Navigating difficult site constraints to facilitate ecological recovery of an impaired watershed

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Abstract
Three high acidity, high iron and aluminum mine water discharges convey into the Lyons Run watershed, Westmoreland County, Pennsylvania. Several miles of the receiving watershed are measurably impaired as indicated by water quality monitoring and the Pennsylvania index of biotic integrity (IBI) assessment. The site is heavily constrained including difficult to interpret hydrogeology, which has been a deterrent to past remediation efforts. The watershed has potential for improved aquatic habitat, ecological function, and recreational development which would benefit from better water quality and aesthetics and will achieve this by utilizing innovative approaches to assessing and treating the acid mine drainage (AMD) sources.

Three AMD sources conveying into the Lyons Run watershed and considered high-risk for passive remediation will be addressed through implementation of a successive alkalinity producing system (SAPS). Given the high-risk nature for passive treatment of these three AMD sources the remediation design utilizes a series of features to assist long-term operations and maintenance and appropriate neutralization and retention sizing to elicit the necessary effluent quality for downstream buffering capacity. In addition to high-risk geochemistry, difficult site constraints also considered in SAPS design include topography, hydrology, the presence of relic spoil, seasonal variation, a modeled 100 year floodway, and property boundaries. The design approach evaluated aspects of an AML property that are often overlooked, specifically related to the interaction of the mine pool with the shallow groundwater aquifer.

Lessons learned focus on ingenuity of design and operations, and thorough site knowledge, as being critical to delivering a functional, high-quality project. Overall project delivery incorporates aspects of abandoned mine land (AML) reclamation, AMD remediation, site development, stormwater management, and stream and wetland restoration methodologies.

Keywords: Passive AMD remediation, site constraints, ecological recovery

Introduction
Lyons Run in Westmoreland County, Pennsylvania, flows 8.2 km and drains 14.7 km² of watershed. It is a tributary to the larger Turtle Creek and Monongahela River watersheds (Fig. 1).

Mining of the bituminous Pittsburgh coal seam was performed in the approximate time range of 1917–1928 by the Irwin Gas Coal Company operating the Irwin Gas No. 2 Mine (Mance, 2020). With closure predating the surface mining control and reclamation act of 1977 (SMCRA) the 0.5 km² of underground mining and associated surface features are classified as abandoned mine land (AML). Abandoned underground mining on the site drains southeast toward the receiving valley of Tributary 37369 to Lyons Run, resulting in an above drainage, free draining configuration. The abandoned mine drainage (AMD) is acidic with elevated iron and aluminum (Table 1). Index of Biotic Integrity (IBI) data displays degradation in downstream receiving waters (Fig. 2, Table 2). During baseline sampling the IBI stations closest to the AMD sources (5, 4, 3b) display score increases from 11.3 to 44.5 with increased distance from the AMD source. IBI data from stations several kilometers downstream of AMD influence (Locations 1, 2, 3a) displayed scores ranging from 60.9 to

68.7 and indicate the potential ecological uplift to be achieved. Passive remediation of AMD is proposed utilizing a successive alkalinity producing system (SAPS) constructed of flushable limestone beds (FLBs), settling ponds (SP), and polishing wetlands (WL) (Fig. 3). The AMD is considered high-risk for passive remediation and several design features will be incorporated to implement effective treatment.

Site conditions were more challenging to remediation design than water quality. Lyons Run Watershed Association (LRWA) purchased a 4,046 m² parcel where the SAPS will be constructed. Parcel selection was based on availability and owner willingness to proceed with the sale. The site displays minimal vertical relief as it relates to the operation of a passive, gravity driven system. Collection of AMD sources will occur mainly on adjacent, privately owned parcels, and conveyance of one source requires greater than 300 m of piping and includes a broad county road crossing. The site is bound to the west by the county road and to the east by Tributary 37369, which includes a modeled 100-year floodway to be avoided, and which will exert stresses on the constructed treatment system during high-flow events. Northern and southern constraints consist of private property which will be affected by the collection and conveyance systems. A high-quality delineated wetland and powerline corridor are located within the limit of disturbance. Spoil piles and spoil influenced soils are present throughout the property and contribute to degradation of the receiving watershed. Barrier seepage from the face of the outcrop creates unconsolidated flows across the valley wall resulting in contamination of the shallow riparian aquifer. The above drainage, free draining configuration causes the site to be susceptible to seasonal variation in flow and chemistry. Existing stormwater management practices convey onto the project property and will be influenced by the remediation design. The high-risk nature of the AMD to passive treatment methodologies required a design that incorporated various operations and maintenance features to maintain function and uninterrupted ecological uplift.

