Habitat and watershed characteristics that limit stream recovery after acid mine drainage treatment

Natalie Alyssa Kruse Daniels[1], Kelly S Johnson[2], Jennifer Bowman[1]

[1]Voinovich School of Leadership and Public Affairs, Ohio University, Athens, Ohio, USA, krusen@ohio.edu
[2]Department of Biological Sciences, Ohio University, Athens, Ohio, USA

Abstract Treatment of acid mine drainage (AMD) often meets with mixed results. Recovery of chemical quality is not always sufficient for recovery of macroinvertebrates and fish. Mixing zones downstream of treatment systems, episodic acidification and habitat degradation can limit biological recovery. Here, we report on three streams impacted by AMD that have been monitored for chemistry and biology for a decade. Improvement or limited improvement has been seen in the biological quality of Monday Creek and Raccoon Creek, but no change has been seen in Huff Run. This paper suggests mechanisms for these differences and provides recommendations for prioritizing treatment expenditure.

Keywords biological recovery, coal mine, mine reclamation, stream restoration

Introduction

A key aim of acid mine drainage (AMD) treatment and mine land reclamation is the restoration of the ecosystems damaged by mining. While this may remain an overarching goal, it is not always a result of specific AMD treatments, which typically focus primarily on water chemistry targets (NPS 2011). While chemical water quality targets are both valid and necessary, they only reveal the quality at the moment that the sample is taken. Biological quality, however, more fully integrates the chemical, physical and functional aspects of the aquatic ecosystem. Good chemical water quality is not always enough to achieve biological recovery. In Ohio, the goal of AMD treatment in the coal bearing region of Ohio is full attainment of Warm Water Habitat (WWH) use designation. WWH represents the biological community expected to be present in the 25th percentile of reference sites that do not support cold water taxa (*i.e.* salmon, trout). In order to achieve this, both the fish and macroinvertebrate community metrics (Index of Biotic Integrity and Invertebrate Community Index) must meet thresholds developed for each eco-region based on comparison to reference sites (Karr 1981, OEPA 1988).

The abandoned mine land program in Ohio has focused efforts on four watersheds: Raccoon Creek, Monday Creek, Huff Run and Sunday Creek. Each was extensively mined before state or federal regulations were in place (pre-1950's). Over $22 million has been spent across the four watersheds on reclamation, stream captures and passive and active treatment projects (NPS 2011). The stream kilometers of mainstem recovered in each watershed, in terms of water chemistry and biological quality, varies, with greater success in some watersheds than others.

The purpose of this analysis it to use these patterns of recovery to suggest factors that lead to successful AMD treatment and those that limit stream recovery. Specifically, the role of in-stream physical habitat, the abundance and location of acid sources and their treatments, and the role of natural alkalinity sources will be examined. We focused on the mainstem sections of the watershed for ease of comparison. These 'lessons-learned' can be used to prioritize treatment dollars to maximize stream miles restored.

Methods

Three watersheds (fig. 1) were assessed to determine factors that limit stream recovery.

While $1.9 million has been spent in the fourth watershed, Sunday Creek, it is not included in this analysis because two large mine discharges remain untreated and impact a large portion of the watershed biology.

Raccoon Creek flows through six counties in southern Ohio, Hocking, Athens, Vinton, Jackson, Gallia and Meigs, and drains directly to the Ohio River in Gallia County. The mainstem of Raccoon Creek is 180 km long and the watershed drains 1,771 m^2. Approximately 20,000 ha of the watershed were mined for coal; about half the mines were underground mines and half were surface mines. The majority of the mines were abandoned before reclamation laws were in place. Abandoned mines in the watershed are concentrated in the headwaters of Raccoon Creek and in the Little Raccoon Creek subwatershed (NPS 2011).

Monday Creek flows through Athens, Hocking and Perry Counties to its confluence with the Hocking River. The mainstem is 43.5 km long and the watershed drains 300 m^2 of land. The watershed was extensively mined for coal. Major acid sources to the mainstem include Lost Run, Snake Hollow and Snow Fork (NPS 2011).

