SLUDGE REMOVAL AND DEWATERING FOR REUSE AT A PASSIVE TREATMENT SYSTEM IN EAST CENTRAL TENNESSEE[1]

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Abstract. A passive treatment system consisting of an anoxic limestone drain (ALD), basins, and wetlands was constructed at a reclaimed surface mine in east central Tennessee in 1995. The system was designed for 200 gallons per minute with iron concentrations of 100 ppm. The system performed remarkably well for 15 years. Several years after construction the flow rates peaked at more than double the design flow which stressed the system, but water quality targets continued to be met. In 1999/2000, a supplemental ALD system was designed and constructed to address high flow periods through hydraulic control and redirection of reclaimed backfill water based on groundwater elevations. Both ALD-based systems continued to function as designed with few maintenance requirements. Basins were inspected on an annual basis and sludge accumulation was carefully monitored. In 2009, sludge cleanout was performed at the primary basin of the original passive treatment system. Treated base flow was directed around the system during sludge cleanout. Iron-laden sludge slurry was mixed with a polymer and injected into Geotubes for dewatering. Sludge is contained in the Geotubes for drying and subsequent testing for beneficial reuse and recycling.

Additional Key Words: acid rock drainage, passive water treatment, anoxic limestone drain, Geotube, AMD, ARD, sludge, recycling

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Introduction

The Sequatchie Valley Coal Corporation (SVC) operated a surface coal mine in the Cumberland Plateau geologic region of Tennessee approximately 45 miles northwest of Chattanooga. Historical coal mining activities occurred in the area since the turn of the century. SVC conducted surface mining activities extracting the Sewanee coal seam from 1978 to 1982. The surface area disturbed during this period covered approximately 175 acres locally referred to as Reclamation Area 1 (RA1). Figure 1 is a project location map outlining the RA1 site. Following mining and reclamation, groundwater elevations increased and acid mine drainage (AMD) was discovered. Initially, water was captured and chemically treated. The transition to passive treatment technologies to remediate the AMD discharges occurred in the mid to late 1990s, concurrent with the advancement of the technology. The first anoxic limestone drain (ALD), ponds, and wetlands system has been in operation since 1995. The first system was designed for 200 gallons per minute (gpm) of flow with iron concentrations of approximately

