West Side of Lower Kettle Creek AMD Remediation Master Plan

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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

The KC204 discharge, a drain from the Kettle Creek Coal Mining Company No. 1 Mine

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Executive Summary

A large deep mine complex on the west side of lower Kettle Creek produces numerous flows of acid mine drainage that enter Kettle Creek, Milligan Run, and the Cooks Run watershed. An assessment was made of the discharges and their impact on Kettle Creek. Discharges were located by reviewing existing reports and by performing reconnaissance with assistance from KCWA and DCNR personnel. An airborne remote sensing survey conducted by the Department of Energy's National Energy Technology Laboratory was especially useful. Twenty-six AMD discharges were identified. Flow rates and water samples were collected and analyzed. All 26 discharges were acidic and most of the discharges were highly toxic AMD. On average the discharges produced a total of 479 gpm of flow with 304 mg/L acidity, 44 mg/L Fe, 21 mg/L Al, 8 mg/L Mn, and 930 mg/L sulfate. The average cumulative contaminant loadings were 1,745 lb/day acidity, 253 lb/day Fe and 123 lb/day Al. Additional non-point discharges were observed in the Short Bend Run and Duck Hollow where AMD seeps are present well below the coal elevation.

The largest source of pollution was a drain from the Kettle Creek Coal Mining Company No. 1 Mine located between Short Bend Run and Duck Hollow. This point, KC204, accounted for a quarter of the AMD flow and half of the contaminant loadings produced on the west side. KC204 has severe chemistry, averaging 700 mg/L acidity, 120 mg/L Fe, and 47 mg/L Al. Historically, the discharge from this area was through another nearby drain, KC204A. During the last 30 years, flow through KC204A has been blocked, probably by subsidence, causing the mine pool to discharge to Kettle Creek through KC204 and to Milligan Run through subsided mine entries near the town of Bitumen. Under high flow conditions the mine pool is estimated to contain about 38 million gallons of AMD. The failure of the KC204A blockage and the sudden release of the mine pool would be catastrophic for lower Kettle Creek.

Kettle Creek contains enough flow and alkalinity to completely buffer current inflows of AMD from the west side. Two surveys of the stream chemistry showed that Kettle Creek had neutral pH and very low metal concentrations below the AMD inflows. On average, the alkalinity loading released at the Alvin R. Bush dam is about 15 times greater than the acidity loading produced by the west side discharges.

Kettle Creek's alkalinity loading is not sufficient to neutralize the sudden release of AMD impounded within the abandoned No.1 mine behind the KC204A drain. If the pool drained suddenly due to failure of the current plug, lower Kettle Creek would become net acidic and the West Branch below Kettle Creek would be temporarily degraded.

The discharges were organized into groups and conceptual treatment plans and cost estimates were developed. Discharges from the Hicks/Slide, Short Bend, Duck Hollow, and Butler Hollow groups have chemistry that is considered suitable for passive treatment with vertical flow ponds and settling/mixing ponds. Discharges from the Slide Hollow, Slide/Short and KC204 are too contaminated for current passive technologies so chemical treatment with NaOH was considered.

A decision matrix was prepared that considered pollution loading, tributary impacts, fishery potentials, impact to Kettle Creek, forestry impacts, and public visibility. The recommended

projects involve KC204 and the Butler Hollow discharges. No action is recommended for the other discharges at this time. KC204 can be more reliably and cost-effectively handled if it is relocated to the west to the Milligan Run watershed. The relocation can likely be accomplished through excavation and grouting. The grouting of KC204A would lessen the probability of a catastrophic blowout. There is more room for construction of a chemical treatment system in the Milligan Run watershed than exists in lower Kettle Creek. Phase I of the relocation, which involves excavation of collapsed entries, installation of observation wells, and monitoring of the new hydrologic conditions, is estimated to cost $77,000. This does not include Phase II grouting projects. Butler Hollow is the only drainage that could provide cold-water fishery benefits if the AMD is treated. The discharges are suitable for passive treatment and sufficient land exists for construction of systems. Two passive treatment systems (BN and BS) are recommended with a total capital cost of $709,000.

Acronyms and Symbols Used Throughout This Report

Symbol	Category	Description
Al	chemistry	Aluminum
CaCO3	chemistry	Calcium Carbonate, the alkaline component of limestone
Fe	chemistry	Iron
Mn	chemistry	Manganese
NaOH	chemistry	Sodium hydroxide, a common reagent for chemical treatment
SO4	chemistry	Sulfate
AASHTO	other	American Association of State Highway and Transportation Officials
BAMR	organization	DEP Bureau of Abandoned Mine Reclamation
DCNR	organization	Department of Conservation and Natural Resources
DEP	organization	Department of Environmental Protection
DOE/NETL	organization	Department of Energy/National Energy Technology Laboratory
HE	organization	Hedin Environmental
KCWA	organization	Kettle Creek Watershed Association
NOAA	organization	National Oceanic and Atmospheric Administration
TU	organization	Trout Unlimited, Inc.
USGS	organization	United States Geological Services
WPA	organization	Works Progress Administration
AMD	other	Acid Mine Drainage or Abandoned Mine Drainage
EM	other	Electromagnetic
GPS	other	Global Positioning System
VFP	other	Vertical Flow Pond
RAMP	other	Rural Abandoned Mines Program
WBSR	other	West Branch of the Susquehanna River
CFS	unit	Cubic feet per second
ft^2	unit	Square feet
g/m2/day	unit	Grams per meter squared per day
lb/day	unit	pounds per day
mg/L	unit	milligrams per liter, a unit of concentration
mL	unit	milliliters

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 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 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 instream 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 northcentral 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 significant benefits to water quality of the West Branch in terms of increased alkalinity inputs and reduced heavy metals contribution.

The benefits gained by 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. AMD flowing from the east side of Kettle Creek is primarily produced in the Twomile Run drainage basin. A report on the occurrence of the Twomile Run AMD and remediation options was prepared as a separate task of this project (HE, 2007). AMD flowing from the west side of Kettle Creek has been recognized for years, but has received less attention because much of the pollution occurs in remote or inaccessible locations. This report presents an assessment conducted by Hedin Environmental of the west side AMD sources to lower Kettle Creek and provides remediation options. This project was funded from grants secured by Trout Unlimited from the DEP Bureau of Abandoned Mine Reclamation, National Fish and Wildlife Foundation, and the Richard King Mellon Foundation.

A. Study Area

The Kettle Creek watershed encompasses 244 square miles in Clinton, Potter, and Tioga Counties. For most of its length, Kettle Creek displays excellent water 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 AMD. Kettle Creek is polluted by acidic flow from Twomile Run to the east and by flow from numerous sources to the west. This project focused on the western discharges. Map 1 shows the position of the study area in the lower Kettle Creek watershed. The 2,814 acre (4.4 square mile) area is bounded by Kettle Creek to the east, Hicks Hollow to the north, and the shared watershed divides with Crowley Hollow, Milligan Run, and North Smith Run to the west, and the West Branch of the Susquehanna River to the south. The existence of a large deep mine complex in the study area complicates geographical boundaries because it extends beyond the surface divide into the Milligan and Crowley watersheds. It is likely that some water that infiltrates within the Kettle Creek watershed enters the deep mine and is discharged into Milligan and Crowley Runs. The opposite may also occur.

Several polluted tributaries to Kettle Creek occur in the study area. Table 1 lists these streams and shows their location relative to Kettle Creek's mouth. The table also includes KC204, a very important AMD discharge that flows directly to Kettle Creek.

Table 1. 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 Gaging 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

At one time Bitumen was a thriving community with more than 100 residents. Today, the village has a permanent population of less than 10 people. The permanent population of the entire study area is less than 50 people. A single improved road (Cattaraugus Road) accesses the project area and generally follows the western watershed divide. There are several homes and seasonal camps on this road. Much of the study area is part of the Sproul State Forest and is managed by the DCNR Bureau of Forestry, Sproul State Forest Office. DCNR, in conjunction with the Rocky Mountain Elk Foundation recently purchased 1,378 acres of property, much of which is located in the study area.

The primary land use in the study area is managed forestry, with small areas of mine spoil, private residences and camps, and roads. There is no industry in the area.

B. Project Goals and General Approach

The purpose of this investigation was to assess the significance of AMD pollution to Kettle Creek arising from the western watershed and to develop remediation options for the AMD flows. The assessment was conducted by sampling discharges that were identified by local residents and DCNR personnel, by reviewing previous studies, and through general reconnaissance. The identified discharges were sampled repeatedly, under different hydrologic conditions for flow rate and chemistry. A data set was developed that was used to characterize the discharges and calculate pollution loadings. The discharges were sorted and grouped using geographic measures and environmental significance. Remediation alternatives were developed for environmentally significant flows. Lastly, the discharges and remediation projects were prioritized based on environmental impact, feasibility, and cost.

II. Previous Studies

A. WPA Mine Seals

In the 1930s the Works Progress Administration (WPA) installed mine seals on several entries that were installed as a result of underground mining. No documentation of the WPA work was located. Apparently, the WPA investigated gravity drains installed into the abandoned underground coal mines and then designed and installed wet seals that provided a free outlet for water while limiting the transfer of oxygen into the mines. Six WPA seals were located in this study. Photo 1 shows a typical mine seal.

B. Operation Scarlift (1973)

Operation Scarlift was a Commonwealth-funded AMD assessment program conducted primarily in the early 1970s. The program was analogous in many respects to the current Growing Greener Program. Every major mining-impacted watershed in the Commonwealth was assessed for AMD problems and remedial recommendations were developed. Kettle Creek was the subject of an Operation Scarlift study. In 1973, a working draft of a report prepared by Neilan Engineers titled "Mine Drainage Pollution Abatement. Kettle Creek, Clinton County, Pennsylvania (SL-115)" was submitted for review. The report was never approved and a final report was not produced.

The draft report was reviewed for this study. 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 completed, however, much has changed in the watershed since the report was produced so it is difficult to verify the validity of the sampling locations. While the data included in the report was extensive, the chemical analysis results are of suspect quality. The acidity and metal concentrations do not exhibit expected interrelationships (Hedin, 2006) and aluminum, an important metal contaminant of acid mine drainage, was not measured. During the study, Hurricane Agnes passed over the area and produced record rainfall and widespread flooding. No mention of this event is made in the report but the extreme high flow rates that occurred are included in flow and loading averages, skewing the results. For these reasons, all flow and water quality data included in this report are considered unreliable.

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 underground miners were still alive to describe the deep mining and some of the surface mining was still active at the time.

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 to for the proposed actions, the remediation plans should be viewed with the same suspicion as the water quality and flow data.

C. Bitumen RAMP Project (1992)

In the early 1990's the Soil Conservation Service (now the Natural Resources Conservation Service) reclaimed surface and deep mines in Bitumen as part of its Rural Abandoned Mines Program (RAMP). No files were found for the project, however, a construction drawing was obtained from the Clarion County Conservation District. Surface mining had removed shallow cover Lower Kittanning and exposed deep mine entries into the Kettle Creek Coal Mining Company Bartoletti deep mine. The project involved the reclamation of the spoils to a level grade and the collection and piping of all AMD away from houses in Bitumen. Several drains were installed that are currently major AMD discharge points.

D. Lower Kettle Creek Restoration Plan (2000)

The "Lower Kettle Creek Restoration Plan" was completed by Hedin Environmental in 2000. The restoration plan focused mainly on the Twomile Run watershed because of the existence of reliable water quality data. This report was funded by a Western PA Watershed Program grant to TU and the KCWA. The only recommendation for the west side of Kettle Creek was to perform a more detailed assessment and sampling of the discharges.

E. Klimkos Study (2000)

In 2000, Michael J. Klimkos of DEP/BAMR performed reconnaissance and sampling of discharges impacting Kettle Creek from the western side. Many of the known discharges were visited, photographed, sampled and described. Several discharges on the steep western slopes were followed to Kettle Creek and sampled at the confluence. The report outlined the challenges associated with remediation of the discharges and also provided a list of recommendations. Most of the recommendations were addressed by follow-up work by Klimkos or by this project (Table 2). The recommendations and their current status are summarized in the following table. Note that a different naming system was used for the Klimkos study but the table also shows the naming system that was used for this report.

F. Airborne Remote Sensing Survey (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 TU, DEP, and the Department of Energy's National Energy Technology Laboratory (DOE/NETL). 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.

Table 2. "Klimkos Report" Recommendations and Status

Recommendation	**Status**
Confirm existence of WS5	***Completed.*** Confirmed by airborne remote sensing as well as subsequent field visits. Identified as KC196. Sampled in this study.
Investigate existence of AML features PA 6674-01 and 02.	***Completed.*** M. Klimkos determined that these points no longer exist.
Place weirs at discharges WS5, 6, 7, 7A and SLH1 and monitor.	***Completed.*** Flow measurements and sampling occurred at KC196, KC194, KC180, KC192A and Slide Hollow Mouth.
Walk WS5 (KC196) and WS6 (KC194) to see where they enter KC.	***Completed.*** M. Klimkos walked KC hillside. No point inflows found, but conductivity measurements suggest groundwater inflow. Same area visited in 2006 by kayak. No visual evidence of AMD flow was found.
Monitor WS8 (KC191)	***Completed.*** KC191 was monitored by this study.
Map Subsidence Features	***Completed.*** M. Klimkos identified and mapped subsidence features.
Map poorly vegetated areas	***Not Completed.*** However, high resolution air photos are available online through the PA Spatial Data Access website.
Perform sampling at the mouth of Twomile Run as part of every sampling round.	***Partially Completed.*** M. Klimkos collected samples at KC Mouth. Several samples collected in this study.
Aquatic surveys in Kettle Creek	***Completed.*** See Twomile Run Report
Conduct transects of Kettle Creek with conductivity meter to characterize AMD plumes.	***Completed.*** M. Klimkos conducted several conductivity transects.

Using aircraft based instruments, thermal and electromagnetic conductance (EM) data were 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. 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. Map 2 is a portion of the map that includes the Study Area. In the entire lower Kettle Creek area, 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.

In addition to surface discharge points, the survey also identified subsurface features such as mine pools. Several mine pools were identified in the deep mines west of Kettle Creek.

During the field verification, water samples were collected. These data are included in the project data base.

G. 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, site reconnaissance, and preliminary treatment design plans for west side discharges. The conceptual plans were never advanced and the project was not finalized due to federal budget cuts.

H. 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.

III. Geology and Mining History

A. Stratigraphy, Topography, and Geologic Setting

Map 3 shows major geologic structural features in the study area Note 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 study area 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. Elsewhere the coal bearing units have been removed by erosion.

