INNOVATIVE WATER TREATMENT PLANT UTILIZING THE SOUTH MINE PIT AT THE COPPER BASIN MINING SITE IN TENNESSEE, USA[1]

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Abstract. To protect the Ocoee River in Tennessee (USA) from acidity and metals loadings from historical copper mining and processing activities, OXY USA is conducting removal actions to alleviate contaminant discharges from North Potato Creek (NPC). One such action is construction of an innovative in-pit lime treatment facility at the South Mine Pit designed to treat NPC flows up to a 10-yr, 24-hr storm of 1,649 m^3/min (972 cfs) prior to discharge to the Ocoee River.

OXY USA performed an Engineering Evaluation / Cost Analysis (EE/CA) to identify and evaluate alternatives to address contaminant discharges from North Potato Creek to the Ocoee River. The alternative that was determined to best meet the evaluation criteria was the in-pit treatment alternative. The in-pit treatment system treats the entire 10-yr, 24-hour storm flow of NPC by adding lime to raise the pH to the level required to precipitate dissolved metals and then settling the precipitated solids in an existing 8.1 hectare (20 acre) abandoned surface mine pit. The treatment system utilizes the existing surface mine pit as a settling pond. The in-pit treatment facility was constructed for 15% of the estimated cost of a conventional lime treatment facility capable of treating comparable NPC flows. The NPC Water Treatment Plant operations began in January 2005 and results show that reductions in aluminum, copper, iron, manganese, zinc, and other dissolved metals loading of over 360 kg (790 lbs.) per day to the Ocoee River are being achieved.

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Introduction

The Copper Basin in Tennessee (USA) is comprised of two watersheds, the North Potato Creek (NPC) and Davis Mill Creek Watersheds. Both of these watersheds discharge into the Ocoee River. A map of this area is shown in Fig. 1. The primary environmental issues in the Copper Basin are associated with the impacts from historical Cu mining and mineral processing operations that were conducted from the mid-1800s until 1987. Acid generating materials at the site are metallic sulfides, including pyrite and pyrrhotite. To protect the Ocoee River from the acidity and metals loading from these historical operations, OXY USA began operating water treatment plants near the mouth of Davis Mill Creek and near the mouth of North Potato Creek. The refurbished Cantrell Flats Water Treatment Plant began treating Davis Mill Creek water in 2002 and the North Potato Creek Water Treatment Plant (NPCWTP) began treating North Potato Creek water in 2005. Together, these two water treatment plants are removing over 95% of the acidity and metals loading from the Copper Basin prior to discharge to the Ocoee River.

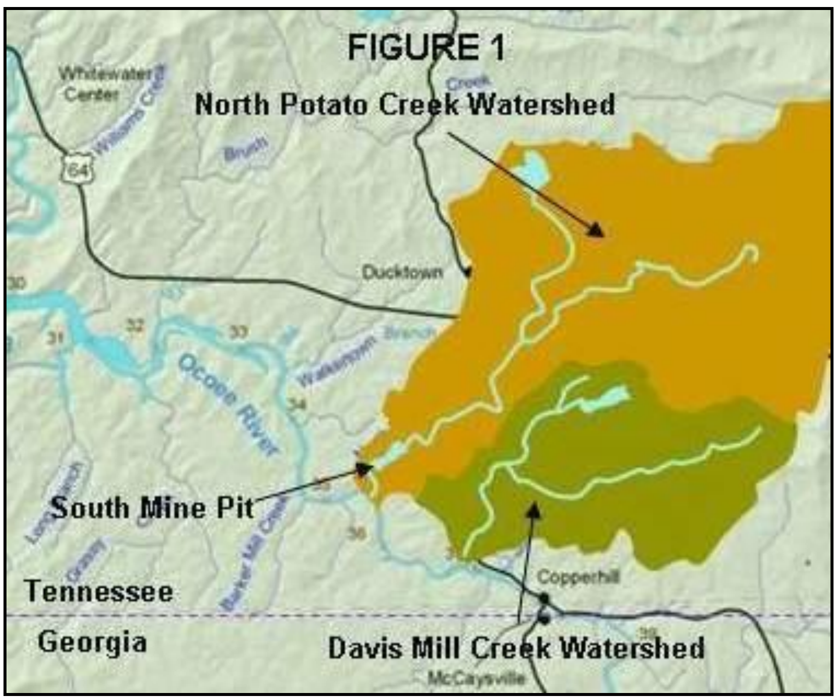

Figure 1. Regional Map of the Copper Basin

The NPC Watershed contains 3,925 hectares (9,700 acres) and discharges into the Ocoee River. North Potato Creek flows through the South Mine Pit (SMP) located 0.64 km (0.4 mile) above the confluence of the NPC with the Ocoee River. The SMP is an abandoned surface mine with a surface area of approximately 8.1 hectares (20 acres) that was opened in the late 1970's. North Potato Creek was routed through the SMP in 1991 to act as a sediment trap prior to discharge to the Ocoee River.

