ACID MINE DRAINAGE TREATMENT BY BEAVER IMPOUNDMENTS IN SOUTHEAST OHIO¹

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Abstract. Nature's engineers, beavers, which have been observed to improve water quality, have created series of dams which act as a passive treatment system for acid mine drainage (AMD). Though this phenomenon has been observed for decades, it has not yet been scientifically quantified. At The Wilds in Southeast Ohio, where this research took place, over 90% of the land was surface-mined for coal. The northern property was mined pre-law and has numerous AMD locations. Strands of beaver ponds with AMD were observed and appeared to treat water similar to engineered passive treatments. Therefore, this study focused on quantifying the differences in water quality in eight series of beaver ponds affected by AMD. Each beaver pond (n=64) was tested for pH, conductivity, Fe, Mn, and temperature on the upstream side of the dam. Findings indicate that Fe and pH have a strong relationship: when pH rose, Fe levels lowered. Fe concentrations were less than 1 mg/L at the end of each strand of ponds, which is considered safe for wildlife. Six out of eight strands had a higher pH at the end than at the beginning. Mn concentrations showed no correlation with distance or pH. Conductivity was relatively constant for all strands. Overall, beaver impoundments did appear to help the water quality, given the final pH levels were raised by an average of 23.5% and Fe concentrations decreased by an average of 22.2%.

Additional Key Words: Coal mining, Strip mining, AMD, Passive treatment.

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Introduction

Surface mining has degraded millions of acres of land in Appalachia through vegetation removal, habitat loss, soil disturbance, and damage to water quality. Each of these components are intertwined, thus disrupting all four simultaneously can result in negative synergistic combinations and significant ecosystem degradation (Collier et al., 1964). Strip mining removes vegetation, rocks, and soil, called overburden, in order to obtain the minerals below. Federal laws in the United States currently require soil and subsoil to be stockpiled and returned to the affected areas and seeded with plants, typically non-native species, after mining concludes (Surface Mining Control and Reclamation Act of 1977). Before the SMCRA was enacted, rules and regulations either did not exist or varied by state, and most reclamation processes did not involve re-covering all mined surfaces with materials. In areas that were mined pre-SMCRA, issues such as highwalls and exposed overburden containing pyritic materials often led to ecological complications such as AMD, erosion, and dead spots (Studlick et al., 1980).

AMD is created when sulfide rich rock is exposed to oxygen and water (Nordstrom et al., 2015); this can lower water pH and have detrimental impacts on water quality, sometimes killing aquatic organisms. However, some plant species can survive and even improve water quality in AMD affected waters. Uptake of metals by plants, such as cattails, is insignificant compared to the high concentration of metals in most AMD streams (Karathanasis and Johnson, 2003), instead cattails treat AMD affected waters by slowing the water's flow, stabilizing the soil, creating an environment for metals to precipitate and collect in the sediment. Other plant species are known to improve water quality as well; after sphagnum bogs were observed to treat AMD (Huntsman et al., 1978; Wieder and Lang, 1982), studies on sphagnum moss began and showed that it is resilient to acidity and adept at removing metals (Watzlaf et al., 2004).

Wetlands that host cattail and sphagnum species can be created by beavers (*Castor canadensis*) through their development of impoundments. Because beavers create new environments for other organisms, they are considered keystone species (Naiman et al., 1986), as well as ecosystem engineers, one of the few species other than humans to be classified as such (Rosell et al., 2005). They often create a series of impoundments, or strands, which decrease the flow rate of streams and can lead to the creation of more wetland area. These strands have a beneficial impact on streams by retaining nutrients and decreasing turbidity. However, the retention of sediments can

prove detrimental to stream health if the dams were to break (Błędzki et al., 2011). Series of beaver dams in AMD impacted areas have been observed to improve water quality, though there has been almost no research on the matter. Given this huge gap in knowledge, this study will investigate the effectiveness of beaver impoundments acting as a natural passive treatment for AMD, looking at several systems within the property of The Wilds, a Surface-mining site in Appalachian Ohio.

Methods and Materials

The Wilds, a nearly 4,050 ha conservation site in southeastern Ohio, is over 95% reclaimed Surface-mined land. Most of the property is under study and restoration efforts such as reforestation and prairie installation have been implemented. The northern part of the property, which will be the focus of this study, was mined between 1940-1970 for coal, before SMCRA. Because of that, it has numerous water bodies affected by AMD, with several of those water bodies being beaver strands (Fig. 2). While some beaver strands began with a source of AMD, some AMD point sources were part way along strands (Fig. 1). The prevailing ecosystem type is deciduous forest, which was planted after mining, mostly in compliance with early state reclamation laws (King, 1990), though some areas were pre-law. The area has rocky, steep, and densely covered terrain with highwalls, earthen dams, and other topographic features remaining from mining. Geological surveys indicate that limestone is found in the bedrock of Muskingum County, where The Wilds is located (Ohio Division of Geological Survey, 2016).