The Kittanning Coals occur in the lower Kettle Creek watershed in higher elevation areas. The Upper Kittanning is a 3-foot thick bituminous coal seam that is limited to the highest hilltops in this area. Its shallow cover allowed it to be mined almost to exhaustion in the watershed. The Lower Kittanning coal is generally located 80-150 feet below the Upper Kittanning. The seam outcrops in the study area at 1400-1500 feet, while Kettle Creek is at about 760 feet. The coal seam is above the groundwater table and can be mined without substantial inflows of water or flooding of the workings.

The overburden of the Lower Kittanning in this area is sandstone and shale on top of the Columbiana Shale, which is immediately above the Lower Kittanning coal. The shales and sandstones are generally inert. There is no limestone in the study area (above the coal) and the shales and sandstones generally have carbonate contents of less than 2%. The Columbiana Shale, however, is not inert. The 6- to 20-foot thick unit is highly acidic due to the presence of pyrite. Samples taken in the Twomile watershed found that Columbiana Shale samples contained 1-5% sulfur and had an acid producing potential of 30-100 ppt. This is a very high value. The shale forms the roof in the underground mines. With mine abandonment and the failure of roof supports, it is likely that considerable amounts of the shale are sitting on the mine floor in an open aerobic environmental with water flowing through. A better environment for pyrite oxidation and the production of acid mine drainage can hardly be imagined.

B. Mining History

The Lower Kittanning coal seam (also referred to as the "B" seam) was mined in the study area by the Kettle Creek Coal Mining Company. The mining began in the 1880s and continued until the mine was shut down in late 1920s. A fire soon after the shutdown burned the mine office and most of the mine's documents and maps. Several poor quality maps survive. Map 4 is a scan of the best available document that shows the extent of the underground mine workings in the study area and also in the adjacent Crowley and Milligan watersheds. This deep mine complex is responsible for AMD produced in the study area as well as adjacent watersheds. Its development and interconnectedness is discussed below.

The Kettle Creek Coal Mining Company was formed in 1874 after Joseph Russell and David Bly explored the area and discovered coal throughout the area. The town of Bitumen was developed as a company town where the mine infrastructure and employee housing would be located. The mine was designed to remove coal through entries immediately northwest of Bitumen and send it down the mountain to the mouth of Cooks Run and a Philadelphia and Erie Railroad line located along the West Branch of the Susquehanna (Parucha, 1986).

The mine was designed to extend from Bitumen to the northwest and remove any coal encountered along this heading. The main portals are located near the base of the Clearfield/McIntire syncline so that the coal rises above the portals in most directions. This feature made the removal of coal by gravity (in rail cars) possible. It also provided a means to drain the mines.

Several distinct mining areas were developed that were given numbered names. The No. 1 Mine was located in Bitumen and extended east to Kettle Creek and Short Bend Run. The No. 2 mine was located to the northwest of the No. 1 Mine and included the primary haulage way for the removal of most of the coal. The No. 2 Mine extended for 11,000 feet to the northwest. The Lower Kittanning coal is fairly consistent in this area with the exception of the Short Bend area, where the stream has eroded much of the seam. Additionally, a portion of the seam has been replaced by sandstone as part of the original depositional process. The sandstone replacement of the coal is known as "channel sand" because it is believed that it represents erosion and deposition by an ancient stream. The mine maps errantly refer to this sandstone discontinuity as a "fault." This channel sand extends completely through the Lower Kittanning coal in the study area and presented mining challenges that were resolved by the development of separate mine complexes. In order to bring coal from mines north of the sandstone channel to Bitumen, two parallel 900-foot long tunnels were cut through the sandstone that attached coal reserves on either side. To the northeast of Short Bend Run, a large block of coal was mined as the No. 6 Mine. Coal from this mine was hauled on a rail that surfaced in Short Bend, crossed the stream valley on an elevated railway, and then reentered the No. 2 mine where it connected with the main haulage way.

Coal cars exited the mine in Bitumen at an elevation of approximately 1365 feet. The coal cars were lowered 440 feet (vertically) by a 3,000 foot long inclined plane. The inclined plane was conceptually similar to ones in Johnstown and Pittsburgh that still carry residents and visitors up and down steep hillsides. At the bottom of incline, the coal was loaded into railroad cars and transported along Milligan Run to the Cooks Run Railroad Station where it was loaded one final time onto trains and sent to market on the Philadelphia and Erie Railroad.

The deep mines shown on Map 4 total approximately 900 acres, of which 460 acres are located within the surface water drainage of Kettle Creek. As previously noted, however, the drainage 'watersheds' of the deep mine do not necessarily follow the surface water drainage patterns of Kettle Creek, Milligan Run, and Crowley Hollow.

Surface mining occurred on the Lower Kittanning coal after closure of the underground mine. Surface mining followed the coal outcrop, removing shallowly covered coal. Most of the surface mining on the Lower Kittanning occurred in the Short Bend Run watershed. Surface mining also occurred on the Upper Kittanning seam. In most places the cover on the Upper Kittanning was moderate and the coal seam was completely removed.

C. Hydrology

The shallow hydrology of the area is dominated by the underground coal mine. The cover above the underground mines is only 150 feet at its thickest point. The mines were developed by the room and pillar method, but when a mine was closed the last mining removed as many pillars as possible. The resulting subsidence caused visible depressions in areas where the cover was only 10-20 feet and likely resulted in extensive fracturing of bedrock in deep cover areas. The subsidence holes and fractures act as conduits that direct surface water and infiltration directly to the mine voids. The water encounters the Lower Kittanning underclay, which acts as an aquatard, and flows downdip through the mine workings. Flow through the mine is affected by local changes in coal strike and dip, subsidence that completely closes flow paths, and the sandstone channel located north of Short Bend Run. Flow through the mine is also affected by drainage channels and ditches that were installed by the miners. While major mine entries were not located on the Kettle Creek hillside, there at least six structures that release water. These structures were likely constructed to drain water from the mine. It is possible that the miners dug ditches in the mines to direct water away from primary work areas. Some of these features likely have survived and continue to carry water to drains and discharge points.

The most important drains constructed by the miners were at KC204 and KC204A. These drains are located in the lowest portion of the mine, directly northeast from the Bitumen entries and inclined plane. The discharge of water through the main entries would have complicated the mining processing, so it appears that drainage in the mine was diverted to the northeast to two tunnels driven out to the steep Kettle Creek hillside. The lowest tunnel in elevation is KC204A which appears to have carried most of the flow from this portion of the mine for decades.

In the 1930s the WPA rebuilt mine drains located on the eastern side of the deep mine. The drains were constructed at existing drainage points in order to assure that the mine continued to drain water and to lessen the inflow of air back into the mines. The latter purpose was achieved with piping and weir design that assured that the end of the drainage pipe was underwater. Six of the drains remain.

While the Lower Kittanning underclay is a good aquitard that usually contains AMD within the mine areas, leakage to underlying aquifers can occur. Deeply incised stream valleys commonly have fractures that extend up the slopes. If mining extends near the edge of the slopes, interception with fractures is possible. In the Twomile Run watershed, at least half of the AMD produced in abandoned underground and surface mines is lost to deeper strata and aquifers and discharges to Twomile Run as baseflow (HE, 2007). Similar hydrologic patterns occur in the west side study area.

IV. 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 recently sampling performed by HE.

Water samples were analyzed for mine drainage parameters. Alkalinity, temperature, and pH were measured in the field. Samples with pH less than 4.5 contain, by definition, no alkalinity. 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. If solids were unavoidably present, the sample was filtered before being acidified using a 0.8 µm Millipore Millex™ filter.

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

Table 3. 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

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 (See Cover Photo). 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.

Flow rates for Kettle Creek at the USGS Westport 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. Exploratory Drilling and Observation Wells

Nine holes were drilled from the surface into the coal or mine void north of Bitumen in order to determine relative coal elevations and the presence of mine pools in the abandoned underground mine. The holes were drilled with a Davey air rotary drill (Photo 2). The distance from the surface to the top of the coal (or void) and the bottom of the coal (or void) was measured. Five of the holes were developed as observation wells by installing a 6-inch diameter 10.5-foot PVC sleeve with a well cap at the top of the hole, and leaving the rest of the hole open to the bottom. The depth of water in each hole was measured with a battery operated water level indicator (Photo 3). The surface elevation of each hole was surveyed to a common local point so that relative elevations of the coal and water surfaces could be calculated between the wells and local discharge points.

E. Data Calculations

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

Load (lb/day) = 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 (Hedin, 2006).

Statistical summaries (mean, standard deviation, standard error, percentiles) were calculated using Excel functions. In some cases, percentiles were calculated using the standard Excel formulas. Percentiles show the amount of data that is estimated to be less than a certain value. For instance, for the 25th 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.

F. Mapping

USGS 7.5' quadrangle maps were used. The study area is located on the Keating and West Renovo USGS quadrangle maps.

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.

Several holes were drilled during the investigation. The drill holes were located using Garmin model Vista handheld GPS. Elevations of these drill holes were measured by surveying the tops of casings to obtain relative elevations between each hole.

G. Treatment Alternative Calculations

Passive and chemical treatment options were proposed as appropriate for the discharges. 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 AMDTreat's default of 99%, is based on our experience with NaOH treatment systems. The primary treatment ponds were sized for 48 hours of retention when empty.

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. Figure 1 is a schematic of a typical VFP based passive treatment system layout. 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.

The choice of a passive or chemical treatment system depended on the water chemistry and site conditions. We assumed that passive treatment was preferred over chemical treatment and in cases where passive treatment was considered reliable, chemical recommendations were not made. The reliability of passive treatment decreases with increasing concentrations of aluminum. Sites with Al concentrations less than 20 mg/L were considered suitable for passive treatment and, as long as site conditions warranted, only passive treatment was recommended. Sites with more than more than 40 mg/L Al were considered too severe for reliable passive treatment. For these discharges, only chemical treatment was recommended. Sites with 20-40 mg/L Al are problematic and both chemical and passive treatment recommendations were made. Site conditions were also considered. Passive systems are larger than chemical systems. If the treatment area was too small to support passive treatment, then only chemical treatment was recommended.

V. Lower Kettle Creek: Flow, Chemistry, and AMD Impacts

USGS operates a flow gage on lower Kettle Creek that is located between the inflows of Slide Hollow and Short Bend Run. Average daily flow rates are available on-line back to 1970. The flows are measured below the Alvin R. Bush Dam, which has a controlled discharge that is intended to protect communities downstream on the West Branch of the Susquehanna River from flooding. Individual flow rates measured at the gage can be indicative of the management of the reservoir behind the dam. For example, large flows can be measured when the reservoir is drained down to provide storage for spring runoff and rain. However, over long periods of time, the flow at the gage should be indicative of long-term precipitation conditions in the watershed.

Figure 2 shows flows at the gage during this study. Flows in the winter and spring of 2005 were sustained at a high level. This reflects the record precipitation that was observed over much of PA between September 2004 (Hurricanes Frances and Ivan) and February 2005. The dry summer of 2005 is reflected in the low stream flows between June and October.

The table below shows statistic summaries for the USGS gage data. The study period (2005-2006) produced flows that were close to the long-term average. In general, 2005 was drier than 2006.

Table 4. Daily Flow Statistics for lower Kettle Creek at the USGS gage near Westport

Flows (CFS)	**1970-2006**	**2005**	**2006**	**2005-2006**
Average	396	380	426	398
Median	208	200	278	234
Minimum	4	12	41	12
Maximum	6,280	4,640	3,290	4,640

Note: To convert to from CFS to gpm, multiply by 449.

Most of the mine discharges in the study area occur near the top of the western bank of Kettle Creek. Because of the steep bank, the mouths of most of the western tributaries are difficult to access from the west. The Short Bend Run and Duck Hollow stream channels were each walked to Kettle Creek in 2006. In August 2005 the tributary mouths were accessed by walking across Kettle Creek from the eastern shore. In July 2006, the tributary mouths were accessed by kayak.

Table 5 shows the chemistry of Kettle Creek at several locations. Slide Hollow is the first major inflow of AMD to Kettle Creek[1], so samples collected above Slide represent unimpacted conditions. Kettle Creek is a poorly buffered stream that is vulnerable to inflows of acidic water. The high flow rate of the stream, however, provides a large enough buffering capacity to assimilate the current acidic inflows. On both days, flow through the AMD-producing lower watershed increased sulfate concentrations, but changes in alkalinity were negligible and the stream at the mouth was still alkaline with neutral pH.

[1] Two discharges exist that flow into an unnamed tributary north of Slide Hollow. The AMD produced by these discharges is minor (Hicks/Slide Group in Table 7). Slide Hollow is the first drainage that carries severe AMD.

Table 5. Chemistry of Kettle Creek above and below the study area.

Location	Date	Flow (gpm)	pH	Concentration, mg/L					
				Alk	Acid	Fe	Mn	Al	SO_4
KC above Slide	8/4/2005		6.5	13		0.2	0.1	0.3	6
Slide Hollow	8/4/2005	8	2.7	0	513	43	19	28	1,556
USGS Gage	8/4/2005	8,064							
KC above Short Bend	8/4/2005		6.8	13		0.1	0.0	0.4	12
Short Bend Run	8/4/2005	65	4.0		170	1	19	6	759
KC above Twomile	8/4/2005		6.7	18		0.3	0.1	1.6	23
KC Mouth	8/4/2005		7.5	15		0.0	0.1	<0.2	27
KC above Slide	7/25/2006		6.5	14		0.2	0.0	0.1	7
Slide Hollow	7/25/2006	16	2.8	0	454	42	13	29	910
USGS Gage	7/25/2006	109,760							
KC above Short Bend	7/25/2006		7.0	13		0.2	0.1	0.1	8
Short Bend Run	7/25/2006	69	3.0		111	2	11	11	431
Duck Hollow	7/25/2006	66	3.0		146	28	13	<0.2	492
KC above Twomile	7/25/2006		6.5	2		0.3	0.1	0.2	16
KC Mouth	7/25/2006		6.9	10		0.4	0.1	0.2	11

A comparison of AMD loadings and stream alkalinity loadings verifies that AMD inflows observed in this study are not sufficient to acidify Kettle Creek. Assuming an alkalinity concentration of 14 mg/L at average flow (178,000 gpm), the stream carries an alkalinity load of 29,000 lb/day. In this study the western discharges produced an average cumulative acidity load of 1,745 lb/day (Table 6). There is, on average, 15 times more alkalinity available in upper Kettle Creek than acidity produced by the western discharges. Under low flow conditions the excess is less, but it still exists. The August 2005 sampling occurred under very dry conditions. The stream flow rate of 8,064 gpm was a 4th percentile value (96% of the daily flow measurements are higher than this value). On this day, uncontaminated flow from upstream contained about 1,300 lb/day of alkalinity. The lowest total acidity loading estimated in this study, 375 lb/day, was based on flows and samples collected in October 2005, when the stream flow rate was 35,000 gpm (23rd percentile). Nonetheless, the conservative application of October AMD loadings to August in-stream alkalinity yields a 4:1 safety factor.

