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Garrett Struble

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By Garrett Struble
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ABSTRACT

The passive coal mine remediation system at Wingfield Pines Conservation Area (Bridgeville, Pennsylvania) failed following a November 2017 rupture of the mining cavern it contained. The event caused a ~2000 gallon/min abandoned mine drainage (AMD) flow to bypass the remediation system, directly entering Chartiers Creek between November 2017 and September 2019. The system was observed during the last 7 months of its ~2-year dormancy and simultaneous repair, which drained the system of water. Personal observation, testimonies, and photographic evidence were analyzed to identify changes in vegetation, flow, and function of the system pre-rupture (2017) and post-repair (November 2019). Major physical and chemical changes occurred in the system and mining cavern during its dormancy, which may affect its function and remediation of AMD well into the future. The ~2-year dormancy of the system acted to dry the saturated AMD-sludge, which accumulated at the bottom of the ponds, allowing opportunistic vegetation to spread throughout the ~20-acre system. Despite receiving no direct influent and the absence of water in previous and subsequent ponds, pond 4 retained water during the ~2-year dormancy. This suggests an alternate water source supplies pond 4 of the system. After water was returned to the system, vegetation accumulated and showed visual evidence of decay at the influent of each pond except pond 4. The physical and chemical alterations to the system have the ability to both directly and indirectly impact conditions such as flow rate and pattern, dissolved oxygen, temperature, and pH. Exposure of the anoxic

sediments within ponds 1, 2, 3, and 5 likely caused the species they contain to become completely oxidized. In the context of AMD remediation, the alteration of multiple biotic and abiotic factors has the potential to cause complex changes to microbial community composition and chemistry at Wingfield Pines. Furthermore, these changes may act to alter the function and remediation efficiency of Wingfield Pines passive remediation system as compared to 2017.

INTRODUCTION

Wingfield Pines Conservation Area spans 87 acres of riparian buffer forest and floodplains which border Chartiers Creek in Bridgeville, Pennsylvania (40° 20' 27" N; 80° 06' 35" W)[1]. Riparian buffer forests are key to maintaining the health of bodies of freshwater and surrounding ecosystems. Therefore, conservation areas like Wingfield Pines are crucial in providing habitat and other ecosystem services in Allegheny County. Along with multiple unique woodland, prairie, and wetland habitats, Wingfield Pines is home to a ~20-acre passive coal mine remediation system[1]. The passive, gravity-operated system was completed in 2009 by Allegheny Land Trust (ALT) with the primary goal of filtering soluble iron from mine water discharge which, if left untreated, would flow into Chartiers Creek at approximately 2,000 gallons/minute[1]. ALT is a 501(c) non-profit organization devoted to permanently protecting land from development. Remediating abandoned mine drainage (AMD) at Wingfield Pines is crucial to their conservation efforts as a land trust. The effect that mining has had on Wingfield Pines and Chartiers Creek is undeniable. In the past 70 years, Chartiers Creek was artificially straightened and rerouted to make way for mining operations, then continually exposed to AMD before the installation of a passive remediation system in 2009[1]. Additionally, the natural sloping hills of the property were sacrificed for an artificial high wall[1]. These changes greatly impact the quality of freshwater stream habitat and disrupt natural processes such as sedimentation and natural nutrient and oxygen gradients[4]. AMD exposure leads to the accumulation of metal-rich sediments in freshwater environments, which may travel long distances and have long-lasting impacts on stream health[4]. The full extent to which legacy mining operations and AMD exposure has impacted Chartiers Creek and its greater watershed, ecological stability and resilience is unknown. It can be said, however, that the operation of passive remediation systems is crucial in maintaining the integrity of Pennsylvania's freshwater ecosystems and drinking water[4,5]. Unfortunately, for the nearly 11,000 AMD sites identified in PA, only ~300 passive remediation systems exist[5].