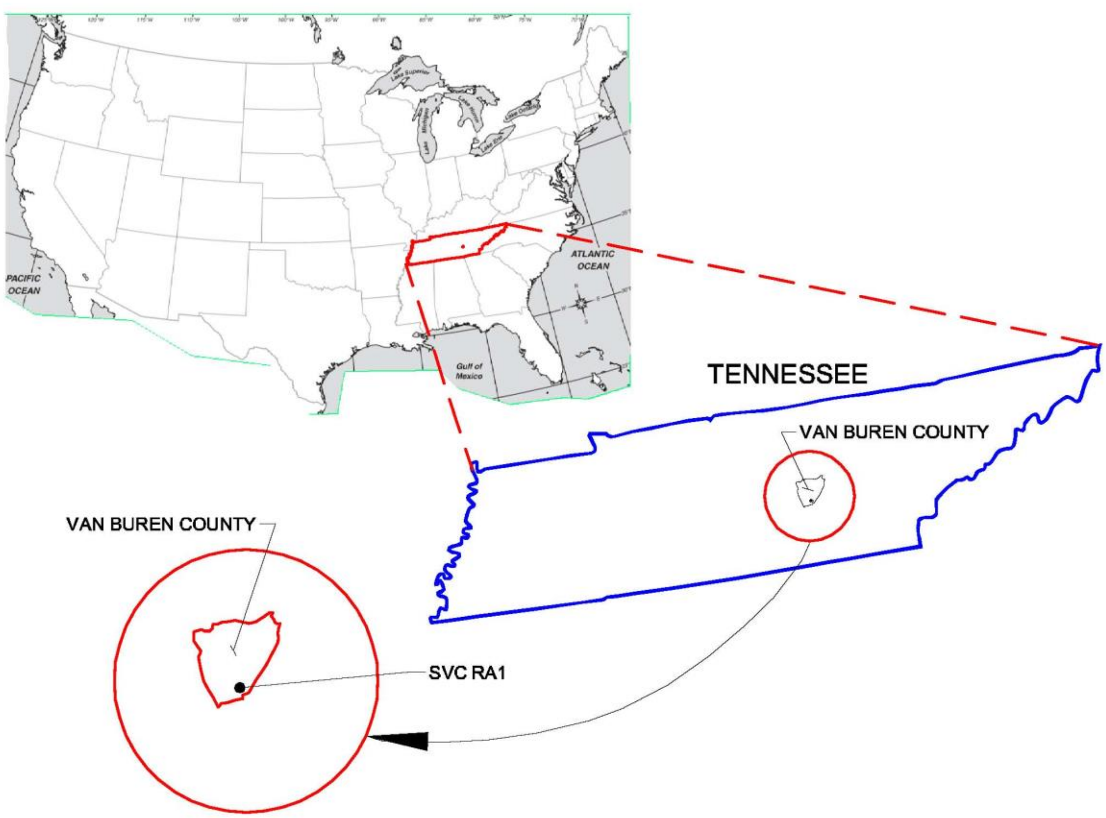

Figure 1. Project location map for SVC RA1.

100 parts per million (ppm). From the beginning, actual flows entering the system, which averaged more than 300 gpm, exceeded the design flow rate. However, the system functioned as intended and consistently met National Pollutant Discharge Elimination System (NPDES) effluent limits. Due to the increased flow rates and to extend the life of the first system, an additional ALD, pond, and wetland system was installed in 1999. During the first 15 years of operation of the first ALD system, a significant quantity of iron was collected in the system, and clean out was recommended in order to maintain system effectiveness. In 2009, iron was removed from the system by collection in Geotubes® for potential recycling use. Geotubes® are a form of dewatering technology made up of specially engineered textiles that retain solids from sludge and allow the water to gradually flow through the material pores. The dewatered sludge, which increases from typically a few percent to over 35% solids, is more easily handled for transporting to the final destination.

Background

The RA1 AMD seeps were initially remediated with a combination of chemical treatment using NaOH and soda ash briquettes, aeration, settling basins, and pumping. The concept of passive treatment using buried limestone beds for AMD was identified during the late 1980s (Turner and McCoy, 1990). By the early 1990s, passive treatment was gaining momentum, and SVC considered the use of constructed wetlands and other passive technologies for perpetual treatment of RA1 AMD seeps (Hedin and Massey, 1995). The new concept of an ALD was considered for evaluation in treating the RA1 seeps to impart alkalinity. Directing the subsurface drainage into a bed of limestone appeared plausible at RA1 based on the groundwater elevations, coal structure, and physical constraints. The water chemistry also appeared applicable for an ALD as the source water contained low concentrations of dissolved oxygen, Fe^{3+} iron, and Al. Aluminum and Fe^{3+} iron will precipitate in the limestone bed, while dissolved oxygen leads to iron oxidation and precipitation. Iron precipitation in the limestone bed can lead to armoring of the stone, reducing the ability of the limestone to effectively dissolve. Aluminum precipitates can accumulate and lead to plugging of the limestone void spaces.

Evaluating the Application of an ALD

A detailed evaluation of the applicability of an ALD for passive treatment at the RA1 AMD seeps was initiated in 1993 (Schmidt et al., 1996). This evaluation included cubitainer testing performed by Skelly and Loy, Inc. to estimate the amount of alkalinity that could be generated by contacting the water with limestone in a closed system as originally studied by Watzlaf and Hedin (1993). The cubitainer results indicated that limestone in contact with the RA1 water for 48 hours increased the alkalinity from 140 ppm to more than 340 ppm (Schmidt et al., 1996). The next step in the evaluation was the construction of a pilot-scale ALD at the RA1 site. In 1995, a small ALD was constructed containing approximately 65 tons of limestone with the ability to adjust AMD flows entering the ALD. The results indicated that the pilot-scale system generated excess alkalinity for flows from 5 to 10 gpm, which is proportional to the flows that would be designed for the full-scale ALD system. As a result, the full-scale ALD was constructed in 1995 for the RA1 AMD seeps that contained over 5,000 tons of limestone. The AMD seepage entering the ALD had the following average chemistry and flow:

- pH = 5.6;
- Iron = 117 mg/L, all as ferrous iron (Fe^{2+});
- Manganese = 42 ppm;
- Aluminum = <1.0 ppm; and
- Flow = 200 gpm (estimated based on hydrologic modeling of the site and groundwater seepage rates as provided by the mine operator).

