Treatment of Acid Mine Drainage in Huff Run, Sunday, Monday, Leading and Raccoon Creek Watersheds, Ohio

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Background

The first reported production of coal in Ohio was in 1800, three years prior to Ohio's entrance as the 17th state. By 1806 there reports of coal mining in 3 counties in the state (Crowell, 1995). Early coal production was minimal during the early 1800's and it wasn't until the mid-1800's that mining began booming. Peak mining occurred in 1918, employing a work force of more than 50,000 (Crowel, 1995). Most of this mining was utilizing underground methods until the mid-1900's when surface mining became the dominant method. By the time Ohio passed the Ohio Strip Mine Law in 1972 and the Surface Mine Control and Reclamation Act (SMCRA) passed in 1977 there had been a century and a half of coal mining with no or little environmental regulations. Most coal mining occurred in the 26 counties in the southeast and eastern part of the state, in the Appalachian foothills. Many streams and entire watersheds were severely impaired by acid mine drainage (AMD) from abandoned mines.

In the mid 1990's ODNR began a program to address AMD from abandoned mines and attempted to restore impacted watersheds. Acid Mine Drainage Abatement and Treatment (AMDAT) plans were developed and provided access to Abandoned Mine Land (AML) funds through the AMD Set-aside program. These funds can also leverage other local, state and federal grant funds for treatment and abatement projects. By the late 1990's and early 2000's the focus of watershed restoration was on 4 watersheds in the state: Monday Creek, Sunday Creek, Raccoon Creek and Huff Run. These watersheds had significant interest from citizen based watershed groups and many other state and federal partners such as United States Forest Service (USFS), Ohio EPA, ODNR Division of Soil and Water, Ohio University, Rural Action, Army Corps of Engineers and many others. Restoration efforts later expanded into Leading Creek, Mud Run and Yellow Creek as well.

AMDAT plans developed by ODNR and local partners, such as Ohio University and Rural Action, directed watershed restoration efforts. Projects identified in the plans were developed and grants were solicited using the AMD Set-aside as match. The first AMD project was completed in 1998 in Monday Creek with the second soon following in 1999 in Raccoon Creek. The general approach to watershed restoration was to address the largest acid and metal loaders in each watershed first to reduce the contaminant loads to the mainstem. Monitoring plans and networks were established to monitor changes in water quality and eventually the aquatic community as well. Eventually AMDAT plans were completed on 14 watersheds and AMD restoration efforts are underway in seven of those watersheds, including Leading Creek, Yellow Creek and Mud Run.

Summary of AMD Treatment

Results of watershed restoration highlighted in this paper will focus on five watersheds: Raccoon Creek, Monday Creek, Sunday Creek, Huff Run and Leading Creek. Mud Run and Yellow Creek projects are within the last year or two and long-term changes in water quality are not measurable at this time. As of 2016, a total of 66 AMD projects have been completed in the five watersheds. Over $30 million dollars has been spent on design, construction and maintenance of these projects since 1998. About 60% of those funds were from the AMD Set-aside fund with 40% coming from various agencies through grants and financial support – most notably Ohio EPA Section 319 Clean Water Act grants, Office of Surface Mining Reclamation and Enforcement (OSMRE), USFS, Ohio Department of Transportation and many others.

AMD treatment and abatement projects in Ohio constitute all three known approaches: active, passive and source control (i.e. reclamation). Each AMD treatment project may or may not contain a combination of approaches and some larger projects even have multiple treatment beds or systems, so 66 projects does not correlate with exactly 66 treatment systems. In addition, some projects only included reclamation of barren spoil and gob and required no water treatment. Currently in Ohio there are 10 limestone leach beds, 3 vertical flow ponds (VFP/SAPS), 1 anoxic limestone drain (ALD), 9 aerobic wetlands, 3 open limestone channels (OLC), 15 steel slag leach beds, 1 newly constructed bioreactor bed and 6 lime dosers that are actively being maintained for AMD treatment. In addition to treatment systems, 16 projects included significant reclamation of barren gob & coal refuse and another 12 projects consisted of the closure of subsidence features that were capturing streams/drainages.

