

ACID MINE DRAINAGE ABATEMENT AND TREATMENT PLAN FOR UPPER RUSH CREEK WATERSHED



**Love's Lane acidic pond and discharges
- site RCLL185t**



Gosline surface mine land - site RCGH055t



Perry State Forest – Lake Essington



Rush Creek mainstem – site RCMS060

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1. SECTION I

1.1 INTRODUCTION

Surface mining, deep mining, and coal processing in the headwaters of the Rush Creek watershed in Perry County, Ohio (Map 1 & 2), have resulted in exposure of substantial amounts of mine spoils and deposition of coal refuse (primarily low-grade coal mixed with shale, sandstone, and pyritic spoils). Oxidation of these materials causes acid mine drainage (AMD) and, along with runoff from abandoned mine sites, results in impairment of water quality in Rush Creek (Darner et al., 2005).

1.1.1 Purpose

The purpose of this study was to conduct source identification of acid mine drainage, tributary mass-balance sampling, and field investigations within specified subwatersheds in the Upper Rush Creek Watershed as directed by ODNR-DMRM. The extent of impact to Rush Creek from tributaries has previously been documented in the U.S. Geological Survey (USGS) Scientific Report 2005-5196 report (Darner et al., 2005). The USGS data was incorporated into this AMDAT plan. USGS data collected in 2003 was used to direct the investigation areas for this AMDAT study. Water quality investigations were refined to identify sources of acid mine drainage within Gosline, Lovers Lane, and Turkey Run, conduct tributary mass-balance chemical water quality sampling within Perry State Forest and Airport, and conduct field investigations with a literature review in Rehoboth (Map 1 & 2). Many of these streams are unnamed tributaries, they have been given these names for purposes of this report, except for Turkey Run.

This AMDAT plan is part one of a two part report. It focuses on elements 1-4, shown below. It includes an analysis of metal and acid contributions from sources and tributaries, mass-balance models of the individual sub-watersheds, and development of the initial restoration strategies. The sources and tributaries were prioritized to direct remediation discussions at the sites and tributaries with the greatest metal and acidity contributions. Production of the AMDAT report followed draft AMDAT guidelines established by the Division of Mineral Resource Management (Borch, 2003):

Part 1:

1. Identification of the qualified hydrologic unit.
2. Determination of the extent to which AMD is affecting the water quality and biological resources within the hydrologic unit for both tributaries and mainstem.
3. Identification of the sources of acid mine drainage within the hydrologic unit (as well as possible alkaline addition locations). Calculate acid and metal loadings in order to establish priority ranking of projects.
4. Identification of individual remediation projects and the measures proposed to be undertaken to abate and treat the causes or effects of acid mine drainage within the hydrologic unit.

Part 2 (not part of this report):

5. Determination of the cost of undertaking the proposed abatement and treatment measures and an analysis of the cost-effectiveness and environmental benefits.
6. Identification of existing and proposed sources of funding for individual projects.
7. Establishment of a monitoring plan for assessment of the actual environmental benefit realized.

Data collected in 2003 - 2004 by USGS described the water-quality conditions in the Rush Creek watershed and determined the areas most affected by AMD. During 2003, a total of 54 water-quality samples were collected at 40 sites on the main stem and tributaries to Rush Creek. The samples were analyzed for major ions, acidity, and alkalinity. In conjunction with the water-quality sampling, a full biological assessment was done at 18 sites. In 2004, a total of 20 water-quality samples were collected from 20 sites during low-flow conditions on Rush Creek mainstem and its tributaries.

Ohio Environmental Protection Agency (OEPA) conducted a Total Maximum Daily Load (TMDL) study on the Hocking River, including Rush Creek in 2004. Chemical and biological data were collected and analyzed. An attainment table, water quality conditions, and a TMDL were developed for Rush Creek. Details from this study are explained in more detail in section 1.4.1 and 1.5.1 of this report.

During 2007 - 2008, a total of 118 water-quality samples were collected by the Voinovich School at Ohio University at 63 sites on the mainstem of, tributaries to, and AMD sources in Upper Rush Creek. The samples were analyzed at ODNR's Cambridge Laboratory for Group I ions as well as acidity, alkalinity, pH, conductivity, sulfate, total dissolved solids, total suspended solids, and hardness. In addition to the laboratory water quality samples, a total of

132 field measurements were collected at 92 sites at tributaries and AMD sources in Upper Rush Creek for pH, conductivity, temperature, and dissolved oxygen (Map 3).

1.1.2 Identification of the Hydrologic Unit

<p>Name: Upper Rush Creek Watershed 11-digit Hydrologic Unit Code (HUC):05030204-020 Tributary To: Hocking River Basin Drainage Area: 63,266 acres (98.85 sq. miles) Length: 21.45 miles Location: Perry County Quadrangles: New Lexington, Fultonham, Deavertown, Junction City</p>

1.1.3 Description of Study Area

Rush Creek drains 234.5 square miles (37.2 river miles) in Perry County, Ohio. The stream reaches of interest for this study drain about 45.6 square miles within HUC -020 and include the headwaters downstream to about river mile 21.1. Reference sites located in the Center Branch Rush Creek watershed (RM 20.85) and Lower Rush Creek were used to set water quality targets (Map 1).

The majority of Rush Creek lies within the Western Allegheny Plateau ecoregion with part of the Center Branch of Rush Creek watershed in the Erie/Ontario Lake Plain Ecoregion (Ohio Environmental Protection Agency, 2002a). From 1931 to 1980, average annual precipitation within the Rush Creek watershed was 39–40 in/yr, and the average temperature was 52^{of} (Harstine, 1991). Perry County is in the Kanawha Section of the Appalachian Plateaus physiographic Province (Fenneman and Johnson, 1946). The lower one-third of the study area was covered by Illinoian glacial drift and “gives rise to long gentle slopes rather than the more abrupt ones such as those found outside the glaciated areas” (Flint, 1951). The bottom of the Rush Creek valley is dominated by nearly level, poorly drained soils formed in lacustrine sediments, loess, and alluvium (Rubel and Jenny, 1988). In the glaciated upland area of the watershed, gently sloping to moderately steep, well-drained soils have formed in loess, glacial till, and residuum and colluvium derived from siltstone, sandstone, and shale (Rubel and Jenny, 1988).

The unglaciated part of Perry County consists primarily of rocks of Pennsylvanian and Mississippian age (Flint, 1951). Mississippian-age rocks are exposed in the deeper valleys that have not been filled with glacial sediment. Upland soils in the unglaciated area are dominated by nearly level to very steep, well-drained and moderately well drained soils formed in colluvium and residuum derived from sandstone, siltstone, shale, limestone, and in mine spoil (Rubel and Jenny, 1988). The land cover in the Rush Creek watershed is predominantly agricultural (51 percent) and wooded (40.6 percent). The remaining land is urban (4.2 percent), scrub (1.2 percent), open water (0.8 percent), unforested (0.4 percent) and barren (1.8 percent) (U.S. Geological Survey, 2000). Barren land cover is indicative of unreclaimed strip mines. In addition, reclaimed surface mine areas appear as agricultural lands (pasture/hay).

1.1.4 Geology

The Rush Creek Watershed lies within the Unglaciated Allegheny Plateau section of the Appalachian Plateau Province (Frost, 1931 and Fenneman, 1938). The strata exposed belong to the Pennsylvanian System which is divided in ascending stratigraphic order (oldest to youngest) into the Pottsville, Allegheny, and Conemaugh Groups. Strata are generally flat-lying and dip towards the south and east. The Pottsville and Allegheny Groups consist of sequences of alternating sandstone, shales, thin limestone, clay, coal, and flint (Slucher and Rice, 1994). Coal beds associated with the Allegheny Group are Lower Kittanning, Middle Kittanning, and Upper Freeport. Coal beds mined either on the surface or subsurface in the Rush Creek Watershed include both the Lower Kittanning (No.5) and Middle Kittanning (No.6).

1.1.5 Mining History

Coal mining began in Ohio in the early 1800s. Early in the century, people mainly depended on wood as a resource used to generate heat. However, as coal proved to be a more efficient resource, the use of wood declined, and the coal industry boomed. Coal became the dominant fuel on many fronts. People began using it to heat their homes instead of firewood, and steamboats began using coal to generate steam. Additionally, as the production of railroads increased, so did the need for coal. As a result, mining in the Southern region of Ohio flourished (Ohio History Central, 2005).

By the start of the twentieth century, coal mining in this region was active. As a result, there were many mines opening and closing in the region, many of which have not been reclaimed since their abandonment. For example, the Lilly Mine was abandoned in the year 1912 and continues to discharge AMD into the Lover's Lane tributary today. Over the next several decades mines throughout the region continued to be abandoned. By the mid-1920s, several mines located in Gosline Headwaters, Rehoboth, and Perry State Forest sub-watersheds were abandoned (Appendix 1). The Rehoboth area served as the coal processing plant (Sunnyhill) and has led to the primary AMD impact in the Rush Creek watershed today. The years from 1961 to 1966 served as the peak for mining in the Rush Creek region. Near the end of the 1960s, several more mines throughout the Rush Creek region had been abandoned, including mines in Airport and Turkey Run. As mapped, there are approximately 3,899 acres of surface mines and 1,965 acres of underground mines throughout the Upper Rush Creek Watershed (Map 2). Thirteen underground mines are mapped and documented on ODNR's mine locator (ODNR, 2009) (Appendix 1). The legacy of coal mining in the Rush Creek Watershed has led to the generation of acid mine drainage (AMD). Due to the numerous unreclaimed strip mines, several tons of AMD enter this watershed daily (ESPA, 1984).

1.2 ACID MINE DRAINAGE

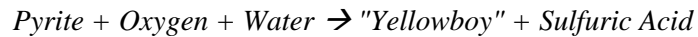
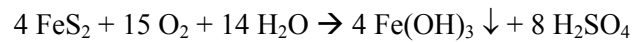
1.2.1 Acid Mine Drainage Formation

Coal mining disturbs large amounts of geologic material and exposes them to the environment. When this material is exposed to air and water, iron sulfide (pyrite) from the coal deposits is oxidized, resulting in acid mine drainage (AMD). These conditions lower pH, increase acidity, increase dissolved metals, and lead to an overall degradation of water quality. AMD is a low pH, high sulfate water, with high acidity usually due to hydrogen ions and oxidation of iron, aluminum, and manganese metals.

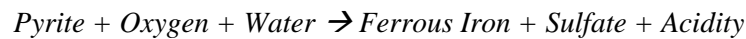
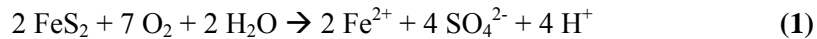
The following discussion is adapted from the Pennsylvania DEP web page (PA-DEP website, 2004). The formation of AMD is primarily a function of the geology, hydrology and mining technology employed at the mine site. AMD is formed by a series of complex geo-chemical and microbial reactions that occur when water comes in contact with pyrite (iron disulfide minerals) in coal, refuse or the overburden of a mine operation. The resulting water is usually

high in acidity and dissolved metals. The metals stay dissolved in solution until the pH rises to a level where precipitation occurs.

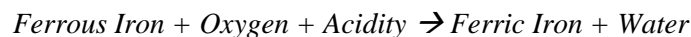
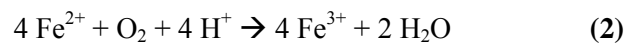
There are four commonly accepted chemical reactions that represent the chemistry of pyrite weathering to form AMD. An overall summary reaction is as follows:



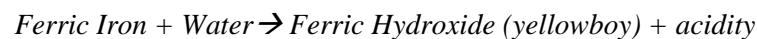
The first reaction in the weathering of pyrite includes the oxidation of pyrite by oxygen. Sulfur is oxidized to sulfate and ferrous iron is released. This reaction generates two moles of acidity for each mole of pyrite oxidized.



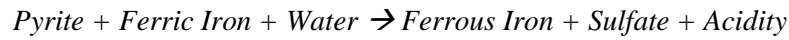
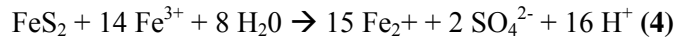
The second reaction involves the conversion of ferrous iron to ferric iron. The conversion of ferrous iron to ferric iron consumes one mole of acidity. Certain bacteria increase the rate of oxidation from ferrous to ferric iron. This reaction rate is pH dependent, the reaction proceeds slowly under acidic conditions (pH 2-3) with no bacteria present and several orders of magnitude faster at pH values near 5. This reaction is referred to as the "rate determining step" in the overall acid-generating sequence.



The third reaction that may occur is the hydrolysis of iron. Hydrolysis is a reaction that splits the water molecule. Three moles of acidity are generated as a by-product. Many metals are capable of undergoing hydrolysis. The formation of ferric hydroxide precipitate (solid) is pH dependant. Solids form if the pH is above about 3.5 but below pH 3.5 little or no solids will precipitate.



The fourth reaction is the oxidation of additional pyrite by ferric iron. The ferric iron is generated in reaction steps 1 and 2. This is the cyclic and self-propagating part of the overall reaction and takes place very rapidly, and continues until either ferric iron or pyrite is depleted. In this reaction, iron is the oxidizing agent, not oxygen.



Approximately 12,500 miles of streams and rivers in the United States are impacted by AMD, and about 85 to 90% of these streams receive AMD from old, abandoned surface and deep mines (Skousen, 1995). Due to the high costs involved for reclaiming abandoned mine lands, AMD continues to contaminate numerous surface and groundwater supplies (Eberhart, 1998).

1.2.2 AMD Impacts on Stream Health

Acid mine drainage has the potential to effect many different aspects of a stream’s biological integrity. The chemical and physical changes to the stream from the AMD result in the impacts on the biological and ecological functions listed in Table 1. AMD is a complex-contaminate effecting streams in many different ways. The full scope of these impacts should be considered in any watershed AMD remediation strategy.

Table 1. Major effects of acid mine drainage on stream systems (Modified from Gray, 1997)

Chemical	Physical	Biological	Ecological
<ul style="list-style-type: none"> • Increased acidity • Reduction of pH and buffering capacity • Increase in metal concentrations 	<ul style="list-style-type: none"> • Substrate modification • Turbidity • Sedimentation • Absorption of metal into sediment • Decrease in light penetration 	<ul style="list-style-type: none"> • Behavioral • Respiratory • Reproduction • Acute and chronic toxicity • Acid-base balance in organisms • Migration or avoidance 	<ul style="list-style-type: none"> • Habitat modification • Niche loss • Bio-accumulation in food chain • Loss of food source • Elimination of sensitive species • Reduction in primary productivity • Food chain modifications

1.3 WATER QUALITY STANDARDS AND TARGETS

1.3.1 Ohio Water Quality Standards

Water chemistry values determined by the USEPA suggest AMD impacts to waters. The parameters include: pH, total dissolved solids (TDS), sulfate, iron, manganese, aluminum, and zinc. The only two aquatic water quality standards established by the USEPA are for pH (6.5 to 9) and TDS (1,500 mg/l). Although there are no standards for the other AMD parameters, criteria limits suggest impacts from AMD and are summarized below (Table 2).

Table 2. Water quality values that suggest AMD impacts (FWPCA, 1968)

Parameter	Criteria Limit
Iron	> 0.5 mg/l
Manganese	> 0.5 mg/l
Aluminum	> 0.3 mg/l
Conductivity	> 800 uS/cm
Sulfate	> 74 mg/l
Alkalinity	< 20 mg/l
pH	< 6

Besides values that show the presence of AMD, certain other known threshold values exist for the effects of heavy metals associated with AMD on aquatic life. These thresholds (Table 3) are based on literary research and suggest that once parameters reach the limit, aquatic life will be affected. Aquatic species are affected by contaminants in various ways, so these thresholds do not suggest that all aquatic life will be affected, but that some species will be negatively affected.

Table 3. Ohio, USEPA, and literature values used as guidelines for analysis of mine drainage systems (Ohio EPA, 1979)

Parameter	Limit
Iron- total (mg/l)	1.0
Aluminum (mg/l)	0.5
Manganese (mg/l)	0.1

Categories of stream attainability also exist in the form of potential Ohio EPA’s “Designated Aquatic Life Uses”. These categories are not chemical parameter specific, but instead use the biological integrity of the stream to classify the health of a stream segment. The contaminants that are affecting the biological health of the stream are then identified and targeted for restoration so the stream can achieve the highest “designated use” attainment possible. The five designated uses consist of:

- Exceptional Warmwater Habitat (EWH) is the most biologically productive environment. These waters support “unusual and exceptional” assemblages of aquatic organisms, which are characterized by a high diversity of species, particularly those that are highly intolerant and/or rare, threatened, endangered, or special status. This use designation represents a protection goal for water resource management efforts dealing with Ohio’s best water resources.
- Warmwater Habitat (WWH) defines the “typical” warm water assemblage of aquatic organisms of Ohio streams. It is the principal restoration target for the majority of water resource management efforts in Ohio.
- Modified Warmwater Habitat (MWH) applies to streams with extensive and irretrievable physical habitat modifications, for which the biological criteria for warm water habitat are not attainable. The activities contributing to the modified warm water habitat designation have been sanctioned and permitted by state or federal law. The representative assemblages are generally composed of species that are tolerant to low dissolved oxygen, silt, nutrient enrichment, and poor habitat quality. **The category applies to dammed or channelized rivers, and can also be applied to streams affected by AMD.**
- Limited Resource Water (LRW) applies to small streams (usually <3 square mile drainage area) and other water courses which have been irretrievably altered to the extent that no appreciable assemblage of aquatic life can be supported; such waterways generally include small streams in extensively urbanized areas, those which lie in watersheds with extensive drainage modifications, those which completely lack water on a recurring annual basis, or other irretrievably altered waterways.
- Coldwater Habitat (CWH) - this use designation is intended for waters which support assemblages of cold water organisms and/or those which are stocked with salmonids with the intent of providing a put-and-take fishery on a year round basis which is further sanctioned by the Ohio DNR, Division of Wildlife; this use should not be confused with the Seasonal Salmonid Habitat (SSH) use which applies to the Lake Erie tributaries which support periodic “runs” of salmonids during the spring, summer, and/or fall. No specific biological criteria have been developed for the CWH use although the WWH biocriteria are viewed as attainable for CWH designated streams.

In determining aquatic life uses, the Ohio EPA surveys fish and macro-invertebrate populations along with chemical and physical water quality parameters throughout a given watershed. The results from the bio-survey at each sampling station are used to calculate a metric score for both fish (IBI and MIwb) and macro-invertebrate (ICI) populations that indicates the biological integrity of that given stretch of a stream.

The Index of Biologic Integrity (IBI) metric is a measure of fish species diversity and species populations. This index gives a score which indicates how much a stream habitat is affected by pollutants, and which types of fish are present. Depending on the pollution tolerance of specific species, the IBI indicates which species are likely to be found and the level of fish diversity in the stream. The MIwb is a metric that incorporates four measures of fish communities: numbers of individuals, biomass, and the Shannon diversity index based on numbers and weight.

The Invertebrate Community Index (ICI) metric is based on measurements of macro-invertebrate communities living in a stream. Macro-invertebrate studies are important to assess because many insect taxa are known to be either pollution tolerant or intolerant. The presence of certain species indicates the general water quality of an area. This index gives indications about the amount of pollution stressing the stream environment (Table 4).

Table 4. Biological criteria for the WAP ecoregion (WAP)

Site Type Index	IBI headwaters	IBI wading	MIwb wading	ICI
EWH Habitat	≥50	≥50	≥9.4	≥46
WWH Habitat	≥40/≥44	≥38/≥44	≥7.9-8.8/≥8.4-8.8	≥36-41
MWH (Mine affected)	24	24	5.5	30
LRW Habitat	18	18	4.5-5.8	8

A Qualitative Habitat Evaluation Index (QHEI), developed by the Ohio EPA, is also used to characterize physical habitat of the stream at each sampling station. Physical features that affect or are critical for fish and invertebrate communities are evaluated. Some of the features evaluated include; type of substrate, amount and type of riparian cover, channel width, sinuosity, and erosion. QHEI scores over 60 are considered conducive to meeting WWH criteria although they are not used to determine the aquatic life designated use (Ohio EPA, 2001).

1.3.2 Rush Creek Watershed Restoration Targets

The goal for this plan is to treat AMD impacted waters in the mainstem of Upper Rush Creek Watershed to extend the warmwater habitat (WWH) section in Lower Rush Creek upstream into Upper Rush Creek. To accomplish this goal, reference water quality data from Lower Rush Creek and Center Branch of Upper Rush Creek were used to set target water quality parameters.

Sites meeting full WWH from data collected as part of the OEPA TMDL study conducted in 2004 were used as reference sites. Thirteen sites within Lower Rush Creek and Center Branch of Upper Rush Creek met full attainment of WWH. Data from these sites were used to set targets for restoration activities. Each of the thirteen sites were measured six times throughout the year. The 10th percentile value for each target parameter was determined from the range of chemical water quality data. Table 5, shows target values for key AMD parameters.

Table 5. Water quality standards (for aquatic use) and targets for the Upper Rush Creek AMDAT

Parameter	Target value	USEPA (aquatic use)	OEPA Association documentation	Units
			WAP 75% percentile	
Net acidity	-80	NA	-145 n=246	mg/l
Iron	0.26	1.0 ccc	0.94 n=250	mg/l
Manganese	0.03	NA	0.25 n=145	mg/l
Aluminum	0.20	0.087 ccc 0.750 cmc	NA	mg/l
Conductivity	311	NA	500 n=195	uS/cm
pH	7.48	6.5-9.0	8.1 n=246	Standard units

ccc = criterion continuous concentration, USEPA's criterion which is equivalent to OEPA's avg. aquatic life criterion.
cmc = criteria maximum concentrations, USEPA's criterion which is equivalent to OEPA's max. aquatic life criterion.

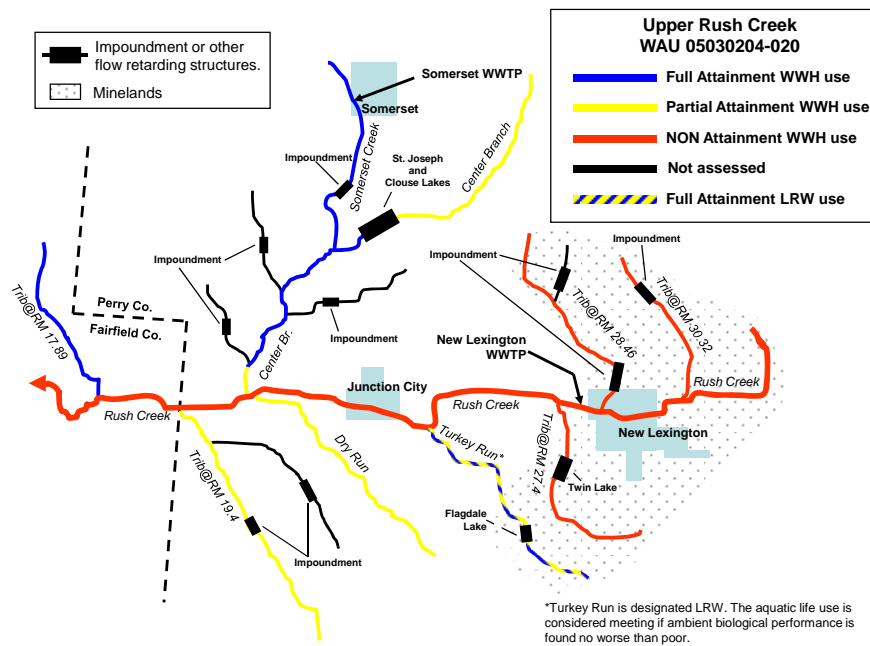
1.4 BIOLOGICAL DATA

1.4.1 Rush Creek Ecological Condition

Two biological studies of Rush Creek have been conducted in the past five years. The United States Geological Survey (USGS) collected and analyzed biological data at 18 sites (8 Upper Rush Creek and 8 tributaries) in 2003 (Darner et al., 2005). Ohio EPA conducted Total Maximum Daily Load (TMDL) monitoring the following year in 2004 and collected biological data at five Upper Rush Creek mainstem and eleven tributary sites. The Ohio EPA study was not limited to upper Rush Creek so the entire watershed was surveyed for water chemistry, sediment chemistry, and aquatic biology.

Profoundly degraded aquatic communities were documented through all of Upper Rush Creek, defined as the upper 14.3 river miles from Little Rush Creek upstream. Upper Rush Creek is designated by Ohio EPA as Limited Resource Water (LRW) and based on the 2004 data the entire 14.3 river miles is in non-attainment of that aquatic life use (ALU) designation (Figure 1).

Figure 1. Biological attainment condition of Rush Creek from 2004 OEPA TMDL study



Fish populations are severely impacted in upper Rush Creek mainstem. Index of Biotic Integrity (IBI) scores from USGS ranged from 12 – 30. Seven out of the eight sites ranged

from 12 – 14, with 12 being the lowest score possible for the IBI. These scores indicate a stream devoid of a fish community. From river mile 23.4 to 31.0 (Map 1), only a few fish were present and included tolerant species such as green sunfish, bluegill, and creek chub. The lower two sites measured by USGS at RM 21.4 and RM 21.1 (near Junction City) had the previous species and additional ones such as Johnny darter, sand shiner, yellow bullhead, largemouth bass, and spotfin shiner as well. Again, numbers of fish were severely depressed due to water quality, which is documented in the modified Index of Well Being (IWB) scores, which incorporates abundance and biomass into the index. Scores ranged from 1.6 to 4.2, these scores are below the criteria of 4.5-5.8 for LRW (Table 4).

From the biological survey conducted by the USGS in 2003, twenty species of fish were found in Upper Rush Creek (excluding Center Branch) (Darner et. al. 2005). The fish were very low in abundance and the majority of the species found were tolerant fishes. However, Center Branch, Little Rush Creek, and lower Rush Creek all have Warmwater Habitat (WWH) fish communities, therefore stock for repopulation does exist if chemical water quality parameters can be improved in the mainstem of Rush Creek. The extent of improvement would depend on pH, metal concentrations, and amount of metal flocculates in substrate.

1.5 CHEMICAL DATA

1.5.1 Upper and Lower Rush Creek

According to Ohio Environmental Protection Agency's (OEPA) Total Maximum Daily Load (TMDL) draft report (2007), Upper Rush Creek's (HUC 05030204-020) leading cause of impairment was low pH and elevated TDS, both directly associated with sources of mine drainage. Mine drainage as an impact type accounted for 31.3 % of impaired miles within the upper Rush Creek HUC. Other leading causes included nutrient enrichment (24.1%) and organic enrichment (19.5%). Organic enrichment principal sources were publicly owned treatment works (POTWs), with agriculture playing a minor role. The entire length of Upper Rush Creek, was found to be impacted by mine drainage (low pH), and secondarily by POTWs. Profound impacts and non-attainment of the aquatic life use were indicated for

three unnamed tributaries that constitute the headwaters of Upper Rush Creek. Identified by the confluence points with Rush Creek, following this convention, these streams are unnamed tributary at river mile 30.32 (Rehoboth), 28.4 (Airport), and 27.4 (USGS site1027) (Appendix 4). The first of these (unnamed tributary at RM 30.32) displayed all of the classic indicators of mine drainage (low pH, elevated TDS, increased acidity, etc.).