The North Potato Creek Water Treatment Plant (NPCWTP) was constructed to address and alleviate contaminant discharge from NPC into the Ocoee River while long-term work and study are proceeding upstream in the NPC Watershed. The NPCWTP was required to treat flow in

NPC attributable to a 10-year, 24-hour storm event. The NPCWTP was constructed based on the results of an Engineering Evaluation / Cost Analysis (EE/CA) (Barge, Waggoner, Sumner, & Cannon, et al., 2003) prepared pursuant to an Agreement on Consent (AOC) between U.S. EPA Region 4 and OXY USA, Inc. In the EE/CA, flow measurements, field parameter measurements, and sampling were performed to characterize NPC and the SMP. Following site characterization, alternatives for addressing the objectives of the AOC were developed and evaluated. This paper describes the design, operation, and performance results of the selected alternative, in-pit treatment, for the NCPWTP.

Site Characterization

The annual flow average for NPC, including base and storm flows, at SW8 the monitoring location at the inlet to the SMP, is 30.84 m^3/min (8,160 gpm or 18.2 cfs). The annual flow average at SW9, the monitoring location at the discharge from the SMP, is 33.72 m^3/min (8,920 gpm or 19.9 cfs). Refer to Fig. 3 and 5 for the location of SW8 and SW9. The difference in flow is from groundwater, rainfall, and surface runoff. The 10-yr, 24-hr storm flow for NPC at SW8 is 1,648 m^3/min (436,000 gpm or 972 cfs).

The water quality in NPC at SW8 has an average pH of 5 s.u., acidity of 23 mg/L as $CaCO_3$, and dissolved iron of 10 mg/L. The corresponding average values for pH, acidity and dissolved iron at SW9 are 3.3 s.u., 37 mg/L and 3.6 mg/L, respectively. Other dissolved metals present in NPC in lower concentrations include: Al, Cd, Co, Cu, Pb, Mn, and Zn.

The South Mine Pit is approximately 550 meters (1,800 feet) long by 146 meters (480 feet) wide, and has a maximum depth of approximately 61 meters (200 feet). The volume of water contained in the SMP is estimated to be 2,102,000 m^3 (556,000,000 gallons).

The South Mine Pit is a meromictic lake. The water quality at depth in the SMP is characterized by a lower density, lower specific conductance layer above a higher density, higher specific conductance layer indicating chemical stratification in the water column. The specific conductance throughout the depth of the pit is depicted in Fig. 2. The figure shows a sharp change in specific conductance indicative of marked differences in chemistry between the upper and lower layers of the pit, or chemocline, at a depth of 7.0 to 7.9 meters (23 to 26 feet). Coincident temperature stratification has also been measured. The pH, acidity, and dissolved iron in the upper layer of the pit were found to be 3.4 s.u., 37 mg/L (as $CaCO_3$), and 3.7 mg/L, respectively. These values were essentially the same as the values measured at the discharge from the pit at monitoring location SW9. The chemistry in the upper layer of the pit is generally homogeneous over the entire 8.1 hectares (20 acres) and through the pit discharge. The pH, acidity, and dissolved Fe values in the lower layer of the pit were found to be 4.7 s.u., 870 mg/L to 1,270 mg/L (as $CaCO_3$), and 530 mg/L to 640 mg/L, respectively. The potential of the SMP to turn over, or become well-mixed, was a major consideration in the design of the NPCWTP because a loss of stratification could potentially result in degradation of water quality in NPC below the pit and in the Ocoee River approximately 0.64 km (0.4 mile) down stream. Density stratification is maintained seasonally as is O_2, pH, temperature, and Eh and all show similar seasonal profiles. The CE-QUAL-W2 model was used to develop a limnologic model of the South Mine Pit, and the results of this modeling show that the density stratification controls the water column and seasonally induced density changes of pit water are insignificant. The details of this investigation are presented in the second reference cited (Colarusso et al., 2003).