While the western discharges do not generate enough acidity to neutralize the alkalinity present in Kettle Creek, the discharges do impair portions of the stream through the precipitation of metals. Photos 4 and 5 show Kettle Creek at the mouths of the Short Bend Run and Butler Hollow, respectively. Habitat degradation clearly occurs, although the effects are limited to the western bank downstream of the inflows. The impact is visually apparent from Kettle Creek Road.

The tributary streams were evaluated as potential cold-water fisheries. The opportunity to restore miles of high quality cold-water fishery is an important component of the Twomile Run Master Plan (HE, 2007). The western tributaries do not provide similar opportunities for fishery restoration. The streams are short with steep grades, waterfalls, and very low drought flows. Only the lower 2,000 feet of Butler Hollow contains potential cold water stream miles.

VI. Discharge Details and Recommendations

The purpose of the following section is to provide a summary of all discharge data. Then, each discharge group is discussed in detail in its own section, along with recommendations and options for addressing each discharge group.

A. General Sampling Results

Table 6 shows the average flows, chemistry, and loadings for discharges sampled in this investigation. Discharges are sorted by the average acidity loading. See Map 5 for discharge locations and discharge group delineations.

Table 6. Average flow, chemistry, and loading of the west side discharges
Includes data collected by PADEP (2000), DOE/NETL (2002), and HE (2005-2006).

Point	**Area***	**Flow, gpm**	**pH**	**Concentration, mg/L**					**Loading, lb/day**		
				Acid	**Fe**	**Al**	**Mn**	**SO4**	**Acid**	**Fe**	**Al**
KC204	KC204	123	2.8	700	120	47	7	960	849	146	57
KC180	Slide	20	2.4	1,095	220	84	12	2,565	205	34	14
Slide-1	Slide	20	2.3	900	138	66	9	2,293	191	29	13
KC194	Sl/Sh	32	3.0	361	54	33	6	738	105	11	7
KC154	Butler-N	67	3.1	160	10	9	12	949	96	6	5
BH-M	Butler-S	65	3.3	128	12	12	12	823	81	9	7
KC198	Short	15	3.2	325	34	25	3	467	35	3	2
KC153	Butler-N	9	3.3	288	20	33	28	882	30	2	4
DH-1	Butler-N	14	3.4	242	38	23	15	829	25	6	2
BH-2	Butler-S	33	3.1	97	4	8	16	941	24	1	2
KC143	Short	11	3.2	257	38	16	7	647	19	3	1
DH-2B	Duck	7	3.2	154	5	13	7	327	13	<1	1
KC196	Sl/Sh	6	3.1	196	19	16	4	409	12	1	1
KC129	Short	4	3.4	248	1	42	9	425	11	<1	2
KC157	Butler-S	11	3.3	75	3	6	11	496	9	<1	1
KC127	Slide	8	3.2	248	40	17	4	590	9	1	<1
KC150	Duck	4	3.2	123	3	10	6	307	8	<1	1
KC153A	Butler-N	3	3.0	254	7	27	25	1,369	8	<1	1
DH-2A	Duck	4	3.6	90	2	10	6	242	4	<1	<1
KC143A	Short	1	3.0	178	12	19	5	421	3	<1	<1
KC195	Sl/Sh	2	3.0	98	1	10	3	251	2	<1	<1
KC122	Hi/Sl	4	3.4	39	<1	5	4	107	2	<1	<1
SB-1	Short	5	3.1	41	1	2	1	95	2	<1	<1
KC191	Hi/Sl	1	3.4	67	3	8	6	400	1	<1	<1
KC196A	Sl/Sh	4	3.5	5	<1	<1	<1	11	<1	<1	<1
KC142	Short	7	4.2	5	2	<1	<1	41	<1	<1	<1
Total **		**479**		**304**	**44**	**21**	**8**	**930**	**1,745**	**253**	**123**

** Area codes area: Hi/Sl=area between Hicks Hollow and Slide Hollow; Slide = Slide Hollow; Sl/Sh=area between Slide Hollow and Short Bend Run; Short =Short Bend Run; Duck=Duck Hollow; Butler-N=Butler Hollow North; Butler-S=Butler Hollow South.*
*** Represents totals for flow and loadings; flow-weighted averages for chemistry*

All the discharges had low pH and were contaminated with Fe, Al, and Mn. None of the discharges contained alkalinity. On average, the discharges produced a total of 479 gpm of flow with 304 mg/L acidity, 44 mg/L Fe, 21 mg/L Al, and 8 mg/L Mn (flow-weighted averages). Of the 26 discharges sampled, 23 had at least 5 mg/L Al and 11 had more than 200 mg/L acidity. The most contaminated discharges were KC180 and Slide-1, which are both in Slide Hollow.

Table 6 also shows average contaminant loadings for each discharge. These average values were calculated from the daily contaminant loading calculations, where feasible. Approximately half (49%) of the contaminant loading measured in this study was produced by the KC204 discharge. This is likely an underestimate of the significance of the discharge. Early January 2007 was very wet and flow rates were measured at KC204 at the end of January of 270 gpm and 350 gpm. Samples were not collected so acidity loadings could not be calculated. If the acidity concentrations were 75% of the average concentration of 700 mg/L, then the discharge produced about 2,000 lb/day of acidity under these wet weather conditions. This value is twice the average loading of all the other discharges combined.

The discharges were divided into groups that were defined by their proximity to each other and their likely combined treatment (active or passive). The treatment groups are shown in Map 5. Table 7 shows the summary flows, flow-weighted chemistry, and loadings for the different groups. On average, the KC204 and the Slide Hollow discharges account for 72% of the total acidity loading.

Table 7. Average flow, chemistry, and loadings sorted by treatment group
The groups are arranged in upstream to downstream order.

Group	**Discharges included in group**	**Flow (gpm)**	**Conc (mg/L)**			**Loadings (lb/day)**		
			Acid	**Fe**	**Al**	**Acid**	**Fe**	**Al**
Hicks/Slide	KC122, KC191	5	45	1	6	3	<1	<1
Slide	KC180, KC127, Slide-1	48	711	113	48	405	64	28
Slide/Short	KC194, KC195, KC196, KC196A	44	229	23	16	120	12	9
Short Bend	KC143, KC129, KC198, SB-1, KC142, KC143A	43	135	12	10	70	6	5
KC204	KC204, KC204A	123	700	120	47	849	146	57
Duck	KC150, DH-2A, DH-2B	16	135	3	12	25	1	2
Butler North	KC154, KC153, KC153A, BH-1	93	142	13	10	159	15	12
Butler South	KC157, BH-M, BH2	108	88	8	8	114	10	10
TOTAL		**479**	**304**	**44**	**21**	**1,745**	**253**	**123**

B. Hicks/Slide Group

The Hicks/Slide Group is located in Sproul State Forest above an unnamed blue-line stream between Hicks Hollow and Slide Hollow (Map 6). There are two seepage areas labeled KC191 (Photo 6) and KC122. The discharges are located beneath spoils believed to be from the Lower Kittanning. Flow and chemical data for the discharges is presented below.

Table 8. Hicks/Slide Group Flow, Chemistry, and Loading Results

Point	Date	Flow (gpm)	pH	Concentrations (mg/L)					Loading (lb/day)		
				Acid	Fe	Mn	Al	SO4	Acid	Fe	Al
KC122	10/12/05	0.0							0	0	0
KC122	01/05/06	3.5	3.7	31	<1	2	5	83	1	<1	<1
KC122	04/24/06	8.0	3.5	46	1	5	6	132	4	<1	1
KC191	04/15/05	3.0	3.7	40	<1	4	4	205	1	<1	<1
KC191	10/12/05	0.0							0	<1	0
KC191	07/06/06	1.0	3.4	95	3	7	13	596	1	<1	<1
Combined Average*		**5.2**		**45**	**1**	**5**	**6**		**2.8**	**<0.1**	**0.4**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

The discharges are among the least polluted AMD discharges sampled. If treatment is considered, passive treatment is recommended.

Passive Treatment

There are approximately 2 acres of land suitable for construction of a treatment system between the discharges. Reliable treatment can be obtained with a VFP system. A system designed to treat a combined high flow (11 gpm) should include collection of KC122 and KC191 and their piping to a VFP that is 3,300 ft^2 (water surface) and contains 220 tons of limestone aggregate and 70 CY of alkaline organic substrate.

The VFP effluent will be alkaline with low metal concentrations, so no settling pond or wetland would be required. The system will have a total footprint of about 0.25 acres. The cost to construct the system is estimated at $72,000. A cost breakdown is provided below.

The consulting costs assume that the project can be installed with minimal permitting (E&S Control Plan, temporary NPDES permit). More complicated permitting will be more expensive. The consulting costs are still a large portion of the total costs because these tasks have fixed components that do not vary considerably with system size (mapping, permitting meetings and applications, project meetings). Costs could be reduced if this project is done in combination with others in this area.

Table 9. Hicks/Slide Group Passive Treatment Costs

Item	**Quantity**	**Unit cost ($)**	**Total Cost**
road into site, ft	3,300	3	$ 9,900
Collection systems for KC191 & KC122	2	1,500	$ 3,000
pipe flows to VFP, ft	200	5	$ 1,000
VFP limestone, ton	251	20	$ 5,019
VFP organic substrate, CY	68	20	$ 1,352
VFP excavation, CY	1,209	5	$ 6,045
VFP synthetic liner (installed), ft2	4,913	2	$ 9,827
Miscellaneous materials		10%	$ 4,114
E&S, Mob/Demob	estimate	5,000	$ 5,000
contingency		15%	6,723
Design/engineer/permit		fixed	$ 20,000
Total			$ 71,980

The annual O&M of the passive system would be minor. Once the system's functionality is verified, it should be inspected and sampled quarterly. The inspection would include measurements of water depths in the VFP and collection of two water samples (VFP influent and VFP effluent). The cost of each inspection is estimated at $200 and the annual cost would be approximately $800.

Because the influent water is mild, the system's performance can be relied upon for at least ten years. Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or simply replaced at a cost of $3,000-$4,000.

Chemical Treatment

Chemical treatment of the Hicks/Slide Group is not recommended, except in combination with chemical treatment of the Slide Hollow AMD. If a Slide Hollow treatment system is constructed (See Section VI.C), then KC191 and KC122 could be collected and piped to the treatment system. A single 2,400-foot pipe could carry both flows. The cost to collect and pipe the flows to Slide Hollow is estimated at $15,000. This estimate includes $5,000 to develop access to the discharges, $3,000 to collect the discharge, and $7,000 to pipe the flows to Slide Hollow.

C. Slide Hollow Group

The Slide Hollow Group discharges drain into Slide Hollow (Map 6). The discharges are located in the Sproul State Forest. The Group includes KC180 which is a WPA mine seal (Photo 7), KC127 which is a deep mine entry, and Slide-1 which is seepage that arises below KC180 and appears to be leakage from the mine entry. Flows and chemistry are shown below.

Table 10. Slide Hollow Discharges Flow, Chemistry, and Loading Results

Point	**Date**	**Flow (gpm)**	**pH**	**Concentrations (mg/L)**					**Loading (lb/day)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**Acid**	**Fe**	**Al**
KC180	08/22/00	1	2.5	1,090	430	20	126	1,840	7	3	1
KC180	07/15/02	4	2.3	1681	294	14	101	1,961	81	14	5
KC180	04/07/05	60	2.6	666	106	8	47	2,586	479	76	34
KC180	10/12/05	0							0	0	0
KC180	01/05/06	54	2.5	901	162	8	62	1,612	584	105	40
KC180	04/24/06	15	2.5	943	136	8	59	1,306	170	25	11
KC180	07/06/06	8	2.5	1,288	191	12	107		116	17	10
Slide-1	01/05/06	12	2.5	823	132	7	54	1,283	118	19	8
Slide-1	04/24/06	40	2.5	732	111	7	45	881	351	53	22
Slide-1	07/06/06	8	2.5	1,146	171	12	99	4,716	103	15	9
KC127	07/16/02	1	2.7	895	164	9	62	1,204	11	2	1
KC127	04/15/05	3	4.0	25	2	1	3	133	1	<1	<1
KC127	10/12/05	0							0	<1	<1
KC127	01/05/06	3	4.5	9	2	1	1	44	<1	<1	<1
KC127	04/24/06	36	3.1	84	5	1	4	109	36	2	2
KC127	07/06/06	3	3.0	226	27	7	17	1,459	7	<1	<1
Combined Average *		**59**		**812**	**127**	**8**	**60**	**1,773**	**495**	**79**	**34**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

The AMD produced by KC180 and Slide-1 is severe. KC127 is variable. There is considerable subsidence above KC180 and KC127 (Photo 8) and surface water clearly flows through these pits into the mine. The KC127 discharge is likely a mixture of highly acidic water flowing from the mine pool and clean surface water that enters the mine just above the discharge point through subsidence pits. The chemistry of the effluent would then depend on the mix of these flows.

The combined Slide Hollow discharges were calculated to flow 59 gpm and contain 812 mg/L acidity, 127 mg/L Fe and 60 mg/L Al on average, with an average acidity loading of 495 lb/day. The highest combined flow was 91 gpm in April 2006. The highest contaminant loadings occurred in January 2006 and were 703 lb/day acidity, 124 lb/day Fe, and 48 lb/day Al.

Slide Hollow produces the second highest inflow loading of AMD to the west side of lower Kettle Creek (Table 7).

The Slide Hollow waters are considered too severe for passive treatment because the Al concentrations were substantially higher than the 40 mg/L cutoff used for passive treatment. Only chemical treatment is recommended

Chemical Treatment

The recommended chemical treatment is the addition of NaOH to the AMD, followed by flow through two serially-connected sludge ponds, and then flow through a final polishing pond. The sludge ponds should be sized for a total of 48 hours of retention. Assuming the high flow of 91 gpm, then the sludge ponds should have a capacity of 262,000 gallons and, if 5 feet deep, then each pond would be approximately 4,000 ft^2. The final polishing pond should provide 24 hours of retention or, assuming a 5-foot depth, be about 4,000 ft^2. A 10,000 ft^2 sludge disposal basin should be constructed above the treatment system. Every year, sludge should be pumped from the treatment ponds to the sludge disposal basin for passive dewatering.

