

# RECLAMATION AND REVEGETATION IN THE COPPER BASIN: LONDON MILL AREA<sup>1</sup>

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**Abstract:** The Copper Basin, located in southeast Tennessee, is the site of extensive copper mining and processing operations dating back to the mid-1800s. The London Mill area within the Copper Basin, which included a mine and a flotation plant to separate metal sulfides from waste rock, was abandoned in 1987. Under a voluntary agreement, Glenn Springs Holdings, Inc., a subsidiary of Occidental Petroleum Company, has developed and implemented a remedial plan for the London Mill area to address safety and human health hazards and conduct environmental restoration activities. The remedial approach for the London Mill area required a combination of reclamation activities including elimination of physical hazards, removal or isolation of waste materials, diversion of clean water, collection and treatment of mine-impacted water, and stabilization of surface conditions.

**Additional Key Words:** acid-rock drainage, acid-sulfate materials

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## Introduction

The London Mine and Flotation Plant are located within the Copper Basin Mining District (Basin) in southeastern Tennessee near the North Carolina and Georgia borders (see Fig. 1). The Basin comprises an area of approximately 130 square kilometers (50 square miles) adjacent to the Cherokee National Forest. The Basin is drained by North Potato Creek and Davis Mill, 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 having left a legacy of environmental degradation. In addition to mining and related operations, associated support infrastructure (railroads, equipment storage and salvage yards, 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 Watersheds (Barge, Waggoner, Sumner and Cannon, 2000).



Figure 1. Copper Basin Regional Location

Through a Memorandum of Understanding, Occidental Petroleum Corporation, through its wholly owned subsidiary Glenn Springs Holdings, Inc. (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 North Potato Creek and Davis Mill Watersheds (Bell et al., 2007).

The objective of this paper is to describe the reclamation and revegetation of the London Mine and Flotation Plant Site, and its related operating units conducted as part of a series of voluntary agreements between GSH and TDEC and USEPA.

### **Background**

The Basin has been the site of extensive Cu mining and processing operations dating back to the 1850s. One of the primary mining and processing operations within the Basin was located in the London Mill area at the head of the Lower North Potato Creek Watershed.

The London Mine (Fig. 2) was first operated in 1853 and continued operating until 1926 when the mine was permanently closed. The underground workings extended to approximately 366 meters (1,200 feet) below the ground surface and produced more than 1,451,200 tonnes (1,600,000 tons) of sulfide ore (BWSC, 2000).



Figure 2. London Mine 1928



Figure 3. London Mill Plant 1975

Ore from the mine was transported by rail to the primary crushers at London Mill where the mined rock was crushed in a two-stage process to a finely ground ore (see Fig. 3). This finely ground ore then went to the London Mill Flotation Plant, which was built in 1922 to process ore from the Burra-Burra, London, Eureka, and Polk County mines. The London Mill Flotation Plant separated metal sulfides from the gangue, or waste rock, by froth flotation and filtration. This process recovered iron concentrate suitable for making Fe sinter and Cu concentrate for production of Cu and lesser amounts of Zn concentrate. The flotation cells within the London Mill Flotation Plant used lime, creosote, pine oil, nalcolyte, cyanide, sodium silicate, acids, and xanthate as flotation reagents (BWSC, 2006d).

The first stage of the flotation process, called bulk separation, yielded products including Zn tailings and small amounts of Zn concentrate. Magnetite was separated from the Zn tailings by a magnetic separator and sold for iron production. The magnetite produced exceeded the demand; thus, much of it was disposed in piles around the London Mill area. Copper was recovered in the next stage of the flotation process using cyanide and sodium silicate as reagents. The Cu concentrate produced at London Mill contained about 20% Cu, 35% Fe, 35% S, 10% Zn, and minor amounts of other metals. The Fe concentrate that was recovered in the last stage of flotation contained about 57% Fe, 38% S, and about 5% other minerals. (BWSC, 2006d)

From 1922 until 1946, the gangue and undesirable mineral particles, or tailings, sank to the bottom of the flotation tank and were disposed in the London Mill area and downstream within North Potato Creek. From 1946 until 1987, the material was pumped primarily to the Tailings Pond north of the London Mill area, and was also placed into the inactive London Mine and the active Calloway, East Tennessee and Isabella Mines. The tailings from the flotation plant were primarily composed of quartz, mica, talc, and other silicates and lime with only trace amounts of metals.