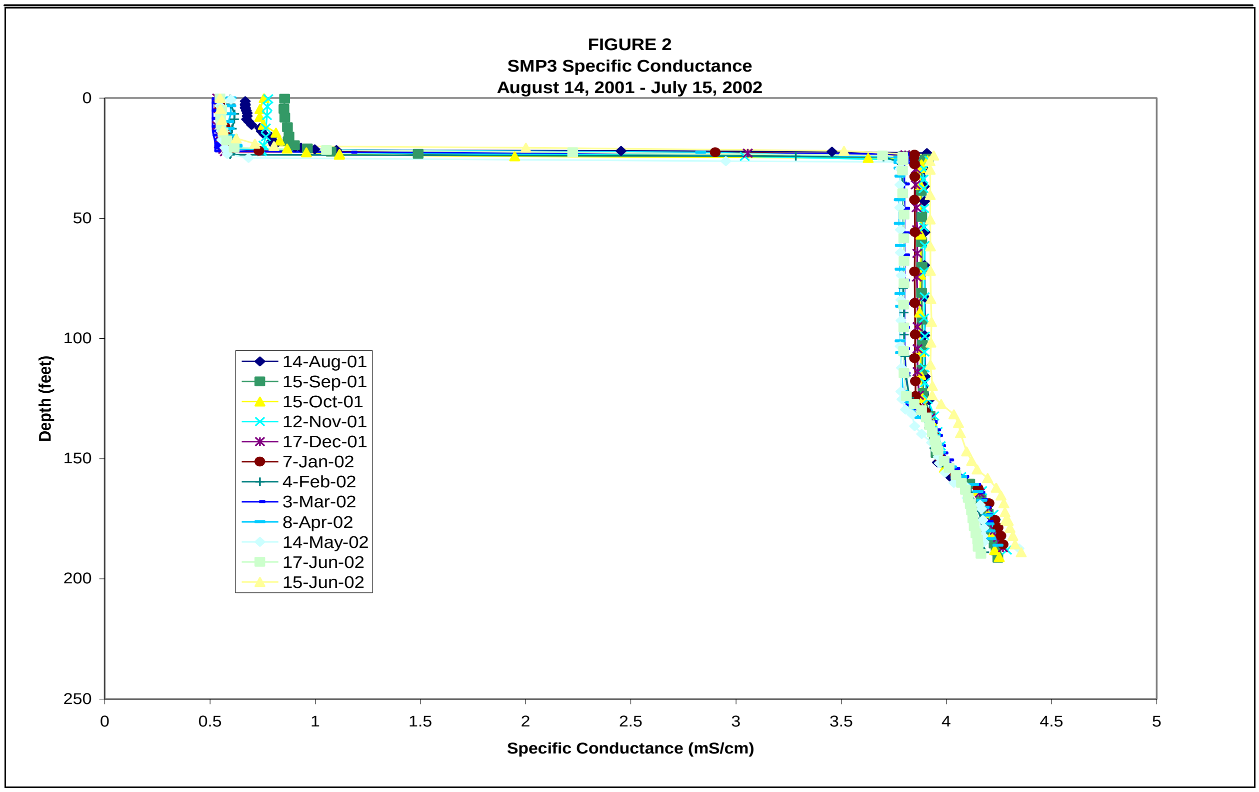

Figure 2. SMP3 Specific Conductance August 14, 2001 - July 15, 2002

NPCWTP Design and Operation

Basic Design and Operation

The NPCWTP design and operation is described in the following and is depicted schematically in Fig. 3. The NPC pump station, located upstream of the SMP, pumps 11.3 m^3/min (3,000 gpm) of NPC flow to the rapid mix tank. In the rapid mix tank, hydrated lime is added to raise the pH of the water. After lime addition, the water discharges from the rapid mix tank into NPC downstream from the NPC pump station where the water recombines with the remaining NPC flow. The NPC pump station, rapid mix tank, and lime silo are shown in Fig. 4. Lime is added to the rapid mix tank in sufficient rates to raise the pH of the combined NPC flow to a pH of approximately 10 that will precipitate iron and other dissolved metals from the NPC flow. Mixing and natural flocculation (i.e., no polymer is used to enhance settling) occur as the combined rapid mix tank discharge and NPC water flow 244 meters (800 feet) downstream and discharge into the north end of the SMP. The SMP serves as a large settling pond where precipitated solids settle to the bottom of the pit prior to the discharge from the south end of the SMP. Laboratory and full scale field studies conducted prior to construction of the NPCWTP indicated that the chemical stratification in the SMP would remain after treatment began creating a high pH layer of treated water overlying the lower pH and high dissolved solids water in the lower layer of the pit. Studies also confirmed that precipitated solids would settle through the chemocline separating the upper and lower layers in the pit. Results of these studies can be found in Barge et. al. (2003) and Colarusso (2003). The main precipitation reaction is the oxidation of iron and formation of iron oxyhydroxides. Geochemical reactions occurring during laboratory and field treatment studies are further discussed in Chermak, et. al. (2004).