The presence of circum-neutral AMD at Wingfield Pines can be attributed to multiple coal-mine operations on the property throughout the 1940s and 50s. Before the Surface Mining Control and Reclamation Act of 1977, many mining operations were simply left abandoned and discharging hazardous AMD after coal deposits were depleted. These abandoned mining caverns may expose pyrite and other metal-sulfide containing rock to groundwater and air. The result is bacterially mediated oxidation reactions, which produce a low-pH solution high in dissolved metal concentrations (AMD)[2]. In the case of Wingfield pines, AMD produced from mine discharge flows over natural limestone beds, which contain calcium carbonate. Calcium carbonate increases the pH of AMD to circum-neutral (~7). Whether acidic or circum-neutral, AMD contains high concentrations of contaminants such as Al, K, Cd, Co, Cr, Fe, Mn, Mg, Cu, As, Hg, Zn, Pb, Ni, Ca and SO_4 (sulfate)[2]. Wingfield Pines, specifically, has high concentrations of Fe and SO_4 and elevated levels of Mn, Al, Zn, and Sr[3]. The main purpose of the Wingfield Pines passive remediation system is to remove dissolved iron from AMD. As constructed in 2009, the system effectively remediated dissolved iron through the use of an aeration pipe, gravity-fed settling ponds, and a constructed wetland[1,3].

This article identifies major physical changes to the Wingfield Pines passive remediation system, which occurred between 2017-2019 as a result of a fracture in the mining cavern. The changes described are relevant to remediation and system performance because they may impact various biotic and abiotic factors. For instance, the growth of plants not accounted for in the original design may change flow patterns and rates, potentially impacting remediation efficiency. In an AMD system, such factors interact in complex chemical and biological gradients which are difficult to fully describe. In addition to the changes identified in this article, factors such as minor contaminants (Zn, Sr), seasonal changes[3], microbial interactions, and redox gradients are also subject to change at Wingfield Pines. Though it is impossible to account for every geochemical factor, identifying major changes to the system may help conservationists understand and improve its function. In order to fully realize the impact of the changes described in this article, data on flow rate and pattern, vegetative cover, contaminants, and microbiology is needed.

SYSTEM FAILURE

On November 6, 2017, ALT staff at Wingfield Pines noticed that the system's fountain pipe was no longer running **(Figure 1A&B)**. The fountain pipe usually feeds the system and exposes ferrous iron (Fe^{2+}) to oxygen to form ferric (Fe^{3+}) iron precipitants[1]. Further investigation attributed the system's failure to a major breach in the mine cavern, causing the AMD to bypass the system[1]. ALT staff suggested that multiple flash flood events in the McLaughlin Run watershed around the time of the blowout likely acted to catalyze the geologic event[1.] Immediately after the blowout was discovered, ALT staff began their proposal to contain AMD and repair the system[1]. Repair of the system would prove difficult, however, due to the magnitude and location of the blowout.

A. 

B. 

Figure 1. Fountain Pipe which Feeds AMD System. (A) The fountain pipe which feeds the passive remediation system and oxidizes ferrous iron in AMD effluent is shown before the system's failure in November 2017. Photo taken 17 February 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. **(B)** After the system's failure, the fountain pipe which feeds pond 1 stopped flowing. The abundance of plant life which appeared in the system during the ~2-year repair is shown. Photo taken 26 June 2019 by Garrett Struble.

Following the major rupture to the mine cavern in November 2017, AMD bypassed the 20-acre passive remediation system, flowing directly into Chartiers Creek at rates of ~2,000 gallons/min (**Figure 2A&B**)[1]. Due to the nature of the sub-surface fracture, the multi-step repair took nearly 2 years to complete—leaving the system dormant. Until the system's re-opening in September 2019, iron-rich AMD flowed directly into Chartiers Creek as it did pre-2009 (**Figure 2B**)[1]. Multiple flooding and severe weather events, which increased in intensity in 2018, paired with the effluent of the AMD breach caused the PVC effluent pipe to become eroded. The result was an iron-laden stream bed connecting the final holding pond directly to Chartiers Creek (**Figure 3 A&B**). Failure of the passive coal mine remediation system at Wingfield Pines, followed by its lengthy ~2-year construction, illustrate the long-lasting effects of previous unsustainable land use.

