Twomile Run Watershed
AMD Remediation Master Plan

February 2007

Developed for Trout Unlimited
and the Kettle Creek Watershed Association

by Hedin Environmental

Funded by DEP Bureau of Abandoned Mine Reclamation,
Richard King Mellon Foundation,
and National Fish & Wildlife Foundation

Closed depression in unreclaimed spoil in Area 5N

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Executive Summary

Twomile Run is a tributary to Kettle Creek in Clinton County, PA that is severely polluted with acid mine drainage (AMD). The pollution arises from deep and surface mines on the Upper and Lower Kittanning coal seams located in the middle of the Twomile Run watershed. Upstream of the AMD impacts, Twomile Run and its tributaries support native brook trout. Below the mines the streams support negligible aquatic life. The pollution also degrades lower Kettle Creek which is a major tributary to the West Branch of the Susquehanna River and a DEP Priority Watershed.

The AMD in the Twomile Run watershed is severe. Most flows have pH 2.5 – 3.5 and contain 200-600 mg/L acidity, 20-50 mg/L Fe, and 20-70 mg/L Al. While some of the AMD discharges from point sources such as deep mine entries, most of the drainage is diffuse and occurs outside of the limits of the mining activities. Unlike many mining areas in PA where AMD is confined to the mined sites by aquitards immediately beneath the coal, much of the AMD that forms in the mines in the Twomile Run watershed escapes into underlying aquifers. The AMD then surfaces on hillsides where kill zones develop or flows into receiving streams as baseflow. Two surveys of Twomile Run that included careful measurements of flows and stream chemistry established that 30-50% of the total AMD pollution present in lower Twomile Run appears as contaminated baseflow. The occurrence of AMD in aquifers below the mining was confirmed through the installation and monitoring of wells above and below the coal mining areas. Above the mines ground water was clean. Within the mines and beyond the mines, groundwater beneath the Lower Kittanning coal was contaminated with acidity and high concentrations of metals and sulfate. The highly diffuse nature of the AMD in the watershed makes conventional "collect and treat" strategies impossible because the AMD cannot be collected.

AMD production must be stopped at its source in order to achieve the restoration of Twomile Run. This can be accomplished by reclamation of acid spoils with alkaline addition and removal of the deep mines that appear to generate AMD and lose AMD into underlying aquifers. This strategy was investigated by characterizing the spoil and coal resources in the watershed. Spoil was sampled and analyzed for soil fertility and acid base parameters. Every spoil sample was acidic and infertile. The average conditions were 3.4 pH, 0.3% S, -13 parts per thousand (ppt) Net Neutralization Potential (NNP). The highly acidic conditions were due to the presence of both available and stored acidity. Spoil more than 8 feet deep retains much of the original pyritic sulfur content. Overburden was sampled in several locations and analyzed for acid base parameters. The overburden in the watershed is characterized by inert sandstones and shales overlying the Columbiana shale and Lower Kittanning coal. The Columbiana shale is 6-12 feet thick with high sulfur and minimal Neutralization Potential (NP). The bulk Net Neutralization Potential (NNP) of overburdens ranged from +2 to -23 ppt and averaged –12 ppt. Neutralization of overburden to a +6 ppt NNP (with thresholds) requires an average of approximately 4,500 tons $CaCO_3$ per acre. This is a very high alkaline amendment rate. The Lower Kittanning coal immediately beneath the Columbiana shale is good quality. The average characteristics of three samples were 3.8% moisture, 9.8% ash, 2.8% S, and 13,343 BTU.

Considerable crop coal was discovered. The coal is good quality and generally is shallowly buried beneath spoil and native ground. The average characteristics of 14 samples were 15.4%

moisture, 8.2% ash, 1.0% S, and 10,548 BTU. Mining of the shallowly covered crop coal appears to be a good way to lessen total reclamation costs.

High priority recommendations of this project include one passive treatment system complex, three reclamation and remining jobs, and continued monitoring. The only location where treatment is currently recommended is the “Swamp” area. TU/KCWA recently completed a reclamation project on the surface mine above the Swamp. The work appears to have decreased flows and contaminant loadings by 30-40%. Acidity and aluminum concentrations were reduced by 20% while iron concentration stayed about the same and sulfate concentration increased. Treatment of the AMD is recommended because of the completed work and because this is the first inflow of AMD to Twomile Run. The recommended passive system and clean-water bypass are estimated to cost $693,000 to design and construct. An alternative chemical system will cost $203,000 to construct and $72,500 per year to operate.

Existing projects and water quality monitoring should continue. These efforts include annual inspections of the Twomile Run Reclamation Project and continued monitoring of water quality at key locations that will allow evaluation of project success in the future.

Remediation of all other AMD-producing areas requires reclamation and remining. Three areas are considered high priorities for remediation. The recommended reclamation involves the removal of deep mines and crop coal and alkaline amendments to overburdens to +6 ppt NNP and spoil surfaces to +12 ppt NNP. While the projects produce considerable coal (475,000 tons), the high overburden, high alkaline amendment rates, and high transportation costs will result in project costs that are more than the coal revenues. The total net costs for the high priority reclamation projects are shown below.

Project	**Cost Estimate**
Area 4 Reclamation and Remining	$ 2,329,317
Area 7 Reclamation and Remining	$ 8,698,804
Area 5N Reclamation and Remining	$ 3,699,662
TOTAL	**$14,727,783**

The total costs of the reclamation projects are sensitive to the amount of coal recovered from abandoned deep mines during remining and the transportation costs of alkaline amendments and coal. The cost estimate assumes 25% recovery of coal from the deep mined areas. If the actual recovery is 40%, the total project cost decreases by $3 million. The estimate assumes that coal is trucked to Sunbury at $12/ton and waste limestone is trucked from Pleasant Valley for $8/ton. If these costs can be both decreased to $4/ton, the total project cost decreases by $7 million.

The first project should be Area 4. This area is the least expensive and there are well characterized AMD discharges that should be remediated through the project. If Area 4 is successful, it is recommended to continue to Areas 5N and 7 where a majority of the AMD is produced.

Common Acronyms Used Throughout This Report

Acronym	Category	Definition
% S	chemistry	Percent Sulfur
CaCO3	chemistry	Calcium Carbonate, the alkaline component of limestone
NaOH	chemistry	Sodium Hydroxide
SO4	chemistry	Sulfate
AASHTO	organization	American Association of State Highway and Transportation Officials
ASTM	organization	American Society of Testing and Materials
BAMR	organization	DEP Bureau of Abandoned Mine Reclamation
DCNR	organization	Department of Conservation and Natural Resources
DEP	organization	Pennsylvania Department of Environmental Protection
DMO	organization	DEP District Mining Office
DOE/NETL	organization	Department of Energy/National Energy Technology Laboratory
EPA	organization	Environmental Protection Agency (federal)
HE	organization	Hedin Environmental
KCWA	organization	Kettle Creek Watershed Association
NOAA	organization	National Oceanic and Atmospheric Administration
OSM	organization	Office of Surface Mining (federal)
PSAASL	organization	Penn State Agricultural Analytical Services Laboratory
TU	organization	Trout Unlimited, Inc.
USGS	organization	United States Geological Services
BTU	unit	British Thermal Units
CY	unit	Cubic Yards
ft^2	unit	Square feet
g/m2/day	unit	Grams per meter squared per day
lb S / MBTU	unit	Pounds of Sulfur per million BTUs
lb/d	unit	pounds per day
m	unit	meters
mg/L	unit	milligrams per liter, a unit of concentration
mL	unit	milliliters
n	unit	number of samples
ppt	unit	Parts Per Thousand (often represents tons per 1,000 tons)
ABA	soil	Acid / Base Accounting
CEC	soil	Cation Exchange Capacity
MPA	soil	Maximum Potential Acidity
NP	soil	Neutralization Potential
NNP	soil	Net Neutralization Potential
ALD	other	Anoxic Limestone Drain
AMD	other	Acid Mine Drainage or Abandoned Mine Drainage
ANOVA	other	Analysis of Variance
AOC	other	Approximate Original Contour
ATV	other	All-Terrain Vehicle
EM	other	Electromagnetic
GFCC	other	Government Financed Construction Contract
GPS	other	Global Positioning System
LK	other	Lower Kittanning coal
NALIS	other	National Abandoned Lands Inventory System
SAPS	other	Successive Alkalinity Producing System
TAG	other	Technical Assistance Grant
TMDL	other	Total Maximum Daily Load
UK	other	Upper Kittanning coal
VFP	other	Vertical Flow Pond

I. Introduction

Kettle Creek is one of the Commonwealth's most valued aquatic resources. The entire watershed above the Alvin R. Bush Dam is classified as exceptional value by the DEP's Chapter 93 Water Quality Standards and all of its tributaries support healthy native brook trout populations. The Kettle Creek watershed contains 8% of the Class A wild trout stream miles in the Commonwealth. For decades, thousands of sportsmen have maintained camps and second homes in the watershed so that they can enjoy fishing, hunting, hiking, and outdoor activities. In 1998, Trout Unlimited (TU) selected Kettle Creek as its third national Home Rivers Initiative project.

For the last eight years, TU has worked with the Kettle Creek Watershed Association (KCWA) to protect and improve the watershed's nationally recognized coldwater resources. In addition to fish habitat improvement projects in the upper part of the watershed where water quality is excellent, but in-stream habitat is degraded, and landowner stewardship education and outreach projects, TU and the KCWA have been working together to address abandoned coal mine drainage that pollutes the lower watershed. In fact, the comprehensive assessment, strategic planning, and prioritized AMD remediation program that TU and its partners developed for the Kettle Creek watershed is being used as a model for the West Branch Susquehanna Restoration Initiative, which is aimed at the cleanup of AMD throughout the West Branch Susquehanna River basin. Although the Kettle Creek Home Rivers Initiative officially ended in December 2006, TU remains committed to completing the AMD restoration job in the lower Kettle Creek watershed and continues to advance Kettle Creek AMD cleanup as part of its lead role for the West Branch Susquehanna Restoration Initiative.

The West Branch Susquehanna Restoration Initiative is supported by the PA Wilds Initiative launched in 2003 by Governor Rendell to promote the growth of tourism and related businesses in north central PA based on the significant outdoor experiences that are available on public lands within this area. Because water quality impairment from AMD is a major limiting factor to the tourism development opportunities and the economic potential of the region, the Governor made cleanup of West Branch Susquehanna AMD a priority for the Commonwealth and charged the West Branch Susquehanna Task Force with this undertaking.

The Task Force, which includes the DEP, DCNR, PA Fish and Boat Commission, PA Game Commission, Trout Unlimited, and others, selected the Kettle Creek watershed as one of two priority watersheds where the initial emphasis is to complete projects that address AMD pollution (see the 2005 West Branch Susquehanna River Watershed: State of the Watershed Report for more information). Addressing Kettle Creek AMD is important not only because it is a priority watershed for the Task Force and serves as a model cleanup effort, it is also the last (or most downstream) major source of AMD pollution to the West Branch Susquehanna River. Water quality improvement in the lower Kettle Creek watershed will yield benefits to water quality of the West Branch.

The benefits gained from the restoration of water quality in lower Kettle Creek and its tributaries are apparent to residents, visitors, KCWA, TU, and the Commonwealth agencies involved in managing the watershed's waterways and forests. The challenge has been to identify a viable plan for the remediation of abandoned mine problems. This report presents the findings of an investigation of the Twomile Run watershed conducted by HE funded from grants secured by TU from the DEP Bureau of Abandoned Mine Reclamation (BAMR), National Fish and Wildlife Foundation, and the Richard King Mellon Foundation. The report provides a detailed description of current water, land surface, and hydrogeologic conditions that is synthesized from historical and recently collected information. Remediation options are described and several alternative plans are presented.

A. Project Organization and Milestones

This project started in the summer of 2004. Funding was provided by BAMR as a pass-through contract with TU. The contract included several specified "scopes of work" for which individual work plans and budgets were developed.

This final report contains information on four of the five "scopes" involved in the overall project:

- Scope #1: Continued Assessment of Twomile Run AMD Discharges
- Scope #2: Continued Huling Branch Hydrogeological Study
- Scope #3: Swamp Area Water Collection, Monitoring, and Final Report
- Scope #5: Robbins Hollow 10A/10B Collection and Monitoring

The final report for Scope #4 (Kettle Creek West Side Hydrogeological Investigation and Alternatives) was completed for this project and has been provided under separate cover.

The five original scopes of work were reduced to four by combining Scope #1 and Scope #2 in early 2006. This was done after it was recognized that one "master plan" was necessary for the entire Twomile Run watershed. This report represents that master plan and also contains the results and recommendations for Scopes #3 and #5.

The primary consultant to TU for this project was Hedin Environmental (HE), which is the principal author of this report. HE hired and coordinated subcontractors to perform excavation/construction, drilling, mapping, water sample laboratory analyses, and other tasks.

The primary project partners were TU, the KCWA, BAMR, the DEP Moshannon District Mining Office, PA Department of Conservation and Natural Resources (DCNR) Minerals Section, and DCNR Sproul State Forest.

The following table shows the approximate dates of major project milestones.

Table 1. Major Project Milestones

Date	Activity
July 2004	Start of project
Nov-Dec 2004	Swamp Collection Systems Installed
June 2005	Robbins 10A/10B 4 collection pipes installed
April 2006	Scope and Budget Realignment
August 2006	Monitoring wells installed
October 2006	Middle Branch Collection (Huling F) completed
November 2006	Spoil and Coal Exploration completed
November 2006	Huling Branch Collection (Huling C) completed
January 2007	Project Completion

B. Study Area

The Kettle Creek watershed encompasses approximately 244 square miles in Clinton, Potter, and Tioga Counties. For most of its length, Kettle Creek displays excellent quality and is valued as a cold water fishery. However, the lower 5.5 miles of Kettle Creek and tributaries are impacted by pollution from abandoned mine drainage (AMD) (See Map 1). The following table shows the stream miles (considering the mouth of Kettle Creek as zero) of various important points along Lower Kettle Creek.

Table 2. Kettle Creek Features by River Mile

Feature	River Mile (From Mouth)	Side
Alvin R. Bush Dam	8.40	
Slide Hollow Mouth	5.54	West
USGS Gauging Station	3.60	
Short Bend Hollow Mouth	3.20	West
KC204 Mouth (“The Beach”)	2.98	West
Duck Hollow Mouth	2.80	West
Twomile Run Mouth	1.73	East
Butler Hollow Mouth	0.64	West

The first major pollution source to Kettle Creek is Slide Hollow. Twomile Run is the only significant source of AMD that enters Kettle Creek from the east. All other sources of AMD noted in Table 2 enter from the west and are discussed in the companion report entitled “West Side of Lower Kettle Creek AMD Remediation Master Plan” (HE, 2007).

The Twomile Run drainage basin covers approximately 9 square miles (See Map 1). Several surface and deep mine complexes are present. Some of these mine complexes straddle the Twomile Run watershed boundary. AMD produced by the mines pollutes 2.3 miles of Twomile Run and 3.0 miles of tributary streams (Middle Branch, Huling Branch, and Robbins Hollow). Small amounts of pollution may enter Kettle Creek directly from mines on the Twomile Run/Kettle Creek watershed boundary.

A small portion of the Twomile Run drainage basin is present on the Tamarack and Hammersley Fork USGS 7.5' quadrangle map, but these areas are unimpacted by mining. The portions of the watershed covered by this report are located on the Keating and Renovo West maps.

The primary landowner in the study area is the PA Department of Conservation and Natural Resources (DCNR), Bureau of Forestry, Sproul State Forest. Note that the State Forest Boundary shown on the USGS maps is not accurate due to recent land acquisitions in the area. DCNR owns all areas of the Twomile Run drainage basin that have been affected by mining.

There are two main types of land cover in the study area. The area is primarily forested and is actively managed by the Sproul State Forest for timber production. Significant portions of the study area have been affected by surface mining and/or placement of deep mine spoils. In general, little or no reclamation occurred, leaving poorly vegetated areas. In addition to these two main cover types, small areas of the watershed are covered by roads, reclaimed grasslands, and parking areas.

The primary land use in the area is recreation. The Whiskey Springs ATV trail complex is located in the Middle Branch and Huling Branch subwatersheds of Twomile Run. Two parking areas and a small campground support the ATV activities. Hunting is also a popular activity in the study area, particularly during bear season and deer season.

C. Summary of Reclamation and Remining Areas

For the purposes of this report, the Twomile Run area has been divided into 10 areas for the consideration of remining and reclamation projects. These areas are discussed in the table below and shown on Map 2.

Table 3. Areas Considered for Remining and Reclamation

Area	**Common Name**	**See Section**
1	Westport Point Mine	X.E
2	Dry Run Mine	X.F
3	Coal Anomaly Area	X.G
4	Robbins Donut	X.H
4A	Swamp Reclamation Area	X.I
5N	The Pit	X.J
5S	Huling-Middle Ridge	X.K
6	Huling Moonscape Mine	X.L
7	Three-Fingered Devil	X.M
8	Huling – Kettle Ridge	X.N

The areas outlined in the table above encompass the vast majority of surface spoils in the Twomile Run watershed, but a few small, isolated areas have not been considered because they are not thought to contribute to the water quality problems in the watershed. The project areas are based upon those established in the Operation Scarlift report (See Section II.A). Subsequent work by BAMR has also followed this scheme. Slight modifications were made to accommodate updated understanding of the individual areas.

The most significant change in the spoil area naming system is the division of Area 5 into two separate areas, Area 5N (north) and Area 5S (south). The line dividing these two areas was determined by a combination of coal structure and overburden thickness. Water flowing on the pit floor of Area 5N would generally flow southeast to Twomile Run. Water flowing on the pit floor of Area 5S would generally flow south-southwest to Huling Branch. A line approximating the pit floor watershed divide was drawn that avoids overburden thicknesses greater than 100'.

D. Goals

The primary goal for the BAMR/TU project is the development of one 'master plan' for restoring the Twomile Run watershed. This document represents that master plan.

The individual scopes of work had more specific goals. However, as the project progressed, it became clear that the projects were inter-related and should be covered by a single final report. Therefore, the goals of this report are to:

- Gather historical information and summarize the work completed to date;
- Obtain new data on discharges throughout Twomile Run and in-stream data on Twomile Run and its tributaries;
- Collect and monitor the Robbins 10A/10B discharges and recommend treatment;
- Evaluate the effectiveness of the Twomile Run "Swamp" reclamation project and recommend treatment;
- Obtain spoil and coal information in order to prioritize and guide reclamation areas and formulate reclamation standards;
- Create a "master plan" and "master map" for the watershed in order to aid project partners in long-term planning, and; and
- Provide cost estimates for recommended projects.

E. Kettle Creek Mine Drainage: A Tale of Two Sides

There are important differences between the Twomile Run pollution impacts and west side impacts. The Twomile Run AMD enters at a single location, causing larger visual and biological impacts in the immediate vicinity of the stream mouth. The west side pollution enters at many points, with Butler Hollow and KC204 being the two largest sources of pollution loading from the west side. In total, ten locations have been identified where AMD enters Kettle Creek from the west side.

Another key difference between the Twomile Run pollution and west side impacts is the nature of their respective hydrographs. The west side discharges are primarily the result of a large, mostly interconnected deep mine complex. As a result, the west side discharges tend to exhibit a significant lag time between precipitation events and increased discharge flow rates. This lag time of 6-8 days has been observed for the KC204 discharge. In contrast, the primary source of Twomile Run pollution is from poorly reclaimed surface mines. Discharges in Twomile Run have been observed to respond to precipitation events in a matter of hours. While the implications of the differing hydrographs on Kettle Creek are unclear, it is a critical consideration when comparing relative loading contributions between Twomile Run and the west side. A sampling round collected during the peak discharge period of Twomile Run could incorrectly result in the conclusion that Twomile Run produces vastly more pollution than the west side discharges. However, the same sampling round conducted 6-8 days later would likely lead to the opposite conclusion. Careful planning is required if one is to perform a detailed comparison of these two pollution sources.

Twomile Run presents a greater potential for the restoration of cold-water fishery stream miles. Twomile Run, Huling Branch, and Middle Branch support native brook trout populations upstream of the mine drainage impacts. On the west side, only Butler Hollow contains potential recoverable cold water stream miles, but the poor habitat and many waterfalls would likely inhibit native trout populations.

A final critical difference between Twomile Run and the west side impacts is the availability of projects that will provide long-term benefits without long-term costs. The Twomile Run contains numerous potential reclamation projects that will permanently decrease pollution loading, while the west side projects primarily require treatment.

For more information, refer to the companion report to this report entitled “West Side of Lower Kettle Creek AMD Remediation Master Plan” (HE, 2007).

II. Previous Studies and Projects

The following sections discuss the primary studies and projects that have been completed in the Twomile Run watershed. Some of these projects also covered the drainages to Kettle Creek from the west. In all cases, the date listed in the title is the date of project completion.

A. Operation Scarlift (1973)

In 1973, a working draft of a report prepared by Neilan Engineers as part of Operation Scarlift titled "Mine Drainage Pollution Abatement. Kettle Creek, Clinton County, Pennsylvania (SL-115)" was submitted for review but never approved. Since the report was never approved, few copies exist and are difficult to obtain. The reason the report was not approved is not known. The copies that do exist are often incomplete. The report was funded by the Pennsylvania Department of Environmental Resources (now DEP) Bureau of Planning and Developmental Research though the Land and Water Conservation and Reclamation Act.

The report included water quality and flow data for all discharges that were identified at the time as well as remediation plans. It appears that a thorough inventory of mine drainage sources was taken, however, much has changed in the watershed since the report was produced so it is difficult to verify the validity of the sampling locations. In particular, several deep mine entries reported to be discharge sources have since been destroyed by strip mining. While the data included in the report was extensive, the chemical analysis is of suspect quality and no analysis of aluminum, a primary AMD pollutant, was performed. Another data quality issue is the fact that the remnants of hurricane Agnes passed over the area during the study period producing record rainfall and widespread flooding. No mention of this event is made in the report yet the extremely high flow rates are included in averages, skewing the results. In addition, more than thirty years have passed, which can make even the best data obsolete. For these reasons, all flow and water quality data included in this report should be considered suspect.

The most valuable aspect of the report is the detailed description of the mine workings. Both surface and deep mines were described in detail because those who worked the deep mines were still alive to describe them and some of the surface mining was still active at the time the report was written.

The recommendations of the report focus almost entirely on remining and reclamation. One exception is the recommendation to place limestone at in-stream locations with neutral waters in order to improve buffering capacity. Since little in the way of supporting evidence is provided for the proposed actions, the remediation plans should be viewed with the same suspicion as the water quality and flow data.

In addition to the report prepared by Neilan Engineers, Operation Scarlift funded exploratory drilling and a mine drainage abatement project. The drilling, conducted in 1982 by L. Robert Kimball, Inc., formed the original foundation of understanding of the geologic structure and remaining coal reserves in the watershed.

One of the remediation projects recommended in the Operation Scarlift Report was implemented. The project involved surface reclamation and deep mine sealing on the north side of Robbins Hollow in Area 4 (See Map 3). What little is known about the project has been gleaned from an incomplete set of as-built plans. According to the plans, the project was completed in 1978 and involved exposure of the highwall and construction of a compacted clay dike against the coal face. The purpose of the clay dike seems to have been to seal and inundate a small deep mine with the intention of creating anoxic conditions that would minimize the acid generating processes. A monitoring well developed into the mine workings (by Neilan Engineers) indicates that water is impounded within the deep mine. A "wet" mine seal with a drain was constructed on the updip side to allow drainage from the mine while still maintaining an inundated condition. The outfall of this pipe was located in the field by HE personnel. There was little evidence that the pipe had ever conveyed water. The pipe is either obstructed or the clay seal is imperfect and the deep mine is unable to fill sufficiently to flow out of the pipe. The surface mine was regraded and revegetated. Vegetative cover is good over much of the project area but a few barren areas remain.

Prior to the reclamation project, historical information indicates that mine drainage emerged from two discharges at the coal crop near pre-strip mining deep mine entries. After the project, four small kill zones developed 30-40 feet downslope of the crop. It is likely that the new kill zones are simply a relocation of the original discharges, but this is difficult to assess due to the lack of background data. In spite of the minimal information available about this project, it still serves as an important precedent for regrading and revegetation of crop mines.

B. BAMR Hydrologic Unit Plan (1998)

This report was completed in 1998 as the first formal discussion of AMD in the Kettle Creek watershed since the Scarlift report. The plan contained new water quality and biological data and described, in general terms, the impacts to Twomile Run and Shintown Run, which flows directly to the West Branch of the Susquehanna River just east of Kettle Creek. The authors found severe impacts to Twomile Run and its tributaries and limited impacts to Shintown Run. The monitoring stations established through this project were maintained and sampled both before and after the report was issued by BAMR, KCWA, and TU. The data obtained from those stations was used to formulate the Lower Kettle Creek Restoration Plan (2000, see Section II.C).

The BAMR report laid the foundations for two of the projects that have been completed in the Twomile Run watershed. The Middle Branch treatment system and the Twomile "Swamp" reclamation project were both recommended in the report. See Sections II.D and II.H respectively for more information.

C. Lower Kettle Creek Restoration Plan (2000)

The "Lower Kettle Creek Restoration Plan" was completed by HE in 2000. This report used data collected from BAMR weirs located at strategic in-stream and discharge locations in the Twomile Run watershed. This report was funded by a grant from the Western PA Watershed

Program to TU and KCWA. The recommendations listed in Section VI of the final project report are listed below. Along with each recommendation are notes on progress that has been made towards the listed recommendation.

Table 4. "Lower Kettle Creek Restoration Plan" Recommendations and Status

Recommendation	Status
Monitor the performance of the recently completed Middle Branch Treatment System	***Completed.*** See Section II.D for more information.
Develop a program to further characterize the western discharges	***Completed.*** See the companion report to this project (HE 2007).
Continue sampling of Twomile Run (at discharge locations and mouths)	***Completed.*** See Section V and the attached data appendix
Develop a Flow Management Plan for the Alvin R. Bush Dam	***Not Completed.*** See Section II.H for a discussion of the US Army Corps of Engineers study of the watershed.
Pursue BAMR-sponsored reclamation of area above the Swamp, including collection systems and post-reclamation monitoring	***Completed.*** See Sections II.H and VII for more information on the reclamation, water collection, and monitoring.
Collect Robbins Hollow discharges and construct a passive treatment system in the headwaters of Robbins Hollow (Growing Greener August 2000)	***Ongoing.*** Collection, monitoring, and passive treatment complex in headwaters completed. See Section X.H for reclamation/remining recommendations and Section VIII.C for treatment system recommendations.
Collect and monitor the Huling Branch tipple site discharges (Map83) (Growing Greener August 2000)	***Completed.*** See Sections II.J and IX.E for more information on collection.
Construct a passive treatment system at the Swamp Area as needed according to post-reclamation monitoring	***In Planning.*** See Section VII.D for recommendations for treating the Swamp discharges.
Using data and experiences gained at the Middle Branch system, continually reevaluate the feasibility of passive treatment options for Huling Branch	***In Planning.*** See Sections II.D and VI for a discussion of the Middle Branch system and Section X.M for new recommendations for Huling Branch.
If passive treatment is not feasible, design and construct an appropriate chemical treatment system on Huling Branch.	***In Planning.*** See Section II.I for information on this recommendation. The focus of the Huling Branch discharges has shifted from treatment to reclamation.

As shown in the table above, many recommendations of the report have been completed or are in process. The recommendations in this report and others lead directly to the funding of this project.

D. Middle Branch Treatment System (2000)

The Middle Branch Treatment System was designed to treat the two primary sources of AMD to Middle Branch (See Map 3). The system was designed by BAMR and constructed in 2000 with funding from the 10% set-aside program (Title IV). Upstream of these discharges, Middle Branch supports native brook trout.

The treatment system did not produce effluent quality as intended. Subsequent investigations determined that the system was highly overloaded (or undersized). A follow-up project funded by a DEP Growing Greener grant in 2003 is rehabilitating the system and decreasing loading. Details of the investigation and current project are presented in Section VI.

E. Twomile Run TMDL (2001)

The DEP (Hawk Run District Mining Office) completed a Total Maximum Daily Load (TMDL) report for the Twomile Run watershed. The final report was approved in April 2001 based on historical sampling and on new in-stream samples taken in 1999 and 2000. The TMDL calculations indicated that major reductions in acidity and aluminum are required in nearly all stream segments in order to meet in-stream water quality standards. Although the purpose of the TMDL program is not to supply specific recommendations and costs, the TMDL report discussed reclamation, remining, and passive treatment as potential ways to decrease pollution in the watershed. A more comprehensive monitoring program was also recommended. Because the Twomile Run watershed has an approved TMDL, funds may be more readily available from federal grant sources such as the EPA 319 program.

F. Airborne Remote Sensing Study (2003)

An airborne remote sensing survey of the AMD impacted area of the Kettle Creek and adjacent Cooks Run watersheds was conducted in 2002. This work was the result of collaboration between Trout Unlimited, DEP, and the Department of Energy's National Energy Technology Laboratory (DOE/NETL), and the USGS. This work was also the basis of a master's thesis by Erica Love at the University of Pittsburgh in 2003. The following summary is drawn from the final report submitted by DOE/NETL.

Using aircraft based instruments, thermal and electromagnetic conductance (EM) data was collected to rapidly identify mine drainage discharges over a large area. Thermal data is useful in locating groundwater seeps because in winter the groundwater is significantly warmer than the surrounding ground surface and therefore stands out as a thermal anomaly. The thermal data, however, cannot distinguish clean groundwater flows from AMD contaminated flows, so follow-up sampling is required to determine if the discharges are AMD. To locate AMD contaminated water in the groundwater system, the electromagnetic conductance of the terrain was mapped. This concept takes advantage of the fact that water contaminated with AMD is a better conductor of electromagnetic energy than uncontaminated water.

Combining the thermal, electromagnetic conductance, geology, mining history and topography data produced a detailed map of anomalies that were most likely to be mine drainage discharges. In total, 103 anomalies were identified, 53 of which were field verified to be AMD. Of the 50 anomalies that were not AMD, 23 were surface water (ponds or other standing water). Eight anomalies could not be identified. The remaining non-AMD anomalies were primarily uncontaminated springs, wetlands, and residential features.

As part of the field verification of the anomalies, flows were measured and samples collected of both the discharges and at in-stream locations. The resulting data were used to perform mass balance calculations of the contaminant loadings. By comparing the sum of loading from contributing discharges to that observed in-stream, the effectiveness of proposed remediation activities on the receiving stream can be calculated. The data resulting from this effort indicated that much of the in-stream loading in Twomile Run could not be accounted for from the contributing discharges. It was hypothesized that contaminated groundwater was entering the stream via the regional groundwater system in addition to surface discharges. See Section V.B for more information.

The EM data delineated a contaminated plume of groundwater emanating from unreclaimed surface mines in the Twomile Run watershed (See Map 4). This is perhaps the most significant finding of the airborne remote sensing study because it provides a mechanism for contaminated groundwater to reach Twomile Run without reaching the surface as a discrete discharge.

G. Robbins Hollow Headwaters TAG (2002) and Treatment Systems (2005)

In April 2002, KCWA/TU requested a DEP Technical Assistance Grant (TAG) to identify and sample AMD in the headwaters of Robbins Hollow, tributary to Twomile Run. The TAG work was a partnership between Stream Restoration, Inc. and HE. This assessment was initiated as a result of an earlier effort to collect and monitor what were thought to be the two major contributors of AMD to Robbins Hollow, the 10A and 10B discharges. However, six months of monitoring led to the realization that the 10A and 10B discharges accounted for only 30-35% of the pollution flowing to Robbins Hollow. A stream walk was performed and 17 new monitoring stations were established in the headwaters of Robbins Hollow. Seven rounds of samples were taken that included field chemistry, laboratory chemistry and discharge flow rates at the stations. In the TAG final report, a conceptual plan for passively treating the water in the headwaters of Robbins Hollow was developed.

The recommendations of the Robbins Hollow TAG project were implemented using funding provided by grants from DEP Growing Greener (2001) and OSM (2001 and 2004). Four passive "mini-systems" were completed in the headwaters area in September 2005 (See Map 3). The systems were designed by HE and constructed by E.M. Brown of Clearfield, PA. The systems were constructed in the East Branch ("EB") and North Branch ("NB") of Robbins Hollow. The system units include the following:

- The EB11/12/13 system is located in the headwaters of the East Branch of Robbins Hollow. This treatment system consists of an anoxic limestone drain to treat EB13 and an open limestone pond to treat EB11, EB12, and the headwaters stream.
- The EB10/15 system consists of two parallel limestone vertical flow ponds to treat two sources of AMD. The limestone ponds are followed by a settling pond, where untreated AMD also enters.
- The EB09 system is an open limestone bed that treats a low-metals discharge to the East Branch.

- The NB system treats several sources of mine drainage to the North Branch of Robbins Hollow, including NB02, NB04, and NB05. The system consists of two parallel vertical flow ponds with limestone and compost and a common settling pond/flush pond.

An Operation and Maintenance Manual was prepared for the systems. A digital copy of the final report and O&M Plan is included in the Appendix (digital form only).