Water Sampling

Water quality data at all streams and ponds were logged, usually with members from the Office of Surface Mining Reclamation and Enforcement, between February 28th, 2018 and May 30th, 2018. Eight strands of beaver ponds were tested, for a total of 64 ponds. At each pond, water was tested as close to the dam as possible on the upstream side at least 48 hours after the last rainfall event to avoid changes in water properties resulting from increased water flow. At each site, a bottle was rinsed twice, and then filled carefully with water in order to prevent the intake of sediment. These samples were tested without filtration. Testing parameters included pH, conductivity, and Fe and Mn concentrations (in mg/L). The pH was measured with an Oakton pH 310 Series. Conductivity was measured with an Oakton Con 400 Series. Both meters were gently placed where the sample was taken. Fe was measured with a Hach Pocket Colorimeter II Iron –

FerroVer device. Mn was measured with a Hach Pocket Colorimeter II Manganese – HR device. ArcGIS online was used in order to determine the length from the first dam to the last, using the GPS points. Each GPS point was taken at a dam, as close to the middle of the dam as was feasible.

Figure 1. Geological representation of pH values on The Wilds property.

Data Analysis

RStudio was used (RStudio Team, 2016) to analyze data using all linear mixed models, with watershed as a random effect. After using GIS to find the length of each strand of beaver dams, pH, Fe, and Mn was compared with distance in Microsoft Excel (2016) and graphed in Excel and Matlab (2018).

Figure 2. Left: The Wilds property. Right: close up map of all the strands tested. Each black dot represents a beaver pond, with a total of 64 ponds sampled. The blue arrow shows direction of water flow, downstream being each arrow-head.

Results

Six of eight strands tested had a higher pH at the last dam than at the starting point (Fig. 3). It is important to note that beaver strand MLK starts after beaver strands M, L, and K join and therefore its starting meter value is not actually zero. Taking this into account means that seven out of eight strands had a higher and more favorable pH by the end since strand L enters strand MLK.

Mn varied with distance, whereas Fe decreased by the end of each strand (Fig. 4). The device that measured Mn read to a maximum of 22 mg/L and the device that measured Fe read to a maximum of 5.5 mg/L. Therefore, when each respective element is at the maximum level, the true value could be higher. The conductivity, measured in mS/cm, was graphed against distance (Fig. 5). The side by side comparison of all beaver strands tested also show that for each stream the conductivity stays relatively constant.

Figure 3. Changes in pH vs. distance of 8 strands of beaver dams, comprising 64 ponds, located within The Wilds conservation site in southeastern Ohio.

Figure 4. Side by side comparison of Mn and Fe measured in mg/L vs. distance for all beaver strands studied. The Mn y-axis goes to a maximum of 22 mg/L, and the Fe y-axis goes to a maximum of 5.5 mg/L as per the maximum reading of specific devices used to measure said metals.

Linear mixed models show that Fe was affected by pH and distance combined, with pH alone having a very similar but slightly better fit (Table 1, AIC= 200.7 vs 200.5). Models with Mn as the dependent variable showed distance to be the best predictor, followed by null model or pH and distance (Table 1). However, for both FE and MN, AIC values were fairly similar between models.

Figure 5. Side by side comparison of conductivity (measured in mS/cm) vs. distance for all beaver strands studied.

Table 1. Linear mixed model tests using R Studio to determine relationships between dependent variables (Fe and Mn) and fixed effects (pH and distance), taking the random effect “watershed” into account.

Fixed Effect(s)	Dependent Variable	Estimate	T Value	AIC
pH and Distance	FE	pH: -0.443 Distance: -0.001	pH: -3.165 Distance: -1.586	200.7
pH	FE	pH: -0.399	-2.949	200.5
Distance	FE	-0.001	-1.143	207.2
Null	FE	---	---	206.2
pH and Distance	Mn	pH: -0.474 Distance: -0.006	pH: -0.785 Distance: -1.859	389.5
pH	Mn	-0.514	-0.831	390.9
Distance	Mn	-0.006	-1.885	388.1
Null	Mn	---	---	389.6

Discussion

The best indicator for water quality improvement found in this study when moving along AMD-impacted beaver strands is increased pH almost all strands measured had a higher pH at the end than in the beginning. These results are similar to results found in 116 human-engineered passive treatment systems (Skousen and Ziemkiewicz, 2005). The increased pH in this instance is likely due to declines in Fe (Table 1). Fe levels were consistently low, 1 mg/L or lower, by the end of the stream (Fig. 4), enough so to be considered safe for wildlife (Oram, 2014); alternatively, Mn levels did not appear to follow a consistent trend (Fig. 4), nor did conductivity (Fig. 5).