A.  B. 

Figure 2. Mine Breach Photographed Shortly after Rupture. (A) Non-remediated AMD can be seen flowing into Chartiers Creek before the system's installation. Wingfield Pines AMD discharge has an orange color due to high iron content. Photo taken 2008. **(B)** The blowout hole which caused the breach of the passive remediation system spews AMD. Photo taken 6 November 2017. Photos by Emilie Rzotkiewicz, Vice President of Land Resources; Allegheny Land Trust

A.  B. 

Figure 3. Discharge of AMD into Chartiers Creek After System Breach. **(A)** Multiple flooding and severe weather events paired with the effluent of the AMD breach led to a wash out of the system's effluent pipe, which previously fed Chartiers Creek (red arrow). **(B)** Debris from the remnants of a land bridge with sub-surface PVC drainage pipe can be seen scattered on the right side of the riverbank (red arrow). Photos taken 26 June 2019 by Garrett Struble.

SYSTEM REPAIR

Repair of the system occurred in several stages: redirecting mine flow, installing an emergency pump, drilling around the fracture and subsequently sealing with a combination of polyurethane foam (Sub technical) and cement (Howard Cement)[6-7]. The mine fracture occurred on the high wall just before the discharge of the system's wetland into a final holding pond (**Figure 4**) before meeting Chartiers Creek. Due to the location of the fracture, a portion of the wetlands bordering the system was replaced with limestone gravel in order to allow the passage of construction vehicles (**Figure 4**). The disturbed portion of the wetlands does not receive AMD and was primarily composed of *Impatiens capensis* (spotted jewel weed) and *Sparganium americanum* (bur reed).

Figure 4. Location of Mine Cavern Breach at Wingfield Pines. The surface location of the mine breach is labelled with a star icon. AMD flowed into a small retention pond (white arrow) that drains into Chartiers Creek after the system's wetlands. The portion of the wetlands removed to allow access to the blowout is denoted with a white rectangle. Locations of the ponds and wetlands are labelled. Image retrieved from Google Earth on 30 November 2019.

Before the fracture could be permanently sealed with cement, the ~2,000 gallon/min breach needed to be slowed to <5 gallons/min, allowing the cement to harden without washing away. Construction, therefore, required the consecutive installation of emergency shut-off piping and pumps to redirect AMD while containing the mine breach. Repair of the rupture required careful monitoring of the mine cavern's volume of AMD and rate of flow via underground sensors. An emergency failsafe and drainage pumps were installed to avoid future breaches. Now, AMD may be redirected into the system from the mine cap located near the 2017 breach.

To achieve this feat, several staging areas and heavy-duty construction equipment were required to drill access holes to the mine cavern breach, install underground fail-safe/redirecting piping, and inject temporary sealant. ALT hired independent contractors Sub-Technical and Howard Cement to inject foam sealant and cement, respectively. Sub-Technical originally estimated that 600lbs of polyurethane foam sealant was needed to seal the mine blowout. Due to the unexpected extent of the fracture, 11,000lbs of polyurethane was actually required to produce the seal. Excess foam sealant, which overflowed from injection holes, is pictured in **Figure 5**.

Figure 5. Temporary Foam Sealant Used in Repair. Excess foam sealant used to seal the AMD breach can be seen on a trailer before removal from the property. Photo taken 26 June 2019 by Garrett Struble.

After the flow of the rupture was diminished by >99%, 1360 yards^3 of cement were injected by independent contractor, Howard Concrete, to provide a more permanent seal to the system's rupture[1]. After the finished repair in September 2019, AMD discharge finally re-entered the system for remediation. The passive remediation system at Wingfield Pines once again filters AMD contaminants while providing wetland habitat to many endangered and migratory birds as well as fish, reptiles, amphibians, and micro/macroinvertebrates.

