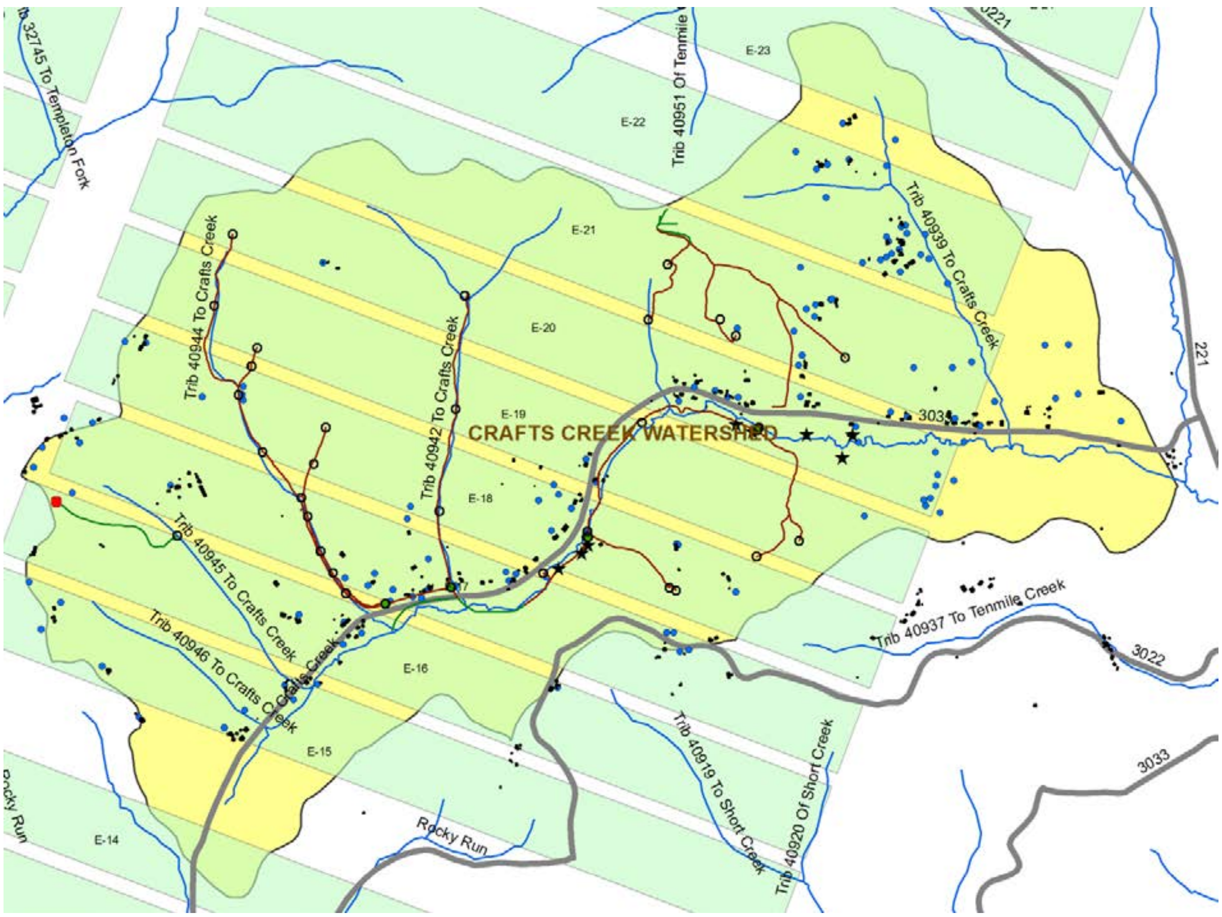
The Effects of Subsidence Resulting from Underground Bituminous Coal Mining, 2008-2013

Bituminous Mine Subsidence and Land Conservation Act
Act 54 Amendments
4th Five-Year Report



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Pennsylvania Department of Environmental Protection

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Research was conducted by the University of Pittsburgh for the Pennsylvania Department of Environmental Protection

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August 30, 2014

Dear Mr. Shuler,

This letter accompanies the University's 4th Act 54 assessment period report entitled "The Effects of Subsidence Resulting from Underground Bituminous Coal Mining, 2008 to 2013". This report is the culmination of work by 24 researchers at the University of Pittsburgh over a two-year period. We believe it to be the most comprehensive Act 54 assessment to date.

