THE LARGEST ACID MINE DRAINAGE TREATMENT PLANT IN THE WORLD?[1]

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Abstract. In its voluntary remediation of the Tennessee Copper Basin, Glenn Springs Holdings commenced operation in January, 2005 a hydrated lime chemical treatment plant with perhaps the world's largest capacity for treatment of acid flow. Meeting its objective of protecting the Ocoee River from acidity and metal contaminants while the North Potato Creek Watershed is being ameliorated by remedial actions, the plant treats the baseflow and stormflow from the entire 15 square mile watershed**.** The process employs a novel approach of adding highly mineralized mine pit water to the relatively mild acidic creek flow to improve neutralization and metal flocculation efficiency. Once neutralized, the combined flow enters a 20 acre mine pit for retention and clarification before flowing to the Ocoee River. Average flow rate of the North Potato Creek inlet is over 8,160 gpm (18 cfs or 31 m^3/min) and the design capacity is over 400,000 gpm (972 cfs or 1651 m^3/min). Hydrated lime can be dispensed at a maximum rate of 7200 pounds per hour. Deep mines are dewatered and neutralized further upstream in the watershed, and Davis Mill Creek is also neutralized by a separate, conventional lime plant. Together, these chemical treatment plants protect the Ocoee as cleanup efforts in the Copper Basin progress.

Additional Key Words: Ducktown TN, acid mine drainage, Ocoee River, hydrated lime, chemical neutralization.

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Introduction

The Tennessee Copper Basin is the site of what has been described as the "largest man-made biological desert in the world". Located where Tennessee, North Carolina, and Georgia meet, (Figure 1) the area was the scene of underground copper and other metal mining from 1847 to 1987. 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, producing sulfuric acid that rained down within a 9,000 hectare (35 square mile) area. Severe erosion of the native soils gave the appearance of un-reclaimed surface mines. As a result of decades of soil conservation and reclamation practices, the Copper Basin sediment load has dramatically diminished, but acid rock drainage and mine drainage pollute the streams with acidity from high concentrations of iron, copper, manganese, aluminum, and zinc. Glenn Springs Holdings, a subsidiary of Occidental Petroleum, has entered into a voluntary cleanup agreement of the site with the Tennessee Department of Environment and Conservation (TDEC) and with USEPA Region 4. Progress since the 2001 agreement has been rapid for a CERCLA site, but GSH realized complete recovery within the North Potato Creek Watershed (as measured by annual biosurveys) would require many years. To protect the Ocoee River (a world class whitewater recreation resource) from metals contamination in the interim, GSH has supplemented its existing London Mill Water Treatment Plant (LMWTP) in an affected tributary of North Potato Creek (NPC) with the North Potato Creek Water Treatment Plant (NPCWTP), to chemically neutralize and remove metals contaminants before the stream reaches the Ocoee River. GSH also funds the Cantrell Flats WTP in Davis Mill Creek.

Treatment Strategy

Although the majority of mining in the Copper Basin was conducted by deep mining methods, limited surface mining at the lower terminus of the watershed was initiated in the 1970's. This was made possible by the construction of a massive diversion dam and 3,000 foot tunnel to pass North Potato Creek into Davis Mill Creek (Figure 2). The balance of the watershed below the diversion dam was routed around the open mine pit which effectively mined through a reach of North Potato Creek near its confluence with the Ocoee River. The final configuration of the surface mining effort (South Mine Pit or SMP) was a 20 acre pit approximately 200 feet deep, 1800' long, and 480' wide holding approximately 556 million gallons. The SMP is connected to partially flooded underground mine works. North Potato Creek was returned to its original alignment in 1991 with the SMP serving as an enormous sediment trap. Because of its strategic location (downstream of all mining and just upstream of the confluence with the Ocoee River) the stratified pit was the subject of a year long Engineering Evaluation Cost Analysis (EE/CA) in 2001-2002 which included a limnological and treatment investigation to determine the best means of chemically treating North Potato Creek. The flow at the SMP inlet is highly variable and is influenced by the intermittent operation of LMWTP calcium oxide treatment plant neutralizing pumped mine water 3.4 miles (about 3 hrs. flow travel time) upstream. SMP outlet flow averages 760 gpm higher than the inlet flow. The difference in flow is not entirely from groundwater (deep mine) influence but includes rainfall and surface runoff. The modeled 10 yr. 24 hr. storm flow for North Potato Creek at the SMP inlet is 972 cfs (436,234 gpm). Only because the diversion dam 1.4 miles upstream remains a functional surge pool to attenuate this peak flow was this in-stream system considered.