WINGFIELD PINES PASSIVE REMEDIATION SYSTEM: 2017 vs 2019

Though the repair has brought the system back to its status as a functional passive coal mine remediation system, substantial changes occurred during its ~2-year dormancy. Besides several intermittent fillings with AMD near the end of the repair to test the emergency piping system, the ponds and wetlands remained largely dry between November 2017 and October 2019 (**Figures 6-10A**). Only pond 4 (**Figure 9A**) remained continually filled with water throughout the duration of the repair.

During the summer months of 2019, pond 4 acquired a relatively high temperature (~28^{o}C), a distinct cyanobacteria/alga layer, and frequent sightings of *Chrysemys picta* (painted turtle)*, Anas platyrhynchos* (mallard), *Ardea Herodias* (great blue heron), various snakes native to PA, and various *Lithobates* (American water frogs) in and around the pond. Additionally, pond 4 became more basic (lab pH ~7.7) than when the system is operating (lab pH ~6.5)[3].

A.

B.

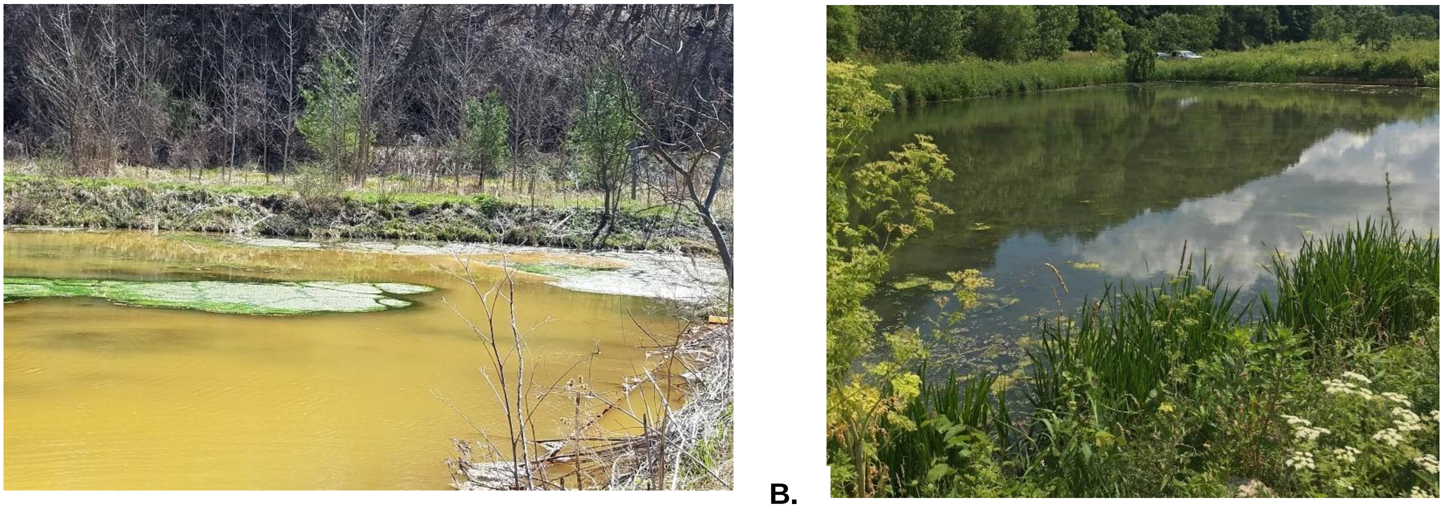
Figure 6. Pond 1 Before and After System Failure. **(A)**. Pond 1 photographed before the system's failure shows functional fountain pipe and absence of plant-life. Photo taken 27 February 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. **(B)** Pond 1 photographed during the system's repair shows abundance of plant cover in dry ponds. Photo taken 26 June 2019 by Garrett Struble.