Table 1: Types of AMD Treatment Systems in Use in Ohio

	Passive Treatment							Active Treatment	Source Control	
Type of System	SLB	LLB	Wetland	VFP/SAPS	OLC	ALD	Bioreactor	Lime Doser	Reclamation	Stream Capture
# of systems	15	10	9	3	3	1	1	6	16	12

Table 2: Number of Projects by Watershed through 2016

	Raccoon Creek	Monday Creek	Huff Run	Sunday Creek	Leading Creek	Totals
# of Projects	20	18	14	12	2	66
Design and Construction Cost	$14,521,361	$7,197,808	$5,308,353	$2,618,273	$728,481	$30,374,277

Additional treatment beds, and some modified systems, have been constructed over the years as well as some experimental practices. Those systems are not included in the above tables if they are not being maintained currently. Some of these treatment beds were constructed before water quality performance criteria for that technology had been fully developed and they did not function as intended and some just are past their useful lifespan and have been replaced with newer systems. In addition, may sediment ponds and limestone channels have been utilized that were not counted since many of these do not have a treatment specific goal, (i.e. load reduction) just sediment control. Active treatment systems are limited to lime dosers. Five of the dosers use calcium oxide, i.e. pebble quick lime, and one doser utilizes crushed limestone (i.e. super fine rock dust). Source control projects include some very large reclamation sites of abandoned fine and course refuse area, which also includes passive treatment after reclamation. Due to low cover and above drainage underground mines in both Monday and Sunday Creek watersheds, many projects have been completed that required filling large subsidence holes in stream valleys that were partially or wholly capturing surface flows into underground mines. These projects don't have quantifiable water quality gains in most instances but overall reduce the amount of unimpaired surface water entering mines that add to the volume of AMD discharges.

The three passive treatment systems most commonly used has been steel slag leach beds, limestone leach beds and aerobic wetlands. The approach with steel slag has been to use non-AMD influenced water to interact with steel slag to "super charge" the alkalinity. Different designs were experimented within the mid 2000's and through monitoring and studying these sites it was determined: 1) leach beds (similar to LLB) worked best for treatment 2) lining channels was only effective for a short time period 3) mixing of the discharge and AMD water needs to be immediate to not lose alkalinity as calcite precipitates 4) sediment ponds below mixing areas can capture solids/metals and 5) treatment rates and lifetimes can be estimated using inflow and amount of slag by calculating lifetime "bed volumes" (Goetz and Riefler 2014). Most SLB's treat AMD successfully for about 5 or more years depending on inflow. Alkalinity rates decrease predictably over time as fines react in the bed which helps with planned slag replacement. Limestone leach beds have been the treatment of choice in Ohio over the past five years when water quality conditions are suitable for limestone treatment. Earlier LLB's were place in areas with too high of iron and aluminum concentrations and clogged within months or a few years. Site selection was adjusted and LLB's placed in the correct location to treat AMD from underground mines has proven successful and at a low cost. Designs that incorporate an Agridrain outlet that allows for raising the water level one foot at a time has created better use of the limestone in the bed (3 feet deep) and extending the treatment lifetime. Two beds installed over 5 years ago are still on the first one-foot layer of limestone and when their performance begins to deteriorate the water level in the bed can be raised to allow the AMD to contact limestone that has not been in contact with AMD yet. Although it appears the system does not clog horizontally completely as hypothesized, the partially flooded stone layer does allow for extended lifetimes regardless. Aerobic wetlands have been used in areas of alkaline or near alkaline water conditions in priority streams or downstream of passive treatment systems. Two types of wetland have been used. One includes the use of in-stream wetlands using dikes or berms that spread out flow behind the structure to slow water down and maximize wetland area. In-stream wetlands have proven very cost effective because berms are low, constructed of stone and do not impound enough water to be classified as dams but increase wetland areas by large amounts. The largest of these wetlands is approximately 30 acres. The other approach is pond-like shallow wetlands downstream of treatment systems with constructed inlets and outlets.

Treatment approaches have changed over time in each watershed as water quality changed and restoration priorities were reevaluated. In addition, as passive and active treatment became more understood regarding site selection for each technology successes in treatment became more prevalent. As opposed to favoring a specific type of treatment system, the programmatic approach for AMD treatment is to look characterize each site individually and determine the most cost-effective treatment approach utilizing the best available technology.