Huff Run flows through Carroll and Tuscarawas Counties in Eastern Ohio to its confluence with Conotton Creek just south of Mineral City, Ohio. The mainstem of Huff Run is short, only 16 km long and the watershed covers 36 m^2. The downstream two thirds of the watershed (west of State Route 542) has been extensively mined for coal and some limestone and clay. In addition to AMD, Huff Run is impaired from agricultural runoff, untreated sewage and poor riparian buffers (NPS 2011).

The number of stream kilometers in each watershed meeting two targets, full biological attainment and pH > 6.5, in 2009, are shown in Table 1. Biological attainment was estimated from scores from a rapid macroinvertebrate bioassessment metric, the Macroinvertebrate Aggregate Index for Streams (MAIS; Smith and Voshell 1997). A MAIS score of ‘12’ is a good estimator of the biological quality needed to meet Warm Water Habitat criteria (Johnson 2009).

To more accurately measure biological improvement, linear regression analysis of MAIS scores from baseline conditions (2001 in Monday Creek 2005 in Raccoon Creek and 2005 in Huff Run) to 2011 conditions were performed. Sites were designated as ‘improved’ if they received a positive regression score significant a $p < 0.05$, and ‘somewhat improved’ if the significance of the regression was between $p < 0.05$ and $p < 0.10$. After the streams were determined to be successfully recovered or recovering using full attainment of WWH based on IBI and ICI scores, where available, and MAIS scores as metrics, the following factors were compared to find which were the most closely associated with stream recovery:

- Habitat (using the Qualitative Habitat Evaluation Index (QHEI); Rankin 1989);
- Abundance and Location of Acid Sources
- Abundance and Location of Natural Alkalinity Sources
- Stream Kilometers Downstream of Acid Sources and Treatment Systems
- Proximity of Treatment Systems to Mainstem
- Known Acidification Events

Results and Discussion

As shown in Table 1, the level of success of watershed-scale treatment varied among the watersheds assessed. Both Raccoon Creek and Huff Run have a large percentage of stream kilometers achieving the pH target of 6.5, while Monday Creek has fewer stream kilometers meeting the pH target. This difference is due to several factors. Mining in Raccoon Creek Watershed was concentrated in Little Raccoon Creek and the headwaters of Raccoon Creek; this has allowed for clustered treatment projects with many kilometers of stream to accrue the benefits of treatment. In Huff Run,

Watershed	Projects	Total Costs	Total Acid Load Reduction (kg/d)	km Meeting WWH	km Meeting pH Target	km Monitored	Mean Mainstem QHEI
Raccoon Creek	14	$9,710,495	2,461	67.1	166	188	65
Monday Creek	18	$5,871,172	1,762	0	34	61	68.5
Huff Run	12	$4,678,279	439	0	16	16	62

Table 1 *Summary of stream recovery in three watersheds evaluated in 2011: Raccoon Creek, Monday Creek, and Huff Run (NPS 2011).*

