsurface soils, up to 20 feet deep, were collected on a 50-foot grid to delineate both horizontal and vertical extent of contamination over an eight-acre area. A portable x-ray fluorescence (XRF) instrument was used as a tool on-site during the investigation to reduce sampling iterations. Lead concentrations ranged from non-detect to 109,000 mg/kg in the 220 samples collected.

The selected remedial action was physical isolation using an engineered cap coupled with site security measures to permanently interrupt exposure pathways (BWSC, May 2003). Soils with lead concentrations equal to or exceeding 400 mg/kg located outside the limits of the five-acre cap were excavated and placed within the limits of the cap. The engineered cap consisted of a sub-base (contaminated soil graded as necessary), geosynthetic clay liner, geonet drainage system, 24-inch barrier soil layer, and established vegetation. Installation of the cap was completed in August 2004. A perimeter security fence was installed and a cap maintenance program is being implemented. An aerial view of the completed cap is shown in Fig. 6B.

Figure 6A. Isabella Lead Chamber Acid Plant

Figure 6B. Completed Containment Cap

Feasibility of Waste Material Disposal in Isabella Collapse. The Isabella Collapse is an existing Site feature that contains water contaminated with acid and heavy metals and is chemically and thermally stratified. This feature intersects flooded underground mine workings that collapsed to the surface and is shown in Fig. 7. Glenn Springs Holdings, Inc. proposed sub-aqueous disposal of various non-hazardous mining-related materials, including calcine, concentrate, ore, and other acid-generating materials from the mining and beneficiation activities, in the anoxic zone at the bottom of the Isabella Collapse. Several studies were completed to evaluate the feasibility of waste material disposal in the Isabella Collapse, including:

- evaluation of the water chemistry and bathymetry of the Collapse,
- water chemistry and flow of North Potato Creek, the adjacent stream,
- groundwater chemistry in monitoring wells adjacent to the Isabella Collapse, and
- a potential connection between Isabella Collapse and North Potato Creek (BWSC, January 2004).

Results these studies indicated that the mine Collapse was hydraulically isolated from North Potato Creek. Modeling was also performed to allow comparison of placing materials in the Collapse to placement in an on-site Class II landfill (BWSC, February 2004a). A disposal capacity of 270,000 cubic yards was estimated within the anoxic zone. However, maps indicated that material may flow into lower stopes under the Collapse, thus increasing the volume available for material disposal.

In 2004, the water in the Isabella Collapse, connected mine workings, and a buffer area around the mined working were classified by TDEC as site-specific impaired groundwater with the quality of acid mine drainage. This classification, along with information obtained from previous studies demonstrating that the Isabella Collapse was hydraulically isolated from North Potato Creek, provided TDEC rationale for placing acid-generating materials into the Isabella Collapse. In 2005, TDEC issued a "Weight of Evidence Decision for Disposal of Material into the Isabella Pit and Underground Workings". Phase One removals within the North Potato Creek Watershed and disposal in the Isabella Collapse with began in 2005 and continue today. As part of the management of this disposal system, water from the Collapse is pumped and treated to maintain the water elevation as material is disposed.

Acid Mine Drainage Passive Treatment Demonstration Project. In 1998, a two-acre anaerobic demonstration wetland was constructed along McPherson Branch. The wetland was designed to treat base flow of McPherson Branch, which ranged from 175 to 400 gpm. The constructed wetland was used to demonstrate the effectiveness of a passive system in treating acidic surface waters and acid mine drainage (AMD) resulting from past mining and processing operations. Consistent with the overall approach for the watershed, a large waste material pile, a source of acidity and metals, was removed from the drainage path prior to construction of the demonstration wetland. The influent to the wetland had an average pH of 3.81, acidity concentrations of 126 mg/L, total iron concentrations of 35.2 mg/L, and sulfate concentrations of 243 mg/L (BWSC, September 2001).

