SEASONAL VARIABILITY OF DISCHARGES FROM WETLANDS CONSTRUCTED BELOW KYANITE MINE TAILINGS PONDS; GRAVES MOUNTAIN SITE, LINCOLNTON, GA[1]

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Abstract. The former Graves Mountain mine site near Lincolnton, Georgia, USA, produced kyanite from a pyritiferrous quartzite-kyanite ore. Tailings were formed during the ore processing and distributed to various areas of the mine property during the approximately twenty year mining operation. While the majority of tailings were placed in large tailings ponds on the south side of the mountain, several smaller tailings ponds were located to the north and west. These tailings impoundments which contained flotation process residues, pyrite, and a variety of other minerals, produced acidic discharges with high iron and sulfate concentrations. These discharges have been actively treated, however, the goal is to provide passive treatment for the majority of the discharges and minimize the active treatment components. To address this goal, two sets of anaerobic wetlands and various *in situ* alkaline technologies were designed to treat the discharges from the north and western sides of the site. Each set of wetlands is approximately the same size and drains a similar sized watershed. Each displays a seasonal variability in discharge quality: fall to early winter – pH 6.5-7.5, late winter to early spring- depressed pH of 3.9-6, spring to summer- increased pH 6-7.5. Variability is attributed to several potential factors including flow variations, FeS_2 oxidation, $CaCO_3$ equilibrium, and temporal and temperature functions. The data indicate, however, that regardless of the cause of the cyclical quality of the effluent, the variations become less pronounced with time and, in the short term, while the range of the data fluctuations remained high (up to 3.5 pH units per cycle) the median values of the water quality parameters improved (from 5.2 to 5.5 over three cycles in the PP Wetland and from 5.5 to 6.8 over 8 years in the 378 wetlands). This study suggests that in a mild, humid climate, more than three years were required to fully evaluate the effectiveness of the wetlands constructed below tailings ponds, but with increasing time, the discharge quality met water quality goals and pH levels consistently exceeded 5.

Additional Key Words: acid mine drainage, acid rock drainage, constructed wetlands

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Introduction

A pyritiferrous quartzite-kyanite ore body at the Graves Mountain site in Lincoln County, Georgia, was mined from the early 1960's through the mid-1980's for kyanite and, at times, pyrite (Cook, 1985; Hartley, 1976). The processing entailed blasting, crushing and further wet-crushing the ore to a minus 28 mesh size. The minerals were separated from the slurry by flotation and the waste minerals, including quartz, micas, pyrophyllite, lazulite, rutile, ilmenite, geothite, hematite and pyrite, were pumped to several tailings ponds. The ponds were initially constructed on the north side of the mountain, an additional tailings pond was constructed west of the main pit, and finally three large tailings ponds were constructed south of the main pit. The tailings were pumped to the ponds as a slurry and, although the tailings ponds were saturated at shallow depths, they were not submerged and surface water was drained from the ponds. Therefore the term "tailings ponds" refers to the tailings retained behind a constructed dam rather than a surface water body.

The tailings ponds contain at least 2% pyrite and at least one, the "Pyrite Pond," may contain considerably more. Apparently, pyrite from the flotation process was at times separated and sold. However, when the market became depressed, indications are that the pyrite was placed with the remaining tailings into the tailings pond that was active at the time and later named the Pyrite Pond. As a result of the weathering and oxidation of primarily the pyrite, acidic waters with depressed pH values and elevated metal concentrations are contained within and emanate from the tailings ponds (Geidel and Caruccio, 2000). In addition, certain sequences of the flotation process utilized acidic solutions, some of which may have been entrained with the tailings and transported to the tailings ponds.

The early stages of the mining operation were smaller scale and the tailings were distributed into three small, less than 0.2 ha (0.5 ac) each, tailings ponds on the north side of mountain. The height of the dams retaining the tailings varied from 4 m (12 ft) to approximately 7m (20 ft). The geochemical characteristics of these tailing varied, but each produced acidic drainages. The three tailings ponds are hydraulically connected and the discharges from the ponds (both surface water runoff and seepage through the dams) are monitored individually and at a final single discharge point.

As the size of the mining operation increased, the tailings ponds on the north side were filled and another pond was constructed on the western side of the mountain. The western tailings pond was constructed in a deeply incised valley and the dam, behind which the tailings are contained, is approximately 13 m (40 ft) in height and the pond is approximately 0.65 ha (1.6 acres) in areal extent. It was during the filling of this pond that pyrite was stockpiled separately and periodically added to the tailings. (The tailings pond is referred to as the Pyrite Pond).

When the Pyrite Pond became filled, a series of three additional tailings ponds were constructed on the south side of the ore deposit. These southern tailings ponds were much larger and varied in size from 5 to 31 ha (12 to 77 ac). They have been successfully revegetated and the surface runoff from these ponds has a neutral pH (Geidel, et al., 1999, Geidel and Caruccio, 2004).

With regard to the tailings ponds on both the north side as well as the western Pyrite Pond, although reclamation efforts were attempted at the conclusion of the mining operation, the discharges from the tailings ponds did not meet the pH and metal concentration water quality goals sought for the site and active treatment requiring pumping and neutralization with lime and/or NaOH. Therefore, in addition to supplemental reclamation of the tailing ponds, anaerobic wetlands were constructed with the objective of replacing active treatments (Hedin and Nairn, 1992; Skousen, et al., 1998). This paper addresses the seasonal variations in discharges from these constructed wetlands treating discharges from the tailings ponds, wetland modifications required for success and the long term monitoring results.