Liquid NaOH should be stored in a tank placed next to Cattaraugus Road. A 1,200-foot buried pipeline would carry the NaOH to the treatment system. Placement of the storage tank next to the road will make deliveries possible year round. Nonetheless, the tank storage capacity should be at least two months of expected usage or 20,000 gallons.

The KC180 and KC127 discharges are located near the top of the steep slope down to Kettle Creek. In order to operate the system by gravity, the ponds should be constructed between the discharges and the slope. There are approximately 2 acres of suitable land to the east of Slide Hollow. The Slide-1 seepage occurs at the crest of the steep slope which is lower than the treatment pond location. An effort to collect the Slide-1 seepage at a higher location should be made. It may be possible to dig a French drain across Slide Hollow just below the KC180 and KC127 discharges in order to intercept Slide-1, allowing it to be piped into the treatment system. Any Slide-1 seepage that cannot be collected will flow untreated down Slide Hollow where it will mix with the treatment system discharge. If half of the Slide-1 seepage is untreated, and the remaining collected water is treated to 100 mg/L net alkalinity, then the combined flows in Slide Hollow downstream of the treatment system and Slide-1would have an estimated net acidity of 50 mg/L. The flow would have high total dissolved solids because the metals contained in the untreated Slide-1 seepage would precipitate in the Slide Hollow channel and be washed into Kettle Creek during high flow events.

NaOH consumption estimates were made using AMDTreat (Version 4.0, OSM, 2006). The calculations assumed average flow and chemistry as shown above and 80% treatment efficiency. The system will utilize 106,000 gallons per year of 20% NaOH.

Table 11. Estimated Chemical Treatment Costs for Slide Hollow Discharges

Capital Items	**Basis**	**Cost Estimate**
Clear & grub	2 acres @ $1,500/acre	$3,000
Construct road	1500 feet road @ $3/ft	$4,500
NaOH storage tanks	20,000 gal @ $1/gal	$20,000
NaOH pipeline	1,200 feet @ $3/foot	$3,600
Treatment ponds, lined	3 X 4,000 ft2 X $2/ft3	$24,000
NaOH metering device	One unit	$4,000
Sludge disposal basin	10,000 ft2 @ $1/ft2	$10,000
E&S, mob & demob	Estimate	$5,000
Design/permit/C.O.	Estimate	$15,000
TOTAL, Capital Costs		**$89,100**
Annual Items	**Basis**	**Cost Estimate**
NaOH	106,000 gal 20% NaOH @ $0.50/gal	$53,000
Operator	15 hr/wk local operator @$35/hr	$27,300
Laborer	Assistant, 10/month @ $25/hr	$3,000
Maintain access to site	Road repair, plow snow	$2,000
routine O&M	Valves, hoses, metering equipment	$1,000
Sludge removal	40 hr pumping at $100/hr plus mob/demob	$5,000
TOTAL, Annual Costs		**$91,300**

Table 11 shows estimated costs to construct and operate the proposed Slide Hollow chemical treatment system. The capital cost estimate is $89,100. The annual operation includes the purchase of NaOH, operation of the system, and sludge maintenance. The operator is assumed to inspect and adjust the system 3 days a week with each inspection requiring about four hours (including travel). The operator must also collect samples periodically and submit paperwork on the system's operation. Occasionally, the operator is assumed to need an assistant. The sludge removal occurs once a year through a specialized sludge pumping subcontractor. The total annual costs are estimated at $91,300 per year.

The system will treat approximately 148,000 lb/yr of acidity. At $91,300/yr, the unit annual treatment cost is $1,230/ton of acidity. Skousen and Ziemkiewicz (2005) analyzed NaOH treatment systems in West Virginia and estimated that the total unit treatment costs were $1,000 – 1,500 per ton acidity. Rose (2006) reports that annual NaOH treatment costs developed using AMDTreat were $900 – $1,100 per ton acidity, not including sludge management. Therefore, the estimate provided for the Slide Hollow system is consistent with other estimates.

Numerous subsidence holes are present above the Slide Hollow discharges that obviously cause clean surface water to flow into the underground mine. During the construction of the treatment system, the filling of these holes should be considered. The areas around the subsidence holes are forested, so this action would substantially increase forestry impacts.

An alternative option is to remove a portion of the deep mine above the KC180 and KC127 discharges. The remining project would create more space for construction of the treatment system and might allow the AMD to be collected at a slightly higher location. The general layout of the underground coal mine is apparent from the rows of subsidence holes, particularly above KC127. If the crop coal and deep mine were removed from Slide Hollow to an overburden depth of 40 feet, it is likely that at least ten acres of room would be generated to construct the treatment system. If the Slide-1 seepage is due to flow through the crop, then this flow could be intercepted at the highwall. The project would also produce saleable coal. Assuming that project removed 10 acres of deep mine, about 22,500 tons of coal would be produced (1800 ton/ac-ft, 5-foot coal thickness, 25% recovery). Assuming a net value after trucking to market of $25/ton ($35/ton coal value and $10/ton trucking cost), the coal could generate $562,500 in revenue. It is possible that the treatment system would be constructed as part of the remining activities at no cost to the Commonwealth.

D. Slide/Short Group

Discharges placed in the Slide/Short Group are located at the top of Kettle Creek hill between Slide Hollow and Short Bend Run (Map 7) and drain directly to Kettle Creek. The area is part of Sproul State Forest. The three discharges in this Group are KC194 which is a WPA mine seal (Photo 9), KC196 which is a WPA mine seal (Photos 10 and 11), and KC195 which is seepage that appears to originate from a deep mine. The following table shows the flow, chemistry, and loading from each discharge.

Table 12. Slide/Short Group Chemistry, Flow, and Loading Results

Point	**Date**	**Flow (gpm)**	**pH**	**Concentrations (mg/L)**					**Loading (lb/day)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**Acid**	**Fe**	**Al**
KC194	07/16/02	30	2.6	432	51	5	29	589	156	19	11
KC194	04/15/05	40	2.9	235	30	4	17	1133	113	15	8
KC194	10/13/05	2	2.8	304	26	5	21	505	7	1	1
KC194	01/05/06	42	2.7	258	27	2	15	355	128	14	8
KC194	04/24/06	70	2.8	231	18	3	14	543	194	15	12
KC194	07/06/06	35	2.9	256	18	3	21	1000	107	8	9
KC196	07/16/02	4	2.9	280	30	5	22	466	13.5	1.4	1.1
KC196	10/13/05	4	3.0	263	47	6	22	597	12.6	2.3	1.1
KC196	01/05/06	5	3.0	117	5	2	8	298	7.4	0.3	0.5
KC196	04/24/06	8	3.0	149	7	3	11	340	14.7	0.7	1.1
KC195	07/16/02	2	3.0	149	1	4	16	296	3.6	0.0	0.4
KC195	04/15/05	3	3.3	62	2	1	5	334	2.2	0.1	0.2
KC195	04/19/05	3	3.4	85	<1	3	9	183	3.1	0.0	0.3
KC195	10/12/05	0							0.0	0.0	0.0
KC195	01/05/06	3	3.2	93	1	3	9	193	3.4	0.0	0.3
Combined Average*		**46**		**223**	**21**	**3**	**16**	**557**	**124**	**10**	**9**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

When combined, the flows average 46 gpm with 223 mg/L acidity, 21 mg/L Fe, and 16 mg/L Al. Approximately 80% of the contaminant loading of the combined flows is produced by KC194. This chemical condition is amenable for passive treatment. On several days the Al content of the combined flows exceeded 20 mg/L Al. Because discharges with 20-40 mg/L Al are considered problematic, both passive and chemical treatment alternatives are presented. Both treatment scenarios make use of a large moderately sloping area that exists north of KC196. Map 7 shows approximately 10 acres, but there is much more suitable land. Both scenarios assume that an existing road that accesses the Short Bend Run watershed will be improved and extended to the treatment site. The system would not be visible from Kettle Creek or Kettle Creek Road.

Passive Treatment

Passive treatment would be accomplished with VFPs followed by a settling/mixing pond that is followed by a constructed wetland. The system was designed assuming a 60 gpm design flow. KC194 should be collected and piped 1,500 feet to the treatment area. KC196 and KC195 should also be collected and piped 300 feet to the treatment area. The flows should enter a flow control box that directs up to 60 gpm to the vertical flow ponds and directs higher flows to the settling/mixing pond. The two parallel VFPs should each be about 18,000 ft^2 at the water level and contain 2,300 tons of limestone and 500 CY of alkaline organic substrate. Because the hillside is very rocky and suitable soils may be difficult to find, a synthetic liner is recommended for both VFPs. The VFPs should discharge to a settling pond sized to provide the design flow (60 gpm) with 48 hours of retention. The overflow from the flow control box will also discharge into the pond. The pond should discharge to a 10,000 ft^2 constructed wetland that will trap any metals that may escape from the pond.

The system will treat high flow events by mixing treated and untreated flows in the settling/mixing pond. The VFPs are expected to produce 80-100 mg/L net alkalinity. On a day when the combined flow is 78 gpm (the highest observed), the mixture of 60 gpm alkaline water with 18 gpm of acidic water (223 mg/L) will yield an effluent with approximately 25 mg/L net alkalinity.

The entire treatment system has a footprint of about 2 acres. As noted, there is much more suitable land available.

The table below shows the cost estimate for the passive system. The system's design and construction is estimated at $450,000.

Table 13. Slide/Short Group Treatment Costs

Item	**Quantity**	**Unit cost**	**Total cost**
road into site, ft	**5,000**	3	$ 15,000
clear and grub, acres	3	1500	$ 4,500
collect KC195; plumb KC194 and KC196	1,500	2	$ 3,000
pipe flows, ft	2,000	5	$ 10,000
flow control box	1	2500	$ 2,500
VFP limestone, ton	4,689	20	$ 93,775
VFP alkaline organic substrate, CY	966	20	$ 19,313
VFP excavation, CY	15,162	5	$ 75,809
VFP synthetic liner (installed) ft2	40,079	2	$ 80,157
Settling pond, ft2	5,775	1	$ 5,775
constructed wetland, ft2	10000	1	$ 10,000
Miscellaneous materials		10%	$ 31,983
E&S, Mob/Demob	5,000	1	$ 5,000
contingency		15%	$ 53,522
Design, Engineering, Permitting, C.O.		fixed	$ 40,000
TOTAL			**$450,335**

The annual O&M of the system would be minor. Once the system's functionality was established, the O&M would involve inspections, sampling, and routine maintenance every two months. The flow control box will need to be inspected and cleaned of debris or metal deposits, and adjusted. It may be necessary to remove leaf litter and other blockages from influent and effluent channels. Monitoring would include four water samples (common VFP influent, each VFP effluent, final effluent), flow measurements at all stations, and measurement of water levels in the VFPs. The inspection and routine maintenance is expected to require four hours. Total cost, per event, is $260 or approximately $2,000 per year. The cost could be decreased if the O&M was combined with other treatment systems.

Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost of organic substrate replacement is estimated at about $20,000 per VFP. Major maintenance of this type should not be required for at least 5 years.

Chemical Treatment

Chemical treatment of the Slide/Short discharges with NaOH will provide highly effective remediation. If chemical treatment is chosen as the preferred alternative for this area, the system should be built in the same general area as the passive system described above. The discharges should be collected and piped to two serially connected treatment ponds that are followed by a polishing pond. The treatment ponds should be designed to retain the highest flow for 48 hours. Two 3,500 ft^2 lined treatment ponds should be followed by a 4,000 ft^2 polishing pond. A 5,000 ft^2 sludge disposal basin should be constructed on spoils above the discharges.

The NaOH storage tanks can placed at the top of the slope above the treatment system. The existing access road through the Short Bend Run watershed will need to be improved to allow deliveries of NaOH in good weather conditions. The NaOH will flow from the tanks to the treatment system in an 800-foot buried pipeline.

Table 14 shows the estimated construction and operation costs for the chemical treatment system. The estimated cost to construct the chemical treatment system is $83,000.

Annual NaOH consumption costs were estimated with AMDTreat (Version 4.0, OSM, 2006). The system will consume about 23,000 gallons/yr of 20% NaOH. A 5,000 gallon tank was assumed to allow for at least two months of NaOH storage at high flows. The annual operation is assumed to require 10 hours per week of attention by the local operator (travel included) and occasional assistance from a laborer. Sludge removal is assumed to require 20 hours of pumping plus mob/demob costs. The total annual cost to operate the chemical treatment system is estimated at $42,000/yr.

Table 14. Estimated costs for Chemical Treatment of the Slide/Short Group

Capital Items	**Basis**	**Cost Estimate**
Clear & grub	2 acres @ $1,500/acre	$3,000
Construct road	5,000 feet road @ $3/foot	$15,000
collect KC195, KC194 and KC196	Two collection systems @$1500 each	$3,000
pipe flows	2,000 ft pipeline @ $5/ft	$10,000
NaOH storage tanks	5,000 gal @ $1/gal	$5,000
NaOH pipeline	800 feet @ $3/foot	$2,400
Treatment ponds, lined	3 X 3,500 ft2 X $2/ft3	$21,000
NaOH metering device	One unit	$4,000
Sludge disposal basin	5,000 ft2 @ $1/ft2	$5,000
E&S, mob & demob	Estimate	$5,000
Design/permit	Estimate	$10,000
TOTAL Capital Costs		**$83,400**
Annual Items	**Basis**	**Cost Estimate**
NaOH	23,000 gal 20% NaOH @ $0.50/gal	$12,500
Operator	12 hr/wk local operator @$35/hr	$21,800
Laborer	Assistant, 5 hr/month @ $25/hr	$1,500
Maintain access to site	Road repair, plow snow	$2,000
routine O&M	Valves, hoses, metering equipment	$1,000
Sludge removal	20 hr pumping at $100/hr plus mob/demob	$3,000
TOTAL Annual Costs		**$41,800**

E. Short Bend Group

The Short Bend Group includes six discharges that are located in the upper portion of the Short Bend Run watershed (Map 8). The watershed is entirely within Sproul State Forest. The upper watershed is highly disturbed by mining activity because the stream cut through the Lower Kittanning coal seam, complicating the underground mining, while also creating surface mining opportunities. Kettle Creek Coal Mining Company's No.6 mine is located in the northeast portion of the watershed. Coal was transported from the No.6 mine on a railroad that surfaced, crossed the watershed on an elevated rail, and then reentered the No.2 mine. KC142 is flow from an entry to the No. 2 mine (Photo 12). It is minimally contaminated and does not require treatment.