AMD Watershed Restoration

The mission statement of the DMRM AMD Program is "To restore, the greatest extent possible, Ohio's acid mine drainage polluted streams to a healthy condition that will support a normal assemblage of aquatic life". The program is science based, relying on water quality and aquatic biology data to make program decisions about projects and funding. The AMD Program seeks to restore a waterbody to meet its designated use as defined by Ohio EPA, when possible. A specific targeted restoration reach has been established for each watershed where AMD treatment is underway. In most cases, AMD is so extensive in the targeted watersheds that it is unrealistic with limited funds to address all sources and improve or recover all streams. The general approach to date has been to treat AMD at sources and in subwatersheds and improve water quality in the mainstem or larger designated tributaries.

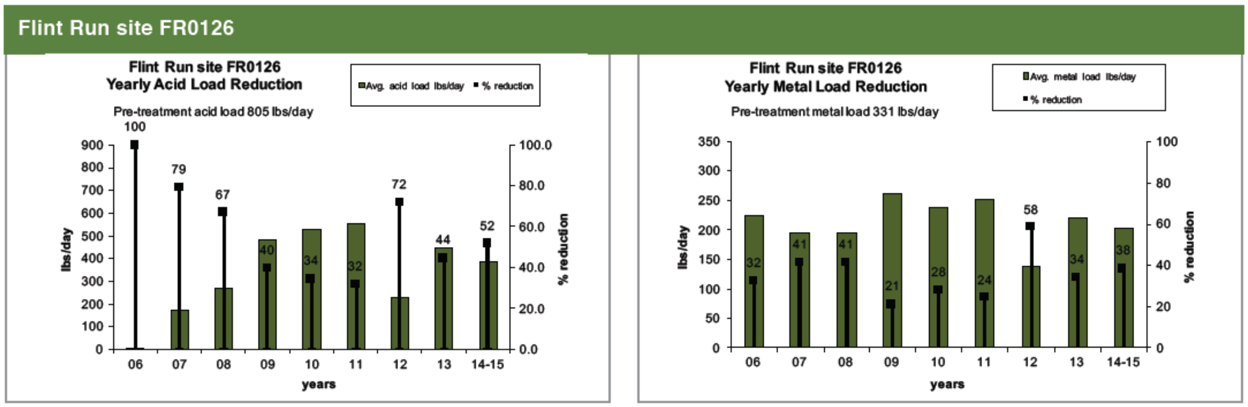
AMD Set-aside funds have been used to support watershed coordinators and local organizations to carry out watershed restoration work. This has been part of a larger effort in Ohio to fund Watershed Coordinators through a grant program from ODNR with Ohio EPA and local/regional partners since 2000. Watershed coordinator grants have allowed a full-time watershed coordinator to focus resources from the local community and partners on watershed restoration goals and monitoring. In addition, Americorps positions and in some cases part time water quality specialists have been funded to carry out monitoring and project development tasks in conjunction with ODNR and partners.

Monitoring plans are developed annually in the five watersheds with active AMD treatment projects. Monitoring includes both chemical and biological monitoring. Biological monitoring includes both fish and macroinvertebrate data. Fish data is collected by DMRM using Ohio EPA approved methods and an Index of Biological Integrity (IBI) and Modified Index of Well Being (MIwB) are calculated and compared to state water quality criteria (Ohio EPA 1987). For macroinvertebrates, a family level metric (Macroinvertebrate Aggregated Index for Streams – MAIS) protocol is developed (Smith and Voshell 1997). Family level criteria has been established for recovery in Ohio's Western Allegheny Plateau ecoregion specific for AMD impaired streams (Johnson, 2007). Chemical monitoring is focused at treatment sites to measure performance and at downstream locations to measure effects of treatment. Long term monitoring stations have been established in each watershed to evaluate recovery and water quality trends over time. Long term sites typically have both chemistry, flow and biology measured at regular intervals to evaluate trends over time. On average about 1,000 water samples are collected annually and are analyzed in-house at the ODNR Cambridge Laboratory.