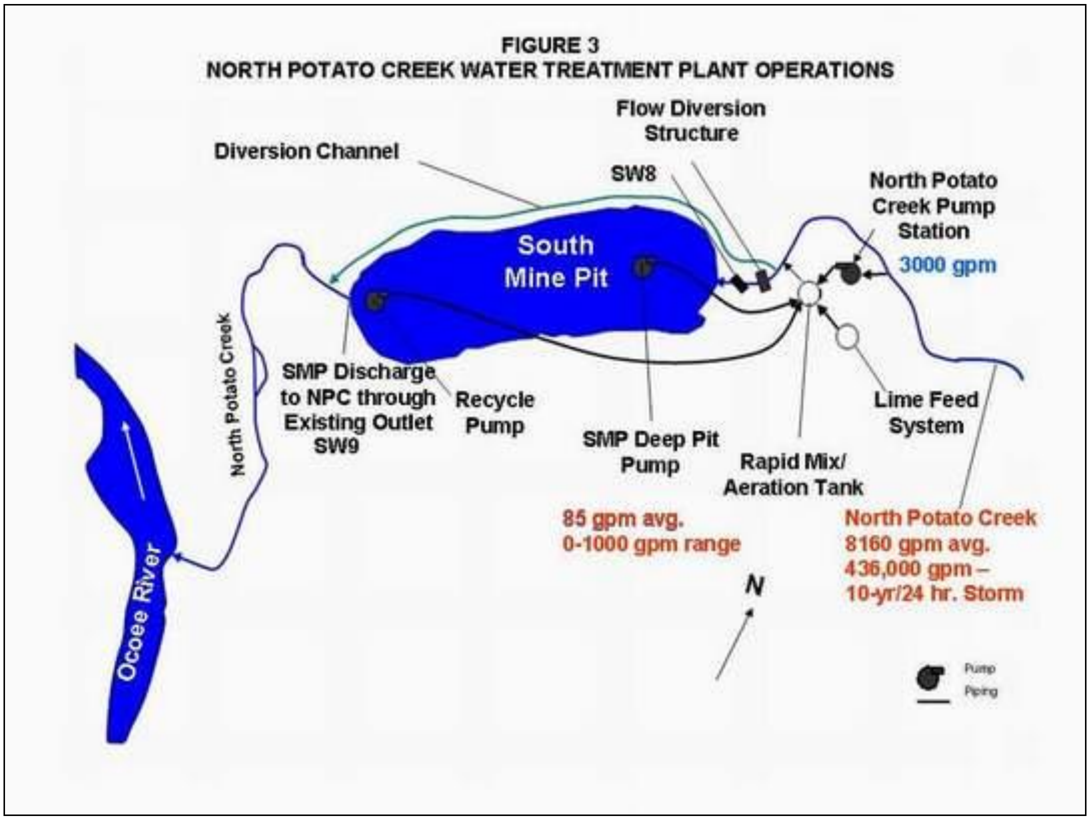

Figure 3. North Potato Creek Water Treatment Plant Operation

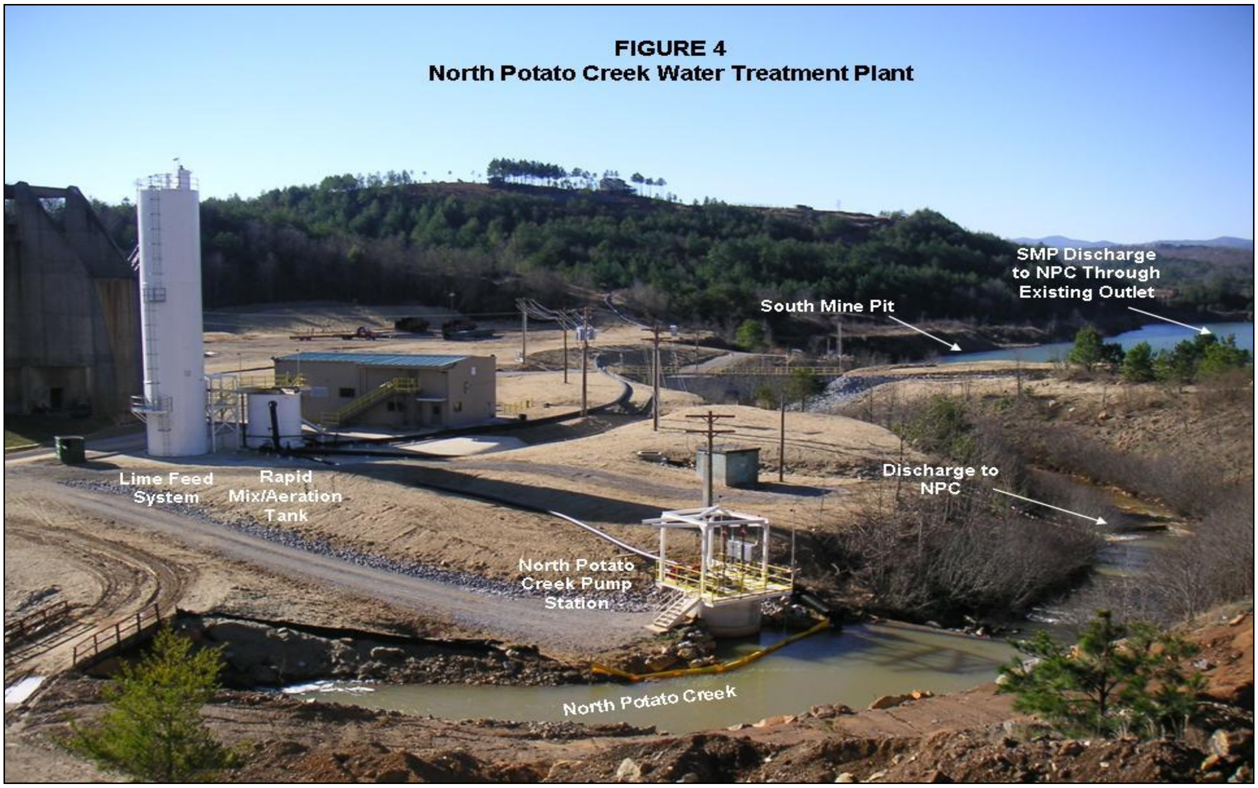

Figure 4. North Potato Creek Water Treatment Plant

In addition to lime feed, high dissolved solids water pumped from the lower layer of the SMP may be added to the rapid mix tank as seed water for iron flocculation. Although sufficient dissolved oxygen is typically present in the NPC flow to oxidize the dissolved iron in NPC, a cascade aerator is incorporated into the design at the discharge from the rapid mix tank into NPC. Additionally, a blower is available to provide oxygen to the rapid mix tank during periods of low flow and/or dissolved oxygen in NPC.

Rapid Mix Tank

The rapid mix tank is mixed by the tangential feed configuration of the discharge from the NPC pump station. Water is discharged into the base of the rapid mix tank at high velocity in a tangential manner that causes centrifugal mixing within the tank. Water discharges from the top of the rapid mix tank through a pipe to NPC. The rapid mix tank has a working volume of 52.9 m^3 (14,000 gallons). Although not normally required, the blower is available to supplement mixing in the tank.

Lime Feed System

Hydrated lime is fed by volumetric lime feeders located in the lime silo. The lime silo has a capacity of 170 m^3 (6,000 cubic feet or 222 yd^3), and deliveries are made every six days on average, with the lime transferred pneumatically. NPC water is utilized for dissolving water for the hydrated lime. A pipe branches from the NPC pump station discharge pipe prior to the pipe connection to the rapid mix tank. The branch pipe carries 0.76 m^3/min (200 gpm) of NPC water to the lime-dissolving tank located in the lime silo. NPC water continually discharges at the 0.76 m^3/min (200 gpm) flow rate into the 3.78 m^3 (1,000 gallon) lime-dissolving tank where hydrated lime is fed at varied rates as required to raise the pH in NPC. The resulting lime solution overflows the lime-dissolving tank and flows into a trough that discharges into the rapid mix tank. The trough discharges into a vertical pipe that feeds lime solution into the base of rapid mix tank at the NPC pump station discharge pipe location. The high velocity of the NPC pump discharge into the rapid mix tank causes the lime solution to be mixed in the lower portion of the rapid mix tank.

pH Control System