The pH was measured in the field using calibrated hand-held water quality meters, while the total and dissolved metals were analyzed using EPA Method 200.7 by a third-party accredited environmental laboratory. Unless noted, the alkalinity measurements were measured in the field using a Hach® field kit.

Passive Treatment System Design and Construction at RA1

Design of the full-scale ALD at RA1 required management of the groundwater hydrology to direct flow to the ALD and subsequent settling ponds and wetlands. The low point in the bowl-shaped coal structure was identified and excavated to create a naturally concentrated and controlled discharge location (Schmidt and Stearns, 2001). A design life of ten years was selected for the ALD based on scientific reliability questions and economic factors. Assuming a design flow rate into the ALD of 200 gpm, the calculated hydraulic retention time within the limestone was approximately 24 hours. The ALD design incorporated the ability for limestone addition to the ALD. After stone placement, a liner cover was installed with two to three feet of soil cover, limiting required excavation for limestone replenishment.

The ALD discharged to settling ponds for the precipitation and settling of iron precipitates. The settling ponds (Basin A and B) covered a 2.4-acre area and provided 16.3 acre-feet of storage volume. At an average flow rate of 200 gpm, the settling ponds have a retention time of 11 days, assuming a 60% effective capacity of the ponds. Final polishing wetlands were constructed in early 1997 for tertiary treatment prior to final discharge to the receiving stream, which is regulated under an NPDES permit.

System Performance Evaluation - 1996

During the first year of operation, performance was regularly monitored by measuring flow, pH, and total alkalinity. Table 1 summarizes the initial data collected for the passive system. These results indicated that the cubitainer tests were reasonable in predicting alkalinity generation in the full-scale system.

Table 1. Water quality and flow of the initial ALD system (Schmidt and Stearns, 2001).

Date	Flow (gpm)	pH (S.U.)	Total Alkalinity (ppm as $CaCO_3$)
2/1/96	319	6.5	345
2/9/96	554	6.5	295
2/16/96	385	6.4	330
2/23/96	289	6.7	350
3/4/96	246	6.5	340
3/8/96	335	6.3	320
3/22/96	304	6.3	330
4/4/96	351	6.5	325
4/12/96	335	6.3	330
4/18/96	304	6.3	330
4/26/96	335	6.2	330
5/2/96	335	6.2	310
5/12/96	330	6.2	330
5/17/96	335	6.2	330
5/24/96	304	6.4	345
5/31/96	275	6.3	330
6/7/96	233	6.4	330
6/14/96	207	6.2	300
6/21/96	195	6.3	330
Average ± Std. Dev.	314±76.6	6.4±0.14	328±14

System Performance Evaluation – 1996 to 2000

The average flow rate measured from 1996 through 2000 was approximately 269±99 gpm, roughly 35% greater than the design flow. Despite higher than expected flow rates, the passive system performed well and met NPDES permit limits that existed during the time period, including biotoxicity. The biotoxicity analyses included acute and chronic toxicity tests using *Ceriodaphnia dubia* and *Pimephales promelas* (Fathead Minnow) with the determined in-stream waste concentrations. Average alkalinity concentration of the system was approximately 328 ± 14 ppm at an average flow rate of 269 gpm, which equates to an annual limestone dissolution rate of 194 tons (Schmidt and Stearns, 2001).

The following three tables summarize analytical data for sampling events conducted for each of the major treatment system components. These data provide insight regarding alkalinity consumption and iron deposition throughout the system. The measured flow rates represent both high and low flow conditions.

Table 2. January 1996, July 1996, and August 2000 Data (Schmidt and Stearns, 2001).