Methods

To sufficiently characterize the site, high resolution light detection and ranging (LiDAR) topography and aerial imagery was collected using a small unmanned aerial system (sUAS). Qualified ecologists performed a stream and wetland identification and delineation to document sensitive resources to be avoided or compensatory mitigated for if influenced by remediation design. Watershed-wide water quality, stream discharge, and macroinvertebrate monitoring

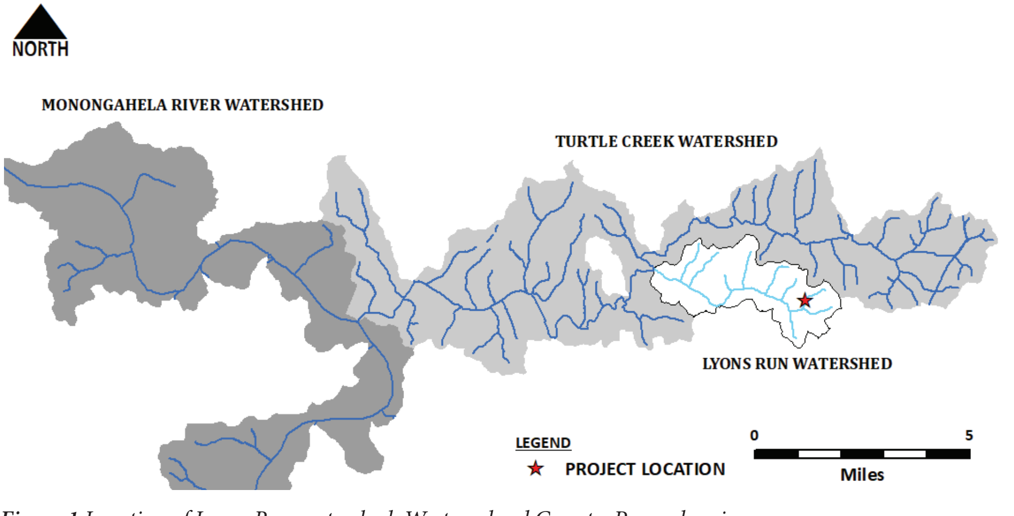

Figure 1 *Location of Lyons Run watershed, Westmorland County, Pennsylvania*

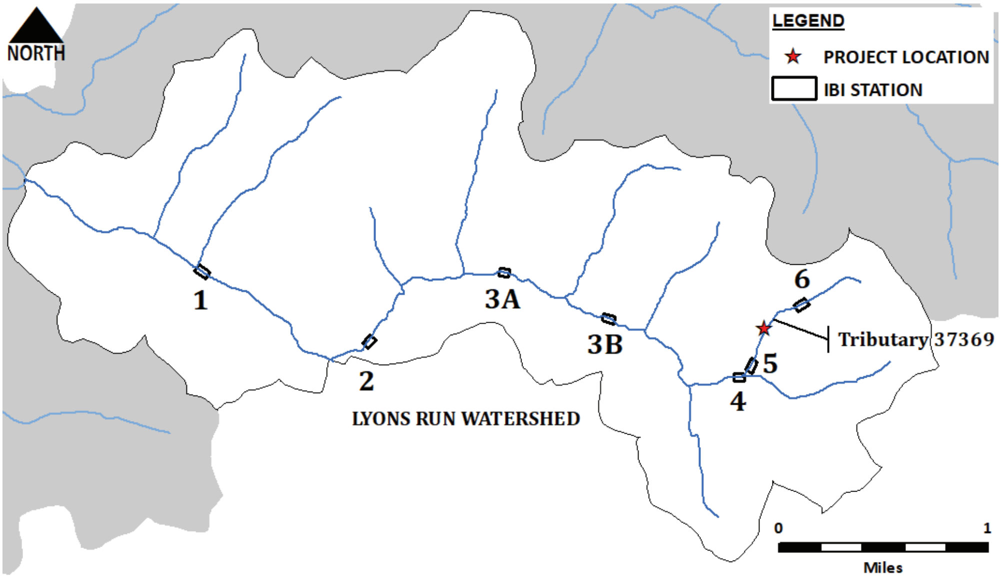

Figure 2 Index of Biotic Integrity (IBI) sampling locations

were performed for comparison to historic data, to characterize AMD, and to characterize the AMD influence on the biological status of the watershed. A geotechnical investigation was performed to assess depth to bedrock, depth to water, and soil characteristics. Hydraulic modeling utilizing Hydrologic Engineering Center-River Analysis System (HEC, 2021) software was performed to identify floodways, estimated discharges, and shear stresses imparted on the constructed treatment components.