The pH control system for the NPCWTP is designed to be operated either manually or automatically. The lime feed rate is based on maintaining set pH values at two locations, monitoring station SW8 at the NPC discharge into the SMP and monitoring station SW9, at the discharge from the SMP. Due to the homogeneous character of the upper layer of the pit, the pH values and dissolved metals concentrations in the upper layer of the pit are the same as the pH values and dissolved metals concentrations at monitoring station SW9.

The pH and acidity in NPC upstream of the SMP varies widely depending upon several factors but mainly upon the flow in NPC. During rainfall events, the pH in NPC initially decreases and the acidity increases. Consequently, lime feed must be increased to maintain the desired pH as storm flows increase. The lime feed system provides lime to the NPC flow at an average dose rate of approximately 57 mg/L. High storm flows in NPC create the greatest demand for lime to maintain the desired pH at the two monitoring locations. The pH may increase rapidly at SW8 during rain events. However, due to the large buffering capacity provided by the 756,000 m^3 (200,000,000 gallon) volume in the upper layer of the SMP, the pH at SW9 does not increase as rapidly and the lime feed rate can be adjusted to maintain a relatively constant pH from the pit discharge and consequently from NPC to the Ocoee River.

The large volume of the upper layer provides a theoretical detention time of 16 days at average NPC flow rates.

Contingency Measures

As mentioned earlier, pit turnover or loss of pit stratification was a concern in the development of the in-pit NPCWTP. Although studies were performed that found the pit stratification to remain stable, concerns over the adverse impacts from the high dissolved solids water from the lower layer of the pit discharging from the pit to the Ocoee River required that contingency measures be developed. The contingency measures that were developed included construction of a diversion ditch to allow diversion of the NPC flow around the SMP and a means to stop discharge from the pit. Additionally, the contingency measures include a pump system to recycle pit water from the discharge end of the pit back to the treatment plant for additional lime treatment. In normal plant operations, NPC water flows through the diversion structure located in NPC. During contingency operations, the sluice gates are closed on the diversion structure to divert flows around the SMP through the diversion ditch. While NPC water flows around the SMP, recycle pumps are utilized to pump water back to the treatment plant for additional treatment until the water quality in the upper layer of the pit is of acceptable quality to resume discharge from the south end of the pit.