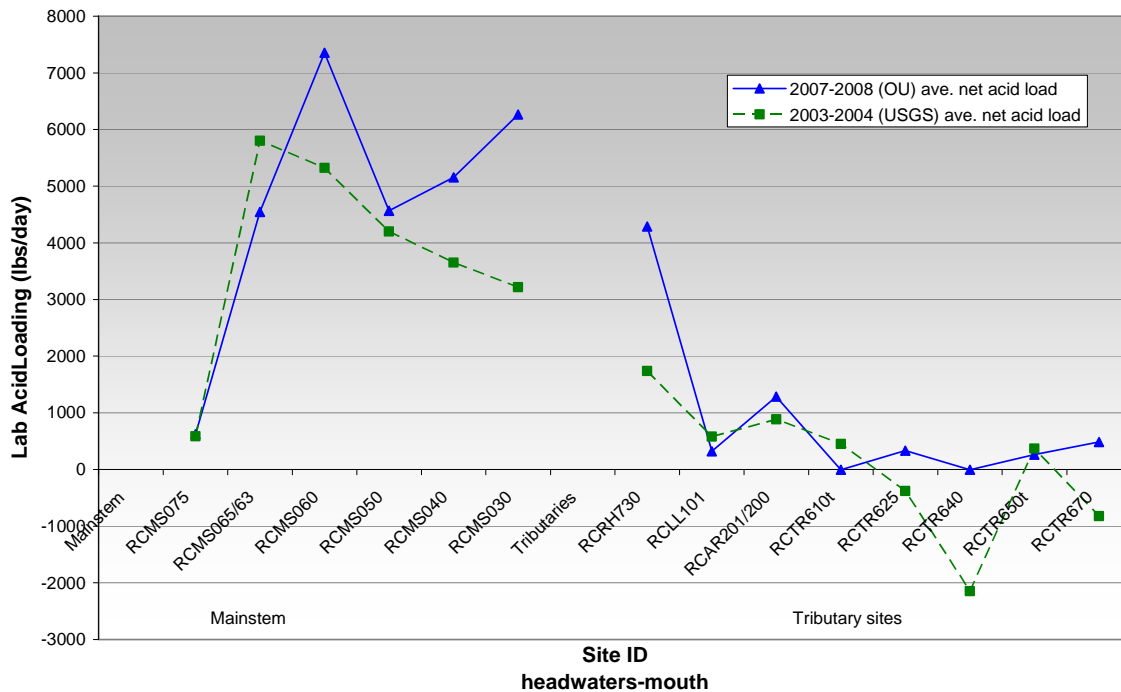
In contrast to the upper Rush Creek HUC, no compelling evidence of mine drainage, and associated impacts, were found in the lower portion of the Rush Creek watershed (HUC 05030204-030). Although no single cause or source appeared overwhelmingly dominant, leading causes and sources were principally associated with land use, including agriculture, and its attendant stressors.

1.5.2 Upper Rush Creek mainstem chemical water quality

From 2003 to 2004, USGS determined from field investigations that Rehoboth was the largest contributor of acid loading (3,674 lbs/day) followed by Airport. Data collected from 2007-2008 show similar results (Figure 5 & 6). Figure 2, shows average acid loads calculated from data collected in 2003-2004 by USGS versus data collected in 2007-2008 by Ohio University. The data collected in 2007-2008 covered a wider range of flow regimes than the data collected by the USGS in 2003-2004. This may explain some of the higher loadings calculated in 2007-2008.

Figure 2. Comparison of average net acid loads from 2003-2004 data to 2007-2008 data

Comparison of average net acid loads from 2003-2004 data (USGS) to 2007-2008 data (OU)



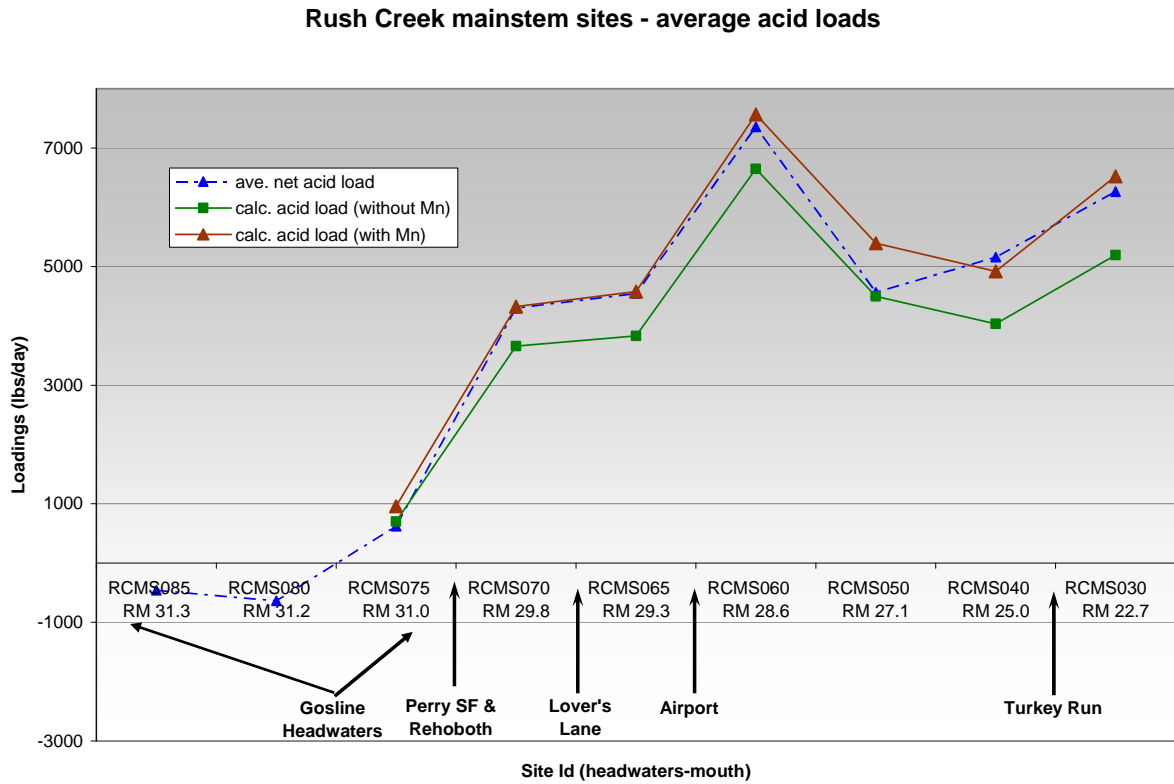
Calculated acidity (Equation 1.0) was used to determine acid loads with and without manganese. In addition net acidity values from the laboratory were used to calculate average net acid loads (Figure 3). Chemical water quality data collected 2007-2008 along the mainstem of Rush Creek shows a steep decline in alkalinity at river mile 31.0 (Figure 3).

Equation 1.0

$$\text{Calculated acidity mg/l} = (50 * ((3 * \text{Al} / 26.982) + (3 * \text{Fe}^{+3} / 55.877) + (2 * \text{Mn} / 54.938) + (1000 * 10^{-\text{pH}})))$$

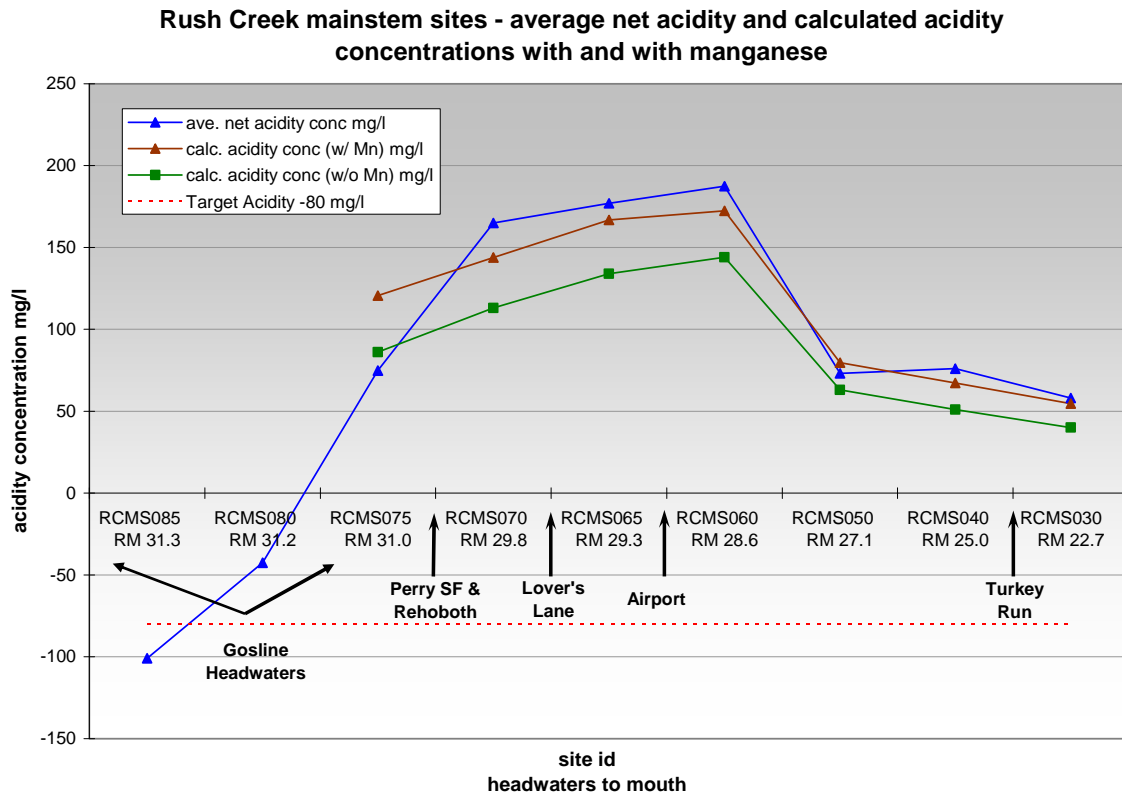
Acid loads continue to increase downstream from river mile 31.0 (RCMS075 – dst. Gosline) to river mile 28.6 (RCMS060 – dst. Airport). Acid loads decrease further downstream at river mile 27.1 and 25.0, but increases again downstream the confluence with Turkey Run at river mile RM 22.7 (RCMS030). Loadings are expected to increase as a function of drainage area and discharge, therefore figure 4, displays concentrations of acidity in milligrams per liter at the same mainstem sites.

Figure 3. Average net and calculated acid loads for Rush Creek Mainstem sites.



The dashed line in figure 4 shows the target net acidity concentration, as discussed in section 1.3.2. Along the mainstem the only site to meet the target is the headwater site at river mile 31.3.

Figure 4. Average net acidity and calculated acidity concentrations for mainstem sites.



1.5.3 Upper Rush Creek tributary mass-balance analysis

As part of this AMDAT plan, Gosline headwaters, Lover’s Lane, and Turkey Run were investigated for abandoned mine drainage (AMD) sources as requested by ODNR-DMRM. Perry State Forest and Airport were sampled for mass-balance analysis not source identification due to the ubiquitous nature of AMD in these subwatersheds. Field measurements were recorded in Rehoboth along with a few water quality laboratory sites to assist in completing a mass-balance of Rush Creek (sites RCRH730, RCRH725, and RCRH699) (Map 6) (Figure 5 & 6).

Figure 5. 2007-2008 subwatershed average net acid loads

2007-2008 average net acid loading lbs/day

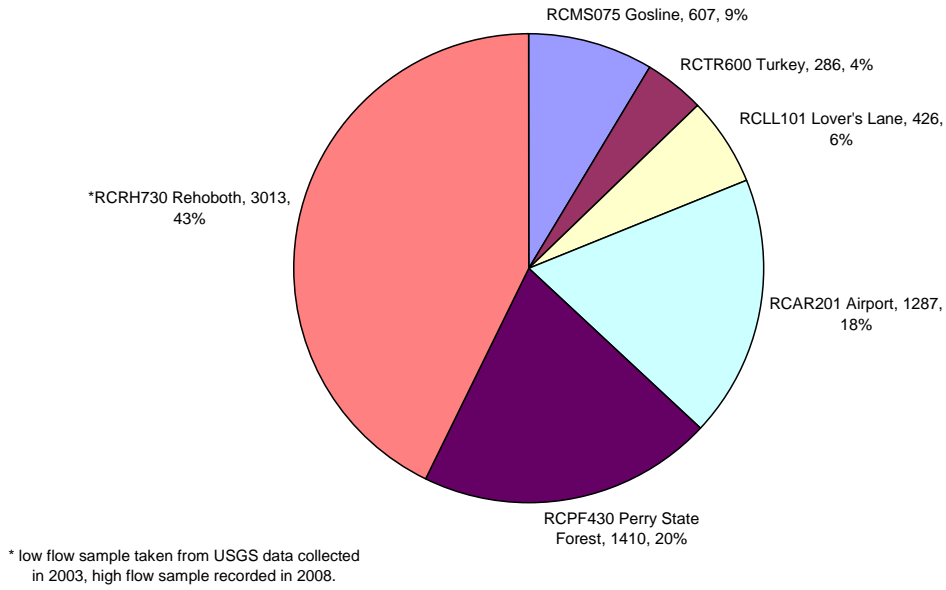
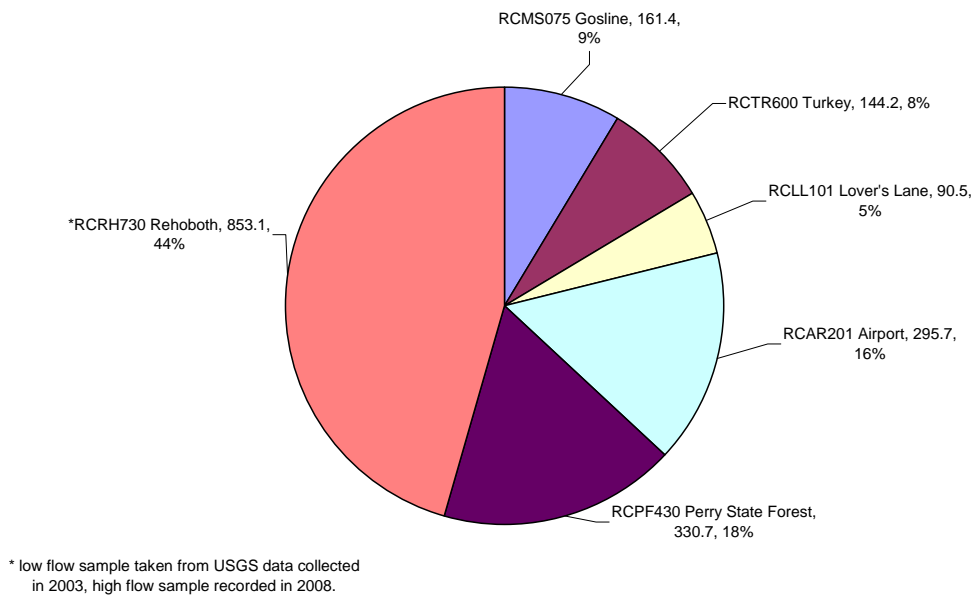


Figure 6. 2007-2008 subwatershed average total metal loads (Fe, Al, Mn)

2007-2008 average total metals (Fe, Al, Mn) loadings lbs/day



Mean annual acid and metal loads were calculated using the Mean Annual Load Method (Stoertz, 2004) with data collected in 2007-2008. Site RCRH730 (USGS 3011) utilized one sample measured in 2003 (low flow) by USGS to fulfill the sample size requirement of n=2. Figure 7, displays the mean annual acid and metal load calculations at key sub-watershed sites. Acid load calculations were based on laboratory net acidity concentrations and measured field discharges. Metal load calculations were based on laboratory concentrations of iron and aluminum; manganese concentrations were excluded. The mouth of Perry State Forest, site RCRH730 reflects chemical water quality discharging from Perry State Forest as well as the water quality discharging from Rehoboth. On average, the sub-watersheds contributing acid and metal loading from highest to lowest are: Rehoboth, Airport, Perry State Forest, Gosline, Lover's Lane, and Turkey Run (with Turkey Run having a slightly higher metal load than Lover's Lane).

Figure 7. Mean annual acid and metal loads at key sub-watershed sites.

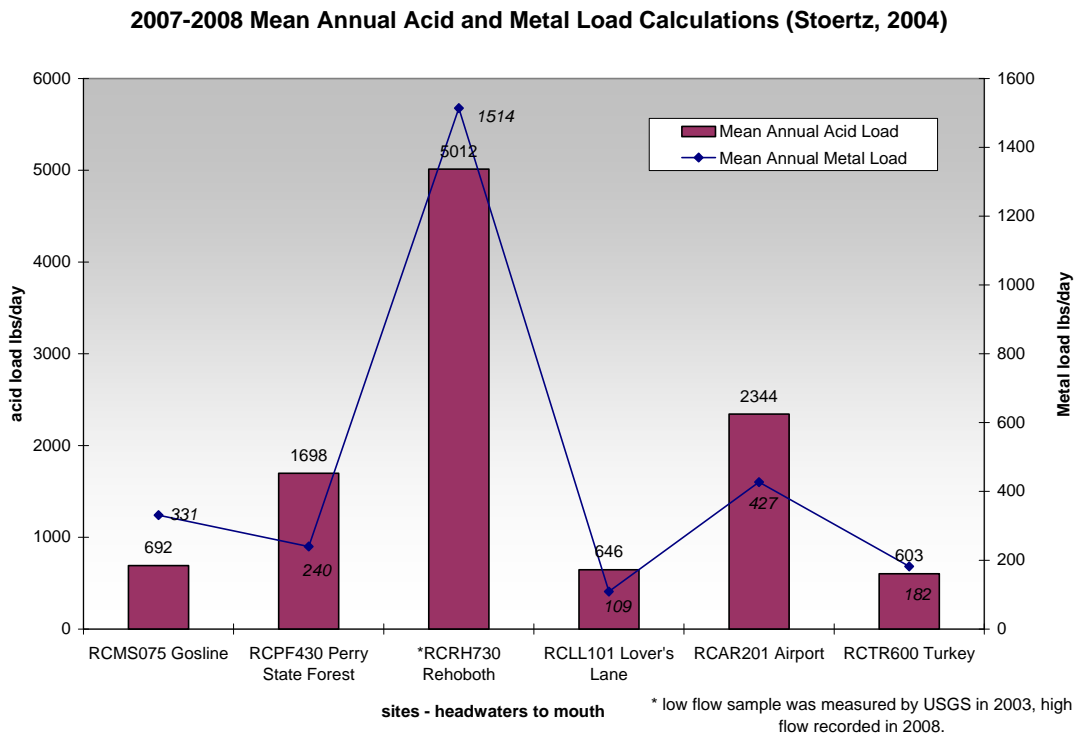
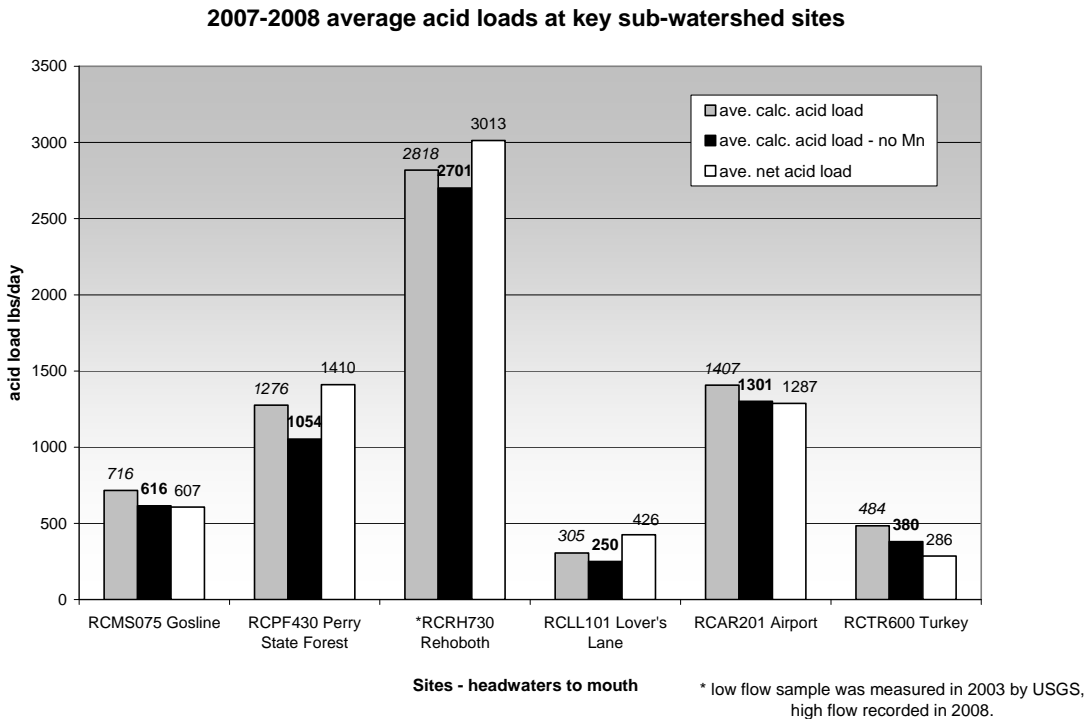


Figure 8, displays the acid load derived from calculated acidity values with and without manganese, and the measured average net acid loads from data collected over 2007-2008. The list of highest to lowest acid load mimics very closely the same results as determined from Figure 7. However, it is important to note that some of the acid load values are lower than the acid loads derived from the mean annual load method in Figure 7. This is due to the flow regime in which the samples were collected in relation to the mean annual discharge. For example, the Rehoboth site, RCRH730, measurements were both recorded at discharges below the estimated mean annual, discharge 3.91 cfs, (USGS, 2009) (note: this may be due to extra storage being provided by the treatment ponds in the area). The mean annual acid loads are calculated from data that has been normalized based on the mean annual daily discharge for each site (Stoertz, 2004). “The mean annual load is a representative measure of water quality because it integrates all probable daily loads over a typical year” (Stoertz, 2004). Therefore the mean annual acid load calculations are important to consider in addition to strict averages.

Figure 8. Average calculated and net acid loads at key sub-watershed sites.



The majority of AMD impacts in Upper Rush Creek are generated from abandoned surface mining sites, deep mines (Perry State Forest), and pre-law coal preparation cleaning facility (Rehoboth). Exposed spoils, surface pit impoundments, etc... create the greatest impact to Rush Creek mainstem during high flow regimes. When comparing the high flow to the low flow water quality data, acid loads are highest during higher flow regimes on the mainstem (Figure 9). This relationship is somewhat expected given loads are calculated as a function of flow. However, concentrations are also highest on the mainstem during high flow regimes. The net acidity concentrations during both high and low flow regimes are displayed in Figure 10. This is contrary to what is usually found near AMD source areas. Near AMD source areas concentrations generally are higher at low flow regimes with higher loads at high flow regimes. Analysis of net acidity concentrations and loadings lead to the following conclusions for the sub-watersheds investigated in Rush Creek:

1) Sites that are located at the AMD sources or near source areas:

- Higher loads are recorded during **higher flow** while higher concentrations are found at **lower flow** regimes

2) Sites that are further downstream from source areas (i.e. at the mouth or on mainstem Rush Creek):

- Higher loads are recorded during **higher flow** while higher concentrations are found during **higher flow** regimes

Surface mine areas tend to exhibit higher concentration and loads downstream from the source area on the mainstem due to the increase in volume of surface run-off and groundwater recharge at exposed spoil, coal refuse, and storage in the pit impoundments at high flow regimes. This scenario has also been found in Little Raccoon Creek Watershed (McCament 2008). Another reason to use the Mean Annual Acid Load Method is given the large difference in concentrations and loadings between high and low flow. A strict average pulls down the high acid peaks experienced in the spring. For example, the mean annual load calculations for Perry State Forest data (Figure 29 & 30) show a higher mean annual acid load (1698 lbs/day) than the average of the two water quality samples (1287 lbs/day). These acid spikes, experienced during spring high flow, limit the ability of the aquatic biology to

flourish in marginal water, therefore the mean annual load calculations are important to determine.

Figure 9. 2007-2008 high and low flow calculated acid loads at selected tributaries

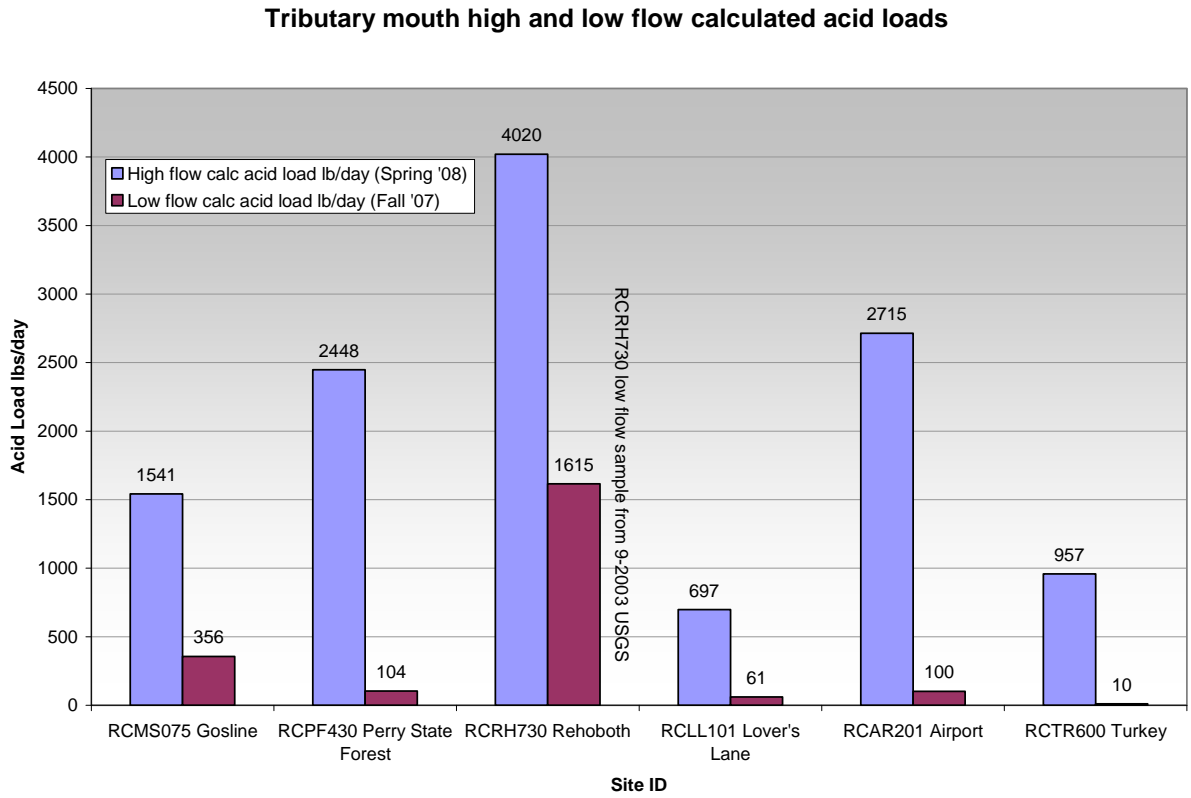
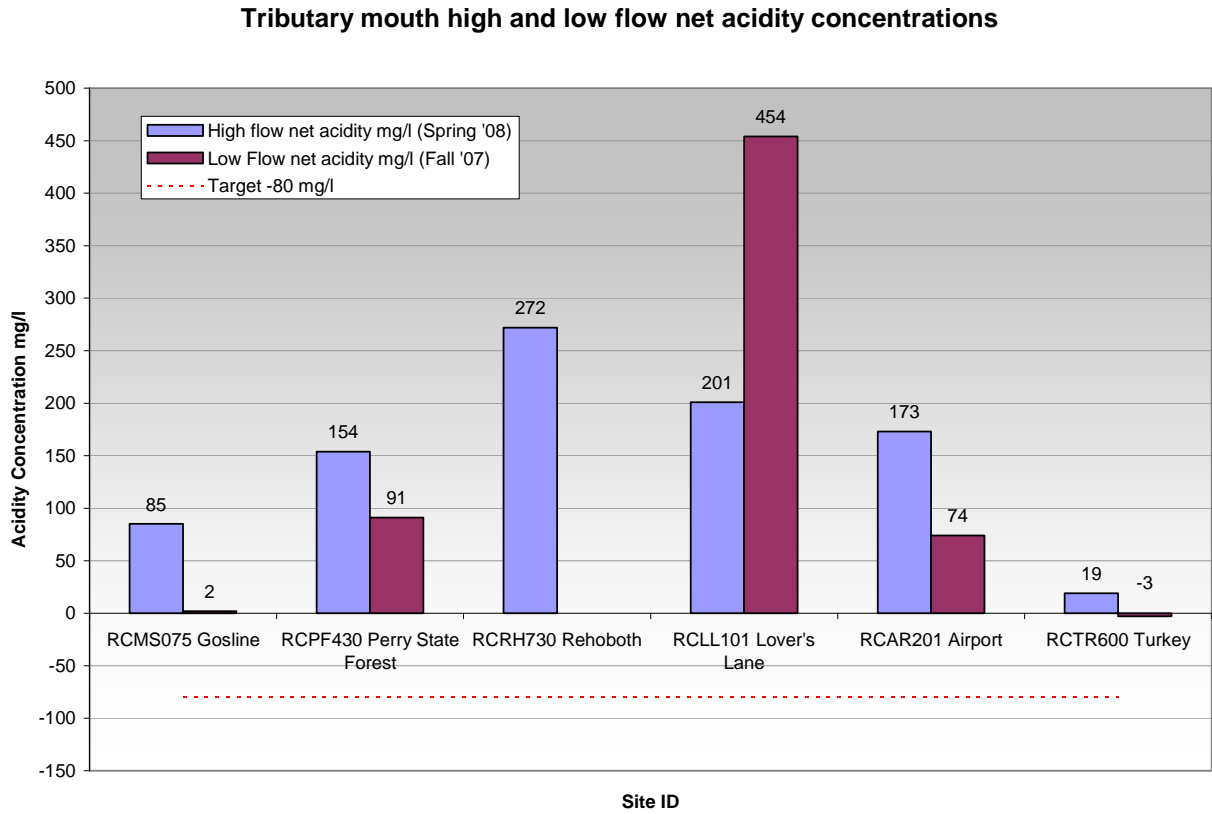


Figure 10. 2007-2008 high and low flow net acidity concentrations at selected tributaries



2.0 SECTION II

Section II provides a description of each of the sub-watersheds investigated including: mining issues, chemical water quality data, map and list of the abandoned mine sources, charts and graphs of the acid and metal loadings, a comparison of the mean annual acid and metal loadings from each of the selected sub-watersheds, and recommendations for further monitoring. This Section ends with a discussion of the restoration strategy for Rush Creek.