To address the high-risk nature of passive remediation on AMD displaying high acidity and metals impairment required the entire footprint of the land parcel to construct oversized best management practices (BMPs). The design incorporated large diameter limestone aggregate ranging from 76 mm to 172 mm diameter for alkalinity generation. The larger diameter rip-rap is nested around flush plumbing and overlain by the smaller diameter rip-rap. The larger diameter rip-rap creates a larger pore volume in proximity to flush plumbing

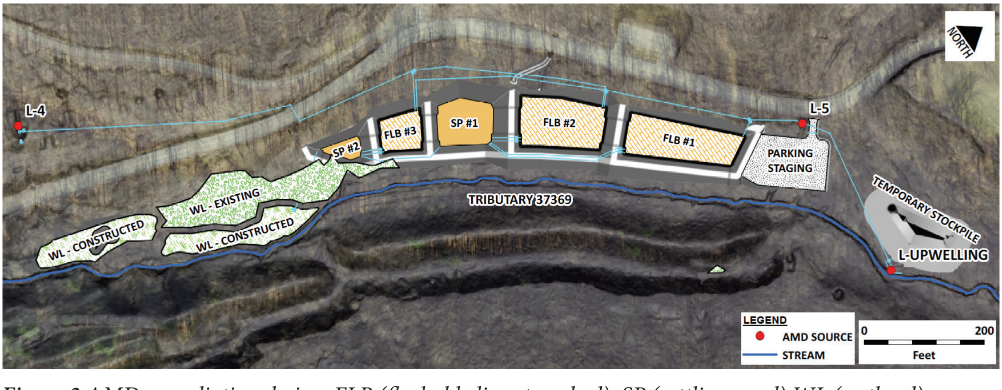

Figure 3 AMD remediation design, FLB (flushable limestone bed), SP (settling pond) WL (wetland)

Table 1 Water quality data at AMD sources

DATE	AMD Source	pH	Specific Conductance	Dissolved Oxygen	Discharge Q	Hot Acidity	Total Alkalinity		Ca Total
m/d/y			µS/cm	mg/L	L/s	mg/L as $CaCO_3$			mg/L
8/19/2019	L-4	2.78	1586	7.95	0.19	276.2	0		94.7
8/19/2019	L-5	2.52	2280	8.48	0.61	447.8	0		74.3
3/1/2023	L-4	2.71	2017	9.14	1.20	335.8	0		97.3
3/1/2023	L-5	2.58	2809	9.69	1.78	490.0	0		83.1
3/1/2023	L-UPWELL	2.69	2190	7.13	1.80	335.3	0		65.4
DATE	AMD Source	Fe Total	Fe Dis	Al Total	Al Dis	Mn Total	Mn Dis	Mg Total	SO_4 Total
m/d/y		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
8/19/2019	L-4	17.5	16.9	23.1	22.8	3.42	3.35	37.2	680
8/19/2019	L-5	25.4	23.4	37.6	34.9	4.33	4.02	28.9	789
3/1/2023	L-4	28.6	28.7	32.7	33.1	3.05	2.9	32.3	816
3/1/2023	L-5	42.8	41.9	49.3	48	4.48	4.42	28.5	988
3/1/2023	L-UPWELL	30.9	29.7	31	36.1	3.2	2.97	22.9	732

to reduce losses of hydraulic conductivity resulting from metals precipitation in the available pore space. The flush piping was sized to accommodate the largest diameter, commercially available automated flush mechanism without requiring customized fabrication and oversized batteries and solar panels. The flush plumbing incorporated a custom perforation pattern and hole diameter to increase hydraulic conductivity during maintenance flushing events. Each FLB includes 1.2 m of limestone overlain by 0.9 m of standing water to increase hydraulic head during flush events. During maintenance activities including limestone rejuvenation the change of aggregate diameter in proximity to the flush piping acts as an indicator to contractors that pipes are nearby. The FLB bottom elevations have a 1% cross slope to consolidate precipitated solids to one side during maintenance and increase the ability to extract solids-contaminated water.

Settling pond 1 is sized to receive the full water volume from either FLB 1 or FLB 2 to prevent flush water being forced to discharge to the next BMP prior to solids settling. The settling pond is designed with two gravel constructed baffles to create a zone facilitating reduced velocity. A perforated standpipe after the second gravel baffle allows the water elevation to decrease slowly to prevent remobilization of settled solids. The treatment process repeats through the smaller FLB 3 and settling pond 2. A system of maintenance bypass plumbing and valves allows water to be switched between FLB 1, FLB 2, or FLB 3 and SP1 and SP2 during maintenance activities. Alkaline treated AMD will discharge from the secondary settling pond through a series of riparian wetlands. The wetlands will