Wetlands below the Pyrite Pond

The drainage basin in which the Pyrite Pond tailing pond was constructed, is a relatively narrow basin from the headwaters to the inflow of the wetland with a steep (10.3%) gradient over the approximately 430 m (1300 ft). The upper portion of the basin in which the tailings pond is constructed has a much steeper gradient (average 15%) from the head of the basin to the base of the tailings pond. The flow into and within the wetland is a combination of flows from surface runoff from the tailings pond, drainage basin surface runoff, groundwater, and a small sustained flow from a seep downstream from the tailings pond (“Seep 9”). The tailings pond surface was previously partially covered with an impervious fabric and covered with 0.3 to 0.6 m (1-2 ft) of soil. Although minor leakage through the tailings pond dam has occurred, this is captured within a small (30m^2 (325 ft^2)) basin at the toe of the dam and diverted by pipe to another on site treatment facility. Seep 9 had been previously diverted to flow through a constructed Anoxic Limestone Drain (ALD); a lined and plastic encased, limestone filled channel 1.3 m wide by 1.6 m deep by 33m long (4 ft x 5 ft x 100 ft). The ADL effectively treated the acidic seep for several months, however, with time the flow through the ALD was curtailed and the water preferentially flowed over the surface of the ALD. It is postulated, based on similar responses reported by Skousen and Faulkner (1992) that the aluminum (Al) associated with the sericite shist, kyanite, and other Al-bearing minerals dissolved in the groundwater and discharged from the acidic Seep 9. Given sufficiently high Al concentrations, the drainage flowing through the limestone of the ALD, with the concomitant increase in pH would cause conditions favorable for Al precipitation and cause the drain to loose sufficient permeability to sustain flow through the system. Attempts to loosen the limestone fill were unsuccessful and the majority of the seep 9 flow continues to flow outside of the ALD.

A wetland, approximately 0.24 ha (0.59 ac) in size, was constructed 260 m (850 feet) downstream from the base of the tailings pond dam and 140m (460 feet) downstream from Seep 9. The wetland was divided into three cells, the first approximately 20m x 30m (65 ft x 100 ft), the second 23m x 30m (75 ft x 100 ft) and the third 30m x 30m (100 ft x 100 ft) each. Surface runoff and seep flow are collected and piped into the wetland.

In an effort to evaluate the hydrologic regimes of the drainage basin, a number of wells were installed throughout the basin. The data obtained from these wells was useful in evaluating the long term hydrologic variability within the Pyrite Pond as a result of reclamation efforts, comparing changes in hydrologic parameters between the tailings pond and adjacent rock units, evaluating the potential source of Seep 9 and monitoring potentiometric surfaces in the vicinity of the constructed wetland. Having experienced a major drought (1998-2000), prior to the installation of the wetland in 2005, ensuring that the constructed wetland would remain wet was a high priority. Therefore, data from two wells in close proximity to the wetland were evaluated. These data indicate a nearly 5.3m (16 ft) variation in groundwater elevations due to drought impacts, but show a relatively quick response to increased rainfall. (Fig 1).

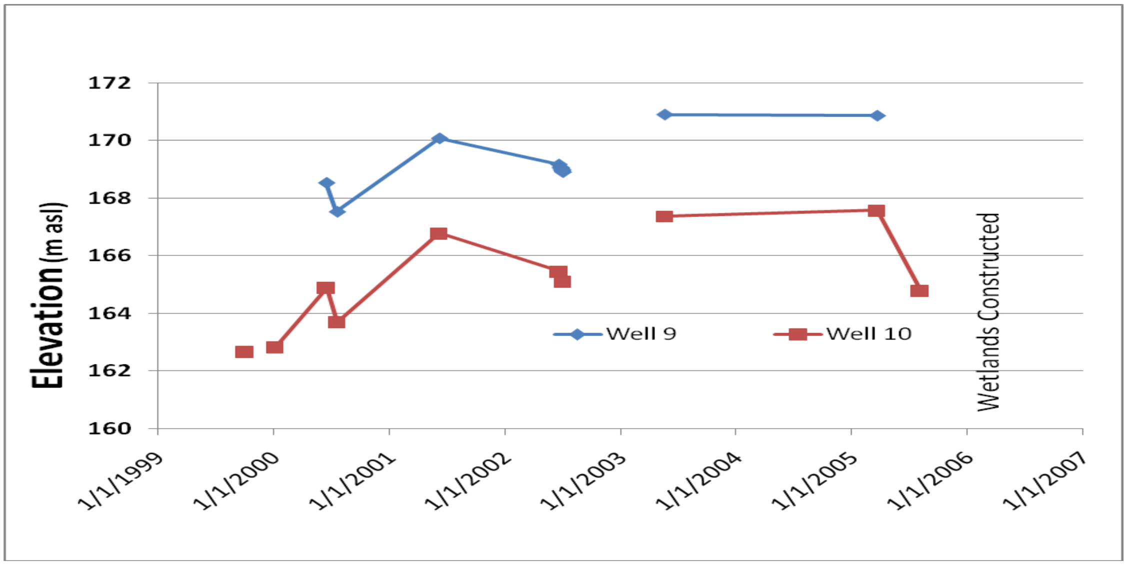

Figure 1. Water Level elevations in Wells 9 and 10 in close proximity to Constucted Wetlands.

Well 9 is located approximately 16m (50 ft) upstream of the wetland and Well 10 is immediately adjacent to the western edge of the wetland. Well 9 was drilled to an approximate depth of 28m (84 ft) below ground surface (bgs) and while the potentiometric water level elevation varied, it varied from 0.6m to 4.1m (2 to 13 ft) bgs. Well 10 is approximately 38m (114 ft) deep and the potentiometric surface varied from 0 to 5.1m (0 to 16 ft) bgs. Therefore, the groundwater gradient to towards the wetland. Given that the wetland was constructed within an area that flooded during rain events, was located within an existing discharge area and received flow from Seep 9, it was anticipated that the area excavated for wetland construction would receive sufficient inflow to remain saturated.

During wetland construction, the wetland site was excavated to elevation 166.7 m (547 ft) in Cell 1, 166.4m (546 ft) in Cell 2 and 166.1 m (545 ft in Cell 3 and surface water flow was diverted around the cells during construction. Between cells, 3m (10ft) of original ground was left in place and 3 pipes (each 0.3 m (1 ft) diameter) were placed within 7.6 m (25 ft) of the outer edge and set to regulate water level elevations with each cell and serve as sampling points between sells. The 0.24 ha (0.59 ac) wetland was excavated and filled with 0.3m (1.0 ft) large (#2) limestone and 0.5m (1.5 ft) mushroom compost. Each of the three cells was filled with water to approximately 1 m (3 ft) above the base of each cell or 15 cm (6 in) above the organic layer. The wetland, referred to as the Pyrite Pond (PP) Wetland, was completed in December 2005 and began discharging on January 23, 2006.