Two of the strands, A and F, may not necessarily reflect the effectiveness of beaver ponds in treating AMD. The sharp decrease in pH in the middle of the strand (Fig. 3) is the result of acidic water inflow from a second AMD source. Despite these influences, beaver impoundments generally resulted in improved water quality. This could be due to a number of mechanisms, including reactions in aerobic and/or anaerobic ponds, limestone, and vegetation. Future studies could focus on systems where AMD enters at the top of a strand to better clarify these impacts.

Potential Mechanisms for AMD Treatment in Beaver Ponds

Aerobic and anaerobic ponds. Aerobic and anaerobic ponds work together to fix acidity in many designed passive treatment systems (Skousen and Ziemkiewicz, 2005). Aerobic ponds naturally oxidize the water with use of bacteria, algae, and wind. This oxygenation helps to precipitate some metals that are dissolved in the water, but also creates hydrogen ions which lower the pH. Anaerobic ponds reduce the acidity through the activity of microorganisms that use the hydrogen ions as energy (Ford, 2003). Some beaver impoundments studied could be aerobic, and others could be anaerobic. Rain and semi-deteriorating dams would be a cause of aeration, causing the precipitation of metals to begin. Some impoundments or sections of impoundments could be anaerobic, absorbing the hydrogen ions and lowering the pH. It would be beneficial to build on this study by measuring dissolved oxygen, alkalinity, and sulfate, in addition to the other factors; this would increase understanding of the mechanisms within these beaver impoundments that improve water quality.

Limestone. Limestone is made out of calcium carbonate, and has been known to treat acidic water through a chain reaction with the hydrogen ions in the water in the following chemical reaction (Cravotta III et al., 1999)

Limestone and H^+ ions can be converted to calcium ions and OH^- ions, which raises pH but also produces dissolved solids. These limestone reactions would be able to occur more extensively when the AMD water is retained in beaver ponds for an extended period of time.

Limestone presence may also explain the conductivity results, which were consistently at high levels and did not follow a particular trend (Fig. 4); conductivity levels for a healthy stream are typically 150-500 $\mu\text{S}/\text{cm}$, while all data points in this experiment were above 1000 $\mu\text{S}/\text{cm}$. Conductivity of water is directly associated with total dissolved solids, and while Al or Fe reactions would result in a precipitate, the above limestone reactions would result in dissolved calcium ions that increase total dissolved solids, displaying a relationship between alkalinity and conductivity (Thompson et al., 2010). In this system, if limestone was not a factor and the metals were precipitating, conductivity should decrease. However, sulfate created from AMD could also be a contributing factor for conductivity.

Vegetation. The increasing pH in this system could be related to local vegetation. Cattails (*Typha* spp.) are prominent within this area, particularly in strand A from the two dams that are on either side of the 700-meter mark. In these locations, the pH was low until there was a big patch of cattail, at which point the pH increased from 4.42 pre-cattails to 6.88 post cattails, matching expectations of their ability to help AMD affected areas (Watzlaf et al., 2004). In future monitoring efforts, it may be beneficial to document plant species and measure vegetation density along beaver strands to see if it relates to changes in pH.

Conclusions

Beaver dams appear to have some positive effects on water quality where AMD occurs. By the end of the beaver strands, the Fe levels were all less than 1 mg/L, which is safe for wildlife (Cadmus et al., 2018). The Mn levels were unpredictable and beaver strands appeared to have no effect on this metal. Conductivity also was unchanged, which is not unexpected since there are many minerals that remained dissolved. Ultimately, pH increased with distance and appeared to be treated by an undetermined mechanism in these strands. The next step in this experiment would

be to increase sampling efforts and focus on finding the exact locations of AMD influxes. Seeing how values fluctuate across seasons and with rainfall events would also be extremely beneficial. Once this study has been replicated and the exact locations where AMD originates are determined, other treatment options such as cattail marshes or limestone treatment could be employed in areas where the pH does not reach a neutral range.

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