There are two AMD discharges from the No.6 mine that are located on the north side of Short Bend Run. SB-1 is flow from a mine entry that is located near the elevated haulage berm (Photo 13). It is minimally contaminated. KC198 is a WPA drain that produces severe AMD at low flow (1-7 gpm) and moderate AMD at higher flows (25-35 gpm) (Photo 14). KC129 drains a small isolated deep mine and appears to be a mined-out WPA drain. The discharge does not flow during dry weather, but during wet weather it produces severe AMD.

Surface mine spoils on the southern side of Short Bend Run produce AMD seeps that have created kill zones. KC143 and KC143A are two seep zones (Photos 15 and 16). The flows and chemistry are variable. Under low flow, the AMD is severe. At higher flow the chemistry is moderate. The seepage is lower than the surface spoils, indicating that AMD has infiltrated into strata beneath the coal seam or that it is flowing through the rocky surface "soil" until it reaches a confining aquitard.

The discharge loadings do not sum to the total amount of loading measured in Short Bend Run. In July 2006 the mouth of Short Bend was sampled. The final discharge flowed 69 gpm and was carrying 92 lb/day acidity (111 mg/L acidity). Earlier that month, the point source discharges in the upper watershed had been sampled under similar weather conditions and had totaled only 38 lb/day of acidity.

Close inspection of Short Bend Run indicated that stream flow increased visibly in the area where KC143 enters. This area is very rocky and is located at the break in topography where the surface changes from moderately sloping to steeply sloping. A station was established in the stream below KC143 so that the stream contaminant loading could be measured. The only known point discharges to the stream above this point are SB-1, KC143, and KC143A. In January 2006, the acidity loading at the stream station was 72 lb/day (150 gpm with 40 mg/L acidity). The summed inflows of SB-1, KC143 and KC143A on the same January day were 44 lb/day acidity. In April 2006, the acidity loading at the stream station was 58 lb/day (100 gpm with 48 mg/L acidity). The summed inflows of point discharges on the same April day were 43 lb/day acidity. Thus, shallow groundwater flow in this area contributed 35-60% more acidity than could be accounted for by visible surface flows at KC143 and KC143A and SB-1.

Table 15. Sampling results for discharges in the Short Bend Run watershed.

Point	Date	Flow (gpm)	pH	Concentrations (mg/L)					Loading (lb/day)		
				Acid	Fe	Mn	Al	SO4	Acid	Fe	Al
KC142	06/25/02	<1									
KC142	04/12/05	2	4.3	9	4.7	0.7	0.0	67	0.2	0.1	0.0
KC142	10/14/05	0							0.0	0.0	0.0
KC142	01/05/06	15	5.4	2	1.6	0.3	0.2	27	0.3	0.3	0.0
KC142	04/24/06	9	5.7	4	0.6	0.2	0.3	30	0.4	0.1	0.0
SB-1	04/12/05	na	3.5	35	0.8	0.3	1.5	174			
SB-1	01/05/06	9	3.4	32	0.5	0.3	0.9	70	3.3	0.1	0.1
SB-1	04/24/06	5	3.3	42	0.8	0.5	1.5	60	2.5	0.0	0.1
SB-1	07/06/06	3	3.3	53	1.3	0.5	2.3	77	1.6	0.0	0.1
KC198	08/22/00	4	2.7	288	57.1	4.0	37.3	596	13.5	2.7	1.7
KC198	07/16/02	5	2.5	442	40.9	3.1	30.1	495	26.5	2.5	1.8
KC198	04/12/05	25	2.9	156	11.3	1.4	10.2	509	46.7	3.4	3.1
KC198	10/03/05	1	2.5	739	85.0	4.4	58.4	739	6.7	0.8	0.5
KC198	01/05/06	27	2.8	175	12.4	1.0	6.5	242	57.3	4.1	2.1
KC198	04/24/06	35	2.9	163	12.1	1.2	8.1	221	68.3	5.1	3.4
KC198	07/06/06	7	2.7	310	21.0	2.5	23.4	470	24.1	1.6	1.8
KC129	10/14/05	0							0.0	0.0	0.0
KC129	01/05/06	1	3.4	268	0.7	6.2	49.0	426	3.2	0.0	0.6
KC129	04/24/06	15	4.1	228	0.7	11.3	35.5	423	41.0	0.1	6.4
KC129	07/14/06	0							0.0	0.0	0.0
KC143	06/26/02	1	3.1	381	16.0	7.2	35.2	561	4.6	0.2	0.4
KC143	04/12/05	12	3.7	50	5.2	3.1	4.9	268	7.2	0.7	0.7
KC143	10/13/05	2	2.8	523	116.0	13.2	24.1	1,513	12.6	2.8	0.6
KC143	01/05/06	30	3.2	105	15.1	3.0	5.4	300	38.1	5.5	2.0
KC143	04/24/06	19	3.1	150	19.0	3.7	6.8	395	34.9	4.4	1.6
KC143	07/06/06	4	2.8	332	57.4	9.5	17.1	848	14.3	2.5	0.7
KC143A	04/12/05	2	3.3	192	20.6	5.4	22.7	574	4.6	0.5	0.5
KC143A	10/13/05	0							0.0	0.0	0.0
KC143A	01/05/06	2	3.2	144	3.8	3.4	16.1	294	2.6	0.1	0.3
KC143A	04/24/06	2	3.1	199	13.0	4.9	18.5	396	4.8	0.3	0.4
Combined Average*		**37**		**156**	**13.2**	**4.2**	**11.7**	**462**	**69.2**	**5.8**	**5.2**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

An estimate of the flow of the missing AMD was made by dividing the missing acidity loading by the average AMD acidity concentration (Table 15, 156 mg/L acidity). In January the missing AMD was calculated to flow 38 gpm. In April the missing AMD was calculated to flow 31 gpm.

The combined discharges are suitable for passive treatment. However, there is very limited acreage that would be suitable for passive treatment. If the KC143 and KC143A discharge cannot be intercepted near the toe of the existing surface mine spoils, then the discharge system will need to be moved downhill and the amount of acreage may become limiting. Because of this concern, both passive and chemical treatment alternatives were considered. Both options include the installation of a drain in the elevated haulage berm so that Short Bend Run north of the berm (which is clean) passes through the area quickly and does not have an opportunity to feed the shallow groundwater system that is producing non-point AMD. This modification will eliminate the pond and wetland that have formed on the north side of the haulage berm due to poor drainage. Because the pond and wetlands contain clean water, there may be permitting challenges to this action.

The treatment area is located north of Short Bend Run between the elevations of 1280 and 1320 feet MSL. There are 2-3 acres of ground at this location that could be benched for the construction of treatment ponds. AMD discharges should be collected and piped to this location. One pipeline can start at KC129 and extend 4,000 feet to the southwest to the treatment area. This pipe would also collect KC198. The SB-1 deep mine should be collected and piped 300 feet to the south to the treatment area. A French drain collection system should be installed on the south side of the stream to collect KC143, KC143A, and shallow groundwater. The system should be installed no lower than 1300 feet so the collected flow can be piped to the treatment area. This area is very rocky and the collection efforts are expected to be very difficult. If successful collection of the AMD requires placing the collection system at a lower elevation, then the feasibility of passive treatment should be reevaluated because the acreage of suitable land may not be sufficient. Chemical treatment may be the only option. If the collection efforts fail and there continues to be a significant flow of AMD to Short Bend Run below the treatment area, the installation of the treatment system should be reconsidered or the design modified.

The following treatment recommendations assume that the collection efforts are successful and substantially all of the AMD is collected and piped to the treatment area.

The treatment cost calculations assume the average chemistry shown in Table 15, an average flow of 71 gpm, and a high design flow of 129 gpm. The average is based on the average flow of collected AMD (37 gpm, Table 15) plus the average estimate of the contaminated ground water flow (34 gpm). The high flow is based on the combined maximum flows of the captured discharges (91 gpm) and the highest estimate for uncaptured AMD groundwater (38 gpm).

Passive Treatment

The recommended passive system should include two parallel VFPs followed by a pond that provides solids settling and mixing for overflow events. Table 16 shows cost calculations for the passive system. Each VFP should be 21,000 ft^2 at the water level and contains approximately 2,800 tons of limestone and 600 CY of organic substrate. Because of the rocky conditions, all ponds should be lined with a synthetic liner. The contingency for this system, 20%, is higher than for other systems (15%) because the construction conditions are expected to be difficult. The design and engineering is larger than other systems because of the inclusion of permits to allow the drainage of the pond and wetland area.

Table 16. Estimated costs for passive treatment of Short Bend Run AMD

Item	**Quantity**	**Unit cost**	**Total cost**
divert upstream SBR	estimate	10,000	$ 10,000
collect KC129, KC198, SB-1	3 systems	1,500	$ 4,500
collect KC143 & KC143A & baseflow with French drain system	estimate	15,000	$ 15,000
pipe AMD flows, ft	4,700	5	$ 23,500
clear and grub	5	1,500	$ 7,500
flow splitter box	1	2,500	$ 2,500
VFP, limestone, ton	5,673	20	$ 113,451
VFP: alkaline substrate,CY	1,169	20	$ 23,373
synthetic liner for VFP and pond, ft^2	60,799	2	$ 121,598
VFP: excavation, CY	18,323	5	$ 91,615
Settling and mixing pond, ft^2	12,417	1	$ 12,417
Miscellaneous materials		10%	$ 42,945
E&S, Mob/Demob	5,000	1	$ 5,000
contingency		20%	$ 95,480
Design/engineer			$ 60,000
TOTAL			**$628,879**

The system should produce a discharge with 80-100 mg/L of alkalinity. Flows in excess of 129 gpm should mix with the treated water in the settling/mixing pond. Assuming that the excess flow is AMD with average chemistry, then the system should be able to neutralize up to 80 gpm of overflow. Alternatively, the treated water will neutralize acidic groundwater not collected by the project that flows into Short Bend Run below the system. Assuming that the groundwater has 156 mg/L acidity, every 10 gpm of treated water (100 mg/L alkalinity) will be able to neutralize 6 gpm of uncollected AMD.

The annual O&M of the system would be minor. Once the system's functionality was established, the O&M would involve inspections, sampling, and routine maintenance every two months. The flow control box will need to be inspected and cleaned of debris or metal deposits, and adjusted. It may be necessary to remove litter and blockage from influent and effluent channels. Monitoring would include four water samples (common VFP influent, each VFP effluent, final effluent), flow measurements at all stations, and measurement of water levels in the VFPs. The inspection and routine maintenance is expected to require four hours. Total cost, per event, is $260 or approximately $2,000 per year. The cost could be decreased if the O&M was combined with other treatment systems.

Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost of organic substrate replacement is estimated at about $23,000 per VFP. Major maintenance of this type should not be required for at least 7 years.

Chemical Treatment

Chemical treatment would involve addition of NaOH to the AMD, flow through two serially-connected sludge ponds, and then flow through a final polishing pond. The sludge ponds should be sized for a total of 48 hours of retention of the high flow. Assuming the high flow of 129 gpm, then the sludge ponds should have a capacity of 370,000 gallons and, if 5 feet deep, then each pond would be approximately 11,000 ft^2. The final polishing pond should provide 24 hours of retention or, assuming a 5-foot depth, be about 11,000 ft^2. A 20,000 ft^2 sludge disposal basin should be constructed above the treatment system. Every year, sludge should be pumped from the treatment ponds to the sludge disposal basin for passive dewatering.

NaOH should be stored in a tank placed next to Short Bend Road. A 900-foot buried pipeline would carry the NaOH to the treatment system. Placement of the storage tank next to the road will make deliveries possible year round. Nonetheless, the tank storage capacity should be at least two months of expected usage. A 10,000 gallon tank is recommended.

NaOH consumption estimates were made using AMDTreat (Version 4.0, OSM, 2006). The calculations assumed 68 gpm average flow with 156 mg/L acidity and 80% NaOH efficiency. The system will utilize 24,000 gallons per year of 20% NaOH.

Table 17 shows estimated costs to construct and operate the Short Bend NaOH treatment system. The capital cost estimate is $204,000. The annual operation includes the purchase of NaOH, operation of the system, and sludge maintenance. The operator is assumed to inspect and adjust the system 3 days a week with each inspection requiring about three hours (including travel). The operator must also collect samples periodically and submit paperwork on the system's operation. Occasionally, the operator is assumed to need an assistant. The sludge removal occurs once a year through a specialized sludge pumping subcontractor. The total annual costs are estimated at $41,840 per year.

Table 17. Estimated Chemical Treatment Costs for Short Bend Discharges

Capital Items	**Basis**	**Cost Estimate**
divert upstream SBR	estimate	$ 10,000
Clear & grub	2 acres @ $1,500/acre	$3,000
collect KC129, KC198, SB-1	Three collection systems @ $1500 each	$ 4,500
collect KC143 & KC143A & baseflow	Major collection system, estimate	$ 15,000
pipe AMD flows, ft	4,700 ft pipeline @ $5/ft	$23,500
Construct road	500 feet road @ $10/foot	$5,000
NaOH storage tanks	10,000 gal @ $1/gal	$10,000
NaOH pipeline	900 feet @ $3/foot	$2,700
Treatment ponds, lined	3 X 11,000 ft2 X $2/ft2	$66,000
NaOH metering device	One unit	$4,000
Sludge disposal basin	10,000 ft2 @ $1/ft2	$10,000
E&S, mob & demob	Estimate	$10,000
Design/permit	Estimate	$40,000
TOTAL, Capital Costs		**$203,700**
Annual Items	**Basis**	**Cost Estimate**
NaOH	24,000 gal 20% NaOH @ $0.50/gal	$12,000
Operator	12 hr/wk local operator @$35/hr	$21,840
Laborer	Assistant, 60 hr/yr @ $25/hr	$1,500
Maintain access to site	Road repair, plow snow	$2,000
routine O&M	Valves, hoses, metering equipment	$1,000
Sludge removal	25 hr pumping at $100/hr plus mob/demob	$3,500
TOTAL, Annual Costs		**$41,840**

The system will treat approximately 46,500 lb/yr of acidity. At $41,840/yr, the unit annual treatment cost is $1,800/ton of acidity. Skousen and Ziemkiewicz (2005) analyzed NaOH treatment systems in West Virginia and estimated that the total unit treatment costs were $1,000 – 1,500 per ton acidity. Rose (2006) reports that annual NaOH treatment costs developed using AMDTreat were $900-$1,100 per ton acidity, not including sludge management. The unit cost for this project is higher because of labor costs that are required regardless of the acidity of the water. The Short Bend AMD is less acidic than the Slide Hollow or KC204 AMD and is thus more expensive, per unit of acidity, to treat.