2.1 Gosline Headwaters

Sub-watershed description

Location: Rush Creek headwaters to river mile 30.4 (RCMS073)

Drainage area: 2.59 square miles

USGS quadrangle: New Lexington

Map: #4

Percent acid and metal load to Rush Creek (Appendix 6): Acid 49% and Metal 67%

Gosline Headwaters sub-basin includes the area within the headwaters of Upper Rush Creek downstream to river mile 30.4 (RCMS073) (Map 4). The area is comprised of abandoned and active coal mining. There are two documented underground mines; one on the border with Rehoboth mine (Wilburn Mine PY-118) and the other is PY-214, Bear Run #1, abandoned in 1924 that mined the Middle Kittanning #6 (Appendix 1 and Map 4). Discharge from deep mine PY-214 drains to either Bear Run in Moxahala Watershed and/or possibly connects through to the headwaters of Gosline (RCGH030 area). The AMD impacts from Wilburn mine and Rehoboth mine area are apparent at site RCGH013/14 (Map 4).

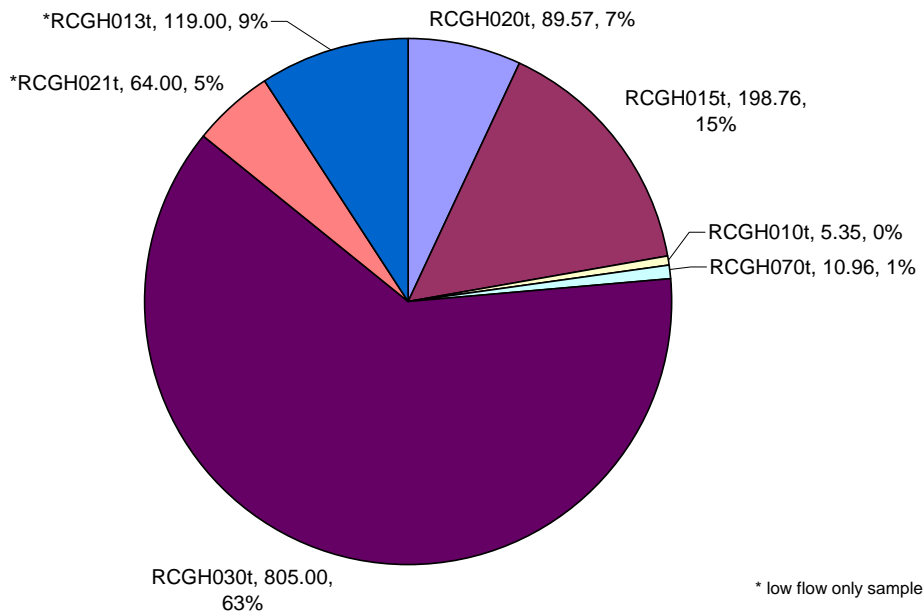
Mass-balance analysis

Mass-balance analysis of the mouths of tributaries in the Gosline Headwaters shows RCGH030 as the main contributor of acid loads (Figure 11). Site RCGH030 is at the mouth of an unmapped tributary, it runs alongside township road 497 in the ditches. It drains land that has been partially reclaimed with numerous AMD sources. It enters into Rush Creek at river mile 31.2. The other four sites that total 36% of the acid loads are located in the lower end of Gosline headwaters downstream of RCGH030. These sources drain directly into Rush Creek, a) site RCGH013 at river mile 30.7site and b) sites RCGH015, RCGH020t, and

RCGH021t at river mile 30.45. Site RCGH070t and RCGH010t are an insignificant portion of the loading <2% (Figure 11).

Figure 11. Mass-balance of average net acid loads at the mouths of tributaries in the Gosline Headwaters sub-watershed

Gosline mass-balance of average net acid loads at mouths of tributaries lbs/day



Source Identification

Specific sources were identified and sampled within the Gosline Headwaters (Map 4). Table 6 shows the high, low, and average net acidity and metal loads from each of the sources measured in the Gosline Headwaters.

Table 6. High flow, low flow, average net acidity and metal concentrations of the sources measured in the Gosline Headwaters.

Site ID	Net acidity concentrations mg/l			Metal concentrations (Fe, Al, and Mn) mg/l		
	High (4/9/08)	Low (9/20/07) (6/25/08)	Average	High (4/9/08)	Low (9/20/07) (6/29/08)	Average
RCGH070	134	89 (6/25/08)	112	41	33 (6/29/08)	37
RCGH060t	96	272 (6/25/08)	184	135	35 (6/29/08)	85
RCGH050t	181	184	182	97	113	105
RCGH040t	225	303	264	133	139	136
RCGH036t		319 (6/25/08)			167 (6/29/08)	
RCGH010t	313	422	368	152	233	192
RCGH020t	453	397	425	125	123	248
RCGH021t		238 (7/30/08)			78 (7/30/08)	
RCGH015	345	417	381	99	132	115
RCGH013		138 (7/30/08)			18 (7/30/08)	

Source descriptions:

RCGH070: This site is located at the upstream end of a culvert that flows under Tunnel Hill Rd and then in to Rush Creek past site RCGH071. The site is about 40m downstream of a newly reclaimed area draining into a riprap channel seeded with soda ash briquettes. Just before it enters the culvert, the stream captures two other small sources leaching from unreclaimed spoil piles outside of the reclaimed zone. The leaching sources flow from opposite directions down the roadway ditches.

RCGH060t: This site is a steadily flowing upwelling that originates from unknown subsurface sources. The temperature and dissolved oxygen of the water indicates a long residence time underground whether from unmapped underground mines or large interstitial spoil complexes. The upwelling is surrounded by many other upwellings that flow across the denuded surface to form the stream channel sampled at RCGH055t.

RCGH050t: This site is located below all visible seeps on the north side of County Rd. 497. The area is characterized by sparse vegetation and sandy spoil. The stream runs parallel to the roadway through the spoil, and then flows into a drainage ditch before mixing with several other sources.

RCGH040t: This is a steadily-flowing stream draining a large strip pit lake. Water is most likely supplied at the far end of the lake by subsurface sources that may be coupled with underground mines. Another channel to the west of this site drains similar pit lakes, but is

filled with sediment and is likely flowing below the surface. These sources join together before crossing the road and joining with the flow from the seep area RCGH050t.

RCGH036t: Field measurements were captured at this “volcano seep” that flows down to the County Rd. 495 and joins the stream below the seep area from RCGH050t. The seep originates from the spoil pile which is sandy and contains larger rubble.

RCGH010t: This site is a small flowing stream that drains a strip pit by leaching through a spoil dam on the east side of the Tunnel Hill Rd. Measurements and samples were collected at the culvert outlet on the west side of the road. The stream then flows into the forest where a wooded wetland is forming. Several unique plant species were noted from this area.

RCGH020t: This site is a small flowing stream that drains through a break in a spoil dam on the east side of Tunnel Hill Rd. The stream drains a reclamation area that is being used for residential development. It is likely coupled with other strip pit lakes in the upper part of the heavily mined headwaters.

RCGH021t: This site is a large seep area that converges into one channel. Water is supplied from unknown subsurface sources through regraded mine spoil. The area is heavily wooded and is slowly becoming a functional wetland.

RCGH015: This is the largest of the three culvert sources identified along Tunnel Hill Rd. Water drains from a wetland and a sediment-filled strip pit just east of the road. The stream drains a reclamation area that is being used for residential development. Water is supplied from a series of strip pits in the upper part of the watershed and may be coupled with underground sources.

RCGH013: This site is a seep complex that originates from beneath graded spoil north of the railroad tracks where the original channel has been filled in. Water pools against the railroad berm before it drains into a culvert under the tracks to join the mainstem of Rush Creek.

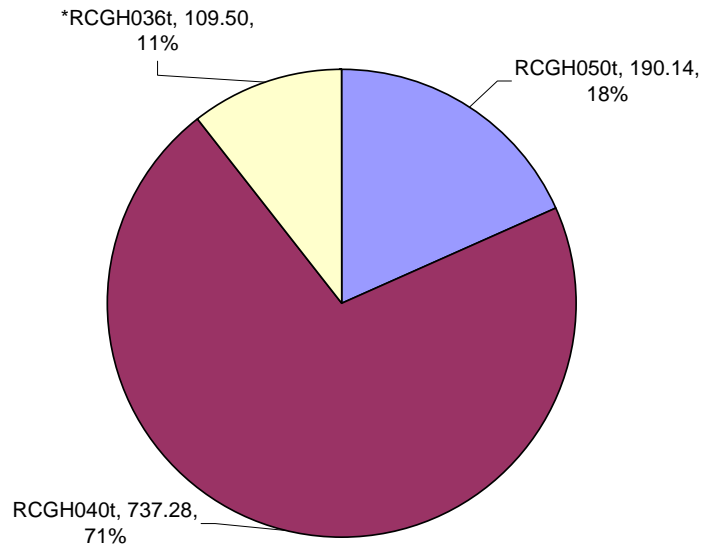


Source in Gosline site RCGH021t

According to the mass-balance analysis, RCGH030 is the largest contributor of acid loads in the Gosline area. This area consists of three AMD sources. Site RCGH040t contributes 71% of the acid load, followed by RCGH050t (18%), and lastly RCGH036t (11%) (Figure 12).

Figure 12. Average net acid loading of sources within site RCGH30t (Owen property)

Gosline RCGH030t - Average Laboratory Net Acid Loading lbs/day



* low flow only sample

For purposes of quantifying the mean annual acid and metal loadings in Gosline Headwaters, site RCGH030 (largest acid contributing tributary in Gosline) and RCMS075 (designated mouth site of the Gosline Headwaters on the mainstem) were used to calculate the mean annual load (Stoertz, 2004). Table 7 and Figure 13-16 shows the mean annual acid and metal loads currently, prior to any AMD treatment.

Table 7. Mean Annual Acid and Metal loads at two stations within the Gosline Headwaters sub-basin.

Site ID	Mean Annual Acid Load (lbs/day)	Mean Annual Metal Load (lbs/day)
RCGH030	355	93
RCMS075	692	331

Figure 13. Mean Annual Acid Load site RCGH030

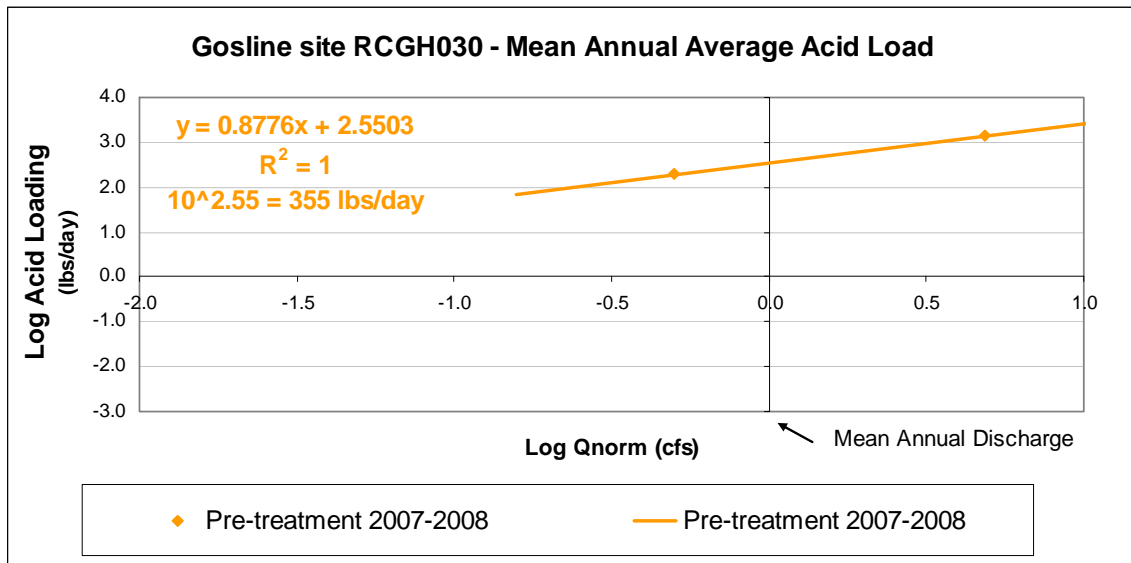


Figure 14. Mean Annual Metal Load site RCGH030

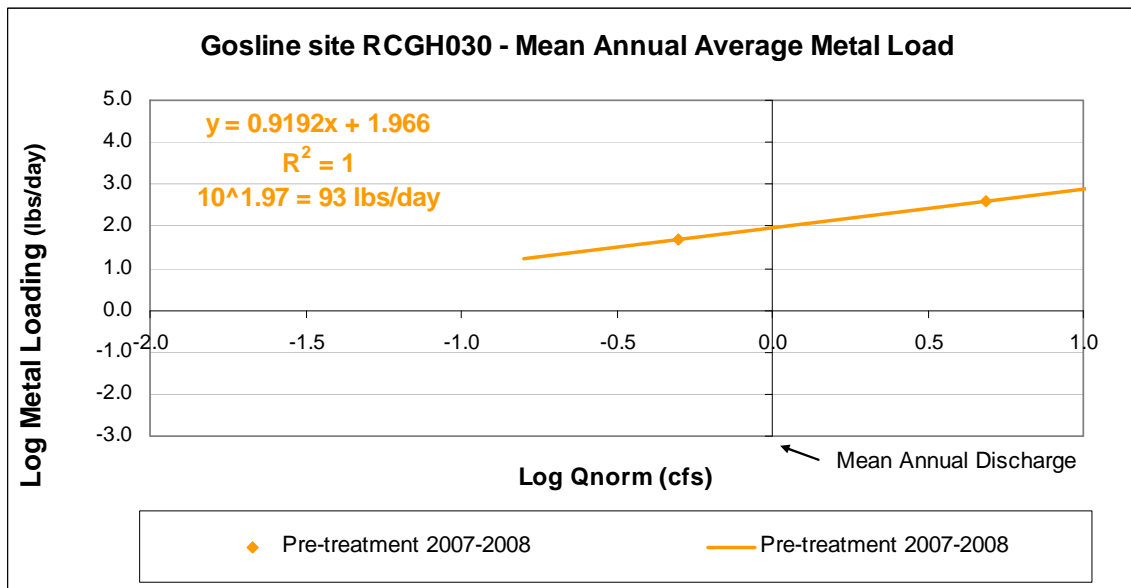


Figure 15. Mean Annual Acid Load site RCMS075

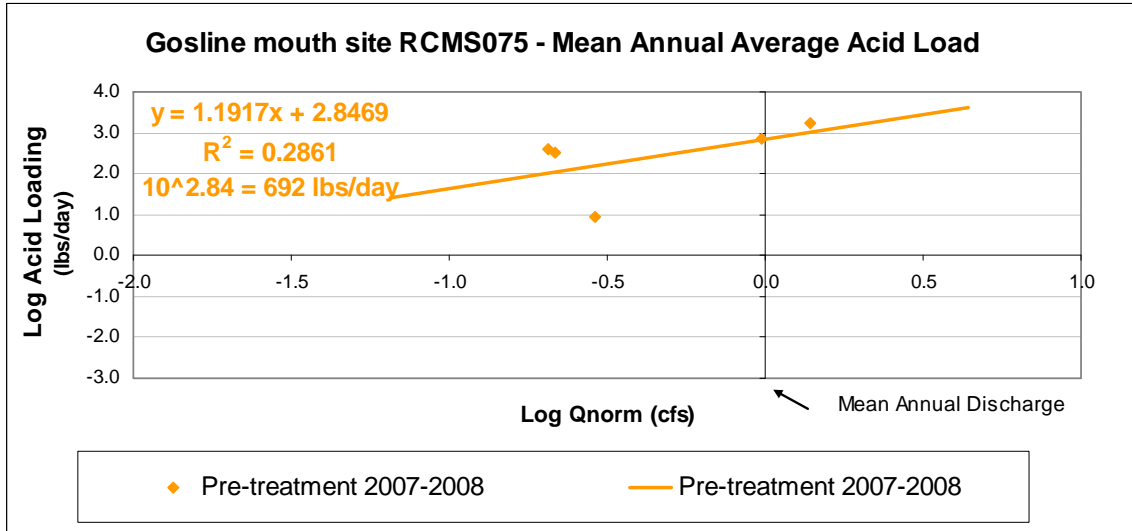
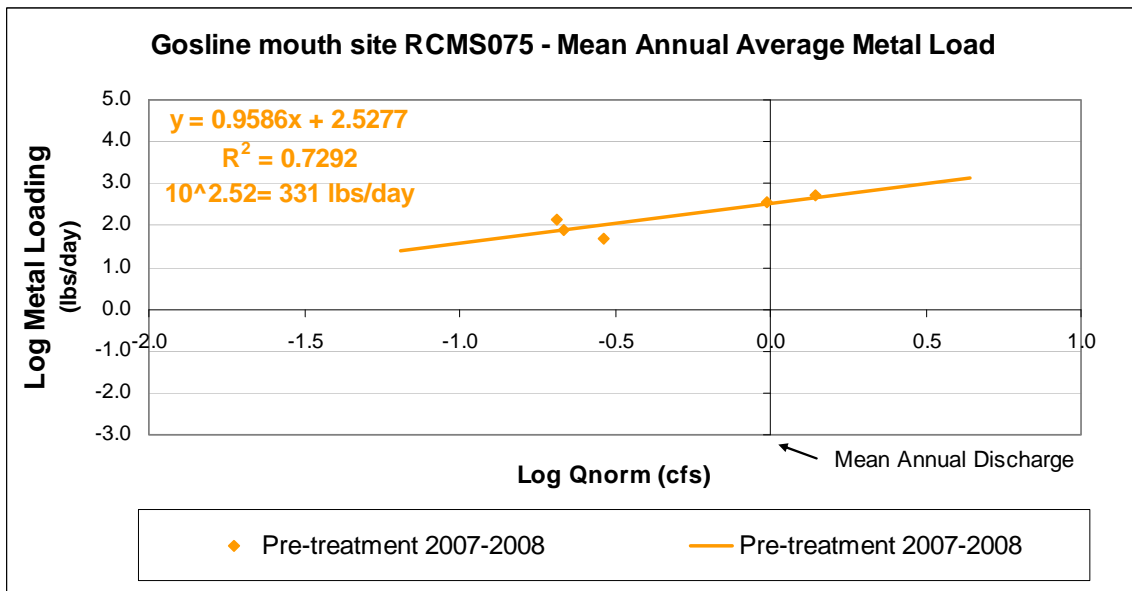


Figure 16. Mean Annual Metal Load site RCMS075



Recommendations for further study

The recharge zones are not clearly understood for the sites within the RCGH030 area (Owen’s property). Site investigations need to be conducted to determine the subsurface hydrologic connections through the partially reclaimed area and spoil overburden.

2.2 Lover's Lane

Sub-watershed description

Location: Small unnamed tributary to Upper Rush Creek at river mile 29.7

Drainage area: 0.48 square miles

USGS quadrangle: New Lexington

Map: #5

Percent acid and metal load to Rush Creek (Appendix 6): Acid 0-9% and Metal 0-30%

Lover's lane sub-basin is a small unnamed tributary that drains a mostly forested watershed. The headwaters have been surface mined and partially reclaimed. One underground mine, PY-024, Lilly Mine was abandoned in 1912 and mined the Lower Kittanning #5 (Map 5). At the mouth of the tributary, the stream flows through a sparsely residential area.

Mass-balance analysis

Water quality data from Lover's Lane shows the greatest contributors of acidity and metals are coming from the northern branch of the two headwater streams. This branch drains from the margin of the reclaimed surface mine area. The deep mine discharge in Lover's Lane (RCLL115t) only flows during higher flow regimes. During the summer the channel is wet, but not flowing. One sample collected at the deep mine indicated net alkalinity conditions however as the water from the mine flows to Lover's Lane, the pH drops and other small seeps appear along the creek (Table 8).

Table 8. Field pH measurements recorded on 5/28/2008 within the Lover's Lane sub-basin.

Site	Description	River mile	pH
RCLL117	mainstem Lover's Lane upstream of confluence with drainage from deep mine	29.7,0.32	4.16
RCLL115t	deep mine pipe	29.7,0.30,0.2	5.30
RCLL110t	mouth of drainage from deep mine site	29.7,0.30,0.1	4.23
RCLL109	mainstem Lover's Lane downstream of confluence with drainage from deep mine	29.7,0.25	4.34

An average of acid and metal loads sampled on 4/30/08 and 7/30/08 are shown in Table 9. Site RCLL185 is the source of mine drainage in the Lover's Lane basin. The deep mine discharging slightly acidic to net alkaline at times improves the pH of the highly net acidic mainstem of Lover's Lane (Table 8).

Table 9. Average pH, net acid, and metal loads measured in the Lover's Lane sub-basin.

Site	Ave. net acid load lbs/day	pH	Ave. Metal Loads lbs/day (w/Mn)	Ave. Metal Loads lbs/day (w/o Mn)
RCLL185 (strip pit in headwaters)	668	2.75	232	166
RCLL145t (pond in headwaters)	-7.8	6.42	2.4	0.22
RCLL101 (mouth)	663	2.93	173	112

Source Identification

Two sources of mine drainage were identified within the Lover's Lane sub-watershed (Map 5) described below. Table 10 shows the high, low, and average net acidity and metal loads from each of the sources measured in the Lover's Lane.

Table 10. High flow (spring 2008), low flow (fall 2007), average net acidity and metal concentrations of the sources measured in the Lover's Lane.

Site ID	Net acidity concentrations mg/L			Metal concentrations (Fe, Al, and Mn) mg/L		
	High	Low	Average	High	Low	Average
RCLL115t		12*			15*	
RCLL185	446	561	504	162	204	183

* sampled once during medium to low flow regime 7/30/08

Source descriptions:

RCLL115t: This site is located behind homes on Tunnel Hill Rd. A black plastic pipe is draining an underground source, Lilly Mine. The channel is filled with sediment and precipitated metals causing the stream to be braided in morphology. The mostly vegetated area is slowly turning into a sphagnum bog where sediment is thickest. Small seeps are also noted along the channel.

RCLL185: This site marks the headwater source of Lover's Lane consisting of surface mine impoundment located at the edge of the reclaimed land. There are two upwelling seeps with alluvial iron deposits at the margins of the pond that drain into the pond. Site RCLL190 seeps/oozes into the strip pit and the other is marshy in the center and encrusted with iron surrounding.



Lover's Lane site RCLL185

For purposes of quantifying the mean annual acid and metal loadings in Lover's Lane, site RCLL101 (mouth of the Lover's Lane) was used to calculate the Mean Annual Load (Stoertz, 2004). Mean annual average acid and metal load at the mouth of Lover's Lane are 646 and 109 lbs/day, respectively (Figure 17 and 18).

Figure 17. Mean annual acid load, site RCLL101, mouth of Lover's Lane.

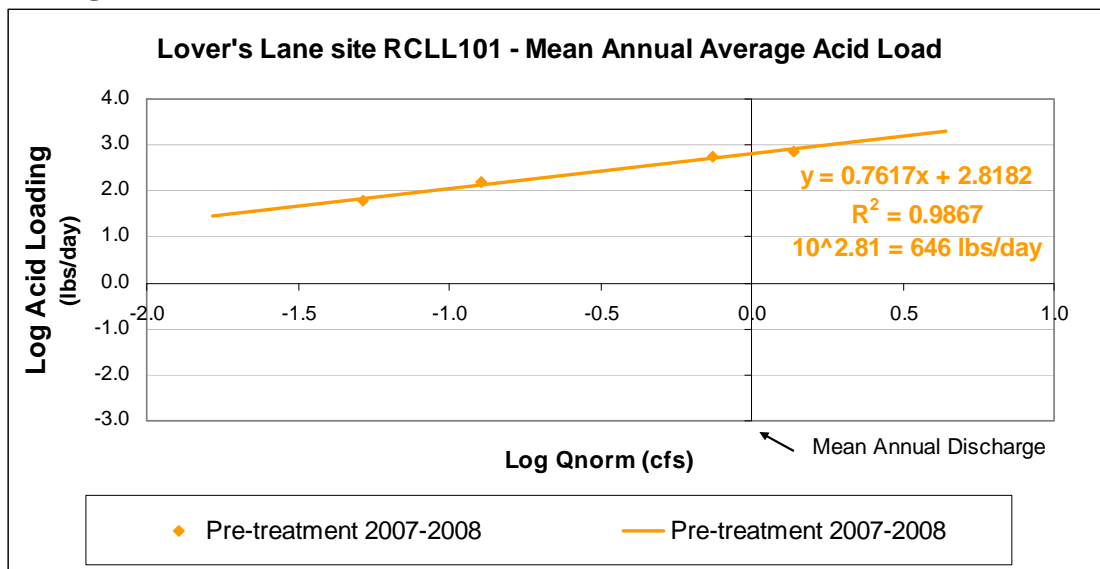
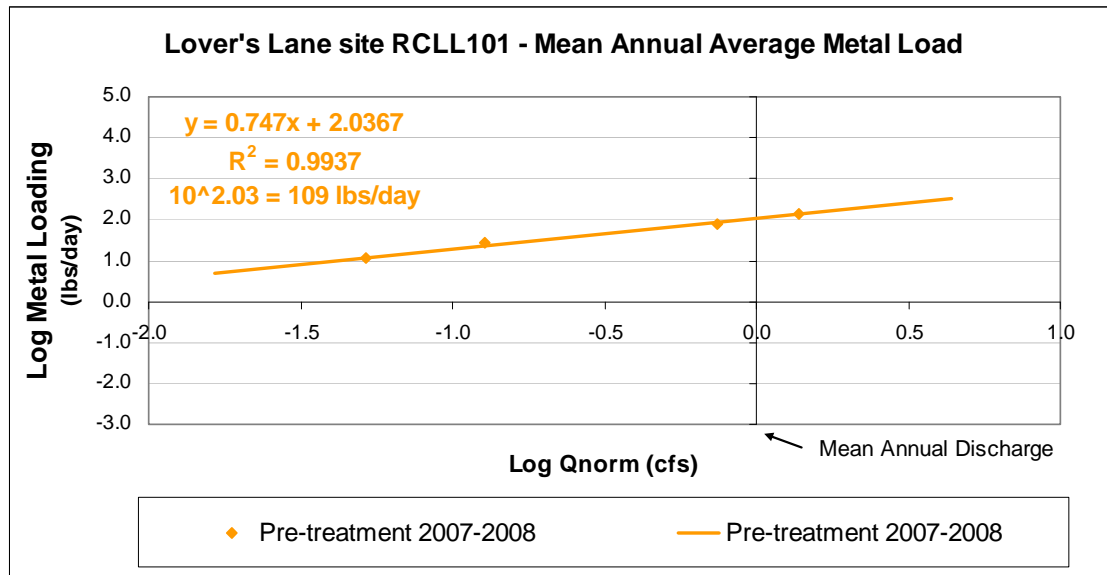


Figure 18. Mean annual metal load, site RCLL101, mouth of Lover's Lane.