The following table shows the in-stream average chemistry both before and after the Robbins Hollow Headwaters systems were installed. Four in-stream stations were sampled, which included the mouth of the North Branch of Robbins Hollow (NB01), the mouth of the East Branch of Robbins Hollow (EB01), just downstream of the confluence of the North Branch and East Branch (RH12) and at the historical station near the mouth of Robbins Hollow (RH05). The "before" data were taken in 2002 and 2003 and the "after" data were taken in 2005 and 2006.

Table 5. Robbins Hollow In-Stream Data Before and After Treatment Systems

				Chemistry Parameters (mg/L)					
Station	**N**	**Field pH**	**Cond (uS)**	**Alk.**	**Net Acid**	**Fe**	**Mn**	**Al**	**SO4**
NB01 pre-treat	5	3.5	725	0	124	1.4	9.1	16.1	393
NB01 post-treat	3	6.9	579	35	-24	1.4	4.0	3.6	265
EB01 pre-treat	7	3.2	783	0	86	6.2	8.0	4.3	382
EB01 post-treat	3	7.1	199	18	-11	2.1	1.1	0.8	69
RH12 pre-treat	2	3.2	556	0	57	2.9	5.4	3.7	279
RH12 post-treat	4	6.7	267	21	-14	2.1	1.6	0.9	96
RH05 pre-treat	10	3.7	503	0	79	4.5	5.7	6.8	179
RH05 post-treat	10	4.7	549	1	42	1.4	6.4	6.2	282

As shown in the table above, the treatment systems resulted in dramatic in-stream improvements at stations NB01, EB01, and RH12. All of these stations were net acidic before treatment and have been net alkaline since treatment began. Although some metals are still present in the stream, concentrations have dropped. Subsequent sampling for total and dissolved metals indicated that 25-40% of the iron and aluminum were in particulate form.

More modest improvements have been noted at station RH05. Note that several sources of pollution, including Robbins 10A/10B, enter between stations RH12 and RH05.

Continued monitoring of key in-stream and treatment system sampling stations was recommended in the operation and maintenance plan for the headwaters treatment systems.

H. US Army Corps of Engineers Study (2004)

The Army Corps of Engineers conducted a feasibility study of AMD remediation options for lower Kettle Creek under the Section 206 Aquatic Ecosystem Restoration Program. A draft plan was submitted in January 2004. The study included funding for the Airborne Remote Sensing

Survey (see Section II.F), in addition to site reconnaissance, preliminary treatment design plans, and regrading plans for several unreclaimed surface mines in the Twomile Run watershed. While the treatment plans may be useful for individual discharges, the construction of the systems would not result in stream restoration due to the large amount of unaccounted loading (See Section V.B). This is due to the fact that little to no prioritization was given to which discharges should be treated. Reclamation recommendations did not include alkaline addition or remining. In the time since the Army Corps study was performed, the Twomile Run Reclamation Project (See Sections II.H and VII) has shown that simply regrading without alkaline addition provides loading reductions but does not eliminate AMD problems. The feasibility study was never finalized due to federal budget cuts.

I. Huling Branch Mine Complex (2004)

The "Huling Branch Mine Complex" report was completed by HE in 2004. This project was funded by a Growing Greener grant to TU and KCWA. The goals of the project were to examine the historical information on the watershed, collect several distinct areas of discharge to the Huling Branch watershed, and propose remedial actions. The report focused on Area 7 (See Map 2). Three collection systems were installed and monitored and coal encountered during excavation activities was characterized. The report concluded that the Huling Branch discharges are not amenable to passive treatment but that remining and reclamation of 120 acres of crop coal, surface mine, and deep mine could result in significant improvements in water quantity and quality. Five alternatives were presented, which varied according to the amount of coal removed and the amount of alkaline material added. Alternative I (Do Nothing) and Alternative II (Chemical Treatment) were not recommended. The following table shows a summary of the other three recommendations contained within the report. Note that these costs represent estimates that were made in 2004 and these costs have been refined and updated for the purpose of this report (See Section X.M).

Although none of these alternatives have been selected or initiated, DCNR plans to hold a timber sale for the entire area in question in order to prepare for reclamation. One of the main purposes of the current project was to expand the type of work done for the Huling report to all of the unreclaimed spoil in the Twomile Run watershed and to obtain more information on the coal reserves and spoil properties. See Sections IX and X.M for more information and updated recommendations for Area 7.

Table 6. Huling Branch Report Recommendations Summary (2004)

Alternative	Option	Potential Benefits	Cost Estimate
III	Surface reclamation only on 120 acres	Reduce infiltration, decrease loadings by 50%	$1.4 million
IV	A. Reclamation of 120 acres with 288,000 tons alkaline addition ($10/ton)	Reduce infiltration, decrease flow rates and acidity concentrations, decrease loadings by 50 – 80%	$12.6 million
	B. Reclamation of 120 acres with no-cost alkaline addition provided by alkaline power plant ash		$9.7 million
V	A. Coal Crop Removal and sale, reclamation of 120 acres with 288,000 tons alkaline addition ($10/ton)	Use coal proceeds to subsidize reclamation, reduce infiltration, decrease flow rates and acidity concentrations, decrease loadings by 50 – 80%	$9.4 million
	B. Coal Crop Removal and sale, reclamation of 120 acres with no-cost alkaline addition provided by alkaline power plant ash		$5.8 million
	C. Coal Crop and Deep Mine removal and sale, reclamation of 120 acres with no-cost alkaline addition provided by alkaline power plant ash	Decrease AMD loadings by 80 – 100%	$8.6 million

J. DEP Bennett Branch and Kettle Creek Cost Estimate Report (2004)

In 2004, the DEP issued a report that estimated watershed restoration costs for Bennett Branch, Kettle Creek, and the entire West Branch Susquehanna River ("A detailed analysis of watershed restoration costs for the Bennett Branch Sinnemahoning Creek and Kettle Creek watersheds"). This report was issued jointly by the Moshannon District Mining Office and BAMR personnel from the Cambria Office.

This report used DEP's existing NALIS inventory and unit treatment and reclamation costs to determine the total cost for cleaning up main stems, and in some cases, important tributaries. In Kettle Creek, this included Kettle Creek, Butler Hollow, and Twomile Run. The report focused heavily on active treatment, with passive treatment and reclamation of less importance. The report yielded a total capital cost of $6.2 million with annual costs of approximately $300,000. One of the primary recommendations of the report is to develop more detailed cost estimates for each area.

K. Twomile Run "Swamp" Reclamation Project (2005)

In 2001, TU and KCWA received grants from the Growing Greener program and the Office of Surface Mining (OSM) to reclaim 56 acres of open spoil that drained to the headwaters of

Twomile Run in Area 4A (See Map 3). The grant also included funding for construction of passive treatment systems in the headwaters of Robbins Hollow (See Section II.G). Acidic groundwater emanating from the surface mine created a large kill zone known as "The Swamp" downslope of the coal outcrop. The diffuse discharges of the kill zone combined into a single watercourse that flowed across the Texas Eastern Pipeline and on to Twomile Run. The confluence of this watercourse with Twomile Run represents the first mine drainage impact to Twomile Run. Upstream of the confluence, Twomile Run supports naturally reproducing populations of Brook Trout. Ample area exists in the vicinity of the discharges for treatment system construction. However, the discharges were of such severe quality that they were considered beyond the realm of passive treatment. With this in mind, a reclamation project was proposed with the intention of reducing the flow and improving the chemistry of the discharges.

A reclamation plan was originally prepared by BAMR that involved regrading the site to a domed shape that would promote sheet flow equally from all sides. This basic but functional grading plan was then revised by Gannett Flemming to a more diverse landscape of variable terrain and vegetation. While many of the habitat features were desirable, the construction cost was exceedingly high. A final grading plan was developed that simply enhanced the existing drainage of the site. The grading plan produced a landscape that readily promotes runoff with minimal earthwork required to complete the project.

The project was competitively bid in May 2003 and the Notice to Proceed was given to the selected contractor, E.M. Brown, Inc. of Clearfield, PA, on August 29, 2003. By June 30, 2004 grading operations were complete.

A unique aspect of this project was the utilization of "WesTan" soils to achieve vegetative cover. WesTan is an alkaline organic byproduct of the vegetable leather tannery industry that has received beneficial use designation from the DEP. Approximately 3,400 tons of WesTan material were mixed into the top 6-8 inches of the regraded site with a chisel plow. A small amount of wood chips was incorporated into the WesTan material as a bulking agent. Cost overruns led to a significant reduction in the amount of WesTan/wood chip material applied to the site compared to the design quantity.

Following the WesTan application, the soils were sampled and analyzed to determine fertilizer requirements. As a result, potash was added at a rate of 110 pounds per acre. The site was then seeded with an elk food plot seed mix in August 2004. Follow-up soil sampling was conducted in fall of 2005. In the spring of 2006, the site was limed at a rate of 1 ton per acre and fertilized at a rate of 0.25 tons per acre. In addition, waste lime was added to the bottom of the storm water retention pond on the southern end of the site.

Section VII discusses the subsequent water collection efforts and the results of the reclamation on the "Swamp" discharges.

III. Study Methods

Methods used for data collection and calculations are described below.

A. Water Chemistry

Most of the recent water quality data in the watershed has been obtained by HE with analyses by G&C Laboratories of Summerville, PA. However, the project database contains chemistry data from a variety of sources, using a variety of methods. The description in this section applies only to the recent sampling performed by HE.

Water samples were analyzed for mine drainage parameters. Alkalinity, temperature, and pH were measured in the field. Alkalinity was measured using a Hach digital titration kit. In this method, samples are titrated to a pH of 4.5 using 1.6 N H_2SO_4. If a sample begins at a pH of 4.5 or lower, there is no alkalinity in the sample. Temperature, conductivity, and pH were measured using a Hanna Combo pH/EC multi-meter.

At each location, a 500-mL raw sample and a 125-mL acidified sample were collected for laboratory analyses. The acidified sample was preserved using 50% nitric acid. Because the samples were not filtered prior to analysis, metals concentrations represent total metals. Efforts were made in the field to collect clear samples as close to discharge points as possible, so dissolved and total concentrations should be similar. Occasionally, a 125-mL sample was filtered in the field before being acidified in order to allow measurement of dissolved metals. Millipore Millex™ 0.8µm filters were used.

All other parameters (conductivity, total acidity, iron, aluminum, manganese, total suspended solids, sulfate) were measured in the laboratory. G&C Laboratories of Summerville, PA (DEP Certification 33-00325) performed the analyses using standard methods as shown in Table 7.

Table 7. Methods used for analysis of water samples

Parameter	**Method**	**Detection limit**
Acidity	SM-3210-B	5.2 mg/L
Alkalinity	SM-2320-B	0.88 mg/L
pH	SM-4500-H+B	0.02
Total Suspended Solids	SM-2540-D	1.0 mg/L
Sulfates	EPA-375.4	0.4 mg/L
Fe, Mn, Al	SM-3111B	0.02, 0.01, 0.03 mg/L

For some discharges, the ability for limestone to generate alkalinity was measured by incubating the water in a closed, anoxic container containing limestone aggregate. This method and the devices, referred to as ALKasts, were developed by HE and have been shown to accurately predict the alkalinity generating capacity of an anoxic limestone drain (ALD) for the tested water.

B. Flow Rate

Several flow measurement techniques were used. At locations where flow could be collected to a common point and was not expected to be above 100 gpm, the flow was directed to a pipe. Flow rate was measured at these sites by capturing the flow in a bucket and timing how long it took to collect a known volume of water. This is called the “timed volume” method.

At sites with higher flow rates where flow could be directed to a single point, H-flumes were installed to measure the flow rate. After installation, flow was determined by measuring the depth of water in the flume and converting the depth to a flow rate using the appropriate flume chart.

At in-stream stations where flow rates were desired, a Swoffer Model 3000 flow velocity meter was used. A cross-section was established and the velocity was measured at several locations along the cross-section. The flow meter automatically calculated the flow rate from these measurements.

Some of the older flow rate data was obtained using V-notch or rectangular weirs. For instance, most of the data collected by BAMR in the mid-1990s was obtained from weirs. Most of these weirs were removed or have been washed out.

Flow rates for Kettle Creek at the USGS gage were obtained from the USGS archive.

At some stations, it was not practical to measure flow rate, so only chemistry was measured.

C. Rainfall Data

Daily rainfall totals from January 1992 to October 2006 were provided by the US Army Corps of Engineers from their rain gage located at the Alvin R. Bush Dam on Kettle Creek.

Long-term precipitation data was also obtained from the National Oceanic and Atmospheric Administration (NOAA) climate station in Williamsport, PA. This station is located approximately 46 miles from the Twomile Run watershed.

D. Data Calculations

Loadings were calculated from the product of flow and concentration as pounds per day (lb/d) as follows:

Load (lb/d) = flow (gpm) X concentration (mg/L) X 0.012

Summary loadings were calculated, whenever possible, using flow rate and chemistry information from the same date and then performing statistical functions in the resulting loadings. If incomplete information was available, then the loading was calculated from the average flow and chemistry.

The quality of the metals and acidity results were assessed by comparing the calculated acidity to the acidity reported by the testing laboratory (HE, 2006).

Statistical summaries (mean, standard deviation, standard error, percentiles) were calculated using Excel functions. Percentiles show the amount of data that is estimated to be less than a certain value. For instance, for the 25^{th} percentile, 25% of the data is estimated to be below the value that is shown. Percentiles are used to select treatment levels for passive treatment.

In some instances, the differences between data sets were evaluated using standard analysis of variance (ANOVA) techniques. The ANOVA calculations were performed by Excel. Statistical significance was evaluated at the 0.05 probability level.

E. Spoil Analysis

Samples of spoil were collected from surface mines throughout the Twomile Run watershed. The sampling area was excavated to a depth of up to 12 feet using an excavator. The spoil produced in the excavation was laid on the surface so that material from different depths could be observed and sampled. Samples of the spoil were taken by collecting at least 5 shovels of material, mixing the shovels on a plastic sheet, and then collecting a single sample of the material. For some excavations, all depths were sampled and blended into a single sample. For others, the spoil was sampled according to position either at the bottom, middle or top of the excavation. Only material less than 2 inches diameter was collected. Therefore, the samples were biased toward the soil-sized fraction.

A portion of each spoil sample was submitted to the Penn State Agricultural Analytical Services Laboratory and analyzed for soil parameters. The analyses included: pH, P, K, acidity, cation exchange capacity, Ca, Mg, K, Zn, Cu and S. The laboratory provided a fertilizer, lime, and magnesium amendment recommendation for each sample. The methods used by the PSAASL can be found at www.aasl.psu.edu.

A portion of each spoil sample was submitted to Geochemical Testing of Somerset, PA for analysis of overburden geochemical parameters (see below).

F. Exploratory Drilling and Observation Wells

Several types of exploration were performed using a Davey air rotary drill contracted by Smith Drilling of Brookville, PA. Exploration included identifying coal reserves, obtaining overburden samples and coal cores, and installing observation wells. Specific information on the installation of the observation wells is contained in Section IX.D.

G. Overburden Sampling and Analysis

Samples of overburden and spoil were collected and provided to Geochemical Testing (Somerset, PA) for analysis of overburden parameters. The laboratory crushed each sample and then measured total sulfur and neutralization potential (NP). The total sulfur value was used to calculate Maximum Potential Acidity (MPA) by:

$$MPA = S^{tot} \times 31.25$$

The net neutralization potential (NNP) was calculated by subtracting the MPA from the NP. A negative result indicated that the sample had a deficiency of neutralization potential and was likely to produce acidity. NP, NNP, and MPA are all measured and reported in parts per thousand, or ppt.

The MPA calculation assumes that all sulfur is reduced and available for acid generation. This assumption is invalid for sulfur present in sulfate or organic forms. In order to evaluate the potential error of the MPA calculation, sulfur forms (pyritic-S, sulfate-S, and organic-S) were determined by Geochemical Testing for several samples.

H. Coal Sampling and Analysis

Coal samples were obtained by excavating trenches in the crop coal, obtaining cores, exposing coal seams at highwalls and excavations into deep mines as part of water collection efforts.

Coal crop areas were sampled by excavating trenches to expose the full width of the coal seam. The trenches were perpendicular to the crop in order to evaluate the width of remaining coal. The trenches typically started on the low wall of the pit and extended away from the mined areas. Once the top of the coal seam was exposed, a trench was excavated through the full depth of the coal seam and into the underlying bottom seat earth.

Areas were selected for sampling and vertical lines were scored onto the exposed face with a rock hammer. These lines were spaced four inches apart starting at the top of the coal and ending at the bottom. A ten quart bucket was placed at the bottom of this marked out area to collect the coal. A rock hammer chipped away between the lines to a depth of three inches starting from the bottom and working up the face of the coal to the top. The contents of the bucket were then transferred to a coal sampling bag, tagged and sent to the coal laboratory for analysis. Sampling included all clay partings unless noted.

Highwall samples and coal pillars were sampled in the same manner as the exposed coal crop locations. Core samples were collected from a drilling rig with the use of a core barrel. The samples were removed from the core barrel and transferred to a wooden core box for logging purposes. Once the core was logged the coal was bagged and sent to the laboratory for analysis.

Coal samples were analyzed by G&C Laboratories (Summerville, PA). The analyses included moisture, ash, sulfur, and BTU. Ash, sulfur, and BTU were reported on both wet (as received) and dry basis. BTU was also reported on a dry ash-free basis. All analyses were conducted according to ASTM procedures.

I. *Mapping*

For the most critical areas, 2-foot contour mapping was obtained from BAMR from recent aerial photography (1994). Some of these areas had been processed into 2-foot contour mapping previously, while other areas were processed by BAMR as part of this project. Map 5 shows the areas of the watershed where 2-foot contour mapping is available. USGS 7.5' quadrangle maps were used for large-scale representations and for areas where more detailed mapping does not exist.

DCNR provided a digital map of the Whiskey Springs ATV area. DOE/NETL provided paper copies of maps from its airborne remote sensing project.

Locations and elevations were obtained for numerous points throughout the watershed using high accuracy (sub-meter) GPS. This was performed by DEM Surveying P.C. of Brookville on several occasions. For all locations and elevations obtained using this method, the error range is reported.

For three of the four monitoring wells that were installed, elevations were determined by transit level from nearby established control points. The fourth monitoring well was too far from any established control point so the elevation was determined based upon its GPS location plotted on 2-foot contour mapping.

J. *Treatment Alternative Calculations*

Passive and chemical treatment options are proposed in this report. Chemical treatment calculations were done with the assistance of AMDTreat (Version 4.0, OSM, 2006). All chemical treatment scenarios assumed that NaOH was the alkaline reagent because it is the best reagent for remote sites without electricity and fulltime operator attention. NaOH calculations assumed that the chemical neutralization efficiency was 80%. This value, which is less than the default 99%, is based on our experience with NaOH treatment systems. The primary treatment ponds were sized with 48 hours of retention. This sizing allows for proper treatment and sludge storage. The sludge solids content was assumed to be 15%.

Passive treatment options were evaluated using the chemical flow chart method developed by Hedin et al. (1994). None of the discharges were amenable to treatment with aerobic systems or anoxic limestone drains. The presence of aluminum in all discharges resulted in the recommendation of vertical flow ponds (VFPs) as the primary alkalinity-generating and metal-removing component of all passive systems. All VFPs were designed with 3 feet of limestone aggregate overlain with 1 foot of organic substrate amended 25% by volume with limestone fines. The VFPs were sized assuming the removal of 40 grams acidity per m^2 per day

(g/m^2/day). Rose (2006) reports that effective VFPs generate alkalinity at 30-40 g/m^2/day. The best performance is from VFPs designed with alkaline organic substrates. Hedin Environmental has installed VFPs with alkaline organic substrates that generate alkalinity at measured rates of 40-50 g/m^2/day. Small VFPs have less limestone per unit of acidity than larger VFPs because the side slopes cause the bottom of the pond to be very small. The sizes of small VFPs were adjusted to assure that there was at least 20 tons of limestone for each gpm of design flow.

IV. Geology, Mining History and Hydrogeology

This section discusses the geologic setting and mining history of the area. The geology and hydrogeology are discussed in general terms. For more specific information on these topics, see Section IX.

A. Stratigraphy, Topography, and Geologic Setting

Map 6 shows major geologic structural features in the Twomile Run watershed. Twomile Run roughly parallels the axis of the southwest-northeast trending Clearfield-McIntyre Syncline which is flanked to the north by the Wellsboro Anticline and to the south by the Hyner Dome. These folds are low amplitude, long wavelength features. Associated with these structural features are two dominant fracture sets. One set parallels the syncline and the other set trends roughly perpendicular to the syncline. The orientation of these fractures strongly influences drainage patterns regionally and is clearly expressed in the surface topography. Huling Branch of Twomile Run is an excellent example of fracture control of stream morphology. The fracture set that causes Huling Branch to have such a narrow and straight valley is also likely to be responsible for the ninety degree bend in Kettle Creek near the mouth of Twomile Run.

Geologic units exposed within the Twomile Run watershed include the Huntley Mountain Formation (Mississippian-Devonian), Burgoon Sandstone (Mississippian), as well as the Pottsville and Allegheny Groups (Pennsylvanian). Both the Pottsville and Allegheny Groups contain several coal seams but only the Allegheny Group contains economically recoverable coals in the Kettle Creek watershed. These coals, the Upper and Lower Kittanning, are limited in occurrence to hilltops along the axis of the Clearfield-McIntyre Syncline that parallels Twomile Run. Elsewhere the coal bearing units have been removed by erosion.

B. Mining History

The Lower Kittanning (LK) Coal (B Seam) is the most consistent in terms of both area and thickness and is therefore the most economically recoverable coal in the watershed. As a result the B seam has been intensively mined by both surface and underground methods. The Upper Kittanning (UK) Coal (C' seam) is the uppermost coal present in stratigraphic column and therefore it is only found on isolated hilltops. What little UK seam was present has been surface mined nearly to exhaustion. It is unclear if deep mines were developed into the UK seam as all evidence has been destroyed by subsequent surface operations.

The earliest coal mines in the watershed were deep mines. Little is known about these early deep mines as all mine maps were destroyed in a fire shortly after the mines closed. What little is known about the deep mines has been interpreted from surface features such as entries and subsidence and from drilling. Many of the drift entries are located on the down-dip side of the mine to provide drainage for the mine. As a result, seeps and kill zones of various sizes are often associated with these down-dip entries.

By the post-World War II era, earth moving equipment was available that made surface mining of both the LK seam and UK seam economically feasible in the Twomile Run watershed. These surface mining operations removed intact coal as well as pillars from earlier deep mines. The LK seam was generally mined to a cover of 60 feet. Large quantities of outcrop coal were left in place. The unmined crop width varied from 65 – 120 feet. Mining regulations during this period required miners to leave the crop coal in place. Additionally, the outcrop coal may have been lower quality than the deeper coal. Regrading and revegetation were performed to highly variable standards and degrees of success. Some mined areas are densely forested with positive drainage, while others are barren and show no signs of regrading.

C. Hydrology

AMD is communicated from the mine environment to surface streams in the Twomile Run Watershed in a number of ways. The most obvious manner in which water can flow off of mined out coal seams is through seepages at the coal outcrop. These seepages result from contaminated water flowing down-dip on the underclay of the mined coal until it reaches the surface where kill zones often develop. These seepages are often found at deep mine entries and at the toe of spoil piles pushed out beyond the coal outcrop. Collection of this type of discharge for monitoring and treatment is relatively straightforward due to its confinement by the underclay.

A second way in which AMD is communicated to surface streams is through the local groundwater system. Figure 1 shows a generalized shallow groundwater system. Since the AMD is unconfined in this scenario, effective collection for monitoring and treatment is challenging if not impossible. The underclay beneath the Lower Kittanning coal is not perfectly impervious. It is unclear whether this is due to the intrinsic properties of the underclay or due to anthropogenic causes (perforation by mine operator) or both. Regardless, the permeability of the underclay allows AMD to enter deeper strata where its migration is most likely controlled by a combination of lithology, structure and fractures. This mechanism seems to account for the majority of AMD flow in the Twomile Run Watershed. The following is a conceptual description of factors influencing AMD migration through the groundwater system in the Twomile Run watershed.

The topography of the study area is typical of the Deep Valleys section of the Appalachian Plateau physiographic province. Dendritic drainage patterns have been incised sharply into the plateau producing steep sided valleys separated by narrow flat-topped ridges. The high stratigraphic position of the economically recoverable coal seams limited their occurrence to the tops of these narrow ridges. As a result, the primary economic seam in the area, the Lower Kittanning, is found only in narrow fields (generally less than 2,000 feet from outcrop to outcrop) under less than 100 feet of cover, with 200 feet being the maximum cover in any location.

The ridge top location of the Lower Kittanning and subsequent mining operations has significant implications both in terms of AMD generating potential as well as its subsequent migration through surface and subsurface systems. The implication most directly related to topography is the ridge top location of the Lower Kittanning that places it “above drainage”. That is, the seam is located above the water table and is therefore unsaturated. Above drainage mines are subject to wetting and drying cycles in an oxygen rich, near-surface environment, greatly increasing the likelihood of AMD production. Another implication of the isolated ridgetop setting is that it places the mines in the primary recharge zones for the local aquifers. The result is that much of the recharge to local aquifers is contaminated by AMD.

Once in undisturbed strata, the AMD moves primarily through fractures and joints that are most likely tectonic in origin. Since different lithologies respond differently to tectonic stress, the joints spacing varies with lithology (Minns, 1993). Shales tend to have joint spacing measured in inches while sandstones have much greater joint spacing, commonly tens of feet apart (Nickelson and Hough, 1967). Subsequently, groundwater migrating through vertical fractures will frequently flow laterally down-dip at lithologic boundaries until additional vertical fractures are encountered. In this manner, lithology, structure and fracturing combine to produce a stair-step pattern of groundwater flow toward surface discharge locations (Figure 1). Where this stair-stepping pattern intercepts the hillside, kill zones form. These kill zones are often 50-100 feet lower in elevation than the contributing coal mine. Alternately, if the stair-stepping pattern does not intercept the hillside or an aquitard that forces it to the surface, the AMD enters the stream directly as contaminated baseflow.

As stated above, fracturing is most likely of tectonic origin. However, the steepness of the terrain lends itself to unloading forces that could serve to open existing tectonic fractures thereby increasing secondary permeability. Such forces would tend to open fractures parallel to the valley walls. This scenario would promote groundwater flow parallel to tributaries such as Middle Branch and Huling Branch and toward Twomile Run.

It is the opinion of the authors that AMD is flowing through the local groundwater system from surface and deep mines in Areas 5N and 7 directly to Twomile Run (See Figure 2). This plume of AMD is the source of unaccounted loading described in Section V.B. Buttressing this theory is the presence of an electromagnetically conductive anomaly indicated by airborne remote sensing studies (See Section II.F). Furthermore, contaminated groundwater was encountered by monitoring wells penetrating the suspected plume (See Section IX.D). These lines of evidence strongly suggest that restoration of Twomile Run cannot be accomplished without eliminating the source of this plume, the abandoned mines found in Areas 5N and 7 (See Sections X.J and X.M respectively).

V. Stream Snapshots and In-Stream Data

The purpose of this section is to discuss samples that were taken in Kettle Creek, Twomile Run, and its tributaries as part of this project. In-stream sampling was performed in order to provide a baseline for future efforts and in order to conduct a pollution mass balance. In addition, several new discharges that were identified by the DOE/NETL remote sensing survey were sampled in order to determine their relative contributions to the pollution of Twomile Run.

A. New Discharge Evaluation

Several new discharges were identified as part of the DOE/NETL remote sensing project (See Section II.F). The following table lists the discharges that were sampled as part of this project and their relative pollution impact to Twomile Run. All of the points shown in the table, with the exception of Map140, had never been sampled prior to the DOE/NETL effort. The points are listed from the upstream to downstream. See Map 7 for point locations.

Table 8. New Discharges Evaluated for Importance

Point	Lat./Long	Impact	Description
KC106	41-20-25 77-51-18	Low	Discharge to Twomile between Swamp and Robbins; forms kill zone. Chemistry only.
KC110	41-20-21 77-51-15	Low	Discharge to Twomile between Swamp and Robbins; forms kill zone. Chemistry only.
KC116	41-20-19 77-51-37	Low	Discharge to Middle Branch from hillside above old weir.
Robbins Ditch		Medium	Discharge to Robbins below flume; mostly road ditch seepage.
KC215 Trib	41-20-00 77-51-33	Medium	Small drainage from west side of Twomile Run; station above break on hill
Map140	41-19-54 77-51-25	Low	Alkaline discharge on east side of Twomile Run
KC121	41-19-50 77-51-30	Medium	Drainage from the west that forms small wetland; measured at Twomile Road.
KC231	41-19-26 77-51-10	Low	Discharge zone on pipeline, flows from the west; measured at Twomile Road.

The discharges were sampled for mine drainage chemistry and, where possible, flow rates were measured several times throughout the course of the project. The complete database is contained in the Appendix.

KC106 and KC110 are large kill zones with numerous areas of seepage that emerge and are then lost back into the subsurface. These kill zones are likely caused by infiltration into mine spoils that are much higher in elevation (Area 4 and Area 4A). The pollution travels subsurface until it encounters an aquitard and emerges as diffuse seepage. The discharges do not flow to Twomile Run on the surface. It was not possible to capture these discharges for flow measurement. However, loading analyses in Twomile Run did not indicate an increase in pollution loading between the Swamp inflow and the Middle Branch mouth. Therefore, these discharges are not considered important at this time. If a treatment system is constructed in this area for the Swamp discharges, Robbins 10A/10B, or both, it may be possible to include these discharges (See Sections VII.D and VIII.C).

When the loadings of the other new discharges (Robbins Ditch, KC121, KC215 Trib, Map140, KC231, and KC116) were measured during the first snapshot and added together, they contributed 5 – 10% of the iron, aluminum, acidity, and sulfate loading that was present in Twomile Run above Huling Branch. No one discharge contributed more than 3% of the total pollution loading. Of this pollution, 67 – 84% originated from three of these "new" discharges; Robbins Ditch, KC121, and KC215 Trib. The others were very minor contributors. Therefore, these three discharges are considered of medium importance and all the others are considered of low importance to the restoration of Twomile Run.

The Robbins Ditch discharges may be able to be incorporated into the eventual treatment of Swamp discharges, Robbins 10A/10B, or both (See Sections VII.D and VIII.C). KC121 and KC215 will hopefully be ameliorated by reclamation activities in Areas 5N and 7 (See Sections X.I and X.L). Therefore, no individual treatment systems are recommended for any of these discharges at this time.

B. Twomile Run Snapshot and Mass Balance

An important aspect of this project and others has been the collection of diffuse AMD seepage so that treatment of the polluted water could be assessed. While these efforts have successfully reduced or eliminated surface flows of AMD in kill zones in Robbins Hollow, Huling Branch, and Middle Branch, the amount of AMD collected has always been less than anticipated given the size of the mining area upgradient of the collection system. Some spoil areas have little or no known surface flow of AMD, despite the fact that large areas of open spoil with infiltration rates near 100% are present. The conclusion is that some of the precipitation that infiltrates in spoil areas is being lost through the pit floor and is entering the underlying aquifer.

Stream "snapshots" were performed in order to assess the relative pollution loading from the various discharges and to conduct a mass balance calculation of the in-stream pollution from known discharges. Photo 1 shows the degraded condition of Twomile Run. Efforts to perform mass balance sampling and calculations were performed in 2002 by the DOE/NETL as described in Section II.F. This effort provided the first conclusive evidence that in-stream pollution loading was greater than the sum of known discharges. Building on this new understanding, a more detailed study was performed to determine not just the quantity of missing loading but also where it is entering Twomile Run.

The two most comprehensive Twomile Run snapshots were performed on May 4 and August 10, 2005. The May snapshot was done during moderate-flow spring conditions. The August snapshot was conducted during very low flow summer conditions. For these sampling dates, flow and chemistry measurements were made at all important discharges and at several in-stream locations on Twomile Run and its tributaries. These snapshots addressed only Twomile Run and its tributaries above Huling Branch due to the widespread nature and severity of the Huling Branch pollution. Table 9 shows the sampling stations that were involved in the two snapshots and the flow measurement method at each station. The complete data set is contained in the Appendix. See Map 7 for point locations.

Table 9. Twomile Run Snapshot Stations and Flow Measurement Methods
"No flow" indicates that the station was dry on that sampling date

Point	**May 4**	**August 10**
Swamp at Pipeline	Timed volume	Timed volume
Swamp at Twomile	Flume	No flow
Swamp #1	Timed volume	No flow
Swamp #2	Timed volume	No flow
Swamp #3	Timed volume	No flow
Swamp #4	Timed volume	Timed volume
Swamp #5	Timed volume	No flow
Middle Mouth	Velocity Meter	Timed volume
Robbins Mouth	Timed volume	Timed volume
Robbins Ditch	Timed volume	Not sampled
KC121	Timed volume	Timed volume
KC215 Trib	Timed volume	No flow
Map140	Timed volume	Not sampled
KC231	Timed volume	Not sampled
KC116	Timed volume	Not sampled
TM Above Swamp	Velocity Meter	Timed volume
TM Above Middle	Velocity Meter	Timed volume
TM Below Robbins	Velocity Meter	Timed volume
TM Below KC121	Velocity Meter	Timed volume
TM Above Gasline	Not sampled	Timed volume
TM Below Gasline	Not sampled	Timed volume
TM Above Huling	Velocity Meter	Timed volume

Table 10 shows flow rates and loading values for the May 4, 2005 snapshot for the most critical stations. The stations are listed from the headwaters towards the mouth and in-stream stations are shown in bold font.