All flotation operations within the Basin were consolidated to London Mill in 1958. In 1987, the London Mill Flotation Plant was abandoned and partially dismantled by salvage companies. Waste materials and excess product remained stockpiled or temporarily disposed at several locations within the London Mill area: London Mill Tailings Pond; Upper Burra-Burra Creek; Magnetite area; London Mine Shaft; London Mill Plant Site; Tailings/Concentrate area; and the Isabella Tunnel Portal area (see Fig. 4).

In 1976, the London Mill Water Treatment Plant (LMWTP) was constructed to treat wastewater from the flotation plant. After operation of the flotation plant ceased in 1987, the LMWTP was used to treat surface water and mine water.

GSH undertook the task of reclaiming the London Mill area in 2001. Since then they have removed and isolated acid-generating material; properly disposed of hazardous wastes, PCBs and asbestos; filled voids with clean fill to address physical hazards; routed clean water away from contaminated areas; collected impacted water for treatment; and graded, covered with soil material and revegetated in each of the operation and waste disposal areas shown in Fig. 4. The following describes the reclamation and remedial actions taken in the areas impacted by mining

and processing. The description begins at the upstream end of the Burra-Burra subwatershed within the North Potato Creek Watershed and proceeds downstream.



Figure 4. London Mill Operation and Waste Disposal Areas

### **London Mill Tailings Pond**

The London Mill Tailings Pond is the northern-most operating unit in the Lower North Potato Creek Watershed. From 1946 until 1987, tailings from the London Mill Flotation Plant were disposed in the Tailings Pond. The Tailings Pond forms a broad, mostly barren, and nearly flat plain covering approximately 1.5 square kilometers (370 acres) (Fig. 5). The tailings are a slightly silty, fine to medium sand with minor amounts of metal sulfides in localized areas. In 1998, the University of Tennessee established revegetation test plots on a portion of the tailings to determine which plants and soil amendments were most likely to grow successfully on the tailings material (Cook, 2000). Several native grass mixtures were tested with various

combinations of mulch, fertilizer and lime. Results of the demonstration showed phosphorus appeared to be the limiting nutrient in the tailings (Cook et al., 2000). When supplemented with phosphorus and biosolids, the tailings were found to be an acceptable medium for plant growth. The study suggested that Korean or Kobe lespedeza be used in the seeding mixture applied to the tailings (Branson and Ammons, 2004).



Figure 5. London Mill Tailings Pond 1993



Figure 6. London Mill Tailings Pond 2007

In 2002, GSH, as a means of controlling fugitive dust from the tailings, revegetated the Tailings Pond by applying agriculture lime at the rate of 6.7 Mg/ha (3 tons/Ac) and 318 kg (700 lbs) of 5/20/10 fertilizer (N-slow release sulfur coated urea) per 0.41 hectare (1 acre) to the tailings, incorporating these amendments by discing, and then seeding the tailings. Seeding rates and mixtures applied are described in the Revegetation Section. Hay mulch was then applied at the rate of about 6.7 Mg/ha (3 tons/Ac). In addition to the hay, compost mushroom was spread over a 12.2 hectare (30 acre) area and tilled into tailings. These seeding efforts were highly successful (see Fig. 6).

In that same year, GSH planted tree seedlings on the tailings, some of which were planted in wet areas that had shallow water cover or were saturated with water for at least part of the year. The seedling mixture included black locust, sawtooth oak, virginia pine, bald Cypress, river birch, and flowering dogwood. These efforts completed vegetation of the Tailings Pond area which began in the late 1990s.