January 1996, Flow Rate = 335 gpm

Component	Total Alkalinity (ppm as $CaCO_3$)	pH (S.U.)	Total Iron (ppm)	Iron Load (tons/year)
ALD	330	6.4	97.3	71.7
Basin A	240	6.7	52.2	38.5
Basin B	180	6.9	18.5	13.6

July 1996, Flow Rate = 120 gpm

Component	Total Alkalinity (ppm as $CaCO_3$)	pH (S.U.)	Total Iron (ppm)	Iron Load (tons/year)
ALD	345	6.2	138	36.4
Basin A	175	6.5	42.7	11.3
Basin B	125	7.1	0.19	0.05

August 2000 Data, Flow Rate = 101 gpm

Component	Total Alkalinity (ppm as $CaCO_3$)	pH (S.U.)	Total Iron (ppm)	Iron Load (tons/year)
ALD	185*	6.3	74.0	16.4
Basin A	170*	6.2	23.8	5.3
Basin B	175*	7.0	0.52	0.12
Wetland A	120*	7.0	0.11	0.02
Wetland B	100*	7.1	0.09	0.02

* Based on laboratory analytical data; prior alkalinity results (1996) were conducted in the field

Treatment System Improvements

The January 1996 and July 1996 data from Table 2 resulted in the decision to construct the polishing wetlands following Basin B. Approximately two acres of wetlands were constructed in late 1996/early 1997 in order to promote iron oxidation and removal, especially during high flow events. The storage capacity of the two polishing wetlands included several deeper pockets with depths of 4 ft, while the average depth was 1.5 ft to allow for the establishment of vegetation. In addition, the wetland spillway height can be increased to provide additional sludge storage and extend the system life. The calculated hydraulic retention time of the two wetlands was approximately 82 hours based on a design flow rate of 200 gpm and an average water depth of 1.5 feet over the two acres of wetlands.

In 1999/2000, a second ALD was designed and constructed at RA1. The supplemental ALD activates during high groundwater elevation periods, reducing peak flows to the first ALD and extending the life of the combined systems. Both passive treatment systems continued to function as designed during the period 2000 through 2009 and produced effluents that consistently met NPDES permit limits for the site during the decade.

Sludge Removal Operations - 2009

Overview

Basin A at RA1 historically removed 70% of the influent iron loading. Basin B removed much of the remaining Fe and the two wetlands remove additional Fe. Calculations performed in 2001 (Schmidt and Stearns, 2001) indicated that after five years of system operation, 90% of the sludge retention capacity remained in Basins A and B combined. Basin A, the smaller of the two basins, had approximately 70% of its capacity remaining, while Basin B had approximately 96% of its capacity remaining.

After annual observation and monitoring of the sludge levels in Basins A and B, SVC initiated Basin A sludge removal in 2009. Fig. 2 is a photo of Basin A prior to the start of the sludge removal and dewatering process. The sludge levels in Basin A were approaching a minimum of two feet with an average of three feet in depth throughout the entire basin. Measurements in the basin varied in depth from roughly two feet at the upstream end to over eight feet near the downstream embankment. Sludge levels in Basin B had not reached the level where sludge removal was recommended.

Sludge Processing Design and Preparation

Skelly and Loy personnel coordinated and managed the sludge removal operation for the RA1 Basin A in the fall of 2009. The conceptual plan for sludge removal included pumping the sludge slurry from Basin A to a polymer makedown and injection system and routing the polymer system effluent to Geotube® dewatering bags. A 20,000-gallon stainless steel bi-level tank was included as a staging unit for the pumped sludge slurry prior to the polymer makedown and injection system. Once the conceptual plan was finalized, the equipment and materials were ordered, and the site was prepared for layout of the sludge removal and dewatering system. Fig. 3 and 4 provide an illustration of the sludge removal and dewatering system schematic and a photo of the constructed system at the RA1 site, respectively.

The site was prepared by clearing an area 150 ft by 150 ft adjacent to and upslope of Basin A, leveling, and placing a 6-inch layer of crushed stone passing ½-inch screen for Geotube® placement. A smaller stone pad was created above the Geotubes® for the 20,000-gallon stainless steel bi-level tank and trash pump placement. Filtrate from the Geotubes® was routed

Figure 2. Basin A prior to sludge removal and dewatering.

back into Basin A to provide slurry water for sludge pumping.