Table 2 Water quality and IBI data and IBI sampling stations

Station No.	pH	Specific Conductance	Dissolved Oxygen	Discharge Q	Total Taxa	Est. Density	Benthic IBI Score
		µS/cm	mg/L	L/s	#Organisms/m^2		
1	8.49	568	15.5	73.69	25	409	60.9
2	8.24	390	14.5	38.23	33	280	68.7
3a	7.61	483	13.7	16.21	24	96	65.0
3b	5.23	595	13.9	9.72	13	28	44.5
4	2.78	1108	14.0	3.97	8	27	14.7
5	2.70	1065	13.9	3.91	4	265	11.3
6	6.03	295	13.7	1.89	11	124	24.6

perform final polishing of suspended solids and will create riparian habitat for ecological uplift. An adjacent ecologically functional wetland is present and presented a constraint to treatment design with care taken to limit negative influences and expand upon its function. The constructed riparian wetlands will be in proximity to the existing high-quality wetland and will expand riparian ecological function.

The site will include a 740 m² staging area of tuff-tract infiltration pavers to aid in equipment and material storage during maintenance efforts while reducing stormwater effluent from the site. The constructed earthen berms will have a 3 m top width to accommodate construction equipment. This configuration allows the earthen berms to be utilized as construction access roads during maintenance activities.

Treatment BMPs will be of unlined earthen construction and in communication with the shallow groundwater aquifer. Unconsolidated acid seeps from the fractured outcrop and valley wall will be captured into the FLBs and neutralized. During the wet season, Tributary 37369 receives water from L-4, L-5, L-Upwelling, upstream ephemeral flow, and the shallow riparian aquifer. During the dry season the tributary receives water from only the shallow riparian aquifer, which is acid and metals contaminated. During the dry season minimal alkaline water will convey through the treatment BMPs to facilitate downstream acid neutralization, however, alkaline water from all BMPs will infiltrate into the subsurface along the entire treatment length facilitating in-situ treatment of the shallow riparian aquifer.

Vertical relief of elevations are minimal for a gravity driven system. To address minimal vertical relief the cross-sectional and longitudinal profiles of each treatment component were thoroughly evaluated and the BMPs, collection basins, and conveyances are designed within 0.03 m tolerances. FLB 1 has the highest maximum water elevation and receives AMD from the L-4 source over 300 m southwest. The elevation of FLB 1 sets the basis for all downgradient features and was designed at water elevation 1.2 m below L-4, giving the 300 m conveyance pipe a 0.4% slope. Greater gradient would consume elevation and less gradient would be at risk of not conveying suspended solids. The conveyance pipe design gradient was consistently maintained through a county road crossing by aligning the crossing with existing stormwater infrastructure. Several existing stormwater BMPs will be routed through or around the treatment system with all components including weir overflow devices specified per hydraulic modeling.

Design calculations accounted for the necessity of a tributary 100-year floodway and design features were incorporated to account for the high shear stresses that flood events will impart upon the best management practices. A stream buffer having an entrenchment ratio of 2.6 was designed for Tributary 37369 to accommodate the 100-year floodway. Entrenchment ratios > 2.2 are considered to have sufficient floodway to accommodate biennial overbank flow (USDA, 2007). The constructed BMP berms parallel to the stream are designed with turf reinforcement matting rated for 92.8 kg/m² shear stress, sufficiently higher than the shear stresses that will be imparted by overbank flows as determined by hydraulic calculations.

Construction borrow material will consist of onsite residual soils and mine spoils. The geotechnical design specied a combination of blending, amending, and drying to achieve conditions suitable for earthwork and construction of embankments. Several hundred meters of relic spoil piles remain on a neighboring private property owned by a land developer. Various approaches to address proximal relic spoil piles were assessed and ultimately a beneficial land use approach was selected. As part of the easement agreement for land access the spoil piles will be graded into a portion of a larger residential golf course serving a neighboring development. The 4,046 m² treatment site will include a series of walking trails and informative signage, ultimately to be incorporated into a larger regional greenway as part of the post construction management plan.

Conclusions

Developing a thorough site knowledge of constraints and hydrogeology and incorporating this knowledge into an innovative design approach will result in water quality improvements and functional uplift of ecological resources along a several kilometer segment of Lyons Run. Utilizing a SAPS to treat acidic AMD is not innovative but designing a functional SAPS into a heavily constrained site and efficiently operating through seasonally induced geochemical and hydrogeologic variations required innovative approaches.

Seasonal variation needs to be addressed through dynamic water quality monitoring approaches and atypical treatment system operation. Design characteristics including operations and maintenance features will facilitate long-term, efficient treatment system function and improvement of water quality, biological, and aesthetic value of the watershed. Future projects will implement site investigation and design approaches utilized and honed on this project.

Acknowledgments

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