The wetland influent consists primarily of flow from Seep 9, which when flowing between 2000 and 2006, maintained a median pH value between 3 and 3.2 and specific conductance values that varied from approximately 1100 to 1400 uS, as shown in Fig. 2. After completion of the wetland, the Seep 9 sampling point was relocated from the seep source to the wetland inflow and variability has increased, with higher pH values noted.

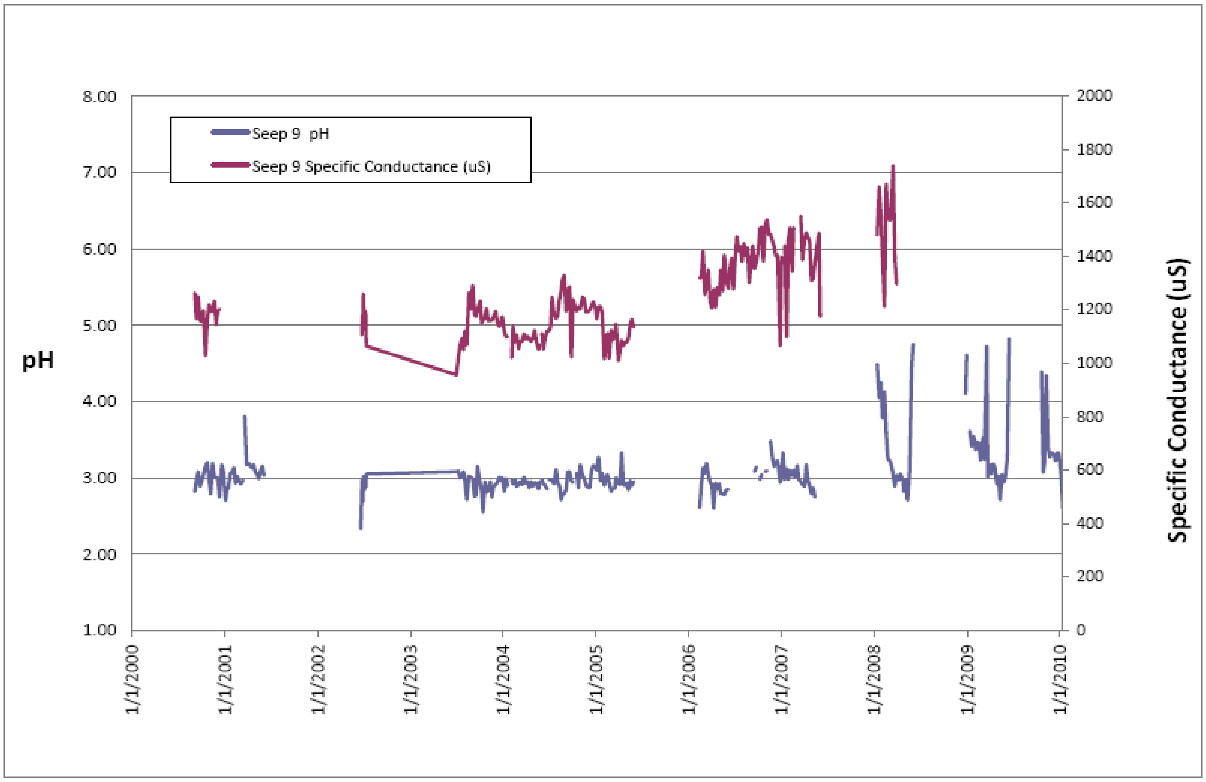

Figure 2. Specific Conductance and pH of Seep 9. Data collected from Seep 9 discharge until wetland completed and then sampling point becomes Wetland inflow.

Seep 9 discharges into the channel containing the previous ALD and is then contained within a 0.3m (12 in) pipe and is conveyed to the wetland inflow. However, during periods of rainfall, the pH and specific conductance has become more variable, which may be attributable to remnant ALD effects and/or surface water runoff dilution.

A second drought occurred in this area of Georgia from 2006 to 2008, which was a record drought for a three-year period since the 1890's, and even though the wetland had been excavated below the creek level and below the level of ground water seeps that were observed during wetland construction, insufficient water was available by late summer 2006 to maintain a discharge flow. In order to protect the limestone layer from potential iron oxide coating if aerobic conditions occurred and to protect the survival of the wetland, well water was pumped into the wetland at a rate of approximately 5.7 liters per minutes (l/m)(1.5 gpm) during the driest times of the year. The well water has a pH of approximately 7.3 and a specific conductance of less than 200 uS. The well water additions were not sufficient to provide for a discharge flow, but maintained water levels above the limestone layer as monitored by peizometers installed within the wetland and seated in the limestone layer.

Wetlands on North side near US Highway 378.

Area 1 Constructed Wetland

On the north side of the Graves Mountain mine site, the discharges from three tailings ponds (referred to as Areas 3, 4 and 6) are collected into a small sediment basin (approximately 0.035 ha (0.086 ac)) that was converted to a anaerobic wetland and the effluent from the basin (Area 2 (A-2)) is directed through an anoxic limestone system and discharged through a standpipe at the base of the containment dam. The standpipe below A-2 is the influent water for Area 1, which is the final treatment/wetland segment in the drainage basin. Prior to the reclamation efforts of the tailings ponds and the surrounding areas, the discharge pH was approximately 2.8 pH with acidity concentrations between 700 and 900 mg/l as $CaCO_3$. A number of reclamation technologies have been previously developed and utilized in this area as reported in Geidel and Caruccio (2002).