F. KC204

The KC204 Group includes KC204 and KC204A. The discharges are located in Sproul State Forest (Map 9). KC204 discharges from a WPA mine seal and flows down a steep slope directly to Kettle Creek (Photos 17 and 18). The discharge is the largest point source of AMD pollution to Kettle Creek. The discharge is considered in conjunction with KC204A because in the past most of the flow that is now observed at KC204 flowed from KC204A. There is a large kill zone below KC204A and a kill zone is developing below KC204. The magnitude of the KC204 discharge is a result of the design of the underground mine, which was designed to promote flow away from the busy portals in Bitumen at the inclined plane.

Local Hydrogeology

The axis of the Clearfield-Mcyntire Syncline passes through the No. 1 mine on a line trending roughly from the inclined plane to the discharge identified as KC204A (See Map 3). The axis is more of a transitional zone rather than a distinct line where the dip abruptly changes from northwest to southeast. As a result, the local coal structure is quite irregular in this area.

A mine map that was prepared as part of Operation Scarlift shows coal structure contours drawn by Neilan Engineers. Many of the spot elevations on the mine map itself are illegible so confirming the accuracy of the contours is difficult. While caution is strongly warranted in the application of the coal elevations, it is believed that the general structure can be used to make some interpretations about the movement of water through the mine.

The structure in No.1 mine directs the majority of the mine drainage toward Kettle Creek (See Map 3). The KC204A discharge is the result of a drain installed by the miners from the lowest point in the mine. A large kill zone, evident on the USGS map, is a testament to the historical flows of AMD from this drain. While KC204A is at the lowest point in the mine, not all of the mine could drain to this location due to an east-west trending roll in the coal that prohibited flow from the northern portion of the No. 1 mine from reaching KC204A. For this reason, a second drain was installed that produces the KC204 discharge. Approximately 34 acres of deep mine is drained directly by KC204. Figure 3 illustrates these conditions.

Sometime during the past 30 years, subsidence at the mouth of the KC204A drain severely restricted the flow at this point. The Operation Scarlift report indicates that flow at KC204A (Weir 27) was at least 10 times greater than the flow at KC204 (Weir 28). Today, the hydrologic condition is reversed, with very little flow emerging at KC204A and very large flows from KC204. It is not unreasonable to expect that subsidence around the KC204A drain caused a 15- to 20-foot deep mine pool to develop. Recent excavations of several collapsed deep mine entries in the Twomile Run watershed revealed mine pools behind the collapsed entries with water depths nearing 10 feet with very little leakage (HE, 2007).

As the primary drainage for approximately 116 acres of the No. 1 mine, the blockage of KC204A has resulted in the formation of a sizable mine pool. The mine pool is clearly depicted in maps produced by an airborne geophysical survey conducted by DOE/NETL (Map 2). The electromagnetic conductive anomaly does not necessarily correspond to the exact limits of the mine pool. Because the ability of the geophysical equipment to detect the pool is proportional to its thickness (depth of water), the deepest portion of the pool appears on the maps as the strongest conductive anomaly. Likewise, the fringes of the pool, where the water is shallow, are not well defined due to resolution limitations. The area north of the roll that is drained by KC204 is not flooded as indicated by its low conductivity.

The geophysical survey results were confirmed by recent drilling and the installation of observation wells between the KC204 discharge and the inclined plane (see Map 11 for locations). The program established that the mine voids in this area contain water of varying depths but similar elevations, indicating a single water table surface. The pool's maximum depth is located in the vicinity of the KC204A drain. In the deeper portions of the pool, the mine is flooded beyond the roof, saturating the overlying strata to a total depth of 15-20 feet. Only shallow water depths (3-4 feet) were encountered in the vicinity of the KC204 discharge.

In addition to the KC204 and KC204A discharges, the No.1 mine discharges from numerous collapsed entries located near the inclined plane. Entries into the No. 1, 2, and 3 mines are all located at this point. The original elevation of these entries appears to have been approximately the same as or slightly lower than that of the structural roll near KC204. The entries and the area around the inclined plane are severely subsided, resulting in obstruction of flow from the mine. Currently, the most important discharge in this area is KC401, which appears to be a collapsed entry located approximately 450 feet southeast of the main entry to the No. 1 mine. Mine maps do not indicate an entry at this location so the exact source of the discharge is unclear.

The inclined plane entries discharge AMD to Milligan Run, a tributary to the West Branch Susquehanna River that enters the river 3.5 miles upstream of Kettle Creek. Milligan Run is a small stream with numerous AMD discharges that is highly acidic and biologically dead.

Conceptual Hydrologic Model

Flow measurements taken at KC204 indicate that a lag time of days to weeks exists between precipitation events and corresponding increase in flow from KC204 (Figure 4). The lag time represents the amount of time required for the mine pool behind KC204A to fill to the point that it spills over the structural roll and flows out at KC204. The lag time is likely proportional to the amount of time between precipitation events. That is, the more time between flow events, the greater the drawdown of the mine pool by the small flow at KC204A. It then takes longer for the mine pool to fill to the elevation of the roll and spill over to KC204. Flows from KC401 seem to share a similar lag pattern as KC204, further suggesting that the discharges are influenced by the same mine pool.

Figures 5, 6 and 7 show the hypothesized hydrologic behavior of the No.1 mine under different flow conditions. It is assumed that the KC204A discharge is the preferred (lowest) drainage point, but that it is blocked. KC204 is at a higher elevation and is free flowing. Drift entries at the inclined plane, which are low enough to receive and discharge water, are also blocked with subsidence. KC401 is a higher-elevation discharge point at the inclined plane that is not blocked by subsidence.

Under low flow conditions (Figure 5), KC204 discharges water produced by the 34 acre updip mine (Figure 3) that is separated from the main mine by the structural roll. KC204A is blocked and can only release a small flow, so the mine pool behind KC204A begins to rise when inflows exceed this amount. Since the roll in the coal is at approximately the same elevation as the mine entries at the inclined plane, all of these discharges are influenced by the rising mine pool in a similar manner and at similar mine pool elevations. As the mine pool rises above the elevation of the roll in the coal and water spills to the north, it discharges at the unobstructed KC204 drain (Figure 7). Under these conditions, flow from the mine is primarily out of KC204 and KC401.

While the flows at KC204, KC204A, and the inclined plane portals impact different surface watersheds, their common origins in the No.1 deep mine make their joint consideration in remediation plans logical and cost-effective.

KC204 Chemistry and Loading

Flows and chemistry for the KC204 discharge are shown in Table 18. The discharge is highly contaminated and has a variable flow rate. In wet conditions, the flow commonly is greater than 100 gpm and the acidity loading is 1,000-2,000 lb/day.

As noted above, during this study KC204A had a very low flow relative to KC204. When sampling KC204, the KC204A discharge was routinely checked and always found to have a much lower flow. The discharge was not sampled because it was considered to flow from the same pool as KC204 and analysis in 2002 established that the two flows had similar chemistry.

The large mine pool present behind the plugged KC204A mine drain creates an environmental hazard. A large release of AMD could occur if the subsided area failed and the pool drained. Such an event is not unprecedented. In January 2005 a blowout occurred at an abandoned deep mine in McDonald PA (Allegheny County). The blowout occurred near a mine drain that had become plugged years earlier, causing water to rise up in the mine. The blowout discharged 10,000 gpm of highly acidic water, but the impact on the receiving stream, Robinson Run, was negligible because the stream was already polluted with AMD.

A blowout of similar proportion at KC204A would devastate lower Kettle Creek and also degrade the West Branch. Table 19 shows calculations for a hypothetical blowout. If the pool drained completely in 24 hours, then Kettle Creek would develop a net acidity below the blowout of 78 mg/L under average conditions. Assuming that Kettle Creek would be flowing higher than average during a blowout, then the stream flow would need to be at least 1.4 million gpm (3,200 cfs) to completely neutralize the acidity loading estimated released. This flow rate is not unprecedented – it occurs 1% of the time. However, the coincidence of a blowout occurring only during extremely high stream flow should not be assumed.

Table 18. Characteristics of the KC204 discharge.

Date	Flow (gpm)	pH	Concentrations (mg/L)					Loading (lb/day)		
			Acid	Fe	Mn	Al	SO4	Acid	Fe	Al
07/17/02	64	2.8	928	157	6	53	1,102	713	120	40
06/22/06	146	2.9	614	92	6	43	977	1,073	161	75
06/30/06	115									
07/06/06	80	2.4	656	102	7	58	1,199	630	98	56
07/11/06	75									
07/14/06	75	2.5	674	110	7	54	1,012	606	99	48
07/25/06	60	3.0	718	105	7	54	947	517	76	39
08/23/06	30		984	185	8	51	1,036	354	67	18
08/31/06	28	3.1								
09/02/06	29									
09/07/06	140	3.3	540	121	6	25	879	908	203	42
09/19/06	150	2.4	570	91	5	52	869	1,026	164	94
10/09/06	90	3.0	706	136	6	40	765	765	147	43
11/28/06	260	2.6	609	103	7	35	811	1,900	321	109
1/26/07	350									
1/30/07	270									
Average	**123**	**2.8**	**700**	**120**	**6**	**47**	**960**	**849**	**146**	**57**
Median	**85**	**2.9**	**656**	**105**	**7**	**51**	**947**	**765**	**147**	**48**
75th %	**144**	**3.0**	**706**	**121**	**7**	**54**	**1,012**	**1,026**	**164**	**75**
90th %	**227**	**3.2**	**771**	**146**	**7**	**55**	**1,068**	**1,238**	**227**	**97**
Max	**350**	**3.3**	**984**	**185**	**8**	**58**	**1,199**	**1,900**	**321**	**109**

It is possible that a blowout event could be neutralized through increased release of alkaline water from the Alvin R. Bush dam. This would require immediate recognition of the blowout event and rapid reaction by the US Army Corps of Engineers (which operates the dams). The coincidence of these events is unlikely.

Table 19. Calculated impact of KC204A blowout on Kettle Creek

Current Kettle Creek Characteristics near KC204	
Average flow	178,000 gpm
Average alkalinity	13 mg/L
Average alkalinity load	28,000 lb/day
Current Mine Pool Characteristics	
Mine Pool Volume (53 acres, 4 feet deep, 60% void)	38,000,000 gallons
Mine pool acidity	700 mg/L
Mine pool acidity load (static)	219,000 lb
Blow Out Scenario: 24 hour drawdown	
flow rate to empty pool in 24 hours	26,000 gpm
Kettle Creek chemistry below blowout during event	78 mg/L acid

Treatment Recommendations

It is not possible to treat the KC204 discharge at its present location due to a lack of suitable land for treatment system construction. In addition, the discharge is not suitable for passive treatment due to its extreme chemistry. Two remediation options were considered. The first option is for chemical treatment at a location adjacent to Kettle Creek near the mouth of Short Bend Run. While the placement of the treatment system at this location may not be preferred, the plan shows the likely capital and annual costs of treatment, wherever it occurs. The second option considers the relocation of KC204 and KC204A to the inclined plane area and Milligan Run, which is already polluted by AMD and where there is room for construction of a treatment plant.

Chemical Treatment of KC204 and KC204A

The discharge chemistry is too severe for reliable passive treatment and requires chemical treatment. There is no room in the vicinity of the discharge for treatment by a gravity-flow system. The only available flat land below the discharge is located at the mouth of Short Bend. There are approximately 9 acres of land available at this site.

Chemical treatment could be achieved using lime or NaOH. Lime (CaO or $Ca(OH)_2$) is the less expensive reagent, but its efficient use requires mixing and aeration that typically is accomplished with electric power. The installation of electricity to the mouth of Short Bend would be very expensive and is unlikely to be realized. NaOH is a much more soluble reagent that does not require as much mixing. A NaOH plant could be operated at this location without electricity.

The following costs were developed using AMDTreat (Version 4.0, OSM, 2006) as a guide. The system involves the collection and piping of KC204 and KC204A in a single 8 in pipe approximately 1,500 feet to the treatment area. The installation of the pipe is assumed to be difficult because the steep rocky conditions and because it would be designed to be inconspicuous. A road must be built down the steep hill that can be maintained and used in winter. The calculations assumed that the ponds were designed for 48 hours of retention of 300 gpm and an average AMD inflow of 123 gpm with 700 mg/L acidity. The efficiency of NaOH neutralization was assumed to be 80%.

The estimated capital costs for the treatment system are $299,000.

The treatment system and/or its access road would be partially visible from Kettle Creek Road. During treatment discussions with the US Army Corps of Engineers, the visibility of treatment systems to visitors was considered a significant negative issue.

Table 20. Estimated capital and annual costs for treatment of KC204 with NaOH.

Capital Items	**Basis**	**Cost Estimate**
Clear & grub	8 acres @ $1,500/acre	$12,000
Construct road	5,500 feet road @ $10/foot	$55,000
NaOH storage tanks	40,000 gal @ $1/gal	$40,000
Collect KC204 & KC204A	estimate	$10,000
Pipe AMD to treatment system	1,500 feet @ $20/foot	$30,000
NaOH pipeline	1,900 feet @ $10/foot	$19,000
Treatment ponds, lined	three 9,000 ft^2 ponds @ $2/$ft^3$	$54,000
NaOH metering device	One unit	$4,000
Sludge disposal basin	15,000 ft^2 @ $1/$ft^2$	$15,000
E&S, mob & demob	Estimate	$10,000
Design/permit	Estimate	$50,000
TOTAL, Capital Costs		**$299,000**
Annual Items	**Basis**	**Cost Estimate**
NaOH	190,000 gal 20% NaOH @ $0.50/gal	$95,000
Operator	30 hr/wk local operator @$35/hr	$54,600
Laborer	Assistant, 20/month @ $25/hr	$6,000
Maintain access to site	Road repair, plow snow	$10,000
routine O&M	Valves, hoses, metering equipment	$5,000
Sludge removal, twice/yr	200 hr pumping at $100/hr plus mob/demob	$25,000
TOTAL, Annual Costs		**$195,600**

The annual unit cost is $1,037 per ton acidity treated. This is on the low end of the $1,000-1,500 per ton acidity range suggested by Skousen and Ziemkiewicz (2005) for NaOH treatment in West Virginia. Rose, using AMDTreat as a guide, suggested $900-1,100 per ton as a total cost for NaOH treatment not counting sludge management.