System Monitoring

The monitoring system for the NPCWTP includes equipment that measures flow, water quality indicators, and other parameters, all fed to a PLC-based system. The monitoring system provides continuous measurement of parameters and includes alarm functions for selected parameters when those parameters fall outside the desired range. Flow is measured at the inlet and outlet of the SMP, at the discharge to the rapid mix tank, and from the pump discharge from lower layer of the SMP to the rapid mix tank. Specific conductance and pH are measured at the monitoring stations SW8 and SW9.

The NPCWTP also includes a water quality parameter monitoring system for the SMP designed to monitor water quality in upper and lower layers of the pit. The system features two Hydrolab® water quality monitoring systems that provide continuous measurement of pH, specific conductance, oxidation-reduction potential, temperature, and dissolved oxygen. Each Hydrolab® is suspended from a buoy located in the middle of the SMP. One Hydrolab® is suspended in the upper layer of the pit at a depth of 3 meters (10 feet) and the other Hydrolab® is suspended in the lower layer of the pit at a depth of 12 meters (40 feet). The Hydrolabs® are cleaned and recalibrated every two weeks. Continuous Hydrolab® measurements are transferred to the control room at the NPCWTP by solar powered radio transmitter located on the buoy. This portion of the monitoring system is designed to monitor the upper and lower layers of the SMP for changes in water quality that may indicate loss of pit stratification. Fig. 5 depicts the pit configuration and monitoring locations.

Construction and Operation and Maintenance Cost

The construction cost, operation and maintenance cost, and the treatment cost per 1000 gallons for the NPCWTP are provided in Table 1. The estimated cost for a conventional water treatment plant to accomplish comparable treatment of NPC is also provided.

Figure 5. Monitoring Locations

Table 1. Cost of Treatment System

TABLE 1 COST OF TREATMENT SYSTEM		
	North Potato Creek In-Pit Water Treatment Plant and Associated Infrastructure	Estimated Cost for Conventional Water Treatment Plant
Construction Cost (Including Engineering Cost)	$4,000,000	$25,000,000
Annual Operation and Maintenance Cost	$400,000	$1,300,000
Treatment Cost Per 1,000 Gallons	0.085	$0.24

Performance Results

Operation of the North Potato Creek Water Treatment Plant began on January 10, 2005. Daily field measurements of dissolved iron by a Hach colorimetric method have been performed at the pit discharge location SW9 since plant operations began. These results are depicted in Fig. 6. Samples were also collected for laboratory analysis at two-week intervals. Laboratory results for Al and Zn are presented in Fig. 7 and 8, respectively. Removal percentages for Cu, Cd, Mn, Pb and Co are shown in Table 2. The largest NPC storm flow treated to date by the NPCWTP is 181.4 m^3/min (48,000 gpm). The concentrations of each constituent are compared to the average concentrations measured during the EE/CA conducted during 2001 and 2002.