Average values over 12 month period 2001-2002 EE/CA at South Mine Pit

Location	gpm	Field pH	Acidity (mg/L)	Dissolved .iron (mg/L)
Pit inlet	8,160	5.0	23	10
Pit outlet	8,920	3.3	37	3.6

The North Potato Creek Water Treatment Plant was designed and constructed to meet the following objectives presented in the Administrative Order on Consent (AOC) with EPA:

- Adequately treat groundwater flow into the South Mine Pit and the flow in North Potato Creek attributable to a 10-year/24-hour storm event.
- Address and alleviate contaminant discharge from the North Potato Creek into the Ocoee River.

No human health risks were found in the Ocoee River as a result of the NPC discharge. A Streamlined Risk Assessment identified nine contaminants in the SMP inlet/outlet of Potential Environmental Concern (COPEC) which pose ecological risk: *pH*, *aluminum*, cadmium, cobalt, *copper*, *iron*, manganese, lead, and *zinc (primary drivers of risk italicized)*. A one year limnological investigation involved monthly collection of water quality samples from near surface and at depth from 3 locations within the SMP as well as thermocline profile (temperature, pH, specific conductance, ORP, dissolved oxygen with depth) at 16 locations within the pit (Figure 3). The pit was chemically stratified with lower density and specific conductivity water overlaying higher density and specific conductivity water (Figure 4). Chemocline monitoring also confirmed that the SMP is consistently stratified throughout its extent. Coincident temperature stratification was also observed during the study period. As North Potato Creek enters the SMP, it rapidly mixes with the shallow water, but is resistant to mixing with the dense water below a chemocline of approximately 21 to 33 feet (at the time of the EE/CA). Dissolved iron rapidly precipitates, releasing hydrogen ions, thereby lowering pH at the outlet. Although this chemocline varied seasonally to a small degree, the deep pit water (approximately 10 times the TDS concentration) remained fairly unreactive in the mass-balance models: The SMP appears to gain water that is more characteristic of the shallow water rather than SMP deep water. The distinct (but shallow – approximately 1 foot) chemocline separating the two waters also is a barrier to diffusion mass transfer. The untreated SMP could be classified as a "meromictic lake" which displays permanent thermal and chemical stratification such that shallow and deep waters do not mix. This stable situation represented a potentially undesirable situation in that if turnover of the pit occurred (as it became neutralized and shallow and deep water densities changed), the concentration of metals leaving the SMP could increase several orders of magnitude, with dramatic visual and ecological impacts downstream. Compare water quality (including average concentrations of dissolved metals) above and below the chemocline:

	pH	s.c.	Acidity mg/L	Al µg/L	Cd µg/L	Co µg/L	Cu µg/L	Fe mg/L	Mn mg/L	Pb µg/L	Zn µg/L	SO_4 mg/L
shallow	3.37	660	30	1147	0.69	25	108	3.6	2.5	5.5	605	262
deep	4.64	3860	1140	995	0.3	68	18.1	551	37.1	0.59	876	2895

Obviously, an understanding of the pit limnology and bathymetric properties is important for understanding the ramifications for utilizing the SMP as a clarifier and as a permanent repository for metal precipitates. Unlike most natural impoundments in temperate latitudes, and because of the low surface area to depth ratio of the pit, there must be an input of sufficient energy (prevailing wind) to cause a "turnover" even if the temperature (and resultant density) of the shallow layer would increase beyond the deep layer (water exhibits maximum density at 4°C). A hydrodynamic model indicated the SMP will remain stratified in a meromictic state, mainly due to high chemically induced density difference between the shallow and deep water, even under extreme wind conditions and changing water chemistry in the shallow SMP water.