Recommendations for further study

- To better characterize the Lilly deep mine complex and the interstitial flow along its channel, it is recommended 2-3 water samples be collected at various flow regimes at the deep mine source (RCLL115t) and at the confluence with Lover's Lane (RCLL110t).
- The pond with good water quality in the headwaters (RCLL145t) has been selected for a potential steel slag bed. Discharge and chemical water quality samples need to be monitored here prior to design to analyze for this potential use.

2.3 Rehoboth

Location: Rehoboth Creek flows into Upper Rush Creek at river mile 30.3

Drainage area: 3.64 square miles

USGS quadrangle: New Lexington and Fultonham

Map: #6

Percent acid and metal load to Rush Creek (Appendix 6): Acid 68% and Metal 73%

2.3.1 Rehoboth literature review

One of the most significant sources of AMD to the Rush Creek watershed is the site of an abandoned surface mine near Rehoboth, in the northeastern part of the watershed (Map 6). Rehoboth area is an abandoned coal preparation plant area for cleaning coal. Coal refuse in the form of coarse refuse and fine (slurry) refuse were land-filled within the mined out area. Total impact area of the refuse was approximately 125-150 acres (Jonard, personal communication, 2009). In 1997, the Ohio Department of Natural Resources (ODNR) began a three-phase reclamation project of the site that included regrading and capping of the refuse with flue-gas desulphurization (FGD) by-product and installation of ponds through the creation of a series of low-head dams (Figure 19). ODNR's reclamation effort includes approximately 450 acres of land that has a long history of use (Bennett & Williams Environmental Consultants, Inc., 1995). A brief summary and chronological history of the site is included; full details are listed in Bennett & Williams Environmental Consultants, Inc. (1995).

The Rehoboth subwatershed has been greatly altered from its original natural state by more than 50 years of coal mining and industrial activities. Deep mining in the early 20th century to contour mining in the 1930's to the complete removal of the coal and overlying rock strata in the 1950's, has left the watershed disturbed and impacted by acid mine drainage.

Most mining and industrial activities had ceased by 1965 leaving behind enormous piles of mine waste, coal fines, and overburden. As "one of the largest uncontrolled gob piles in the state," with a reported 2.3 million tons of coal refuse, all of the stream channels in the upper part of the basin became choked with sediments creating braided stream morphology. By 1971, railroad embankments that had previously blocked much of the sediment from

reaching the main channel were breached. Sediment then began a measurable migration downstream toward the Rush Creek and significantly advanced the braiding effect in Rehoboth Creek.

Alterations in the topography of the watershed have intensified the physical and chemical instability of the spoil due to a tendency toward geometric equilibrium within the watershed boundary. Soils are dominantly sandy with a large portion of mineral-rich shale causing high rates of erosion, leaching, and contaminant transport. Sandy soil textures may also account for the lack of vegetative cover still found at the site.

In the mid-70's, minor reclamation was attempted by constructing a detention impoundment along the erosion channel. Rehoboth I was a reclamation/operator cost share project that consisted of a small 5-acre tract near the wash plant facilities. This project was intended to control sediment eroding from the large gob pile that was impinging on Rehoboth Creek. The project was largely unsuccessful due to disturbance by subsequent industrial interests in the area. A large wash plant, HDPE pipe system, and detention basin complex were constructed by some of these interests and were used for slurry operations. Coal wastes were imported to this site and washed in an effort to generate revenue. While these ventures were unsuccessful, many tons of wastes were added to the volume of material already filling this headwater valley. These additional materials and industrial structures further complicated the land use history and the overall geomorphic stability.

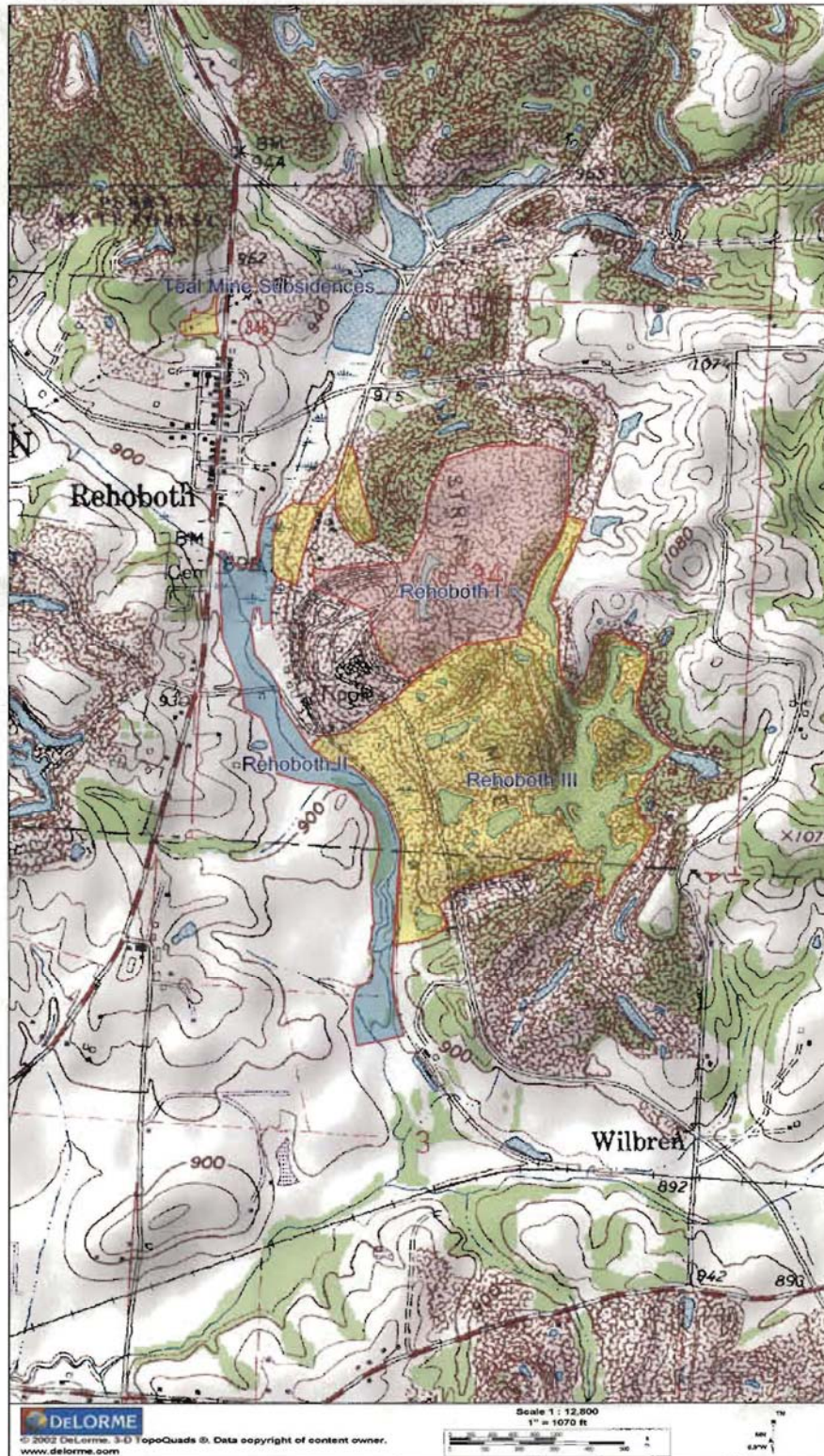
A larger reclamation project was attempted in the 1990's known as Rehoboth II. Reclamation plans issued in 1995 were developed by Bennett and Williams as a 3-phase effort to mitigate flooding and erosion problems in Rehoboth Creek area. A 450-acre area was chosen for this project primarily because of a 2000 lb/ac/yr erosion sediment load with more than 6,100 linear feet of stream channel destroyed. The primary motivation for reclamation at Rehoboth II was to control flooding along SR 345 and to control sediment loading for long-term flood mitigation in the stream channel. Efforts were also made to control AMD whenever possible, however early examination of the water chemistry indicated that Rehoboth II only contributed a small portion of the chemical loading with

major contributions from the Perry State Forest tributary and the upper reaches of the Rehoboth Creek. Therefore, only minor improvements to AMD were anticipated through this effort.

Chronological summary of activity at the Rehoboth mine site:

- 1917 Underground coal mining.
- 1938 Surface mining of No. 6 coal.
- 1951 Entire site has been surface-mined.
- 1958 Onsite mining ceased, began receiving regional mine waste.
- 1965 All activities ceased.
- 1971 Railroad demolished.
- 1971-1977 Rehoboth I – reclamation/ operator cost-share project consisted of a 5-acre area to establish detention embankments to aid in settling sediment.
- 1977 Sedimentation from the site has moved downstream toward New Lexington.
- 1980s Efforts were made by many companies to re-mine the refuse.
- 1993 field research conducted by both Burgess and Nipple, Limited of Columbus Ohio and Damariscotta, Clarion Pennsylvania led to the design plan produced by Bennett and Williams in 1995 to conduct Rehoboth II reclamation in three separate phases.
- 1997 Phase 1: The refuse pile was graded and capped (42 acres) with FGD (185,404 cubic yards) Conesville Power Plant, total reclamation area was 58 acres.
- 1999 Phase 2: Permanent wetland-type pools were established to keep deposits in place, creating pools totaling 31 acres. About 1,000 linear feet of stream channel and 1,375 linear feet of dikes were created.
- 2002 Phase 3: The coal stockpile was removed from the flood plain and relocated at higher elevation. Fine coal refuse (65 acres) was covered with a minimum of two acres of material. Total reclamation on this phase was 125 acres.

Figure 19. Three phases of reclamation delineated in the Rehoboth Mine Site Perry County, Ohio.



Water quality investigation of the Reboth area have been conducted by a number of entities; USGS in 2003 (Darner et al., 2005), ATC associates in 2001 (Jonard personal communications, 2009), and Ohio State University (OSU) in 2000 (Centeno et al., 2004). Similar sites were measured for field parameters in 2008 as part of this study (Table 11). Water quality conditions, even though still detrimental to the biological community, have been improving since Phase III reclamation.

Table 11. Field measurements at selected sites along flow path in Reboth, Ohio.

Field site	Parameter	ATC 2001 prior Phase 3	USGS 2003 post Phase 3	OU 2008 current conditions
RCRH700, 1003		Date 6/18/2002	Date 2003-2004	Date 2/15/2008
	pH	4.0	2.5-3.1	3.3
	Conductivity us/cm	1863	1950-2760	1620
RCRH715t, seep 3001	Temperature ^{oC}	21.29	23.3-28.4	2.1
		Date	Date 8/26/2003	Date 2/15/2008
	pH	NA	3.0	4.65
RCRH727t, seep 3007	Conductivity us/cm	NA	2970	3247
	Temperature ^{oC}	NA	25.9	9.9
		Date 6/18/2002	Date 8/29/2003	Date 2/15/2008
RCRH730, 3011	pH	3.1	3.2	5.66
	Conductivity us/cm	2820	3360	2276
	Temperature ^{oC}	29.67	22.3	1.1
RCRH730, 3011		Date 6/18/2002	Date 9/9/2003	Date 2/15/2008
	pH	2.8	2.8	3.48
	Conductivity us/cm	3110	2150	1860
RCRH745t, tile drain 3004	Temperature ^{oC}	29.83	24.1	3.7
		Date 6/18/2002	Date 8/27/2003	Date 2/15/2008
	pH	3.54	3.2	3.9
RCRH747t, pond 3005	Conductivity us/cm	3400	6360	3999
	Temperature ^{oC}	25.17	15.5	11.9
		Date 6/18/2002	Date 8/27/2003	Date 2/15/2008
RCRH747t, pond 3005	pH	2.60	2.3	3.55
	Conductivity us/cm	1390	3900	1980
	Temperature ^{oC}	32	25.9	3.5
RCRH755t, 3009		Date 6/18/02	Date 9/9/2003	Date 2/15/2008
	pH	3.14	3.6	3.68
	Conductivity us/cm	1320	1130	1289
	Temperature ^{oC}	31.72	20.6	3.2

In 2000, a study in fractionation of chemical elements including rare earth elements and radium was conducted in Upper Rush Creek and Reboth Creek by researchers from Ohio

State University (Centeno et al. 2004). The purpose of this study was to determine the chemical fractionation of REEs (rare earth elements) and other groups of elements with similar properties. Cations of different elements are sorbed selectively by Fe and Al hydroxide precipitates which form with increasing pH. Therefore, Rush Creek's low-energy environment and mine drainage affecting its streams and tributaries provided a favorable site for this research.

Water samples were collected for analyses along a 30 km stretch of Rush Creek. Water samples were filtered and analyzed by ICP-MS to track the sorption of trace metals and of the REE's. Sediment samples were also collected as well as pH of the water at the collection site.

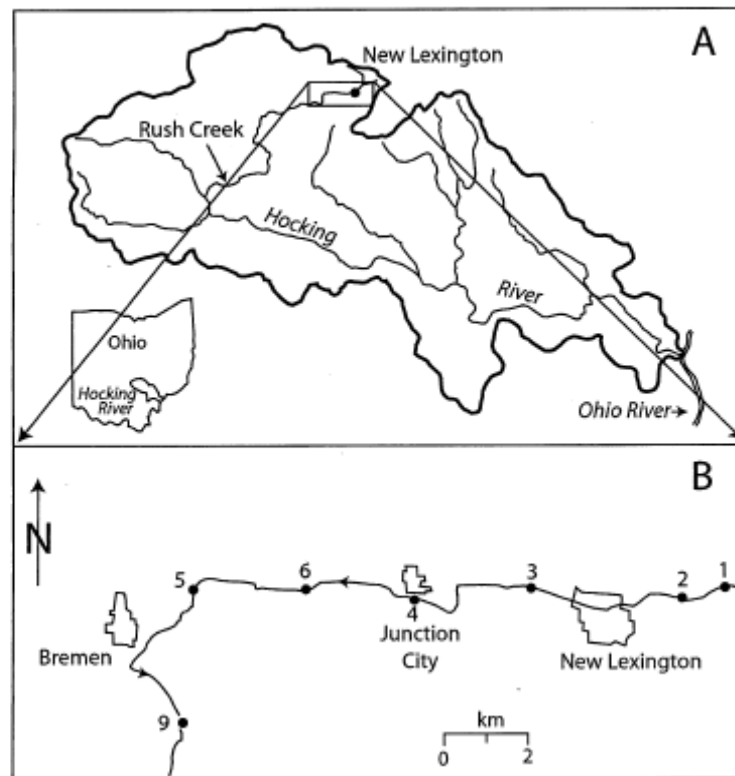
According to Centeno et al. 2004, the results from this study showed between sites one and two (Figure 20), acid mine drainage occurs resulting in a decrease in pH from 6.1 at site one to 2.5 at site two, and a gradual increase to pH 7.1 at site nine, 30 km downstream of site one. Calcium (Ca) rose by a factor of 16.8 between sites one and two, due to the mine drainage, and then decreases gradually downstream. Ca excess is removed by precipitation of gypsum. The concentrations of other major cations (Na, K, and Mg) also increase between site one and two and then decrease and remain constant downstream. Ratios of these elements also remain constant, Mg/Na, Ca/Na, and K/Na downstream. Na, Ca, and Mg remain constant even though their concentrations decrease downstream from site 3 which demonstrates that these elements are not significantly fractionated from the composition of the water or each other. "Fe, Al, and Mn decrease downstream in response to the pH control of the solubility of their hydroxides." The concentrations of Fe decrease from 18.9 mg/L at site two to 0.30 mg/L at site three. The concentration of Al remains constant at about 7.5 mg/L and then declines to less than 0.05 mg/L at site 6 about 18.5 miles downstream of site two. A constant relation between Mn and Na was found with an average Mn/Na ratio of 0.25+ or - 0.23 between site two to nine. Downstream, Fe, Al, and Mn are separated by the differences in solubility of their hydroxides. Results demonstrated that ferric hydroxide precipitates at pH < 3.2, Al precipitates out at pH of 3.2 and 5.9, and Mn stays in solution at a pH < 7.1 in Rush

Creek. Downstream of site 6 (pH 5.9) Fe and Al are not detectable but Mn remains in constant proportion to Na.

For the trace metals, results showed between sites two to nine, trace metals (Pb, Cu, Zn, Ni, Co) decrease as a result of sorption onto $\text{Fe}(\text{OH})_3$. Rare earth elements also decrease from site two to almost indistinguishable levels by site nine. As pH increases, sorption of their ions to $\text{Fe}(\text{OH})_3$ precipitates occurs. Lanthanum (La) and Cerium (Ce) are found at higher concentrations than all other REEs because they are sorbed less strongly by $\text{Fe}(\text{OH})_3$ and are retained in Rush Creek.

Figure 20. (A) Drainage basin of the Hocking River including Rush Creek and the town of New Lexington, Ohio. (B) Collecting sites of water samples along Rush Creek near New Lexington Ohio.

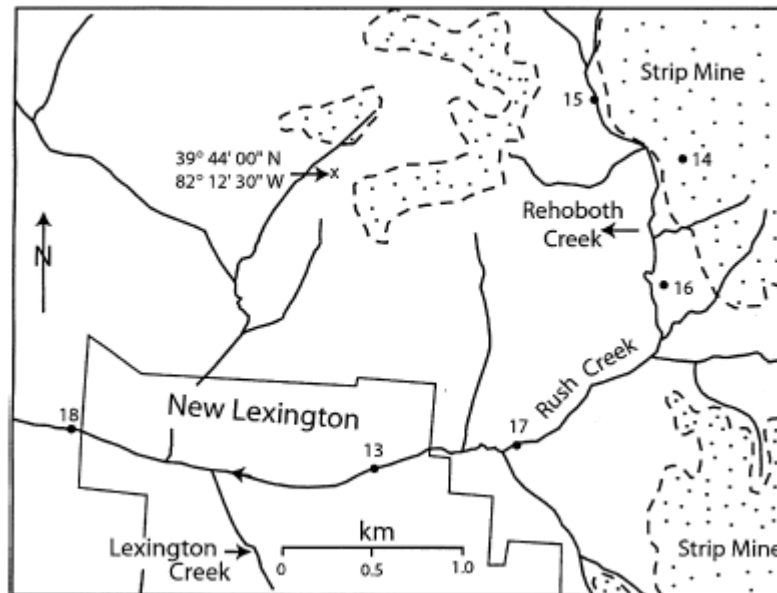
L.M. Centeno et al. | Applied Geochemistry 19 (2004) 1085–1095



²²⁶Radium was also found in Rush Creek and its sediments. Although the presence of Radium in coal-mine effluent has not yet been reported for Ohio, it is expected because the

Middle Pennsylvanian coal of southeastern Ohio contains on average 2.29 ppm U as determined neutron activation of whole coal by Botoman and Stith (1988). Peaks of ^{226}Ra can be found in Rush creek and in the tributaries that are affected by mine drainage. ^{226}Ra sorbs to the $\text{Fe}(\text{OH})_3$ and is therefore found in $\text{Fe}(\text{OH})_3$ precipitates. The sorption of ^{226}Ra is dependent on the pH resulting in fluctuations of ^{226}Ra of the $\text{Fe}(\text{OH})_3$ precipitates which rise initially and decrease downstream as the ^{226}Ra is removed from solution as pH increases. ^{226}Ra activities increase along Rehoboth Creek. Figure 21, shows site 15 (552 dpm/kg) increases its ^{226}Ra further downstream at site 16 (1813 dmp/kg). Site 17 and 13 show a decrease once Rehoboth Creek waters mix with mainstem Rush Creek, 1680 dpm/kg and 1070 dpm/kg, respectively. Further downstream on the mainstem after the confluence with Lexington Creek “Airport”, the ^{226}Ra activities rises to 1727 dpm/kg in response to the AMD contaminated water discharging into Rush Creek (Centeno, 2000).

Figure 21. Collecting sites of $\text{Fe}(\text{OH})_3$ precipitates along Rehoboth Creek and Rush Creek (Centeno et al., 2004).



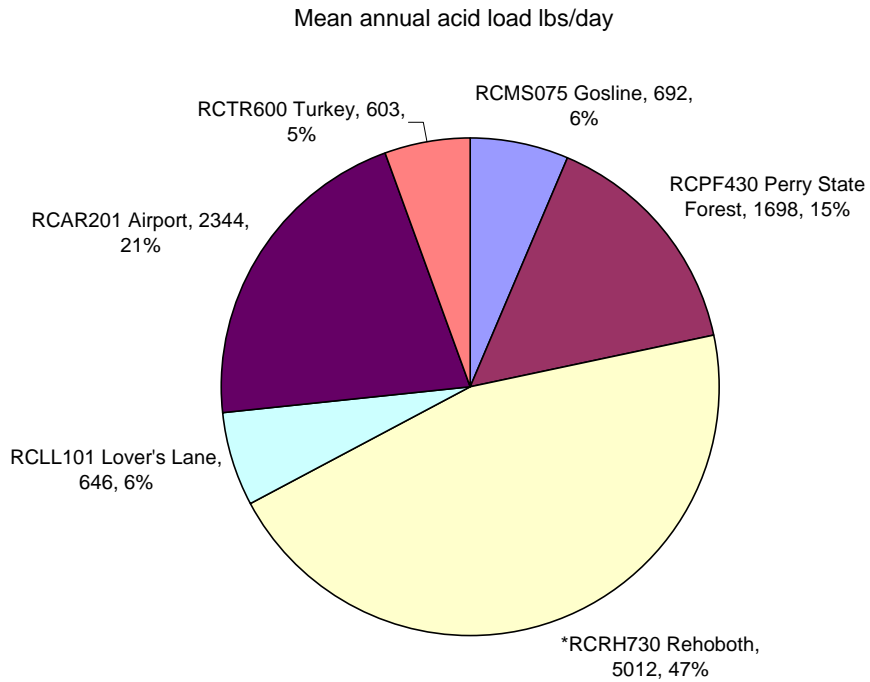
Sub-watershed description

Rehoboth subwatershed, as discussed previously, has been extensively surface mined and partially reclaimed. Two underground mines are mapped in the Rehoboth subwatershed: 1) PY-118, Wilburn Mine abandoned in 1923 mined the Lower Kittanning #6 coal and 2) PY-318, Whitmer Mine, abandoned in 1932 mined the Middle Kittanning #5 coal seam. Wilburn mine is located on the eastern boundary of Rehoboth subwatershed. Whitmer mine is a very small mine located centrally in the Rehoboth subwatershed (Map 6). The eastern boundary of the watershed is actively being mined by Oxford Mining Co. LLC permits D-1086, D-2254 & D-2318. The major AMD impacts found in the Rehoboth area are from the surface mine and washing activities occurring here through history as described previously.

Mass-balance analysis

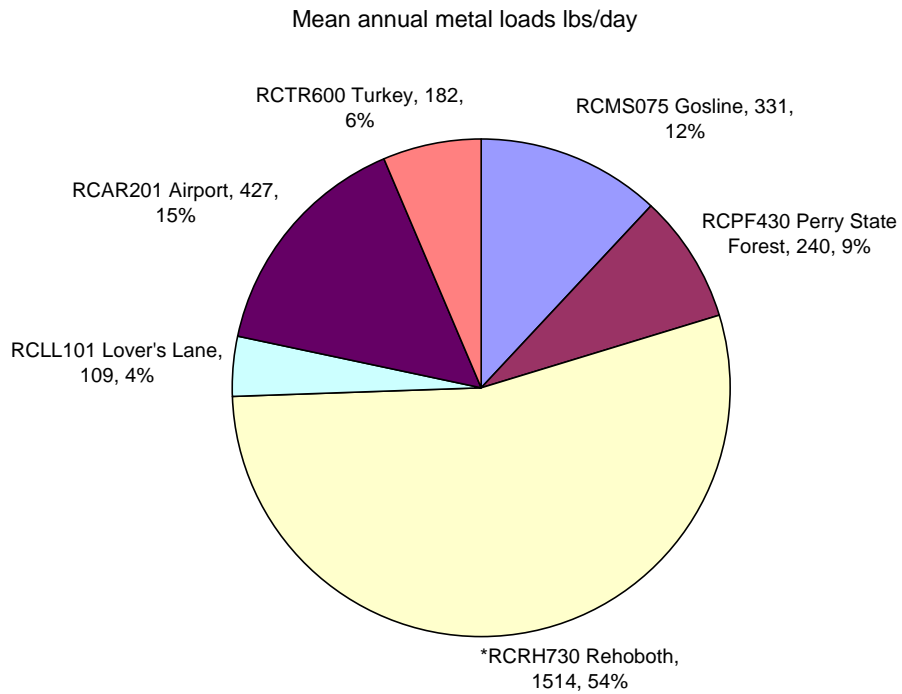
Rehoboth is the greatest contributor of acid (47%) and metals (54%) to the Upper Rush Creek watershed (Figure 22 & 23). Site RCRH730 is the three culverts site downstream the settling pond (USGS 3011). Any sources entering into Rehoboth mine area downstream of site RCRH730 are not included in Figures 22 and 23. Therefore, site RCRH699 was established later in the project at the mouth of Rehoboth, to have a representative sample of all AMD contributions in the watershed. It was sampled once on 7/31/2008 (Appendix 2).

Figure 22. Mean annual acid loads from key subwatersheds in Rush Creek.



* low flow sample was measured by USGS in 2003, high flow recorded in 2008.

Figure 23. Mean annual metal loads from key sub-watersheds in Rush Creek.



* low flow sample was measured by USGS in 2003, high flow recorded in 2008.

Source Identification

Source identification was not conducted in this basin as part of this AMDAT plan. For purposes of quantifying the mean annual acid and metal loadings from the Rehoboth area, site RCRH730 was used in the mean annual load calculation (Stoertz, 2004). Mean annual average acid and metal loads at the RCRH730 in Rehoboth are 5012 and 1514 lbs/day, respectively (Figure 24 & 25).

Figure 24. Mean annual acid load, site RCRH730 in Rehoboth sub-watershed.

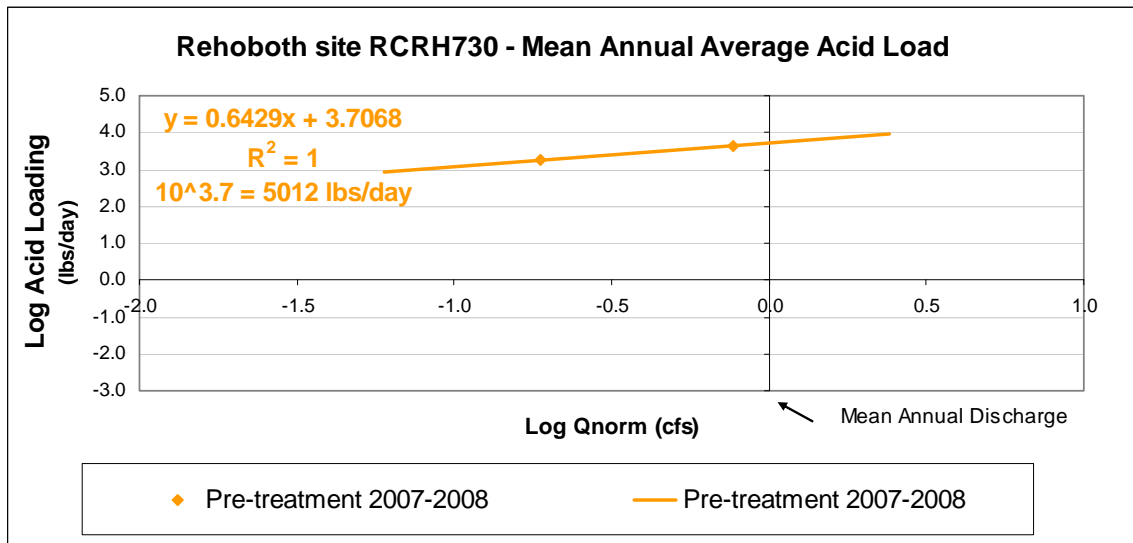
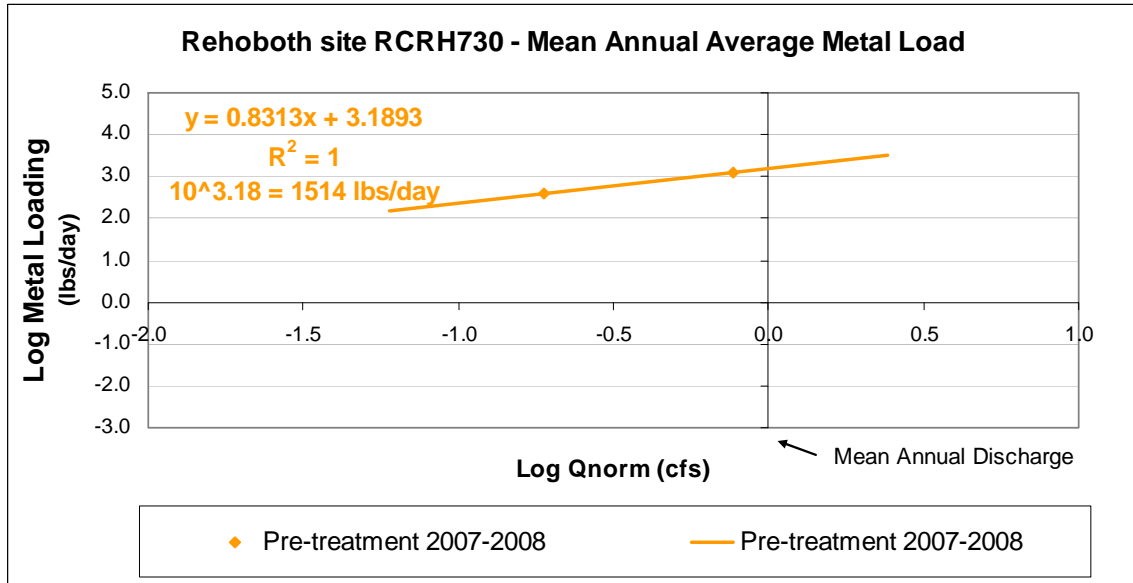


Figure 25. Mean annual metal load, site RCRH730, in the Rehoboth sub-watershed.