Figure 7. Tailings Pond Water Body 2007



Figure 8. Low-Head Dam & Impoundment 2007

In addition to revegetation of the Tailings Pond, remedial actions were also completed to secure physical hazards and divert good quality water. In 2002, approximately 23 m<sup>3</sup> (810 cu-ft) of clean fill was placed in the surface opening at the southwestern adit at the Tailings Pond. This action eliminated the safety hazard present in the area.

The starter dike for the Tailings Pond was constructed in the mid 1940s. The outfall of the surface water retained by the Tailings Pond is a spillway that was relocated in 1962 (see Fig. 7). Additional modifications were made to the spillway in 1976 and 1996 to include a concrete weir and then a system to regulate flow from the Tailings Pond to Burra-Burra Creek after the previously installed sluice gate became inoperable. Water from the Tailings Pond outfall and upper portion of Burra-Burra Creek is of relatively good quality; however, as the surface water entered the London Mill area there was a significant decrease in water quality (BWSC, 2006b). The base flow and storm flow, up to and including the 10-year/24-hr storm, from the Tailings Pond outfall and the upper portion of Burra-Burra Creek has been diverted to McPherson Branch of Lower North Potato Creek. Diversion of this water prevents commingling of good quality water with poor quality water and reduces the volume of water in the London Mill area requiring treatment. Completion of this diversion required modification of the existing Tailings Pond spillway, construction of a low-head dam on Upper Burra-Burra Creek, and installation of a diversion pipeline (see Fig. 8). Construction of this diversion began in mid-October 2006 and was completed in March of 2007.

## Magnetite Area

The London Mill Magnetite Area was located at the northern end of the London Mill area. The pile was approximately 30.5 m (100 ft) by 45.7 m (150 ft) and contained an estimated volume of 1,758 m<sup>3</sup> (62,100 cu-ft) of magnetite (see Fig. 9). Neither sulfides nor oxidation salts were visible in the field. The magnetite contained elevated levels of Cd, Cu, Fe, Pb, Se, and Zn.

In 2007, GSH hauled the magnetite to the Isabella Pit for sub-aqueous disposal, graded the remaining material, established drainage control, covered the graded area with 0.46 m (18 in) of soil material, and revegetated the area consistent with the revegetation methods described later in the Revegetation Section (see Fig. 10). The Isabella Pit is located east of the London Mill Area and is the result of several planned collapses of stopes in the Isabella Mine that occurred in 1960 through 1974. After several years of study of the pit and associated groundwater conditions, the sub-aqueous disposal of materials was determined to be an efficient, environmentally safe, and permanent method of disposal of acid-generating, non-hazardous materials and was approved by the TDEC (TDEC, 2005).



Figure 9. London Mill Magnetite Area - Before



Figure 10. London Mill Magnetite Area - After

An upland area, located just south of the magnetite area, was not directly impacted by mining and processing operations and the storm water runoff is of good quality. The storm water runoff from this upland area entered the London Mill area and Burra-Burra Creek via both surface flow and infiltration through fill/waste material. This surface water and seeps from the fill/waste material were collected in a retention pond and treated by the LMWTP. A channel was designed and constructed in 2007 to divert storm water run-off, up to and including a 10-year/24-hour storm, from the upland area of London Mill to McPherson Branch. This prevented the good



quality surface runoff from commingling with poor quality water in the retention pond and reduces the volume of water in the London Mill area requiring treatment.

### **London Mine Shaft Area**

The London Mine Shaft Area is located immediately north of the plant site extending to the magnetite area to the north, to the flotation plant to the south and includes the London Shaft, ore pockets, calcine bins, former location of a cyanide tank, and railroad grades (see Fig. 11). The mine shaft, calcine bins and other underground voids presented a physical hazard to humans. Approximately 2,770 m<sup>3</sup> (97,875 cu-ft) of clean fill was placed into these voids in 2002 before other reclamation activities began in the area.