The two most important parameters to examine in Table 10 are flow rate and sulfate loading. Iron, aluminum, and acidity are usually not considered conservative in natural stream systems due to deposition, erosion, dilution, alkaline inputs, and other factors. However, acidity is likely conserved in this case because of the lack of alkaline inputs. Figures 3 and 4 are pie charts representing the contributions from each area with respect to the total loading in Twomile Run above Huling Branch.

Table 10. Twomile Run Snapshot Flow and Loading Results from May 4, 2005

Point	**Flow (gpm)**	**Fe (lb/d)**	**Al (lb/d)**	**Acid (lb/d)**	**SO4 (lb/d)**
TM Above Swamp	**511**	**0.9**	**2.7**	**17**	**51**
Swamp at Twomile	75	20.2	20.7	246	1,942
TM Above Middle	**618**	**7.6**	**21.0**	**205**	**1,207**
Middle Mouth	578	0.8	20.5	160	705
Robbins Mouth	120	1.5	4.0	52	431
TM Below Robbins	**1402**	**25.2**	**51.0**	**468**	**2,472**
KC215 Trib	8	0.7	0.0	12	40
Map140	1	0.3	0.0	0	3
KC121	15	0.0	0.7	12	58
TM Below KC121	**1893**	**37.9**	**67.5**	**701**	**2,326**
KC231	7	0.0	0.3	4	24
TM Above Huling	**2258**	**11.9**	**85.4**	**957**	**3,433**

Performing a mass balance on each stream segment requires adding all of the pollution that is contained in the previous in-stream sample plus any new pollution that enters between the two stations and comparing the result to the downstream station. For instance, 511 gpm is present in Twomile Above Swamp and 75 gpm entered from the Swamp at Twomile station for a total of 586 gpm. This is within 5% of the measured value at the next in-stream station, representing good flow capture. The same procedure can be repeated for loadings of conservative parameters such as sulfate.

Continuing this analysis, good flow and loading capture was obtained in the first two stream segments representing Twomile Run from the above the Swamp to below Robbins Hollow. However, the next two stream segments had poor flow and loading capture. Twenty five percent of the flow and 30% of the acidity loading present in Twomile below KC121 was not accounted for. Sixteen percent of the flow, 26% of the acidity, and 31% of the sulfate loading in Twomile above Huling was not accounted for. Examining the entire stream from above the Swamp to above Huling, 42% of the total flow, 47% of the total acidity loading, and 5% of the sulfate loading was not accounted for during this snapshot. If all of the missing flow (943 gpm) on this date was contaminated baseflow, 2 – 3 mg/L Al and 40 mg/L acidity in the baseflow would account for the missing loading. However, it is likely that the missing volume includes both clean and polluted baseflow.

These increases in loading are not solely an artifact of increased flow because the in-stream chemistry actual worsened between Robbins Hollow and Huling Branch on this date despite few known inputs of pollution.

The amount of loading to Twomile Run that was not accounted for from known discharges was higher than expected. Therefore, a second snapshot was performed on August 10, 2005. This snapshot was performed during very low flow conditions in an attempt to further isolate and understand the origin of the missing loading. The following table shows flow rates and loading values for the August 10, 2005 snapshot for the most critical stations. The stations are listed from the headwaters towards the mouth and in-stream stations are shown in bold font.

Note that for the August snapshot, additional samples were taken immediately above and immediately below the Texas Eastern Pipeline crossing of Twomile Run. It was hypothesized that additional contamination could be reaching the stream by following the pipeline.

Table 11. Twomile Run Snapshot Flow and Loading Results from August 10, 2005

Point	Flow (gpm)	Fe (lb/d)	Al (lb/d)	Acid (lb/d)	SO4 (lb/d)
TM Above Swamp	**51.2**	**0.1**	**0.3**	**1.6**	**4**
Swamp at Pipeline	7.0	14.4	1.6	55.2	156
Swamp at Twomile	0	0	0	0	0
TM Above Middle	**71.0**	**0.2**	**0.7**	**17.6**	**40**
Middle Mouth	3.0	0.0	0.0	0.5	3
Robbins Mouth	2.5	0.1	0.5	4.7	21
TM Below Robbins	**78.0**	**0.0**	**1.3**	**18.6**	**63**
KC121	0.8	0.0	0.0	0.6	3
TM Below KC121	**104.0**	**4.4**	**2.2**	**56.5**	**204**
TM Above Pipeline	**115.0**	**0.5**	**3.4**	**47.3**	**256**
TM Below Pipeline	**116.0**	**0.4**	**3.2**	**42.5**	**268**
TM Above Huling	**94.0**	**0.1**	**4.2**	**45.6**	**240**

Note that several stations had no flow on this date, including the Swamp at Twomile, KC231, and the Robbins Ditch. This is particularly significant for the Swamp at Twomile station. On this date, there were 7 gpm present at the Swamp at Pipeline station as shown in Table 11. However, none of this flow reached Twomile Run on the surface. In fact, the pollution loadings in Twomile Run do not reflect the majority of the pollution loading from the Swamp at Twomile station until the TM Below KC121 station. This indicates that, on this date, the loading from this station either did not reach Twomile Run or that the loading reached Twomile Run downstream of Robbins Hollow by flowing subsurface.

As on the May 4 snapshot, significant loading is missing in the segment between Robbins Hollow and below KC121. 24% of flow and 68% of the sulfate loading were missing on this date. In addition, 10% of the flow and 21% of the sulfate loading present above the Pipeline were not accounted for in the TM Below KC121 station. It is possible that the lost loading arises as contaminated baseflow between these two stations. This interpretation has important implications for reclamation and remining considerations for Areas 5N and 7.

Small changes in flow, chemistry, or loading were noted when comparing the stations above and below the pipeline crossing. Additionally, small changes were noted from those points down to Huling Branch. The differences in flows and loadings were small enough to be attributable to errors associated with flow measurements.

Based on these two stream snapshots, the stream segment between the mouth of Robbins Hollow and the Texas Eastern Pipeline crossing appears to collect significant quantities of contaminated baseflow (See Map 7). This represents approximately 3,700 linear feet (0.7 miles) of stream. Smaller amounts of additional loading appear to enter the stream between the pipeline crossing and the mouth of Huling Branch.

The magnitude of the contaminated baseflow is such that complete treatment of all known discharges will not result in a biologically restored stream. The implications of this contaminated baseflow are critical for the planning of future restoration efforts. Recognition of this fact led to an effort to determine the most likely source of the contaminated baseflow and develop appropriate remediation options. Areas 5N and 7 have been identified as the most likely sources of this contaminated baseflow (See Sections X.J and X.M respectively).

C. Impacts to Kettle Creek

Kettle Creek in the vicinity of Twomile Run is circum-neutral with low metals concentrations. The following table shows recent data on the chemistry of the mouth of Twomile Run.

Table 12. Twomile Run Chemistry at the Mouth, 1999-Present

Date	Lab pH	Cond (uS)	Net Acid (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)
10/7/1999	3.40	971	128	7.2	9.3	10.9	353
11/23/1999	3.30	1053	150	9.2	11.7	15.2	463
12/16/1999	3.90	294	40	1.9	2.4	3.3	104
3/8/2000	3.80	291	44	2.1	2.4	4.9	71
5/30/2000	3.90		36	1.5	2.1	3.6	88
6/5/2000	3.70		56	0.8	2.9	7.3	109
7/13/2000	3.60	525	70	2.6	4.2	7.1	148
8/1/2000	3.30		92	2.5	5.6	7.7	270
9/12/2000	3.30	898	116	5.8	7.8	10.1	328
7/29/2002	3.30	761	102	3.4	6.2	7.9	229
10/21/2002	3.30		128	9.0	9.6	10.8	426
8/2/2005	3.40	761	86	1.1	6.3	8.1	406
7/25/2006	3.54	415	43	1.3	3.0	4.3	150
Average	**3.52**	**663**	**84**	**3.7**	**5.6**	**7.8**	**242**

The flow of Kettle Creek is measured at the USGS gage (#01545000) approximately 1.9 miles upstream of the mouth of Twomile Run. No large flows enter in this stream reach. At the gage, the flow is controlled by releases from the US Army Corps of Engineers' Alvin R. Bush Dam. The daily mean flow rates for the last 44 years of record were obtained for this station from the USGS website. The data show that the months of March – April are generally high flow months, while July – October are low flow. The average mean flow for Kettle Creek was 168,000 gpm with a range of 32,000 – 539,000 gpm.

Flow rates at the mouth of Twomile Run measured in the last few years by DEP, DOE/NETL, and HE have ranged from 200 to 10,000 gpm. It is reasonable to assume that the low flow rates of Twomile Run correspond somewhat with the low flow rates of Kettle Creek. If that is the case, Kettle Creek flows between 50 and 160 times greater than Twomile Run, providing significant dilution of the pollution loading from Twomile Run.

Despite the relatively low flow of Twomile Run compared to Kettle Creek, serious visual impacts are present in Kettle Creek downstream of the mouth of Twomile Run. Photo 2 shows the confluence of Twomile Run and Kettle Creek. When the acidic, metal-laden water from Twomile Run mixes with the alkaline water of Kettle Creek, the metals precipitate, forming white and orange solids on the streambed. This "plume" persists along the eastern bank of Twomile Run for 150-450 feet downstream of the confluence. The size and length of the "plume" varies with the flow conditions.

The magnitude of the pollution loading from Twomile Run appears to be approximately equal to the loading from all of the discharges to Kettle Creek from the west side combined. The exact proportion is difficult to determine because the west side discharges enter in numerous locations with difficult access.

D. Fish and Benthic Macroinvertebrate Surveys

Twomile Run

The upper half of Twomile Run from its headwaters to 100 meters upstream of its confluence with Middle Branch has a healthy reproducing population of native brook trout and is classified by the PAFBC as a Class A Wild Trout Stream. Twomile Run is devoid of fish life immediately upon the first inflow of AMD at the "Swamp at Twomile" sampling station. At this location the change in water quality is drastic as a person can stand with one foot in net alkaline water with a pH of 6 where clean stream substrate is covered with benthic macroinvertebrates and one foot in net acidic water with a pH of 4 where stream substrate is stained by heavy metal precipitates and devoid of aquatic life. TU reports that brook trout habitat on Twomile Run is in excellent condition, other than sections where Fe and Al precipitates coat the stream substrate, and water quality problems from AMD appear to be the only factor limiting a healthy fish population in Twomile Run downstream of its confluence with the Swamp discharges.

Huling Branch

The PA Fish and Boat Commission and TU conducted an electrofishing survey at two sites on Huling Branch in July 2004. Two 100-meter reaches were surveyed, "Huling 1" above the AMD, and "Huling 2" just downstream of where the first major source of AMD (Huling A) had at one time entered the stream. The purpose for the survey was to document restoration of native brook trout within a section of stream that had been severely degraded from the first major input of AMD into Huling Branch. This first major flow of AMD, which emanates from a deep mine, was collected and piped to a site approximately 2000 feet downstream prior to the fish survey. Although several small AMD seeps were still observed along the banks of "Huling 2", an improvement in water quality was supported by the results of the electrofishing survey of "Huling 2" that documented the existence of a native brook trout population throughout the entire reach surveyed. The PA Fish and Boat Commission estimated brook trout biomass at 24.9 kg/ha for “Huling 1” and 13.9 kg/ha for “Huling 2.” According to TU, brook trout habitat on Huling Branch is in excellent condition, other than sections where Fe and Al precipitates coat the stream substrate, and water quality problems from AMD appear to be the only factor limiting a healthy fish population in the rest of Huling Branch.

The PA Fish and Boat Commission and TU collected benthic macroinvertebrate samples in July 2004 at “Huling1” and “Huling 2.” Samples at “Huling 1” indicated the presence of several pollution sensitive taxa in the mayfly, stonefly, and caddisfly orders (Ephemeroptera: Heptageniidae; Plecoptera: Leuctridae, Nemouridae, Perlodidae; Trichoptera: Hydropsychidae, Philopotamidae, Rhyacophilidae). In addition, dragonfly (Odonata: Cordulegastridae, Gomphidae) and beetle (Coleoptera: Elmidae) individuals were also present.

Benthic macroinvertebrate samples from “Huling 2” included slightly reduced populations of pollution sensitive taxa of the stonefly and caddisfly orders (Plecoptera: Leuctridae, Nemouridae; Trichoptera: Hydropsychidae, Limnephilidae, Philopotamidae, Rhyacophilidae). In addition, dragonfly (Odonata: Cordulegastridae, Gomphidae) and beetle (Coleoptera: Elmidae) individuals were also present. Although this site is located downstream of an acid mine drainage seep there is only a slight reduction in abundance and diversity of pollution tolerant taxa.

TU and the KCWA sampled benthic macroinvertebrates in July 1999 near the confluence of Huling Branch and Twomile Run (HUB 001) that revealed only two pollution tolerant taxa (Diptera: Chironomidae, Simulidae). The marked decrease in abundance and diversity of benthic macroinvertebrates indicates severely degraded conditions as a result of the AMD originating upstream. See the Appendix for more information.

Kettle Creek

Electrofishing surveys on lower Kettle Creek were conducted upstream and downstream of the AMD impacts in 1997 (USGS and PA Fish and Boat Commission), 2001 (TU and PA Fish and Boat Commission), and 2006 (TU and PA Fish and Boat Commission). Because sampling efforts were not consistent, comparisons between non-AMD impacted and AMD-impacted stream reaches cannot be made using the Index of Biotic Integrity for individual fish species, biomass calculations, or relative abundance estimates. Nevertheless, 2001 and 2006 surveys appear to indicate that the number of fish species in Kettle Creek downstream of the confluence with Twomile Run is comparable to the number of species found upstream of the AMD (see the Appendix). According to TU, the major impacts to the fish are the slightly elevated Al concentration and in-stream habitat degradation caused by the Al and Fe precipitates. Every mg/L of excess alkalinity generated and every mg/L of heavy metals removed as a result of successful remediation activities within the lower Kettle Creek watershed will positively impact the fish population.

Electrofishing surveys should be conducted at least every other year during low-flow conditions in late summer to document changes in fish species composition and relative abundance. While the water reaches temperatures that are too high to support a self-sustaining wild trout fishery, a sustainable smallmouth bass fishery or a stocked brown trout put-and-take fishery are both viable considerations for lower Kettle Creek. These potential management options should be periodically evaluated as remediation projects are completed and water quality and habitat conditions continue to improve.

TU and KCWA collected benthic macroinvertebrate samples in July 1999 above the AMD impacts ("KEC030") and downstream of all AMD impacts near the mouth of Kettle Creek at Westport ("KEC002"). Samples collected at "KEC030" contained several pollution sensitive taxa of the mayfly, stonefly, and caddisfly orders (Ephemeroptera: Isonychidae, Heptageniidae; Plecoptera: Perlidae; Trichoptera: Hydropsychidae, Polycentropodidae, Brachycentridae, Psychomyiidae). These collections also indicated the presence of beetles (Coleoptera: Elmidae) and other more pollution tolerant individuals (Annelida and Diptera: Chironomidae).

Benthic macroinvertebrate collections at KEC002 contained only beetle (Coleoptera:Elmidae) and true fly (Diptera: Chironomidae) taxa. The marked decrease in abundance and diversity of benthic macroinvertebrates at this site indicates degraded conditions as a result of the AMD that originates upstream.

VI. Middle Branch Collection and System Reconstruction

The Middle Branch passive treatment system was constructed in 2000 by BAMR to treat two highly acidic discharges identified as R1 and R2 (See Map 3 and Map 10). Both the initial construction and recent reconstruction of the system were performed under grants that were not part of this project. However information is included here for completeness.

Design parameters of the system are shown in the following table.

Table 13. Middle Branch Treatment System Original Influent Design Parameters

Avg. Design Flow (gpm)	50	Total Iron (mg/L)	15
pH	3.0	Aluminum (mg/L)	75
Net Acidity (mg/L)	750	Manganese (mg/L)	20

The original system consisted of a pair of Vertical Flow Ponds (VFPs), which are also known as Successive Alkalinity Producing ponds (SAPS). The layout is shown on Figure 5. The VFPs consisted of 3 feet of limestone with 2 feet of organic compost over the limestone. The VFPs were arranged in parallel and discharged to a common oxidation/settling pond. Effluent from the oxidation/settling pond passed through a small aerobic wetland before the flow was split evenly between two manganese removal beds.

Effluent from the treatment system degraded in quality over time leading to the performance of an "autopsy" on June 15, 2004. The limestone was examined and was found to be coated with solids but not plugged. Photo 3 shows an excavator digging into the limestone of one of the VFPs. Photo 4 shows a close-up of the condition of that limestone after excavation. Several design flaws were noted during this autopsy, most of which served to promote short-circuiting. However, no one cause for the systems poor performance could be determined from the examination of the systems components.

The VFPs had a combined area of 1,240 m^2. Given this treatment area and the data in Table 13, the VFPs would have had to produce alkalinity at a rate greater than 160 g/m^2/day in order to produce a net alkaline effluent. Typically, VFPs generate alkalinity at a rate of 30-40 g/m^2/day (Rose 2006). While in operation, the VFPs generated alkalinity at an average rate of 52 g/m^2/day. Therefore, it is not accurate to describe the Middle Branch Treatment System as "failed" because it was producing alkalinity at a rate greater than what would be expected. The primary problem was that the system was undersized for the design acidity loading.

The discharges treated by the system have been identified as sampling locations R1 and R2. The following table provides a characterization of these discharges. While it is clear that the system was undersized for even the design average flow, the highly variable acidity loading from the R2 discharge contributed further to the poor effluent quality from the system. The R2 discharge is characterized by wide variation in flow rate with little dilution even at the highest observed flows (note high standard deviations in Table 14). As a result, the loading to the treatment system from the R2 discharge is extremely erratic.

Table 14. R1 and R2 Discharge Characteristics.

R1 (n=24)	**Avg**	**sd**	**Min**	**Max**
Flow (gpm)	14	5	3	24
Acidity*	420	194	98	795
Fe (mg/L)	8	5	1	21
Al (mg/L)	54	26	9	105
Mn (mg/L)	15	6	4	24
Acid (lb/d)	66	39	4	143

R2 (n=17)	**Avg**	**sd**	**Min**	**Max**
Flow (gpm)	45	49	0	182
Acidity*	737	249	362	1,128
Fe (mg/L)	21	11	6	38
Al (mg/L)	87	41	12	147
Mn (mg/L)	20	7	9	31
Acid (lb/d)	236	324	0	1,297

**Net Acidity as $CaCO_3$; sd is standard deviation*

In summary, the two main factors that contributed to the poor effluent water quality from the Middle Branch Treatment System were – 1) the system was undersized; and 2) the highly variable and severe loading rates from the R2 discharge frequently overwhelmed the system. Based on this understanding, a project is underway as of the writing of this report to increase the treatment capacity of the system as well as minimization and normalization of flows from the R2 discharge.

A. Water Collection

The Middle Branch R2 Collection system was installed in September of 2006 in order to decrease loading to the Middle Branch Treatment System. The goal was to collect and divert a portion of the highly variable R2 discharge. Site investigations suggested a connection between the R2 discharge and a collapsed drift entry upslope of the treatment system. Excavation of the collapsed drift revealed six to eight feet of impounded water within the deep mine. Photos 6 and 7 show the excavated mine entry and intact mine timbers. The water elevation was sufficient to force seepage through an adjacent surface mine (also on the Lower Kittanning Seam) that appeared to be the source of the R2 discharge. A collection system was installed within the entry that lowered the mine pool and relocated the collected flow to the Huling Branch watershed (See Photo 8 and Map 10). The relocation removed excessive loading from Middle Branch and, by putting it into Huling Branch, moved the loading 3,700 feet downstream on Twomile Run. The relocation did not further degrade Huling Branch, because the stream is already dead from other flows of AMD.

Installation of the collection system resulted in an immediate reduction in flow rate at the R2 discharge. It appears that flow and loadings at R2 have been decreased by 60-80% (Figure 6). The decrease should be sufficient to allow the existing system, with modification, to reliably treat the summed AMD loading produced by R1 and R2. These modifications are described in detail in Section VI.B.

Continued monitoring of the Huling F collection system will provide valuable base-line data for assessment of any reclamation efforts and/or treatment system design.

B. System Rehabilitation

As discussed in Section II.D, the treatment system was undersized for the loading conditions on the site. The success of the water collection effort (See Section VI.A) has resulted in a more manageable treatment load. However, the system is still too small as originally designed. To increase treatment capacity a number of repairs and operational improvements have been proposed. The improvements utilize the existing ponds. The most significant change will be the conversion of the manganese removal beds to vertical flow ponds with compost. See Figure 7 for the planned layout. The existing VFPs will be refilled with new limestone and compost. DCNR removed the fouled limestone in late October 2006 and used it for road aggregate (See Photo 5). The system improvements will double the treatment capacity of the overall system. It also will allow for the original vertical flow ponds to be reconstructed with little modification. The modifications will be implemented in spring 2007.

VII. Swamp Reclamation Results and Recommendations

One main goal of this study was to evaluate the effectiveness of the Twomile Run "Swamp" reclamation project that was completed in 2005 and to provide recommendations for the discharge (See Map 3). The project was implemented with an expectation that it would reduce the flow and/or improve the chemistry of the discharge.

A. Effectiveness of Reclamation

Historically, the "Swamp" discharges were sampled where the aggregated discharges cross the Texas Eastern pipeline. BAMR started a major sampling effort in 1995. Although earlier data exists for this station, only the more recent data will be used to evaluate pre-reclamation conditions. The reclamation job was completed in 2004 (See Section II.K).

The following table shows statistics for the flow, chemistry, and loading at this station both pre-reclamation and post-reclamation. The pre-reclamation data ranged from August 1995 to July 2002, which included 50 chemistry samples and 41 flow rates. Although final accounting and project close-out tasks were completed in 2005, the grading was completed in June 2004. Post-reclamation data ranged from September 2004 to October 2006, which included 24 chemistry samples and 23 flow rates. Note that the pre-reclamation sampling included flow rates measured in a v-notch weir while post-reclamation flow rates were measured using the timed volume method. Also shown are the percent decreases in each parameter.

Table 15. Pre- and Post-Reclamation Discharge Statistics (Swamp Pipeline)

	Flow (gpm)	**Lab pH**	**Cond (uS)**	**Chemistry Parameters (mg/L)**						**Loading (lb/d)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**TSS**	**Acid**	**Al**	**SO4**
25^{th} Pre*	13	2.9	1659	424	31	21	27	610	4	94	4	146
25^{th} Post	15	2.9	1402	335	33	17	23	835	3	109	9	266
% Change	**14**		**-15**	**-21**	**7**	**-20**	**-16**	**37**		**16**	**106**	**82**
Ave. Pre	74	3.1	1929	522	80	31	41	906	4	389	39	531
Ave. Post	45	3.0	1793	402	79	24	32	1140	7	238	24	602
% Change	**-39**		**-7**	**-23**	**-1**	**-23**	**-23**	**26**		**-39**	**-38**	**13**
Median Pre	44	3.1	1897	505	50	27	37	814	4	217	19	352
Median Post	30	3.0	1713	374	50	19	29	1003	5	143	10	366
% Change	**-31**		**-10**	**-26**	**1**	**-30**	**-23**	**23**		**-34**	**-44**	**4**
75^{th} Pre*	123	3.1	2200	641	144	43	54	1100	4	517	51	684
75^{th} Post	54	3.1	1983	456	86	25	41	1495	8	310	33	885
% Change	**-56**		**-10**	**-29**	**-40**	**-41**	**-22**	**36**		**-40**	**-36**	**29**
90^{th} Pre*	184	3.2	2420	694	161	48	62	1513	4	931	114	1410
90^{th} Post	117	3.1	2632	553	167	44	48	1772	11	586	64	1308
% Change	**-37**		**9**	**-20**	**4**	**-7**	**-23**	**17**		**-37**	**-44**	**-7**

* Percentiles

General trends can be identified in the data above. The flow rate decreased by 30 – 50% in all categories except the 25th percentile. Acidity concentration decreased by 20 – 30% and aluminum concentrations decreased by about 20%. Sulfate, and in some cases iron, increased after the reclamation. This may have been due to the exposure and leaching of pyrite and sulfate salts that were present in the spoils prior to reclamation. More recent data indicates that iron and sulfate may be returning to their pre-reclamation levels.

In order to determine if the decreases in flow rate were due to the reclamation or if they were due to the general hydrologic condition during sampling, monthly rainfall data were obtained from a weather station located in Williamsport, PA and certified by the National Oceanic and Atmospheric Administration. This station is located approximately 46 miles to the east of the Twomile watershed. Data were also obtained from the US Army Corps of Engineers for a station maintained at the Alvin R. Bush dam. Annual precipitation totals reported for each station are shown in Table 16.

Table 16. Yearly Precipitation Totals (Inches), 1992-2005

Year	**NOAA Williamsport**	**Alvin R. Bush Dam**
1992	41.1	43.1
1993	42.3	42.2
1994	45.3	46.0
1995	31.3	33.6
1996	53.9	47.5
1997	30.1	31.8
1998	40.1	30.8
1999	45.5	30.9
2000	41.9	31.1
2001	35.1	28.6
2002	43.0	33.8
2003	53.2	51.2
2004	51.6	49.9
2005	48.1	33.3

Analysis of the precipitation data suggests that the ACE reports are recently in error, so only the Williamsport NOAA data were used in precipitation analyses. Between 1992 and 1997, both stations averaged 40.7 in/yr of precipitation. Between 1998 and 2005, the Williamsport station averaged 44.8 in/yr while the Dam station averaged 36.2 in/yr. It is unlikely that the KC watershed has received 20% less precipitation than Williamsport during the last eight years. The more likely explanation is the under-measurement of precipitation at the dam.

Decreased flow at the Swamp Pipeline station cannot be attributed to year-to-year variation in precipitation. During the pre-reclamation monitoring period (1995-2002), the average annual precipitation (Williamsport NOAA station) was 40.1 inches. During the post-reclamation monitoring period (2004-2005), the average annual precipitation was 49.9 inches. Precipitation in the post-reclamation period was 24% higher than the pre-reclamation period, yet the average flow rate decreased by 31%.

The reclamation caused this change in three primary ways. First, establishing vegetation on the site allowed for evapotranspiration, which was virtually non-existent prior to reclamation. In addition, grading the site caused water that was flowing towards the kill zone to flow to other areas. Of the 127-acre drainage prior to reclamation, approximately 3 acres now drain to Shintown Run. Finally, the grading and vegetation reduced infiltration and increased runoff, which means that more water leaves the site during and immediately after precipitation events, rather than infiltrating the spoil and being released slowly over time.

Based on the analysis of flow, chemistry, loading, and rainfall data, it appears that the reclamation job was successful in reducing the overall acidity and aluminum loading from the area by about 30-40%. Therefore, the size and cost of a treatment system for the discharge will be reduced by 30-40% compared to pre-reclamation levels. This reduction in loading has been due to a decrease in both flow rate and pollution concentrations (see Table 15). Acidity concentration, and therefore loading, may decrease further if the iron concentration continues to decrease and reaches pre-reclamation levels.

B. Swamp Collection

In order to better quantify the discharges emanating from the reclaimed surface mine, five subsurface collection systems were installed along the downdip edge of the mine. These collection systems were intended to intercept shallow contaminated groundwater flow before it reached the large area of diffuse seeps known as the "Swamp Kill Zone". In addition to consolidating the diffuse discharges into five points, the collection was intended to capture the discharges at a higher elevation thereby increasing the available treatment area. The collection systems, identified as Swamp #1 through #5, are shown on Map 8.

The collection systems were constructed by intercepting and following shallow flows of AMD using an excavator. Once the source of groundwater was found and the maximum amount of flow intercepted, perforated SDR 35 pipe was installed in a bed of 2-4 feet of non-calcareous #3 sandstone aggregate. Solid pipe was used to carry the flows to the surface. The transition between perforated and solid pipe was accompanied by a clay plug in the trench and around the pipe to ensure maximum collection. Final outfall locations were chosen to take advantage of existing surface drainages thereby minimizing erosion and vegetation stress. Ultimately, these drainages combine and flow to the "Swamp at Pipeline" monitoring station. A construction description of each collection system follows.

The Swamp #1 collection system is located just south of an impoundment left on the site by the last coal operator mining in this area. The trench was excavated on contour starting in the wooded area to the south for a distance of 150'. This trench was 8 – 10 feet deep and aggregate was placed 3– 5 feet deep. The surface elevation of the trench was at least 25 feet lower in elevation than the Lower Kittanning coal seam. The water flowing into this trench originated from a very hard brown to gray blocky shale/siltstone in the bottom 4 feet of the ditch. The shale/siltstone unit was iron stained and contained many plant impressions. An iron stained gray to white large grained sandstone unit was on top of this water bearing zone.

At the end of the perforated pipe (150’), an 8-inch Tee with 6-inch reducer was installed, followed by 90 feet of 8-inch solid pipe to daylight the discharge to a small channel in the kill zone. The other arm of the Tee has another 6-inch by 8-inch reducer along with 26 feet of perforated 6-inch pipe and aggregate collecting seepage.

The Swamp #2 collection system extends underneath the reclamation collection pond and was placed directly into a wooden drainage box from an abandoned deep mine or pit drain. Photo 9 shows the collection system pipe and mine box. The wooden box measured 6 inches high by 10 inches wide. A rubber 12-inch fernco fitting was used to connect the box to a 5-foot length of 12 inch diameter pipe. A PVC reducer was used to connect the 12-inch pipe to 8-inch pipe. The 8-inch solid pipe was then trenched for a distance of 140 feet and discharges into a small drainage channel at the edge of the kill zone. No other water was found to be flowing within this channel.

The Swamp #3 collection system contained 155 feet of pipe, of which 30 feet is perforated pipe. The soils in the trench were heavily mottled with iron-stained yellow sandstone. The trench was less than 3 feet deep and was excavated into soils at least 20 feet lower than the Lower Kittanning coal seam. The trench terminated beside the Swamp #2 collection system.

The Swamp #4 collection system was intended to intercept shallow flow of groundwater before it emerged in the Swamp kill zone. Water collected by this trench was at least 30 feet lower in elevation than the Lower Kittanning coal seam. The trench started at the westernmost end of the kill zone and was excavated at the very edge of the kill zone upslope of the kill zone area. Water was found in soils from the surface down to 3 feet in depth. The soil was weathered yellow sandstone that was heavily mottled. Many of the roots from the trees were iron stained and helped direct water to the subsurface. The trench was 676 feet long and used 654 feet of perforated 6-inch pipe. Aggregate was used in the entire length of the ditch except for the first 46 feet from the discharge end of the trench. The collection trench ended with the last 22 feet of ditch containing only aggregate without pipe.

A 150 feet section of the Swamp #4 trench beginning about 300 feet from the discharge end was excavated in the Lower Kittanning leader coal horizon. The coal was characterized as mostly carbonaceous shale with some blocky coal streaks mixed in layers. This portion of the trench ranged between 6 feet and 9 feet in depth.

The Swamp #5 collection system was excavated in the wooded area west of the Swamp kill zone. This collection trench used 183 feet of 8-inch pipe to collect shallow ground water flowing adjacent to a small drainage. Approximately 30 feet of perforated pipe was used to collect this water.

The discharges from the collection systems were monitored for flow and chemistry between December 2004 and October 2006. Flows and chemistry were also measured at the Swamp at Pipeline station and the Swamp at Twomile station, but on a less frequent schedule. Figure 8 tracks the individual flows of the collection system pipes. Figure 9 compares for each day the summed flow of the Swamp Collection pipes and the flow at the Swamp at Pipeline and Swamp at Twomile. Both figures ignore a huge flow event that occurred on September 9, 2006 after a 24-hour 2.4 inch precipitation event occurred just after a series of rainstorms that produced 8 inches of precipitation over the previous 7 day period. The collection pipes produced approximately 560 gpm of flow on this day and the flumes at the Gas Pipeline and at Twomile were overtopped, which occurs at flows > 880 gpm. Samples were not collected during this event because all flows were very turbid with sediment.

Table 17. Swamp Collection and Swamp Pipeline Average Results, 2004-2006

Station	**Flow (gpm)**	**Field pH**	**Cond (uS)**	**Chemistry parameters (mg/L)**					**Loading (lb/d)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**Acid**	**Al**	**SO4**
Swamp #1	3.2	3.3	867	217	6	9	28	523	10	1	22
Swamp #2	10.3	3.0	2267	726	18	21	95	1697	89	12	177
Swamp #3	5.8	3.5	645	189	1	4	25	452	12	2	22
Swamp #4	4.7	3.2	939	181	20	12	15	480	11	1	28
Swamp #5	1.3	4.0	131	18	1	1	1	37	0	0	1
Sum of Pipes *	**25.3**	**3.2**	**1359**	**400**	**12**	**13**	**51**	**950**	**122**	**15**	**250**
Swamp At Pipeline	46.6	3.3	1785	401	84	24	31	1150	248	25	628
Swamp At Twomile	51.9	3.1	1402	287	15	18	30	869	270	29	781

*Represents totals for flow and loading; weighted averages for chemistry parameters

Table 17 shows the average results of the sampling program. The chemistry varies between the collection systems. Swamp #2 has the most contaminated water and, because the flow is also highest, produces most (73%) of the acidity loading. Swamp #2 is the only collection system that extends back into the original surface mine pit and collects water off of the mined out Lower Kittanning coal seam. The other Swamp collection systems are located at a lower elevation and collect water that is flowing through strata beneath the original coal seem. Swamp #2 was completely dry from May – August 2005, while the other pipes continued to produce acidic water. This result suggests that a portion of the water flowing on the abandoned pit floor is lost through the pit bottom. Swamp #4 collection system is located at the lowest elevation and was never dry during the monitoring period.