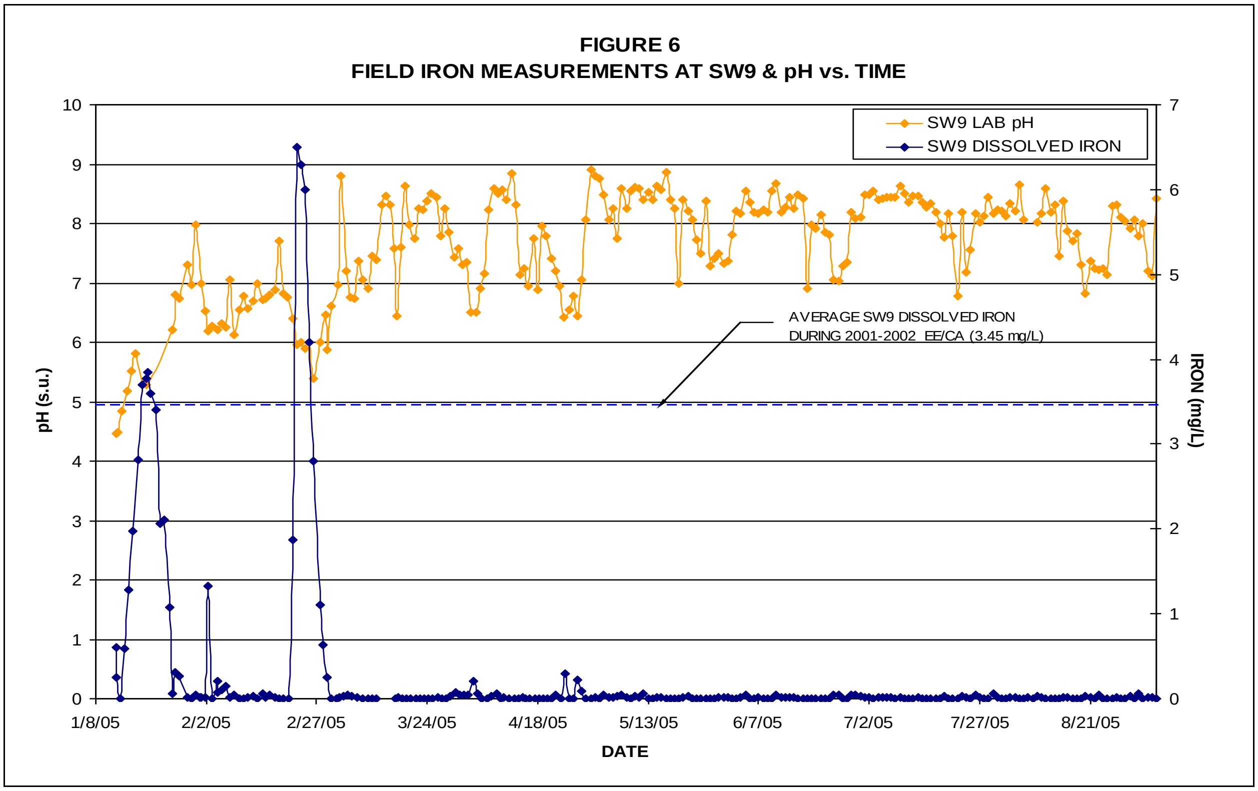

Figure 6. Field Iron Measurements at SW9 & pH vs. Time

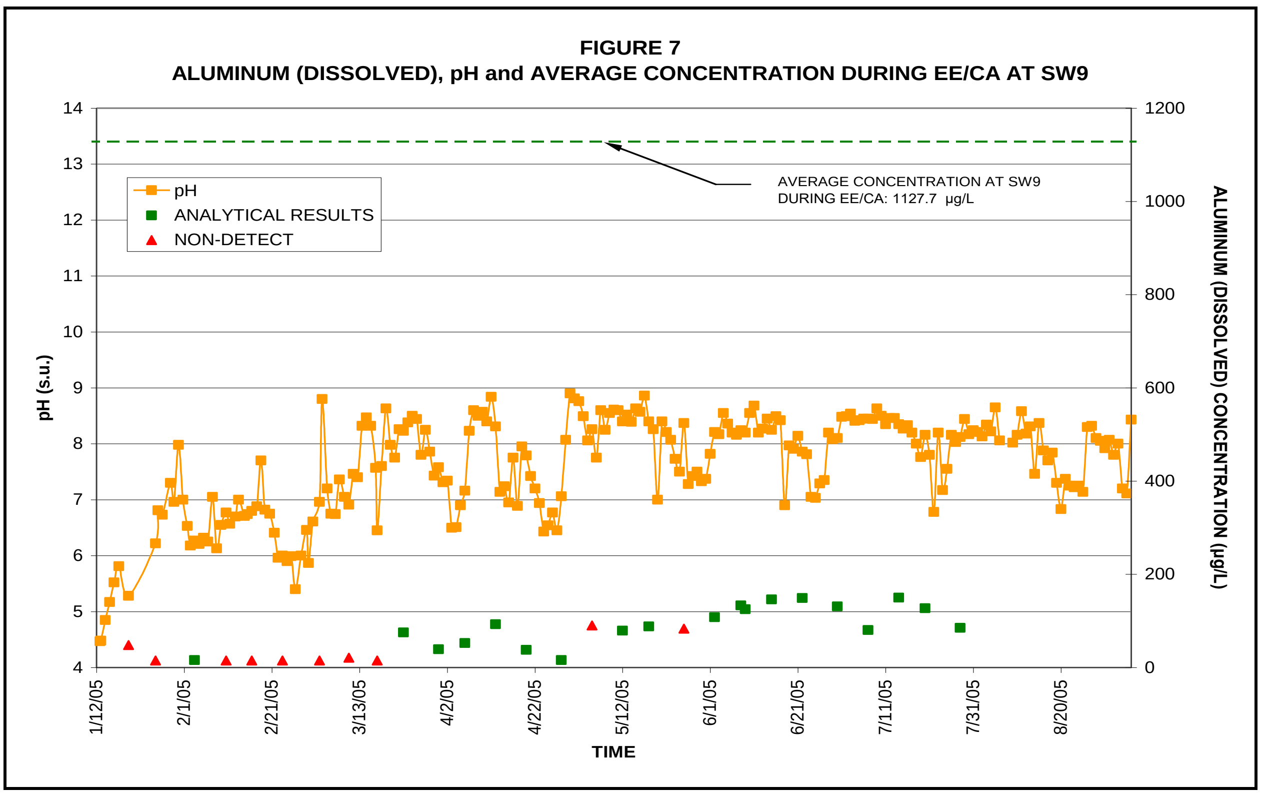

Figure 7. Aluminum (Dissolved), pH and Average Concentration during EE/CA at SW9

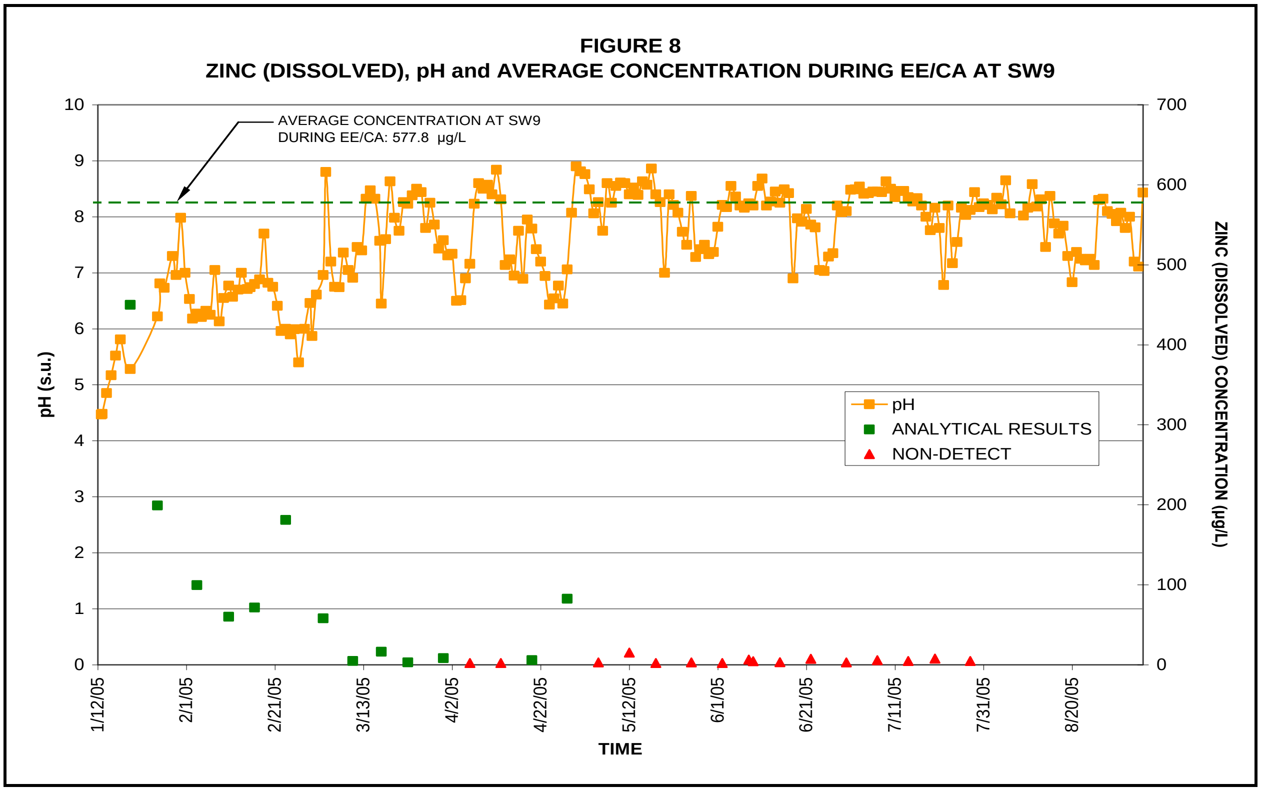

Figure 8. Zinc (Dissolved), pH and Average Concentration during EE/CA at SW9

Based on the laboratory results at monitoring location SW9 and the average annual flow rates measured during the EE/CA, loading removal calculations were performed and are presented in Table 2. These loading calculations indicate that dissolved metals daily average loading reductions to the Ocoee River of 359 kg (790 lbs.) per day and over 131,000 kg (290,000 lbs.) annually are being achieved. No significant operational or maintenance problems have been encountered with the system.

Table 2. Loading Removal Calculations

TABLE 2 LOADING CALCULATIONS					
	Average Concentration at SW9 During EE/CA	Average Concentration at SW9 After Plant Start-Up	Percent Removal	Daily Loading Reduction Based on SW9 Average Flow From EE/CA, 14.6 MGD	Annual Loading Reduction at SW9 Based on Average Annual Flow From EE/CA
	(µg/L)	(µg/L)	(%)	(lbs.)	(lbs.)
Aluminum (Dissolved)	1100	74	93	130	47,000
Copper (Dissolved)	110	1.0	99	13	4,700
Iron (Dissolved)	3500	43	99	420	150,000
Zinc (Dissolved)	580	26	96	68	25,000
Cadmium (Dissolved)	0.70	0.08	89	0.08	28
Manganese (Dissolved)	2500	1200	53	160	58,000
Lead (Dissolved)	5.7	0.06	99	0.70	250
Cobalt (Dissolved)	24	5.5	77	2.3	840
			TOTAL:	**790**	**290,000**

Conclusions

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 design concepts and construction details utilized may have applicability for addressing other acid mine drainage flows.

Acknowledgements

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