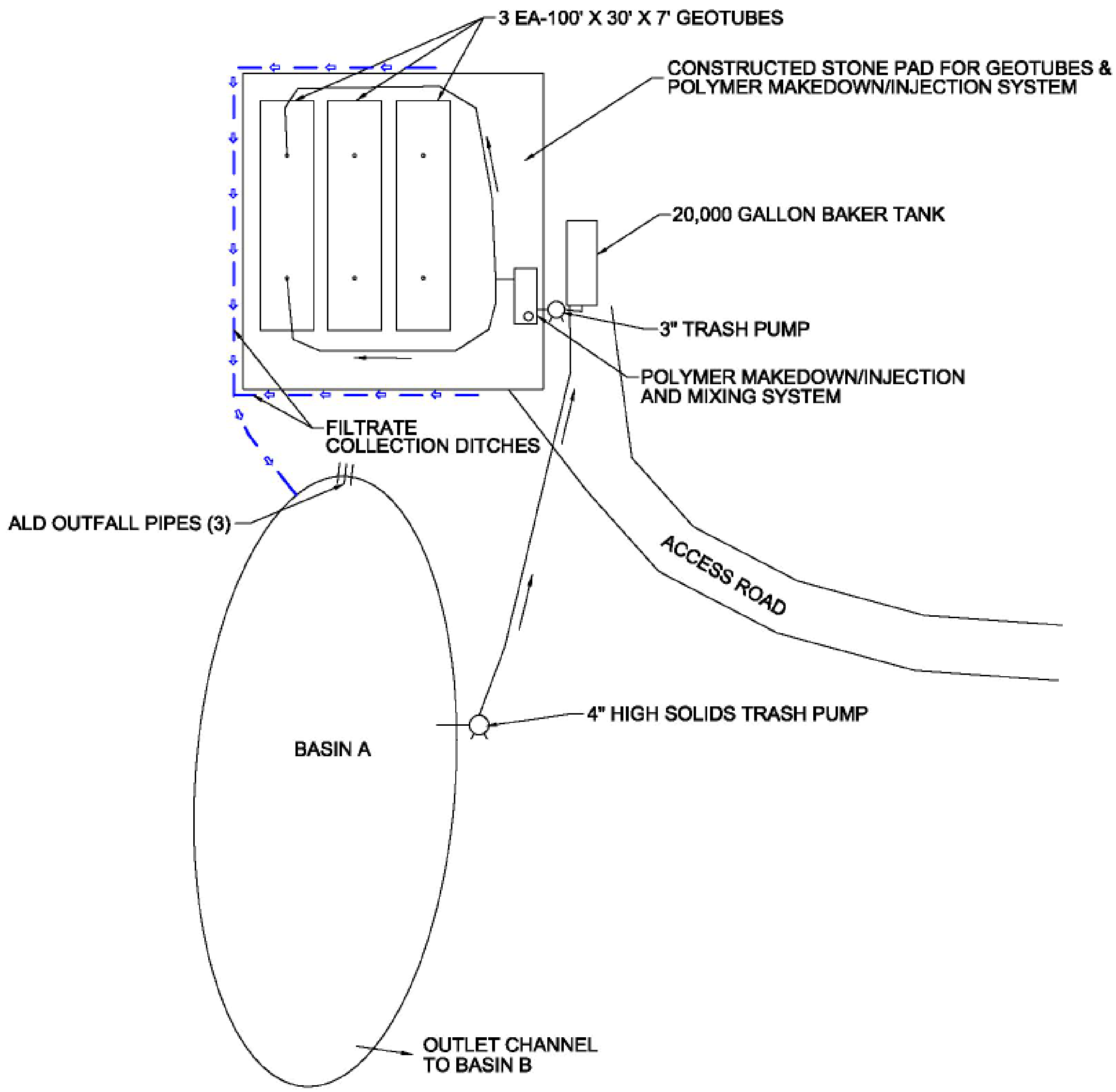

Figure 3. Sludge removal and dewatering system schematic.