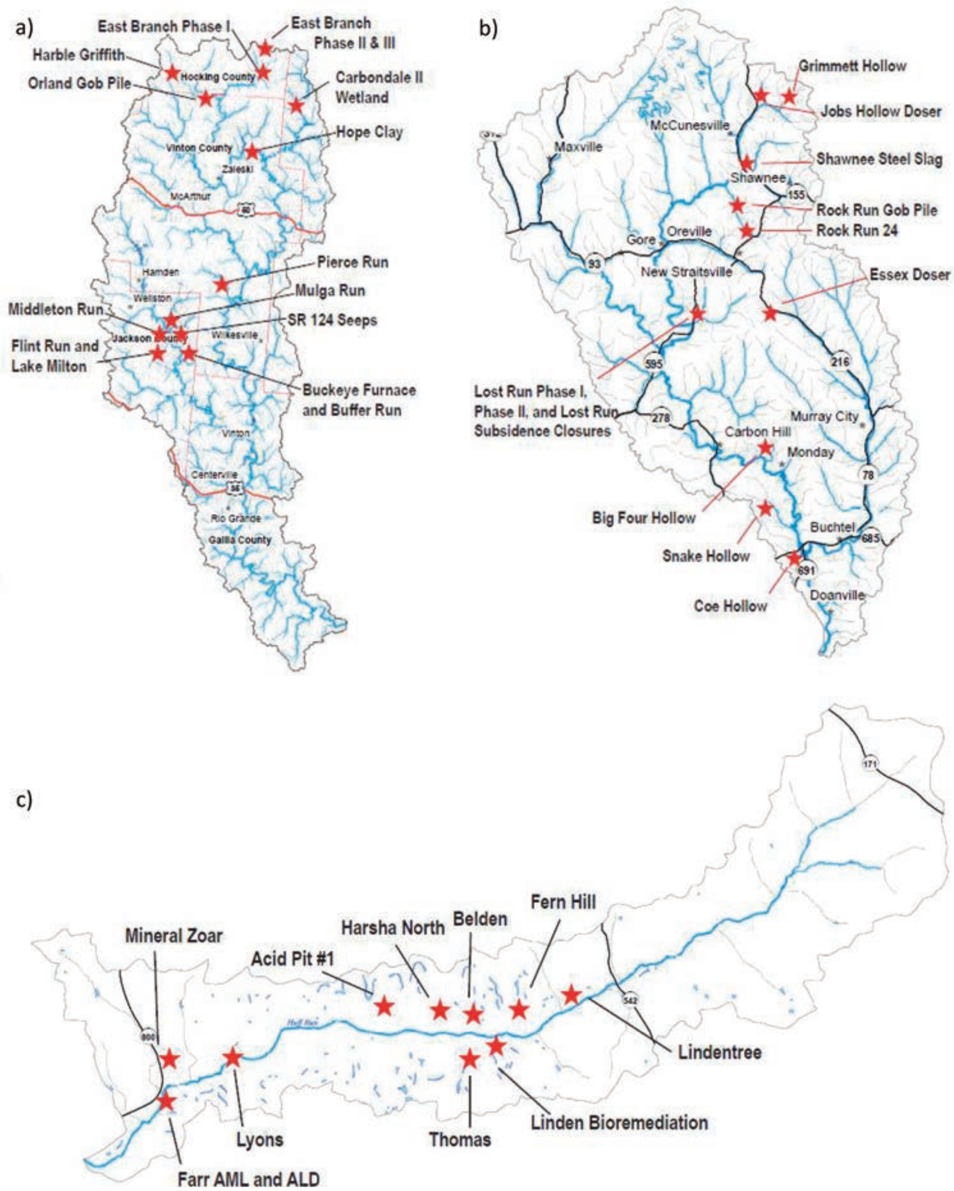

Fig. 1 *Watershed maps depicting treatment and reclamation project locations with red stars, a) Raccoon Creek, b) Monday Creek, c) Huff Run. Scales are not consistent between maps (NPS 2011).*

mining was all to the west of highway 542 (fig. 1c), impacting about 10 km of stream, within those 10 km, 12 projects have been installed to ameliorate AMD. This has allowed for successful pH adjustment in the mainstem of Huff Run. Monday Creek, on the other hand, has significant acid sources in virtually every tributary, some of which are treated and some remain either partially or fully untreated (NPS 2011).