Figure 7. Aerial View of the Isabella Collapse

Removal of grossly acidic waste materials in the watershed has been completed; however, there may be diminishing environmental improvement returns from subsequent removal and remedial actions. Comprehensive removal or capping of marginally acidic materials is impractical due to the widespread presence within the watershed and the limited availability of suitable cap material due to widespread erosion over many decades. Passive systems have been used at other mining sites to provide effective treatment with limited operations and maintenance requirements for seeps and other non-point sources along stream corridors.

The anaerobic wetland successfully reduced concentrations of key metals, including Fe, Cu, Zn, and Al from milligram per liter concentrations by one or more orders of magnitude. The wetland also consistently neutralized influent acidity and increased effluent alkalinity from 0 mg/L to 80 mg/L with a corresponding increase in effluent pH from $< 4$ s.u. to $> 7$ s.u. Typical of anaerobic processes, effluent dissolved oxygen concentrations were essentially zero and both chemical and biological oxygen demand increased in the effluent.

In 2003, additions to the demonstration system were constructed immediately downstream of the anaerobic wetland, including a 0.4-acre aerobic wetland, a 0.13-acre rock filter, and a 160-LF restored stream segment. The aerobic wetland and rock filter components were constructed to achieve reductions in effluent Mn and sulfide concentrations and to increase effluent dissolved oxygen concentrations. The restored stream segment was designed and constructed to evaluate the effectiveness of passive treatment effluent, in concert with suitable habitat, in supporting biological performance goals included in the Order.

After the first twenty nine months of monitoring the modified demonstration system shown in Fig. 8, the following conclusions were reached:

- The anaerobic wetland continues to neutralize acidity of McPherson Branch under all seasonal conditions after seven years of operation.
- The aerobic wetland rapidly oxygenates the flow and sulfides are quickly removed or are not measurable in the influent. Dissolved oxygen saturation rates are variable and appear to be seasonal and/or temperature related.
- The rock filter, located immediately downstream of the wetland system, consistently removes small concentrations of manganese from the McPherson Branch base flow.
- The restored stream segment, which receives the effluent from the demonstration wetlands and rock filter system, provides improved aquatic habitat compared to pre-construction conditions.
- The demonstration system effluent and resultant in-stream water quality do not seem to be limiting factors in the colonization of benthic macroinvertebrates.