Treatability Studies

The geochemical reactions that occur during neutralization of ARD water with alkalinity are complicated and are generally controlled by the most abundant heavy metal in the water, iron. Therefore, the reactions of this constituent will tend to control the mobility and availability of the less abundant cationic metal species. AMD plant operators have long realized it is very difficult to treat elevated aluminum only or elevated manganese only – without the presence and co-precipitation of iron, these parameters are very difficult and expensive to reduce to low concentrations. The precipitation and removal of iron oxyhydroxide from solution in turn affects the concentrations of other metals in the aqueous phase through sorption and co-precipitation reactions. Laboratory and field studies were conducted using low volumes of deep SMP water high in Total Dissolved Solids (TDS) to treat much larger volumes of lower TDS North Potato Creek water to reach applicable ecological standards in the effluent stream. The commingling of high TDS water and low TDS water can be used to control the chemistry of treated water. The goal is to provide sufficient iron in solution to promote nucleation, growth, and production of flocs of adequate size and density to settle quickly. Bench–scale treatability studies conducted in the laboratory on NPC and SMP water showed that the high TDS SMP deep water should be mixed with the creek water at a ratio of 10:1 to 40:1 (creek: deep). Laboratory experiments involving the titration of the high TDS and low TDS mixture to various endpoints using alkaline additives were conducted to evaluate the potential and possible limitations of pH adjustment for the reduction of metal concentrations. Limitations of the laboratory bench scale test (pressure, temperature, residence time, short circuiting) created uncertainty as to the settling properties of the metal precipitates within the SMP. To increase confidence, a full scale pilot study was conducted in July and August, 2002. Both baseflow and stormflow conditions were simulated with the LMWTP both operating and idle. A storm event was simulated as the 30" pipe in the diversion dam was closed, impounding several acre feet of water behind the dam. As it was abruptly released, flows at the SMP entrance exceeded 25,000 gpm. Monitoring of the simulated storm and over 500 laboratory samples in an extended storm water monitoring program indicated the design storm will have very little less acid load than during normal flow, so lime feed to neutralize the flow is not the limiting factor in plant design.

Results of the field treatability studies showed that the generated, iron-rich sludge settled through the SMP shallow and deep water, and average removal efficiencies of most metals from NPC water were greater than 95%. Bench scale testing and literature review indicated limited variability in the sludge formed from a 10:1 to 40:1 (creek: deep) mix neutralized with hydrated lime. The removal of COPECS from NPC water via alkaline addition is principally by adsorption reactions onto the iron oxyhydroxide sludge. While partial desorption of metals may occur at the anoxic, non-reducing conditions present at the bottom of the SMP at pH 4.6, bench scale testing over a six week period indicated the sludge was stable even under more acidic conditions than present at the SMP bottom. Analysis of sediments collected (by Kemmerer sampler) from the SMP floor indicated the predominance of stable ferric iron (goethite) suggesting that ferric iron phases remain in the bottom of the pit.

Plant Construction and Operation

Start up of the NPCWTP began on January 10, 2005 after 6 months of construction. Initially, 3300 gpm creek water was rapid mixed with 300 gpm of deep water and over 400#/hour hydrated lime. The resulting slurry was returned to NPC where it was allowed to mix with the creek flow for 200' before being sampled at the flow weir 450' upstream of the pit entrance. Creek water, deep SMP water, and lime flow rates were varied over the next few hours and days to determine the optimum ratio at the pit entrance. Field pH and field dissolved (filtered) iron are the primary parameters monitored. Within 8 days of operation, the pH of the upper 35' of the SMP (approximately 200 million gallons) was raised from 3.7 to 5.8 (Figure 5). With the possible exception of early pH excursions due to a 3.7" rainfall event and associated lightning strikes to the new instrumentation, the dissolved iron concentration at the pit discharge has been reduced to <0.1 ppm. Preliminary (not validated) laboratory data suggest that the objective of reducing COPECS to below conservative ECO screening values will be achieved by the plant operation.