Recommendations for further study

It is recommended to sample RCRH699 along with RCRH730 to characterize the sources of AMD between these two sites (Appendix 2 water quality data). Rehoboth continues to be the largest contributor of acidity and metals in the Rush Creek watershed. Previous reclamation efforts were successful at controlling flooding and erosion issues. However, further investigations are needed to focus possible treatment options on AMD treatment which would reduce acidity and metal loads.

- First, upon completion of current mining by Oxford Mining Company, the headwaters and surrounding area of Rehoboth will be investigated to document possible recharge zones (i.e. strip pits, impoundments, ponds, etc...) to the spoil, buried coal fines, and rich mineral substrates further downstream. Eliminating or reducing the recharge through the mine area would reduce the amount of treatment that is needed. A similar restoration strategy was applied to the Flint Run project in Little Raccoon Creek in Jackson County, Ohio.
- Second, existing flood control and sediment ponds could be batch treated with an alkaline material to provide needed buffering capacity along the stream channel.

2.4 Perry State Forest

Sub-watershed description

Location: Perry State Forest, unnamed tributary to Rehoboth Creek at river mile 1.2.

Drainage area: 2.13 square miles

USGS quadrangle: New Lexington and Fultonham **Map: #7**

Percent acid and metal load to Rush Creek (Appendix 6): Acid 64% and Metal 50%

Perry State Forest is an unnamed tributary that flows into Rehoboth Creek from the west at river mile 1.2, in the town of Rehoboth. Perry State Forest is primarily forested state land with few inhabitants. The majority of the area has been strip mined for coal with few underground deep mines. Many remnant strip pits wiggle through the landscape following the contour of the coal crop. The state acquired the area in 1961. One underground mine, PY-305, Teal Mine was abandoned in 1921 and mined the Lower Kittanning #5. It is located near the mouth of the tributary (Map 7).

Mass-balance analysis

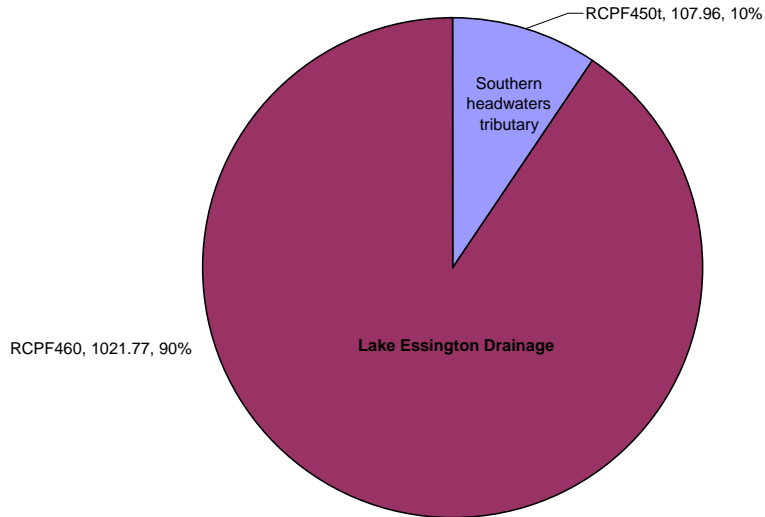
Two headwater tributaries were sampled as part of the mass-balance analysis of water quality data in Perry State Forest sub-basin. Comparing these two sites to each other clearly shows Lake Essington tributary is the higher contributor of acid loads (Figure 26). Similar results were calculated for metal loading, Lake Essington tributary contributed 82% of the metal loads compared to only 18% from the southern headwaters tributary.



Source area draining into Lake Essington, RCPF480t

Figure 26. Average net acid loads from two headwaters tributaries in Perry State Forest

Perry State Forest Tributaries Average Net Acid Load lbs/day (n=3)



Analyzing the acidity values and discharge values along the flow path within the Perry State Forest sub-basin reveals concentrations of acidity are higher at lower flows (fall 2007). Of the two headwater source areas, Lake Essington (RCPF460) and the southern tributary (RCPF450t), Lake Essington has a higher concentrations of acidity during higher flow (spring 2008), while the southern headwaters tributary (RCPF450t) contains higher acidity concentrations during lower flows. Regardless of the acidity concentrations, Lake Essington contributes the highest loading of acid to Perry State Forest throughout the year.

Figure 27. High flow water quality data collected in Perry State Forest (Spring 2008).

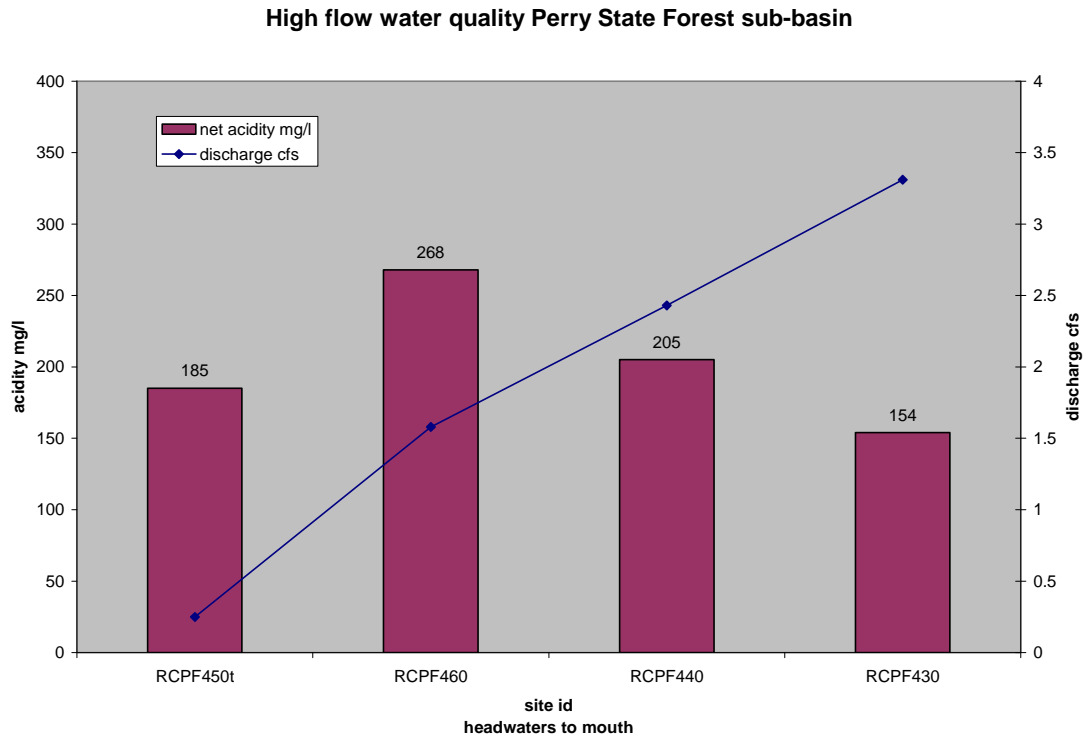
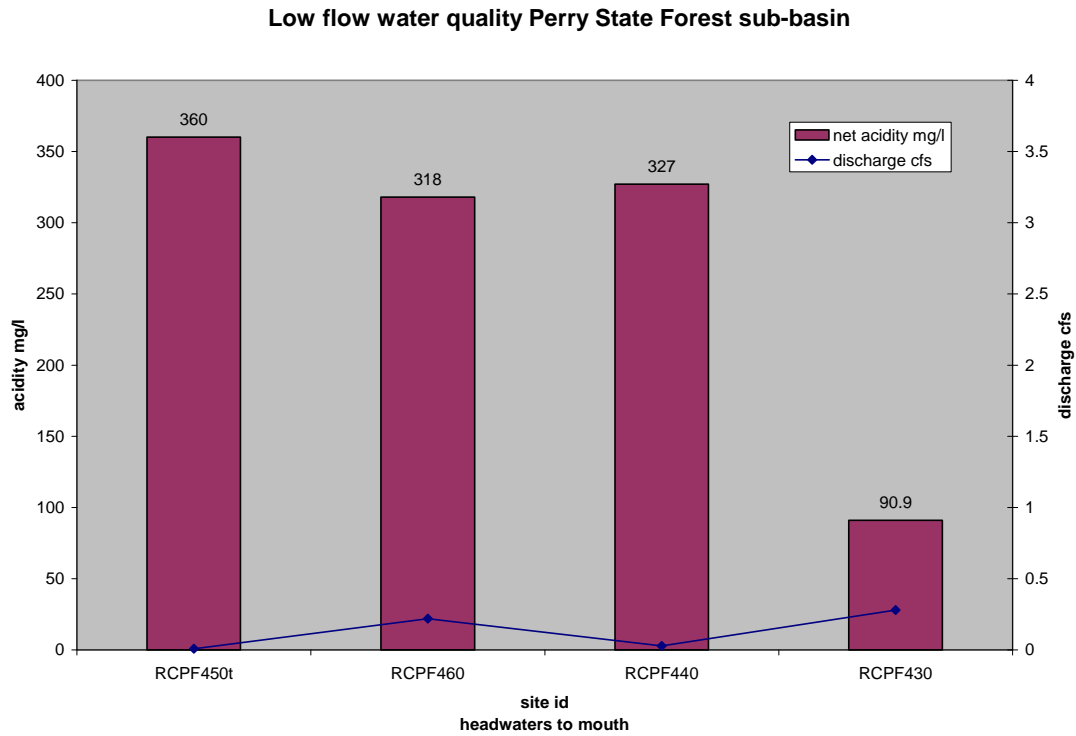


Figure 28. Low flow water quality data collected in Perry State Forest (Fall 2007)



Source Identification

Source identification was not conducted in this basin as part of this AMDAT plan. For purposes of quantifying the mean annual acid and metal loadings from the Perry State Forest sub-basin, site RCPF430 (the mouth of Perry State Forest) was used in the mean annual load calculation (Stoertz, 2004). Mean annual average acid and metal loads at the RCPF430 site are 1698 and 240 lbs/day, respectively (Figure 29 and 30).

Figure 29. Mean annual acid load at site RCPF430 in Perry State Forest sub-basin

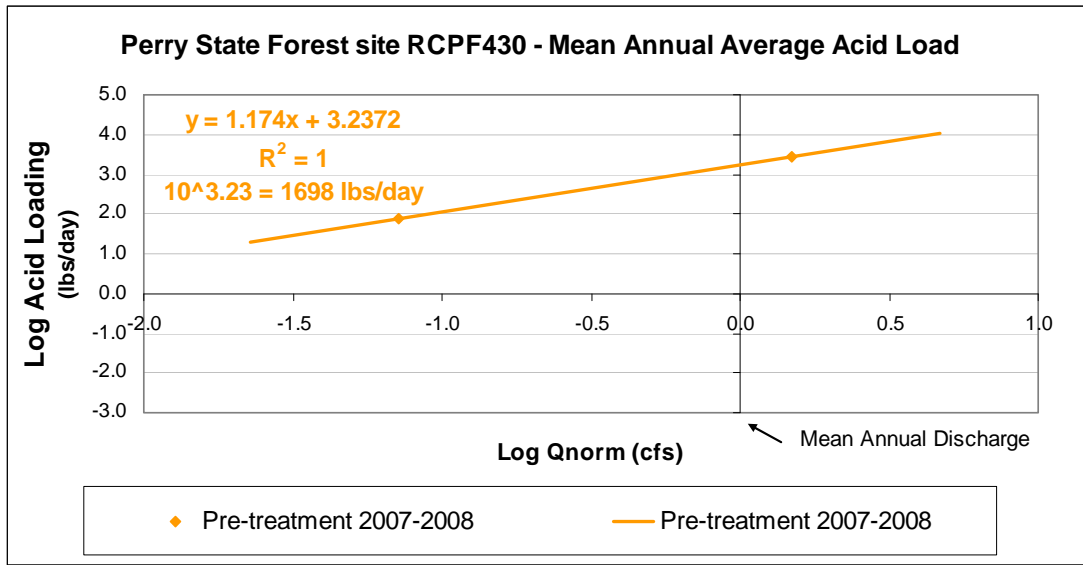
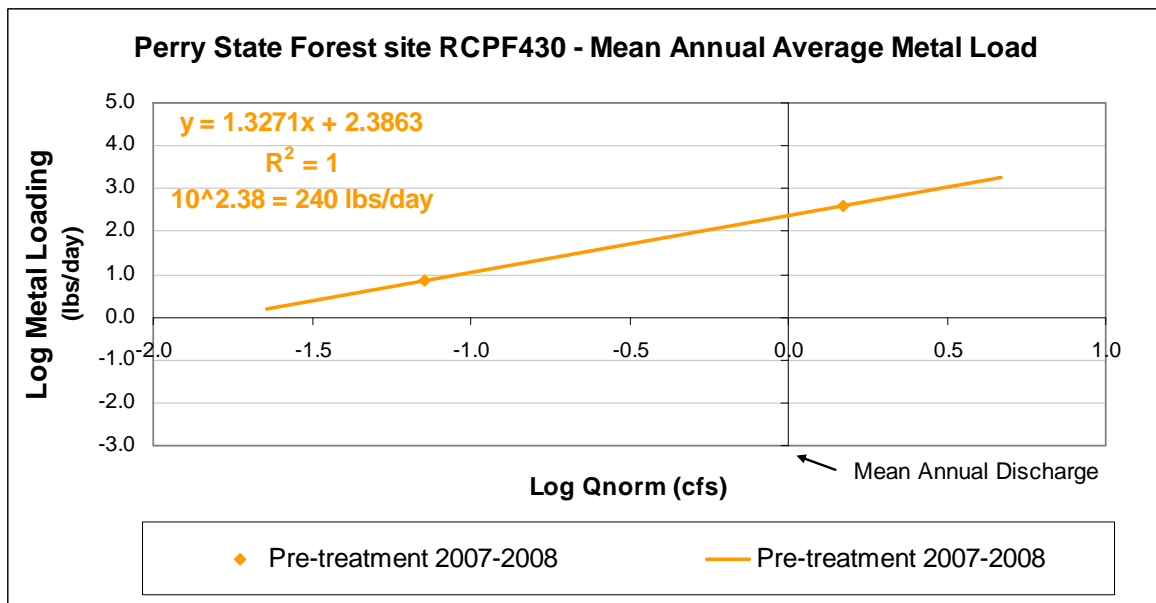


Figure 30. Mean annual metal load at site RCPF430 in Perry State Forest sub-basin



Recommendations for further study

Further water quality investigations in this area are recommended to identify areas of clean water for remediation with steel slag beds. In addition, many strip pits are found in the headwaters to Lake Essington. Investigation of these strip pits are recommended to determine the hydrologic connection through the overburden and spoil surrounding the lake.

2.5 Airport

Sub-watershed description

Location: Airport, an unnamed tributary, drains to Upper Rush Creek at river mile 28.6

Drainage area: 2.43 square miles

USGS quadrangle: New Lexington

Map: #8

Percent acid and metal load to Rush Creek (Appendix 6): Acid 55% and Metal 64%

Airport is an unnamed tributary (the National Hydrography Dataset (NHD) names this stream Oxawoosie Creek) to Upper Rush Creek. The mouth of the watershed flows through New Lexington proper and the headwaters originate in rural rolling grassy hills and forested areas (Map 8). Airport sub-basin is impacted from both abandoned surface mines and deep mines. Four underground deep mines consist in this sub-basin, two likely discharge into Airport while the other two likely discharge into the Moxahala Watershed (Table 12).

Table 12. Abandoned underground mine information for Airport sub-basin

Common name sub-watershed	Mine name	Mine number	Coal	Mine elevation	Abandonment date	Discharging to:
Airport (headwaters)	Lexington	PY-257	Unidentified		1927	To airport
Airport (headwaters)	Lexi	PY-269	Middle Kittanning #6	925	1948	To airport
Airport (headwaters)	Sunnyhill #2	PY-332	Middle Kittanning #6	956	1969	To Moxahala
Airport (headwaters)	Sunnyhill #1	PY-159	Middle Kittanning #6		1966	To Moxahala

A senior thesis titled “Geochemistry of an acid-contaminated stream in New Lexington, Ohio” was written by Linda Centeno in 2000 under Dr. Faure at Ohio State University. The senior thesis consisted of collecting water and sediment samples from the tributary referred to Lexington Creek (Airport Run). Laboratory analyses were performed to provide pH, suspended sediments, alkali metals, alkaline earth, and trace element values. Centeno also estimated percent composition of the source water: ground water, meteoric water, and mine

effluent. Ground water made up 65%, meteoric water 9.6%, and acid mine drainage was 25% at the highest level located at the confluence of Lexington and Rush Creeks.

Sampling stations were established along Lexington Creek and upstream and downstream on Rush Creek (Figure 31). At site three, AMD increases from 9% to 25% at site two and then remains at 20-25 % (Figure 32). Centeno found that the pH of the water to be as low as 2.6 in Lexington and Rush Creek. At Lexington Creek pH decreases from 5.8 at site three to 3.8 at site two. Centeno found the pH to vary from 3.3-4.2 downstream and the pH of Rush creek to have a pH of 3.0-3.2. Tributaries six and eleven have a neutral pH and it was evident that they were not affected by mining. Tributary seven had a pH of 3.9, marked as a source of acid mine drainage. Aluminum (Al) had a relatively low concentration in the headwaters but rose at site three and then remained constant. At tributary seven Al was measured at 40.9 mg/l and Fe at 35.0 mg/l. The highest concentration of Mn was at 44.8 mg/l. The sediment load of Lexington creek increased downstream from 67.6 mg/l at site three to 177.6 mg/l at site one and then decreased to 83.2 mg/l at site nine. It was estimated that tributaries five, six, and eleven, being low in discharge, have no effect on sediment load for Lexington Creek (Centeno, 2000).

Centeno concludes that water in New Lexington Creek is acidic and enriched in sediment and trace metals, producing water that is 25% acid-mine drainage. She concludes that abundant metal ions sorb to the sediment and these toxic metal ions can be released back into the water as pH rises.

Figure 31. Map of sampling stations (1-12) in Lexington Creek (Airport) and Rush Creek (Centeno, 2000).

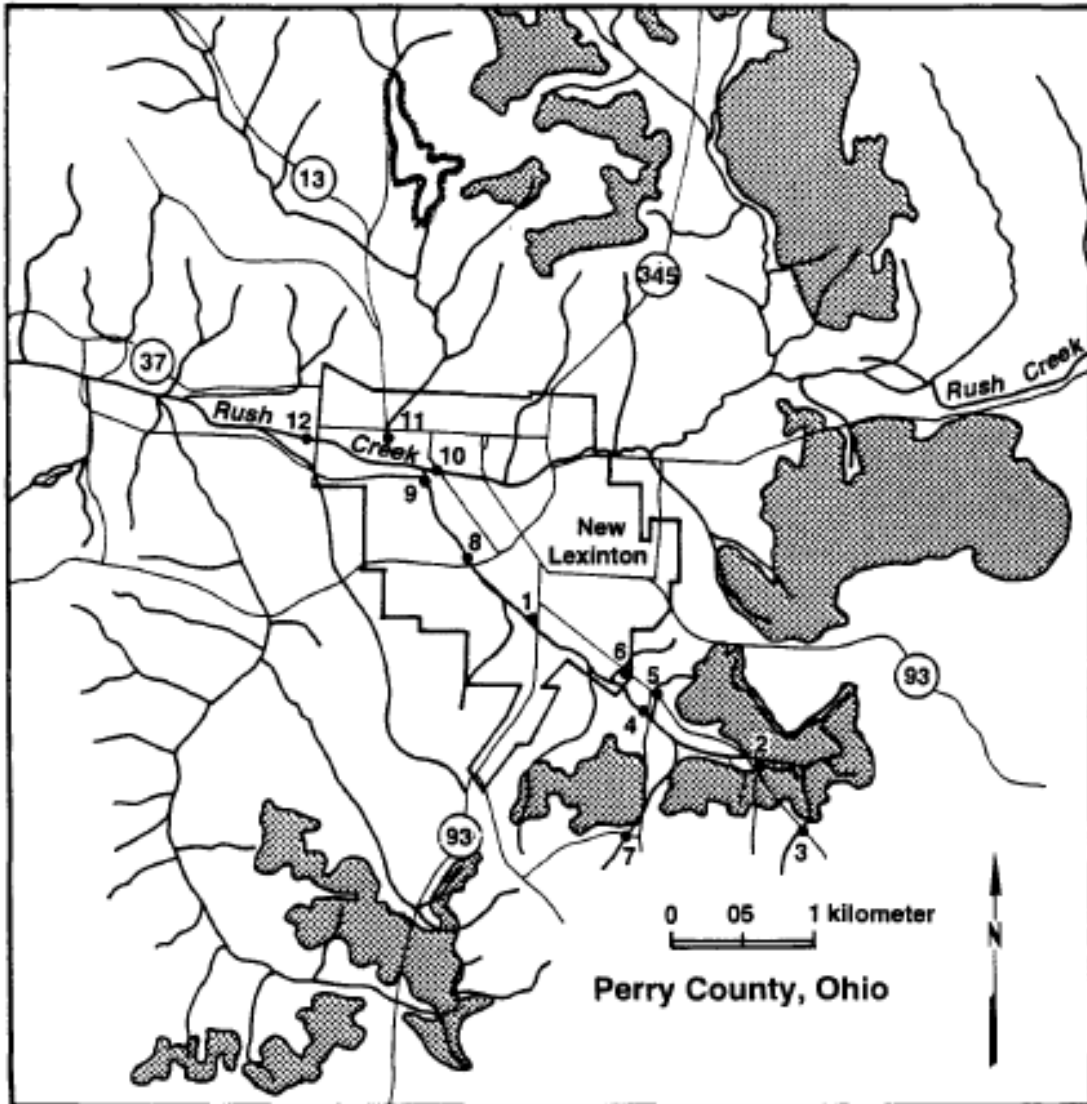
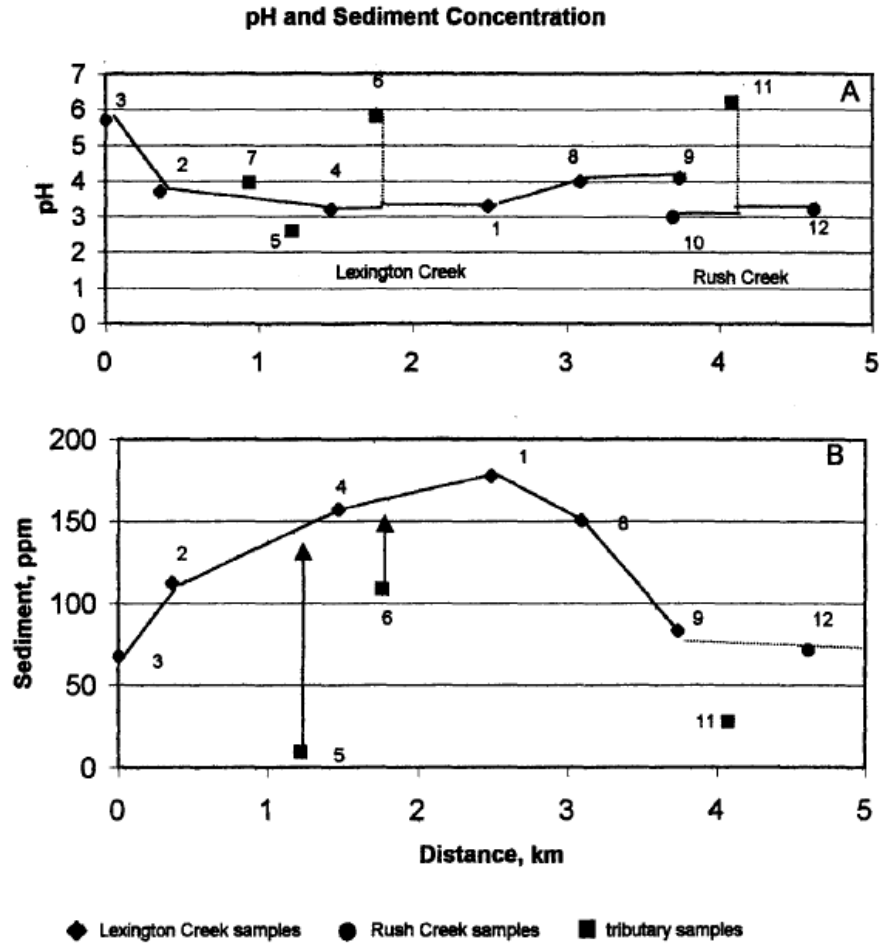


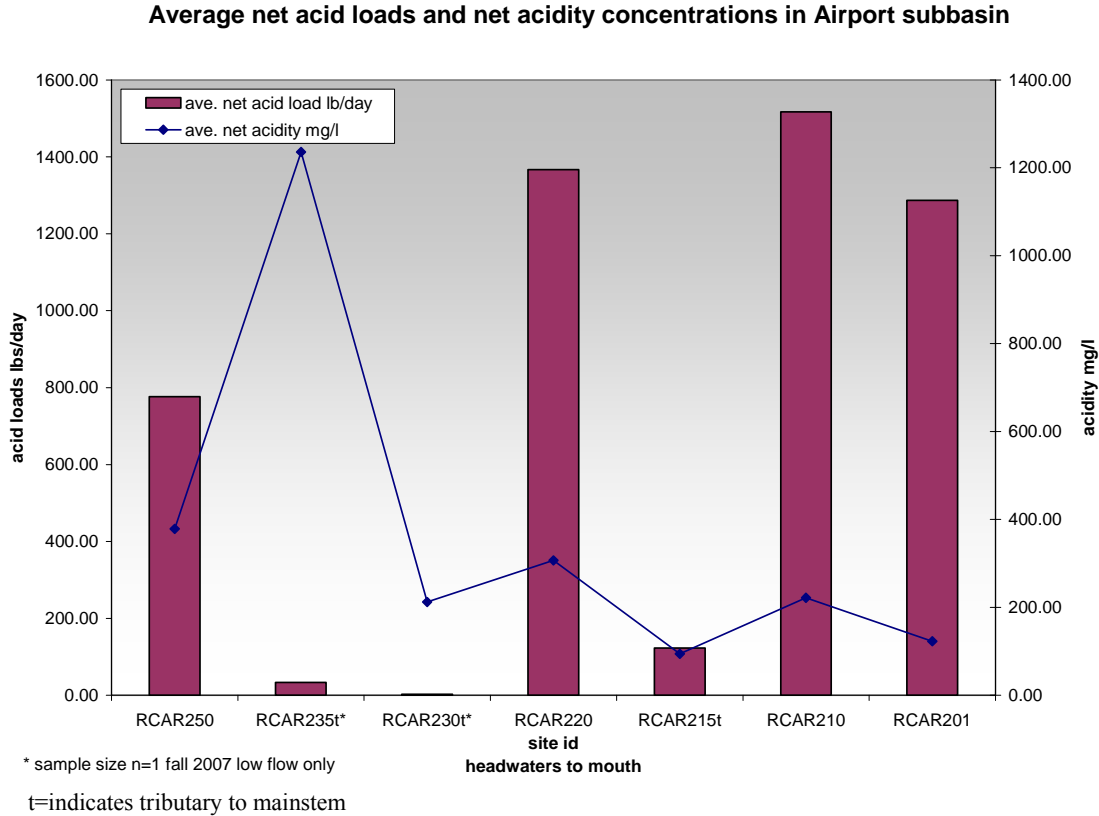
Figure 32. (A) pH vs. distance downstream of Lexington Creek and Rush Creek, pH = 5.8 at the head of the creek and drops to 2.6 after flowing through the abandoned mine area. (B) Sediment load vs. distance downstream. Sample 7 and 10 are not included due to intentional collecting of excess sediment (Centeno, 2000).