An annual report of the monitoring data is produced by Ohio University's Voinovich School for Leadership and Public Affairs at http://www.watersheddata.com/UserView_Report.aspx. An acid and metal load reduction for each "active" AMD project is calculated annually. A minimum of two samples with flow are required annually at the designated treatment outflow location to determine the load reduction using a mean annual daily flow normalization method (Stoertz and Green, 2004). This method uses the mean annual flow of a site to normalize the flow data and report the load reduction based on the mean annual daily flow. A sample above and below the mean annual daily flow for a site is required for the analysis to be precise. Using this procedure for all AMD treatment sites creates a consistency in reporting load reductions and allows for evaluating performance with a minimal number of samples. Long term stations compare chemical data such as pH, iron and aluminum to state and federal water quality standards to determine if chemical goals are being met. Fish data is compared to state ecoregion criteria for warm-water habitat (WWH) for IBI and MiWB and macroinvertbrates MAIS scores 12 or greater than 12 are considered meeting normal assemblages. Data is also compared to baseline data established prior to watershed recovery efforts and AMD projects were installed.

Monitoring data collected by DMRM and partners has shown significant improvement in water quality in all five watersheds since concentrated efforts to treat AMD were initiated. Acid and metal load reductions are tracked by each project over time and included in the annual report for each project. This allows for a yearly load reduction to be analyzed for trends in treatment performance (Figure 1).

Figure 1: Flint Run Passive Treatment System Annual Acid and Metal Load Reductions

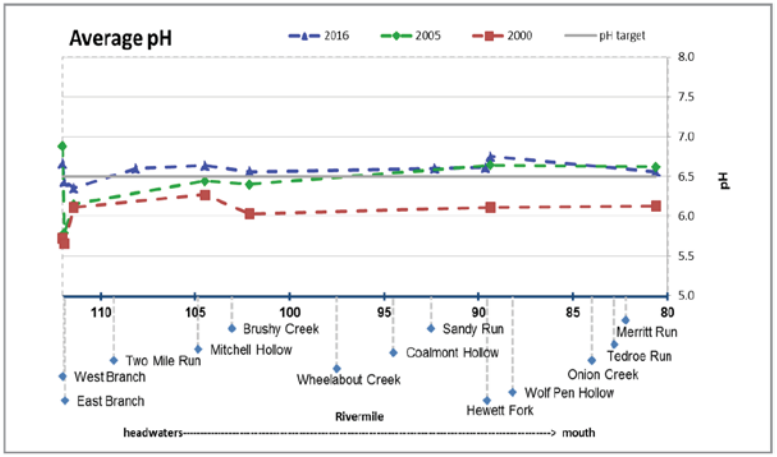


All the project results are tallied by watershed and for all sites annually to get a total acid load and metal load reduction per year. Metal load reductions are a combined total of Iron and Aluminum. Metal load reductions are calculated at the project specific level but not included in the annual report due to complexity of metal load reductions since some treatments are in stream and only converting dissolved to solid form. Long term monitoring stations are used to analyze trends in specific AMD parameters compared to baseline conditions and to water quality standards or aquatic life criteria (Figure 2). Figured 2 shows the change in pH from baseline conditions to most recent data (2016). pH levels have risen above the water quality standard of 6.5 in the measured reaches in all watersheds, except for areas in Monday Creek and Huff Run where AMD treatment has not been initiated due to limiting factors or where additional treatment is needed. Iron, aluminum and net-alkalinity concentrations are also analyzed and graphed for each targeted reach. This data is used to make programmatic decisions about future project site selection and funding of operation and maintenance of existing AMD treatment sites.