The Swamp #5 collection system is only marginally contaminated. This pipe represents the water quality, but not necessarily the total flow, of a small drainage basin located to the west of the kill zone.

The summed flow produced from the collection systems was substantially less than the flow measured at the pipeline. Figure 9 graphically compares the flow of the pipes and at the pipeline. Flow at the pipeline (maroon bar) was always substantially higher than the summed pipe flow (blue bar). The difference was reflected in contaminant loadings as well. Table 18 shows the percentage of flow and loadings measured at the pipeline that could be attributed to the summed collection systems. Generally, the collection systems accounted for less than 50% of the flow and contaminant loading observed at the pipeline.

Table 18. Swamp Pipeline and Collection Pipe Loading Comparison

Date	Flow at Pipeline (gpm)	Sum of Pipes / Pipeline (%)			
		Flow	Acid Load	Al Load	SO4 Load
5/4/2005	39	43%	29%	46%	30%
3/22/2006	51	35%	25%	43%	21%
5/17/2006	57	30%	15%	20%	13%
6/14/2006	35	54%	71%	101%	35%
7/14/2006	30	27%	24%	52%	18%
8/31/2006	184	46%	72%	76%	65%
9/19/2006	84	46%	71%	104%	70%
Average	**69**	**40%**	**44%**	**63%**	**36%**

When differences between the collection systems capture and the pipeline flow were recognized, the Swamp area was searched for additional flows of AMD. No additional point sources of AMD were discovered. The collection systems successfully collected all of the water originally flowing on the surface of the Swamp. The kill zone is now dry at the surface, except for the ditched flows of water discharging from the collected systems. Despite the dry surface conditions, the channel carrying the collected water between the kill zone and the pipeline gains contaminated baseflow.

The AMD channel crosses the pipeline and flows down a steep hill approximately 1,700 feet to Twomile Run. Table 19 shows flows and percentage changes in loadings for 11 dates when both flow and chemistry data are available for both stations. The data were used to compare the loadings at each station on those dates to determine if additional loading is being produced in the channel between the Pipeline and the stream.

With the exception of two dates (5/4/05 and 8/10/05), the flow and loading between the two stations is comparable. Note that the sampling round on 8/10/05 was conducted under extremely low flow conditions when no flow from the Swamp was reaching Twomile Run in the discharge channel. Seven gallons per minute were present at the Pipeline crossing but this flow was lost to evaporation and to the subsurface before reaching the stream. Therefore, on this date, 100% of the loading present at the pipeline was missing.

Based on the flow and loading comparisons between the collection pipes, the pipeline crossing and the Swamp At Twomile station, it is recommended that any treatment system be constructed between the Pipeline and Twomile Run. This will allow treatment of a majority of the loading while still providing sufficient room for treatment. See Section VII.D for more detailed recommendations.

Table 19. Comparison of Swamp At Pipeline and Swamp At Twomile, % change

Date	Flow at Pipeline (gpm)	Flow at Twomile (gpm)	% Change from Pipeline to Twomile			
			Flow	Acid Load	Al Load	SO4 Load
9/3/2004	27	29	7%	-6%	3%	-6%
5/4/2005	39	75	94%	44%	99%	143%
8/10/2005	7	0	-100%	-100%	-100%	-100%
12/5/2005	125	100	-20%	-38%	-35%	-31%
1/12/2006	125	150	20%	-1%	5%	-1%
3/22/2006	51	65	28%	9%	46%	22%
5/17/2006	57	69	21%	8%	56%	25%
6/14/2006	35	38	9%	-25%	1%	-62%
7/14/2006	30	38	25%	-15%	13%	-18%
8/31/2006	184	217	17%	1%	-11%	4%
9/19/2006	84	98	17%	-14%	-11%	-3%
Average	**69**	**80**	**11%**	**-13%**	**6%**	**-3%**

C. Recent Results

Recommendations for the Swamp discharge will be made based on the most recent data. Statistics on the data taken over the last two years are shown below.

Table 20. Statistical summaries for Swamp at Pipeline stations, Sept 2004 – Oct 2006

	Flow (gpm)	Field pH	Cond (uS)	Chemistry Parameters in mg/L						Loading (lb/d)		
				Acid	Fe	Mn	Al	SO4	TSS	Acid	Al	SO4
Count	23	10	15	15	15	15	15	15	14	15	15	15
Average	45	3.3	1793	402	79	24	32	1140	7	238	24	602
75^{th}*	54	3.4	1983	456	86	25	41	1495	8	310	33	885
90^{th}*	117	3.5	2632	553	167	44	48	1772	11	586	64	1308

* Percentiles

Although the reclamation appears to have reduced the acidity and aluminum of the discharge, the water quality is still severe. However, it is important to note that the data above represents statistical summaries, not conditions that occurred simultaneously. For instance, the highest measured acidities occurred at the lowest measured flow rates. Note the extreme differences in flow rate and loading between the 75^{th} percentile and 90^{th} percentile. This indicates that the calculations are being skewed by several very high flow rates.

Treatment at the 90^{th} percentile level is recommended because these discharges represent the first AMD impacts to Twomile Run. Upstream of this point, Twomile Run supports native brook trout populations. Therefore, it is important to treat all flows from this area whenever possible so that gains in stream restoration are not lost during high flows.

It is also important to note that one extremely high flow event was observed on September 2, 2006. The rain gauge at the Alvin R. Bush dam had reported 2.4 inches of rain in the preceding 24 hours. Nearly eight inches of rain had fallen over the preceding seven days. The flow at the pipeline station on that date was visually estimated to be 1,500-2,500 gpm but the flow rate could not be measured. Photos 10, 11, and 12 were taken on this date and show the unusually high flow at several locations. Flow from Swamp #5, normally the lowest flowing and least contaminated system, was over 300 gpm. Most of this flow was surface water captured by the collection system. Surface water flowing down the drainage above Swamp #5 was found to have eroded into the collection area, exposing the aggregate drain system. A portion of the flow was entering the aggregate and was therefore incorporated into the 300 gpm flow rate measured. More surface water flow was bypassing the collection system than was captured by it.

While this high flow event has serious implications for treatment in this area, it should be noted that the reclamation project probably had the positive effect of allowing more precipitation to run off of the site immediately, rather than infiltrating the spoils and emerging as mine drainage. This high flow event highlights the importance of routing clean surface water around the treatment system and of installing a high flow bypass structure for the system.

D. Recommendations

The quality of this discharge is on the upper limits of water that is being successfully treated by passive treatment systems. Therefore, both passive and active treatment alternatives are presented below. However, there are three recommendations that should be followed regardless of whether a passive system or an active system is chosen. These recommendations include:

- Continued monitoring of the Swamp At Pipeline station;
- Construction of a clean-water by-pass channel for the Swamp #5 collection area; and
- Periodic liming/fertilization of the reclaimed area, if necessary (See Section X.I).

Recent results indicate that iron and sulfate are returning to pre-reclamation levels, which will further reduce the overall acidity of the discharge. Sampling of the flow rate and chemistry at the pipeline location should continue on a quarterly basis in order to track this trend.

The clean-water drainage that originates north and west of the Swamp kill zone should be separated from the contaminated Swamp flows. This drainage is represented by the Swamp #5 collection pipe (See Table 17). This flow has very low metals and acidity and represents clean surface and ground water with minimal AMD influence. A new channel should be constructed to transport this clean water through the site and across the Texas Eastern and Dominion gas pipelines separate from the contaminated flows in this area. Note on Map 8 that Dominion Energy has proposed to construct a new pipeline parallel and to the west of the existing pipeline. Permission from the pipeline companies will be required in order to construct the channel over the pipeline. The channel must extend below the pipeline and beyond the capture point for the eventual treatment system. Approximately 1,400 feet of channel should be constructed with a capacity of at least 3,000 gpm. The channel should be located north of the existing channel that carries the contaminated mine water and it should be lined with impervious material and 1 foot of R4 limestone aggregate. The limestone will provide some treatment of the marginally contaminated water, especially at low flow, but the primary purpose of the channel is to allow this flow to reach Twomile Run without mixing with the more contaminated Swamp discharges.

Table 21. Design Parameters and Cost Estimates for Bypass Channel

Capacity (gpm)	2,000
Length (feet)	1,400
R3 Limestone Aggregate (tons)	1,050
Impervious Liner (ft^2)	24,500
Cut volume (CY)	1,000
Materials	\$27,500
Earthwork and construction	\$8,500
Site difficulty contingency (25%)	\$7,000
Design/Engineering/Permit (20%)	\$10,000
TOTAL ESTIMATED COST	**\$53,000**

This channel could be constructed before the treatment system and the subsequent flow and chemistry at the Swamp at Pipeline station could be monitored to determine the effects of channel construction on total flow and loading. However, it is anticipated that this action will remove modest amounts of flow at normal flow conditions. The primary reasons for constructing this channel are to prevent clean water from becoming contaminated and to manage large flows from storm events.

The reclamation was successful at reducing the flow and loading of the discharge. These reductions depend entirely on the success of the vegetative cover on the site since no excess alkalinity was mixed with the spoil column below 6 inches in depth. Therefore, maintaining a robust vegetative cover is crucial. The reclamation was completed in 2005 and the site was sampled for soil parameters and re-limed and re-fertilized in April 2006. The site should be visually inspected quarterly to assess vegetation stress and tested as necessary to determine if more lime or fertilizer are required. See Section X.I for more detailed recommendations.

Passive Treatment Option

The aggregate Swamp discharge represents severe AMD that is near the limit of what is considered suitable for reliable passive treatment. Similar water chemistry is being passively treated, however, at the Anna S Deep Mine treatment project in Babb Creek (Tioga County). The Anna S project treats the Hunters Drift discharge with a vertical flow pond approach. The Hunters Drift passive system was built as a full scale experimental system. The site includes another treatment system for the more moderate discharges (Anna S1 and S2), which were the original treatment targets. As the project progressed, plans to install a similar vertical flow technology for the Hunters Drift discharge were formulated and implemented. Table 22 compares the Hunters Drift (HD) and Swamp (SW) chemistry.

As shown in Table 22, the two discharges have similar chemistry. Both discharges are acidic with high iron and aluminum concentrations.

Table 22. Hunter's Drift (HD) and Swamp Pipeline(SW) Data Comparison

	Flow (gpm)		**Acid (mg/L)**		**Fe (mg/L)**		**Mn (mg/L)**		**Al (mg/L)**		**SO4 (mg/L)**	
	SW	**HD**	**SW**	**HD**	**SW**	**HD**	**SW**	**HD**	**SW**	**HD**	**SW**	**HD**
Average	45	278	402	491	79	44	24	10	32	36	1140	715
75th	54	334	456	567	86	56	25	12	41	39	1495	863
90th	117	538	553	626	167	76	44	13	48	48	1772	1013

The Hunters Drift passive system consists of four VFPs arranged in parallel. A flow control box limits the flow to each VFP to 80-100 gpm. The VFPs each contain 3 feet of AASHTO #1 limestone aggregate overlain with 1 foot of spent mushroom compost that is amended with limestone fines. The VFPs were sized assuming an acidity removal rate of 50 g/m^2/day. This rate is higher than the 30-40 g/m^2/day currently recommended (Rose 2006). The system was undersized because of site constraints.

The design resulted in:

- 565 ft^2 of VFP (water surface area) per gpm of average flow;
- 66 tons of limestone per gpm of average flow;
- 12 CY of organic substrate per gpm of average flow.

The Hunters Drift passive system was constructed in 2003 and first discharged in January 2004. The system has functioned well since it was constructed. Flows during the first two years were higher than average, but lower acidity and metal concentrations resulted in loadings similar to the design parameters.

The system is sampled semi-annually by the Babb Creek Watershed Association. Table 23 shows the average influent and effluent chemistry.

Table 23. Hunter's Drift Average Chemistry

Point	**Flow (gpm)**	**pH**	**Net Acid (mg/L)**	**Fe (mg/L)**	**Al (mg/L)**	**Mn (mg/L)**
HD		2.8	323	20.9	22.2	5.6
VFP 5	93	7.0	-137	5.0	< 0.5	3.8
VFP 6	92	7.1	-177	6.7	< 0.5	3.8
VFP 7	94	7.1	-146	5.0	< 0.5	4.8
VFP 8	94	7.0	-144	7.1	< 0.5	5.2
Final	380	7.7	-132	0.5	< 0.5	1.5

The adjacent Anna S system, which receives an average acidity loading of 40 g/m^2/day, has also continuously produced an alkaline discharge with low metals concentrations.

The long-term effectiveness of the Hunters Drift system is unknown. Flushing capabilities were installed in the limestone portion of the VFPs to facilitate the removal of accumulated metals. To date, flushing has not produced appreciable metals (based on visual assessments of flushate). It is thought that the metals are accumulating primarily in the organic substrate.

One advantage of a passive treatment system for the Swamp discharges is that treatment system inspections could be suspended during winter months when site access is difficult. The Hunters Drift system is located in an area with difficult winter access and it has been abandoned during winter months, with no ill effects. The three years of positive results for the Hunters Drift system give some confidence to the consideration of passive treatment at the Swamp. Therefore, the passive system design recommendations for the Swamp are based on the Hunters Drift system.

Figure 10 shows a flow diagram for the recommended Swamp passive treatment system. Map 8 shows the treatment system layout. One of the most critical aspects of this recommendation is the flow collection vault, which should be located just downstream of where the Swamp discharges cross the Texas Eastern Pipeline. This chamber should perform the following functions:

- Capture the total flow from the combined discharges;
- Equally divide any flow rate less than 80 gpm evenly between 2 VFPs;
- Send any flows between 80 and 130 gpm to the sediment pond that follows the VFPs. This will allow the untreated water to be treated via mixing and neutralization; and
- Send any additional flow over 130 gpm to the existing channel. This flow will not be treated.

This design will allow for treatment of the 95th percentile flow rate through a combination of direct treatment and mixing. The collection vault should be designed so that the operator can adjust the flow rates listed above based on treatment system performance.

As shown on Figure 10, two VFPs that operate in parallel should be constructed. This will allow one of the VFPs to be turned off for maintenance during average or low flows while the other VFP treats the entire flow. The VFPs should discharge to a common settling/mixing pond. If the total flow rate of the discharge is over 80 gpm, up to 50 gpm of untreated water from the flow control vault will be introduced in this pond, where it will react with the treated flow and be neutralized. The pond should be followed by a shallow, alkaline-amended wetland that will provide polishing and supply some extra alkalinity. The following table contains the assumptions and calculated parameters for the proposed passive treatment system for the Swamp discharges.

Table 24. Design Parameters for Swamp Passive Treatment System

Treated Flow (VFPs)	80 gpm
Acidity loading (VFPs)	182 kg/d (400 lb/d)
Acidity removal rate	40 g/m^2/day
Calculated VFP Surface Area	4,540 m^2 (48,900 ft^2)
Number of VFPs	2
Net Acidity out of VFPs	-150 mg/L
Bypass flow (to pond)	50 gpm
Total treated flow	130 gpm
Pond Area (at 4 feet deep)	4,700 ft^2
Wetland Area (at 6 inches deep)	25,000 ft^2

The treatment system should be located between the Texas Eastern Pipeline and Twomile Run. Approximately 28 acres of moderately sloping land are present in this location at an elevation below the discharge elevation at the pipeline. Map 8 shows where the treatment system cells should be placed. As shown on Map 8, it will be necessary to extend the area of 2-foot contour mapping prior to final design. Also note that the system can be constructed west of the proposed pipeline right-of-way expansion.

Although the area available for treatment is more than sufficient, the soils in this area are very shallow and rocky. Therefore, it will be necessary to provide impervious liners for the VFPs and the settling/mixing/flush pond. In addition, it may be necessary to bring soil material from off-site in order to construct the berms. One possible borrow area is the Area 4 reclamation job (See Section X.H).

The following table shows the cost estimates for the system described above. Note that the Swamp #5 bypass channel, estimated at $53,000, should be constructed before or during the construction of the passive treatment system (See Table 21). These estimates are based on the construction of similar treatment systems throughout Pennsylvania.

Table 25. Cost Estimates for the Swamp Passive Treatment System

	Unit cost	Cost
VFP: 6,100 ton AASHTO #1 LS	$20	$ 122,000
VFP: 1,300 CY Alkaline Organic Substrate	$20	$ 26,000
VFP: excavation and construction, 20,000 CY	$5	$ 100,000
VFP: liners, 70,000 ft^2	$2	$ 140,000
VFP: Plumbing and misc materials	Estimate	$ 20,000
Flow Control Structure (custom)	Estimate	$ 10,000
Settling Pond with liner, 5000 ft^2	$3	$ 15,000
Constructed Wetland, 25,000 ft^2	$0.50	$ 12,500
E&S, Mob/Demob, Misc	Estimate	$ 20,000
Subtotal, Construction and Materials		**$ 465,500**
Design, Permit, Construction Oversight	15%	$ 70,000
Contingency (fuel volatility, difficult site, prevailing wage)	20%	$ 105,000
TOTAL		**$ 640,000**

If the passive treatment system is constructed as described above, periodic monitoring should include stations within the treatment system, overall treatment system influent and effluent, the flow and chemistry of the Swamp #5 bypass, Twomile Run above the Swamp, and Twomile Run above Middle Branch. It will also be critical to measure the flow rate and chemistry of any water that is being bypassed around the treatment system.

The annual O&M of the system will involve monthly inspections, sampling, and routine maintenance. The bypass, influent, and effluent channels should be inspected and debris should be removed. The flow control box should be inspected and cleaned of debris or metal deposits, and adjusted if necessary. Monitoring should include four water samples (common VFP influent, each VFP effluent, final effluent), flow measurements at all stations (each VFP influent and the overflow), and measurement of water levels in the VFPs. The inspection and routine maintenance is expected to require four hours, which includes travel. The total cost is estimated at $160 for labor and $120 for sample analysis or approximately $3,400 per year. The cost could be decreased if the inspections were combined with other activities in the Twomile watershed.

Assuming no catastrophic event, the system's failure would occur slowly and be recognized by a decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be caused by lost viability in the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost for rejuvenating the substrate through the addition and mixing of 25% (by volume) new limestone fines is estimated at $17,000 (for both VFPs). The cost to completely replace the organic substrate is estimated at $52,000. It is anticipated that the compost will require rejuvenation after 6 years and replacement after 10 years.

Chemical Treatment Option

The Swamp discharges can be treated chemically. Calcium-based or sodium-based alkaline reagents are available. The most cost-efficient chemical systems use hydrated lime ($Ca(OH)_2$), but they also employ electrical mixers and aerators. There is no electrical service to the Twomile Run watershed and its installation was not considered feasible. Pebble lime (CaO) can be used in systems where mechanical energy is provided by the AMD flow and a waterwheel. These systems have varying effectiveness because a portion of the lime settles without dissolving and providing treatment. Several waterwheels installed in Cambria and Clearfield Counties on permitted mine sites failed to provide reliable treatment and were removed. The Moshannon DMO manages a forfeiture mine site where pebble lime is providing good treatment. The most common chemical used for AMD treatment at remote sites without electricity is liquid sodium hydroxide (NaOH). The reagent is highly soluble and its dissolution does not require mechanical mixers. AMD can be reliably dosed with liquid NaOH using passive waterwheel or a siphon-based method. As opposed to dry lime-based products, which require special, moisture-resistant housing, NaOH can be stored in tanks. Storage of enough reagent to last months is feasible. This is a concern for Twomile Run because winter access to the Swamp is not maintained in the winter.

Chemical treatment recommendations for the Twomile discharges assumed the use of NaOH because it can provide reliable continuous treatment at remote systems with only part-time attention by an operator.

The recommended chemical treatment scenario for the Swamp discharges is to by-pass the clean Swamp #5 channel, over treat the collected Swamp #1-#4 discharges in the Swamp kill zone area, and construct an additional holding/polishing pond below the Texas Eastern Pipeline in order to treat additional pollution that arises in this area. In this recommendation, all of the infrastructure for chemical treatment, including chemical storage and metering, will be performed in the kill zone area and will be accessed via the reclamation area.

Table 26 shows information on the components of the chemical treatment system, capital costs, and annual O&M costs. Note that the Swamp #5 bypass channel, estimated at $53,000, is included in the table and should be constructed before or during the construction of the treatment system (See Table 21). The system is designed to provide a 90th percentile flow event (120 gpm) with 48 hours of retention time.

A flow control structure should be installed above the system to bypass extremely high flows of water to the polishing pond in order to avoid system damage. Two serially-connected 7,500 ft^2 treatment ponds are proposed in the 'kill zone' area. The ponds must be lined with a synthetic liner. The cost to construct these two lined ponds is estimated at $30,000. The treatment ponds will discharge to the 20,000 ft^2 lined polishing pond located below the gas pipeline.

The system must operate in winter months when access by chemical trucks is impossible. Metal tanks with 15,000 gallons of capacity (4 months) are proposed. NaOH would be added to AMD in the treatment ponds using a flow-dependent metering device. Sludge would be periodically pumped from the treatment ponds to a sludge disposal basin located upgradient of the treatment system. A 20,000 ft^2 unlined basin is proposed. Clean surface and ground water would be diverted around the system using the same channel as described in the passive treatment section.

Table 26. Estimated cost to construct and operate NaOH system at the Swamp Area.

Capital Costs		
Item	**Detail**	**Cost Estimate**
Treatment ponds	Two 7,500 ft^2 lined treatment ponds	$30,000
Sludge disposal pond	One 20,000 ft^2 unlined basin	$10,000
Final polishing Pond	One 20,000 ft^2 lined pond	$20,000
NaOH storage tanks	15,000 gallon total capacity	$15,000
NaOH metering	Flow-dependent meter equipment	$5,000
AMD flow control	Custom structure	$10,000
Road for NaOH trucks	Improve access and/or bury pipeline	$20,000
Contingency	20% of system construction: difficult conditions	$20,000
Engineering	Design, permitting, construction oversite	$20,000
Clean Water Diversion	Swamp 5 diversion channel	$53,000
Total Capital Costs		**$203,000**
Annual Cost		
NaOH	45,000 gal/yr	$22,500
Plant Operator	Twice weekly system inspection and O&M	$40,000
Sludge removal	Hire sludge pumping company once/yr	$10,000
Total Annual Costs		**$72,500**

NaOH deliveries are made by 5,000 gal tanker trucks. 4-wheel drive tractor trailers suitable for off-road deliveries would be required. Improved access to the treatment system and a small buried chemical delivery line are proposed. The total cost to install the NaOH treatment system is estimated at $203,000.

Operation of the system will require the purchase of NaOH, sludge management, and routine site inspections and water testing. NaOH consumption was estimated using AMDTreat (Version 4.0) as approximately 45,000 gallons of 20% NaOH per year. The calculation assumed 25% inefficiency of NaOH treatment arising from overtreatment, as commonly occurs with minimally-managed NaOH systems. The delivered cost for the NaOH is estimated at

$22,500/yr. Sludge management is assumed to be done by a contractor who mobilizes to the site once per year to clean the treatment ponds. This one-week effort is estimated to cost $10,000. The routine operation of the system would require regular visits by the site operator. The estimate assumes two visits each week by the site operator. Because of the remote location of the system, a full day of work and travel was assumed. While NaOH deliveries would not be made in winter months, it is expected that the operator will have access throughout winter in order to inspect the site. The total annual cost to operate the system is estimated as $72,500/yr.

If the chemical treatment system is constructed as described above, periodic monitoring should include stations within the treatment system, overall treatment system influent and effluent, the flow and chemistry of the Swamp #5 bypass, Twomile Run above the Swamp, and Twomile Run above Middle Branch. It will also be critical to measure the flow rate and chemistry of any water that is being bypassed around the treatment system. A comprehensive record of the amount of chemicals used at the site should also be kept.

Figure 19 shows 25 years of estimated cumulative costs of the passive and chemical systems discussed above. The maintenance costs and time-frames presented above were used. Figure 19 shows that the high capital costs of passive treatment are offset by annual O&M costs after about seven years.

VIII. Robbins 10A/10B Collection and Recommendations

Prior to the construction of the passive treatment systems in the headwaters of Robbins Hollow (See Section II.G), the entire length of Robbins Hollow was polluted. This section addresses the AMD that continues to impact Robbins Hollow downstream of the treatment systems.

Robbins Hollow is a small drainage that arises south of an abandoned surface mine and intact underground coal mine (See Map 8). The stream flows into Twomile Run 100 feet downstream of the confluence of Twomile and Middle Branch.

A road that follows the drainage crosses an obvious AMD flow. In 1999, BAMR installed a weir on the flow between the road and the stream that was named "Weir 10." Samples and flows were collected for several years from Weir 10. The station received both seepage of mine drainage arising from multiple sources and runoff from the road.

In 2001, an attempt was made to collect the diffuse sources of AMD in this area in a manner that excluded surface water. Two shallow French drain collection systems, called 10A and 10B, were installed. After several months the 10A system became plugged with iron and silt. AMD was soon observed seeping around the plumbing system and discharging to Robbins Hollow in an uncontrolled manner. 10B was more effective in collecting the source of water below the road.

Also in 2001, the DEP's TMDL study established that Weir 10 only accounted for a portion of the AMD loading measured at the mouth of Robbins Hollow. Robbins Hollow was noted to be acidic above the inflow of Weir 10 and additional AMD sources were noted along the road below Weir 10. A subsequent TAG investigation of the headwaters area of Robbins Hollow (above Weir 10) discovered multiple sources of AMD. In 2001 and 2004, funds obtained from Growing Greener and OSM supported the construction of several passive treatment systems (See Section II.G). As a result, the flow of water in the headwaters of Robbins Hollow is improved, however AMD from 10A, 10B, and other sources continues to pollute Robbins Hollow and Twomile Run.

The TAG project identified a new flow of AMD that flowed into Robbins Hollow through a culvert below the 10A and 10B stations. The source of water was flow from the failed 10A collection system that did not flow through the original 10A point, and seepage from the north side of the road below the 10A and 10B points. The culvert was established as point 10C and sampled during the TAG project. 10C was found to account for approximately 20% more AMD than produced by 10A and 10B.

In spring 2005, another effort was made to collect AMD from the Robbins Hollow area. The primary goal of the project was to create a defined AMD condition so that remediation options could be developed. The project was intended to collect the AMD as completely as possible and at the highest elevation possible. Once the collection system was installed, the discharges from the pipes were monitored for flow and chemistry.

A. *Water Collection*

AMD collection occurred in June 2005. The collection proved difficult because the AMD was not confined to the abandoned surface mine or to a single strata beneath the Lower Kittanning coal seam. The AMD was found to be flowing in several stratigraphic units beneath the coal seam. A confining aquitard (such as clay) was not found within reach of excavation equipment, so the collection trenches were not constructed into a flow-confining unit.

Four collection trenches were installed. Each started in the wooded area below the toe of spoil and extended perpendicular to the toe of spoil. None of the trenches encountered the Lower Kittanning crop coal. The trenches extended through the surface mine spoil for at least 150 feet and eventually intercepted the pit floor of the abandoned surface mine. The trenches encountered a carbonaceous unit 6-20 feet below the Lower Kittanning coal seam that was variously identified as coal, carbonaceous mudstone, and carbonaceous shale. This unit appears to be a Lower Kittanning "leader" seam. Evidence of this leader unit was also found during construction of the EB13 ALD in the Robbins Hollow passive treatment systems in summer of 2004 and during the construction of the Swamp Area collection systems in the fall 2004.

In all of the trenches, water was found in a layer of highly fractured shale/siltstone between the abandoned pit floor and the leader seam. When found under several feet of overburden out of the weathering zone, the shale/siltstone layer consisted of a fine grained highly compacted somewhat laminated brown to black rock. This layer of rock contained many plant impressions between the laminated layers. When this unit was present near the surface, the rock was weathered into very dense plastic white clay that appeared to be impermeable.

All of the collection systems were constructed with non-calcareous AASHTO #3 sandstone aggregate and 6 inch diameter SDR 35 PVC pipe. Perforated pipe was used in areas of water collection and solid pipe was used to transport collected water to the surface. Generally, the trenches were excavated and left open for several days to ensure that the trenches were carrying groundwater flows and not simply draining pore water from saturated spoils. The trenches were numbered #1 - #4 from east to west and are shown on Map 8. A description of the construction of each collection system is presented below.

<u>Trench #1</u> was excavated from east to west beginning at the edge of spoil and cutting across the abandoned pit floor. This trench is positioned highest in elevation of the four trenches and thus represents the shallowest flow of collected water. The total length of the trench is 180 feet with 100 feet of perforated pipe and aggregate.

<u>Trench #2</u> began just below the toe of spoil and extended north toward Trench #1. Trench #2 began 20 feet lower in elevation than Trench #1 and stopped just before intercepting Trench #1. This trench exposed 4-5 feet of the leader seam.

<u>Trench #3</u> was excavated starting 75 feet downslope of the toe of spoil and excavated toward the toe. Water was found in a layer of highly fractured shale that extended deeper than the trench. The drain was constructed of 50 feet of perforated pipe and aggregate. Shortly after the ditch was backfilled, the flow rate dropped from 10 gpm to 3 gpm.

Believing that the flow was lost to the shale layer below the original trench, a second trench was excavated parallel to Trench #3 but at a lower elevation. Aggregate and perforated pipe were installed and connected to the drain from Trench #3. Similar fractured shale conditions were encountered in the second trench and as a result, water continued to be observed flowing within the shale, outside of the collection system. The collection system used 175 feet of pipe of which 100 feet were perforated.

Trench #4 was excavated from toe of spoil paralleling Trench #3. This trench is the westernmost trench in the collection system. Water was found flowing in the same fractured shale/siltstone unit above the leader. This collection trench used 180 feet of pipe of which 100 feet were perforated.

All four collection systems were extended by 200 to 300 feet to the south side of Robbins Road so that water would not flow over the road and to facilitate sampling. The pipes discharged to a ditch that carried the flow to Robbins Hollow. Much of the flow was lost to infiltration within the ditch. The flow of 10B, located downgradient of the ditch, gained flow during this period. In March 2006, the outfalls of the four pipes were combined into one 4-inch pipe and extended to the stream. The pipe extension caused the flow of 10B to decrease within a week from 14 gpm to 5 gpm.

B. Chemistry and Flow Rate Results

Water samples and flow rates were collected from the four pipes and the original 10B and 10C sampling points. Flow from the original 10A area that was not collected into the pipes flowed down the road to the 10C location. Very little AMD discharged from the original 10A area. Most of the flow at 10C was seepage arising lower in elevation than 10A and 10B.

The following table shows the average flow and chemistry for the sampling points after the collection systems were installed. These six points represent essentially all of the point sources of AMD produced along the Robbins Hollow Road above the pipeline.

Table 27. Robbins Hollow Point 10 average flows and chemistry, 2005-2006
Flow for Point 10B is after the collection pipe extension was installed in March 2006.

Station	Flow (gpm)	pH	Acid (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)	Acid load (lb/d)
Pipe #1	1.0	3.0	293	21.4	14.6	30.6	678	4.1
Pipe #2	0.7	3.1	305	17.1	14.9	48.2	790	3.4
Pipe #3	3.0	3.1	330	8.9	12.5	52.1	758	14.8
Pipe #4	0.6	3.2	320	9.1	13.7	52.2	679	3.0
10C	3.6	2.8	285	20.5	16.8	28.7	847	11.2
10B	4.3	3.5	195	2.1	10.3	30.2	457	8.4
Sum/Ave*	**13.2**	**3.1**	**269**	**11.3**	**13.3**	**36.7**	**676**	**44.9**

** flow and load are sums; acidity, metals and sulfate are flow-weighted average concentrations*

The new collection system (pipes #1 - #4) produced 40% of the water collected and 56% of the acidity loading. Collection system 10B produced 33% of the water collected and 19% of the acidity loading. 10C, which represents AMD not collected by the original 10B collection or by the recent collection accounted for 27% of the water and 25% of the acidity loading.

Table 28 compares pre-collection (2001-04) flows and acid loadings to those measured post-collection (2005-06).

Table 28. Pre- and Post-collection flow and chemistry at 10A/10B/10C

	Pre flow (gpm)	**Post flow (gpm)**	**Pre acid load (lb/d)**	**Post acid load (lb/d)**
10A	9.9	<1	25.6	<1
10B	5.0	4.3	12.3	8.4
10C	4.4	3.6	20.3	11.2
Collection system		5.3		25.3
Total	**19.3**	**13.2**	**58.2**	**44.9**

The collection lowered flows by 32%. This decrease was expected because the collection system collected only AMD. The original Weir 10 and 10A monitoring points had collected AMD and surface water. The summed acidity load produced from the Robbins Hollow area decreased by 23%. It is unclear why the collection decreased the acidity loading.