Below A-2, the discharge flows into a previously intermittent stream segment and this segment was designated for use as a constructed anaerobic wetland and as a final passive treatment system. The leveled segment is approximately 66m (200’) long and approximately 11 m (40’) wide and is divided into six sections; each separated by a sandbag dam approximately 0.9 m (3’) high. The spillway from each sandbag dam is located on alternating sides of the wetland to provide the maximum flow path through the wetland.

The wetland (A-1 Wetland) was constructed, after leveling the area, by installing 15-18 cm (6 to 8”) of coarse grained limestone in each section, covering with 60 cm (18”) of mushroom compost, allowing water to fill the wetland and subsequently planting with cattails (*Typha* *latifolia*). Additionally, in each of the summers of 1998 and 1999, the entire northern drainage basin (approximately 12 ha (30 acres)) which included the wetland, had approximately 4 mT/ha (10 t/ac) of fine-grained limestone applied by aerial application. At the terminal end of the wetland, the flow is discharged to a sump area that is then discharged to the stream and flow is monitored at a V- notch weir. The flows and quality of the wetland discharge have been monitored on a routine basis since A-1 Wetland completion in the summer of 1994.

Three additional wetlands were constructed upstream from A-1 wetland; the upstream flow is bifurcated with approximately half of the flow from each direction. A-2 wetland is described above and discharging into A-2 are flows from two small, yet separate drainage basins; one from the south and one from the east. From the south, the flow originates at the drainage divide between the flow to the Pyrite Pond and reclamation in this area has included surface application of limestone to effect ground water quality (Caruccio and Geidel, 1996) and the installation of a wetland on the surface of Area 3, a small tailings pond, designated A-3. The wetland construction in A-3 included: leaving the tailings in place, raising the containment dam by 0.5 to 1.0m (1.5 to 3 ft), placing 15 cm (6”) limestone on the tailings, adding 0.5 m (1.5 ft) of mushroom compost and allowing water to flow through the system. The discharge from A-3 flows, albeit with very low flow, directly into A-2 and has been alkaline with a pH exceeding 6.5 since completion.

From the east, the discharge to A-2 includes flows from Areas 4 and 6 (A-4 and A-6), both of which were originally tailings ponds. A-6, the uppermost and largest tailings pond of the three (approximately 0.3 ha (0.75 ac)) was previously reclaimed in the 1970s with long needled pine (species unknown), but during a major ice storm in the early 2000s, the trees were broken, toppled and subsequently died. Prior to the ice storm, A-6 was modified by the addition of an alkaline trench and a limestone channel (Geidel and Caruccio, 2002). Due to the highly permeable nature of A-6, most rainfall and runoff infiltrates into the tailings pond and alkaline trench. Below the A-6 tailings pond dam is A-4. The tailings and dam from A-4 pond were removed and an anaerobic wetland consisting of two cells (upper and lower) was constructed in 2002 with 0.3 m (1 ft) limestone and 0.5 m (1.5 ft) mushroom compost. In summer 2003, an additional 0.23m (9”) of limestone was added to the surface of the lower cell in the wetland. A permeable limestone collar dam (approximately 0.5m (1.5 ft) thick and 0.7 m (2 ft) high) was constructed approximately 1.5 m (4.5 -5 ft) above the A-4 wetland discharge to A-2.

Therefore, the flow entering into Wetland A-1 has been sequentially treated by two upstream wetlands (A-2 and either A-3 or A-4). The discharge from A-2, while it characterizes the influent flow to Wetland A-1 does not represent a true “initial” influent, but the quality of treatment to that point. The discharge from A-1 represents the sequential treatment and therefore, the area of each wetland is included in an evaluation of the effectiveness of wetland system. For reference purposes and due to their proximity to US Highway 378, this collective wetland sequence is referred to as the “378 Wetlands” and the final discharge as A-1.

Results: Seasonal Variation and Comparison of Wetland Effectiveness

The 378 Wetlands have evolved over a number of years. Initially (and while separate, active water quality treatment was ongoing) the wetlands exhibited widely disparate pH and acidity values and as a result, modifications were made during the first several years as described above. The former mine site has also been subject to weather patterns which have resulted in conditions leading toward variations in discharge quality and quantity. Between extended droughts and several tropical storms, the flows through the wetlands and drainage basin have been subject to significant variability as shown in Fig. 3. Figure 3 includes three plots: monthly rainfall totals for the site (A) and weekly discharges from the 378 Wetland (B) and Pyrite Pond Wetland (C). Rainfall and flow rates are most closely related temporally in plots A and B while plots A and C suggest a lag time between high rainfall events and discharge rates.

These differences may reflect or capture several variables between the two wetland systems: 1) the maturity of the wetland systems - the 378 wetlands were constructed approximately ten years prior to the PP wetlands; or 2) construction differences - the 378 cells were constructed within narrow segments of the existing drainage system while the PP Wetlands excavated a wider area; or 3) due to monitoring methods, the weekly monitoring of the wetland flows did not always capture peak flow rates. The watershed basins for the two wetland areas share a common drainage divide; therefore, it is unlikely that one wetland area received significantly different rainfall than the other.