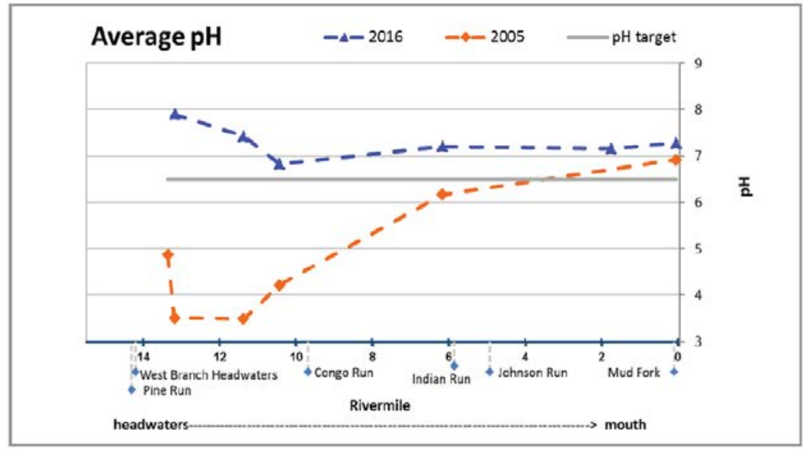
For tracking and reporting purposes, acid load reductions and total miles improved to meet biological targets are reported by watershed (Table 3). Raccoon Creek, the largest of the watersheds, has the highest acid load reduction and miles recovered. Sunday Creek has a low reported load reduction in 2016 due to missing data. Sunday Creek averaged about 10 times that amount in previous years, but still below Huff Run and Leading Creek since 7 of the 12 projects have been source control and don't report load reductions. Huff Run has a mixture of source control and passive treatment projects and is a small watershed like Leading Creek. Although water quality and biological improvements have been documented in all five watersheds, the two that have shown significant stream miles recover to meet water quality criteria are Raccoon Creek, 82 miles, and Sunday Creek, 11.5 miles.

Figure 2: pH Measurements in Four Watersheds from Baseline to 2016

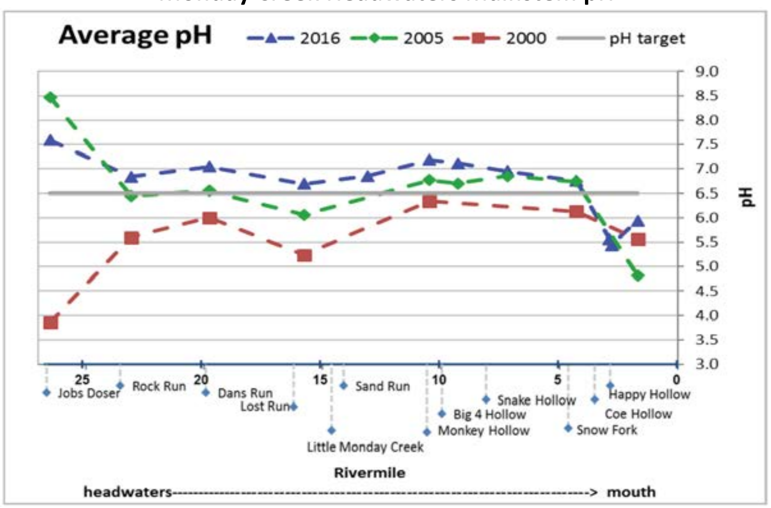
Raccoon Creek Headwaters Mainstem pH



West Branch Sunday Creek Mainstem pH



Monday Creek Headwaters Mainstem pH



Huff Run Mainstem pH

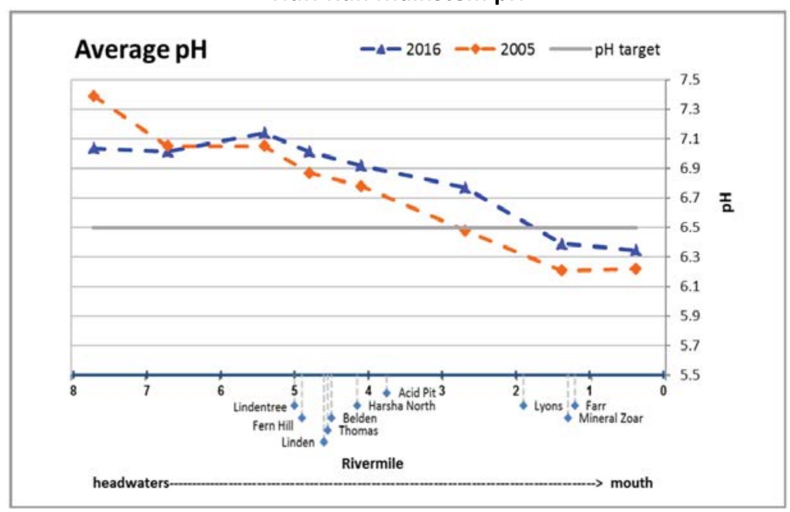


Table 3: Acid Load Reductions and Stream Miles Recovered by Watershed in 2016

Watershed	Cumulative # of Projects	Acid Load Reduction annually lbs/day	Cumulative Costs	Stream Miles Meeting
Raccoon Creek	20	4,267	$14,521,361	82
Monday Creek	18	4,360	$7,197,808	0
Sunday Creek	12	22*	$2,618,273	11.5
Huff Run	14	1,129	$5,308,353	0
Leading Creek	2	663	$728,481	0