Most of the surface materials present within the London Mine Shaft Area were acid-generating and some had high concentrations of Fe, Pb, Zn and Cu. The acid-generating materials were hauled to the Isabella Pit for sub-aqueous disposal. Cyanide, polycyclic aromatic hydrocarbons (PAHs), and Hg were also identified in the surface materials in concentrations below action levels for protection of human health. Materials containing these constituents were segregated from other materials in the area, consolidated within the footprint of the London Mill Flotation Plant, and placed under an engineered cap.

After removal of the acid-generating materials, the surface was graded, slopes stabilized, drainage controls constructed, and then the area was revegetated using the seedbed preparation, lime, fertilizer, seeding mixtures and mulch as described in the Revegetation Section. The revegetation in this area has been in place for two growing seasons, one of which was abnormally dry (see Fig. 12).



Figure 11. London Mill Shaft Area - Before



Figure 12. London Mill Shaft Area - After

## London Mill Plant Site

The London Mill Plant site is located south of the London Mine Shaft. During the late 1800s and early to mid 1900s, the London Mill Plant site included a flotation plant, crushers, fine ore storage bins, warehouse, laboratory and site office (see Fig. 13). Portions of these structures remained after the site was abandoned and partially dismantled in 1987 (see Fig. 14). Significant volumes of mining wastes, processing wastes, processing chemicals, stockpiles of products including Cu, Fe and Zn concentrates, construction debris, and demolition waste also remained on the site (BWSC, 2004). The mining wastes, processing wastes, and concentrates were acid-generating materials.



Figure 13. London Mill Plant 1976 - Before



Figure 14. London Mill Flotation Mill - Before

The first phase of the reclamation in this area was removal of constituents that were potential health risks to humans. In 2001, GSH removed polychlorinated biphenols (PCB) – contaminated oils and equipment from the London Mill area and other areas within the Lower North Potato Creek Watershed. The oil and equipment were properly disposed through a commercial PCB contractor. PCBs were not detected in soil samples collected from the former equipment areas (BWSC, 2002). Additional sampling was conducted in 2006 at the former transformer pad and it was determined that the pad and adjacent asphalt would be covered during future remedial actions to eliminate exposure to humans (BWSC, 2006a). An asbestos survey was completed in 2006 to identify any asbestos-containing materials (ACM) that would require removal prior to demolition. Two of the remaining structures at London Mill, the shop building and warehouse, contained friable ACM (BWSC, 2006c). The ACM was removed from the shop building by a

licensed contractor in 2006, prior to demolition of the building. The warehouse building remains in place.

In 2006, GSH began reclamation of the site by demolishing the remaining structures and removing waste to either an offsite, commercial disposal facility or other locations onsite for final disposal. Potentially hazardous materials, PCBs and ACM were segregated from the excavated materials and disposed at a commercial disposal site. Construction and demolition debris and materials known to contain cyanide, PAHs, or mercury were hand-sorted from the excavated materials and placed within the footprint of the former London Mill Flotation Plant. A geosynthetic clay liner (GCL) was placed over the former London Mill Flotation Plant to eliminate infiltration through the fill/waste material (see Fig. 15). Acid-generating materials were excavated and hauled to the Isabella Pit. Approximately 194,000 tonnes (214,000 tons) of non-hazardous, acid-generating materials from London Mill were placed in the Isabella Pit for sub-aqueous disposal.

The Plant Site reclamation will be completed in 2008 (see Fig. 16). The remainder of the area will then be revegetated using the seedbed preparation, lime, fertilizer, seeding mixtures and mulch as described in the Revegetation Section.



Figure 15. GCL at London Mill Flotation Plant



Figure 16. London Mill Plant Site

### **Tailings/Concentrate Area**

From 1922 until 1946, tailings were disposed in the London Mill area behind a rock and timber dam creating the tailings/concentrate area (see Fig. 17). The tailings/concentrate area is located east of the London Mill Flotation Plant within the former flood plain of Burra-Burra

Creek. The area covers approximately 4.5 hectares (11 acres) and extends 488 m (1600 ft) along the former location of Burra-Burra Creek.