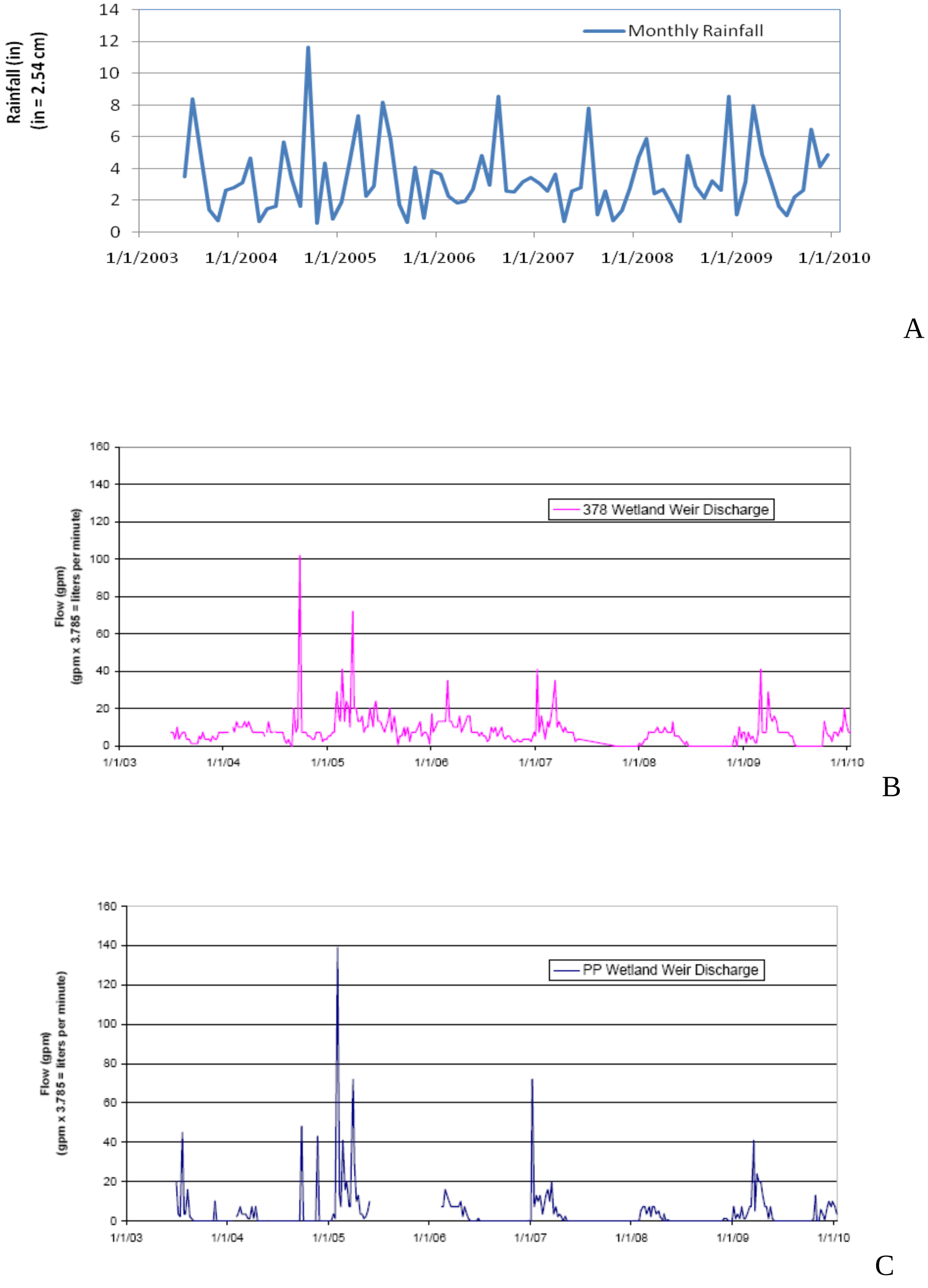

Figure 3. Site monthly Rainfall totals (A) and weekly flow at Wetland discharge weirs (B,C). PP Wetland (C) completed in January 2006; prior flow is background data. (Due to overlapping data during some events, the flows are shown separately to minimize data masking.)

Related to wetland functions and efficacy, a more direct concern were the periods of no flow at the discharge weirs and whether the wetlands themselves would become dry. However, even though there was no flow, the wetlands were not observed to have become dry, merely insufficient water was available to create a discharge through the spillway. During the construction of each cell, piezometers were installed within each wetland cell and seated at the base of the limestone layer, to allow monitoring of water levels within the wetland. The wetlands appeared to retain water during periods of no discharge as evidenced by water elevations in the piezometers. Therefore, while the surficial evapotranspiration exceeded the precipitation, the limestone layer is not anticipated to have become dry and subject to oxidizing conditions. Within the PP wetland, however, the concern for potential drying of the limestone layer was greater due to the drought during the early stages of the wetland establishment. Therefore, as noted above, well water was added to the PP Wetland during periods of no flow at the weir and when the surface of the compost layer appeared dry. The water was distributed between cells on a rotating, approximately weekly basis.

The area of the two watershed or drainage basins for the 378 Wetlands and the Pyrite Pond (PP) basins are similar and the collective size of the wetlands are similar. The three cells of the PP Wetland are collectively approximately 0.24 ha (0.59 ac) and the collective size of the 378 Wetlands in Areas 1, 2, 3 and 4 is approximately the same; 0.26 ha (0.63 ac). As a result, the differences and similarities noted to exist between effluents from the wetlands are not significantly related to differences in size.

As shown above in Fig. 3, the discharge flow rates follow similar patterns. However, the peak flows corresponding to high precipitation events are usually more flashy from the PP Wetland and the peak flows are usually extended over a longer period within the 378 Wetlands. This suggests that the rainfall residence time within the 378 wetland may be greater than that in the PP Wetland. Presumably, duration and, therefore, effectiveness of passive treatment within the anaerobic wetlands would be maximized within the wetlands with the longer residence times. What is apparent from a comparison of these two wetlands is that during the initial years of wetland performance, the water quality of the discharge exhibits a seasonal cycle. This cycle is apparent in all parameters. During the summer, the wetland has undergone successive years of moist wetland conditions, but no discharge flow.

As shown in Fig, 4, after a dry period, the flow that resumes initially has a pH between 6 and 7.5; it then decreases, but makes a subsequent rebound. This is not fully explained by flow rates; while an inverse relationship between pH and flow exists, the relationship has a low correlation coeffecient (R^2=0.034).