A.  B. 

Figure 7. Pond 2 Before and After System Failure. (A) Pond 2 photographed before the system's failure shows absence of plant-life. Photo taken 8 August 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. (**B)** Pond 2 photographed during the system's repair shows abundance of plant cover in dry ponds. Photo taken 26 June 2019 by Garrett Struble

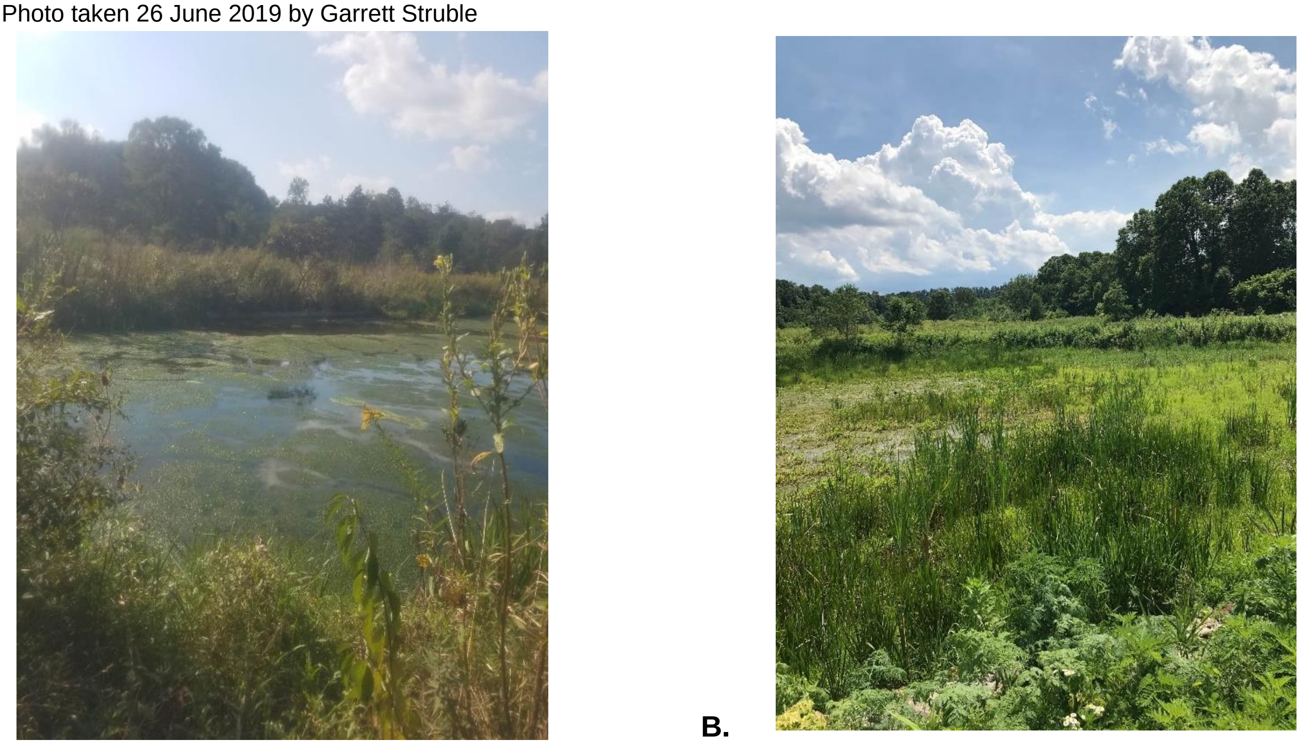
A.  B. 