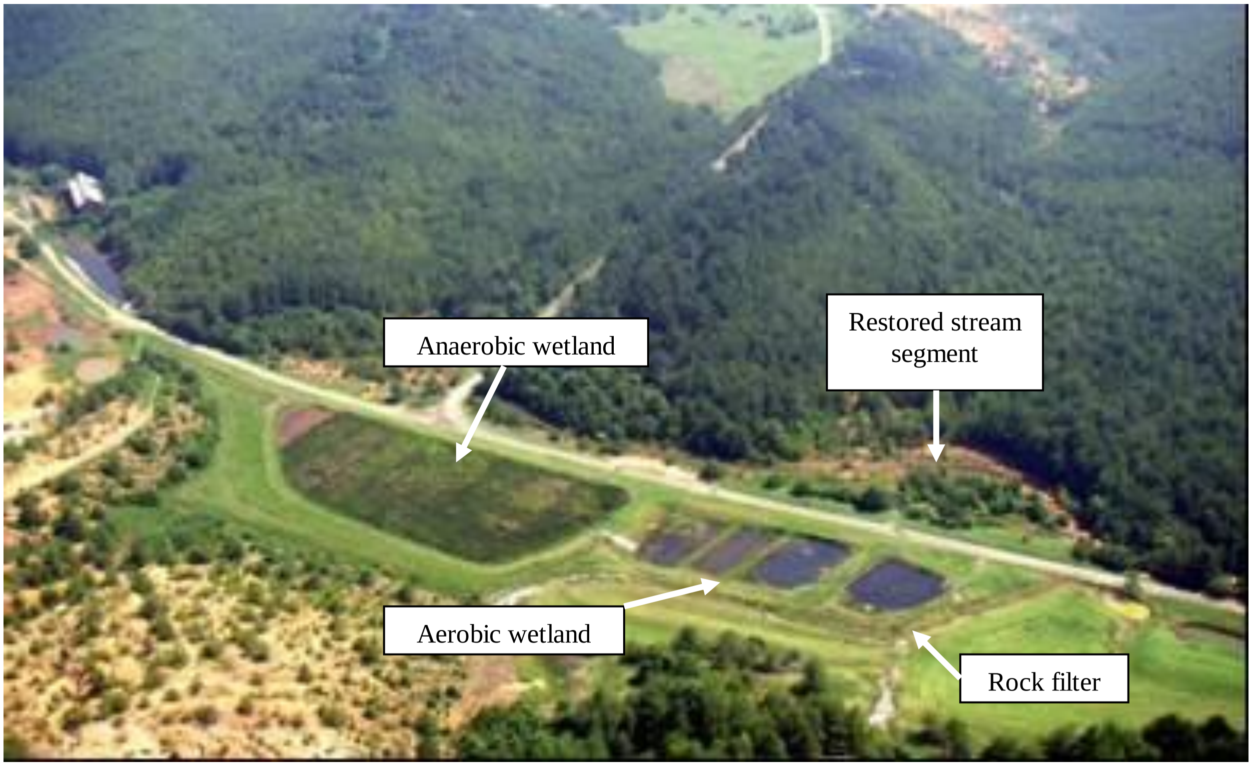


Figure 8. AMD Passive Treatment Demonstration System

Additional Agreed Interim Actions in North Potato Creek

In addition to the immediate interim remedial actions that were specified in the original North Potato Creek AOC, three additional agreed interim actions were identified during and appended to the Order. These actions included:

- Covering of slag at Ellis Branch to reduce risk to ecological and human heath,
- Removal and disposal of acid-generating material that is detrimental to water quality and the macoinvertebrate community, and
- In-stream removal of mining and process wastes and habitat development to support achieving the biological performance goal established in the Order.

Cover of Slag along Ellis Branch. Granulated slag, a product of the Isabella processing area, was stockpiled adjacent to a public road, Ellis Branch and near residential dwellings and was accessible to trespassers. The stockpile, shown in Fig. 9A, comprised an approximate nine-acre area with an estimated 175,000 cubic yards of slag on the ground surface. Testing indicated that the slag contained lead concentrations above 400 mg/kg and could pose potential ecological and human health concerns. The material was not found to be acid-generating but rather had the potential for neutralizing acid. A vegetated buffer area existed to separate Ellis Branch from the granulated slag stockpile.

A detailed evaluation of remedial alternatives addressing technological feasibility, elimination of threat to human health and the environment, and cost was completed (BWSC, December 2003). The following alternatives were considered:

- no action,
- permeable cover system,
- impermeable cover system, and
- excavation and disposal of material in Isabella Collapse (as described above in the Feasibility of Waste Material Disposal in Isabella Collapse)

The permeable cover system was selected as the most appropriate alternative for implementation. The nine-acre area was graded to minimize infiltration and allow collection of runoff. An 18-inch soil cover was placed over the area to restrict direct human contact and support vegetative growth. The cover was vegetated with a mixture of native grasses and legumes to control subsequent erosion as shown in Fig. 9B. Long-term plans in this area include maintenance of the vegetated permeable cover and the buffer strip along Ellis Branch.

 


Figure 9A and 9B. Before and after Photographs of the Ellis Branch Slag Cap

Phase One Removal and Disposal. Surface waste materials, such as calcine, concentrate and ore, are one of the major continuing sources of acid rock drainage and elevated metal concentrations to Site surface waters (BWSC, February 2004b). The acidity and resulting leaching of metals is detrimental to the water quality and the macoinvertebrate community. Remedial actions were approved to remove solid, non-hazardous, mining and mineral processing related materials from the Site that had the greatest potential to produce acid; and dispose of these materials in the Isabella Collapse as described previously in the Feasibility of Waste Material Disposal in Isabella Collapse.