Table 29 shows statistical summaries for flow and acidity loading measurements for 2005/06 data. The collection systems were summed on each date into a single total flow. The analysis excludes an extremely high flow event that occurred on September 2, 2006. As noted in Section VII.C, approximately 2 inches of rain fell on September 1-2 and 8 inches of rain had fallen in the previous 7 days. The summed flow from the collection systems was 110 gpm. This flow rate was 9 times higher than the second highest flow rate measured for the summed collection pipes (11.8 gpm). Flow rates were not obtained for the other points and no water samples were collected because all flows were highly turbid. We believe that deleting this anomalous flow from the analysis is appropriate because no cost-effective treatment system can be designed with a safety factor of 10. Also huge flows of clean (non-AMD) runoff during this period probably diluted the AMD to non-toxic concentrations.

Table 29. Summary of Robbins Discharges flow and acid loading, 2005-2006.

	Flow (gpm)			**Acid load (lb/day)**		
	Ave	**75%**	**90%**	**Ave**	**75%**	**90%**
Collection pipes	5.3	7.4	9.8	25.3	33.2	39.0
10B	4.3	4.5	6.3	8.4	9.8	10.7
10C	3.6	5.4	6.0	11.2	16.8	18.0
Total	*13.2*	*17.3*	*22.1*	*44.9*	*59.8*	*67.7*

C. Recommendations

This section presents passive and chemical treatment options for the Robbins Hollow discharges. However, a recommendation for reclaiming Area 4 is presented in Section X.H and is the preferred alternative. The reclamation project would address all of the Robbins Hollow AMD, including Pipes 1-4, 10B/C, as well as Robbins Ditch, KC110, and KC106 (See Section V.A). However, the following sections present passive and chemical alternatives that could be constructed if reclamation is not considered feasible.

Passive Treatment Option

The Robbins Hollow discharges are highly contaminated. The average flow-weighted Al concentration is 37 mg/L. This concentration is similar to Al concentrations found in the Swamp discharges. The short-term success of the Hunters Drift passive system (Babb Creek, Tioga County) for AMD contaminated with 35-40 mg/L Al was noted in Section VII.D and used as a basis for a passive treatment system design. The passive treatment system will target the 90th percentile flows and loadings from both the collection pipes and 10B/10C.

Figure 11 shows a flow diagram for the recommended passive treatment system. DCNR plans to permanently re-route Robbins Road in this area. The recommended treatment system layout calls for two Vertical Flow Ponds (VFPs) in parallel that will treat the combined discharge from collection pipes 1-4. These VFPs will be located north of Robbins Hollow and just downstream of the existing North Branch passive treatment system. The flow from the collection pipes should be discharged into two parallel VFPs that each have a surface area (at design water elevation) of 4,500 ft^2. The size of the individual VFPs is larger than calculated from the acidity loading (Table 30) because the side slopes for these small units cause the limestone quantities to decrease substantially. The VFP size was selected to assure that each VFP contained 60 tons of limestone aggregate per each gpm of flow. This is the same limestone to flow ratio realized for the Hunters Drift system and the proposed Swamp passive system. The VFPs would discharge to a small settling pond, whose flow would be conveyed to a 5,000 ft^2 mixing pond located below 10B and 10C that also receives these flows. The pond is designed to retain the 90th percentile combined flow (22 gpm) for 48 hours. The mixture will result in the precipitation of solids (mainly Al) and the effluent from the pond will have a net acidity of approximately 100 mg/L. This flow will be directed into a single 7,000 ft^2 VFP that is located below the gas pipeline. The discharge from the final VFP will flow to Robbins Hollow.

Construction will occur along Robbins Hollow. Previous work in the area has established that good clay soils exist. The design assumes that the VFPs can be constructed in native clay and that a synthetic liner is not necessary. Table 31 contains cost estimates to construct the system described above.

If the passive treatment system is constructed as described, periodic monitoring should include stations within the treatment system, overall treatment system influent and effluent, RH12, and RH05. It will also be critical to measure the flow rate and chemistry of any water that is being bypassed around the treatment system.

Table 30. Design Parameters for Robbins Road Passive Treatment System

Treated Flow (VFPs)	10 gpm
Acidity loading (VFPs)	18 kg/d (39 lb/d)
Acidity removal rate	40 g/m^2/day
Primary VFP Area Calculation	440 m^2 (4,800 ft^2)
Number of VFPs	2
VFP Area necessary to assure LS target of 60 ton per gpm of flow	840 m^2 (9,000 ft^2)
Net Acidity out of VFPs	-100 mg/L
10B/10C Flow	12 gpm
Total treated flow	22 gpm
Mixing Pond Area (at 4 feet deep)	5,000 ft^2
Net acidity out of Mixing Pond	100 mg/L
Secondary VFP Area	7,000 ft^2

Table 31. Cost Estimates for the Robbins Road Passive Treatment System

	Unit cost	**Cost**
Pipe Flows to VFPs (buried line)	Estimate	$ 5,000
First set of VFPs: 600 ton AASHTO #1 LS	$20	$ 12,000
First set of VFPs: 200 CY Alkaline Organic Substrate	$20	$ 4,000
First set of VFPs: excavation and construction, 4000 CY	$10	$ 40,000
First set of VFPs: Plumbing and misc materials	Estimate	$ 10,000
Settling Pond, 3,000 ft^2	$1	$ 3,000
Convey treated water to Mixing Pond	Estimate	$ 5,000
Mixing pond with 10B and 10 C, 5000 ft^2	$1	$ 5,000
2nd VFP, 1,000 tons AASHTO #1 LS	$20	$ 20,000
2nd VFP, 250 CY alkaline organic substrate	$20	$ 5,000
2nd VFP, excavation and construction, 4,500 CY	$10	$ 45,000
E&S, Mob/Demob, Misc	Estimate	$ 10,000
Subtotal, Construction and Materials		**$ 164,000**
Design, Permit, Construction Oversight	15%	$ 25,000
Contingency (fuel volatility, difficult site, prevailing wage)	20%	$ 38,000
TOTAL		**$ 227,000**

The annual O&M of the system will involve monthly inspections, sampling, and routine maintenance. Inspections and simple maintenance should be done for all influent and effluent channels. Monitoring should include measurement of AMD flow rates, measurement of the water levels in the VFPS, and six water samples (the common influent to the upper VFPs, the discharge of each upper VFP, the 10B/10C influent to the settling pond, and the final discharge from the lower VFP). Once the performance of the system was established, it is likely that the frequency of laboratory sample analyses could be lessened. The inspection and routine maintenance is expected to require four hours, which includes travel. The total manpower and travel cost is estimated at $160 and sample analysis is estimated at $180. The annual cost is estimated at approximately $4,100 per year. The cost could be decreased if water sampling (laboratory analyses) was lessened and if inspections were combined with other activities in the Twomile watershed.

Assuming no catastrophic event, the system's failure would occur slowly and be recognized by a decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to lost viability in the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost of rejuvenating the substrate in the upper VFPs through the addition and mixing of new limestone fines (25% by volume) is estimated at $4,000 (for both VFPs). The cost to completely replace the organic substrate is estimated at $8,000. The cost to rejuvenate the organic substrate in the lower VFP is estimated at $5,000, while complete replacement is estimated at $10,000. It is anticipated that the compost will require rejuvenation after 6 years and replacement after 10 years.

Chemical Treatment Option

If chemical treatment is selected as the preferred alternative for addressing these discharges, the system should be constructed below the 10B and 10C discharges. A system cost estimate is provided in Table 32.

Table 32. Chemical treatment costs for the Robbins Hollow Discharges

Capital Costs		
Item	**Detail**	**Cost Est.**
Collect all flows	Collect and discharge to treatment ponds	$5,000
Treatment ponds	Two 1,500 ft^2 lined treatment ponds	$8,000
Polishing pond	One 3,000 ft^2 unlined pond	$2,000
Sludge disposal pond	One 4,000 ft^2 unlined basin	$4,000
NaOH storage tanks	6,000 gallon total capacity	$6,000
NaOH metering	Flow-dependent meter equipment	$3,000
Road for NaOH trucks	Improve access to system	$5,000
Contingency	20% of system construction: difficult conditions	$7,000
Engineering	Design, permitting, construction oversight	$20,000
Total Capital Costs		**$60,000**
Annual Cost		
NaOH	8,000 gal/yr	$4,000
Plant Operator	Once a week system inspection and O&M	$20,000
Sludge removal	Hire sludge pumping company once/yr	$7,500
Total Annual Costs		**$31,500**

The proposed system includes two serial 1,500 ft^2 treatment ponds that provide the 90^{th} percentile flow (22 gpm) with 48 hours of retention. The treatment ponds discharge to a final 3,000 ft^2 polishing pond below the pipeline. A sludge disposal basin is installed above the system. The system is estimated to consume about 700 gal/month of NaOH (20%). A 6,000 gallon tank should be installed in order to provide sufficient chemical storage for 4 months when winter access is impossible. A modest improvement to the current road system would be required to allow a tanker truck to unload and turn around. The total capital costs are estimated at $60,000.

Annual costs include chemical purchases, sludge removal, and routine O&M. The NaOH quantity was developed with AMDTreat (Version 4.0) assuming 20% NaOH and 75% utilization efficiency. Sludge removal is assumed to occur once each year through the hiring of a contractor. It is expected that the treatment system would need to be inspected at least once a week and that the remote location would make each site visit a full day job. The total estimated annual cost of the chemical system is $31,500.

If the chemical treatment system is constructed as described above, periodic monitoring should include stations within the treatment system, overall treatment system influent and effluent, RH12, and RH05. It will also be critical to measure the flow rate and chemistry of any water that is being bypassed around the treatment system.

IX. Spoil, Overburden, and Coal Explorations

The Twomile Run watershed was investigated to assess reclamation needs and opportunities for coal remining. Historic mining activities left conditions that inhibit vegetative growth and favor the production of acid mine drainage (See Photo 18). If these conditions can be decreased, then the production of AMD from the site should also decrease. Large scale reclamation involves the same heavy equipment used in surface mining activities. In areas where economically recoverable coal is present, its removal and sale should be considered in order to offset some of the reclamation costs. If deep mines that produce mine drainage can be eliminated through remining and reclamation, substantial water quality benefits will be realized. This section presents the results of overburden, spoil, and coal sampling activities.

A. Spoil Characteristics

All of the surface mining in the watershed occurred before the passage of tougher state and federal reclamation regulations in the 1970's. As a result, the mining occurred without conservation of topsoil or final grading to approximate original contours. The current surface soils are weathered overburden that typically are acidic and bare. The surface mines were generally not regraded to a contour that considered post-mining surface water drainage or erosion control. The spoils contain many closed depressions that collect water and promote infiltration through the spoils. When the spoils are acidic, infiltration causes water quality degradation. This acidic infiltration either emerges as seepage, causing kill zones, or discharges to the streams as contaminated baseflow.

The reclamation of unreclaimed spoils involves regrading so that positive drainage away from the site is promoted and revegetation so that infiltration and erosion are lessened. Reclamation may also include addition of alkaline amendments that neutralize spoil acidity. As part of the investigation, the chemical characteristics of spoils were investigated so that the neutralization and soil amendment requirements could be estimated.

Spoil pits were dug at 46 locations within the Twomile watershed. Photos 16 and 17 show two of these locations. Sixty-two spoil samples were collected and analyzed for soil fertility parameters by the Pennsylvania State University Agricultural Analytical Services Laboratory and for acid-base parameters by Geochemical Testing. The complete data set is contained in the Appendix. Table 33 shows the characteristics of the samples. The locations of spoil sampling sites are shown on Map 9.

All of the samples were acidic and the average pH was 3.4. All of the samples were deficient in P and K. Mg was deficient in 54 samples (87%). Concentrations of the metals Zn and Cu were generally less than 5 ppm, which is well below levels considered toxic to vegetation.

Table 33. Characteristics of spoil in Twomile Run watershed.

	Average	St dev	Range
pH	3.4	0.5	2.5 - 4.8
P, ppm	1.9	1.9	1.0 – 11.0
K, ppm	41	13	14 – 71
Mg, ppm	34	26	8 – 159
Ca, ppm	88	53	29 – 268
Zn, ppm	1.2	1.4	0.1 – 6.4
Cu, ppm	2.1	1.3	0.4 – 6.3
S, ppm	213	140	14 – 590
Acid, meq/100g	11.5	3.1	6.3 – 20.1
CEC, meq/100g	12.1	2.6	6.8 – 16.5
LS add, ppt	4.9	1.5	2.5 – 9.0
Total S, %*	0.3	0.4	<0.1 – 2.4
NP, ppt*	-2.8	1.9	-8.0 – +4.0
NNP, ppt*	-13.0	14.0	-79.2 – +1.2

*These parameters were analyzed by Geochemical Testing; all others by PSAASL

The soil laboratory recommended limestone addition of 4.9 ppt (average, assuming 100% pure $CaCO_3$). This value was greater than the limestone deficiency measured by the NP (-2.8 ppt) but less than the NNP (-13.0 ppt). The NP is a measurement of the sample's ability to neutralize acidity. When a negative result is reported, the sample has no neutralization capacity and actually releases acidity when in contact with water. The amount of acidity released is measured by the test. Only 4 of the 62 samples had a positive NP. The other 58 samples had negative NPs. The limestone addition test done by the soils laboratory measures the acidity of the sample and recommends an amendment quantity that neutralizes the current acidity and also provides additional alkalinity for the neutralization of acidity in the future. This "reserve" is the reason that the Lab's limestone addition recommendation is greater than the NP.

The NNP accounts for unrealized acidity that is stored within the sample as pyrite. The inherent assumption is that eventually the sample will be fully weathered and the acidity tied up in the pyrite will be released. The Maximum Potential Acidity (MPA) of a sample is calculated by multiplying the sulfur content by 31.25. The NNP is calculated by subtracting the MPA from the NP. The calculation assumes that all sulfur is reduced (FeS or FeS_2). While this assumption is reasonable for unweathered overburden samples, it might not be appropriate for weathered spoil samples and result in an errantly low (negative) NNP. An error in the assumption is especially important for the spoil analyses because, on average, 75% of the acidity contained in the NNP calculation arose from S. Only 25% of the acidity was already present and measured as NP.

In order to judge the potential error of the sulfur determinations, sulfur forms were determined for four spoil samples with >1% total sulfur. The test provides estimates of the sulfur present in a pyritic form, in a sulfate form, and in an organic form. Only the pyritic form is acid producing. The results are shown in Table 34. For these high-sulfur samples, an average of 79% of the sulfur was present in a pyritic form. When the sulfur values in the spoil data set were all adjusted downward by 21%, the average NNP increased to -10.8 tons per 1,000 tons.

Table 34. Fractionation of sulfur (%) for four spoil samples with TS greater than 1%.

Location	Point	Total S	Pyritic S	Sulfate S	Organic S	% Pyritic S
Area 7	B-17	2.43	2.10	0.17	0.16	86%
Area 7	B-24	1.19	0.73	0.46	<0.01	61%
Area 5	B-28	1.06	0.94	0.07	0.05	89%
Area 5	B-35	1.11	0.88	0.16	0.07	79%

Spoil samples were collected in several areas of Twomile Run. The following table shows the summarized results from Areas 7, 5N, and Areas 1 and 2. Single-factor analysis of variance (ANOVA) was used to evaluate the significance of the differences. The testing found no significant differences between the sites. Only one parameter, Limestone Addition, varied significantly between the areas and the significance was marginal (p=0.04). The difference is not considered meaningful for the purposes of developing reclamation recommendations. Therefore, average spoil characteristics will be used to develop the reclamation plans throughout the watershed.

Table 35. Characteristics of spoil in three Spoil Areas

	Area 7 (n=18)		**Area 5N (n=34)**		**Areas 1 and 2 (n=9)**	
	Mean	**St dev**	**Mean**	**St dev**	**Mean**	**St dev**
pH	3.2	0.5	3.5	0.6	3.5	0.3
P, ppm	1.3	0.8	1.8	1.3	3.3	3.8
K, ppm	41	12	45	12	31	11
Mg, ppm	36	20	333	32	31	11
LS add, ppt	11,389	3,310	9,059	2,570	9,667	3,391
Ca, ppm	81	29	91	59	91	73
Acid, meq/100g	13.2	34	10.8	2.5	11.2	3.5
CEC, meq/100g	13.3	2.6	11.6	2.3	11.8	3.2
Zn, ppm	1.2	0.8	1.4	1.7	0.8	0.6
Cu, ppm	1.8	0.9	2.5	1.5	1.2	0.6
S, ppm	295	165	165	102	201	129
Total S, %	0.45	.61	0.22	.33	0.48	0.16
NP, ppt	-3.3	2.68	-2.4	1.4	-3.4	1.0
NNP, ppt	-17.4	19.9	-9.2	10.4	-18.5	4.1

Pits were excavated at eight locations in Area 5N and spoil samples were collected by depth. The pits were approximately 12 feet deep. Samples were taken to represent the top four feet, the middle four feet, and the bottom four feet. Table 36 shows the average results and the results of single-factor analysis of variance.

The only parameters that varied significantly with depth were Total S and NNP. Recall that NNP is calculated using the Total S. Bottom samples had higher concentrations of Total S than the top or middle. This result indicates that weathering is more significant closer to the surface and that there is substantially less reserve acidity present. The result indicates that, if spoil neutralization is a reclamation objective, a different liming strategy might be used for surface spoils than for deeper spoils. The result also cautions against regrading plans that move less weathered deeper spoil to the surface, where acid-producing weathering processes can occur.

Table 36. Characteristics of spoil at different depths made at 8 excavations in Area 5N.

Parameter	**Units**	**Top (0-4 feet)**	**Middle (4-8 feet)**	**Bottom (8-12 feet)**	**Difference significant?**
pH	S.U.	3.5	3.3	3.3	no
LS add	ppt	4.6	4.3	4.6	no
Mg	ppm	20	30	68	no
Ca	ppm	68	53	95	no
S	ppm	154	180	210	no
Total S	%	0.12	0.15	0.53*	yes, $p<0.02$
NP	ppt	-2.5	-3.1	-2.7	no
NNP	ppt	-6.1	-7.9	-19.2*	yes, $p<0.03$

**Only this depth displayed significant variance*

B. Overburden Analyses

Overburden samples were collected by drilling at five locations and analyzed for acid-base parameters. Locations for overburden sample collection were chosen to represent the greatest possible thickness of overburden. One historical overburden analysis performed by BAMR was obtained from DEP records. The BAMR overburden analysis was from a hole identified as B6-22 OB located in the northeastern portion of Area 6. The locations of the drill holes are shown on Map 9.

All of the analyses and calculations follow standard protocols used in the permitting of coal mines in Pennsylvania. The analysis of acid/base accounting data is typically accomplished with a spreadsheet made available by the DEP. With appropriate inputs of data, the spreadsheet calculates the MPA, NP, and NNP for each strata and then sums the full overburden on a volume-weighted basis. The spreadsheet can recognize threshold values that are set to eliminate analytical results that are near detection limits or simply are so low that their significance with respect to predicting the generation of AMD is uncertain. The threshold values were 0.5% Total Sulfur and 30 ppt NP. Add, any value less than 0.5% total sulfur was assumed to be zero and any NP less than 30 ppt was assumed to be zero. The alkaline amendment rates were obtained using summaries calculated *with* thresholds. Unless otherwise indicated, any discussion of overburden acid base accounting and overburden alkaline amendment rates assumes the values were calculated *with* thresholds.

The purpose of the calculations is to determine how much alkaline material would have to be imported to prevent AMD formation and to abate AMD from previous mining. Research has determined that analysis of the balance of an overburden's acidic and basic (alkaline) characteristics is one of the most effective predictive tools to determine whether AMD will form (DEP, 1998). The DEP analysis shows strata that are particularly acidic or particularly alkaline and calculates the characteristics of a completely homogenized condition. The DEP has determined that sites with a total net neutralization potential (NNP) greater than +6 ppt (parts per thousand or tons per 1000 tons) rarely make AMD. Sites with a negative NNP usually make AMD. Some sites with NNP between 0 and +6 NNP produce AMD and some do not. At sites with NNP less than +6 or with other indicators of potential acid mine drainage, the DEP permitting staff requires incorporation of alkaline amendments to the backfill to make up for the base deficiency.

Overburden lithology in the Twomile Run watershed varies from shale to coarse sandstone. In the central portion of the watershed (Areas 2, 5N and 5S) the overburden is comprised almost entirely of fine grained shales, siltstones and mudstones. Areas 1, 4, 6 and 7 all have shale of varying thickness overlain by medium to coarse grained sandstone. It is unclear whether the sandstone was deposited in place of the shale or if the sandstone had been deposited after erosion of the shale. Some evidence for both occurrences exists. In a highwall in the southeastern portion of Area 7, rip-up clasts of dark shale were observed embedded along the irregular contact between the sandstone and shale. This suggests that the shale was eroded as part of the sandstone deposition. In Area 4, BAMR drill logs show shale grading to "sandy shale" and then to sandstone suggesting that a change in depositional environment occurred that did not include erosion. In much of Area 3, the Lower Kittanning coal has been partially or completely replaced by sandstone.

Table 37 shows the overburden results for three cores that penetrate the deep mines that are believed to be primarily responsible for the watershed's severe AMD. The table shows drilling information (depth), laboratory results (total sulfur, NP, and NNP), and geological information (rock type). This information was used to calculate the net neutralization potential excess or deficit (negative) for each strata and the actual tons of overburden and NP excess or deficiency. The tonnage calculations were done with a volume-weighted procedure that takes topography into account. For these calculations, thresholds were not used so that the actual average results of the analyses could be shown.

The cores shown in Table 37 are representative of the two general types of overburden in the watershed. KC-33 is located in Area 5 and penetrates overburden that is entirely fine grained rock. The hole was begun above the fringe of a surface mine in the Upper Kittanning coal seam and captured the outcrop. The hole was used to characterize overburden in both Area 5N and 5S. KC-42 OB and KC-45 OB represent overburden in Area 7 that is almost entirely sandstone with only four feet of shale present.

The sandstones and shales that make up most of the overburden in the watershed have very low NP and do not contain buffering capacity. Based on overburden analysis results, these materials appear unlikely to create acidic conditions. However, experience at other Lower Kittanning sites with similar overburden results have shown that acidic conditions sometimes result. The black shale immediately above the Lower Kittanning has high sulfur content and is responsible for virtually all acid potential in the overburden. This shale is known as the Columbiana Shale and it is present throughout the watershed. In areas where the shale is absent, it is replaced with a sandstone unit that is most likely of fluvial origin. In the bituminous coal fields of Pennsylvania, the Columbiana Shale varies from marine to brackish. Where deposition occurred under brackish conditions, as in the Twomile Run watershed, the Columbiana Shale has very high sulfur content (DEP, 1998). The result is high acidity generating potential that is the source of most of the AMD in the watershed. Table 38 shows the thickness and acid/base characteristics of the LK rider and the overburden above the rider for each core. See Map 6 for test locations.

Table 37. Summarized Overburden characteristics (without thresholds) in Areas 5S and 7 The acidic strata are in ***bold italics****.*

Depth (feet)	Unit	S^{tot} (%)	NP (ppt)	NNP (ppt)
KC-33 OB (Area 5S)				
3-15	Shale	0.00	2.2	2.2
15-16	Coal (UK leader)	0.00	-2.5	-2.5
16-58	Shale & clay	0.00	5.6	5.6
58-73	Shale	0.19	10.7	4.9
73-100	Shale	0.01	7.3	7.0
100-103	Coal (LK rider)	0.86	0.76	-27.1
103-108	***Shale***	***1.47***	***3.48***	***-42.1***
108-113	Coal void (LK)	na	na	na
KC-45 OB (Area 7)				
2-55	Sandstone	0.00	2.9	2.9
55-56	Sandstone	0.67	5.3	-15.6
56-60	***Shale***	***4.58***	***0.9***	***-142.1***
60-65	Coal (LK)	3.00	0.0	-93.8
KC-42 OB (Area 7)				
3-30	Sandstone	0.00	1.9	1.9
30-38	Shale	0.03	7.2	6.3
38-41	Shale	0.85	13.8	-21.8
41-44	***Shale***	***1.81***	***13.8***	***-42.7***
44-47	***Shale***	***2.50***	***13.9***	***-64.2***
47-50	***Shale***	***4.06***	***-0.3***	***-127.2***
50-51	***Shale***	***8.88***	***-6.9***	***-284.4***
51-56	Coal (LK)	1.65	0.5	-51.1

Table 38 shows the summed volume-weighted NNP for the six cores calculated both with and without thresholds. On average, using thresholds lowered the NNP by 4 ppt.

Table 38. Acid-base characteristics of Twomile overburden and Columbiana Shale

	B6-22 OB	KC-09 OB	KC-18 OB	KC-33 OB	KC-42 OB	KC-45 OB
Area Designation	**6**	**2**	**1**	**5S**	**7 (west)**	**7 (east)**
Above Col. Shale, feet	58	86	54	100	41	56
Above Col. Shale, NNP	+0	+6	-9	+5	+3	+2
Columbiana Shale, feet	9	12	15	8	10	4
Columbiana Shale, NNP, ppt	-107	-65	-48	-35	-79	-137
Total, NNP, without thresholds, ppt	-17	-8	-19	+2	-23	-10
Total NNP, with thresholds, ppt	-18	-15	-23	-3	-26	-13

Highwall excavations that uncovered the intact Lower Kittanning and Columbiana Shale were observed to contain lenses of pyrite at and near the coal/shale contact. This is hypothesized to be due to interaction between brackish water associated with the shale deposition and the reducing conditions associated with the organic material to later become the Lower Kittanning coal. The result is high levels of sulfide mineralization.

All of the mining that took place in the watershed occurred with little regulation with regard to post-mining water quality. It appears that no special handling of the Columbiana Shale was performed and no addition of alkaline materials occurred. As a result, during mining the Columbiana Shale was widely distributed within the mine spoils.

C. Coal Characteristics

Considerable reserves of coal remain in the Twomile watershed. Drill logs and excavations in Areas 4, 5N, 5S, 6, and 7 regularly discovered 5 feet of Lower Kittanning coal. The coal is present in two forms: shallow cover crop coal intentionally left in place during surface mining; and deep cover coal left as pillars in underground coal mines or as blocks of unmined (virgin) coal. Photos 19 and 20 show two of the coal test trenches that were excavated through the coal crop.

Crop coal was left in place for regulatory reasons. At the time of mining, there was a belief that leaving a block of crop coal would result in flooding the abandoned pit floor and lessen the production of acid mine drainage. This theory may have merit where the coal is level and water impounded behind the crop extends a long distance into the pit and inundates the pyritic wastes that lie on the pit floor. The coal in Twomile Run is not flat. The coal dip is up to 8%, resulting in limited pooling of water behind the coal. Leaving crop coal is no longer a recommended mining action. In fact, many remining operations occur where crop coal is the principle target.

Crop coal was encountered throughout the watershed beneath the outslope spoils and beneath unmined ground beyond the spoils. The width of the crop, determined by digging completely through it on several occasions, was 65-120 feet. The cover on the crop is generally low. In several locations, the crop was covered with only 1-5 feet of spoil. In some locations, especially Area 5N, the crop is covered with 40-70 feet of spoil. On average, the crop coal in the Twomile watershed is covered with approximately 20 feet of spoil and/or original ground.

Coal is also present as deep mine pillars and unmined (virgin) blocks. The Twomile watershed was extensively deep mined, and unmined blocks are rare. Drilling, by this project and previous projects, indicates that there are no large unmined blocks in Areas 5S, 5N, or 7. A large block of unmined coal appears to exist on the west side of Huling Branch (Area 6).

Coal samples were collected during drilling and excavation activities. Coal sampling sites are shown on Map 9. Table 39 shows the average coal analysis results for 14 crop samples and 3 deep samples. The complete data set is contained in the Appendix.

The crop coal has a higher moisture content and lower sulfur and BTU content than the deep coal. These differences arise from the more weathered nature of the crop coal. The average crop coal sample had ash content less than 10%, sulfur less than 1% and was 10,500 BTU. If dried, BTU content of the crop coal could increase to about 12,000 BTU. The less weathered deep coal was 10% ash, 2.8 % sulfur, and 13,300 BTU.

Table 39. Characteristics of deep and crop coal in the Twomile watershed

	Deep coal (cores & highwall)			**Crop coal**		
Parameter	**Average**	**St dev**	**Range**	**Average**	**St dev**	**Range**
H_2O (%)	3.8	3.2	1.7 - 6.3	15.4	6.3	4.0 - 26.3
Ash (%)	9.8	1.5	8.7 - 11.6	8.2	3.8	3.6 - 17.4
S (%)	2.8	1.2	1.5 - 3.8	1.0	0.2	0.6 - 1.2
BTU	13,343	504	12,987 - 13,920	10,548	1,287	8,266 - 12,368
Ash-dry (%)	10.2	1.5	9.3 - 12.0	9.6	4.1	4.6 - 18.2
S-dry (%)	3.0	1.2	1.6 - 3.8	1.1	0.2	0.9 - 1.3
BTU-dry (%)	13,868	370	13,450 - 14,154	12,446	950	10,534 - 13,877
BTU-dry, Ash free (%)	15,444	175	15,279 - 15,628	13,766	918	11,929 - 15,128
lb S/MBTU	2.12	0.8	1.19 - 2.71	0.90	0.11	0.69 - 1.03

P&N Coal evaluated the coal resources in the Twomile watershed in 2005. Crop coal and a section of deep mine were exposed in Area 7 at the southern end of the western deep mine. Three crop exposures and two deep mine pillar exposures averaged 58 inches in coal thickness with a range of 50 to 63 inches. Seven coal samples were collected from the five locations. The average results are shown below. P&N's samples contained higher ash content, which was attributable to a clay parting present in the middle of the coal seam. The clay parting was present in most of the samples taken for this study. The BTU values were slightly lower than the samples collected by TU.

Table 40. Results reported by P&N Coal for coal samples collected in 2005

	Moisture	**Ash**	**Sulfur**	**BTU/lb**	**Ash-dry**	**S - dry**	**BTU - dry**	**BTU – dry AF**	**lb S/ MBTU**
Avg:	13.7	12.9	0.9	9,834	15.2	1.0	11,257	13,245	0.92
Max:	29.1	15.6	1.1	12,427	21.1	1.2	13,220	15,030	1.00
Min:	6.0	11.3	0.6	6,699	12.0	0.9	9,067	11,496	0.88

The deep mine coal present in the Twomile Run watershed is high quality and could be marketed to power plants. The crop coal is also marketable, though at a lower value because of the higher moisture content. The challenge is transportation costs because of the remote location.

D. Ground Water Wells

Comprehensive sampling of Twomile Run, its tributaries and contributing discharges revealed that a significant amount of pollution is entering Twomile Run in the form of contaminated baseflow (See Section V). Review of geophysical mapping produced by DOE/NETL (Section II.F) revealed that a conductive anomaly existed between the unreclaimed surface mines in Areas

7 and 5N and Twomile Run. The conductive anomaly was originally interpreted as a deep mine pool by the DOE/NETL. However, there are no known deep mines in much of the area covered by the anomaly and furthermore there are no known economic coal seams located at the elevation of the anomaly. The authors of this report interpret the conductive anomaly as a plume of contaminated groundwater. Both geologic structure and fracturing, as suggested by topographic expression, favor groundwater flow in a southeasterly direction from the mines to Twomile Run. Figure 2 illustrates this concept. See Map 10 for cross section location.

To verify the existence of this plume, four monitoring wells were installed (See Map 9). Well GW-A is located northwest of Area 7 and is structurally upgradient of the Huling Branch mines. GW-B is located in the Middle Branch ATV parking lot between Areas 5N and 7. This location contains both a shallow (GW-Bs) and deep (GW-Bd) well. Monitoring well GW-Bd was cased and grouted to a depth of 60 feet to exclude interaction with the aquifer penetrated by GW-Bs. GW-C is located beyond the coal crop on the southeast corner of Area 5N. Two of the monitoring wells draw from the suspected plume (GW-Bs and GW-C) and two were developed in locations believed to be unaffected by the plume (GW-A and GW-Bd). Construction diagrams for the wells are shown in Figure 12. Photo 14 shows the drill rig and Photo 15 shows operations during the installation of Well GW-Bs.

The ground surface in the ATV parking lot is just below the Lower Kittanning coal elevation. The coal was not present in this area due to erosion. The well penetrates only strata that are below the LK coal seam and thus is stratigraphically below all surface mining and deep mining activities in Areas 5N and 7. The location was selected because it is in the middle of the high conductivity plume mapped by DOE/NETL. Table 41 shows the average results of the ground water sampling. The complete data set is contained in the Appendix.