Figure 8. Pond 3 Before and After System Failure. (A) Pond 3 photographed before the system's failure shows absence of plant-life. Photo taken 29 August 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. (**B)** Pond 3 photographed during the system's repair shows abundance of plant cover in dry ponds. Photo taken 26 June 2019 by Garrett Struble



A. B.

Figure 9. Pond 4 Before and After System Failure. (A) Pond 4 photographed before the system's failure shows absence of plant-life. Photo taken 29 March 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. (**B)** Pond 4 photographed during the system's repair shows maintained absence of plant cover due to maintained fill. Photo taken 26 June 2019 by Garrett Struble



A. B.

Figure 10. Pond 5 Before and After System Failure. (A) Pond 5 photographed before the system's failure shows absence of plant-life. Photo taken 27 September 2017 by Michelle Valkanas, Ph.D. candidate; Duquesne University. (**B)** Pond 5 photographed during the system's repair shows abundance of plant cover in dry ponds. Photo taken 26 June 2019 by Garrett Struble

The system's wetland, which usually supports a variety of birds and fish, remained drained but saturated during the repair through summer 2019. Fixing the AMD system that feeds the wetlands at Wingfield Pines was crucial in maintaining its ecological significance as wetland bird habitat[1]. The wetland's overall composition of plant life remained primarily *Sparganium americanum* (bur reed), as it was in 2017 when the system was filled and operational. When drained in the summer of 2019, isolated patches of cattails in the genus *Typha,* various grasses, *Alisma subcordatum* (American water plantain), bittercresses in the genus *Cardamine,* Peltandra virginica (green arrow arum), and *Impatiens capensis* (spotted jewel weed) were observed in the wetlands.

Before the system's failure, ponds 1-5 did not contain emergent vegetation (**Figures 6-10B).** During the system's repair, dry ponds were not dredged of iron sludge, a practice usually repeated every 10 years for passive remediation systems. Dredging the precipitated iron sludge from the bottom of AMD ponds acts to remove precipitated metals from the system and maintain efficient remediation. The soil-like sludge in ponds 1, 2, 3, and 5 gave host to a variety of common grasses, sedges, and rushes, as well as cattails in the genus *Typha*. Several isolated patches of the highly invasive plant *Lythrum salicaria* (purple loosestrife) were identified and removed within the ponds. After ~2 years of dormancy, ponds 1, 2, 3, and 5 became covered in a grassy bed and densely populated with *Typha* and tall grasses (**Figures 6-10A**). After the repair and refill of the system, wetland grasses and cattails continued to grow as emergent plants. Non-wetland opportunist plants and the grassy bed which spread throughout the dry ponds were not retained after the system refilled.

Pond 4 remained clear of vegetation except around its shore as a result of remaining filled during the system's repair (**Figure 9A**). The impact that these changes have had on the system from a physical standpoint alone will likely prove significant. During the ~2-year dormancy, pond 4 was also exposed to vastly different redox conditions than ponds 1, 2, 3, and

5. While the soil-like sludge of ponds 1, 2, 3, and 5 became completely dry and exposed to air, the sludge in pond 4 remained covered and saturated in water during the repair. Therefore, the species in pond 4 likely remained reduced (anoxic conditions), while those of ponds 1, 2, 3, and 5 were oxidized. When compared visually, the differences in the system between pre-November 2019 (**Figures 6-10B**) and post-October 2019 (**Figure 11A-E)** can truly be appreciated. The incorporation of vegetation may change the flow pattern of water in the system, impact oxygen levels, and filter water particulates mechanically. The new pattern and lack of vegetation in pond 4 may act to distinguish it from other ponds either chemically, biologically, or both. From a biological standpoint, the incorporation of vegetation within the ponds may change the soil's microbiome and overall soil processes/structure, as well as providing habitat for many terrestrial/aquatic organisms.