**Sunday Creek averaged 10 times this amount in previous years, missing monitoring data for 2016*

Since recovery of a healthy aquatic ecosystem takes years, even decades in some cases, as water quality improves it is important to track changes in water chemistry and biology over time during implementation of treatment projects. In addition to analyzing when recovery goals are met, incremental improvements are analyzed and leads to project funding and future monitoring decisions. Monday Creek, as an example, is a watershed that was one of the most severely impaired watersheds by AMD in Ohio based on data from the early 1990's. The majority of the mainstem of Monday Creek had no real assemblage of an aquatic ecosystem throughout most of its 26-mile length due to pH measurements as low as 3.5 and never meeting the standard of 6.5. However, by 2005 with the addition of multiple treatment projects (including a doser in the headwaters) and source control projects water quality had improved. Over the next decade more treatment projects were added in targeted locations and by 2016 pH is meeting the standard of 6.5 for over 20 miles (Figure 2). The only exception being the lower 4 or so miles where a very large AMD tributary called Snow Fork lowers the pH before entering the Hocking River. Treatment in Snow Fork has not been attempted due to extremely high long-term costs. For the AMD Program to determine that a stream or stream section has recovered it must meet the criteria for both fish and macroinvertebrates and the pH standard. The upper 20 miles of Monday Creek would the meet the pH standard. Macroinvertebrate meet criteria as well (Figure 4) but fish metrics are still below criteria. Monday Creek is not reported as recovered, even though it has gone from a nearly dead stream to a stream with many species of fish and macroinvertebrates. As seen in Figure 4, MAIS scores show a statistical improvement from 2006 – 2016 at 10 of 11 sites and only two sites in the headwaters don't meet the criteria score of 12 because it is too close to the mixing zone of an instream lime doser. This is the case in all five targeted watersheds to some degree, with Raccoon Creek and Sunday Creek the only ones that have recovered to the point where pH, macroinvertebrates and fish scores all meet standards/criteria currently.