Treatment Process, Monitoring

The NPCWTP and LMWTP are networked in a computer process control program marketed as Prophecy®. At the NPCWTP, North Potato Creek flow, inlet pump flow, pH and specific conductance are monitored, and as the high TDS water from the SMP deep pump (or alternately flow from the recycle pump) is added to creek water in the rapid mix tank, lime feed rate from the baseflow or stormflow lime feeders of the 90 ton silo and its level, blowers, and mixers are monitored, along with pH and specific conductance. This combined flow (typically about 3300 gpm) of elevated pH water joins the main flow in North Potato Creek and is monitored again at the pit entrance for pH and conductance (along with regular field lab samples for pH and dissolved iron). The system also monitors the SMP outlet for flow, pH and conductance. To provide early warning for upsets within the process or in the SMP, alarms are programmed where pH or specific conductance exceeds a threshold value. Of particular interest is a pair of Hydrolabs® mounted on buoys at 10' and 40' depth in the SMP. Powered by solar panels and linked by radio to the network, the plant operator continuously monitors pH, conductance, dissolved oxygen, temperature and ORP in the shallow and deep layers of the SMP. Weekly field measurement indicates the depth of the chemocline has increased about 4' in the first 60 days of plant operation, and that deep water chemistry has remained unchanged. A contingency plan for SMP upset is initiated when the shallow Hydrolab® or SMP outlet exceed field confirmed pH or specific conductance alarm values. Sandbag and barriers can effectively prevent discharge to the Ocoee River as North Potato Creek is diverted to a refurbished channel around the SMP via closed flood gates in the concrete diversion dam at the pit entrance. Recirculation pumps would circulate SMP water through the plant until the upset was resolved and creek flow restored.

Summary

The Copper Basin Project operates three chemical treatment plants (Figure 1) that are removing approximately 96% of the contaminant load to the Ocoee River while remedial actions reduce the sources of contamination within the North Potato Creek and Davis Mill Creek watersheds (Figures 6 and 7). Glenn Springs, TDEC, USEPA, and the water users of the Ocoee River are encouraged that as the Copper Basin Project works toward the cleanup of the Basin, the Ocoee River will be protected.

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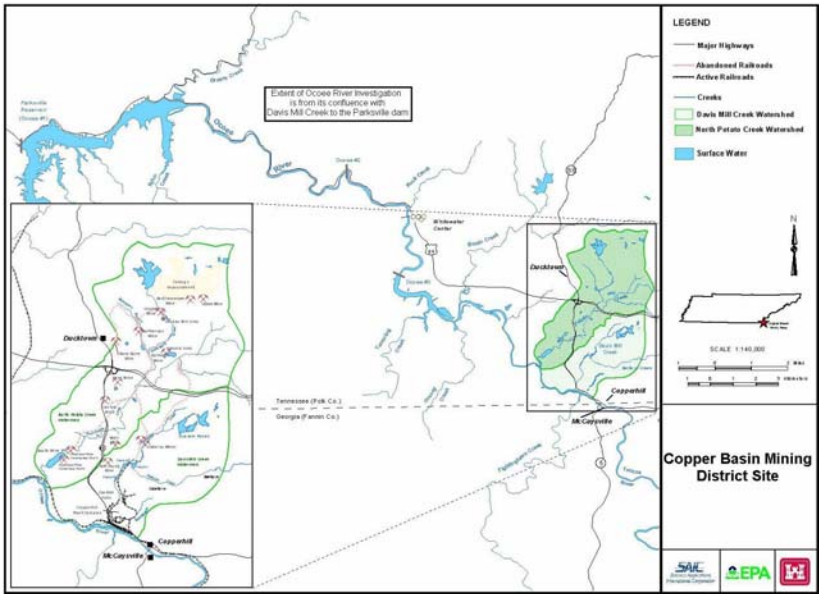