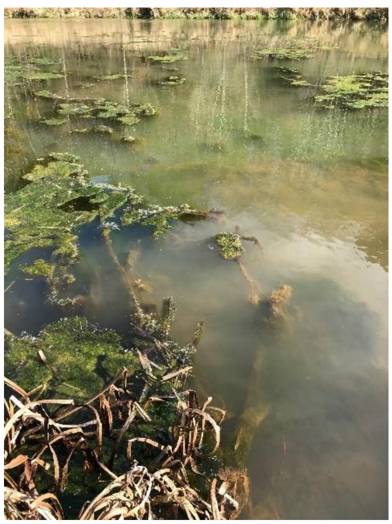
These changes also have great potential to change the soil's overall chemistry via increased soil aeration, introduction of a carbon source for microbial growth, and complex interactions between plants, soil bacteria, and soil nutrients. The addition of plant material and decay (carbon source) in ponds 1, 2, 3, and 5 (**Figure 11 A-E**) is a major factor in determining microbial growth and diversity. The unique situation that the ~2-year dormancy of the system has created is best appreciated in photographs (**Figure 11A-E**). The bed of grasses which covered the bottom of the dry ponds became fully submerged. The emergent grasses and cattails remained most prevalent around the influents and edges of ponds 1, 2, 3, and 5. Visible signs of decay were visible in areas where non emergent plants were fully submerged after the repair (**Figure 11 A-E)**. Undoubtedly, these changes only add to the complex system of chemical and biological interactions to consider within a passive AMD remediation system.

A.

B.

C.

D.



E.

Figure 11. System Appearance After the Repair. (A) Vegetation surrounding the influent trough of pond 2. Photo taken 21 November 2019. **(B)** Dense vegetation of *Typha* in pond 3 following repair. Photo taken 21 November 2019 **(C)** Iron plaque on vegetation observed in ponds following repair. Photo taken 10 November 2019 **(D)** Cyanobacteria/algae mat in pond 4 following repair. Photo taken 10 November 2019. **(E)** Dense cluster of grassy vegetation holds iron plaque in pond 5 following repair. Photo taken 10 November 2019.

DISCUSSION AND CONCLUSION

Comparison, testimony, and observation of the system's appearance and function in 2017 and 2019 was useful in identifying changes relevant to AMD remediation in a repaired passive remediation system. The greatest visible difference between the Wingfield Pines passive remediation system in 2017 and 2019 is the expansion of vegetation into ponds 1, 2, 3, and 5. After the system was filled with water in September 2019 following its repair, vegetation persisted at the influent of ponds 1, 2, 3, and 5, changing the flow rate as compared to 2017. The bed of grasses and cattails which grew in the dry ponds during the system's dormancy remained most present around the edges of the ponds after being filled in September 2019. Signs of vegetative decay were present at the influent of the ponds and in areas where non-emergent plants were fully submerged. Any non-wetland plants which opportunistically spread in ponds 1, 2, 3, and 5 died and decayed after being submerged in September 2019. The observed changes in vegetative cover, growth, and decay have the potential to directly and indirectly impact dissolved oxygen, temperature, pH, flow rate/pattern, microbial carbon sources, and microbial community composition/diversity. These conditions are all factors relevant to the remediation of iron at Wingfield Pines.

During the period between November 2017 and September 2019, pond 4 remained continually filled with water despite the rest of the ponds being drained. This phenomenon led to the chemical and biological separation of pond 4 after the system's repair. Unlike ponds 1, 2, 3, and 5, the sludge at the bottom of pond 4 remained saturated and anoxic. Additionally, the presence of water in pond 4 prevented the growth of non-wetland and opportunistic plants, as in ponds 1, 2, 3, and 5. The unique findings associated with pond 4 have several implications. First, pond 4 likely has a separate source of water such as runoff from rain or a groundwater recharge. Second, pond 4 gained very little vegetation during the 2-year dormancy of the system as compared to ponds 1, 2, 3, and 5. Lastly, the sludge at the bottom of pond 4 likely remained reduced (anoxic conditions) while the dry soils of ponds 1, 2, 3, and 5 were completely oxidized. When water was returned to the system, the oxidized sediments in ponds 1, 2, 3, and 5 were suddenly returned to saturated, anoxic conditions. Therefore, the already unique conditions of pond 4 were exaggerated by the ~2-year dormancy of the system. These changes may act to chemically and or biologically distinguish pond 4 from the rest of the system.