Figure 3: Fish Community Scores in Monday Creek 2017

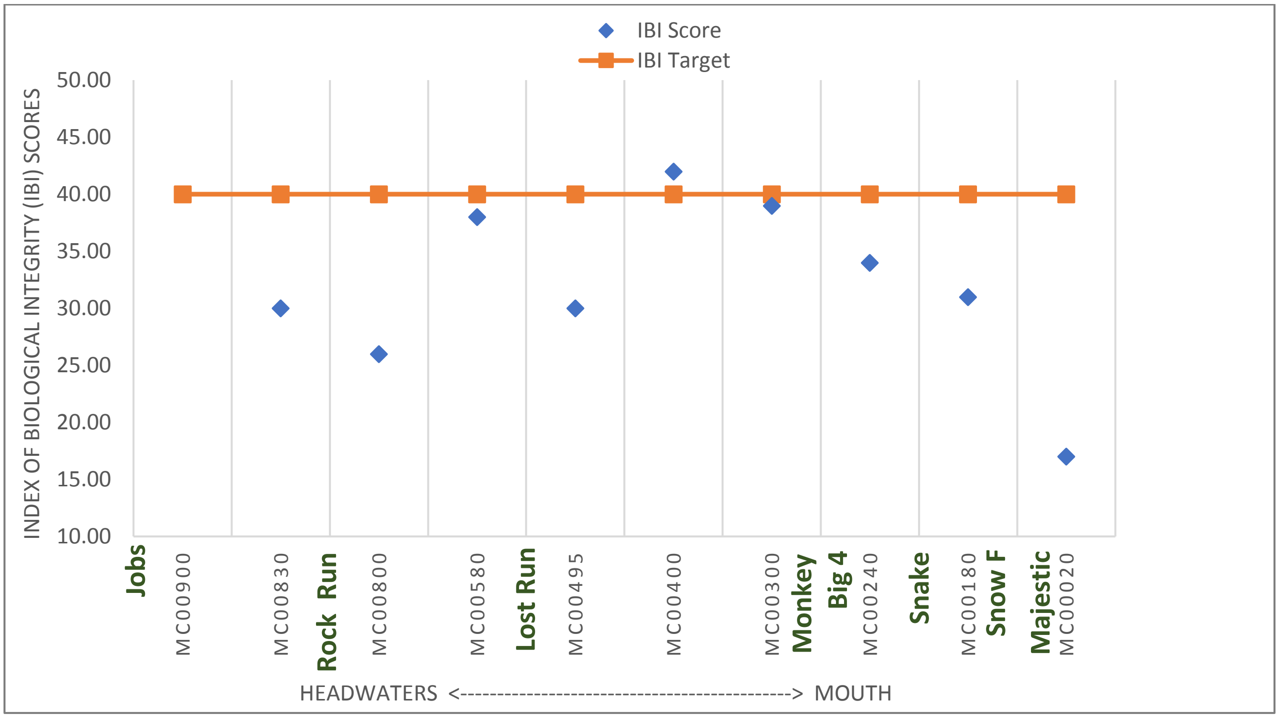


Figure 4: Monday Creek Macroinvertebrate (MAIS) Scores 2005 – 2016

Monday Creek MAIS Regressions

Site ID Rivermile	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Linear trend	R square	P-value	Years
JH00500 RM 26.5	6	5	4	7	8	9	11	10	13	8	5	no change	0.217	0.1492	11
MC00950 RM 25.3	8	7	4	9	6	10	10	10	12	13	11	improved	0.610	0.0045	11
MC00900 RM 24.3	8	12	12	11	11	12	12	14	12	15	12	improved	0.447	0.0244	11
MC00800 RM 23.5	7	9	12	7	13	11	13	12	14	14	13	improved	0.595	0.0054	11
MC00580 RM 19.6	11	12	12	13	16	14	16	15	14	16	15	improved	0.601	0.0050	11
MC00510 RM 16	12	11	10	10	10	*	14	14	14	14	14	improved	0.598	0.0053	11
MC00500 RM 15.9	7	8	*	5	*	*	15	16	9	13	11	improved	0.407	0.0346	11
MC00300 RM 10.5	12	14	*	12	16	16	15	16	16	18	16	improved	0.666	0.0022	11
MC00280 RM 9.4	8	9	10	9	14	12	10	15	11	14	12	improved	0.436	0.0269	11
MC00240 RM 7.3	7	7	8	10	14	10	8	11	13	11	12	improved	0.432	0.0280	11
MC00180 RM 4.3	6	9	7	4	13	9	9	15	11	13	12	improved	0.470	0.0198	11

* Missing values were replaced with arithmetic averages of preceding and following years for graphing.

Since load reductions and stream miles recovered are calculated annually, along with project costs tracked by project and watershed, the cost of recovery or improvement of water quality can be analyzed (Table 4). The average cost per pound of acid removed per day is approximately $3,600 across all the watersheds. The lowest cost is Leading Creek at $1,102 and the highest is Sunday Creek at $7,438 per pound per day. Leading Creek has two dosers operating in one subwatershed so initial capital cost is low but operation and maintenance costs will increase this number over time. Sunday Creek has a lot of subsidence closure projects completed initially which didn't include acid load reductions in the analysis but costs were included. Most of the recovery in Sunday Creek is attributed to a lime doser and several passive treatment projects.

Table 4: Watershed Recovery and Improvement Cost Analysis

Categories	Leading Creek	Sunday Creek	Raccoon Creek	Huff Run	Monday Creek	Total	Average
No. of Projects	2	12	20	14	18	66	
Project Costs	$728,481	$2,618,273	$14,521,361	$5,308,353	$7,197,808	$30,374,276	
Acid Load Reduction (lbs/day)	661.00	352.00	4,267.00	1,129.00	4,360.00		2,153.80
Cost per lb of acid removed	$1,102	$7,438	$3,403	$4,702	$1,651		$3,659
Miles Improved*	7			6	21	34	
Miles Recovered	0	11.5	82	0	0	93.5	
Cost per mile improved	$104,069	NA	NA	$884,726	$342,753	NA	$443,849
Cost per mile recovered	NA	$227,676	$177,090	NA	NA	NA	$202,383
Cost per foot improved	$20	NA	NA	$144	$195	NA	$119
Cost per foot recovered	NA	$43	$34	NA	NA	NA	$38