Figure 4. RA1 site sludge removal and dewatering system.

A polymer makedown and injection system consisting of a two-inch trash pump, diesel-powered generator, and polymer was used to flocculate the sludge before injection into the Geotubes®. The polymer makedown system dilutes the raw polymer product to improve mixing and effectiveness with the sludge slurry. An anionic emulsion Solve 9330 polymer was selected by WaterSolve, LLC after performing a dewatering performance trial and Rapid Dewatering Test (RDT) on a five-gallon sample of sludge from Basin A at a dosage of 200 ppm for an 8% solids sludge mixture. The Solve 9330 was a highly viscous material transported in a 55-gallon plastic drum. A custom inline mixing manifold equipped with a flow splitter and valves was constructed on-site to mix the injected polymer with the sludge slurry prior to entering the Geotubes®. Fig. 5 is a photo of the polymer makedown system and 20,000 gallon stainless steel staging tank at the RA1 site.

Figure 5. Photo of the polymer makedown system and 20,000 gallon stainless steel tank components of the sludge dewatering process at the RA1 site.

Sludge Processing System Operations

The process was initiated by capping the outlet pipes from the ALD into Basin A, causing the groundwater level to rise in the reclaimed backfill area, temporarily forcing all groundwater flow to the second ALD system. As sludge processing began, the four-inch pump intake was frequently moved using a backhoe bucket to improve sludge pumping efficiency by stirring up the sludge near the bottom of the basin. Every few days, the four-inch pump was also relocated, working around the basin perimeter in order to reach as much of the accumulated sludge as possible.

The sludge dewatering process included sludge slurry pumping from Basin A to the 20,000-gallon stainless steel bi-level tank staging cell, polymer injection of water pumped to the Geotubes®, and dewatering of the Geotubes® while capturing the sludge. Typically, the flocculated sludge was directed into both ends of the Geotube® for more even filling until reaching the maximum fill height of seven feet. Each 45x100-foot Geotube® is capable of holding 365 cubic yards of dewatered material. Figure 6 shows a partially filled Geotube® at the

RA1 site shortly after beginning operations. Two Geotubes® were filled to near the seven-foot maximum fill height and an additional Geotube® was partially filled after roughly one month of sludge removal. Basin A was returned to the approximate original capacity. The Geotubes® will be left in place until the spring of 2010, when the sludge material should be sufficiently dewatered (>35% solids) to allow for ease of handling and transport. The ultimate fate of the iron sludge will be determined when it is sampled to explore recycling opportunities.

Conclusions

Completion of the Basin A sludge removal provides renewed retention time and sludge storage capacity for the oxidized and settleable iron in the RA1 ALD passive system. This cleanout preserves and protects the downstream components of the treatment system. Managing the sludge in Basin A, which has relatively easy access, ensures predictable and cost-effective operations and maintenance associated with this passive treatment system. Basin B may also require sludge removal in the future but at less frequent intervals. The next expected sludge removal at Basin A and/or B would occur in approximately 10 to 15 years, but actual cleanout timing will be based on measured accumulated sludge volumes. This cleanout frequency should minimize deposition of iron in Wetlands A and B, which are more difficult to clean out. There are currently no plans to consider cleaning out either of the wetlands since most of the iron is removed in Basins A and B and it would be relatively easy to raise the spillway height and increase storage.

Overall, the original RA1 ALD has generated significant levels of alkalinity and promoted oxidation and settling of the ferrous iron. Along with the two settling basins, two wetlands, and additional ALD system for managing and treating the higher groundwater conditions at the RA1 site, this application of passive treatment has proven an effective and reliable means of treating a moderate flow of AMD with high levels of dissolved iron and the system has been capable of consistently meeting NPDES permit limits currently in place for this outfall. Sludge clean-out of Basin A occurred approximately 14 years after the system went into operation, which is a reasonable expectation for future clean-out frequencies without any significant changes in the AMD chemistry and flow rates.

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Note this was the 13th Annual Meeting, not the 18th

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