During the operation of the London Mill Flotation Plant, occasionally the production of Fe and Cu concentrates exceeded the capacity of the other mineral beneficiation plants in the Basin for the concentrates. In the 1970s, the excess production of the concentrates was temporarily stored within bermed areas of the former tailings collection area. These storage practices lead to the mixing of the tailings with Fe and Cu concentrate when portions of the concentrate were reclaimed for processing in the mid 1980s. Two types of concentrate have been reported in the tailings/concentrate area, Cu concentrate and Fe concentrate. The Fe and Cu concentrates are a dark gray to black silt sized material.

In 2002, an investigation of the area showed that the tailings/concentrate area contained 263,615 m<sup>3</sup> (9,315,000 cu-ft) of acid-generating material. During 2006 and 2007, material was excavated from the area to modify the slope to allow for the placement of a 40-mil HDPE liner over the area (see Fig. 18). A total of 114,809 m<sup>3</sup> (4,056,858 cu-ft) of waste materials were removed from the area and disposed within the Isabella Pit.



Figure 17. Tailings/Concentrate Area - Before



Figure 18. Tailings/Concentrate Area - During

While the liner will significantly reduce infiltration through the tailings/concentrate material, poor quality interstitial water will still likely be present along the toe of the tailings/concentrate material adjacent to Burra-Burra Creek. Seepage of poor quality water was identified at the toe

of the Retention Pond dam just north of the tailings/concentrate area. An infiltrator system was installed to collect this poor quality seepage and direct it further downstream for treatment.

### **Tunnel Portal Area**

Starting in the 1950's, Fe concentrate was transported from the London Mill Flotation Plant to the Fe roasters via a pipeline passing through a tunnel in the ridge between the London Mill and Isabella processing areas. The pipeline, which had a clean out at the inlet to the tunnel, was occasionally drained. Iron concentrates accumulated in and around the portal and in the adjacent tributary to Burra-Burra Creek. The cut bank at the entrance to the tunnel covers an area 45.7 m (150 ft) by 12.2 m (40 ft). The entrance area had weathered iron concentrate and oxidation salts. Sulfide minerals comprised > 25 percent of the material (see Fig. 19). Samples of surface water collected from the tributary above and below the Tunnel Portal area indicated that water quality in the tributary deteriorated immediately downstream of the Tunnel Portal.



Figure 19. Tunnel Portal Area - Before



Figure 2. Tunnel Portal Area - After

In 2006, remedial actions were implemented to help isolate poor quality water from the Tunnel Portal area from good quality water to decrease the overall amount of water in the London Mill area requiring treatment. This diversion generally consists of collecting the base flow and storm flow, up to and including the 10-year/24-hour storm, from the tributary and diverting the flow to Burra-Burra Creek. This project included construction of an earthen dam to detain the surface water from the tributary upstream of the Tunnel Portal and installation of a pipeline to direct the discharge to Burra-Burra Creek downstream of the Tunnel Portal area. The diversion also prevented the surface water from entering the Tunnel Portal area so that excavation of Fe concentrate and other waste mining materials could be performed in dry

conditions. Approximately 1,528 m<sup>3</sup> (54,000 cu-ft) of Fe concentrate and waste materials were removed from the Tunnel Portal area and the stream bed (see Fig. 20) during the reclamation process. This material was taken to the Isabella Pit for disposal.

### **Revegetation**

The lack of topsoil in the Basin made revegetation challenging. In the earliest days of Cu production in the Basin, copper sulfide ore was processed by burning cordwood with ore piled on top (i.e., roasting) to burn off sulfides from the ore followed by smelting of the ore. This ore processing method required extensive logging of the area for roasting fuel. Sulfur dioxide fumes from ore roasting killed much of the remaining vegetation in the area. This method of ore processing continued from the 1850's to the 1900's. It has been estimated that about 1.2 m (4 ft) of the upper soil horizons have been lost to erosion throughout most of the Basin. Revegetating the remaining natural parent materials requires intensive management of seedbed preparation and application of soil amendments to produce acceptable revegetative results.