Relocation of KC204 and KC204A to the Milligan Run Watershed

The goal of this alternative is to move KC204 out of lower Kettle Creek, which is good quality, and into Milligan Run, which is highly degraded by AMD. A chemical system that treats KC204 and other discharges could be constructed in the Milligan Run watershed. Because there are more sites suitable for construction of a plant, the treatment would likely be less costly to construct and operate and provide a greater positive environmental impact than constructing a system in the Kettle Creek watershed.

It may be feasible to construct of a lime plant in the Milligan Run watershed that would treat existing flows of AMD plus the flow from the reopened Bitumen mine entries. A lime plant is a more cost-effective treatment method because lime is cheaper than NaOH. However, lime plants require electricity and because they involve mechanical devices, have a larger manpower requirement. Electrical service already exists along lower Cooks Run Road from SR 120 to the Sproul State Forest Maintenance Facility. A plant could be constructed on flat land near the bottom of the inclined plane that would treat AMD collected from the Bitumen area, the inclined plane, and Crowley Hollow. The discharge from a plant at this location could be directed to Crowley Hollow or Milligan and provide an alkaline flow to these acid streams.. This plan would require improvement of an existing road and extension of electrical service about one mile. Alternatively, a lime plant could be built along Cooks Run Road between Cooks Run and Milligan Run near the Maintenance Facility. This plant could treat all of Milligan Run or receive piped AMD flows from the inclined plane and Bitumen area. A plant at this location could also treat AMD flow from the Crowley Hollow watershed.

BAMR is currently developing plans and costs for the construction and operation of a lime plant in Hollywood PA on Bennett Branch (tributary to West Branch upstream of Kettle Creek). This information should be useful for accurately estimating the costs to construct and operate a lime treatment plant in Milligan Run.

In order to reliably and cost-effectively relocate the KC204 mine pool to the inclined plane, the local structure of the Lower Kittanning coal and associated deep mine should be better determined because, as noted, the coal structure appears to be highly irregular in this area. Drilling should be conducted to determine the exact location and nature of the roll that controls water flows in the mine. The presence and characteristics of the mine pool(s) should be determined. It is estimated that the initial information could be collected by drilling 20 holes and developing 5 of the holes as monitoring wells. Based on the recent costs to drill 10 holes and develop 5 observation wells, the estimated cost for this task is $20,000.

The entries around the inclined plane should be excavated and collection drains installed. This action should allow the mine pool to freely drain and therefore reduce the flow at KC204. This should be done after the completion and analysis of the drilling so that the amount of impounded water can be estimated. The excavation plan should include provisions to drain the pool at a rate compatible with DEP and DCNR interests. There are 6 entries at the inclined plane. The cost estimated for engineering, excavation, controlled drainage, and collection of all six entries is estimated at $50,000.

Allowing the mine to drain at the inclined plane would have additional advantages. Impoundment of water behind the inclined plane entries could possibly be directing some flow from the No.2 and No. 3 mines to the No.1 mine. Once in the No. 1 mine, this flow would contribute to the KC204 discharge that impacts Kettle Creek. If the mine were freely draining at the inclined plane, these flows would not impact Kettle Creek.

Following the collection of the inclined plane discharges, monitoring should be conducted to assess the change in flow at KC204, KC204A, and the inclined plane discharges. Monitoring well water elevations should be measured when discharge flow rates are measured. 18 months of monitoring, including an analysis of the results and recommendations, is estimated to cost $20,000. Therefore, the total cost for Phase I is $90,000.

Depending on the results of this monitoring, three main options exist to encourage the mine to discharge at the inclined plane collection systems rather than KC204:

- Option 1: If the KC204 discharge continues to show influence from the mine pool, grouting along a small section of the roll could minimize this influence. Although the mine pool is not expected to increase in elevation, grouting of KC204A would help protect against blow-out. Figure 8 shows the location of this grouting.
- Option 2: If the KC204 discharge shows significant reduction in flow (suggesting that the collection systems at the inclined plane have lowered the mine pool below the elevation of the roll), sealing of the KC204 discharge could be performed. This would direct all flow from KC204 to the inclined plane. Although the mine pool is not expected to increase in elevation, grouting of KC204A would help protect ensure against blow-out. Figure 9 shows this option.
- Option 3: If no change in the KC204 discharge flow rate is observed, more must be learned about the detailed coal structure before a new strategy is conceived. This additional knowledge should come from a detailed drilling program.

G. Duck Hollow

Flows of AMD to Duck Hollow are associated with surface mining on the eastern side of the hollow. The discharges are accessed by a powerline right-of-way. KC150 occurs in an abandoned pit beneath the powerline (Photos 19 and 20) and from spoil seepage that may be related to deep mines. The discharges all occur above 1360 feet MSL and there is considerable suitable land for treatment located between the discharges and the steep drop-off to Kettle Creek (Map 10). Table 18 shows the chemistry of the identified discharges. The discharges and area proposed for treatment are on newly purchased Sproul State Forest property.

While the point sources of AMD in Duck Hollow can be collected and treated above the steep slope down to Kettle Creek (see next section), there are groundwater sources of AMD that enter Duck Hollow near the mouth that are not easily collected or treated. Photo 21 shows the iron stained channel of Duck Hollow. Discharges identified at the headwaters of Duck Hollow all have low iron concentrations so the stream must be gaining iron from contaminated baseflow. Photo 22 shows AMD that is flowing from fractured sandstone bedrock next to Duck Hollow. The loading of AMD measured at the mouth of Duck Hollow on two occasions was double the loading of the point sources near the headwaters. Because of these groundwater discharges near the mouth, treatment of the point sources (KC150, DH-2A, and DH-2B) will not result in complete restoration of Duck Hollow.

Table 21. Duck Hollow Discharges Flow, Chemistry, and Loading Results

Point	**Date**	**Flow (gpm)**	**pH**	**Concentrations (mg/L)**					**Loading (lb/day)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**Acid**	**Fe**	**Al**
KC150	06/26/02	9	2.9	281	6	11	24	506	30.3	0.7	2.6
KC150	04/07/05	5	3.3	94	2	5	12	384	5.6	0.1	0.7
KC150	10/12/05	0	3.0	107	6	5	6	224	0.3	0.0	0.0
KC150	01/05/06	4	3.6	55	1	3	7	274	2.8	0.1	0.4
KC150	04/24/06	5	3.1	109	1	5	7	261	6.1	0.0	0.4
KC150	07/06/06	5	3.1	106	1	6	8	252	6.3	0.0	0.5
KC150	08/04/06	3	3.0	110	1	5	7	248	3.9	0.0	0.3
DH-2A	05/02/06	8	3.4	86	1	5	10	221	7.8	0.1	0.9
DH-2A	07/06/06	3	3.4	101	2	6	11	268	3.0	0.0	0.3
DH-2A	08/04/06	2	3.2	84	4	7	7	237	1.8	0.1	0.1
DH-2B	05/02/06	12	3.0	146	3	6	13	298	21.0	0.4	1.9
DH-2B	07/06/06	6	3.1	170	5	7	15	333	11.2	0.3	1.0
DH-2B	08/04/06	4	3.0	145	8	10	11	350	7.0	0.4	0.5
Combined Average*		**15**		**124**	**2**	**6**	**10**	**291**	**22.7**	**0.5**	**2.0**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*
Note: DH-1 is included in Butler Hollow North area.

All of the discharges are low flow and contain moderate acidity and metal concentrations. The average combined flow was 15 gpm with a flow-weighted acidity of 124 mg/L, 2 mg/L Fe and 10 mg/L Al. This water is suitable for passive treatment with vertical flow ponds followed by a settling/mixing pond.

Passive Treatment

If the discharges are treated, the recommended remediation is passive treatment with a single vertical flow pond followed by a settling/mixing pond. The VFP was sized based on the highest combined flow (24 gpm). The three discharges should each be collected and piped to the treatment area (total piping, 1,800 feet). The flows should enter a flow control box that limits flow to the VFP to 24 gpm and diverts higher flows to the settling pond. Primary treatment will be provided by one VFP with a surface area of 7,000 ft^2 at the water level and 700 tons of limestone with 170 CY of alkaline organic substrate. The VFP should discharge to a settling pond that also receives the flow control box overflow. The pond should provide the design flow with 48 hours of retention.

Table 22. Duck Hollow Cost Estimate

Unit	Quantity	Unit cost	Total cost
clear and grub	1	1500	$ 1,500
collect DH-2B, DH-2A, KC150	3	2000	$ 6,000
pipe flows, ft	1800	5	$ 9,000
flow splitter box	1	2500	$ 2,500
LS cost, $/ton	703	20	$ 14,059
SMC cost, $/CY	165	20	$ 3,307
excavation, $/CY	2,739	5	$ 13,696
pond, 48 hr high flow, ft2	2,310	1	$ 2,310
Miscellaneous materials		10%	$ 5,237
E&S, Mob/Demob	1	5000	$ 5,000
contingency		15%	$ 9,391
Design/engineer		estimate	$ 30,000
TOTAL			$ 102,001

The treatment system should discharge water with 80-100 mg/L alkalinity. The highest combined flow observed for the discharges was 36 gpm. The combination of 30 gpm treated water and 6 gpm of untreated water should result in mixture with approximately 60 mg/L alkalinity.

The annual O&M of the passive system would be minor. Once the system's functionality is verified, it should be inspected and sampled quarterly. The flow control structure should be opened, cleaned, and adjusted. Debris should be removed from inlet or outlet channels. Monitoring would include the collection of three water samples (VFP influent, VFP effluent, final effluent), measurement of flow rates, and measurement of the water elevation in the VFP. Each inspection is estimated to cost $230 or approximately $1000 per year. The cost could be decreased if the O&M was combined with other treatment systems.

Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or simply replaced at a cost of approximately $7,000.

H. Butler Hollow North

The Butler Hollow North discharges arise on the north side of T-307, which provides easy access to the AMD (Map 10). The site appears to have been affected by the by the Natural Resources Conservation Service in the early 1990s through its Rural Abandoned Mine Reclamation Program (RAMP). The primary discharge, KC154, is a piped discharge that likely collects flow from a backfilled deep mine opening or drain (Photo 23). There are several small spoil discharges to the northeast of KC154 that are called KC153 (Photo 25) and KC153A. Flow from a discharge into Duck Hollow (DH-1) is considered with this group because of its proximity (Photo 24). The following table shows the flow, chemistry, and loading from the discharges. The discharges and area proposed for treatment are on newly purchased Sproul State Forest property.

Table 23. Butler Hollow North Discharges Flow, Chemistry, and Loading Results

Point	**Date**	**Flow (gpm)**	**pH**	**Concentrations (mg/L)**					**Loading (lb/day)**		
				Acid	**Fe**	**Mn**	**Al**	**SO4**	**Acid**	**Fe**	**Al**
KC154	04/07/05	70	3.1	134	13	8	8	985	112	11	7
KC154	10/12/05	19	2.9	199	13	17	12	1588	44	3	3
KC154	01/05/06	125	3.0	130	9	8	6	528	195	13	9
KC154	04/24/06	62	2.9	166	9	12	8	792	122	7	6
KC154	07/06/06	49	2.9	174	8	15	11	854	103	5	7
KC154	08/31/06	80									
KC153	04/07/05	20	3.2	251	36	31	32	1628	60	9	8
KC153	10/12/05	2	3.2	269	21	26	27	640	6	1	1
KC153	01/05/06	9	3.2	231	16	24	27	716	25	2	3
KC153	04/24/06	9	3.2	267	14	26	27	640	29	2	3
KC153	07/06/06	6	3.1	253	14	27	32	690	18	1	2
KC153A	01/05/06	5	3.4	145	4	15	15	605	8.7	<1	1
KC153A	04/24/06	2	3.2	281	6	23	21	2010	6.7	<1	1
KC153A	07/06/06	2	3.1	334	12	37	44	1493	8.0	<1	1
DH-1	04/07/05	25	3.2	197	52	14	21	887	59	16	6
DH-1	10/12/05	0	3.1	279	63	18	29	989	1	<1	<1
DH-1	01/05/06	23	3.6	251	67	15	20	873	70	19	6
DH-1	04/24/06	6	2.9	236	3	14	21	626	16	<1	1
DH-1	07/06/06	1	2.9	245	6	14	23	769	2	<1	<1
DH-1	08/31/06	28									
Combined Average*		**92**		**180**	**15**	**14**	**13**	**936**	**177**	**17**	**13**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

The principle discharge is KC154. The flow is chemically similar to the BH-M discharge, suggesting a common mine pool origin. KC154 is acidic with moderate concentrations of metals.

KC153, KC153A, and DH-1 combine to produce approximately the same acidity loading as KC154. The discharges have lower flows but more contaminated conditions. In general, the acidity concentrations are ~260 mg/L (compared to 160 mg/L for KC154), iron concentrations are 25 mg/L (compared to 10 mg/L) and Al concentrations are 20 mg/L (compared to 10 mg/L). The combined flows were calculated for 5 sample days. The combined flow is acidic with moderate concentrations of Fe and Al. The average Al concentration is 10 mg/L. Because this concentration can be reliably treated with passive techniques and there is suitable land available for construction of a system, only passive treatment is recommended.

Passive Treatment

Passive treatment with VFPs is the recommended approach to addressing the discharges in this group. An area suitable for construction of a treatment system is located below the KC154 discharge (Photo 26) where all of the discharges in this group could be commonly treated. KC154 should be collected and piped 1,500 feet to the treatment area. DH-1 should be collected and piped 900 feet to the treatment area. KC153 and KC153A should be collected and piped (800 feet and 400 feet, respectively) to the area.

The discharges should be combined in a flow control structure that will allow 120 gpm to flow to the vertical flow ponds and bypass higher flows to the settling pond. The 120 gpm design flow rate represents the 75^{th} percentile flow condition. The AMD should be directed into two parallel VFPs that are each about 20,000 ft^2 at the water level and contain approximately 2,650 tons of limestone and 550 CY of alkaline organic substrate. The discharges from the VFPs should flow into a common settling/mixing pond where they will mix with untreated bypass AMD. The pond should be sized to provide the 120 gpm flow with 48 hours of retention and will provide a high flow of 167 gpm (the maximum observed) with 35 hours of retention. A final 10,000 ft^2 polishing wetland is recommended after the settling/mixing pond to assure very low metal concentrations.

The proposed system should produce a fully treated final effluent under all flow conditions observed in this study. The highest combined flow measured during this study was 167 gpm. Assuming that 120 gpm of this flow is passively treated to 100 mg/L net alkalinity and that the 47 gpm bypass contains 180 mg/L acidity, then the calculated mixture would have a net alkalinity of 21 mg/L. This is a conservative calculation because during the highest flow event monitored, combined flows had about 20% less acidity and metal concentrations.