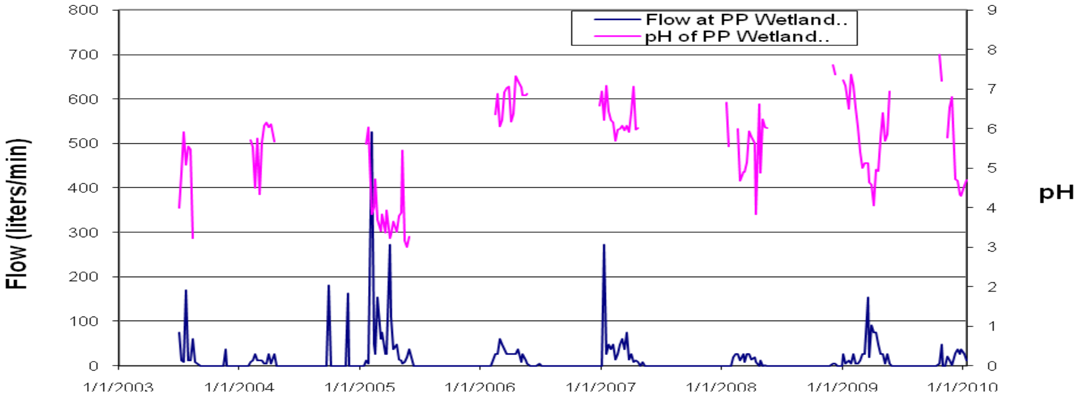

Figure 4. Flow (l/m) and pH for Pyrite Pond Wetlands discharge collected at the downstream weir. When no data are presented from 2006 forward, there is no flow.

The flow following a dry period is usually a low (0.9 to 27 lpm (0.2 to 7 gpm)) which suggests the first flow is not usually in response to a high precipitation event with a large component of surface runoff. Due to continued saturation of the wetland even during periods of low rainfall and when there is no discharge, the data suggest that the water contained within the wetland is alkaline and with sufficient rainfall and runoff, is flushed through the cells and the resultant pH and conductivity is consistent with a water-$CaCO_3$ equilibrium system and suggesting an alkaline rather than a neutralized acidic discharge. The flow rate may explain the depressed pH during periods of high flow when there is insufficient time for carbonate equilibrium. These depressed pH values could result from either a flushing of oxidation products or a lack of time for carbonate dissolution equilibrium or a biological response to increased temperatures and biotic production. The mechanism responsible for the lower pH values has not been resolved at this time and is discussed in more detail below. Of particular note, however, is that the minimum pH values are increasing with time as shown in Fig. 5 which provides over fifteen years of pH and specific conductance data for the 378 wetlands.

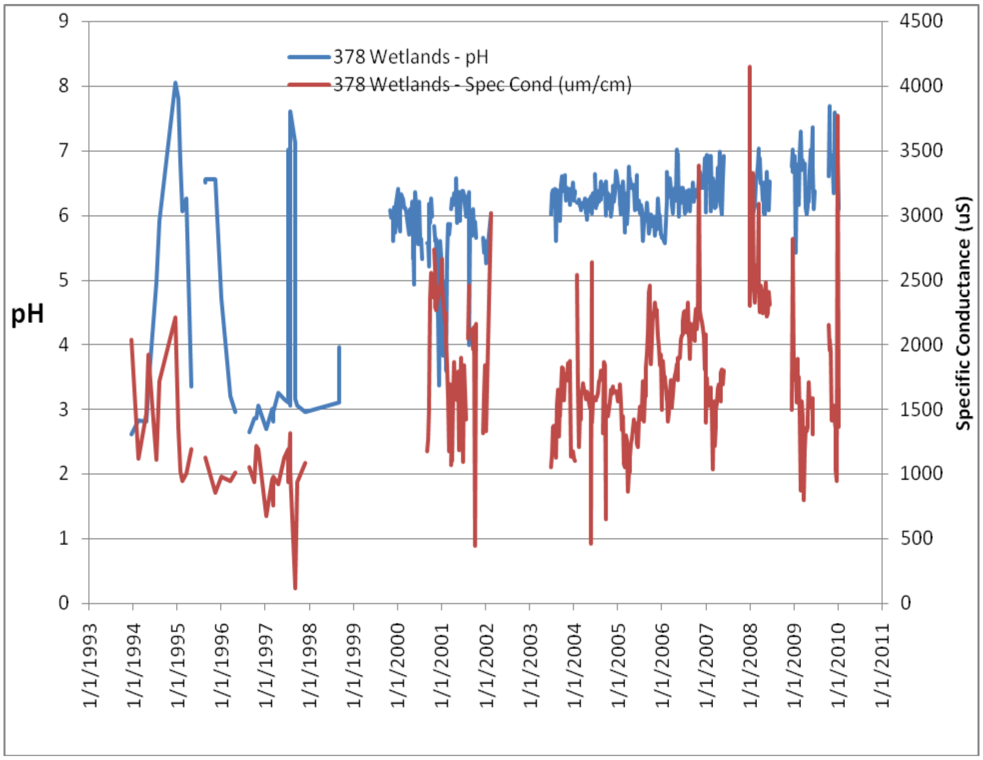

Figure 5. pH and Specific Conductance for 378 Wetlands at A-1 discharge collected at the weir.

As Fig. 5 indicates, when the 378 A-1 Wetland was completed in 1994, the pH increased, but went through several years or cycles of variable pH and conductivity fluctuations prior to the drought of 1999 and 2000. Between 1994 and 2002, additional wetlands and alkaline additions were being constructed within the drainage basin, with minor modifications continuing until 2008. Therefore, it was not until 2002, that the full areal extent of the wetlands was completed and the flow from A-1 reflected the total of the wetland system. Thus, when normal rainfall and flow conditions returned in late 2000, the wetland system was just becoming established. The fluctuations in water quality at the discharge point, A-1, during the next three years (from mid 2000 to late 2002) were pronounced, exhibiting variations of over 3 pH units per cycle (e.g. in 2001, pH ranges from 3.5 to 6.5 and in 2002, pH ranges from 4 to 6.5). However, with time and after approximately three years, the extent of the variability decreases and pH ranges per year or cycle are approximately 1 pH unit; between 5.5 and 6.5 or between 6 and 7 pH.

The fluctuations observed in the 378 Wetlands in 2000 to 2002, were similar to those subsequently observed in the PP wetland during three cycles from 2007 to 2010. When the pH values of the two sites are compared, as shown in Fig. 6, the variability of effluent and similarity of the trends between the two systems is apparent.