Despite pH improvement, attainment of biological recovery goals has not been consistent. As shown in Table 1, neither Monday Creek nor Huff Run has had any stream kilometers of the mainstem meeting full attainment status, whereas over 67 km of Raccoon Creek now meet WWH status (NPS 2011). While none of the mainstem sites in Monday Creek are in full attainment of WWH, nine of the thirteen mainstream sites assessed using the MAIS show statistically significant improvement, while one shows slight improvement, between the 2001 baseline and 2011. The seven sites assessed on the mainstem of Huff Run, however, show no significant change in MAIS scores, between the 2005 baseline and 2011, despite nearly $6 million of investment (fig. 2). In Raccoon Creek, while a large number of stream kilometers now meet WWH designation when compared to the IBI and ICI baseline in 2001, only four of the twelve sites assessed on the mainstem of Raccoon Creek and Little Raccoon Creek have shown significant improvement in MAIS scores between the 2005 baseline and 2011. Nearly half of the stream kilometers that have improved since baseline in Raccoon Creek improved before 2005, so the assessment may be skewed.

It is clear from the analysis that Huff Run has achieved chemical improvement without

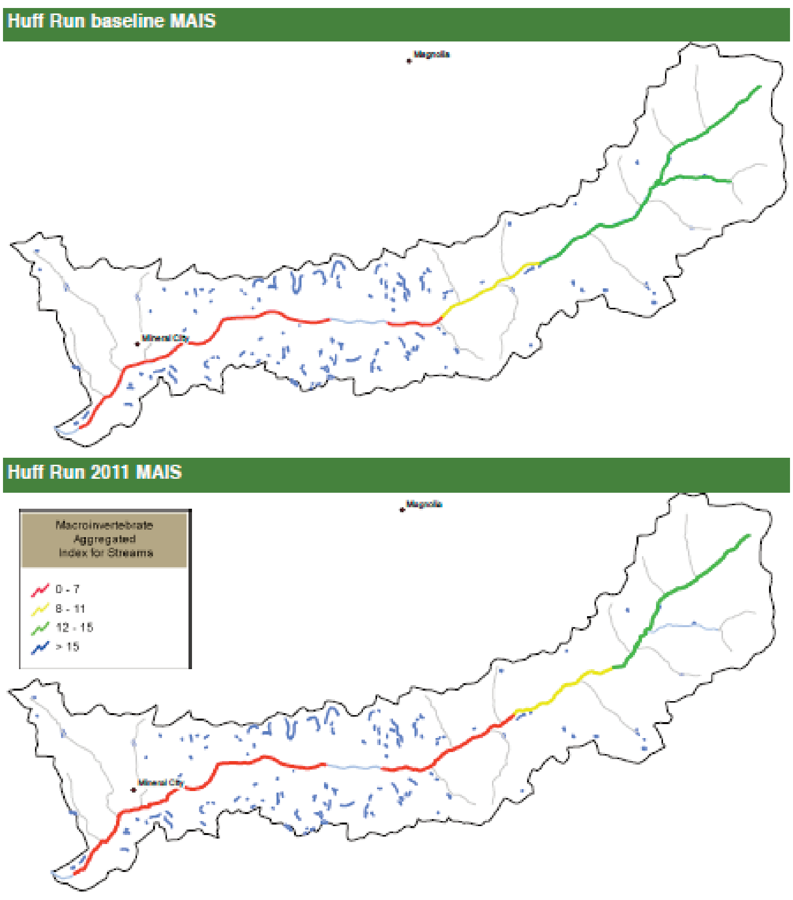

***Fig. 2** Baseline versus 2011 MAIS scores along the mainstem of Huff Run (NPS 2011).*

biological improvement, while Monday Creek has achieved some chemical and some biological improvement and Raccoon Creek has had significant chemical and biological improvement. The mechanisms that drive this difference are varied.

The analysis presented here suggests that the overall habitat assessment used in Ohio, the QHEI (shown in Table 1), suggests that the habitat of the mainstem of Monday Creek is better than Raccoon Creek and Huff Run. In addition, the watersheds have different quantities and locations of natural alkalinity sources—Raccoon Creek has many natural alkalinity sources often downstream of acid sources that lead to some natural attenuation of AMD. Monday Creek has only a few alkaline tributaries that are far outweighed by the acid sources. Huff Run has alkaline sources upstream of the acid sources that, along with treatment projects, leads to circum-neutral pHs and slightly alkaline conditions along the mainstem.