Mass-balance analysis

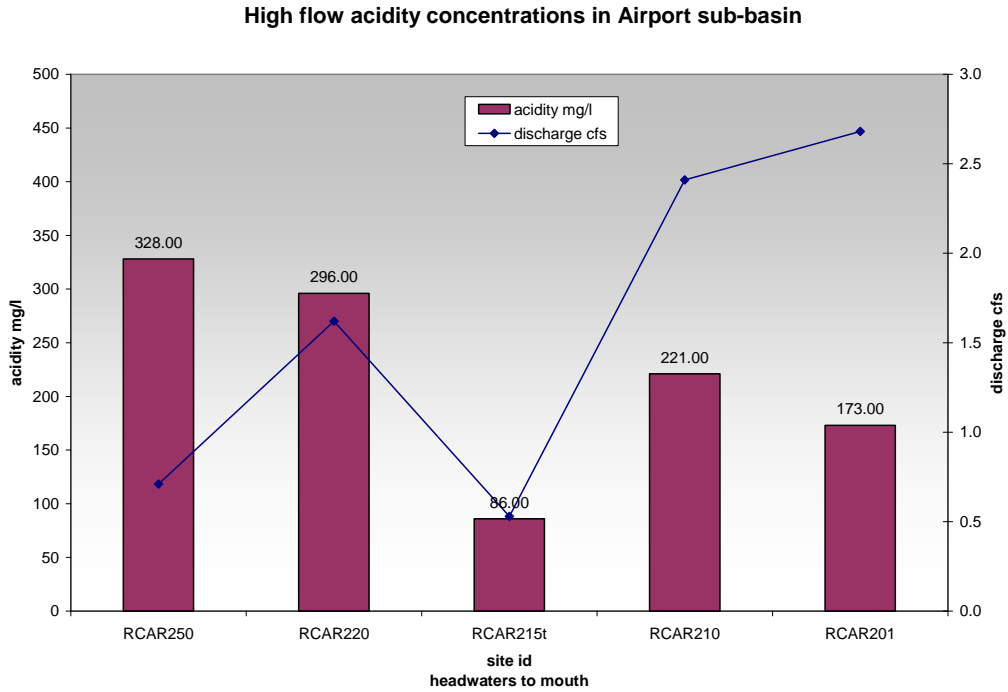
Four mainstem sites and three tributaries were measured during both low flow (fall 2007) and high flow (spring 2008) regimes as part of the mass-balance analysis of water quality data in Airport sub-basin. Figure 33 shows average acid loads and acidity concentrations along the flowpath in Airport (site id followed by a “t” represents a tributary site).

Figure 33. Average net acid loads and net acidity concentrations along the flowpath in Airport.



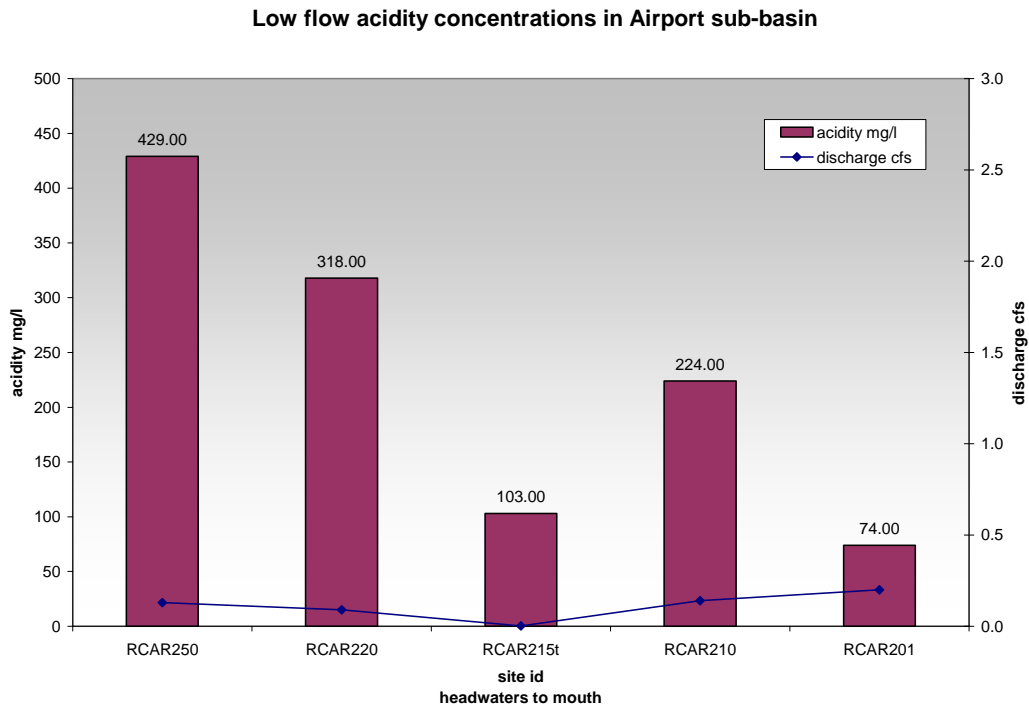
Analyzing the average acid loads along the flow-path in Airport shows a steady increase in loads and decrease in acidity concentrations moving downstream. Moving downstream the acid loading continues to increase as a function of the flow while the acidity concentration decreases. Concentrations of acidity measured at sites in the Airport sub-basin are all higher during the low flow sampling in fall of 2007 than during high flow except for the mouth of Airport (RCAR201). The mouth of Airport had a higher acidity concentration during the high flow sampling in the spring of 2008. One hypothesis to explain this is at higher flow conditions the AMD sources in the headwaters of Airport transport acidity and metals further downstream given the increase in flow. During low flow conditions the AMD originating in the headwaters of Airport remains closer to their sources and precipitate metals higher up in the sub-watershed. The pH values support this theory, during low flow pH=5.7 while at high flow pH=3.73 at site RCAR201. Indicating the metals and acidity are precipitating before reaching the mouth of Airport during low flow regimes (Figures 34 & 35).

Figure 34. Acidity concentrations during high flow (spring 2008) in Airport



t= indicates tributary to mainstem

Figure 35. Acidity concentrations during low flow (fall 2007) in Airport



t= indicates tributary to mainstem

Source Identification

Source identification was not conducted in this basin as part of this AMDAT plan. For purposes of quantifying the mean annual acid and metal loadings in Airport sub-basin, site RCAR201 (mouth of Airport) was used in the mean annual load calculation (Stoertz, 2004). Mean annual average acid and metal load at the mouth of Airport are 2,344 and 427 lbs/day, respectively (Figures 36 & 37).

Figure 36. Mean annual acid load at site RCAR201 in Airport sub-basin

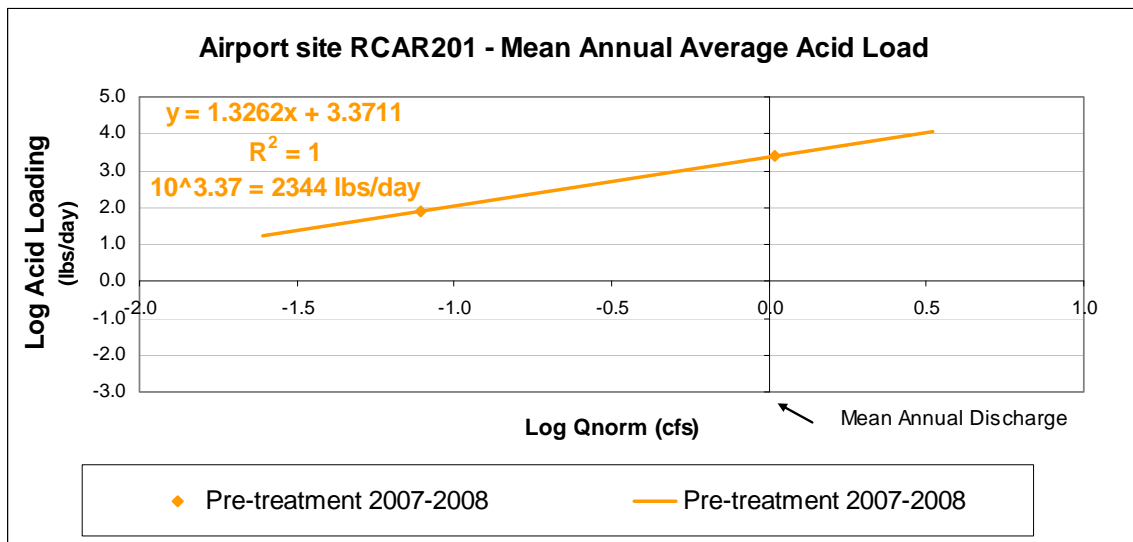
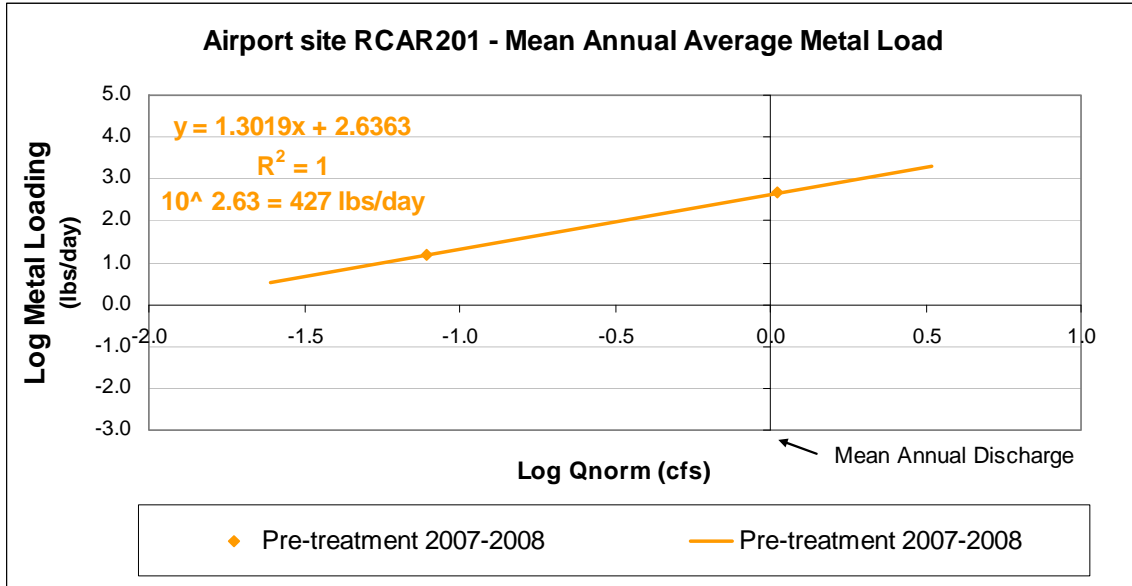


Figure 37. Mean annual metal load at site RCAR201 in Airport sub-basin



Recommendations for further study

Being the second highest contributor of acid and metals to Rush Creek, further water quality investigations in this area are recommended to identify sources of AMD in the headwaters of RCAR250 and tributary site #7 (Figure 31). From the Centeno study discussed earlier a source of AMD was documented entering tributary #7. Also investigate site # 6 for potential good water source for remediation utilizing a steel slag bed. In 2000, the Centeno study recorded a pH of just below 6.0 at site #6 (Figure 32).

2.6 Turkey Run

Sub-watershed description

Location: Turkey Run flows into Rush Creek at river mile 24.37

Drainage area: 5.47 square miles

USGS quadrangle: New Lexington and Junction City

Map #: 9

Percent acid and metal load to Rush Creek (Appendix 6): Acid 24% and Metal 27%

Turkey Run, one of the larger named tributaries in Upper Rush Creek enters the mainstem at river mile 24.37 upstream of Junction City. Surface mines are located in the headwaters and western side of the watershed. There are a four mapped underground mines in the headwaters of Turkey Run (Table 13). However, only one underground mine is documented as discharging to Turkey Run, Mine E & F (site RCTR688t) (Map – 9). It was abandoned in 1960 and mined the Lower Kittanning #5 coal seam.

The surface mines on the western side of the basin were reclaimed by ODNR-DMRM in the 1980's. According to ESPA consulting engineers (1983), the area consisted of approximately 135 acres of unreclaimed strip mines. The coal layer mined was the Middle Kittanning #6. The majority of the area was unvegetated with only sparse grass and few isolated trees. There were approximately 8,000 feet of exposed unprotected highwalls (35-90 ft), 1:1 steep slopes on spoil piles, exposed toxic materials, and pit impoundments. Skelly and Loy, Engineers and Consultants of Columbus, Ohio prepared a Watershed Feasibility Study for Mine Reclamation in the Rush Creek Watershed. This report, prepared for the Ohio Department of Natural Resources, states that "...the Dry Run and Turkey Run Watersheds contribute over 7,000 lbs/day of acid to the Rush Creek Watershed yet represent less than 5% of the total land area. Further investigation strongly suggests that this entire acid load is generated from one 200 acre unreclaimed strip mine." If the above statement is true, the reclamation activities conducted in the 1980's (ESPA, 1983) have been successful at reducing acid loads to Rush Creek from Turkey Run. Mean annual load calculations suggests only 600 lbs/day enter Rush Creek Watershed from the Turkey Run sub-basin today.

Table 13. Documented underground mines in the Turkey Run basin (ODNR underground mine locator add source here).

Common name sub-watershed	Mine name	Mine number	Coal	Mine elevation	Abandonment date	Discharging to:
Turkey Run	E & F	PY-158	Lower Kittanning #5	930	1960	Headwaters of Turkey Run
Turkey Run	Pike	PY-126	Middle Kittanning #6	950	1934	Possible undocumented connection to E & F
Turkey Run	Sunnyhill #2	PY-332	Middle Kittanning #6	956	1969	Moxahala Watershed
Turkey Run	Sunnyhill #3	PY-334	Middle Kittanning #6	940	1971	Moxahala Watershed

Mass-balance analysis

High and low flow data collected along the flow path in Turkey Run indicate net alkaline conditions in the headwaters with increases in acid load further downstream during high flow, while low flow regimes show slightly net acidic conditions between river mile 3.5 and 2.2 with net alkaline conditions downstream to the mouth (Figure 38 and 39). Mass-balance analysis of the source areas in Turkey Run shows three main contributors of acid loads (Figure 40); RCTR650t (36%), RCTR685t/688t (31%), and RCTR615t (29%). Sites RCTR615t and RCTR650t are both tributaries that drain from the 1980’s reclaim area entering Turkey Run at river mile 1.20 and 2.12, respectively. RCTR685t/688t located in the headwaters (river mile 3.1) drains a strip pit impoundment. The strip pit is located at the intersection of the surface mine area and underground mine E & F. The strip pit drains to the headwaters of Turkey Run at two separate locations: river mile 3.6 (RCTR685t) and 3.72 (RCTR688t). Site RCTR685t is the lower or main discharge point of the two. Mainstem site, RCTR670, marks the site in Turkey Run where net acid loads are the highest during both high and low flow events.

Figure 38. Net acidity and acid loads along Turkey Run during low flow

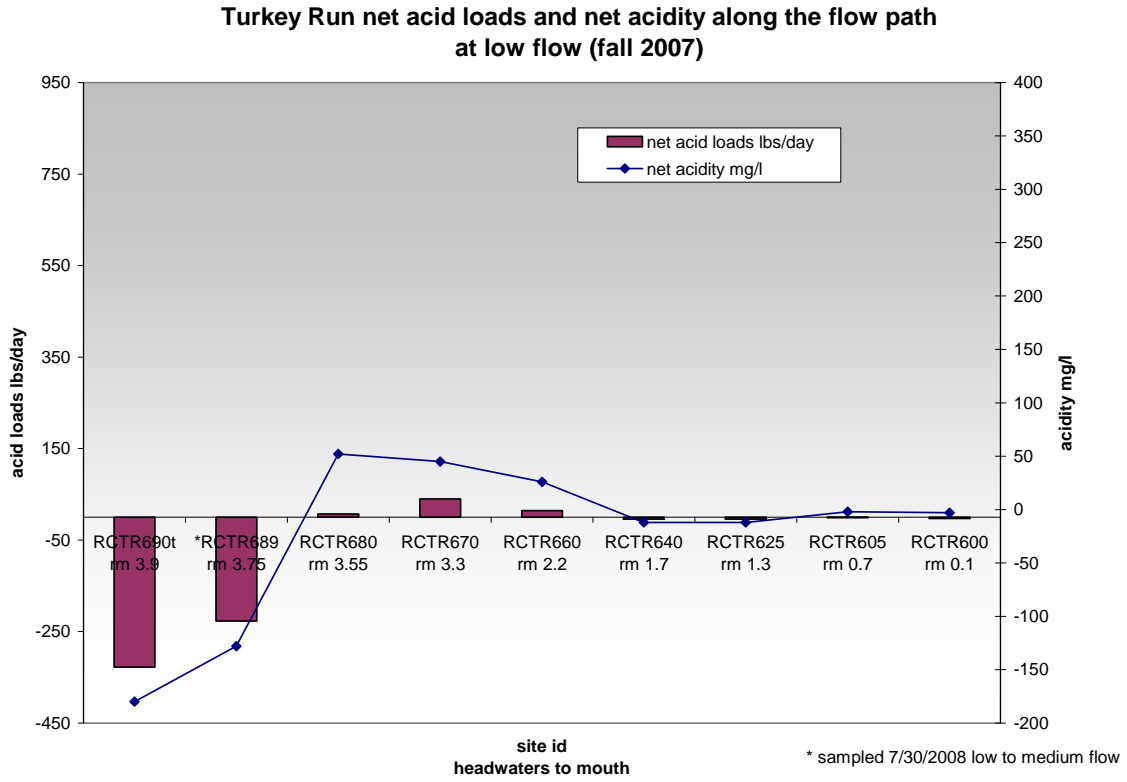
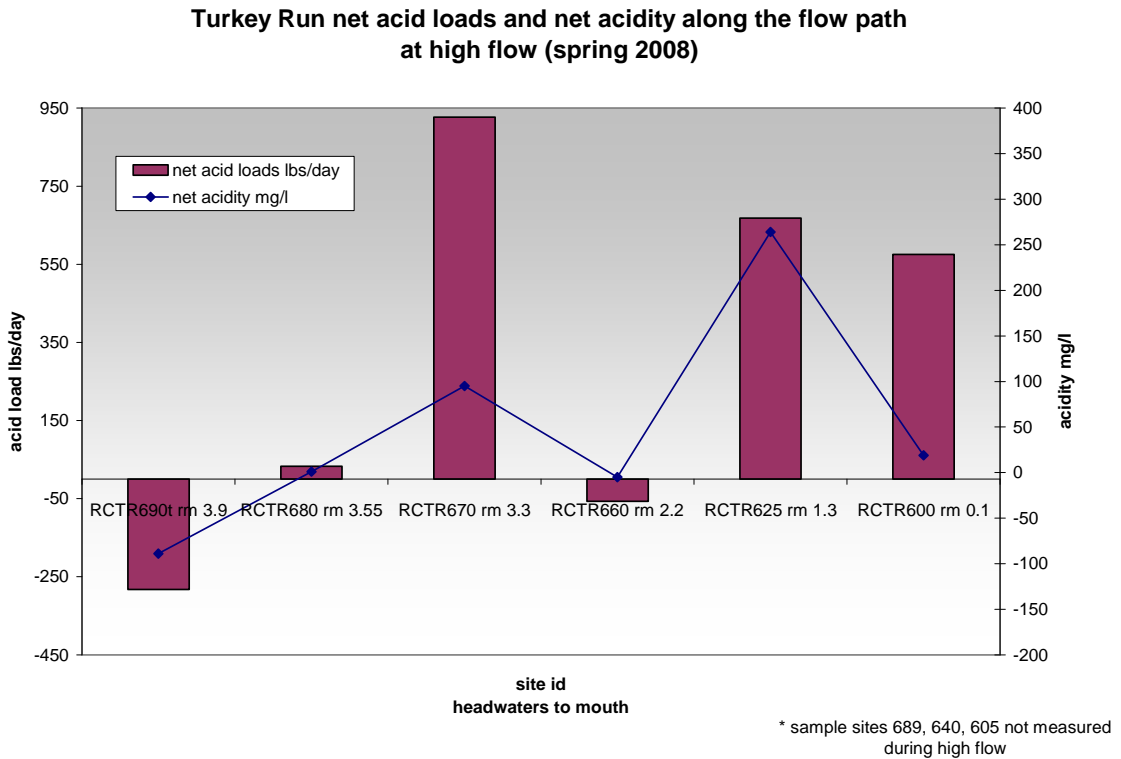


Figure 39. Net acidity and acid loads along Turkey Run during high flow



Source Identification

Specific sources were identified and sampled in the Turkey Run basin (Figure 40 and 41). When comparing water quality of sources identified in Turkey Run to each other, RCTR650t is the highest contributor of both acid and metal loads (36% and 37%, respectively) (Figure 40 and 41). Table 14 shows the high, low, and average net acidity and metal loads from each of the sources measured in Turkey Run. All sources identified exhibit higher concentrations of acidity and metals during lower flow regimes. However, the impact to the receiving stream is higher during high flow.

Figure 40. Mass-balance of average net acid loads at source areas within Turkey Run

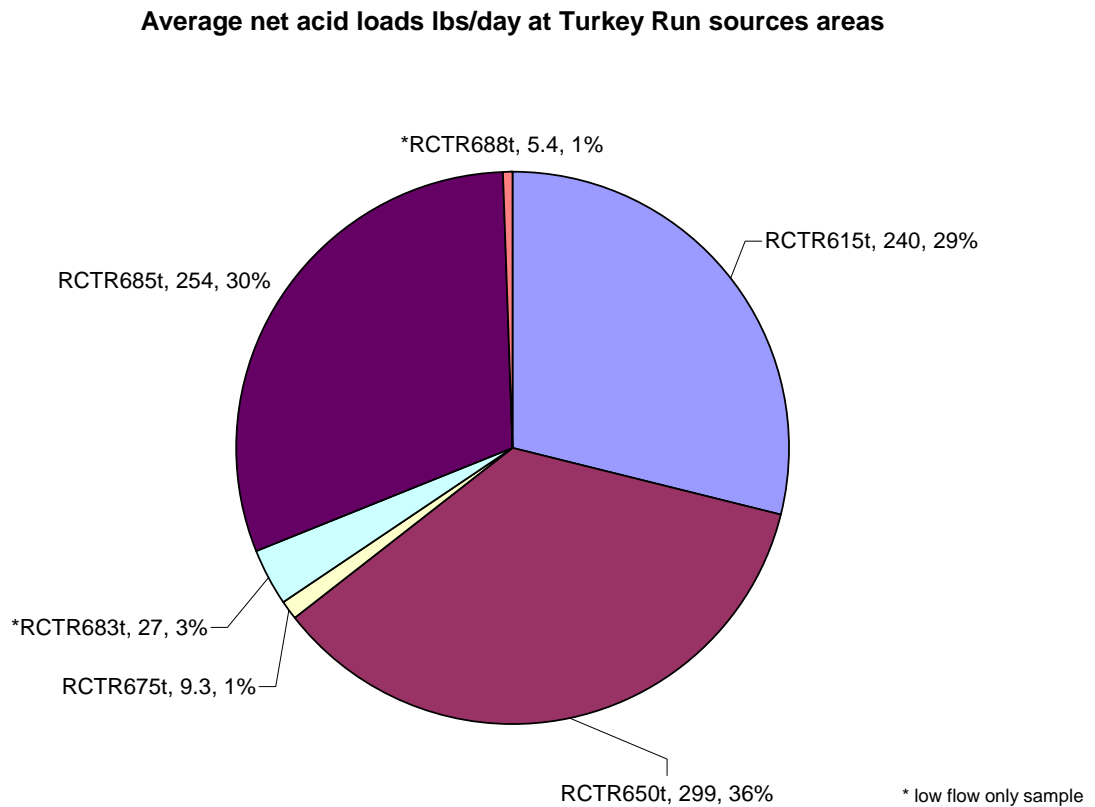


Figure 41. Mass-balance of average total metal loads at source areas within Turkey Run

Average total metal loads lbs/day from Turkey Run source areas

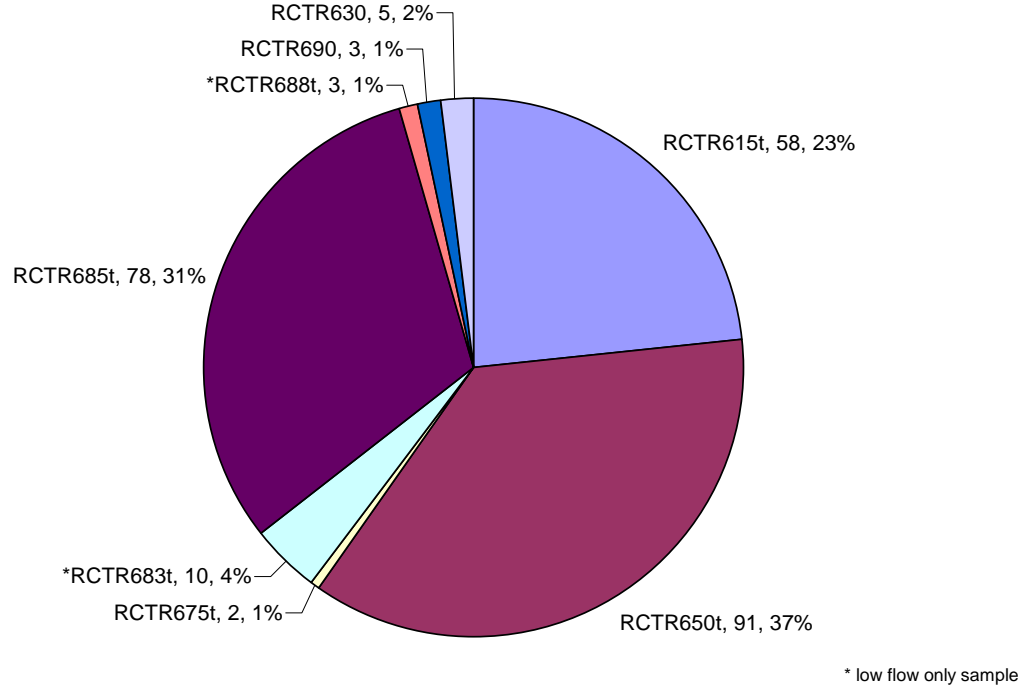


Table 14. High flow (spring 2008), low fall (fall 2007), average net acidity and metal concentrations of the sources measured in the Turkey Run.

Site ID	Net acidity concentrations mg/L			Metal concentrations (Fe, Al, and Mn) mg/L		
	High	Low	Average	High	Low	Average
RCTR650t	153	167*	160	39	51*	45
RCTR685t	135	223	179	42	56	49
RCTR688t		34 (7/30/08)			15 (7/30/08)	
RCTR683t		50 (7/30/08)			18 (7/30/08)	
RCTR675t	42	52	47	8	11	10
RCTR615t	338	526*	432	76	138*	107

* sampled on 1/24/2008 during medium flow regime.

Source descriptions:

RCTR650t: This site is a small tributary to Turkey Run that is influenced by abundant surface mining in the headwaters. At the margin of the 1980's reclamation, upwelling of AMD exists at the head of the hollow. Graded bedding indicates normal sediment transport, but water quality indicates influences from acid mine drainage leaching from the headwater

interface. It is characterized by a heavily vegetated, well-defined riparian zone. Some recent excavation to install a municipal water main has disturbed the area with little impact to water quality.