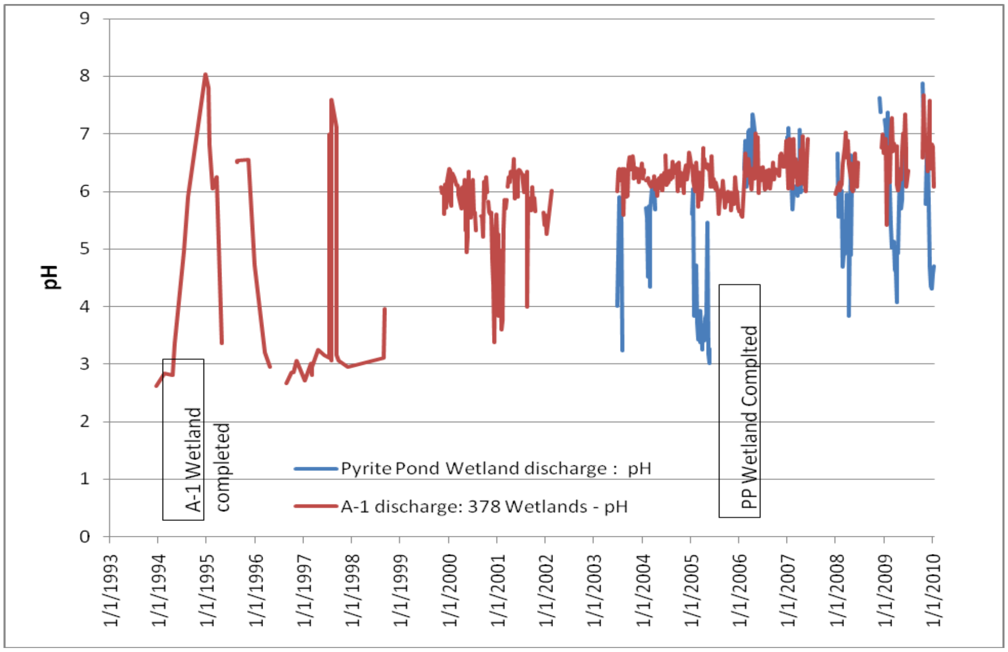

Figure 6. Pyrite Pond (PP) Wetland and 378 Wetlands pH values with time.

Comparing the pH data from 378 Wetland discharge from 2000 forward to the pH data from the PP wetland suggests that wetlands at this site exhibit a cycle of increased pH followed by depressed pH under periods of higher precipitation followed by pH recovery. However, the correlation between pH and flow is low (R^2=0.034 for PP discharge from January 2006 (wetland completion) to January 2010) and suggests that other factors influence this cycle. One of the secondary factors is temperature. Under the climatic conditions of Georgia, discharges are rarely frozen and flow year round with sufficient precipitation; however, it is observed that the decreased pH values occur following periods of cold weather. Cold weather occurs during the winter months, but rarely persists for longer than several weeks between January and March. Several of the sharp decreases in pH may to be more strongly correlated with large temperature fluctuations than high flow conditions. With time, however, regardless of the conditions influencing pH variations, these fluctuations decrease as evidenced in the long term pH trends shown in A-1, 378 Wetland (Fig. 6).

Several other potential causes for the reduced pH levels have been considered but based on current data, the results are inconclusive. Possible explanations for the depressed pH values include the flushing of oxidation products from the wetlands or a lack of time for carbonate dissolution equilibrium or a biological response to increased temperatures and biotic production. If sulfide oxidation products were causing the depressed pH, a resultant increase in conductivity and sulfate should accompany the lower pH values. While this occurs on occasion, (see 2000 to 2002 data for 378 Wetland, Fig. 5) during subsequent years, there was an inverse relationship of lower pH values and lower conductivity values. In the PP Wetlands, there is a slightly better relationship between pH and Specific Conductance (SC), see Fig. 7, which indicates that during the most recent cycles, slightly increased conductivity correlates with lower pH values. However, the highest SC values do not correlate with the lowest pH values; pH 4.0 and SC 810 uS versus pH 4.59 and SC of 1530 uS.

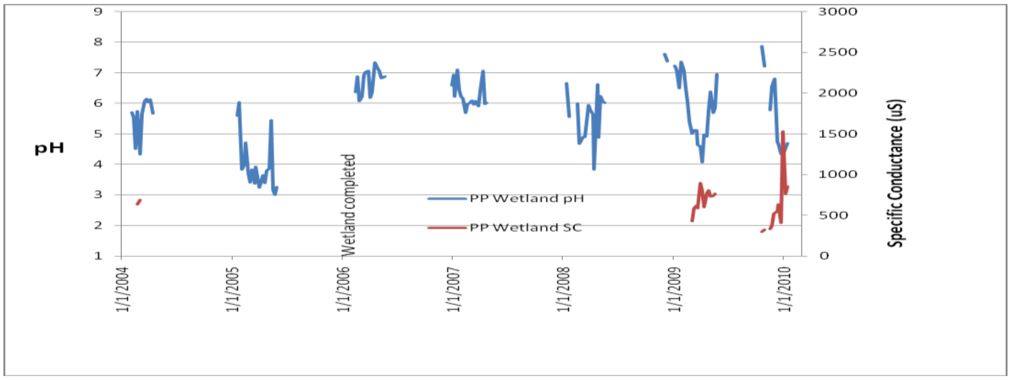

Figure 7. PP Wetland pH and Specific Conductance.