Removals are being implemented in phases, with Phase One addressing distinct piles of the most acid-generating materials. The potential to generate acid was determined by the acid-base potential of the material. Acid-base potential is measured in equivalent tons of calcium carbonate per 1,000 tons of material and is the balance between acid production and acid neutralization properties of a material. If the acid-base potential is < -20 $TCaCO_3/kT$, it is generally accepted that the material is acid producing (BWSC, August 2005b). Additional considerations for removals include proximity of material to drainage ways or streams, remaining available volume for disposal in the Isabella Collapse, and the difficulty of excavation.

As of March 2007, approximately 288,000 cubic yards of acid-generating materials have been excavated from ten areas within the watershed similar to actions shown in Fig. 10A and disposed in the Isabella Collapse. A conveyor is used to safely dispose of materials in the Collapse as shown in Fig. 10B. Material staging areas and the conveyor have been located to minimize activities in areas with higher potential for future subsurface subsidence. As material is disposed in the Collapse, monitoring will be conducted to track the remaining volume of the anoxic zone available for disposal. Water quality monitoring will also be performed during disposal activities to evaluate water with the collapse, groundwater between the Isabella Collapse and North Potato Creek, and surface water within North Potato Creek.

Figure 10A and 10B. Phase One Removal for Disposal in Isabella Collapse – Loading onto the Conveyor.

In-Stream Removal and Habitat Development. As a result of mining and processing operations in the watershed, North Potato Creek and its tributaries have been severely altered. Alterations included open roasting of ore and acid production, which led to loss of vegetation, erosion and sediment deposition. Streams were often filled with materials, channelized and disturbed to meet operational needs. Portions of North Potato Creek and its tributaries contain mining and process-related waste and much of this material must be removed and habitat created to support achieving the biological performance goal established in the Order.

In-stream removals are being planned and implemented to address acid-generating materials that adversely impact water quality and prevent establishment of macroinvertebrate communities. Priority will be given to the most impacted stream reaches adjacent to former mining and processing areas. Materials will be removed from creek banks, channel beds, and floodplains, as necessary, to achieve the long-term goal of biological integrity. While some aquatic life may be affected during short-term disturbances, long-term benefits will far exceed any short-term loss.

Restoration activities on a segment of McPherson Branch, upstream of the Passive System Demonstration Project have been completed. Acid-generating materials were removed from the previously channelized creek bed and the stream was restored to a geomorphologically stable form that provides bankfull depths and flood prone areas for sediment management. Additionally, limestone bed materials were used in the stream restoration project to provide alkalinity to the surface water as well as in-stream macroinvertebrate habitat.

Stream restoration plans are being implemented on Ellis Branch near its confluence with North Potato Creek. Acid generating materials will be removed from the stream banks and beds and the stream channel will be restored to a geomorphologically stable form; in-stream structures are planned to be installed for enhancement of macroinvertebrate habitat.

## Summary and Conclusions

Glenn Springs Holdings, Inc. has implemented a series of USEPA removal orders in the Davis Mill Creek watershed and established the Davis Mill Creek Water Treatment system. The USEPA required short-term actions in the North Potato Creek watershed to temporarily alleviate contaminant discharge of North Potato Creek to the Ocoee River while long-term actions under the State Voluntary Cleanup Program proceeded. Implementation of short-term remedial actions has resulted in a reduction of more than 10,400 pounds of metals loading per day to the Ocoee River. Recent sampling on the Ocoee River indicates the water quality meets Tennessee Water Quality Criteria for all parameters except Cu and Zn which are being addressed.

Long-term goals for North Potato Creek watershed are defined in a TDEC Commissioners Order. The Order established biological integrity as its long-term goal and requires shorter, interim remedial actions to protect the health and safety of the public and the environment. Glenn Springs Holdings, Inc. has completed or is in the process of completing these actions.

Although work remains to be done in Copper Basin, cooperative planning has resulted in streamlined implementation of cleanup activities which are already reducing current and future impacts to human health and the environment (USEPA, 2005). Use of an adaptive management approach to watershed restoration has been the key to early identification and remediation of the most significant problems. Early, measurable success has been achieved in part because of the flexibility resulting from regulatory collaboration and stakeholder cooperation.

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