Table 41. Ground Water Monitoring Well Chemistry Results

Well	**Location**	**pH**	**Chemistry Parameters (mg/L)**						**Elevation (MSL)**	
			Alk	**Acid**	**Fe**	**Al**	**Mn**	**SO_4**	**TOC**	**GW Ave.**
GW-A	Above mining	5.9	9	-.6	4.6	0.3	0.7	12	1578.42	1500.92
GW-Bs	Between mines shallow	5.8	0	329	219.0	0.5	10.3	824	1426.95	1401.60
GW-Bd	Between mines deep	7.3	137	-117	4.1	1.3	0.6	355	1426.61	1273.21
GW-C	Below mining	3.8	0	444	68.5	45.5	6.3	1243	1373.0	1342.22

GW-A yields less than 0.5 gpm. The water produced is alkaline with very low dissolved solids. This well characterizes uncontaminated ground water in the Twomile watershed. GW-Bs intercepted a producing aquifer at approximately 43 feet below the ground surface. The yield is about 2 gpm. The water is highly acidic and contains very high concentrations of Fe. The presence of elevated sulfate ties the contamination to mining activities. The water quality is unusual because of the presence of some alkalinity and the very low Al concentrations. Similar chemistry is observed in Clarion County where low-pH Al-containing AMD infiltrates into siderite-containing aquifers. It is possible the well intercepted an isolated siderite-containing aquifer. GW-C intercepted groundwater approximately 14, 43, and 50 feet below the surface.

The well yield is about 7 gpm. The water is highly acidic and the chemistry is more typical of the AMD observed in the Twomile watershed.

The GW-Bs monitoring well appears to have penetrated a perched contaminated aquifer. This perched aquifer was not encountered in the GW-A well and represents the contaminated plume of groundwater detected by the DOE/NETL geophysical study. The existing wells are insufficient for constructing a detailed groundwater model. However, a reasonable hypothesis would be the infiltration rate from the abandoned surface mines is so great that it exceeds the vertical transmissivity of at least one of the underlying bedrock units. Since vertical flow through the aquifer is retarded, horizontal flow becomes preferred. This results in a stair-stepping flow down-dip from fracture to fracture toward Twomile Run (See Figure 1).

GW-Bd shows elevated sulfate concentrations, suggesting that contamination from AMD is reaching that well. The low iron concentration relative to the sulfate concentration suggests that the well was not completely purged at the time of sampling. Improved sampling technique could more accurately reflect groundwater conditions.

Regardless of the mechanisms of transport, it is clear that unreclaimed mines in Areas 7, 5N, and possibly 5S are generating contaminated baseflow to Twomile Run as well as surface discharges to Huling Branch. Reclaiming these mines is the only way to reduce or eliminate baseflow pollution to Twomile Run. If this baseflow is not treated, Twomile Run cannot be restored to a viable condition.

E. Water Collection Efforts

During the spoil and coal exploration, water collection systems were installed in two locations, now called Huling C and Huling E (see Map 10).

The Huling C collection system was originally planned as part of the Huling Branch Report (HE, March 2004). At that time, collection systems were installed at Huling A, B, and D (See Map 10). The Huling C collection system was not installed due to the difficulty in locating the source and the early arrival of winter weather that year.

The Huling C collection system was installed in October 2006. The collection system starts at the base of an abandoned highwall where the road crosses the drainage upslope of the “bear wallow” or tipple area in Area 7. Collection of the water was achieved by excavating to the pit floor parallel to the highwall and installing 30 feet of perforated pipe and sandstone aggregate. The collected water was then piped 650 feet to the existing Huling B collection pipeline. To join the two collection systems but still allow them to be monitored individually, an 18-inch corrugated pipe was installed vertically much like a manhole (See Photo 21). The Huling C pipe outfalls mid way up the side of the “manhole” and then flows out the bottom of the “manhole” to Huling B. A cement lid was placed on top of the “manhole”. To evaluate flow from Collection B the flow from C is subtracted from the total amount measured at the end of B.

The flow from Huling C is highly contaminated. Flow and chemistry from a one-time sampling event are shown in Table 42

Table 42. Huling C Flow and Chemistry

Flow (gpm)	pH	Acid (mg/L)	Fe (mg/L)	Al (mg/L)	SO4 (mg/L)
6	2.7	730	37	98	1400

The Huling E collection system was installed in September 2006. This system originates from a collapsed deep mine opening that discharges AMD to Huling Branch. The deep mine opening is situated along a road leading from the Middle Branch Parking area to the eastern side of Area 7. The mine opening was exposed by excavating collapsed material with an excavator for a distance of 100 feet. Photos 22 and 23 show the excavation of the mine entry and intact mine timbers. Once the mine opening was exposed, 30 feet of 6 inch SDR 35 PVC perforated pipe was placed into the mine to collect water. Non-reactive aggregate was placed around the perforated pipe to collect water. A clay dam was placed at the end of the perforated pipe to force water into the perforations. Geotextile fabric was place over the aggregate to prevent soil from plugging the collection system. The water was then conveyed to an existing kill zone with 70 feet of 6 inch pipe. The area was then backfilled, seeded and mulched.

The following table shows the average flow from this collection system based on 3 flow measurements and two chemistry samples.

Table 43. Huling E Average Flow and Chemistry

Flow (gpm)	pH	Cond (uS)	Acid (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)	SO4 (mg/L)
5.75	3.0	2012	411	42	4	20	461

X. Reclamation and Remining Options

The highly degraded water quality in Twomile Run is a consequence of AMD produced by abandoned deep mines and poorly reclaimed surface mines. The two strategies conventionally used in AMD remediation projects are: 1) elimination through reclamation or remining or 2) collection and treatment. Reclamation and remining are the only option for Twomile Run because all of the AMD cannot be collected. This project discovered that a large portion of the polluted water is escaping from the mined areas into the underlying aquifer and polluting Twomile Run as baseflow. Treatment of the flow that *can* be collected would not result in restoration of Twomile Run. Remediation requires that the elimination or neutralization of acid-producing processes within the mined areas so that water infiltrating into the underlying aquifer is not polluted.

In mitigation projects the pollution-producing materials are addressed, normally in a single effort, so that pollution production is substantially lessened or eliminated. For AMD-producing mine spoils, reclamation can lessen or eliminate AMD production. This section describes several reclamation project types that were considered for the Twomile Run watershed.

Source mitigation targets both hydrologic and chemical contributors to AMD production. Reclamation can lessen the flow of clean water through spoils and deep mines, thus lessening AMD. The principle source of water to abandoned mines in the Twomile Run watershed is precipitation. When rain or snow falls in the Twomile Run watershed, it can evaporate, runoff, or infiltrate. Many of the Twomile area spoils have limited vegetative ground cover, so evaporation and plant transpiration are minor. The unvegetated, porous spoils do not promote runoff. Additionally, the haphazard grading of the spoil has resulted in many trapped areas where runoff collects and infiltrates down through the acid spoil (See Photo 18). Therefore, nearly all precipitation infiltrates into the acid-producing spoil (See Figure 13). Since many surface mines encountered pre-existing deep mines, the improper grading of spoils can direct surface runoff directly into deep mine openings at the coal face. In some up-dip cases, it appears that spoils drain water into pits along highwalls that likely act as conduits into the abandoned deep mines. Reclamation can decrease the infiltration of water into the spoil and deep mines by creating a regraded landscape that collects surface water and directs it off site before it is contaminated and also by providing a densely vegetated surface that retards rapid infiltration and promotes evapotranspiration.

Water that flows through spoils and deep mines is affected by the chemistry of these materials and environments. All of the spoil in Twomile Run watershed is acidic and contaminates water. The remediation of acidic spoil is generally accomplished by neutralization through the incorporation of alkaline materials. This project measured the acid and base characteristics of spoils and overburdens, so that the amount of alkaline material necessary to partially or fully neutralize the acidity can be calculated (See Section IX).

The reclamation of deep mines is a special case that must be considered in the Twomile watershed. It is unlikely that all water can be prevented from entering the abandoned mines. The only proven method for eliminating AMD production from deep mines is their removal and reclamation. This activity typically involves the removal of saleable coal and the neutralization or special handling of any acid producing materials that must be placed in the backfill.

Several reclamation and remining alternatives were considered. The section that follows explains how the quantities were developed for the alternatives and the predicted water quality improvements for each project type.

A. Project Types

It is not enough to simply recommend "reclamation" of a certain area, since reclamation projects vary widely in the type of work that is performed and in their outcomes with respect to water quality improvement. In addition, the Twomile Run watershed contains extensive amounts of crop coal and lesser amounts of deep mine pillars, adding remining possibilities to the evaluation. The purpose of this section is to discuss the various general reclamation options that were evaluated as part of this project.

Three primary types of reclamation and several "add-on" options are discussed below. When selecting the type of reclamation that is best for each site, it is important to note that both cost and effectiveness with respect to water quality improvements increase as the reclamation intensity increases. Also, predicting the effects of reclamation on water quality is difficult prior to project completion because each site is unique. In general, a more intensive reclamation project is warranted in situations where water pollution is so severe that passive treatment is not possible and chemical treatment will be extremely expensive over time. In addition, reclamation is the only proven way to reduce contamination of a regional aquifer from unreclaimed mines.

Type I: Regrading with Revegetation

Project Type I, Regrading with Revegetation, is the least intensive type of reclamation. It involves establishing positive drainage from the site, removing any pits or closed depressions, and establishing vegetative cover. This type of project is most effective in areas were there are large areas with poor drainage, where there is little or no net acidity in the spoil column, or where erosion control is the primary concern. Figure 14 provides a conceptual depiction of a Type I project. For new mining projects, regrading to "Approximate Original Contour" (AOC) is required. For abandoned mines, the regrading project may be performed to AOC or to some other configuration that promotes positive drainage from the site but requires less spoil handling. For each spoil area, either AOC or a more efficient grading scheme has been proposed. The spoil volumes were calculated by creating an approximation of the desired contours and calculating the cut and fill necessary to achieve the original contours. In all cases, cut and fill balance within 5% was required.

After regrading, surface spoils are amended as necessary to establish vegetation. For this project, estimates were based on amending the top foot of reclaimed spoil at a rate consistent with the PSU recommendations and planted with a reclamation seed mix. Type I reclamation does NOT involve the addition of alkalinity to offset acidity produced by the mine spoil.

Vegetation established without significant alkaline incorporation in the full root zone is unable to establish deep roots that make it drought-tolerant and is unlikely to survive in the long term without maintenance liming.

The Twomile "Swamp" reclamation project was a Type I reclamation project. The spoils were regraded to promote positive drainage and the surface was revegetated without substantial alkaline amendment. Therefore, the water quality benefits achieved from that project are assumed to be transferable to other projects (See Section VII.A). Those benefits are: 1) increased runoff and evapotranspiration of clean water, 2) decreased infiltration of water into acid spoils, and 3) decreased contamination of the drainage produced by the reclaimed spoils. The effect on drainage from the spoils is predicted to be:

- Decrease in infiltration into spoils of 25-35%;
- Decrease in contaminant concentrations of 20-30%; and
- Decrease in acidity loading of 30-40%.

The reclamation is also expected to decrease flows into deep mines through unreclaimed pits, where applicable. The effect is predicted to be:

- Decrease in flows from deep mines of 10-20%;
- No change in the chemistry of deep mine discharges; and
- Decrease in the loadings produced by deep mines of 10-20%.

The minimalistic approach of this type of reclamation (Type I) is the least expensive option in terms of construction costs but long term costs are higher because periodic liming is required in order to assure vegetative success. In contrast, Type II reclamation (see below) has a higher construction cost because it incorporates much more alkaline material but long term costs are minimized or eliminated because future spoils liming would not be required**.**

Type II: Regrading with Alkaline Surface Amendment

Type II reclamation includes the regrading activities of Type I plus heavy alkaline amendment to the surface spoil. After regrading, the surface of the site is amended to a predetermined depth through the incorporation of alkaline materials. The surface is then revegetated (See Figure 15). The depth of alkalinity amendment used in these calculations was 4 feet. This depth is sufficient to support a deep root zone for vegetation and thus make the vegetation more drought-resistant. Complete neutralization of the targeted spoil will lessen future liming requirements. The excess alkalinity should counter acidification of the root zone (by upward migrating acidity) for decades. The vigorous vegetative cover will shed clean water more effectively than the Type I reclamation. Water that infiltrates through the amended spoil will be partially buffered and, due to biological activity in this zone, will be anoxic. These benefits, however, will not be enough to eliminate acidification of water that infiltrates beyond the amended zone and into unamended acidic spoil.

Alkaline addition rates vary and are based on the existing NP or NNP of the spoil, the target NNP of the root zone, and the depth of incorporation. The calculations presented here assume a 4 feet depth of amendment. The alkaline amendment quantities were based on the average spoil NNP value of -13 ppt (Table 33) and a targeted post-reclamation NNP for the targeted spoil of +12 ppt.

Type II reclamation is expected to have the same hydrologic effect as Type I reclamation. AMD contamination and loadings are predicted to decrease. The effect on drainage from the spoils is predicted to be:

- Decrease infiltration into spoils of 30-40%;
- Decrease in contaminant concentrations of 50-75%; and
- Decrease in acidity loading of 70-80%.

Type II reclamation is also expected to decrease flows into deep mines through unreclaimed pits. Water that does infiltrate through spoil to the deep mines will be less acidic. The effect is predicted to be:

- Decrease in flows from deep mines of 15-25%;
- Decrease in contaminant concentrations of 10%; and
- Decrease in contaminant loadings produced by deep mines of 20-30%.

Type III: Regrading with Whole Spoil Neutralization

Type III reclamation involves whole-spoil neutralization and is the most intensive type of reclamation considered for this report. This type of project involves creating positive drainage and incorporating enough alkaline material to completely neutralize the acidity present in the spoil column (See Figure 16). The first goal is to provide positive drainage from the site, which may be accomplished by AOC or by another more efficient grading plan.

The amendment rates for Type III reclamation were calculated from the spoil volumes, existing NNP, and targeted NNP. The spoil volumes were calculated from the difference between the existing topography and the original coal elevations. The alkaline amendment was based on the current NNP, –13 ppt, and a targeted final NNP of spoil of +12 ppt.

Type III assumes that all spoils are exposed, amended with alkaline material, and then regraded. The unit cost for handling the spoil in this alternative was assumed to be higher than shallow spoil handling because the exposure of deeper spoil will require more movement of spoil.

Type III reclamation is expected to eliminate all AMD associated with surface mine spoils. The effect on AMD production from surface mines is predicted to be:

- Decrease infiltration into spoils of 30-40%;
- decrease in acidity concentrations of 90-100%; and
- decrease in acidity loading of 90-100%.

The reclamation is also expected to lessen AMD produced by deep mines because the regrading will lessen the flow of water into the mines through unreclaimed pits and the water that does infiltrate through spoil will be alkaline (not acidic as is currently the case). The effect on AMD production from deep mines is predicted to be:

- decrease in flows from deep mines of 15-25%;
- decrease in contaminant concentrations for deep mines of 20-30%; and
- decrease in contaminant loadings produced by deep mines of 25-35%.

It is possible that the neutralized spoils will discharge iron as the pH and redox conditions within the spoil re-equilibrate. The iron would be in an alkaline matrix and any point discharges would be amenable to reliable and inexpensive passive treatment.

The following table summarizes the reclamation project types and their anticipated impacts on water pollution.

Table 44. Summary of Spoil Reclamation Project Types and Anticipated Impacts. See text for explanation of estimates.

	Anticipated % Decrease in Pollution Loading	
Project Type	**Discharges and Shallow Flows**	**Deep Mine and Aquifer Flows**
I. Regrading with revegetation	30-40%	10-20%
II. Regrading with alkaline surface amendment	70-80%	20-30%
III. Regrading with whole-spoil neutralization	90-100%	25-35%

Reclamation Project Add-Ons

In addition to the major project types discussed above, several other variables affect the intensity, cost, and effectiveness of reclamation. Note that these variables represent add-on features of the reclamation project types described above. The two most important add-on options in the Twomile Run watershed are coal crop removal and deep mine removal.

This project documented 3-5 feet of intact crop coal located around surface mines throughout the Twomile Run watershed. The quantity, quality, and ease of recovery of this coal make it attractive to mining and the generation of project revenue. In many locations, the crop coal is covered by only a few feet of spoil. Crop coal removal can be recommended in conjunction with any of the reclamation types discussed above. The spoil volume associated with the mining was calculated from difference of the current surface and the coal elevation in areas where crop coal is present. For projects where crop removal is recommended, spoil volumes for the rest of the site were adjusted to account for spoil removed and reclaimed during crop mining. The spoil associated with the crop is assumed to have a NNP of –13 ppt, which is amended to a NNP of +12 ppt. Crop coal mining is not expected to have any direct impact on water chemistry.

However, removing the crop coal can generate income to help offset the cost of other aspects of reclamation, such as alkaline addition.

Deep mines are present in Spoil Areas 4, 5N, 5S, 6, and 7. The mines contain pillars of coal with a high quality. Mining could produce a saleable product. Deep mine removal can be recommended in conjunction with any of the reclamation types discussed above.

To calculate the cost of deep mine removal, the quantities and characteristics of the coal and overburden were measured. The boundaries of abandoned deep mines were estimated from surface mine highwalls and drilling information. The depth of the overburden was estimated from the difference of the current land surface and the coal elevation. Data from the overburden cores were used to identify rock units and thicknesses. The volume and tonnage of each delineated unit was calculated using DEP procedures. Each unit's MPA, NP, and NNP were determined from laboratory data. A volume-weighted average NNP was calculated for each mining area using thresholds. The alkaline addition was calculated based on a reclamation target for the NNP of +6 ppt for all overburden disturbed during deep mining operations.

AMD production from mining operations can be lessened through special handling of especially acidic bedrock units. The acidic material is separated from other spoil and then placed within the spoil in a manner that is intended to minimize pyrite oxidation and leaching of acidic water. Often, the material is placed above the pit floor to keep it dry, amended with alkaline materials, and then encapsulated with clay. This approach should be considered for deep mine removal or virgin coal removal projects that disturb the Columbiana shale, since virtually all of the acid potential is found within this unit. However, the large quantities of the material will make encapsulation logistically difficult. As shown in Table 38, the acidic portion of Columbiana shale is typically 4-12 feet thick and comprises approximately 20% of the overburden on a volume basis.

DEP has analyzed the results of special handling projects and, at this time, believes that special handling cannot eliminate or lessen the value of alkaline addition. Even if the special handling is considered in mining plans, alkaline amendment to +6 NNP will likely be required.

The removal of deep mines combined with neutralization of all of the associated overburden is expected to eliminate AMD flowing from the deep mines. The effect on AMD production from deep mines is predicted to be:

- Decrease in flows out of deep mines of 100%;
- Decrease in contaminant concentrations for deep mines of 100%; and
- Decrease in contaminant loadings produced by deep mines of 100%.

The deep mines were left intact during the more recent surface mining activities because the high cover and limited coal recovery made mining unprofitable. While mining practices have become more efficient during the last 40 years and the price of coal has recently risen, the remining of deep mines is still an unprofitable activity. Therefore, deep mine removal adds to the net cost of reclamation and remining projects. The justification of the deep mine removal lies with the potential to completely eliminate AMD production.

The cost calculations assume that the $CaCO_3$ deficit will be met with waste limestone obtained from the Pleasant Gap area. Other sources of alkaline material may be identified. For example, the Twomile Swamp Reclamation Project made use of an alkaline tannery byproduct. While the material was available for free, trucking costs were substantial. In some cases, owners of alkaline wastes will provide the materials free and subsidize transportation costs in order to avoid landfilling costs. Fluidized bed power plant bottom ash is often alkaline and used in AML reclamation. The ability of fly ash to provide long-term in situ neutralization is unproven and therefore should be proposed only in combination with conventional alkaline materials. At this time, there are no plants close enough to the Twomile Run watershed to likely warrant subsidized ash. However, the situation may change as plans to develop refuse-burning power plants progress around the Commonwealth. Some industrial processes produce alkaline byproducts that, once approved as beneficial use products by the DEP, might be made available cheaper than limestone. Lime wastes from historic acetylene production have been discussed recently as a large source of $CaCO_3$ that could be available at highly subsidized costs. At this time, however, none of these wastes have actually been used in AML reclamation.

The placement of alkaline materials in a manner that maximizes acidity neutralization or alkalinity generation may be considered. One experimental treatment method involves the intentional infiltration of surface water through surface pits containing a highly reactive alkaline product. The concept is that the water will gain >500 mg/L alkalinity, which will then neutralize underlying untreated spoil. The approach requires continual replacement of the reactive alkaline material. Alternatively, the alkaline amendment might be concentrated on the pit floor where water will presumably flow after completion of mining and reclamation. The directed use of alkaline amendments, in place of whole-spoil neutralization, will need to be approved by the permitting agency. At this time, DEP does not consider the selected placement of alkaline materials as a proven or effective technology.

The use of biosolids as a soil substitute should also be considered for reclamation projects in Twomile Run. Biosolids do not provide alkalinity, but they do promote vegetative success by providing a nutrient-rich soil substitute. The use of biosolids can also reduce or eliminate the need for commercial fertilizers. Several mine reclamation projects throughout Pennsylvania have used biosolids successfully. Individual contracts are negotiated between the biosolids generator and the end user, who usually obtains the material for free but must provide funds for trucking and incorporation. These costs are not included in the reclamation scenarios presented below. Backhauling biosolids with coal from the site could reduce transportation costs.

If biosolids application is planned for a project, additional permits and notifications will be required from the DEP. Plans to use biosolids should be developed in close coordination with the project landowners, DEP, count conservation districts, and other stakeholders.

Table 45 summarizes the other variables that should be considered in projects in the Twomile Run watershed (and anywhere in the Commonwealth). Note that these activities can be combined with each other and may apply to any of the major project types discussed above. A detailed understanding of the site conditions is necessary in order to select the most cost-effective combination of project type and project add-ons for each site.

Table 45. Other Variables for Reclamation Projects

Variable	**Discussion**	**Potential in Twomile Run**
A. Coal Crop removal	Remaining crop coal is removed and sold. Money generated by mining is used to reduce overall reclamation costs. Water quality improvements arise form neutralization of spoil affected by mining.	High
B. Deep mine day-lighting and pillar removal	Deep mines are day-lighted and pillars are removed for sale. The overburden is neutralized. Major water quality improvements are expected.	High
C. Virgin coal removal	High-cover coal that was not disturbed by past mining is removed. If the coal removal is profitable, the activity could generate funds for reclamation projects.	Low: only one block of coal identified
D. Refuse removal	Refuse and coal cleanings are removed and sold as fuel. Reclamation funds are generated and water quality improves because the acidity source is removed.	Low: high BTU refuse does not exist in watershed
E. Soil Substitute / Beneficial Use products	Beneficial use products such as biosolids, dredge materials, or industrial wastes are used to create a soil substitute for plant establishment.	High: sources exist but transportation costs can be high
F. Special Handling / Placement of Materials	Materials having a high potential to create acidic conditions are handled in an manner that lessens acid production	Low: Special handling benefits are unproven; Acid materials are well distinguished but large volumes will be problematic
G. Special Placement of Alkaline Materials	Instead of dispersing $CaCO_3$ uniformly throughout the backfill, the alkalinity is placed in a manner that provides maximum benefit and lessens the total amount of $CaCO_3$ needed.	Low: Unproven effectiveness

B. *Assumptions*

In order to provide cost estimates for the reclamation projects discussed below, many assumptions were made. These assumptions are summarized in the following table and are used in the reclamation and remining spreadsheet, which is attached in electronic form.

The bases for several of the assumptions are presented below.

- Spoil Density Value was obtained from "Analysis of surface coal mine spoil bulk density" by Phelps, Wells, and Saperstein (1983). The average value for "small dragline" was used.
- Overburden Density This is an average value for sandstone and shale and is equivalent to 3,780 ton/ac-ft.
- Coal Density This is a typical value for coal and is equivalent to 1,800 ton/ac-ft.
- NNP target for Remining The +6 ppt NNP value was recommended by DEP and is consistent with existing permits.
- NNP target for Acid Spoils The +12 ppt NNP value was recommended by DEP.
- Unit Overburden removal and reclamation costs Based on bonding costs developed by DEP (April 2007 proposed guideline) and high cover (>80 feet) costs estimated by a PA mining firm experienced in deep mine removal projects in western PA.
- Blasting Costs Based on February 2007 bid to provide blasting for 95 ft thick overburden. The unit cost of this bid was $0.38/CY. Because overburden in Twomile averages 55 ft, adjusted unit cost down by 25%.
- Coal Values Based on recent estimates of the value of coal present in lower Kettle Creek area.
- Design and Engineering The design and permitting aspect of the projects is assumed as 8%. The percentage is less than the 15% value assumed for water treatment projects because the mapping is already completed for the high-priority areas (See Map 5), much of the conceptual design work has been completed (See Sections X.E through X.N), and the design and permitting of remining and reclamation projects is generally less expensive than the design of treatment systems.

Table 46. Assumptions used in reclamation and remining cost calculations

Spoil	**Value**	**Units**	**Reclamation and Remining**	**Value**	**Units**
spoil bulk density	116	lb/ft^3	regrade spoil, short push (<500 ft)	$ 0.75	$/CY
NNP, top 8 feet	-7	ppt	regrade spoil, long push (>500 ft)	$ 1.10	$/CY
NNP, bulk	-13	ppt	Blasting (average 55 ft overburden depth)	$0.29	$/CY
Total S, bulk	0.3	%	overburden removal / replacement, 0-40 feet depth	$ 0.80	$/CY
Overburden	**Value**	**Units**	overburden removal / replacement, 40-80 feet depth	$ 1.20	$/CY
overburden density, (sandstone and shale)	169	lb/ft^3	overburden removal / replacement, 80-120 feet depth	$ 1.60	$/CY
Coal	**Value**	**Units**	Coal removal	$ 1.00	$/CY
coal density	83	lb/ft^3	Waste limestone, loaded onto truck at quarry	$ 1.00	$/ton
deep mine % intact (pillars remaining)	40	%	limestone incorporated into loose spoil (short push)	$ 0.50	$/ton
crop coal recovery, % of current reserve	85	%	Limestone deep plowed into regraded spoil (Type II)	$ 5.00	$/ton
deep mine recovery, % of original reserve	25	%	E&S controls	$ 500	$/acre
coal value, crop	$ 25.00	$/ton	revegetate disturbed soils	$ 1,000	$/acre
coal value, deep	$ 35.00	$/ton	Mobilization and demobilization	By site	Estimated
Coal royalties to landowner (DCNR)	$ 0	$/ton	**Trucking (distances to Westport plus 10 miles)**	**Value**	**Units**
$CaCO_3$	**Value**	**Units**	truck cost, tri-axle	$ 60.00	$/hr
Limestone, waste, density	111	lb/ft^3	Truck load	23	ton
limestone, waste, purity	90	$CaCO_3$ %	Pleasant Gap - Twomile - Pleasant Gap (80 mi)	3.25	hours
Amendment Parameters	**Value**	**Units**	Pleasant Gap - Twomile - Pleasant Gap (80 mi)	$ 8.48	$/ton
Type II alkaline amendment depth	4	feet	Sunbury - Twomile - Sunbury (109 mi)	4.5	hours
Net NNP target for spoil	+12	ppt	Sunbury - Twomile - Sunbury (109 mi)	$ 11.74	$/ton
Net NNP target for overburden	+6	ppt	**Design and Permitting**	8	%

The acidic nature of the overburden in the Twomile Run area has been noted. Mining and reclamation will require alkaline addition. Several potential sources of alkalinity exist that vary in both purchase price and delivery price. The following table summarizes several sources that could be used for reclamation in Twomile Run. The prices do not include transportation.

Table 47. Potential Sources of Alkaline Material

Material	**Source(s)**	**Mine cost ($/ton)**	**Distance from site (miles)**	**% $CaCO_3$**
Limestone (marketable)	Local limestone quarries	$ 7-8	70-80	85 – 95%
Limestone (fine waste)	Local limestone quarries	$ 1-2	70-80	60– 95%
Dent's Run Limestone	Dents Run Project	$ 4-5	40	40 – 80%
Fly Ash	Power plants	$ 0	>100	10 – 15%
Wet Lime Wastes	Local lime producers	$ 1-2	80	50 – 60%
Waste Lime	Historic Acetylene Waste	$ 0	180	60%

The cost calculations assume that the spoils were amended with waste limestone from the Graymont quarry and lime plant near Pleasant Gap (80 miles from Twomile Run). This material is a mixture of Valentine limestone and waste lime that has a $CaCO_3$ equivalency of 95-100%. This material is already permitted for mine reclamation projects elsewhere. The use of other waste alkaline products must be approved by DEP and may require a Beneficial Use designation.

C. Factors Affecting Reclamation and Remining

The primary factor that will control the amount of reclamation performed and the reclamation time frame is the availability of funds for reclamation projects. However, there are several other critical factors that may affect the cost, scheduling, and completion of reclamation projects.

Most of the Twomile Run watershed and all of the areas targeted for reclamation and treatment systems are contained within the Sproul State Forest, which is under the jurisdiction of the PA DCNR. All projects will have to be coordinated with DCNR with regard to site access, coal royalties, ATV trails, timber management, hunting, habitat and other land uses.

The Whiskey Springs ATV trail system encompasses much of the area planned for reclamation on the west side of Twomile Run. The trail system includes a small campground and 45 miles of marked ATV trails under the jurisdiction of DCNR Sproul State Forest Office. These trails are shown on Map 11 and Map 12. Spoil Areas 5S, 5N, 6, 7, and 8 contain ATV trails. Coordination will be required with DCNR and the ATV community for any reclamation projects that propose to either temporarily close trail miles or completely alter ATV areas. Reclamation projects in trail areas should be coordinated during the design phase for trail reconstruction coordination, during the construction phase for safety, and after construction for rider education and awareness. ATVs can cause damage to vegetation, which can lessen the effectiveness of reclamation. Coordination with and education of the ATV community throughout all stages of project planning, design, and implementation will help to ensure that this group of stakeholders support the restoration of Twomile Run.

Another important land-use factor that will affect the final planning and design stages of any reclamation project, as well as the final cost, is the desired post-reclamation land use. The current reclamation scenarios assume that the land is reclaimed as open grassland that can serve as important habitat for elk and deer as well as many species of birds and small mammals. However, other land uses, including various types of forest habitat, may also be desired. The final reclamation plans should be formulated with the desired land uses in mind. For instance, if forestry is the desired final land use, factors such as root zone depth, final compaction, and competition from grasses become important. Collaboration with partners such as the Appalachian Regional Reforestation Initiative is recommended.

Obtaining local, state, and federal permits could also impact the budgets and schedules of proposed reclamation and remining projects. Environmental permitting can be time-consuming and expensive, particularly in areas where wetlands are present. Given the large scale of many of the proposed projects, permitting could require over a year of preparation and meetings with local, state, and federal agencies.

For projects that involve coal removal, mining permits will be necessary. The Moshannon District Mining office would be responsible for issuing the mining permits. Instead of traditional mining permits, other types of authorizations may be used in order to facilitate coal removal and reclamation in the watershed. In the past, Government Financed Construction Contracts (GFCCs) have been used to remove coal from areas that also require reclamation. These projects are limited in size and are negotiated with the DMO and OSM on an individual basis. GFCC projects must perform reclamation above and beyond typical reclamation in exchange for concessions on the coal revenues. Mining could also be performed as part of a subsidized reclamation project, where coal revenues offset some of the reclamation costs. In either case, contracts should be formulated that clearly define the scope of mining and reclamation activities. Although mining is expected to generate revenue that is then used for reclamation, this revenue will not be sufficient to fund the reclamation that is required without the addition of subsidies. It is unlikely that any coal removal permits of any kind would be issued for projects that do not contain a significant reclamation aspect.

Because of the remote location of the Twomile Run watershed, transporting alkaline amendments and other materials to the site and transporting coal from the site to coal markets will also have a large effect on the cost of projects. If coal removal is planned, backhauling of alkaline material to the site could decrease trucking costs. One impediment to site access is the SR 555 bridge over Driftwood Branch of Sinnemahoning Creek at Driftwood, PA. This bridge is currently a one-lane structure with a weight limit of 10 tons. Therefore, loaded triaxle trucks cannot cross the bridge. This bridge is scheduled for replacement in 2008-09, which should make several markets and sources of alkaline material more accessible. Another project that would greatly increase accessibility to the site would be the creation of an access point to the Norfolk Southern rail lines located along the West Branch of the Susquehanna River. Coal trains currently travel this line, carrying coal from northern tier counties to power plants along the Susquehanna River north of Harrisburg. Recently, some rail sidings in Renovo have been reopened to allow for train car maintenance. Obtaining alkaline material and/or delivering the coal to markets via rail could decrease transportation costs.

D. Summary of Pollution from Spoil Areas

While reclamation eliminates safety hazards and restores the land surface to a more productive use (such as wildlife habitat), the primary reason for pursuing reclamation in the Twomile Run watershed is for water quality improvements.

As discussed in previous sections of this report, historical mining in the Twomile Run left many areas of acidic, unreclaimed spoil that create water pollution in three main ways. Some polluted discharges run directly off the open spoils. The water becomes polluted through contact with the spoils. It is more common for discharges to emerge below the toe of the spoil after infiltrating into the spoil and then moving laterally until they reach the surface. These shallow groundwater flows are contaminated when they encounter acidic spoil. In some cases, the flow reaches abandoned deep mines that further acidify the water through contact with acidic materials within the mine. The large open voids of the deep mines also transmit the water to the surface at old mine openings. In addition to these two mechanisms of pollution, the open spoils are also contributing to the overall pollution of the local groundwater aquifer. Water that flows down through the spoils can reach the ground water table, and then move laterally as directed by local groundwater flow patterns. In the case of Twomile Run, this mechanism is providing contaminated baseflow to Twomile Run.