** Miles Improved is estimated by ODNR-DMRM staff, not in annual stream health reports*

Sunday Creek's cost per mile recovered is $227,676 per stream mile while Raccoon Creek is $177,090 per stream mile. That equates to $43 per foot for Sunday Creek and $34 per foot for Raccoon Creek. In the watersheds without full recovery, the number of stream improved was estimated based on water quality and biological monitoring. The average cost per mile improved in Leading, Huff Run and Monday Creek was $443,849 compared to the cost per mile recovered of $202,383 in Raccoon and Sunday Creek, nearly double. The difference in cost is possibly due to the nature of treatment projects and complexity impacts in those watersheds. When cost is broken down by foot, which is typical of mitigation requirements, the average cost per foot for recovered streams is $38 per foot and $119 per foot for improved streams. Although not directly comparable, current stream mitigation rates by In Lieu Fee (ILF) provider The Nature Conservancy in Ohio usually range from $240 to $315 per foot in Southeast Ohio (The Nature Conservancy Ohio, 2018).

Challenges

Complete ecological recovery is challenging in watersheds that have been severely impacted by AMD, especially in cases where sources are multiple and widespread. Deciding on targeted reaches for recovery has focused resources and led to some restoration success. Some streams or reaches of streams may never meet full recovery criteria. In these cases, intermediate goals of improvement may need to be set or the concept of a recovered stream may need to be adjusted. Some watersheds have been impacted by AMD for over 100 years so expecting them to recover in a few years or even a decade may be unrealistic. However, as documented in the five targeted watersheds in Ohio recovery and improvement does occur with sustained AMD treatment and abatement efforts in targeted locations over decades as cumulative treatment effects is realized and aquatic organisms begin to repopulate.

Incremental or partial recovery goals may need to be established in some streams or stream segments where recovery does not look feasible in the near future.

The most pressing challenge in Ohio is funding to continue treatment and maintain the recovery that has been realized. Funding for operation and maintenance is severely needed and many grant programs that help fund the initial projects will not fund operation and maintenance of those systems long term. Much of that burden will fall on states AMD Set-aside funds which are discretionary at the state level and can be used for operation and maintenance purposes. Several states have implemented long term water treatment investment funds to secure the long-term funding needed. Ohio is pursuing this option but has not implemented a statutory provision to allow for the fund creation to date. A 30-year analysis of Ohio's AMD treatment operation and maintenance needs in 2017 categorized all active projects into 3 priorities. Priority 1 projects are considered essential for treatment, Priority 2 is needed and Priority 3 projects are contributing to water quality improvements but their direct impact if not continued is unknown or minimal. A total of 46 projects are considered active with 8 scheduled to be abandoned at the end of their life cycle, leaving 38 total projects to budget and plan for. Of the 38 projects, 23 were considered Priority 1 and if they are not maintained a significant reduction in water quality and degradation of aquatic resources would happen. It was estimated that $15.8 million dollars would be needed over a 30-year span to properly maintain those Priority 1 sites. Adding in Priority 2 and 3 sites raises the cost to $19.5 million. If $15 million could be placed in an investment fund and generate 4% interest annually, the interest off the fund could be sufficient to fund all Priority 1, 2 and 3 projects. As of 2018 ODNR-DMRM has approximately $10 million in the AMD Set-aside fund designated for this purpose, so planning for additional $5 million in set-aside funds and creating the Treatment Trust Fund is critical for the program and the continued recovery of the five Ohio targeted watersheds.

Summary

AMD watershed restoration efforts in Ohio have been successful due to long term partnerships and commitments in funding for project implementation and monitoring. Extensive annual monitoring allows for tracking of successes across targeted watersheds and for planning on new projects and operation and maintenance of existing treatment sites. Significant recovery is now being realized after decades of treatment project implementation. In addition, incremental improvement is happening in areas not fully recovered and these changes need to be tracked and reported on to show the progression of recovery. AMD abatement and treatment on a watershed scale in Ohio has proven successful and cost effective, however sustained treatment is needed to protect gains in watershed improvement long term through the development of a water treatment trust fund.

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