RCTR685t (main outlet) and 688t (secondary outlet): Field measurements and samples were collected at the outlet of a large strip pit just above a large beaver dam. The lake appeared rich in suspended iron load which was heavily encrusted on woody debris within the dam. The lake seems highly coupled with an underground source as the water level does not appear to fluctuate significantly during high and low flow periods.

RCTR683t: This tributary was sampled at the exit of two narrow, parallel strip pits. The stream has a braided morphology caused by above normal fine sediment and chemical load. It seems coupled with an unmapped underground AMD source, but is influenced by surface run-off. A seemingly inactive underground seep is located downstream of the sample point.

RCTR675t: This small tributary was sampled just before entering Turkey Run. The stream drains a complex of adjoining strip pits with multiple beaver impoundments and steep slopes. The mining activity here has altered the original headwater confinement by pirating drainage from an adjacent stream. The pirated stream channel has been filled-in during reclamation just upstream of RCTR681.

RCTR615t: This perennial stream lies within a heavily wooded area with frequent native rock outcroppings. Graded sediments and normal sinuosity characterize this reach. Water quality is greatly influenced by AMD leaching from the margins of 1980's reclaimed pits that dominate the entire headwater region of this and adjacent streams.

For purposes of quantifying the mean annual acid and metal loadings in Turkey Run site RCTR670 (Upper Turkey Run mainstem site) and RCTR600 (mouth of Turkey Run) were used in the mean annual load calculation (Stoertz, 2004). Table 15 and Figures 42 to 45 shows the mean annual acid and metal loads prior to AMD treatment.

Table 15. Mean Annual Acid and Metal loads at two stations within Turkey Run sub-basin.

Site ID	Mean Annual Acid Load (lbs/day)	Mean Annual Metal Load (lbs/day)
RCTR670	60	54
RCTR600	600	182



Drainage from surface pit, site RCTR685t

Figure 42. Mean annual acid load at site RCTR670 in Turkey Run sub-basin

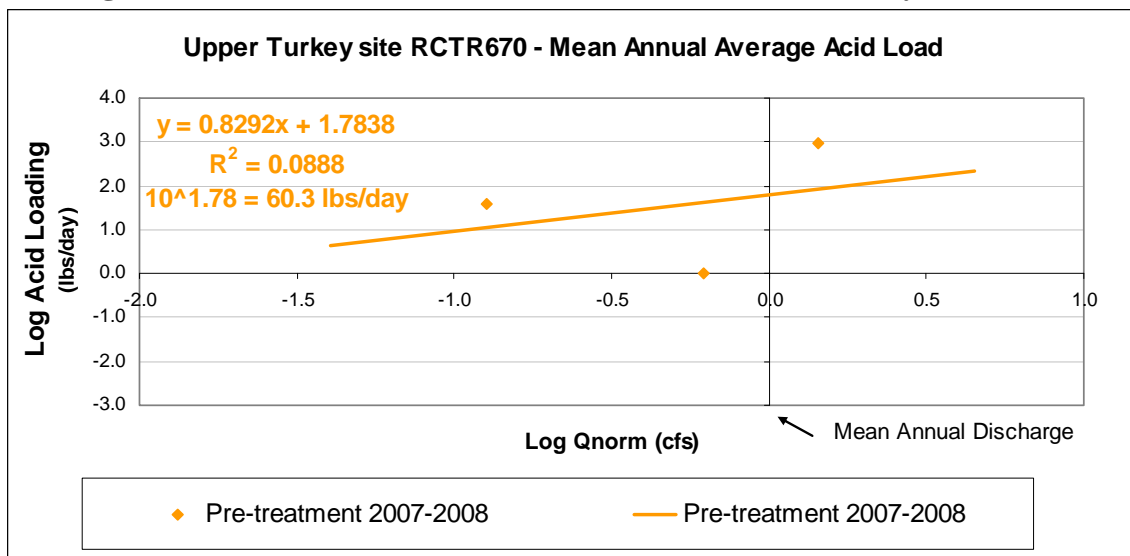


Figure 43. Mean annual metal load at site RCTR670 in Turkey Run sub-basin

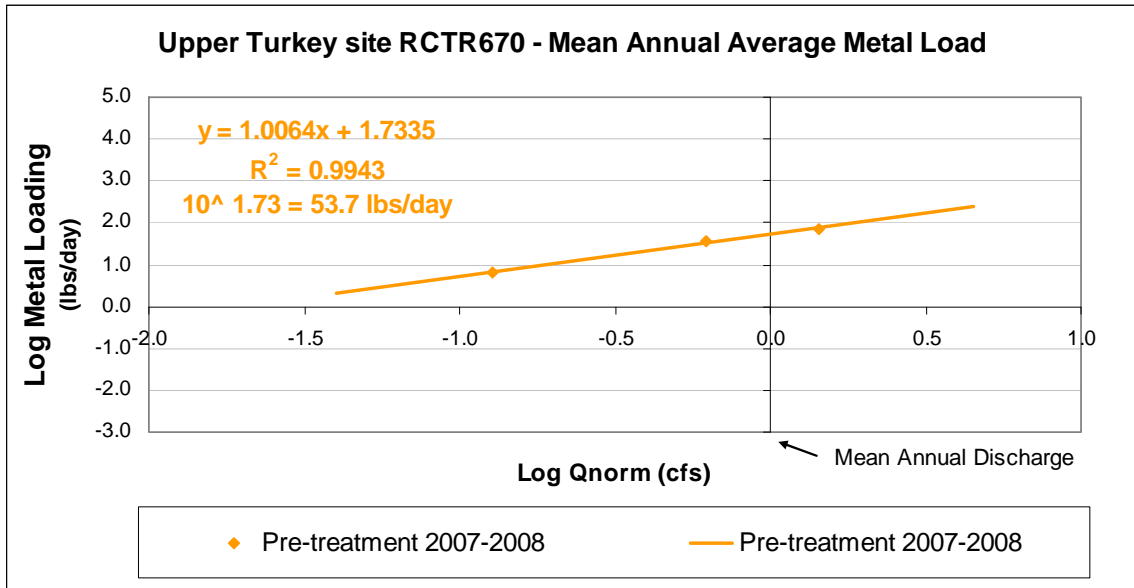


Figure 44. Mean annual acid load at site RCTR600 in Turkey Run sub-basin

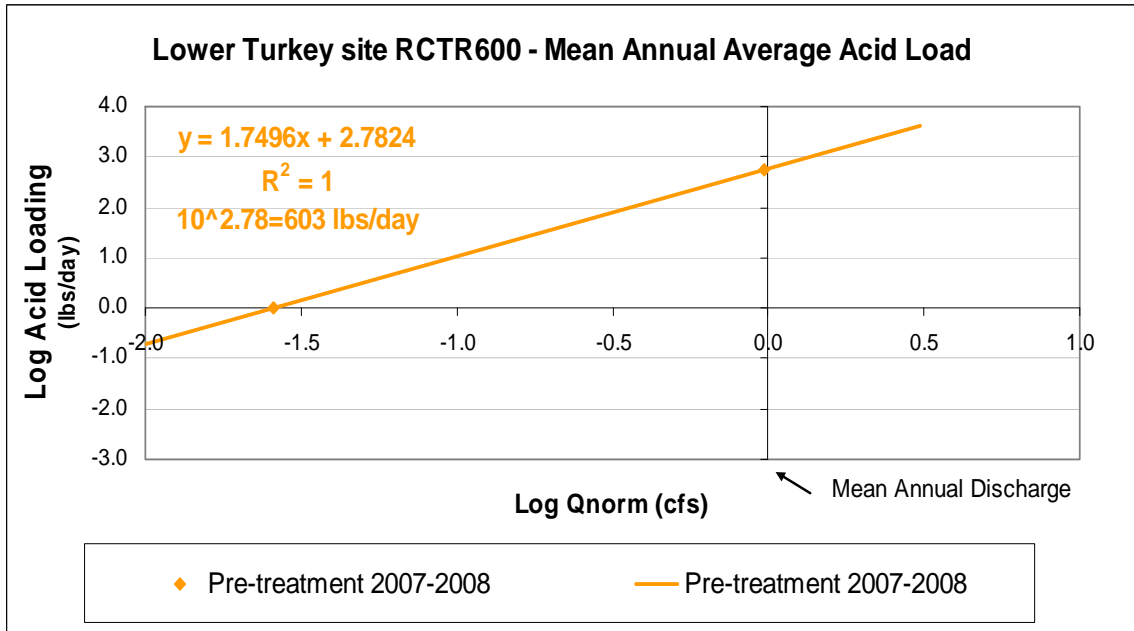
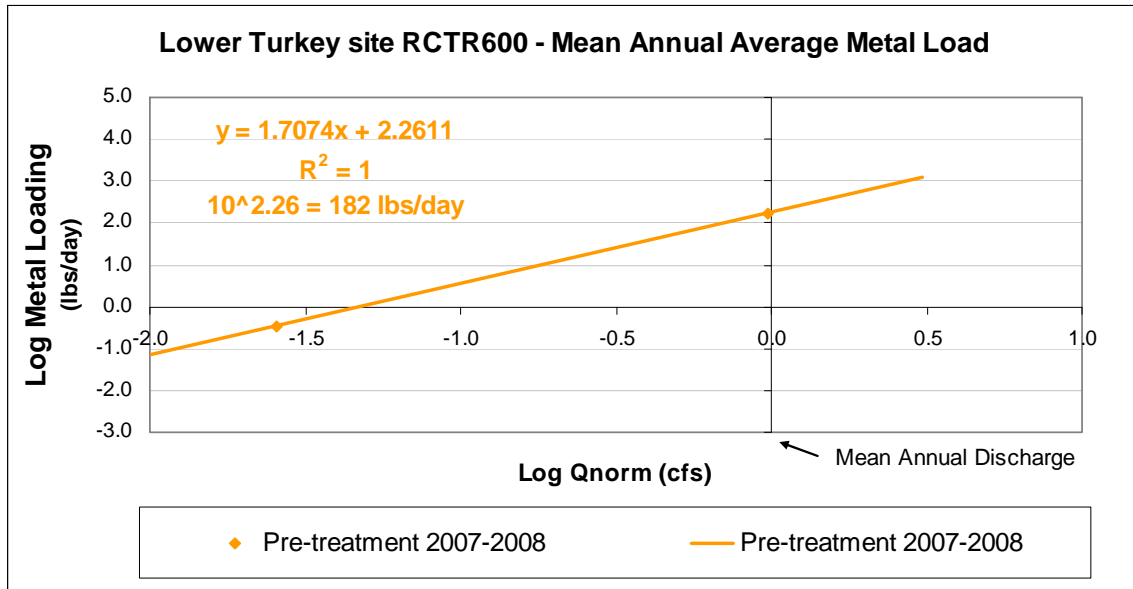


Figure 45. Mean annual metal load at site RCTR600 in Turkey Run sub-basin



Recommendations for further study

There are sources of good water that exist in the headwaters of Turkey Run that could be used to introduce additional alkalinity. The mouth of Turkey Run discharges approximately between 10 to 957 lbs/day of acid load to Rush Creek. These loads could be eliminated and add additional alkalinity to Rush Creek. This would help in reaching the restoration goal of restoring the mainstem of Rush Creek. These sites need to be monitored for metals, acidity, pH, and flow. Site RCTR630t sampled in 2003 by USGS indicated it has a good source of water that is located further downstream. This site is in close proximity to AMD sources RCTR615, and RCTR650t.

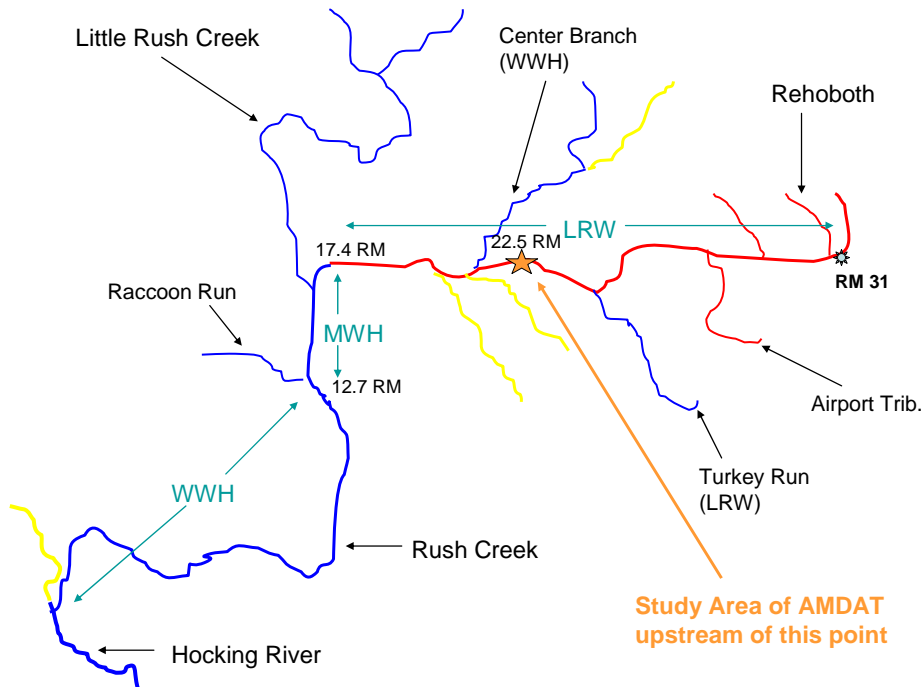
Before restoration of Turkey Run is considered, it is recommended a better understanding of the potential impacts that the “dry dam” poses to Turkey Run to be studied. There may be more than just AMD influencing the biological communities of Turkey Run. A full biological assessment including macro-invertebrates and fish is needed along the mainstem and major headwater tributaries to Turkey Run to locate healthy populations. The effect that mine drainage and/or physical habitat features have on the biological community needs to be understood.

2.7 Restoration Strategy

The restoration goal for the Rush Creek AMDAT is to improve water quality associated with AMD in the Upper Rush Creek Watershed by abating elevated acidity and metals from traveling downstream to the lower section of Upper Rush Creek where mining was not as prevalent. The lower section of Upper Rush Creek is degraded from AMD water discharging from the Upper Rush Creek Watershed. The lower section of Upper Rush Creek has adequate physical habitat features to support biological life and adjacent streams contain stock fish communities to re-populate Upper Rush Creek with improved water quality. The lower 12.7 miles attain WWH in Lower Rush Creek from Raccoon Run to the Hocking River, Figure 46. The goal is to improve Upper Rush Creek mainstem from river mile 17.4 upstream with reclamation in the AMD source tributaries in the headwaters.

Section of Lower Rush Creek is modified warmwater habitat (MWH) and is maintained by the Rush Creek Conservancy District for flood management.

Figure 46. Schematic of the ecological condition of the Rush Creek Watershed



Three remediation strategies are suggested for further refinement and consideration:

- Installation of steel slag beds throughout the Upper Rush Creek Watershed at sources with sufficient water quality that are in close proximity to mine drainage water (Map 10).
- Installation of an active treatment system in the Rehoboth mine area
- Elimination or treatment of AMD recharge zones (i.e. strip pit impoundments) surrounding mined areas with exposed and/or buried spoil material.

Remediation strategy #1

Seven small tributaries have been identified where relatively good water ($\text{pH} > 5.5$) exists adjacent to heavily impacted AMD (Map 10) (Appendix 5). Tables 16-18 show the amount of alkalinity that could potentially be generated from these seven steel slag beds given the proper consideration and design. The following two assumptions were used when developing this restoration scenario: effluent from the steel slag beds was estimated to generate 50 gpm or less based on the available drainage area and steel slag material was estimated to generate 500 mg/l of alkalinity. Table 16 shows the potential alkalinity generation and the potential acidity reduction based on **average acid loads**. Estimated acid load reduction is 32% percent. However, given the high amounts of manganese in the watershed, it was suggested to determine the acid load reduction without treating the manganese component of the mineral acidity (Table 17). Excluding manganese from the treatment scenario potentially could yield a slightly higher 37% acid load reduction. Striving to reach a higher acid load reduction the following scenario was considered (Table 18), increasing the effluent from the beds with larger drainage areas to be able to discharge at 100 gpm instead of 50 gpm.

Table 16. Utilization of seven steel slag beds to potentially reduce

average acid loads by 32% percent

Site id of the acid source	Average acid load lbs/day	Site id of steel slag bed	Potential alkaline generation lbs/day *	Residual acid load
RCMS075 Gosline	607	RCGH080t	300	307
RCPF430 Perry State Forest	1410	RCPF441t (bed 1)	252	1158
RCPF430 residual	906	RCPF442t (bed 2)	168	738
RCRH730 Rehoboth	3013	RCMS067t	300	2713
RCLL101 Lover's Lane	426	RCLL125	300	126
RCAR201 Airport	1287	WWTP x 2	600	687
TOTAL	6744		1920	4572
Load reduction				32 %

*slag beds based on a maximum output of 50 gpm of 500 mg/l alkaline water (300 lbs/day)

Table 17. Utilization of seven steel slag beds to potentially reduce calculated acid loads without manganese by 37% percent

Site id of the acid source	Calculated acid load w/o Mn lbs/day	Site id of steel slag bed	Potential alkaline generation lbs/day	Residual acid load
RCMS075 Gosline	616	RCGH080t	300	316
RCPF430 Perry State Forest	1054	RCPF441t (bed 1)	252	802
RCPF430 residual	550	RCPF442t (bed 2)	168	382
RCRH730 Rehoboth	2701	RCMS067t	300	2401
RCLL101 Lover's Lane	250	RCLL125	300	-50
RCAR201 Airport	1301	WWTP x 2	600	701
TOTAL	5922		1920	3750
Load reduction				37 %

*slag beds based on a maximum output of 50 gpm of 500 mg/l alkaline water (300 lbs/day)

Table 18. Utilization of seven steel slag beds to potentially reduce calculated acid loads without Manganese by 52% percent

Site id of the acid source	Average acid load lbs/day	Site id of steel slag bed	Potential alkaline generation lbs/day *	Residual acid load
RCMS075 Gosline	616	RCGH080t	600	16
RCPF430 Perry State Forest	1054	RCPF441t (bed 1)	252	802
RCPF430 residual	550	RCPF442t (bed 2)	168	382
RCRH730 Rehoboth	2701	RCMS067t	600	2101
RCLL101 Lover's Lane	250	RCLL125	300	-50
RCAR201 Airport	1301	WWTP x 2 **	900	-401
TOTAL	5922		5640	2850
Load reduction				52 %

*slag beds based on a maximum output of 100 gpm of 500 mg/l alkaline water (600 lbs/day)

** WWTP slag beds based on a maximum output of 75 gpm of 500 mg/l alkaline water (450 lbs/day)

Potential steel slag beds have not been characterized for their water quality. These sites will need to be monitored for metals, discharge, alkalinity, acidity, pH, conductivity, etc... Further attention needs to be directed to the engineering of these beds and impoundments needed.

Remediation strategy #2

With Rehoboth mine area contributing the largest acid load throughout the Rush Creek Watershed it was chosen for the active treatment dosing location. Table 19 displays the various types of alkaline chemicals and the volume needed to neutralize 3,070 lbs/day of acid loading (RCRH699 7/31/2008) determined from West Virginia University’s (WVU) Water Research Institute spreadsheet (Ziemkiewicz, 1996). Volume of estimated sludge is 261,771 cubic yds/yr (Ziemkiewicz, 1996). Sludge may be able to be stored in the sediment ponds already on site at the Rehoboth mine Phase II site, at least 260 acre-pond is needed. AMD Treat version 4.1 (OSM 2006) was also used to generate volumes of chemical needed (Table 19) and sludge generated. However, the results for the sludge generation from AMD Treat were less than the results generated from (WVU) by several orders of magnitude. This difference is most likely attributed to the difference in the methods these programs use to generate their volumes. WVU bases their results on TDS concentrations while AMD Treat bases their results on concentrations of iron, aluminum, and manganese. Sludge volumes generated from AMD treat for site RCRH699 using data collected on 7/31/2008 was 16 cubic yds/yr.

Table 19. Chemical reagents and volumes needed to neutralize acid loads from Rehoboth site RCRH699

Reagent	Chemical composition	WVU Volume (lbs/day)	WVU Volume (tons/day)	AMD Treat Volume (lbs/day)	AMD Treat Volume (tons/day)
Quicklime	CaO	1,916	1.0	2,287	1.14
Ammonia	NH ₃	1,047	0.5	1,110	0.55
Hydrated lime	Ca(OH) ₂	2,532	1.3	2,959	1.48

Remediation strategy #3

Investigation of the surface pit impoundments surrounding Lake Essington and potential recharge zones to Rehoboth needs to be conducted. Determining and understanding the hydrogeologic connection in these two sub-basins will lead and inform the best reclamation practice for design. Keeping the water out of contact with overburden and spoil will reduce the acid loading generated and ultimately reduce costs in treatment.

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4.0 APPENDICES

Appendix 1. Abandoned underground mine table for Upper Rush Creek

All mines are above drainage

Common name sub-watershed	Mine name	Mine number	Coal	Mine elevation ft.	Abandonment date	Discharging to:
Gosline	Bear Run #1	PY-214	Middle Kittanning #6		1924	Bear Run in Moxahala Watershed and Gosline Headwaters
Rehoboth	Wilburn	PY-118	Middle Kittanning #6	945	1923	To Rehoboth confirm with Bill Jonard
Rehoboth	Whitmer	PY-318	Middle Kittanning #5	921	1932	To Rehoboth
Perry State Forest/Rehoboth	Teal	PY-305	Lower Kittanning #5		1921	To Rehoboth and Perry State Forest confirm with Bill
Lover's Lane	Lilly	PY-024	Lower Kittanning #5	909	1912	To Lover's Lane at high flow only
Airport (headwaters)	Lexington	PY-257	Unidentified		1927	To airport
Airport (headwaters)	Lexi	PY-269	Middle Kittanning #6	925	1948	To airport
Airport (headwaters)	Sunnyhill #2	PY-332	Middle Kittanning #6	956	1969	To Moxahala
Airport (headwaters)	Sunnyhill #1	PY-159	Middle Kittanning #6		1966	To Moxahala
Turkey Run	E & F	PY-158	Lower Kittanning #5	930	1960	To headwaters of Turkey Run
Turkey Run	Pike	PY-126	Middle Kittanning #6	950	1934	Possible undocumented connection to E & F
Turkey Run	Sunnyhill #2	PY-332	Middle Kittanning #6	956	1969	To Moxahala
Turkey Run	Sunnyhill #3	PY-334	Middle Kittanning #6	940	1971	To Moxahala

Appendix 2. Field and laboratory chemical water quality data collected 2007-2008

All field and laboratory data can be accessed and downloaded from www.watersheddata.com under Rush Creek ArcIMS

Appendix 3. Water quality data from Airport sub-basin 2000 (Centeno, 2000), includes sub-appendices tables A, B, and E.

Appendix A

Threshold levels for trace elements in water (from Gough and Severson, 1995)

Element	Drinking Water mg/L	Aquatic Organisms mg/L	Sample 7 mg/L	Sample 10 mg/L
Arsenic	0.05	0.01	nd	0.073
Copper	1.0	0.005	0.011	0.068
Lead	0.05	0.01	nd	0.206
Manganese	0.2	0.02	44.81	14.34
Nickel	ng	0.025	0.776	0.227
Zinc	5.0	0.03	1.61	0.369

ng: no guidelines

nd: not detected

Appendix B

Analytical results of water samples. Analyzed by inductively coupled spectrometry (ICP-OES).
The detection limit is given. Samples that do not reach the detection limit are left blank.

	Be (ppm)	Na (ppm)	Mg (ppm)	Al (ppm)	P (ppm)	K (ppm)	Ca (ppm)
detection limit	0.005	0.500	0.500	0.050	0.050	0.100	0.500
OSU-L-1	0.005	22.50	37.30	9.77	0.077	3.75	61.80
OSU-L-2	0.009	20.80	41.90	18.99	0.054	3.32	61.20
OSU-L-3		3.70	6.00	0.072		1.33	26.90
OSU-L-4	0.006	28.70	40.80	13.36	0.053	3.78	69.40
OSU-L-5	0.010	9.10	44.20	18.82	0.063	4.32	49.00
OSU-L-6		41.20	9.70	0.148		5.05	31.20
OSU-L-7	0.014	5.50	174.0	40.85	0.251	4.21	162.0
OSU-L-8		22.30	32.70	8.26		3.58	60.90
OSU-L-9		23.30	33.40	8.17	0.050	3.38	63.70
OSU-L-10		20.90	82.80	10.75	0.177	5.18	151.0
OSU-L-11		22.30	27.70	0.079		2.47	56.10
OSU-L-12		20.60	58.40	7.85	0.081	4.02	108.0

	Sc (ppm)	Ti (ppm)	V (ppm)	Cr (ppm)	Mn (ppm)	Fe (ppm)	Co (ppm)
detection limit	0.001	0.010	0.010	0.010	0.005	0.050	0.010
OSU-L-1					5.380	0.431	0.091
OSU-L-2					5.610	1.130	0.111
OSU-L-3					0.053	0.122	
OSU-L-4					5.750	0.793	0.103
OSU-L-5					9.980	14.38	0.218
OSU-L-6					0.208	0.427	0.012
OSU-L-7		0.019			44.81	35.03	0.749
OSU-L-8					4.720	1.240	0.088
OSU-L-9					4.840	2.120	0.087
OSU-L-10	0.004			0.014	14.34	0.761	0.168
OSU-L-11					0.382	0.119	
OSU-L-12					9.810	1.460	0.116

	Ni (ppm)	Cu (ppm)	Zn (ppm)	As (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)
detection limit	0.010	0.005	0.005	0.030	0.001	0.005	0.010
OSU-L-1	0.121	0.010	0.242		0.391	0.054	
OSU-L-2	0.191	0.005	0.425		0.383	0.093	
OSU-L-3	0.012	0.007	0.011		0.103		
OSU-L-4	0.155	0.025	0.304		0.546	0.074	
OSU-L-5	0.237	0.019	0.429		0.175	0.140	
OSU-L-6					0.113		
OSU-L-7	0.776	0.011	1.610		0.340	0.392	
OSU-L-8	0.107	0.015	0.221		0.354	0.048	
OSU-L-9	0.116	0.020	0.231		0.364	0.046	
OSU-L-10	0.227	0.068	0.369	0.073	0.647	0.056	0.037
OSU-L-11		0.010	0.005		0.208		
OSU-L-12	0.156	0.020	0.229		0.497	0.043	0.012

Appendix B continued

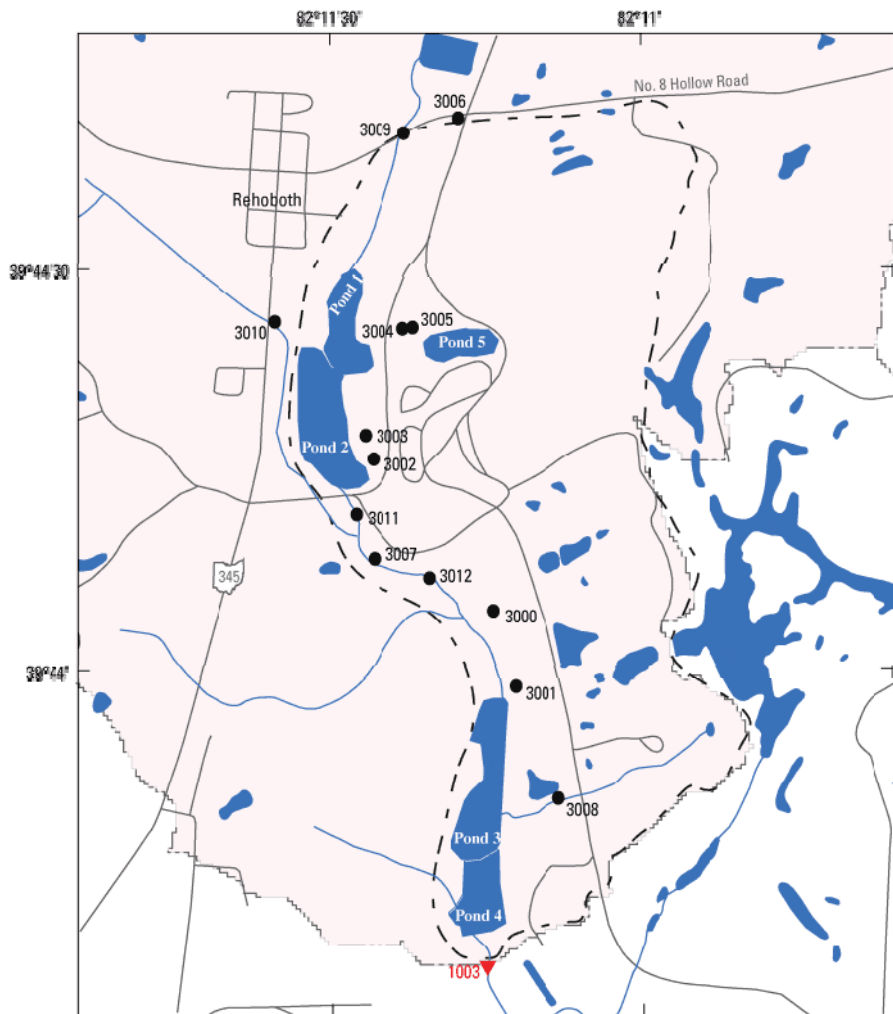
	Mo (ppm)	Ag (ppm)	Cd (ppm)	Sn (ppm)	Sb (ppm)	Ba (ppm)	La (ppm)
detection li	0.010	0.001	0.010	0.050	0.050	0.010	0.010
OSU-L-1		0.002				0.038	0.025
OSU-L-2						0.032	0.030
OSU-L-3						0.178	
OSU-L-4						0.048	0.022
OSU-L-5						0.030	0.048
OSU-L-6						0.145	
OSU-L-7		0.007				0.016	0.154
OSU-L-8		0.002				0.063	0.014
OSU-L-9						0.034	
OSU-L-10	0.010	0.009				0.026	0.050
OSU-L-11						0.045	
OSU-L-12		0.001				0.024	0.023

	W (ppm)	Pb (ppm)	Bi (ppm)
detection li	0.050	0.030	0.050
OSU-L-1			
OSU-L-2			
OSU-L-3			
OSU-L-4			
OSU-L-5			
OSU-L-6			
OSU-L-7			
OSU-L-8			
OSU-L-9			
OSU-L-10	0.073	0.206	
OSU-L-11			
OSU-L-12			

Appendix E







Concentrations of trace elements in solution and in ferric hydroxide, site 7 in ppm.