Figure 1. The Tennessee Copper Basin and the Ocoee River

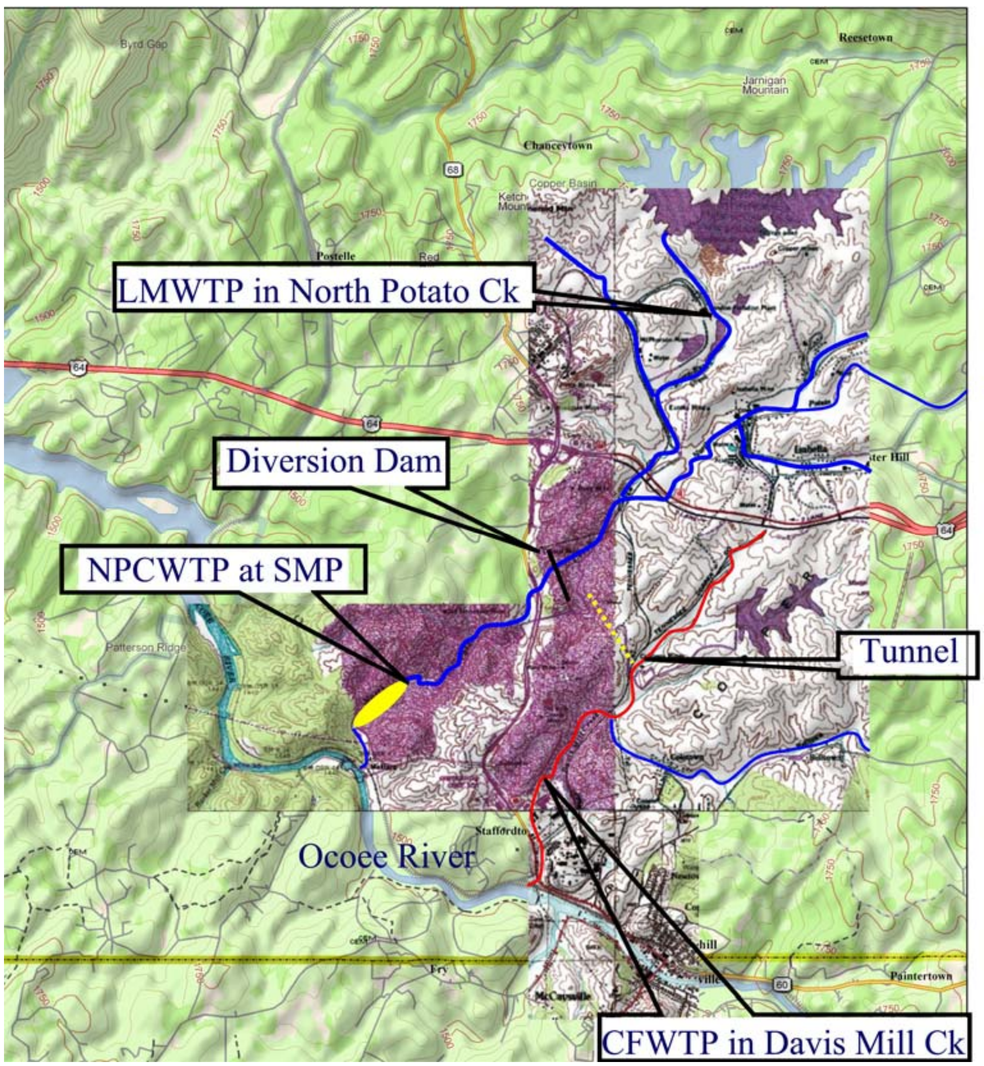

Figure 2 Copper Basin and Water Treatment Plants

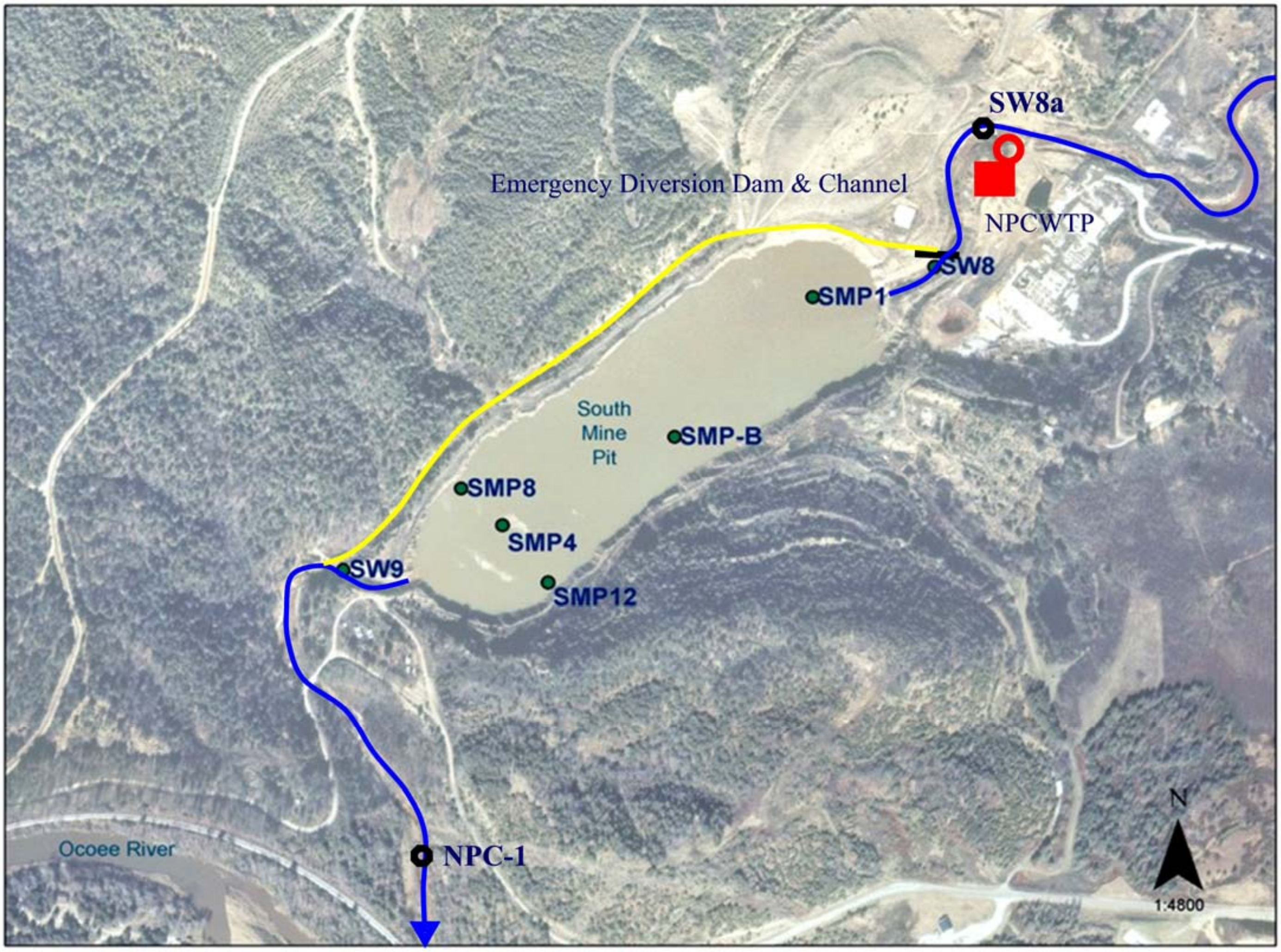

Figure 3 South Mine Pit Monitoring

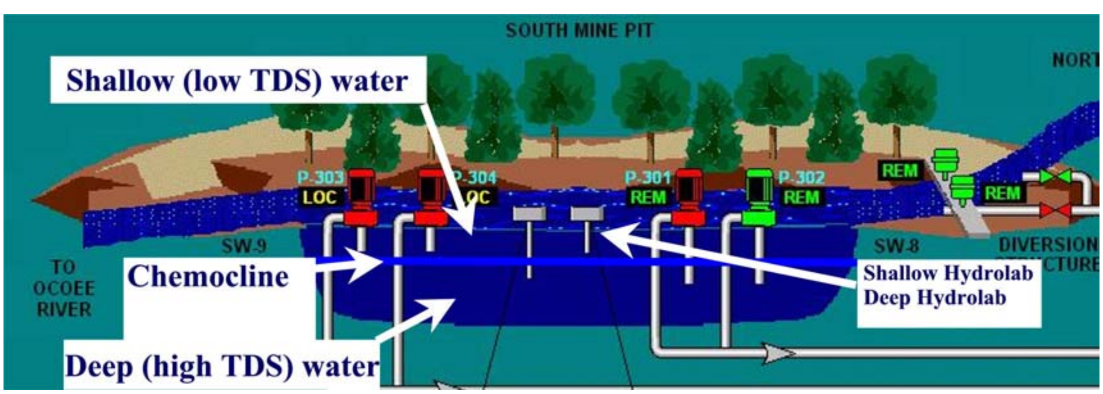

Figure 4 South Mine Pit x-section