Acid sources in the three watersheds have three spatial patterns. Acid sources in Raccoon Creek are clustered in Little Raccoon Creek and the headwaters of Raccoon Creek; they allow for treatment of water bodies and many kilometers of stream in which to accrue the biological benefits of chemical improvement. Acid sources in Monday Creek are distributed throughout nearly every tributary; there is some improvement downstream of treatment and reclamation projects, but it is not continuous due to continued acidification. In Huff Run, the acid sources are clustered in the lower two-thirds of the watershed in tributaries, but in close proximity to the mainstem.

Treatment projects installed in each watershed have varied proximity to the mainstem of each watershed (fig. 1). In Raccoon Creek and Monday Creek, the watersheds are larger with longer tributaries. The treatment projects are installed in the tributaries with stream reaches in which metal precipitates deposit rather than introducing precipitates to the mainstem. The furthest downstream treatment project in Raccoon Creek is 91.2 km upstream of the mouth, while the furthest downstream treatment project in Monday Creek is in a tributary, 4.5 km upstream of the mouth. The tributaries in Huff Run Watershed are shorter due to the narrow shape of the watershed; by necessity, the treatment projects are located close to the mainstem or on the mainstem and clustered in the lower reaches of the watershed; the furthest downstream treatment project is on the mainstem, only 2 km from the mouth. This can lead to both sedimentation and periodic acidification of the mainstem of the watershed, limiting biological recovery. The short length of the mainstem of Huff Run means that there is no space in which to accrue the benefits of treatment within Huff Run and the receiving stream Conotton Creek is impounded along its length and has had historically poor biological quality that does not further deteriorate downstream of Huff Run. Conotton Creek's poor biological community may restrict recolonization of Huff Run.

Conclusions

The mechanisms for improvement and limitations on recovery vary by watershed. In Monday Creek watershed, \$5.8 million of treatment has been installed, including 18 projects with an acid load reduction of 1762 kg/d. The major acid sources in Monday Creek are in tributaries and are found along all 43 stream kilometers. In Raccoon Creek watershed, \$9.7 million of treatment was installed by 2011, including 14 projects with an acid load reduction of 2461 kg/d. The major acid sources in Raccoon Creek are found in headwaters tributaries and in Little Raccoon Creek in the upper 122 km of the 180 kilometer-long mainstem. In both watersheds, treatment systems have limited acid sources reaching the mainstem and have decreased episodic acidification in many reaches of the streams. In Huff Run watershed, \$4.6 million in treatment has been installed, consisting of 12 projects with a total acid load reduction of 438 kg/d along 16 stream kilometers. The acid sources are all clustered in the lower 10 km of the watershed and treatment systems are physically close to the mainstem (<1 km). The lower reaches have historically degraded habitat and high erosional sediment loads. The limited recovery in Huff Run is due to historical habitat degradation, the extension of treatment system mixing zones into the mainstem and insufficient natural attenuation to mitigate episodic acidification and accrue the benefits of treatment.

These results suggest that recovery is dependent upon connected improvement in the mainstem not interrupted by the sedimentation and habitat degradation and that treatment funds should be used preferentially in cases that will lead to greater recovery. Further work is needed to find thresholds for the factors identified here and to explore the role of episodic acidification.

Acknowledgements

The authors thank the Appalachian Watershed Research Group, the Raccoon Creek Partnership for ongoing research collaborations. Chemical and biological data was collected with the assistance of the Monday Creek Restoration Project, the Sunday Creek Watershed Group and the Huff Run Watershed Restoration Partnership and many of their volunteers. Chemical and biological data collection was supported by the Ohio Department of Natural Resources Division of Mineral Resources Management and data analysis was supported by the American Electric Power Foundation.

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