However, given the general correlation between pH and SC, this could partially explain some of the variability. The data available also suggest that the low pH values relate to a lack of sufficient time for maximum alkalinity generation within the wetland coupled with iron oxidation. The primary factor working against either of these hypotheses is the wetland function. Based on observations, coupled with peizometer measurements, the limestone and compost layers remained wet and saturated throughout the year. Under these conditions, pyrite oxidation should be minimized. Some oxidation could and probably does occur within or near the system, but the majority of the wetland system should be anaerobic and conducive to pyrite formation rather than pyrite oxidation. Therefore, another potential source of depressed pH is related to biological activity and temperature. Temperature fluctuations of 20º C are not uncommon during the spring when most of the lower pH values occur. It is suggested that with increasing biological activity and photosynthesis within the wetland, the gas composition of the surface water changes from O^2 depleted to O^2 enriched and, thus, impacts the discharge quality. Data is currently being collected to evaluate this potential.

Regardless of the cause of the depressed pH, both wetlands show that even when depressed pH values occur, the extent of the depressed values decreases with time. The overall pH of the 378 Wetland at A-1 is increasing with time; in 2006 the median pH value was 6.2 while in 2009, the median value was 6.5. In the PP wetland, a similar trend is occurring; the minimum pH during a depressed cycle has increased from 3.84 to 4.35 and over the last three years, the median pH has increased from pH 5.2 to approximately 5.5. Assuming this trend will continue and follow the trend exhibited by A-1, 378 Wetland discharge, it is anticipated that the wide ranging pH changes should be minimized within an additional one to two years.

Summary and Conclusions

The former Graves Mountain mine site near Lincolnton, Georgia, USA, produced kyanite from a pyritiferrous quartzite-kyanite ore and tailings were formed during the processing and deposited in various areas on the mine property. While the majority of tailings were placed in large tailings ponds on the south side of the mountain during the final stages of the mining operation, several smaller tailings ponds were located to the north and west of the mountain. These tailings impoundments contained pyrite, among a variety of other minerals, and the oxidation of the pyrite as well as some residual acid from the flotation process, created conditions which produced acidic discharges with high iron and sulfate concentrations from the tailings ponds. These discharges have been actively treated, however, the goal for this site was to provide passive treatment for the majority of the discharges and remove the active treatment components.

Two sets of anaerobic wetlands were designed to treat the effluents from the north side (378 Wetlands) and the western side (Pyrite Pond (PP) Wetlands) of the site. The first wetlands were constructed in 1994 on the north side (A-1 Wetland) and subsequent modifications to areas contributing to this flow continued through 2002. In the western drainage basin, an anaerobic wetland was constructed downstream of the PP tailings pond and completed in January 2006. Both sets of wetlands drain approximately similar sized drainage basins and the wetlands are similar in size. The 378 Wetlands are a combined size of 0.26 ha (0.63 ac) and the Pyrite Pond (PP) wetland with three cells is 0.24 ha (0.59 ac).

Each of the wetlands displayed a seasonable variability in discharge quality; some of which is attributed to flow variations due to precipitation events, but in other cases the variability tends to be related to a temporal function. Although the climate of Georgia does not usually produce periods of frozen flows, the temperature or seasonal effect may also be related to decreases in pH as well as flushing of oxidation products. The data suggest that following a coldest period, a decrease in pH occurs. However, at times, the depressed pH also corresponds to a significant precipitation event which increases flow from the wetland. The data suggest that regardless of the cause of the depressed quality of the discharge effluent, the changes become less dramatic with time and that with time, while the extent of the data fluctuations decreases, the minimum pH increases and maximum specific conductance values moderate. The median pH shows an increase with time; both in the short term as shown by the PP wetlands (from pH 5.2 to 5.5) and in the long term as evidenced by the 378 wetlands (from 5.5 in 2002 to 6.8 in 2009). Furthermore, this study suggests that in the climate in which these wetlands were evaluated and under the geochemical conditions of the site, more than three years are required to fully evaluate the effectiveness of the wetlands.

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Literature Cited

Caruccio, F. T. and G. Geidel, 1996. Limestone additions to affect changes in loading to remediate acid mine drainage. American Society for Surface Mining and Reclamation, Knoxville, TN. May 18-23, 1996. pp. 695-700.
https://doi.org/10.21000/JASMR96010695

Cook, R. B., Jr., 1985. The Mineralogy of Graves Mountain, Lincoln County, GA. The Mineralogical Record, Vol.16, no.6, pp. 443-458.

Geidel, G and F.T. Caruccio, 2000. Geochemical Factors Affecting Acid Mine Drainage, *In:* R.I. Barnhisel (Ed.), Reclamation of Drastically Disturbed Lands, 2nd Ed, Chap 5. , ASA, Ohio.

Geidel, G. and F. Caruccio, 2002. The Use of Multiple and Synergistic Reclamation Technologies To Improve Water Quality From Kyanite Mine Tailing, Proceedings America Society of Mining and Reclamation, 2002 pp 41-57. http://dx.doi.org/10.21000/JASMR020100041

Geidel, G. and F. Caruccio, 2004. Long Term Effects of Reclamation of Kyanite Mine Tailings with Surface Reconfiguration. 32nd International Geological Congress, Abstracts. Florence, Italy. Aug. 20-28, 2004.

Geidel, G., F. T. Caruccio, and E. R. Dotson, 1999. Reclamation of kyanite mine tailings with surface reconfiguration. American Society for Surface Mining and Reclamation, Scottsdale, Arizona, August 13-19, 1999, R.I Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502
https://doi.org/10.21000/JASMR99010208

Hartley, M.E.,III, 1976. Graves Mountain. Georgia Geological Society, Field Trip Guidebook, Vol 16, Pp. 42-52.

Hedin R.S. and R.W. Nairn, 1992. Designing and sizing passive mine drainage treatment systems. In: Proceedings, 13th West Va. Surface Mine Drainage Task Force Mtg., Morgantown, WV.

Skousen, J.G. and B.B. Faulkner, 1992. Preliminary results of anoxic limestone drains in West Virginia. In: Proceedings, 13th West Va. Surface Mine Drainage Task Force Mtg., Morgantown, WV.

Skousen, J., A. Rose, G. Geidel, J. Foreman, R. Evans, W. Hellier, and ADTI, 1998. A Handbook of Technologies for Avoidance and Remediation of Acid Mine Drainage, ADTI, WV NMLRC, Morgantown, WV. 131 p.