The practices used by GSH in their revegetation efforts are specifically designed for the remaining soil materials that have low pH (average 4.5 s.u.) and low or non-existent organic content. Even though adjustments to the practices are made to suit local site conditions, the general practice is to remove acid-generating materials, grade the site, stabilize the slopes, establish surface drainage controls, and cover the area with soil material generally to a thickness of about 0.46 meter (18 inches). The soil materials, obtained from designated borrow areas within the watershed, was limed at a rate of 11.2 to 15.7 Mg/ha (5 to 7 tons/Ac), and fertilized with 13-13-13 at the rate of 1 Mg/ha (900 lbs/Ac) the first season and 0.5 Mg/ha (450 lbs/Ac) the next season. No additional lime or fertilizer is applied after those applications. The seedbed is prepared by discing to a depth of 7.6 to 10.2 cm (3 to 4 inches) or, on slopes, tracked with a dozer. To this prepared surface, one of the following seed mixtures, (See Table 1) depending on the season, is applied at the rate of about 84 kg/ha (75 lbs/Ac). Annual rye grass is added in spring seedings at the rate of about 10.1 to 11.2 kg/ha (9 to 10 lbs/Ac). Rye grain is added in late fall/winter and Bermuda grass is added in hot dry weather.

Table 1. Spring and Fall Seed Mixture

Spring Seed Mixture (kg per 22.7 kg)	Fall Seed Mixture (kg per 22.7 kg)
Sericia lespedeza (scarified) – 3.6	Sericia lespedeza (scarified) – 4.1
S. lespedeza (unscarified) – 3.6	S. lespedeza (unscarified) – 4.1
Big Blue Stem – 2.7	KY tall fescue – 3.6
Korean lespedeza – 2.7	Ryegrass – 2.3
Kobe lespedeza – 2.7	Birdfoot trefoil – 1.8
Indian grass – 2.3	Orchard grass – 1.8
Switch grass (Alamo) – 2.3	Big Blue Stem – 1.4
Sideoats gramma – 0.9	Indian grass – 1.4
Red clover – 0.5	Sideoats gramma – 0.9
Ladino clover – 0.5	Red clover – 0.5
Weeping lovegrass – 0.5	Ladino clover – 0.5
Sunflower – 0.2	Weeping love grass – 0.5
Beggarweed – 0.2	

### Conclusion

Mining began at London Mill in 1853. In 1987, the site was abandoned and partially dismantled leaving acid-generating mining and processing wastes and physical hazards such as partially dismantled structures, shafts, underground voids, and steep slopes and highwalls.

GSH, through its agreements with the TDEC and US EPA Region 4, began reclaiming the Lower North Potato Creek Watershed in 2001, and is currently in the process of completing reclamation and revegetation. Much has been completed; more than 229,230 m<sup>3</sup> (8,100,000 cu-ft) of non-hazardous acid-generating material has been removed, all known hazardous or potentially hazardous material has been properly disposed, and more than 202.5 hectare (500 acres) have been graded, covered with soil, and revegetated. The diligent efforts of GSH and its knowledge of grading and revegetating mining-impacted soils with high acidity and very low organic content have resulted in a safe, environmentally protective area that will become part of the future use of historical interpretation of one of the few hard-rock mining sites in southeastern United States.

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actions at the London Mine and Flotation Plant Site. We would also like to recognize the cooperation of the Tennessee Department of Environmental Conservation and USEPA Region 4 in support of GSH's efforts to rapidly and efficiently complete the reclamation and revegetation of the London Mill area.

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Note: The documents prepared by BWSC are work products prepared for GSH and submitted to EPA Region 4 and TDEC in accordance with the Consent Orders and Commissioner's Order. Copies of the documents can be requested by contacting the Ducktown, TN GSH project office at 423-496-7900.