The findings from this article may inform future research of passive remediation systems. Additionally, as the infrastructure of Pennsylvania's ~300 passive remediation systems[5] begins to age, articles describing changes associated with repair and dormancy will become even more relevant. Furthermore, such findings are important in describing the long-term changes associated with passive remediation systems. The findings of this article will supplement future data on flow rate and pattern, vegetative cover, chemistry, and microbiology of Wingfield Pines' passive remediation system.

The AMD system at Wingfield Pines is a great demonstration of the complex nature of environmental hazards and the efforts required to manage them. Allegheny Land Trust, a non-profit organization dedicated to land conservation, has taken the responsibility of managing the AMD at Wingfield Pines. Without their intervention, it is likely that the AMD would be left completely untreated. Due to their efforts to remediate AMD at Wingfield Pines, an estimated 43 tons of iron oxide is prevented from entering Chartiers Creek each year[1]. The lengthy repair has demonstrated the many decisions that come with managing a passive remediation system. Luckily for ALT, the nature of a passive remediation system requires very little intervention under normal operating conditions. Interestingly, Wingfield Pines also illustrates how natural processes can be utilized to achieve passive remediation that acts to filter pollutants, while enriching ecosystem services. In addition to managing AMD discharge, the passive remediation system and extensive wetlands at Wingfield Pines act to provide habitat to a variety of plants, birds, amphibians, reptiles, fishes, and invertebrates. The importance of properties like Wingfield Pines to the health of Pennsylvania's rivers is undeniable. Furthermore, Wingfield Pines is a part of Pennsylvania's larger riverscape and provides a variety of habitats that are becoming increasingly rare within Allegheny County[1]. Riparian buffer forests like the sycamore and early-transitional boxelder forests along Chartiers Creek are crucial in maintaining proper river ecology, as well as geobiological processes such as runoff filtration, natural buffers for flood control, and erosion control via sedimentation. Unfortunately, thousands of miles of Pennsylvania's streams remain devastated due to AMD pollution. The need for unique strategies to enrich river ecosystems while managing AMD pollution is undeniable. For more information about Allegheny Land Trust or Wingfield Pines Conservation Area, visit their website at https://alleghenylandtrust.org/green-space/wingfield-pines/.

REFERENCES

1. "Wingfield Pines." *Allegheny Land Trust*, Allegheny Land Trust, 2019, alleghenylandtrust.org/green-space/wingfield-pines/.

2. Nordstrom, D. K. Mine waters: Acidic to circumneutral. *Elements* **2011,** *7* (6), 393-398, DOI: 10.2113/gselements.7.6.393.

3. Valkanas, M. M.; Trun, N. J. A seasonal study of a passive abandoned coalmine drainage remediation system reveals three distinct zones of contaminant levels and microbial communities. *MicrobiologyOpen* **2018,** *7* (4), DOI: 10.1002/mbo3.585.

4. Jones, J. I.; Murphy, J. F.; Collins, A. L.; Spencer, K. L.; Rainbow, P. S.; Arnold, A.; Pretty, J. L.; Moorhouse, A. M. L.; Aguilera, V.; Edwards, P.; Parsonage, F.; Potter, H.; Whitehouse, P., The Impact of Metal-Rich Sediments Derived from Mining on Freshwater Stream Life. In *Reviews of Environmental Contamination and Toxicology*, 2020; Vol. 248, pp 111-189.

5. Cravotta, C. (2010). Coal-mine-drainage projects in. Pennsylvania. URL: http://pa.water.usgs.gov/projects/energy/amd/index.php

6. "Underground, Ground Control." *Sub Technical*, Sub Technical Inc., www.sub-technical.com/mining-services/underground-ground-control.

7. "Howard Concrete Pumping Pittsburgh PA Office." *Howard Concrete Pumping*, Howard Concrete Pumping Co., Inc., www.howardconcretepumping.com/service-highlights/mine-grouting.

Struble, G. (2020). Substantial Changes Follow 2-Year Dormancy of Wingfield Pines Abandoned Mine Drainage Remediation System. *D.U.Quark*, 5 (1). Retrieved from https://dsc.duq.edu/duquark/vol5/iss1/article4