Table 48 shows each spoil area and lists the discharges or pollution that can be attributed to each spoil area. In some cases, more than one area can be responsible for the same pollution. In other cases, uncertain attribution is marked with a "(?)".

Areas 6 and 8 may contribute baseflow to Kettle Creek, but the very high flow of Kettle Creek dilutes any baseflow to undetectable levels. Based on this analysis alone, Spoil Areas 4, 4A, 5N, 5S, and 7 are the most important areas to reclaim.

The impact remediation activities have on water quality depends on the proposed project and on the type of pollution flowing from each site. As discussed in Sections X.A and X.B, there are varying intensities of reclamation and numerous reclamation "add-ons" that can be installed to enhance the results of reclamation. Therefore, the recommended reclamation plan for each area will be unique and will be based on the type/severity/number of discharges from the area, spoil condition, total area, and other factors. The follow sections discuss each spoil area in detail.

Table 48.   Known Discharges from Each Spoil Area

Area	Name	Discharges	See Section
1	Westport Point Mine	KC135	X.E
2	Dry Run Mine	KC135	X.F
3	Coal Anomaly Area	None known	X.G
4	Robbins Donut	• All NB headwaters discharges • Robbins Hollow Pipes #1-4 • 10A/10B • KC110 and KC106 • Robbins Ditch	X.H
4A	Swamp Reclamation Area	• Swamp #1-5 • Swamp at Pipeline	X.I
5N	The Pit	• Baseflow to Twomile Run • KC215 Trib • KC116	X.J
5S	Huling-Middle Ridge	• KC121 • KC231 • Baseflow to Twomile Run (?) • Baseflow to Huling Branch (?)	X.K
6	Huling Moonscape Mine	• KC188 • MAP13 • Baseflow to Kettle Creek (?) • Baseflow to Huling Branch (?)	X.L
7	Three-Fingered Devil	• Baseflow to Twomile Run • Old BAMR Weir 4 (Huling Tipple) • Huling A-F collection systems • Middle Branch R1 and R2 • Baseflow to Huling Branch (?)	X.M
8	Huling – Kettle Ridge	• KC137A • Baseflow to Kettle Creek (?)	X.N

E. Area 1: Westport Point Mine

Area 1 is referred to as the “Westport Point Mine” and is located on two isolated and distinct knobs containing Lower Kittanning coal overlooking the town of Westport and the West Branch Susquehanna River (See Map 2). The total affected acreage of Area 1 is 46 acres. The outer 7 acre southern knob was an island of coal that was completely surface mined except for the coal crop, which was left in place for a width of approximately 60 feet. The northern knob has a footprint of 39 acres of Lower Kittanning coal of which 26 acres has been affected while 16 acres of virgin coal remains in the center of the knob that has yet to be surface mined. Within the affected 26 acres of Lower Kittanning coal mining 13 acres remains as crop coal that can be removed. No evidence of deep mining in Area 1 was found. There is no occurrence of Upper Kittanning coal in Area 1.

The Area 1 spoils support a variable vegetative cover. The southern knob spoil is largely barren with poor stands of pines and larch. The northern spoil has several areas with dense volunteer vegetation and other areas that are bare with poor stands of planted trees.

A single kill zone identified as KC135 exists in the hollow separating Area 1 from Area 2 on the Twomile Run side. It is likely that both Area 1 and 2 contribute to the flow from the kill zone that was first located and sampled by DOE/NETL (See Section II.F). The 8 gpm flow had pH 3 and contained 190 mg/L acidity, 3 mg/L Fe and 13 mg/L Al.

The DOE/NETL survey also documented that Dry Run was degraded by AMD. The stream flow had low pH and contained 1.6 mg/L Al. The most likely source of this impairment is the abandoned surface mines in Areas 1 and 2. If these mines are in fact the source of the impairment to Dry Run, then it is possible that some AMD is also flowing to Twomile Run as contaminated baseflow. The amount of contaminated baseflow to Twomile Run would be small compared to other upstream sources.

Because of the downstream location of Area 1 no remedial actions are recommended at this time. Known impacts to Twomile Run upstream of this area should be addressed first. After reclamation in Areas 4, 7, and 5N have been completed, the remaining pollution to Twomile Run should be evaluated in order to determine the importance of other areas such as Areas 1, 2, 5S, 6, and 8. If improvement to the neighboring Dry Run watershed is desired, then remedial actions in Area 1 would become a higher priority. Though no action in this area is recommended at this time, the following analysis and calculations were performed in order to support potential future efforts.

The coal reserves were assessed. Table 49 shows the summary coal reserves for Area 1. Map 13 shows the overburden thicknesses for Area 1.

Table 49. Coal reserve and overburden measurements for Area 1

Overburden depth (feet)	**Area (Acres)**	**Overburden (CY)**	**Coal (tons)**
5-30 (crop)	10.3	333,000	45,000
30-50	6.9	445,279	38,471
50-69	5.5	527,962	30,665
69-75	3.0	348,479	16,727
Total	**25.7**	**1,654,720**	**141,663**

The Lower Kittanning coal in this part of the watershed is approximately 3 feet thick. A channel sample was collected from a highwall in Area 1, after a fresh surface was exposed by an excavator. The sample was 6% moisture, 9% ash, 3% sulfur and 13,000 BTU (See the Appendix for complete results).

The overburden was sampled in Area 1 at point KC18 OB. Summary characteristics of the overburden were presented in Table 38. The highly acidic Columbiana shale is present and the overburden has a bulk NNP of -19 ppt. Mining will require substantial alkaline addition.

There is unmined crop coal surrounding the spoils of both the southern and northern knobs. The coal is covered by shallow spoil and intact overburden. The spoil covering much of the crop is acidic. Mining of the crop would require alkaline addition to neutralize the acidic spoil. The spoils are fine-grained, which means that regrading would be easier and more cost effective than grading spoils with massive sandstone. With alkaline addition these fine-grained spoils will produce a soil amenable to plant growth.

Area 1 is accessible from Westport. If the ATV trail system is closed due to reclamation projects in Areas 5S, 5N, and 7, DCNR may consider opening up the Area 1 and Area 2 surface mines to ATV riders.

F. Area 2: Dry Run Mine

Area 2 is immediately north of Area 1 (See Map 2). The total affected footprint for mining in this area is 61 acres. Surface mining on the Lower Kittanning seam affected 30 acres but left 31 acres of high cover virgin coal. Within the footprint of the 30 acres of affected coal area, 6 acres falls under the category of Lower Kittanning crop coal covered by mine spoil that can be mined. In addition, there was a small 4.6 acre surface mine overlying the Lower Kittanning coal seam that removed an isolated occurrence of the Upper Kittanning Coal. No evidence of a deep mine in Area 2 was found.

The spoils in Area 2 are sparsely vegetated with pine, larch, and locust. Ground cover is limited. The poor vegetation is due to the acidic nature of the spoils.

One small flow of AMD was discovered to be flowing directly from Area 2 towards Twomile Run. The flow was from a spoil toe on the western side of Area 2. The AMD flowed less than 3 gpm when discovered and later was observed to be dry. The significance of this flow to Twomile Run is negligible. In addition to this small discharge, Area 2 likely contributes to the small kill zone in the hollow between Areas 1 and 2 identified as KC135 and described in the Area 1 discussion.

No remediation is recommended for Area 2 at this time because larger impacts to Twomile Run upstream of this area should be addressed first. After reclamation in Areas 4, 7, and 5N have been completed, the remaining pollution to Twomile Run should be evaluated in order to determine the importance of other areas such as Areas 1, 2, 5S, 6, and 8. If improvement to the neighboring Dry Run watershed is desired, then remedial actions in Area 2 would become a higher priority. Though no action in this area is recommended at this time, the following analysis and calculations were performed in order to support potential future efforts.

The coal reserves were assessed. Table 50 shows the summary coal reserves for Area 2.

Table 50. Coal reserve and overburden measurements for Area 2

Overburden depth (feet)	**Area (Acres)**	**Overburden (CY)**	**Coal (tons)**
5-30 (crop)	5.8	187,000	25,600
40-70	14.3	1,268,881	73,938
70-98	13.3	1,802,412	68,768
98-115	3.0	515,459	15,512
Total	**36.4**	**3,773,752**	**183,818**

The area contains about 150,000 tons of solid lower Kittanning coal, but the cover is quite high. The overburden quality in Area 2 is similar to Area 1 (See Table 38). Area 2 also contains crop coal that is covered with modest depths of spoil and intact overburden. Because the spoil is acidic, mining of the crop or high cover coal would require alkaline addition. The spoils are fine-grained, which means that regrading would be easier and more cost effective than grading spoils containing sandstone boulders. With alkaline addition these fine-grained spoils will produce a soil amenable to plant growth.

As noted in the previous section, Area 2 could be considered as an alternative ATV area should the Whiskey Run system be shut down by reclamation and remining activities.

G. Area 3: Coal Anomaly Area

Area 3 covers 300 acres between Area 2 and Area 4 (See Map 2). This is an area where the Lower Kittanning coal is largely absent because it was eroded and replaced by sandstone. Map 14 shows the distribution of coal in Area 3. A small surface disturbance is present at the northern edge of the area where mining was attempted. The small size (13.6 acres) likely attests to the lack of success. The mine is vegetated and is not known to produce AMD. The principle drainage from Area 3, Mackintosh Hollow, is not polluted.

Drilling performed as part of this project has confirmed that the Lower Kittanning coal is inconsistent and that this area is not suitable for mining. Previous mine operators drill records and records from Operation Scarlift all show the inconsistent manner of coal occurrence. There is no Upper Kittanning coal in Area 3.

No remedial action is recommended for Area 3 because no water quality impacts exist and limited surface impacts exist.

H. Area 4: Robbins Donut

Spoil Area 4 is located in the headwaters of Robbins Hollow and drains to Robbins Hollow, Twomile Run, and Shintown Run (See Map 2). The total affected area is 86 acres, which includes 34 acres of intact deep mine, 20 acres of reclaimed surface spoils, and 32 acres of unreclaimed surface spoils. The deep mine area includes 27 acres of confirmed deep mine within the Robbins "Donut" area and an additional 7 acres or more of unconfirmed deep mining on the eastern edge of Area 4 (See Map 8). The shape of Area 4 has led to it being referred to as "the Donut." Cross sections of "the Donut" are shown in Figure 17. See Map 8 for cross-section locations.

As described in Section II.A, BAMR completed a reclamation job on 20 acres of surface spoils in this area in 1978. These spoils are well-vegetated. It is assumed that the crop coal remains intact under this area. The BAMR project also placed a compacted clay seal over the coal face to seal any deep mine openings that were encountered by the surface mine, in an attempt to impound water in the deep mine. Measurements of water levels in a BAMR monitoring well (B4-6) show that water is in fact impounded within the deep mine. The seal appears to be imperfect, however, and as a result water seeps through the mine floor into underlying strata and eventually discharges diffusely at lower elevations. Area 4 produces all of the AMD pollution to Robbins Hollow and has created several kill zones above Twomile Run.

Remediation alternatives for Area 4 including reclamation and remining. The area is considered a high priority because:

1. The mining complex produces multiple AMD discharges including Robbins Hollow 10A/B/C, Pipes 1-4, Robbins Ditch, KC110, and KC106.
2. The pollution caused by this area enters Twomile Run upstream of most other discharges (but downstream of the Swamp area discharges).
3. The area is relatively small and isolated, and thus could serve as an important "proof of concept" project before much larger projects in Areas 7 and 5N go through final design phases.

Removal of the deep mine and reclamation of the spoils should eliminate all of the AMD produced by the deep mine and surface mine complex. Therefore, this is the ideal recommendation. The estimated cost for this recommendation is $2.3 – 2.9 million, depending on various projects options, which are discussed in detail below. Other options for reclaiming this area are also presented below.

Reclamation and crop removal of this area was divided into two sections. Spoils in the western half of Area 4 have been regraded and generally well vegetated (See Map 8). While crop coal is likely present in this section, removal of crop coal from this area is unlikely to produce economic or environmental benefits, therefore, no additional reclamation is recommended in this area. The eastern half of Area 4 mine contains crop coal that is less deeply buried and the spoils in this section have not been regraded and are less well vegetated. Removal of this crop coal as part of the regrading process could provide economic and environmental benefits.

Table 51 shows pertinent acreage and volume measurements for Area 4. Map 15 shows the overburden thickness in this area.

Table 52 shows the costs of various reclamation and remining alternatives. Note that these costs assume that intact overburden disturbed by mining is amended to +6 ppt NNP and that spoil is amended to +12 ppt NNP.

Table 51. Area 4 Spoil and Coal Quantity Summary

Item	Quantity	Unit	Notes
Site size	86	acres	
Reclaimed Spoil	20	acres	
Unreclaimed Spoil	32	acres	
Unreclaimed Spoil, Total [1]	712,448	CY	Current surface minus original coal elevation
Crop Coal [2]	46,440	tons	Extrapolation from exploration
Crop coal acreage [2]	9	acres	
Crop Coal overburden [2]	265,159	CY	Current topography minus coal elevation
Portion of Unreclaimed Spoil above Crop Coal	13	%	Unreclaimed spoil that will be reclaimed by crop mining
"Donut" Deep Mine	27	acres	
"Donut" DM Coal	57,855	tons	27 acres @ 5 feet thick @ 25% remaining
"Donut" DM average depth	40	feet	From current surface and coal elevation
"Donut" DM Overburden	1,518.950	CY	From current surface and coal elevation
Spoil surface top 4 feet after regrading	206,507	CY	Input to Type II surface neutralization calc
Unreclaimed Spoil NNP	-7	ppt	Average site-wide for shallow spoil
DM overburden NNP	-17	ppt	Average overburden east of Twomile Run

[1] total spoil includes spoil sitting on crop coal
[2] crop coal to the west is not included (see text and Map 8)

Table 52. Estimated cost for reclamation and remining alternatives for Area 4 Targeted overburden and spoil material are all amended to +6 ppt NNP.

Activity	Net Cost	Affected Acres	Earthmoving Total (CY)	Coal (tons)[1]	$CaCO_3$ (tons)[2]
Type I	$0	0	0	0	0
Type II	$190,961	32	206,507	0	6,144
Crop Mining	$12,655	9	265,159	39,474	10,381
Type II and Crop Mining	$179,746	32	445,852	39,474	15,757
Type III and Crop Mining	$764,910	32	712,448	39,474	29,838
Deep Mine	$2,140,163	27	1,518,950	57,855	80,226
Type II, Crop and DM mining	$2,329,317	59	1,964,803	97,329	97,681
Type III, Crop and DM mining	$2,889,636	59	2,231,398	97,329	108,118

[1] recoverable coal: 85% of delineated crop coal reserve and 25% of original deep mine reserve
[2] must be adjusted for $CaCO_3$ content of alkaline product used

All of the spoils in Area 4 have positive drainage and support modest vegetative cover. Therefore, a Type I project represents the status quo and is not recommended.

The Type II reclamation project would target only the unreclaimed spoils in the eastern half of Area 4 (See Map 8) and would involve clearing and grubbing, amending all spoil within 4 feet of the surface to +12 ppt, and revegetating. The underlying spoil would not be disturbed or amended with alkaline materials. This project would require 6,100 tons of $CaCO_3$, which could be supplied with 6,800 tons of waste 90% $CaCO_3$ limestone from the Pleasant Gap area. The estimated cost to purchase and truck the limestone to Area 4 is $65,000. Deep incorporation (4 feet) is estimated to cost $34,000. The total project cost would be approximately $191,000. The reclamation would modestly lessen the acidity of water infiltrating the spoils. A decrease in the acidity loadings in Robbins Hollow of only 10% should be expected.

Coal crop removal would have a net project cost of approximately $13,000. This represents the net cost for the project, which would require reclamation of 4 of the 32 acres of unreclaimed spoil. This estimate is strongly affected by the value of the crop coal and the cost to truck it to market. As noted in Table 46, we assume that crop coal has a $25/ton value and trucking to Sunbury costs $12/ton, resulting in a net value of the crop coal of $13/ton. A $1/ton increase in the net value of the coal (higher price or closer market or backhaul savings) results in the crop mining being marginally profitable. The removal of crop coal is not expected to substantially improve water quality beyond that achieved by Type II reclamation without crop removal.

Combining the Type II reclamation and crop mining is estimated to cost $180,000. The combination is less than the sum of the individual efforts because the affected areas overlap. That is, spoils reclaimed as part of the crop mining no longer have to be reclaimed under the Type II scenario. As noted above, the net cost is highly dependent on coal value and trucking. It is possible that this alterative could be accomplished at no cost if the net value of the coal increases by $5/ton.

Type III reclamation involves the complete neutralization (to +12 ppt NNP) of all spoil in the unreclaimed area. All unreclaimed mine spoil is excavated, amended with alkaline materials to +12 ppt NNP, regraded, and revegetated. Because the spoil disturbance would in many cases uncover the crop coal, Type III is only considered in combination with crop coal removal. The estimated net cost is $765,000. Type III reclamation should eliminate all AMD produced by spoils. Because the spoils are already well graded and already provide positive drainage, it is likely that this effort will only decrease AMD production in Robbins Hollow by 30% over current conditions.

Area 4 contains two deep mines. The analysis only considered the western deep mine that defines the donut area. There is a deep mine located to the east that extends beyond DCNR property and is not considered in these calculations. The extent and condition of this mine is not known.

The Area 4 deep mine is 27 acres, has an average cover of 40 feet, and is estimated to contain 58,000 tons of recoverable coal. The overburden is acidic due to the presence of the Columbiana shale above the coal. The overburden is estimated to have an NNP of -17 ppt. Amending the disturbed overburden to +6 ppt NNP would require 80,000 tons of $CaCO_3$.

Removal of the deep mine was assessed in combination with crop mining and Type II and Type III reclamation of the unreclaimed surface spoils. The cost for the two alternatives is $2.3 – 2.9 million.

Removal of the deep mine in combination with spoil neutralization should eliminate all AMD flowing from the Donut mine complex. AMD will continue to flow from the deep mine on the eastern boundary of Area 4, but these flows are likely already captured and treated by the Robbins Hollow East Branch passive systems. The implementation of either of these alternatives is expected to result in the restoration of Robbins Hollow.

The success of any of the remediation alternatives can be assessed by comparing pre-project and post-project AMD loadings in the Robbins Hollow watershed. Monitoring is recommended at the following stations:

- RH12 and RH05 (chemistry only)
- Pipes #1-4 (can be measured as one aggregated discharge, flow and chemistry)
- Robbins 10A/B/C (flow and chemistry)
- NB04, NB02, and NB Source

The monitoring results should be compared with the existing data at each station in order to determine how effective the project was at decreasing the water pollution. Two years of quarterly monitoring is recommended in order to assess the effectiveness of the project.

The results of the Area 4 Remining and Reclamation project should be used to influence the final planning, design, and cost estimation for other, similar projects, such as remining and reclamation of Area 7 and Area 5N. See Sections X.J and X.M for more information.

I. Area 4A: Swamp Reclamation Area

Area 4A covers approximately 92 acres (See Map 2). About half of this area is within the Twomile Run drainage basin, with 42 acres draining directly to the neighboring Shintown Run watershed. Subsurface drainage, on the other hand, strongly favors Twomile Run due to the south to southwest dip of the Lower Kittanning Coal. As a result, nearly all AMD generated by this spoil area is discharged at or near the “Swamp” kill zone that drains to Twomile Run.

In 2005, 57 acres of this area were reclaimed as part of the Twomile Run Reclamation Project. Section II.K describes the reclamation work. Section VII.A discusses the effect of reclamation on pollution that is flowing from this area. Section VII.D discusses treatment options for the remaining discharges.

Since only minimal alkaline addition was performed in the Twomile Run Reclamation Project, periodic liming of the site will be required to maintain vegetative cover. In fact, sampling conducted soon after the reclamation was completed showed that the site was not sufficiently alkaline, so 1 ton/acre of lime was added in 2006 (See Section II.K). Although no further reclamation of this area is recommended at this time, it is critical that the vegetative cover established on the site survive. The site should be visually inspected annually for signs of vegetation decline or soil toxicity. If any problems are noted, the affected soils should be analyzed for standard soil parameters and then amended according to laboratory recommendations.

Even if no visual signs of vegetative stress are noted during the inspections, random soil sampling over the entire site is recommended every 5 years. Soils sampling and amendment should be conducted in accordance with the "Kettle Creek Bio-Capping Project - Supplementary Soil Amendment Plan" prepared by the project engineer (Gannett Fleming of Clearfield, PA) should be conducted in the eight sub-areas outlined in the project final report and sent to PSAASL for analyses. These samples will show if the soil parameters are changing over time and may allow for preventative liming and/or fertilizing before problems develop.

While the Soil Amendment Plan provides detailed instructions as to how to perform the soil amendment, it does not give a predicted interval of required amendment activities. For cost estimating purposes, it was assumed that the site must be limed and fertilized every 5 years at a cost of $100/acre. The cost to periodically sample and analyze the soils is estimated at $500. The total cost to maintain the vegetation of the reclaimed spoil in Area 4A is thus $6,000 every 5 years.

J. Area 5N: The Pit

Area 5N is located on the ridge between Middle Branch and Huling Branch (See Map 2). The total area is 93 acres, which includes 15 acres of intact deep mine and 78 acres of unreclaimed surface spoils. Area 5N includes the "Pit", an unreclaimed, largely barren mine pit that is popular with ATV riders. Cross sections depicting the "Pit" are shown in Figure 18. Cross section locations are shown on Map 10.

Vegetative cover in Area 5N is highly variable. In areas near the outcrop, spoil piles are thickly vegetated while interior portions of the mine are often barren. The area contains 2.6 miles of ATV trails as well as 43 acres of "play area" (See Map 12). Remediation work in Area 5N would temporarily impact access to ATV trails in Area 5N.

Area 5N contains a deep mine that extends to the south into Area 5S. Map 10 shows the mining features. Surface mining occurred to the northwest and southeast of the deep mine. The surface mining at the northern edge of the area is updip of the deep mine. As a result, infiltrating precipitation is likely flowing into the deep mine from these unreclaimed spoils. Once in the deep mine, the water quality is likely degraded further and either discharges into acid spoils to the south east or flows south into Area 5S where it is lost to the local groundwater system (there are only two small surface discharges from Area 5S).

Few surface flows of AMD are present in Area 5N. Two flows of AMD emerge at the surface during periods of wet weather at the coal outcrop at the head of the hollow on the southeast side of the surface mine. Considering the size and unreclaimed state of the surface mine, one would expect a far greater amount of AMD from this site.

Despite the lack of surface flows of mine drainage from this area, reclamation of Area 5N is considered a high priority because it contributes to contaminated baseflow of Twomile Run (See Section V.B).

Table 53 shows spoil, coal, and overburden quantities for Area 5N. Map 16 shows the overburden thickness in this area.

Table 53. Area 5N spoil and coal quantity summary

Item	Quantity	Unit	Notes
Site size	93	acres	Surface and deep mines
Unreclaimed Spoil, Total [1]	3,544,684	CY	Current surface minus coal elevation
Crop Coal	107,460	tons	Extrapolation from exploration
Crop coal acreage	20	acres	
Crop Coal overburden	743,684	CY	Current topography minus coal elevation
Portion of total Spoil above Crop Coal	20	%	Spoil that will be reclaimed by crop mining
Deep Mine Coal	29,250	tons	4.5 feet thick @ 25% remaining
Deep Mine average depth	60	feet	From current surface and coal elevation
Deep Mine Overburden	1,484,264	CY	From current surface and coal elevation
Spoil surface top 4 feet after regrading	469,803	CY	Input to Type II surface neutralization calc
Unreclaimed Spoil NNP	-13	ppt	Average site-wide for spoil
DM overburden NNP	-3	ppt	Average overburden east of Twomile Run

[1] total spoil includes spoil sitting on crop coal

Area 5N differs substantially from Area 4 by the much larger ratio of spoil and overburden to coal. In Area 4 there is an estimated 8 CY of spoil for each ton of crop coal, and the deep mine has an average 40 feet of cover (See Section X.H). In Area 5N, the ratio of spoil (CY) to crop coal (ton) is 32:1 and the deep mine has an average 60 feet of cover. The economic gain from mining the crop coal will thus be less, and the cost of removing the deep mine will be more.

A positive aspect of Area 5N is that the overburden is less acidic than in any other area investigated. The overburden sampled at KC-33 OB had a bulk NNP of +2 ppt. The core encountered the same highly acidic Columbiana shale above the coal. However, the shale was less acidic and thinner than other cores.

Table 54 shows the costs of various reclamation and remining alternatives.

Type I costs were developed by creating a general regrading plan for Area 5N and then calculating earthmoving quantities. The regrading plan is shown in Map 10. The plan requires the regrading of 825,000 CY of spoil at an estimated cost of $899,000. This alternative would lessen the infiltration of water into acidic spoils and through the deep mine by eliminating trapped areas and creating a vegetated surface.

Table 54. Estimated cost for reclamation and remining alternatives for Area 5N.

Activity	**Net Cost**	**Affected Acres**	**Earth-moving Total (CY)**	**Coal (tons)[1]**	**$CaCO_3$ (tons)[2]**
Type I	\$898,587	78	825,576	0	0
Type II	\$1,244,384	78	1,295,379	0	18,393
Crop Mining	\$216,007	20	743,684	91,341	29,115
Type II and Crop Mining	\$1,088,846	78	1,684,969	91,341	42,480
Type III and Crop Mining	\$4,651,835	78	3,544,684	91,341	150,959
Deep Mines	\$2,650,816	15	1,484,264	29,250	31,967
Type II, Crop and Deep mining	\$3,699,662	93	3,169,233	120,591	74,447
Type III Crop and Deep mining	\$7,262,652	93	5,028,948	120,591	170,742

[1] *recoverable coal: 85% of delineated crop coal reserve and 25% of original deep mine reserve*
[2] *must be adjusted for $CaCO_3$ content of alkaline product used*

Type II costs were developed using Type I regrading quantities and adding alkalinity to the top 4 feet of the final graded surface. The alkalinity amendment is 18,000 tons $CaCO_3$, which is equivalent to 20,000 tons of 90% pure waste limestone. This effort would create a vegetated alkaline layer that should eliminate the diffusion of oxygen into the spoils or deep mine (which will prevent further oxidation of pyrite) and partially buffer infiltration. The cost for this option is \$1.24 million.

Table 55. Coal reserve and overburden measurements for Area 5N

Overburden depth (feet)	**Area (Acres)**	**Overburden (CY)**	**Coal (tons)**
5-40 (crop)	20	743,684	107,460
40-60	10	806,665	19,500
60-108	5	677,599	9,750
Total	**35**	**2,227,948**	**136,710**

Crop coal was extensively investigated in Area 5N. The crop was uniformly present on the eastern and northern sides of the site and is covered with 5-40 feet of spoil. Cost calculations suggest that removal and sale of the 91,000 tons (85% recovery) of crop coal will cost about \$216,000. This cost is sensitive to coal value and transportation costs. If the net value (coal revenue minus transportation which is assumed at \$15/ton) can be increased by \$3/ton, the crop mining becomes marginally profitable. Even if the crop mining requires a subsidy, the cost per acre is much lower than without crop removal.

The combination of Type III reclamation with crop coal mining is much more expensive than the Type II alternative because much of the spoil is *not* associated with the crop. Of the 3.5 million CY of spoil present in Area 5N, only 740,000 CY are associated with crop coal. The Type II reclamation amends the top 4 feet of this spoil to 12 ppt NNP (after regrading for positive drainage), while Type III excavates and amends the full volume.

The portion of the deep mine within Area 5N contains approximately 29,000 tons of coal. The overburden is thick, so the cost to remove the deep mine and amend all associated spoils to +6 ppt NNP is higher. The cost is much higher because there is more overburden per ton of coal and also because the cost estimator assumes that mining costs increase with the depth of cover (see Section X.B).

Removal of the deep mine was assessed in combination with both Type II and Type III reclamation of the surface mine spoils. Removal of the deep mine, crop coal *and* complete neutralization of all of the spoil to 12 ppt and overburden to 6 ppt (Type III) is estimated to cost $7.3 million. The high cost is due to the large quantity of spoil that must be moved long distances in order to apply and mix the alkaline amendments. The implementation of Type II reclamation of surface mine spoils along with removal of the deep mine and amendment of the deep mine overburden, is $3.7 million.

Type III reclamation combined with deep mine removal will eliminate substantially all of the AMD produced by Area 5N because of the acidic materials will be removed or neutralized. Type II reclamation combined with deep mine removal will significantly decrease AMD loadings because infiltration of water into the spoils will be substantially decreased and flow through the deep mine will be eliminated.

A conceptual analysis of the remedial challenges suggests that a single mining plan for the reclamation and deep mine removal could save earthmoving costs. Part of the high-cover deep mine is located adjacent to “the Pit” (See Figure 18). Regrading costs could be lessened by pushing the mine overburden, much of which is 5-20 ppt NNP into the Pit, essentially beginning the deep mine removal process where the surface mine operator stopped. This would provide a more cost-effective manner of dealing with the highest cover overburden. We believe that this concept, fully developed into a combined reclamation and remaining plan, could lessen the earthmoving costs of the project by at least $500,000.

After reclamation of Area 5N, water quality and flow monitoring should be performed in order to assess the effectiveness of the project. The monitoring wells installed as part of this project should be sampled periodically in order to assess the impacts of reclamation on the groundwater quality (See Section IX.D). Finally, the snapshots of in-stream water quality on Twomile Run should be repeated (See Section V).

K. Area 5S: Huling-Middle Ridge

Area 5S covers 151 total acres on the southern part of the ridge between Huling Branch and Twomile Run (See Map 2). The area includes a 103-acre Lower Kittanning deep mine that also contains of 29 acres of Upper Kittanning surface mine spoils. The deep mine is ringed with 48 acres of Lower Kittanning surface mine spoils.

The main access to Area 5S is via ATV trails (See Map 12) that have been established on old mining roads. The best access is from the Middle Branch side via the campground but access can also be made via trails from the Huling Branch Tipple area. There are 2.9 miles of ATV trail in Area 5S (See Map 12).

Area 5S contains spoils that are graded and are well vegetated. No highwalls are exposed. Many of the original pines survive and the spoils have been heavily colonized by volunteer hardwoods. The spoils are covered with plant litter and herbaceous ground cover. Little bare spoil is found. In many places, the spoils blend smoothly into the native forest, making the mine boundary difficult to discern.

Only two surface flows of AMD have been found in Area 5S. The discharges, located and sampled by DOE/NETL (See Section II.F) are identified as KC121 and KC231 (See Map 7). Both are small flows with moderate acidities (<200mg/L). Sample results can be found in the Appendix. KC121 emerges as a toe of spoil discharge on a very steep slope above Twomile Run. The discharge is lost into the ground and likely contaminates a natural wetland area along Twomile Run Road. Sampling conducted for the Twomile Run "snapshots" (See Section V.B) was at this lower location along the road. KC231 is a diffuse area of seepage along the gas pipeline at the southern end of the ridge. Both KC121 and KC231 drain directly to Twomile Run.

The absence of visible AMD flowing from Area 5S does not indicate that AMD is not generated in this area. Some poorly reclaimed parts of Area 5S likely have infiltration rates that approach 100%. It is probable that the mine complex produces AMD that escapes into underlying strata. If this is the case, the geologic structure of the area indicates that the AMD would discharge as contaminated baseflow primarily to lower Huling Branch (See Map 6). However, this contamination is being masked by contribution from areas further upstream.

No remedial actions are recommended for Area 5S at this time. After reclamation in Areas 4, 7, and 5N have been completed, the remaining pollution to Huling Branch and Twomile Run should be evaluated in order to determine the importance of other areas such as Areas 1, 2, 5S, 6, and 8. Though no action in this area is recommended at this time, the following analysis and calculations were performed in order to support potential future efforts.

Area 5S contains the highest cover deep mine in the watershed. Its removal would be very expensive. Using the same cost estimators that were used for the Area 5N deep mine, the net cost (after coal revenue is subtracted) to remove the deep mine is $22 million. This does not include reclamation of surface spoils or crop coal removal, which would increase the cost. Map 16 shows the overburden thickness in this area.

Table 56. Coal reserve and overburden measurements for Area 5S

Overburden depth (feet)	Area (Acres)	Overburden (CY)	Coal (tons)
Crop	na	na	na
0-40	3	96,800	6,446
40-60	35	2,815,261	74,991
60-108	47	6,410,083	101,636
108-120	8	1,526,533	17,835
120-150	9	2,047,316	20,198
Total	**102**	**12,895,993**	**221,106**

Since Area 5S is downstream of several major sources of AMD, quantifying its present impact on water quality is difficult. As restoration projects are completed in Area 4, Area 7, Area 5N, and at the Swamp passive treatment system, the relative importance of Area 5S will become more clear through in-stream sampling. At that time, reclamation of this area may be necessary.

L. Area 6: Huling Moonscape Mine

Area 6 is located on the ridge between Huling Branch and Kettle Creek (See Map 2). Area 6 covers a total of 335 acres. The area has been mined on the Upper and Lower Kittanning seams. The top of the ridge originally contained shallow Upper Kittanning coal, which was surface mined to exhaustion disturbing 6 acres. The Lower Kittanning coal bed has been deep mined (118 acres) and surface mined (145 acres). Crop coal likely remains in place, but its extent is unknown. The surface mine along the northwestern edge of Area 6 is referred to locally as "The Moonscape" because of its rocky, barren appearance. Two blocks of intact Lower Kittanning coal exist with acreages of 16 and 56 acres.