Element	Detection limit (ppm)	Concentrations in 100mL solution	Concentrations in ferric hydroxide
As	0.0001	0.711	67700
V	0.0001	0.294	28000
Zn	0.0001	0.0657	6260
Cr	0.0001	0.0604	5750
Cu	0.0001	0.0244	2320
Ba	0.0001	0.0142	1350
Zr	0.0001	0.0097	924
Ni	0.0001	0.0084	800
Mn	0.0001	0.0071	676
Pb	0.00001	0.00316	301
Sr	0.00001	0.00249	237
Se	0.0001	0.0015	143
W	0.00001	0.00128	122
Ce	0.00001	0.00107	102
Ga	0.00001	0.00084	80
Nd	0.00001	0.00075	71.4
Rb	0.0001	0.0006	57.1
Sn	0.00001	0.0006	57.1
Nb	0.00001	0.00058	55.2
Y	0.00001	0.00054	51.4
Sc	0.0001	0.0004	38.1
Te	0.0001	0.0004	38.1
La	0.00001	0.00035	33.3
Co	0.0001	0.0003	28.6
Sm	0.00001	0.00024	22.9
Gd	0.00001	0.00017	16.2
Pr	0.00001	0.00016	15.2
Cd	0.00001	0.00015	14.3
Dy	0.00001	0.00012	11.4
Th	0.00001	0.00012	11.4
Sb	0.0001	0.0001	9.52
Ta	0.00001	0.00008	7.62
U	0.00001	0.00008	7.62
Er	0.00001	0.00006	5.71
Cs	0.00001	0.00005	4.76
Eu	0.00001	0.00005	4.76
Yb	0.00001	0.00004	3.81
Hf	0.00001	0.00003	2.86
Ho	0.00001	0.00002	1.90
Tl	0.00001	0.00002	1.90
In	0.00001	0.00001	0.952
Be	0.0001	nd	nd
Mo	0.001	nd	nd
Tm	0.00001	nd	nd
Lu	0.00005	nd	nd
Hg	0.0002	nd	nd
Bi	0.00001	nd	nd



Base from U.S. Geological Survey
 1:25,000 Digital Data
 State Plane Projection
 NAD 1983, Ohio South

EXPLANATION

-  Surface water
-  Approximate extent of reclamation
-  Subwatershed boundary
-  Road
-  Site location and identification number
 1003 Rush Creek tributary sampling site
-  3000-3012, 3002, 3004, 3005, 3006, 3008, 3009 Rehoboth reclamation area sampling site

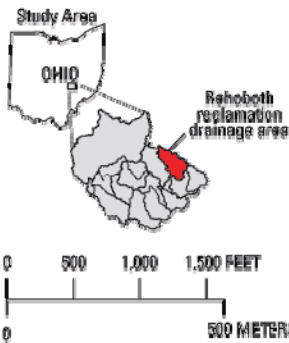


Figure 3. Water-quality sampling sites in the Turkey Run subwatershed, Perry County, Ohio.

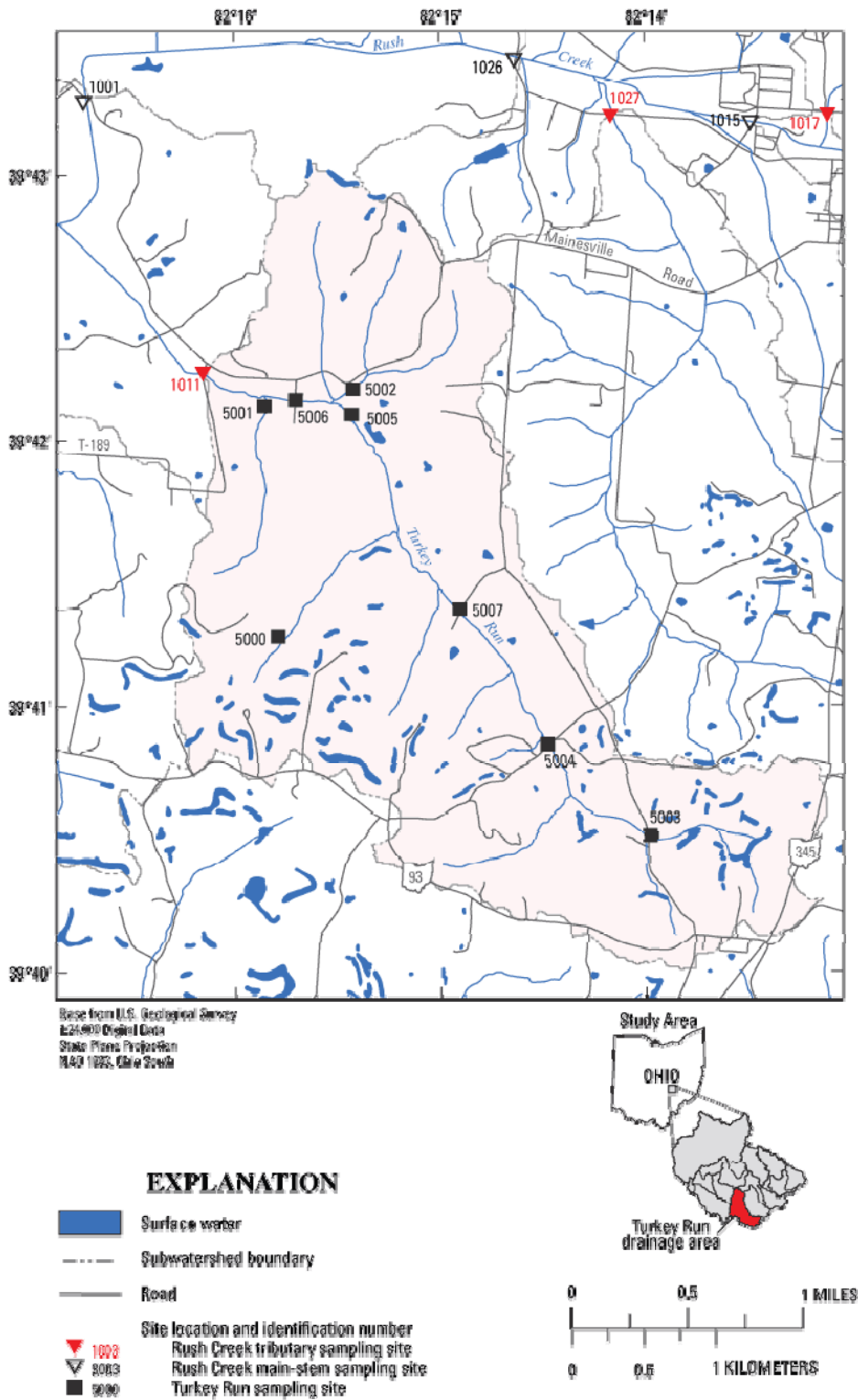


Table 5. Biological data collected at water-quality sampling sites in Rush Creek and its tributaries, Perry County, Ohio, 2003.

[RM, river mile, designates RM on Rush Creek at the confluence of tributary; mi², square miles; IBI, Index of Biotic Integrity; IWB, Index of Well-Being; —, not applicable; QHEI, Qualitative Habitat Evaluation Index; ICI, Invertebrate Community Index; LRW-AMD, Limited resource water-Acid mine drainage; ND, no data; WWH, Warmwater habitat, BOLD type indicates meeting LRW-AMD standard; ITALIC font indicates meeting WWH standard]

Site	RM	Drainage area (mi ²)	IBI	IWB	QHEI	ICI	LRW-AMD attainment status
Main stem							
1006	31	2.6	12	—	51	2	Non
1018	29.3	9.1	12	—	49	ND	Non
1014	28.6	12.2	12	—	51	4	Non
1015	28.2	16.8	12	—	51	10	Non
1026	27.1	23	14	2.4	45	2	Non
1001	25	28	12	1.6	50	2	Non
1000	23.4	35.3	14	2.7	49	0	Non
1007	21.4	39.5	30	4.2	43	16	Full
1024	21.1	45.6	14	3.5	44	30	Non
Tributaries							
1003	30.32	3.9	12	—	49	10	Non
1012	28.65	2.4	12	—	42	2	Non
1017	28.46	4.6	26	—	48	32	Full
1027	27.4	3.8	26	—	61	40	Full
1002	26.13	1.7	28	—	57	30	Full
1011	24.37	4.6	32	—	54	4	Non
1025	22.38	2.1	32	—	59	50	Full
1023	22.18	5.2	28	—	51	30	Full
1009	20.85	22.4	42	7.0	73	40	Partial ¹

¹ Site 1009 met partial attainment for WWH

Appendix 5. Descriptions of the seven potential steel slag bed locations

Appendix 5 - description of potential steel slag beds

7 Potential steel slag bed sites

Site ID	Drainage Area sq. mi.*	Mean Annual Discharge cfs*	gpm	maximum slag bed effluent	alkaline generation at 500 mg/l	pH	Cond us/cm	Date	comments
RCGH080t	0.68	0.7	314.2	50	300	7.32	1678	12/17/2008	open area site accessible from mining road
RCPF441t	0.09	0.093	41.7	42	252	5.72	370	12/17/2008	site logistic need reviewed
RCPF442t	0.06	0.062	27.8	28	168	6.32	2340	8/21/2007	site logistic need reviewed
RCMS067t	0.25	0.26	116.7	50	300	6.7	427	12/17/2008	site logistic may interfere with storage facilities
RCLL125	0.12	0.13	58.3	50	300	6.46	818	10/10/2007	impoundment already exists
WWTP (RCMS052t, 1051)			divert 100 gpm effluent discharge into two systems	50 x 2	600			8/18/2004	lab alkalinity 118 mg/l, measured by USGS - no pH, conductivity, or acidity values were not reported
Total					1920				

* Drainage area and mena annual discharge were calculated from USGS stream stats

Appendix 6:

Percentage of acid and metal loads from tributary mouths to receiving stream

Gosline	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream	RCRH699	7/31/2008	3070	590.1
	Mouth of trib	RCMS073	7/31/2008	1435.2	445.65
	downstream	RCMS070	7/31/2008	5974.7	1258.64
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	2904.7	49		668.54	67

Lovers Lane	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream	RCMS070	9/19/2007	8013.3	2328.15
	Mouth of trib	RCLL101	9/19/2007	746.15	212.3
	downstream	RCMS065	9/19/2007	7996	697.25
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	-17.3	-4313.01		-1630.9	-13.02
	more acid and metal load exist upstream than downstream, in significant contributions from Lover's Lane				
	% of total			% of total	
	downstream	9		downstream	30

Airport	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream	RCMS065	4/10/2008	7996	2299.65
	Mouth of trib	RCAR201	4/10/2008	2494.4	566.6
	downstream	RCMS060	4/16/2008	12539	3189.82
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	4543	55		890.17	64

Perry State Forest	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream				
	Mouth of trib	RCPF430	4/14/2008	2742.4	643.9
	downstream	RCRH730	4/14/2008	4287.6	1290.8
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	4287.6	64		1290.8	50

Appendix 6, (cont):

Percentage of acid and metal loads from tributary mouths to receiving stream

Rehoboth	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream	RCMS073	7/31/2008	1435.16	445.65
	Mouth of trib	RCRH699	7/31/2008	3069.9	590.1
	downstream	RCMS070	7/31/2008	5974.7	1258.64
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	4539.54	68		812.99	73

Turkey Run	Location	site id	date	acid loads lbs/day	metal loads lbs/day
	Upstream	RCMS040	4/16/2008	9213.5	2504.07
	Mouth of trib	RCRH699	4/15/2008	658.89	282.7
	downstream	RCMS070	4/16/2008	12006.2	3532.68
		% acid		metal dst-upst	
	acid dst-upst lbs/day	load		lbs/day	% metal load
% acid					
calculations	2792.7	24		1028.61	27

**Appendix 7:
AMD TREAT and West Virginia University (WVU) data results in support of
restoration strategies (active chemical and sludge generation volumes).**

SLUDGE GENERATOR
site: RCRH699 7/31/2008

INPUT DATA

Sludge solids content	1.5 %
TDS	1230 ppm
Flow	1243.2591 gpm
CFS	2.77 cfs
Pond depth	6 ft.
life of sludge pond	10 years

OUTPUT

Solids production	18,351 lbs/day
	9.2 tpd
Sludge production	602.5 tpd
	717.2 cu yd/day
	261,771 cu yd/yr
	4,490,994 gal/mo

Pond size required:	11,779,715 sq. ft.
	3,432 ft/side
	269.7 acres

ALL SPREADSHEETS:
COPYRIGHT 1996 PAUL ZIEMKIEWICZ
West Virginia Water Research Institute
West Virginia University

ESTIMATED COST OF CHEMICAL TREATMENT OF ACID MIE DRAINAGE
FLOW IN CUBIC FEET PER SECOND

data entry in double lined boxes only

SITE: RCRH699 7/31/2008

ACIDITY: 206.0 mg/L
 VOLUME: 2.8 cfs
 CHEMICAL CODE:* 2.0
 Name: hydrated lime
 Efficiency: 90.0 %
 MWE: 74.0
 Unit cost: 0.0 \$/lb
 CHEMICAL
 REQUIRED: 1,150.7 kg/day
 2,531.5 lbs/day
 1.3 tons/day

ESTIMATED 88.6 /day
 COST: 32,340.0 /year
 ACID LOAD: 1.3 t/yr
 COST/TON ACID: 25,761.5 \$/t/yr

TABLE OF CHEMICAL TREATMENT INFORMATION

code	chemical comon name	formula	MWE	efficiency (%)	unit cost (\$/ton)	unit cost (\$/lb.)
1.0	limestone	CaCO3	100.0	30.0	12.0	0.0
2.0	hydrated lime	Ca(OH)2	74.0	90.0	70.0	0.0
3.0	quicklime	CaO	56.0	90.0	120.0	0.1
4.0	soda ash	Na2CO3	106.0	60.0	260.0	0.1
5.0	ammonia	NH3	34.0	100.0	300.0	0.2
6.0	20% caustic	NaOH	80.0	100.0	540.0	0.3
7.0	50% caustic	NaOH	80.0	100.0	540.0	0.3
8.0	EAF slag	CaO	112.0	70.0	7.0	0.0
	lbs NaOH X		0.5 =gal. @ 20%			
	lbs NaOH X		0.2 =gal. @ 50%			

* enter code from table

** molecular weight equivalents in CaCO3 equivalents.



AMD TREAT ANHYDROUS AMMONIA

AMDTREAT

Anhydrous Ammonia Name

Opening Screen Water Parameters

Influent Water Parameters that Affect Anhydrous Ammonia

Calculated Acidity
 mg/L
Alkalinity
 mg/L

Calculate Net Acidity (Acid-Alkalinity)
 Enter Net Acidity manually
Net Acidity (Hot Acidity)
 mg/L

Design Flow
 gpm
Typical Flow
 gpm
Total Iron
 mg/L
Aluminum
 mg/L
Manganese
 mg/L

- 1. Ammonia Purity %
- 2. Mixing Efficiency of Ammonia %
- 3. Titration?
- 4. Ammonia Titration Volume gal amm/
gal water treated

- TANK SIZE
- 8000 Gallon Tank?
 - 5. Length of Footer ft
 - 6. Width of Footer ft
 - 7. Depth of Footer ft
 - 8. Excavation Unit Cost \$/yd³
 - 9. Concrete Unit Cost \$/yd
 - 10. Cost of 8000 Gallon Tank \$
 - 1000 Gallon Tank?
 - 11. Cost of 1000 Gallon Tank \$

- 12. Number of Tanks ea
- 13. Schedule 80 Line Unit Cost \$/ft
- 14. Feet of Feeder Line ft
- 15. Needle Valve Unit Cost \$
- 16. Nbr. of Needle Valves ea
- 17. Pressure Regulator Unit Cost \$
- 18. Nbr. of Pressure Regulators ea
- 19. Vaporizer Unit Cost \$
- 20. Nbr. of Vaporizers ea
- 21. Check Valve Unit Cost \$
- 22. Nbr. of Check Valve ea

- 23. Globe Valve Unit Cost \$
- 24. Nbr. Globe Valves ea
- 25. Vaporizer Control Unit Cost \$
- 26. Nbr. Control Box for the Tank Vaporizer ea
- 27. Automated System ?
 - 28. PID pH Controller Unit Cost \$
 - 29. Nbr. PID pH Controllers ea
 - 30. Proportional Valve Unit Cost \$
 - 31. Nbr. Proportional Valves ea
 - 32. pH Probe Unit Cost \$
 - 33. Nbr. pH Probe ea
 - 34. Metal Enclosure for Prop. Valve Unit Cost \$
 - 35. Nbr. Metal Enclosure for Prop. Valve ea

- Safety Items
- 36. Eye Wash Station Unit Cost \$
 - 37. Nbr. Eye Wash Station ea
 - 38. Twin Cylinder Oxygen Kit Unit Cost \$
 - 39. Nbr. Twin Cylinder Oxygen Kit ea
 - 40. Gas Mask Unit Cost \$
 - 41. Nbr. of Gas Masks ea
 - 42. Package of 2 Mask Cartridges Unit Cost \$
 - 43. Nbr. of Packages of 2 Mask Cartridges ea

- 44. Pounds of Ammonia per Year lbs/yr
- 45. Gallons of Ammonia per Day gal/day

Anhydrous Ammonia Cost Summaries

- 46. Excavation Cost \$
- 47. Concrete Cost \$
- 48. Cost of Tanks \$
- 49. Steel Feeder Line Cost \$
- 50. Needle Valve Cost \$
- 51. Pressure Regulator Cost \$
- 52. Vaporizer Cost \$
- 53. Check Valve Cost \$
- 54. Globe Valve Cost \$
- 55. Vaporizer Control Cost \$
- 56. PID pH Controller Cost \$
- 57. Proportional Valve Cost \$
- 58. pH Probe Cost \$
- 59. Prop. Valve Enclosure Cost \$
- 60. Cost of Safety Items \$

61. Total Cost \$

Record Number 1 of 1



AMDTREAT

AMD TREAT HYDRATED LIME

Hydrated Lime Name RCRH699 7/31/2008

Opening Screen Water Parameters

Influent Water Parameters that Affect Hydrated Lime

Calculated Acidity mg/L
Alkalinity mg/L

Calculate Net Acidity (Acid-Alkalinity)

Enter Net Acidity manually
Net Acidity (Hot Acidity) mg/L

Design Flow gpm
Typical Flow gpm
Total Iron mg/L
Aluminum mg/L
Manganese mg/L

Record Number

1 of 1

- 1. Annual Hydrated Lime lbs/yr
- 2. Annual Hydrated Lime tons/yr
- 3. Daily Hydrated Lime lbs/day
- 4. Pounds per Hour of Hydrated Lime lbs/hr

5. Purity of Hydrated Lime %
6. Mixing Efficiency of Hydrated Lime %
 7. Titration? lbs of hydrated lime /gal of h2o
8. Titration Amount

9. Mechanical Aeration System \$

Silo Storage System	Quantity	Price	Refill Freq. Days
10. <input type="checkbox"/> 20 Ton	<input type="text"/>	<input type="text"/>	<input type="text" value="13"/>
11. <input type="checkbox"/> 35 Ton	<input type="text"/>	<input type="text"/>	<input type="text" value="23"/>
12. <input type="checkbox"/> 50 Ton	<input type="text"/>	<input type="text"/>	<input type="text" value="33"/>
13. <input type="checkbox"/> 60 Ton	<input type="text"/>	<input type="text"/>	<input type="text" value="40"/>

14. Clarifier

Cost of Clarifier \$
 Cost Est based on Clarifier Diameter
15. Diameter ft
16. Cost Multiplier
 Cost Est based on Flow
17. Design Flow gpm
18. Estimated Diameter ft
19. Cost Multiplier

- 20. Vibrator Air Sweep
- 21. Pneumatic Air Sweep
- 22. Blower Blocks

23. Mixing Tank (Assumes a Two Cell Mixing Tank)

Mixing Tank Cost \$
 Cost Est based on Volume of Mixing Tank
24. Tank Volume gal
 Cost Est. based on Desired Retention Time
25. Mixing Tank Volume gal
26. Design Flow gpm
27. Retention Time min
Specifications of Concrete Tank
28. Tank Wall Thickness ft
29. Tank Bottom Thickness ft
30. Tank Freeboard ft
31. Construction Labor Cost \$
32. Concrete Unit Cost \$/yd3
33. Excavation Unit Cost \$/yd3

- 34. Number of Motorized Mixers qty
- 35. Unit Cost of Motorized Mixer \$
- 36. Number of Slide Gates qty
- 37. Unit Cost of Slide Gate \$
- 38. Cost of Electric Panel \$

39. Control Building

Cost of Control Building \$
 Cost Est. Based on Building Area
40. Building Length ft
41. Building Width ft
42. Building Unit Cost \$/ft2

43. Polymer Feed System \$

44. Clearing and Grubbing?

45. Clear and Grub Area acres
46. Clear and Grub Costs \$/acre

Hydrated Lime Sizing Summaries

- 47. Tank Length ft
- 48. Tank Width ft
- 49. Tank Depth ft
- 50. Excavation Volume for Mixing Tank yd3
- 51. Volume of Concrete for Mixing Tank ft3

Hydrated Lime Cost Summaries

- 52. Silo(s) Cost \$
- 53. Clarifier Cost \$
- 54. Mixing Tank Cost \$
- 55. Construction Labor (Mixing Tank) \$
- 56. Excavation Cost (Mixing Tank) \$
- 57. Concrete Cost (Mixing Tank) \$
- 58. Motorized Mixer & Aeration Cost \$
- 59. Sweep and Blower Cost \$
- 60. Slide Gate Cost \$
- 61. Electric Control Panel Cost \$
- 62. Building Cost \$
- 63. Polymer Feed System \$
- 64. Clear and Grub Cost \$
- 65. Total Cost \$



AMDTREAT

AMD TREAT PEBBLE QUICK LIME

Pebble Quick Lime Name: RCRH699 7/31/2008

Opening Screen Water Parameters

Influent Water Parameters that Affect Pebble Quick Lime

Calculated Acidity
 mg/L

Alkalinity
 mg/L

Calculate Net Acidity (Acid-Alkalinity)

Enter Net Acidity manually

Net Acidity (Hot Acidity)
 mg/L

Design Flow
 gpm

Typical Flow
 gpm

Total Iron
 mg/L

Aluminum
 mg/L

Manganese
 mg/L

Record Number
1 of 1

1. Annual Pebble Quick Lime tons/yr
2. Pebble Quick Lime 50 Lbs Bags per day
3. Pounds per Hour of Pebble Quick Lime lbs/hr
4. Refill Frequency for 1 Ton Bin days
5. Refill Frequency for 35 Ton Silo days
6. Purity of Pebble Quick Lime %
7. Mixing Efficiency of Pebble Quick Lime %
8. Titration?
9. Pebble Quick Lime Titration Amount lbs of Pebble Lime /gal of H2O
10. Excavation Unit Cost \$/yd3
11. Aggregate Unit Cost \$/yd3
12. Aggregate Placement Unit Cost \$/yd3

13. Ditching System

Default Ditching System Based on Flow

14. Default Ditch Length ft
15. Default Ditch Bottom Width ft
16. Default Ditch Depth ft

Custom Ditching System

17. Ditch Length ft
18. Ditch Bottom Width ft
19. Ditch Depth ft

- Run Rise
20. Slope Ratio of Ditch Sides :
 21. Rock Depth in Ditch ft
 22. Length of Rock Lined Ditch ft

23. Clearing and Grubbing?

- 24a. Land Multiplier ratio
- 24b. Clear/Grub Acres acres
25. Clear and Grub Cost \$/acre

26. Select One Delivery System

- 1 Ton Bin System \$
- 35 Ton Silo System \$

27. Electric Mixer ?

28. Electric Mixer System Cost \$

29. Slaker ?

30. Slaker Cost \$

Pebble Quick Lime Sub-Totals

31. Clear Grub Area acres
32. Storage System Cost \$
33. Electric Mixer Cost \$
34. Aggregate Cost \$
35. Ditch Excavation Cost \$
36. Clear and Grub Cost \$
37. Slaker Cost \$

38. Total Cost \$

Company Name

Project Rehoboth

Site Name RCRH699



AMDTREAT

AMD TREAT SLUDGE REMOVAL

Opening Screen
Water Parameters

Sludge Removal Name RCRH699 7/31/2008

Influent Water Parameters that Affect Sludge Removal

Calculated Acidity mg/L

Alkalinity mg/L

Calculate Net Acidity (Acid-Alkalinity)

Enter Net Acidity manually

Net Acidity (Hot Acidity) mg/L

Design Flow gpm

Typical Flow gpm

Total Iron mg/L

Aluminum mg/L

Manganese mg/L

Selection for Method of Removing Sludge

1. Select One

Sludge Removal by \$ per Gallon

2. Sludge Removal Unit Cost \$/gal

Sludge Removal by Vacuum Truck

3. Vacuum Truck Unit Cost \$/hr

4. Mobilization Cost \$

5. Hours to be Used hr

Sludge Removal by Mechanical Excavation

6. Mechanical Excavation Unit Rate \$/hr

7. Mobilization Cost \$

8. Hours to be Used hr

Sludge Removal by Lagoon Cleaner

9. Lagoon Cleaning Unit Rate \$/hr

10. Mobilization Cost \$

11. Hours to be Used hr

Actual Sludge Removal Cost

12. Actual Sludge Removal Cost \$

13. Off Site Disposal Cost \$

Record Number 1 of 1

Concentrations from Main Water Quality Screen

14. Iron Concentration mg/L

15. Manganese Concentration mg/L

16. Aluminum Concentration mg/L

17. Total Miscellaneous Concentration mg/L

18. Percent Solids %

19. Sludge Density lbs/gal

20. Titration?

21. Gal. of Sludge per Gal of Water Treated gal

22. Estimated Sludge Volume yd3/yr

Cost for Sludge Removal Types

23. Removal by \$ per Gallon \$

24. Removal by Vacuum Truck \$

25. Removal by Mechanical Excavation \$

26. Removal by Lagoon Cleaner \$

27. Actual Sludge Removal Cost \$

Sludge Removal Sub-Totals

28. Currently Selected Removal Cost \$
Plus Off Site Disposal Cost