The estimated total cost for design and construction of the passive system is $385,000.

Table 24. Butler Hollow North Cost Estimate

Item	Quantity	Unit cost	Total cost
Clear and grub treatment area, acres	3.5	1,500	$ 5,250
collect DH-1, KC153, & KC153A	2,000	3	$ 6,000
pipe flows, ft	3,600	5	$ 18,000
flow splitter box	2,500	1	$ 2,500
VFP, limestone, ton	5,341	20	$ 106,811
VFP, alkaline substrate, CY	1,094	20	$ 21,877
VFP, excavation, CY	17,147	5	$ 85,734
pond, 48 hr design flow, ft2	11,551	1	$ 11,551
wetland polish, ft2	10,000	1	$ 10,000
Miscellaneous materials		10%	$ 26,772
E&S, Mob/Demob	1	5,000	$ 5,000
contingency		15%	$ 44,924
Design/engineer			$ 40,000
TOTAL			**$ 384,421**

The annual O&M of the system would be minor. Once the system's functionality was established, the O&M would involve inspections, sampling, and routine maintenance every two months. The flow control box will need to be inspected and cleaned of debris or metal deposits, and adjusted. It may be necessary to remove leaf litter and other blockage from influent and effluent channels. Monitoring would include four water samples (common VFP influent, each VFP effluent, final effluent), flow measurements at all stations, and measurement of water levels in the VFPs. The inspection and routine maintenance is expected to require four hours. Total cost, per event, is $260 or approximately $2,000 per year. The cost could be decreased if the O&M was combined with other treatment systems.

Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost of organic substrate replacement is estimated at about $20,000 per VFP. Major maintenance of this type should not be required for at least seven years.

I. Butler Hollow South

Butler Hollow is polluted by flows from a deep mine and surface mine complex on the south side of T-307, which provides easy access to the discharge locations (Map 10). The property was recently purchased by DCNR and added to Sproul State Forest. The site was reclaimed in 1991 by the same RAMP project that affected KC154 (Butler Hollow North). The project involved the regrading of mine spoils and the collection and piping of AMD flowing from the deep mine away from houses located directly north of the deep mine opening. The primary flow currently discharges from a pipe and flows over spoil to Butler Hollow (Photo 27). The point was labeled BH-M (Butler Hollow Mine). The flow is acidic with moderate metal concentrations and never stopped flowing in this study.

The collection system appears to have partially failed along the reclaimed highwall and water now upwells in a small basin and flows on the surface toward the existing houses. Recently the flow was ditched away from the houses. This flow was labeled BH-2. KC157 is a separate discharge that flows from reclaimed spoil southeast of BH-M and BH-2. The discharge is likely connected to a backfilled deep mine opening. The flow enters Butler Hollow about 1,500 feet downstream of the inflow of BH-M.

The discharges were sampled five times between April 2005 and July 2006 (Table 25). The sampling included a high flow period in April 2005 and low flow period in October 2005.

Table 25. Butler Hollow South Discharges Flow, Chemistry, and Loading Results

Point	Date	Flow (gpm)	pH	Concentrations (mg/L)					Loading (lb/day)		
				Acid	Fe	Mn	Al	SO4	Acid	Fe	Al
BH-M	04/07/05	150	3.4	100	17	12	9	869	180	30	16
BH-M	10/12/05	21	3.1	168	16	16	14	879	42	4	4
BH-M	01/05/06	50	3.3	124	12	10	11	764	74	7	7
BH-M	04/24/06	68	3.3	126	8	11	10	706	102	7	8
BH-M	07/06/06	60	3.3	120	8	12	14	899	86	6	10
BH-M	08/31/06	40									
BH-2	04/07/05	100	3.7	55	1	12	5	718	66	1	6
BH-2	10/12/05	0							0	0	0
BH-2	01/05/06	15	3.5	67	3	12	6	600	12	0	1
BH-2	04/24/06	13	4.0	35	1	5	3	244	5	0	1
BH-2	07/06/06	3	3.0	185	8	29	14	1779	7	0	1
KC157	10/17/05	2	3.4	73	3	11	6	481	2	0	0
KC157	01/05/06	23	3.7	44	1	6	5	281	12	0	1
KC157	04/24/06	12	3.4	107	4	16	8	746	15	1	1
KC157	07/06/06	5	3.5	42	1	5	2	226	2	0	0
Combined Average*		**104**		**113**	**9**	**12**	**10**	**727**	**121**	**11**	**11**

**Represents totals for flow and loadings; flow-weighted averages for chemistry*

The average Al concentration is 10 mg/L. Because this concentration can be feasibly treated with passive techniques and there is suitable land available for construction of a system, only passive treatment is recommended.

Passive Treatment

Passive treatment with VFPs is the recommended approach for the discharges in this area, which are moderately polluted AMD. The approach should include the collection and transfer of all the flows to the current BH-M discharge point. Between the BH-M discharge location and T-307 there are approximately 3.2 acres of spoil and undeveloped property that could be used for the passive system.

The passive system was designed based on a design maximum flow rate of 150 gpm. This is approximately equal to the 85^{th} percentile flow rate.

The BH-2 discharge zone should be excavated and the exposed discharge should be collected and piped 600 feet to BH-M. KC157 should be collected and piped 2,000 feet to BH-M. All three flows should be directed into a flow control box that limits the amount of flow to the passive system. The system should be designed so that it will treat all the flow through combination of direct treatment in VFPs and neutralization in a common settling/mixing pond. The flow control box should direct flow up to 150 gpm to two parallel VFPs. The VFPs will be each be about 14,500 ft^2 at the water level and contain 2,300 tons of limestone and 500 tons of alkaline organic substrate. The VFPs will discharge to a common settling/mixing pond sized to retain the design flow (150 gpm) for 48 hours. Flows exceeding 150 gpm should be diverted around the VFPs into the settling pond to mix with the treated water. The VFPs are expected to produce effluent with 80-100 mg/L net alkalinity. The bypass water is expected to contain 80-100 mg/L net acidity. The treated water will be able to neutralize up to about 150 gpm of bypass and provide full treatment for 300 gpm. The settling pond will retain water the 300 gpm flow for 24 hours.

The total footprint of the system is estimated to be about 2 acres. There are about 3 acres of land available below the BH-M discharge pipe. The system requires at least 10 feet of elevation difference to operate. The site has about 20 feet of elevation difference.

The collection of BH-2 will benefit local property owners because it currently flows on spoil behind houses and contributes to drainage problems during wet weather. If this project is phased, the collection of BH-2 should occur in an early phase so that the local landowner concerns are addressed.

The estimated costs for the treatment system are shown in Table 26. Total design and construction costs are estimated at $325,000.

Table 26. Butler Hollow South Cost Estimate

Item	Quantity	Unit cost	Total cost
Clear and grub, acres	1	1500	$ 1,500
collect BH2 and KC157	2	1,500	$ 3,000
pipe flows, ft	2600	5	$ 13,000
flow splitter box	1	2500	$ 2,500
VFP, limestone, ton	4,589	20	$ 91,773
VFP, alkaline substrate, CY	955	20	$ 19,096
VFP, excavation, CY	15,010	5	$ 75,049
Settling and mixing pond,ft2	14,439	1	$ 14,439
Miscellaneous materials		10%	$ 22,036
E&S, Mob/Demob	5000	1	$ 5,000
contingency		15%	$ 37,109
Design/engineer/permit			$ 40,000
TOTAL			$ 324,500

The annual O&M of the system would be minor. Once the system's functionality was established, the O&M would involve inspections, sampling, and routine maintenance every two months. The flow control box will need to be inspected and cleaned of debris or metal deposits, and adjusted. It may be necessary to remove leaf litter and other blockage from influent and effluent channels. Monitoring would include four water samples (common VFP influent, each VFP effluent, final effluent), flow measurements at all stations, and measurement of water levels in the VFPs. The inspection and routine maintenance is expected to require four hours. Total cost, per event, is $260 or approximately $2,000 per year. The cost could be decreased if the O&M was combined with other treatment systems.

Assuming no catastrophic event, the system's performance would eventually decrease as the viability and quantity of the reactive materials is consumed. This performance decline would be recognized by a gradual decrease in alkalinity production or an increase in the water level in the VFPs. Both of these problems would likely be traced to the organic substrate which could be rejuvenated with limestone addition or it could be replaced. The cost of organic substrate replacement is estimated at about $20,000 per VFP. Major maintenance of this type should not be required for at least seven years.

VII. Recommended Plan

A. Project Prioritization Methods

The study identified 26 AMD discharges that were organized into 8 groups based on proximity and likely remediation combinations. Prioritization of the groups was accomplished by considering a variety of factors. Table 27 is a matrix that shows the factors that were considered and the ratings each received. Each is discussed below.

- Acid Loading % Each group's proportional contribution to the total acidity loading measured in this study was calculated. On average, KC204 produced 49% of the acidity loading produced by the point source discharges.
- Tributary Impact The miles of tributary stream that are polluted by the discharge groups was measured on USGS maps. Several groups discharge directly to Kettle Creek and do not pollute a defined tributary.
- Fishery Potential The ability of tributary streams to support fisheries if the AMD pollution was removed was evaluated. All of the tributary streams are very steep and there is little physical habitat to support a fishery. Some fishery potential exits in the lower reaches of Butler Hollow.
- Kettle Creek Miles The amount of Kettle Creek potentially affected by the discharge group was determined by measuring the mileage between each discharge group's inflow and the Kettle Creek mouth.
- Kettle Creek Impact The impact of the AMD inflow on overall Kettle Creek water quality was assessed. None of the discharges cause substantially chemical degradation of the stream.
- Forestry Impact Most of the study area is in Sproul State Forest and the impact of the discharges on the forest is of interest. Several of the discharges on the Kettle Creek slope have created kill zones. The most extensive kill zone is below KC204A. Most of the flow from this discharge has moved to KC204 and the development of a large kill zone beneath it is likely.
- Visibility Most of the discharges are remote and the general public has no awareness of their existence. The metal staining produced in Kettle Creek by Slide Hollow is visible from Kettle Creek Road on the east side of the stream. Butler Hollow is in the most populated part of the study area and is visible from T-307.

A consideration not shown in the matrix table is the possibility of an event that could catastrophically affect Kettle Creek and the West Branch of the Susquehanna River. A large pool of highly contaminated AMD has developed behind the plugged KC204A mine drain. The failure of this plug could produce a surge of acidity that would overwhelm Kettle Creek's buffering capacity.

Table 27. Discharge Group Priority Matrix

Discharge Group	% Acid Loading[1]	Trib Impact (miles)[2]	Fishery Potential[3]	KC miles[4]	KC Impact (miles)[5]	Forestry Impact[6]	Visibility[7]
Hicks/Slide	<1	0.6	None	5.7	0	Low	Low
Slide Hollow	23	0.6	None	5.5	0	Moderate	Moderate
Slide/Short	7	0	None	4.9	0	Moderate	Low
Short Bend	4	1.6	None	3.2	0	Low	Low
KC204	49	0	None	3.0	0	High	Low
Duck	1	0.4	None	2.8	0	Low	Low
Butler North	9	1.0	Moderate	0.6	0	Low	Moderate
Butler South	7	1.0	Moderate	0.6	0	Low	Moderate

[1] percentage of the total measured acidity loading accounted for by this group
[2] miles of USGS blue-line tributary stream polluted
[3] potential for cold water fishery if water quality is restored
[4] miles of Kettle Creek below the inflow of the AMD
[5] miles of Kettle Creek polluted by discharge
[6] high: large kill zone; moderate: small kill zone; low: no kill zone
[7] high: readily apparent to large public audience; moderate: readily apparent to small public audience; low: remote location that is rarely visited

B. Recommended Projects

Based on these assessments shown in the matrix, the following observations are provided:

- The AMD produced on the west side of Kettle Creek causes localized degradation of Kettle Creek but it is not sufficient to acidify the entire flow. The Creek above and below the inflows of AMD is alkaline with pH 6.5-7.5. Remediation projects should not be implemented for the purpose of restoring lower Kettle Creek.
- Tributary streams in the study area have limited potential for restoration as fisheries. With the exception of Butler Hollow, remediation projects should not be implemented for the purpose of restoring fisheries to the tributaries.
- The discharges generate acidity and toxic metals that cause localized habitat degradation in Kettle Creek and consume alkalinity that may be important to the downstream restoration of the West Branch. Remediation to lessen localized impacts to Kettle Creek and lessen acidity loading to the West Branch should be considered.
- The existence of a large highly acidic mine pool behind the plugged KC204A drain is a precarious situation. The plug is a result of subsidence and could fail. The rapid release of the acidic mine pool could be devastating to lower Kettle Creek and would degrade the West Branch of the Susquehanna River.

The highest priority projects are listed below and summarized in Table 28.

1. **Relocate the KC204 and KC204A discharges to Milligan Run and install seals to help protect against blowout.** Phase I would create free drainage of AMD to the inclined plan and would implement a monitoring program to determine impacts on the KC204 and KC204A discharges. Phase II, the development of a grouting plan for the discharges would depend on the Phase I results.

2. **Construct the passive treatment systems for groups Butler Hollow North (See Section VI.H) and Butler Hollow South (Section VI.I).** Butler Hollow is the most visible western AMD flow into Kettle Creek. It is likely that the treatment of the identified flows will result in restoration and the opportunity to reestablish a fishery in lower Butler Hollow. The Butler Hollow AMD discharges have moderate chemistry and passive treatment can be installed that should be reliable and require modest O&M for 7-10 years before more involved work may be necessary.

Table 28. Summary of High Priority Projects

Project	**Cost Estimate**	**See Section**	**Notes**
KC204 Relocation, Phase I	$90,000		
Butler Hollow North Passive Treatment	$384,421		$2000 annual O&M
Butler Hollow South Passive Treatment	$324,500		$2000 annual O&M

Other projects developed in this plan are considered a low priority.

C. Monitoring Recommendations

As each project is completed, monitoring should be conducted in order to assess project effectiveness. Specific stations for monitoring are discussed in the project sections. However, on-going monitoring should be performed regardless of project development.

KC204 and KC204A should be visited on a quarterly basis to assess flow rate and chemistry. Once the KC204 relocation project begins, more intense monitoring of these and other stations, as well as the mine pool, will be required. In addition, a monitoring station should be established at the mouth of Butler Hollow. This station should be sampled for chemistry on a quarterly basis. The resulting data will form a baseline that can be used to assess the effectiveness of the Butler Hollow North and South projects after they are completed.

VIII. References

All References are listed chronologically

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