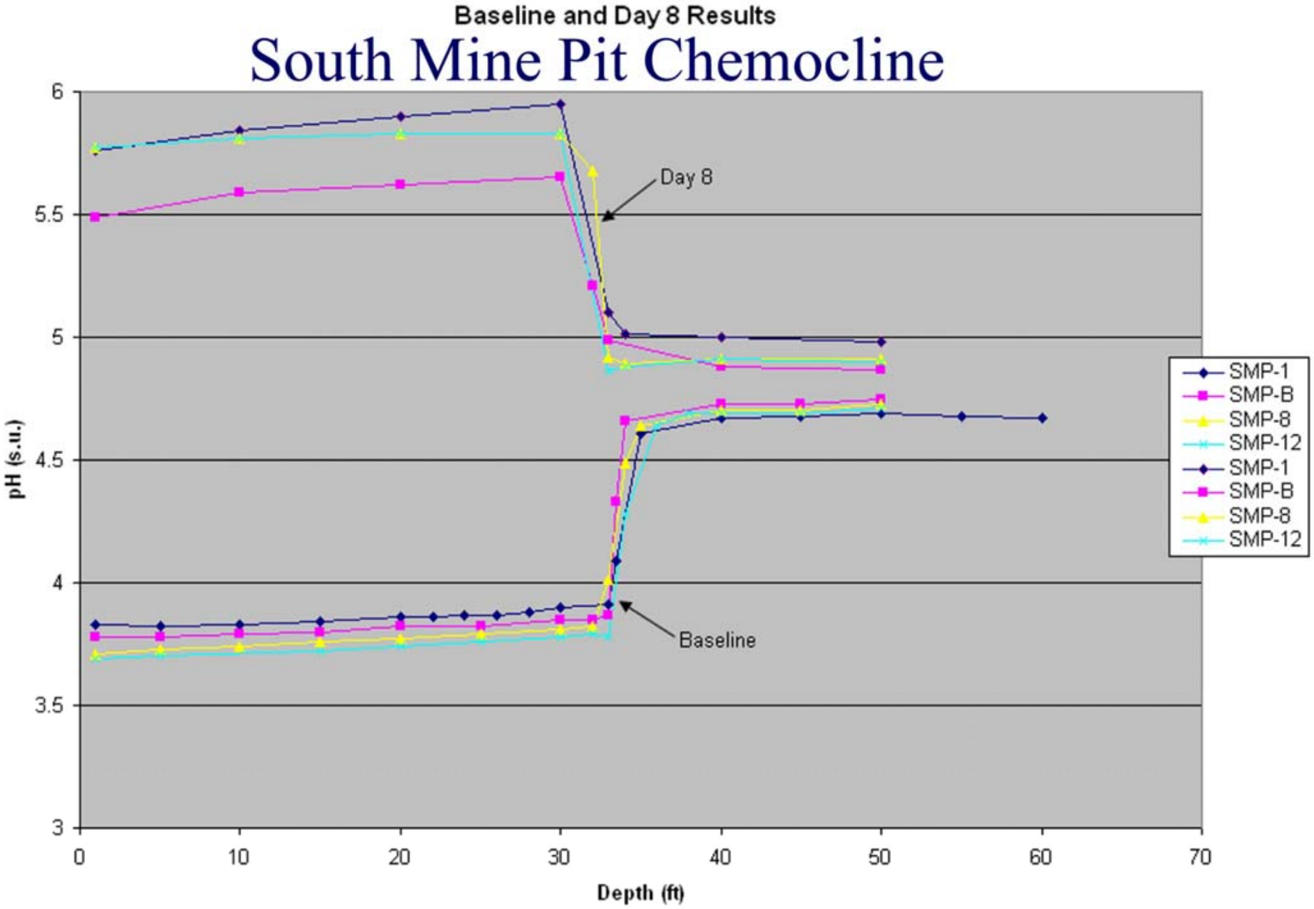

Figure 5 South Mine Pit Chemocline before and after NPCWTP commencement.

Figure 6. Note the plume of treated water at the pit entrance (left side of left photo) which settles in the pit, protecting the Ocoee River, left. This may be the first clear discharge to the Ocoee from North Potato Creek in over 100 years.

Figure 7. Davis Mill Creek in 1970 dramatically diminished the water uses of the Ocoee River. With the Cantrell Flats WTP and associated diversion of unaffected drainage, the Ocoee is being restored.