Access to Area 6 is by an unimproved road along the western side Huling Branch or though Area 8 via the Whisky Springs ATV access along Kettle Creek road. Area 6 contains 7.9 miles of ATV trails and 26 acres of "play area" (See Map 12).

Little AMD was found in Area 6. Huling Branch flows adjacent to Area 6 and does not become seriously impacted until it reaches the Huling tipple area where major flows of AMD enter from the east (Area 7, See Map 2). The primary flow of AMD found in Area 6 was KC188 which flows down an unreclaimed cut to Kettle Creek. The discharge, which was 0-13 gpm when investigated, flows down the steep hill to Kettle Creek. The AMD flow could not be located along Kettle Creek Road and there was no visible plume of AMD or staining in Kettle Creek.

During wet weather AMD flows out of a deep mine entry identified as MAP13. This entry is located near ATV marker 17 and it drains to Huling Branch. Flows have been observed from 0-5 gpm.

The absence of AMD flowing from Area 6 does not indicate that AMD is not generated in this area. The poorly reclaimed parts of Area 6 have infiltration rates that approach 100%. It is probable that the mine complex produces AMD that escapes into underlying strata. If this is the case, the geologic structure of the area indicates that the AMD would discharge as contaminated baseflow to lower Huling Branch, Twomile Run between Huling Branch and Kettle Creek, and Kettle Creek itself (See Map 6).

However, no remediation is recommended for Area 6 at this time because known impacts to Twomile Run upstream of this area should be addressed first. After reclamation in Areas 4, 7, and 5N have been completed, the remaining pollution to Huling Branch and Twomile Run should be evaluated in order to determine the importance of other areas such as Areas 1, 2, 5S, 6, and 8. Though no action in this area is recommended at this time, the following analysis and calculations were performed in order to support potential future efforts.

Coal and overburden quantities are shown in Table 57.

Table 57. Area 6 coal reserves and overburden quantities.
Crop coal reserves, which are not known, are not included in the table

Overburden depth (feet)	Acres	Overburden (CY)	Coal (ton)
0-40	25	796,985	121,593
40-70	82	7,293,865	404,652
70-100	77	10,490,678	376,592
100-125	6	1,125,298	30,521
Total	**190**	**19,706,826**	**933,358**

Area 6 coal resources were investigated in the past by BAMR and several coal companies (See Map 6). A total of 83 holes are known to have been drilled in Area 6. Of 38 reliable drill logs, only 8 encountered deep mines, indicating that large tracts of intact coal remain. Map 17 shows the Lower Kittanning overburden thickness. The coal reserves analysis assumed 72 acres of solid coal and 118 acres of deep mined coal. The Lower Kittanning coal is 5 feet thick in this area.

The overburden was characterized from a core logged by the USGS working with BAMR (B6-22 OB). The summary results of the sampling were shown in Table 38. The overburden results are similar to those found in other spoil areas in Twomile Run. The overburden is inert sandstone down to the Columbiana shale. The Columbiana Shale is 9 feet thick and averages 3.6% sulfur and a NNP of -107 ppt. Because of this highly toxic stratum, the entire overburden has a NNP of -17 ppt.

Based on the cost assumptions used for other sites, the complete mining and reclamation of Area 6 would likely have a net cost of approximately $30 million. This does not include crop coal, which would decrease the total cost. Because so much coal could be recovered from Area 6, the final economic analysis of a remining/reclamation project will be especially dependent on coal prices.

M. Area 7: Three Fingered Devil

Area 7 is located on the northern part of the ridge between Middle Branch and Huling Branch and represents the furthest upstream impact to both tributaries (See Map 2). Area 7 covers a total of 162 acres, which includes 96 acres of surface mine spoils (of which 9 acres have been reclaimed) and 67 acres in two intact deep mines (28 acre eastern deep mine and the 39 acre western deep mine). Area 7 was the subject of the report entitled "Huling Branch Mine Complex: Investigation of Acid Mine Drainage and Recommendations for Remediation" (HE 2004). See Section II.I for more information on that report.

Vegetative cover in Area 7 is highly variable. In areas near the outcrop, spoil piles are thickly vegetated while interior portions of the mine are often barren. There are 3.6 miles of ATV trail in Area 7 as well as a 50 acres of "play area" (See Map 12).

The spoils and deep mines in Area 7 produce large flows of highly toxic AMD. The AMD flows directly from mine openings, collection systems Huling A – F, kill zones downgradient of spoils, and into underlying aquifers. Surface mines abut the deep mines and appear to funnel water into the deep mines. The situation is especially apparent to the northwest of the eastern deep mine where the surface spoils are "graded" in such a way that 28 acres of surface drainage terminates at a highwall. In addition, the coal also dips toward the deep mine so both surface water and infiltration that has reached the pit floor have a tendency to flow toward and into the eastern deep mine in Area 7.

Reclamation of Area 7 is considered to be a high priority because:

1. Surface flows from Area 7 are not amenable to reliable passive treatment
2. Area 7 is likely contributing to contaminated baseflow to Twomile Run

The recommended alternative for Area 7 is the removal of both deep mines and crop coal with Type II reclamation on all other spoils. The mining plan for the eastern mine should include a drainage channel that moves water through the reclaimed area and minimizes infiltration into the unneutralized acidic spoils that remain beneath the regraded and revegetated surface. Other reclamation alternatives are also discussed in case the recommended alternative is not economically feasible.

Table 58 shows spoil, coal, and overburden quantities for Area 7. Map 18 shows the overburden thickness in this area. The area is similar to Area 5N in the large amount of acid spoil relative to crop coal. The spoil to crop coal ratio is 20:1 (Area 4, 8:1; Area 5N, 32:1). The crop coal, which was intensively investigated, is shallowly buried under spoil and original ground. The average spoil cover is only about 18 feet. The crop thickness in Area 7 was less variable than in Area 5N and is estimated to average 4 feet, one foot thicker than Areas 4 and 5N.

Table 58. Area 7 spoil and coal quantity summary

Item	**Quantity**	**Unit**	**Notes**
Site size	162	acres	Surface and deep mines
Unreclaimed Spoil, Total [1]	3,826,576	CY	Current surface minus coal elevation
Crop Coal	189,615	tons	Extrapolation from exploration
Crop coal acreage	22	acres	
Crop Coal overburden	633,765	CY	Current topography minus coal elevation
Portion of total Spoil above Crop Coal	17	%	Spoil that will be reclaimed by crop mining
Eastern DM	28	acres	
Eastern DM Coal	55,545	tons	4 feet thick @ 25% remaining
Eastern DM average depth	46	feet	From current surface and coal elevation
Eastern DM Overburden	2,054,576	CY	From current surface and coal elevation
Western DM	39	Acres	
Western DM Coal	70,354	tons	4 feet thick @ 25% remaining
Western DM average depth	37	feet	From current surface and coal elevation
Western DM Overburden	2,350,783	CY	From current surface and coal elevation
Spoil surface top 4 feet after regrading	558,213	CY	Input to Type II surface neutralization calc
Unreclaimed Spoil NNP	-13	ppt	Average site-wide for spoil
DM overburden NNP	-20	ppt	Average overburden east of Twomile
Type I and II regrade	800,000	CY	
Drainage channel through eastern deep mine	500,000	CY	

[1] total spoil includes spoil sitting on crop coal

The two deep mines are estimated to contain a total of 126,000 tons of coal. The overburden depths average 42 feet. The overburden chemistry is similar to other areas. The overburden is largely inert sandstone with the exception of 5-6 feet of highly acidic shale above of the Lower Kittanning coal. The average NNP of two overburden cores was -20 ppt.

Table 59 shows the costs of various reclamation and remining alternatives. Type I and II regrading calculations were based on the general plan shown in Map 10. The plan includes creating positive drainage and the excavation of a drainage channel through the middle of the eastern deep mine. The channel, designed with 3:1 side slopes, requires 500,000 CY of earth work. The creation of this channel, in the absence of removal of the deep mine, was assumed to cost $1.50/CY, double the standard spoil movement cost. The cost of the channel accounts for 50% of the Type I reclamation costs and 40% of the Type II reclamation costs.

Unmined crop coal around the surface mine is extensive with minimal spoil cover in Area 7. The calculations suggest that removal of crop coal can be profitable. This situation lessens the cost of Type II reclamation when it is added.

Type III reclamation, even when combined with crop coal removal, is very expensive. The large volume of spoil, almost 4 million CY, makes its complete neutralization economically impractical.

Table 59. Estimated cost for reclamation and remining alternatives for Area 7 Targeted overburden and spoil material are all amended to +6 ppt NNP.

Activity	**Cost**	**Affected Acres**	**Earthmoving Total (CY)**	**Coal Mined (ton)**[1]	**$CaCO_3$ (ton)**[2]
Type I	$1,541,520	96	800,000	0	0
Type II	$1,940,243	96	1,358,213	0	21,854
Crop Mining	-$332,113	22	633,765	131,274	24,812
Type II and Crop Mining	$1,241,074	96	1,646,537	131,274	41,108
Type III and Crop mining	$5,357,341	96	3,826,576	131,274	163,699
Deep Mines	$8,121,430	67	4,405,359	125,904	262,948
Type II, Crop and DM mining	$8,698,804	162	6,051,896	257,178	304,056
Type III Crop and DM mining	$13,438,771	162	8,231,935	257,178	412,759

[1] recoverable coal: 85% of delineated crop coal reserve and 25% of original deep mine reserve
[2] must be adjusted for $CaCO_3$ content of alkaline product used

Removal of the deep mines is a large, costly project. Combined with crop coal removal, the complete mining of Area 7 would produce approximately 260,000 tons of coal. Deep mine removal is not a profitable operation in the remote Twomile Run area. The total cost of deep mine removal is related to the area of deep mine removal and therefore the quantity of coal removed. In this way, though seemingly counterintuitive, the amount of subsidy required for deep mine removal increases with the amount of coal produced.

The recommended alternative is Type II reclamation with crop coal and deep mine removal. This alternative eliminates AMD associated with the deep mines and flow over barren spoils. Creation of a vigorous vegetative cover that drains water off the spoils will lessen infiltration. Due to the large areas of closed depression and poor vegetative cover over much of the site, this alternative is expected to dramatically reduce AMD produced in Area 7 even without complete neutralization of all spoils. Reduction in AMD loading is expected to be 70-90%.

After reclamation and remining of Area 7, water quality and flow monitoring should be performed in order to assess the effectiveness of the project. The Huling A-F collection systems will be destroyed during the crop removal process. The remaining points that should be monitored include R1 and R2 in the Middle Branch Watershed, the discharge from the new surface diversion channel that will be placed through the eastern deep mine (See Map 10), and the old BAMR Weir 6 (Huling Tipple) location. In addition to these surface water sampling points, the monitoring wells installed as part of this project should be sampled periodically in order to assess the impacts of reclamation on the groundwater quality (See Section IX.D). Finally, the snapshots of in-stream water quality on Twomile Run should be repeated (See Section V).

N. Area 8: Huling-Kettle Ridge

Area 8 is referred to as the “Huling-Kettle Ridge” due to its ridgetop location between Huling Branch and the main stem of Kettle Creek. The smallest of the mined areas discussed in this report, Area 8 contains 47 acres of surface mine disturbance. A small deep mine exists in this area but its extent is unknown. However, the maximum size is restricted to 10 acres by surface mining and outcrop of the coal seam.

Vegetative cover in Area 8 is comparable to that of Area 5S with dense groves of coniferous trees separated by bands of barren spoils. There are 3.9 miles of ATV trail in Area 8. Remediation work in this area would temporarily impact access to the trail system from the Whisky Springs parking area (See Map 12).

One source of AMD is known to exist in Area 8. The discharge, first located and sampled by the DOE/NETL (See Section II.F), is identified as KC137A. The discharge emanates from a collapsed deep mine entry on the southeast tip of the ridge (marked on the USGS quad with a 1336 spot elevation) forming a small kill zone. The discharge is lost into the ground and does not enter any stream at the surface. Topography suggests that the discharge ultimately flows directly to Kettle Creek. The discharge was sampled in June 2002 and the 2.5 gpm flow had pH 2.6 and contained 544 mg/L acidity, 85 mg/L Fe, and 26 mg/L Al.

Any subsurface flow of AMD would likely go to Kettle Creek due to the coal structure in the area. Regardless, the impact of AMD produced in Area 8 on Kettle Creek is insignificant.

Little is known about the coal reserves in this area.

No remediation is recommended for Area 8 at this time due to the minor quantity of AMD and the downstream location of the mines. Because the amount of AMD produced by Area 8 seems to be so small, it cannot even be quantified fully until the much larger contributors upstream (Area 7 in particular) are addressed. However, a combination of reclamation and remining similar to that proposed in Area 5N would be suitable for addressing AMD problems in Area 8 at the appropriate time.

O. Cost Summary and Sensitivity Analysis

Table 60 summarizes the estimated costs for the Type II spoil reclamation & deep mine and crop coal removal alternative for Areas 4, 5N, and 7. This is the recommended alternative for each of these high-priority areas. Figure 20 shows the breakdown for the total costs. The net total cost for all three high-priority reclamation projects is $14.7 million.

The total costs are dependent on cost and value estimates that may be inaccurate or may change with time and market conditions. The purpose of this section is to discuss how changes in the reclamation targets, value of coal, and cost of transportation affect the net cost of the projects.

Table 60. Total costs for the Type II reclamation, deep mine, and crop coal removal

Cost Category	**Area 4**	**Area 5N**	**Area 7**	**Total**
Mobilization/demobilization	$40,000	$40,000	$40,000	$120,000
E&S Controls	$177,677	$235,079	$570,695	$983,451
Earthwork (including blasting)	$2,420,129	$3,775,716	$7,923,299	$14,119,144
Alkaline amendment	$158,872	$116,654	$497,706	$773,232
Alk amendment trucking	$920,373	$701,460	$2,864,881	$4,486,715
Revegetation	$93,536	$129,944	$226,440	$449,920
Engineering and permitting	$306,082	$403,108	$973,042	$1,682,232
Coal value	($3,011,775)	($3,307,275)	($7,688,503)	($14,007,553)
Coal trucking	$1,224,423	$1,604,975	$3,291,243	$6,120,642
Total	**$2,329,317**	**$3,699,662**	**$8,698,804**	**$14,727,783**

Table 61 shows how changes in several key cost or value assumptions affect the total cost of the recommended alternative (Type II spoil reclamation plus deep mine and crop removal). The calculations assume that waste limestone is obtained in the Pleasant Gap area and trucked to the project. In the past the waste limestone has been offered for a $1/ton loading fee. If waste limestone is provided at no cost, $600,000 is saved. If the material must be purchased for $5/ton then the project costs increase by $2.4 million.

The default cost estimate assumes that overburden is amended to +6 ppt NNP and spoil is amended to +12 ppt NNP. Decreasing the target NNP for spoil to +6 ppt saves $300,000. Several other NNP targets are also shown.

Coal recovery from deep mines was assumed to be 25% of the original reserves. This is likely a conservative assumption as the recovery of 40% is not uncommon. If the coal recovery from the deep mines is 40%, the net cost of the project decreases by $2.8 million.

The analysis assumed different values for deep coal and crop coal. This is a common condition at deep mine removal operations in western PA where several coal products are produced. In the Twomile case, crop coal would have less value than deep mine coal because it has a lower BTU content. The analysis assumed the deep coal value was $35/ton and the crop coal was $25/ton. This cost does not include delivery costs. The $35/ton value may be conservative. In 2005, two mining companies mined small blocks (<500 tons) of Lower Kittanning coal in the Twomile Run and Short Bend watersheds. The coal, a mixture of crop and shallow-cover mine pillar, sold for $28-30/ton. According to the Energy Information Administration, the spot price for northern Appalachia coal on December 28, 2006 was $43/ton. In 2006, this coal averaged ~$45/ton. If the price of deep coal is $45/ton, the project cost decreases by $2.1 million. If the price of crop coal is $35/ton, the project cost decreases by $2.6 million. If both of these price advantages occur, the project cost deceases by $4.8 million.

The remote location of the Twomile Run project makes transportation a major cost factor. Trucking costs for coal and alkaline amendment total $10.6 million and account for 37% of the total gross project cost. The cost to truck coal to the nearest power plant in Sunbury PA (109 miles) was estimated at $11.74/ton. The cost to truck waste limestone from Pleasant Gap (80 miles) was estimated at $8.50/ton. Cheaper transportation might be gained by finding closer markets, through truck backhauls, or by using railroads. A loop that used the same trucks to haul limestone from Pleasant Gap and coal to Sunbury could decrease trucking costs by about 20% ($2.4 million, not shown). Norfolk Southern has an active line along the Susquehanna River only 5 miles from the Twomile Run watershed. If a coal loading facility was constructed in the area, less expensive rail transportation might be possible. Railroad freight rates that do not involve multiple lines are about $0.05 per ton per mile. This is half of the assumed trucking rate of about $0.10 per ton per mile. Short haul trucking (from Twomile Run to the tipple) combined with railroad delivery to power plants along the Susquehanna could decrease total coal transportation costs by $5-6 per ton. Table 61 shows the impact of speculative changes in trucking costs on project costs.

Waste alkaline materials can sometimes be obtained at highly subsidized costs. For example, some power plants will deliver alkaline ash to projects because the transportation costs are less than disposal in an on-site landfill. Recently the DEP notified watershed organizations about 80,000 tons of waste lime that may be available for free to locations within 200 miles of Buffalo, NY (about 170 miles from Twomile Run). The material must be received within the next 8 months, so it is not applicable to current Twomile Run projects. TU, KCWA, and DEP should remain cognizant of these opportunities because of the potential to substantially decrease project costs. Any waste alkaline material must be approved by DEP as a beneficial use waste product.

The last analysis in Table 61 considers a scenario where the coal is delivered to a tipple site near Westport and then transported via rail from Westport to a power plant at no cost. It is not uncommon for companies to provide such services in lieu of paying penalties for environmental infractions. The table also considers that waste lime is transported for free or, assuming that it is unloaded at the railroad tipple site, costs $4/ton for transportation. This admittedly optimistic scenario results in total project costs $5.6-8.0 million.

Combinations of several favorable factors could result in a project that does not require public subsidy. One combination that was identified occurs if the value of both coals is $10 higher than assumed ($45/ $35), the deep mines yield 35% of their original reserve instead of 25%, and free transportation is available from Westport for coal and alkaline amendments.

In summary, there are many factors that could cause a significant change in the costs presented in this report. The project spreadsheet allows the user to change these assumptions and obtain new project cost estimates. Before funding is sought for any project, the project spreadsheet should be updated to reflect the best information available at the time.

Table 61. Cost Sensitivity Analysis for Total Reclamation Costs

	Base value	Cost ($million)	New value	New Cost ($million)	New value	New Cost ($million)
Waste 90% $CaCO_3$ amendment cost (at source)	$1	$14.7	$0	$14.1	$5	$17.1
Final NNP of reclaimed overburden (using thresholds)	6 ppt	$14.7	3 ppt	$14.1	9 ppt	$15.4
Final NNP of reclaimed spoil (top 4 ft)	12 ppt	$14.7	6 ppt	$14.4	18 ppt	$15.1
Coal Recovery and Values						
Deep Mine Coal recovery (% of original reserve)	25%	$14.7	40%	$11.9	15%	$16.6
Deep coal value	$35/ton	$14.7	$45	$12.6	$25	$16.9
Crop Coal value	$25/ton	$14.7	$35	$12.1	$15	$17.3
Coal Market changes (Deep/Crop)	$35/25	$14.7	$45/35	$9.9	$25/15	$19.5
Coal and $CaCO_3$ Transportation						
Coal Trucking cost	$11.74/ton	$14.7	$6	$11.7	$14	$15.9
Limestone trucking cost	$8.50/ton	$14.7	$4	$12.0	$12	$16.8
$CaCO_3$ wastes trucked to site at discounted cost	$8.50/ton	$14.7	$0	$9.6	$4	$12.0
Transportation costs/ton from Westport for coal (top) and for $CaCO_3$ (bottom)	$11.74/ton $8.50/ton	$14.7	$4/ton $0/ton	$5.6	$4/ton $4/ton	$8.0

NOTE: The values shown under "New Cost" represent the total project cost if only the variable listed in changed. All other variables remain at their "Base Value" as shown.

XI. Recommended Plan

Presenting a reclamation plan for Twomile Run is complex for many reasons. The Twomile Run watershed receives pollution from many distinct sources of mine drainage and from contaminated baseflow. Both surface mining and deep mining were extensive within the watershed. Some discharges are too severe to be addressed by passive treatment. The purpose of this plan was to present a step-by-step approach to restoring Twomile Run. The previous sections discussed alternatives for addressing the various sources of pollution. The purpose of this section is to present the selected alternatives for each pollution source and the relative importance of each project. However, this plan is not set in stone and may change based on landowner requirements, project funding availability, the coal market, outcomes of similar projects elsewhere, and many other factors. The recommendations discussed below should be used as a guide.

A. Project Prioritization Methods

Many factors were considered when assigning a priority to the projects below. The factors included:

- Potential for Twomile Run and tributary stream-mile recovery
- Pounds per day of pollution loading
- Preference for permanent abatement over perpetual treatment
- Preference for passive treatment over chemical treatment, where feasible
- Impacts to public lands access, ATV trails, forestry, etc
- Terrestrial wildlife habitat detriments and improvements
- Cost/benefit

Projects were assigned a priority of high, medium, or low based on these general priorities.

B. Treatment Systems Recommendations

Treatment systems are not recommended for discharges that may be affected by future reclamation projects. Reclamation has already been done above the Swamp discharges (Section VII.D), so treatment is recommended at this site. This project can be pursued immediately based on the data and recommendations in this report. The Swamp discharges are severe, but similar discharges are being treated passively in the Babb Creek watershed at the Anna S site. A similar system is recommended for the Swamp. The total cost for the passive system and clean-water bypass channel is estimated at $693,000. If the passive system is rejected, then a chemical NaOH system should be installed for a capital cost of approximately $203,000 and an expectation that annual costs will be approximately $72,500/yr.

In all other areas, reclamation is recommended prior to treatment system construction. However, a preliminary treatment recommendation has been provided for Robbins Hollow (See Section VII.C) if the reclamation option for Area 4 is not possible.

Other treatment systems will be necessary in the future to treat discharges that are not completely eliminated by reclamation. These include the Huling Branch Collection systems A-F and the Huling Tipple (BAMR Weir 4 discharges). While it is likely that these discharges will be reduced by reclamation, completely eliminating all of the discharges is unlikely. In addition, it may be necessary to over-treat some discharges in order to offset contaminated baseflow.

Specific treatment recommendations for these discharges should be developed after reclamation is completed in these areas and new monitoring data is obtained.

C. Reclamation Recommendations

Sections X.E through X.N discussed the 10 reclamation areas that were considered as part of this project. The purpose of this section is to select an alternative for each area and assign a priority to each project. The following table summarizes the recommended projects. The projects are listed in the approximate order that they should be performed. For more information on how these priorities were assigned, see the individual section listings.

Table 62. Summary of Reclamation Recommendations

Area	Recommended Project Description	Priority	Acres*	Cost Est.	Section
4A	Periodic liming/fertilizing	High	57	$6,000/5 yr	X.I
4	Type II reclamation and remining	High	59	$2,329,317	X.H
7	Type II reclamation and remining	High	162	$8,698,804	X.M
5N	Type II reclamation and remining	High	93	$3,699,662	X.J
5S	Monitor High priority project impacts; consider reclamation and remining	Medium	Up to 151	About $22 million	X.K
6	Monitor High priority project impacts; consider reclamation and remining	Medium	Up to 335	About $30 million	X.L
8	Monitor High priority project impacts; consider reclamation and remining	Low	Up to 47	unknown	X.N
1	Monitor High priority project impacts; consider reclamation and remining	Low	Up to 59	unknown	X.E
2	Monitor High priority project impacts; consider reclamation and remining	Low	Up to 61	unknown	X.F
3	no remediation necessary	Low	Up to 300	$0	X.G

*Acres affected by the proposed project

Area 4 reclamation is recommended as the first project because its impact can define subsequent projects. The choice of the Type II reclamation over Type III reclamation potentially saves $8 million (all three high priority projects considered). The savings arise because heavy alkaline amendment is limited to the surface four feet of the regraded spoil. The total volume of acid spoils is *not* excavated, amended and then regraded. Water quality benefits arise because the surface is graded for positive drainage and the heavy vegetative cover is established that absorbs or sheds most precipitation. Precipitation that does infiltrate is made alkaline and anoxic through contact with the alkaline biologically-active soil. These characteristics buffer acidity and inhibit further pyrite oxidation. The deep mine, which is believed to be a major incubator for AMD production, is eliminated and replaced with neutralized spoil. Likewise, spoil associated with the crop coal is completed neutralized. Spoils infiltration that moves through these environments will be treated *in situ*. The ability of this approach to substantially eliminate the AMD generation by Area 4 is uncertain. The AMD production by Area 4 is well characterized and it should be straightforward to determine the effect of the remediation on AMD production and stream quality.

The Area 4 project can be considered a demonstration project whose effectiveness and final cost will influence remediation in Areas 5N and 7, as well as at dozens of similar sites in the West Branch watershed. Several factors make Area 4 a good choice for a demonstration project. First, the upstream location of the area allows for the results of the project to be more easily assessed in terms of in-stream improvement. Second, the project is relatively small compared to the other high priority projects in Areas 5N and 7 thus improving the likelihood of funding. And finally, the Area 4 project contains all of the elements of the larger projects so lessons learned are directly applicable.

Areas 5N and 7 are considered high priority projects because they are the most likely sources of contaminated baseflow to Twomile Run, which can only be addressed through reclamation. Area 7 is also the source of numerous AMD discharges, including Huling A-F and the tipple discharges.

If more reclamation is needed after the high priority projects are completed, Areas 5S and 6 will probably be the next areas to address. These areas are not considered high priority projects at this time because they contribute little if any surface AMD and the geologic structure indicates that subsurface contributions from these areas would flow to Huling Branch, Kettle Creek, or the furthest downstream reaches of Twomile Run.

D. Monitoring Recommendations

Although copious amounts of data exist for many locations in the Twomile Run watershed, some points still warrant additional monitoring. In most cases, the water quality monitoring points have been affected by recent projects such as water collection, reclamation, or treatment system construction. The following table describes the stations where further water quality sampling is recommended and the type and frequency of sampling that should be performed. Unless otherwise noted, standard mine drainage chemistry parameters are recommended. Whenever possible, samples from the same general area of the watershed should be taken on the same day.

The stations in Table 63 should be monitored as described independent of projects that may or may not take place. Sample analysis at a private analytical lab is estimated to cost $30/sample and sample collection is estimated at $20/sample. The total annual cost of sampling would be approximately $10,000/year. However, costs could be near zero if samples are collected by volunteers and analyzed by the DEP laboratories.

There are additional stations which should be monitored during and after projects as they are completed. Some stations may cease to exist and new stations may need to be added, for instance, if a treatment system is constructed or reclamation alters flow regimes. Suggested monitoring points for each major project are listed in the project description.

In addition to the water quality sampling, additional soil sampling is recommended in areas that are reclaimed in order to ensure vegetative success. See Section X.I for recommendations on soil sampling in Area 4A, which was reclaimed in 2004. These general guidelines should be followed for all areas after they are reclaimed.

Table 63. Summary of Water Quality Monitoring Recommendations

Point	Description	Flow Rate	Chemistry	Notes
Swamp at Pipeline	Discharge from the Twomile reclamation area at the pipeline crossing weir	Monthly	Monthly or Quarterly	Continued evaluation of the Twomile Swamp reclamation job
R2	Middle Branch treatment system influent	Monthly	Quarterly	To evaluate effectiveness of Huling F collection
MB Various	After treatment system is reconstructed, follow O&M plan recommendations	Quarterly	Quarterly	To evaluate the performance of the MB system
RH12	Robbins Hollow below confluence of North Branch and East Branch	Quarterly, if possible	Quarterly, total and filtered metals	To evaluate the in-stream improvements from the headwaters systems
RH05	Old weir location near mouth of Robbins Hollow	Quarterly, if possible	Quarterly, total and filtered metals	To evaluate the in-stream improvements from the headwaters systems and need for additional projects
RH Various	Various points as discussed in the RH Headwater systems O&M Plan	Quarterly	Quarterly	To evaluate the performance of the RH headwaters systems
Huling C	New collection system above Huling tipple	Monthly	Quarterly	To evaluate effectiveness of collection
Huling E	New collection system in Huling deep mine	Monthly	Quarterly	To evaluate effectiveness of collection
Huling F	Middle Branch discharge collection system that is piped to Huling Branch	Monthly	Quarterly	To evaluate effectiveness of collection
Twomile Mouth	A regular sampling station should be created at the mouth	Quarterly	Quarterly	To evaluate the overall success of restoration

E. Summary of High Priority Recommendations

The mine drainage problems in Twomile Run are widespread and complex, requiring a combination of treatment and reclamation. The following table summarizes the high priority projects for the watershed.

Table 64. Summary of High Priority Recommendations

Project	**See Section**	**Cost Estimate***
Continued Annual Monitoring	XI.D	$ 10,000 / year
Monitoring and Liming of Area 4A Reclamation Area	X.I	$ 6,000 / 5 years
Twomile "Swamp" Passive Treatment and Cleanwater Bypass	VII.D	$ 693,000
Area 4 Reclamation and Remining	X.H	$ 2,329,317
Area 7 Reclamation and Remining	X.M	$ 8,698,804
Area 5N Reclamation and Remining	X.J	$ 3,699,662

**For construction projects, this is the net total cost, including engineering and design and any revenues that may be produced via mining.*

As discussed in Section XI.D, continued monitoring is recommended for several areas of the watershed. Continued monitoring is important in order to assess the effectiveness of past projects and to assist with the design and scoping of future projects. The recommended monitoring includes flow and chemistry of discharges, treatment systems, and in stream stations as well as visual and chemical sampling of completed reclamation jobs. See Section XI.D for detailed information. It is anticipated that periodic liming of the Area 4A reclamation project may be necessary. This is a high priority because ensuring vegetative success at this site will ensure that water quality improvements caused by the reclamation project are maintained.

The other two projects that should be advanced immediately are the Twomile "Swamp" Passive Treatment System and Area 4 Reclamation and Remining. The Swamp treatment system is a high priority because reclamation has already been completed in this area and this pollution represents the furthest upstream impact to Twomile Run. This recommendation includes the construction of a clean-water bypass channel. Section VII.D discusses the recommended treatment system in detail.

The Area 4 reclamation and remining project is considered a high priority because this area generates several sources of AMD and because it is a small, relatively isolated project that could provide useful information about the effectiveness of more extensive reclamation and remining. The recommended plan includes removing 27 acres of deep mine and reclaiming 32 acres of spoil. Section X.H discusses the Area 4 reclamation and remining project in detail.

Lessons learned in Area 4 should then be applied to the Area 7 and Area 5N reclamation and remining projects. These projects are discussed in detail in Sections X.M and X.J, respectively. Addressing these areas is considered crucial to the recovery of Twomile Run because they contribute large amounts of contaminated baseflow to Twomile Run.

After these high-priority projects are completed, monitoring should be performed in order to assess the success in terms of AMD pollution to Twomile Run and its tributaries. Because the AMD problem includes aquifer contamination, it may take several years to confidently know if the reclamation has eliminated polluted inflows to the shallow aquifers. It is possible that the projects will result in the remediation of acidic conditions in the streams, but alkaline iron-contaminated seeps may remain. These flows can be reliably treated with inexpensive passive techniques.

After the water quality impacts of the high-priority projects have been quantified, it is likely that other projects will be necessary to completely restore Twomile Run and its tributaries. These possible future projects include reclamation and remining in Area 5S and Area 6 (See Sections X.K and X.L, respectively) and the construction of treatment systems for any discharges that persist after remining and reclamation in Areas 4, 5N, and 7. Because the results of reclamation are extremely difficult to predict, it is impossible to say at this time which of these projects will be required.

It is important to note that these projects represent the Twomile Run watershed only. Additional recommendations for the west side of Kettle Creek are contained in the companion report to this final report (West Side of Lower Kettle Creek AMD Remediation Master Plan, HE, 2007).

These projects represent recommendations based on the best information available at the time this report was finalized. It is possible that project priorities will change based on new findings in the field, results of other similar reclamation, remining, or treatment projects, changes in the coal market, availability of free or cheap alkaline amendment materials, or advances in mine drainage science.

Because the recommended projects involve extensive earthmoving activities and high rates of alkaline addition, the costs are high. Much of the net cost of the projects is associated with transportation expenses. If alkaline materials can be brought into the watershed or coal can be transported to markets with subsidies, the total cost of the projects will decrease substantially. The subsidies do not necessarily need to come from the public sector. The partners should be alert for alkaline materials that could be transported to the watershed at subsidized cost because the alternative disposal costs are high. The partners should also be alert to settlements with private companies that might provide subsidized transportation costs in lieu of paying penalties for environmental damages elsewhere in the West Branch Susquehanna watershed.

XII. References

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