Thank you for the opportunity to work with you in providing this information to the citizens of the Commonwealth of Pennsylvania.

Sincerely,

Stephen J. Tonsor	Alison N. Hale	Daniel J. Bain	Anthony T. Iannacchione
Associate Professor	Postdoctoral researcher	Assistant Professor	Associate Professor

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ACRONYMS AND ABBREVIATIONS

Units of measurement

%	percent
cfs	cubic feet per second
ft	feet
ft^3	cubic feet
GB	gigabytes
gpm	gallons per minute
in	inches
lbs	pounds
m	meters
MA	million years ago
mi	miles

General

Act 54	1994 amendments to BMSLCA
Act54GIS	University of Pittsburgh's Act 54 geographic information system
ArcGIS	geographic information systems software produced by ESRI
AutoCAD	design software produced by Autodesk
BMSLCA	Bituminous Mine Subsidence and Land Conservation Act
BUMIS	Bituminous Underground Mining Information System
CAD	computer-aided design
CDMO	California District Mining Office
DEM	digital elevation model
EIA	United States Energy Information Administration
EHB	Environmental Hearing Board
EPA	United States Environmental Protection Agency
ERRI	Environmental Resources Research Institute
GIS	geographic information system
GPS	global positioning system
MrSID	multi-resolution seamless image database
MSI	Mine Subsidence Insurance
NAD 1983	North American Datum of 1983
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
PADEP	Pennsylvania Department of Environmental Protection
PAGWIS	Pennsylvania Groundwater Information System
PASDA	Pennsylvania Spatial Data Access
PennDOT	Pennsylvania Department of Transportation
PSU	Penn State University
RMSE	root mean squared error
RPZ	rebuttable presumption zone
SE	standard error
SMCRA	Surface Mining Control and Reclamation Act of 1977
SSA	Surface Subsidence Agent

TIF	tagged-image format
USGS	United State Geological Survey
UTM	Universal Transverse Mercator coordinate system

Hydrology

HMR	Hydrologic Monitoring Report
NWIS	National Water Information System
TGD 563-2000-655	Technical Guidance Document 563-2000-655, "Surface Water Protection – Underground Bituminous Coal Mining Operations"

Streams

ANOVA	Analysis of variance
EPT	Ephemeroptera, Plecoptera, and Trichoptera taxa
FRAGSTATS	spatial pattern analysis software by the University of Massachusetts
MBII	Macroinvertebrate Biotic Integrity Index
NMDS	Non-metric multi-dimensional scaling
PLS regression	Partial least squares regression
SAS	Statistical Analysis System software produced by SAS Institute
TBS	Total Biological Score
TGD 391-0300-002	Technical Guidance Document 391-0300-002, "Water Quality Antidegradation Implementation Guidance"
TGD 563-2000-655	Technical Guidance Document 563-2000-655, "Surface Water Protection – Underground Bituminous Coal Mining Operations"
UNT	unnamed tributary
WRDS	Water Resources Data System

Wetlands

NWI	National Wetlands Inventory
PEM	Palustrine emergent wetlands
PEM1	Palustrine emergent wetlands that are dominated by vegetation that remains standing until the following growing season
PEM1B	Palustrine emergent wetlands that are dominated by vegetation that remains standing until the following growing season and that are characterized by a saturated water regime
PFO	Palustrine forested wetlands
PFO1	Palustrine forested wetlands that are dominated by broad-leaved deciduous vegetation
POW	Palustrine open water wetland
PSS	Palustrine scrub/shrub wetlands
PUBHh	Palustrine unconsolidated bottom wetlands that are permanently flooded due to a dike or impoundment
TGD 363-0300-001	Technical Guidance Document 363-0300-001, "Design Criteria – Wetland Replacement and Monitoring"

ACKNOWLEDGEMENTS

The University would like to thank many individuals and groups for their assistance with various aspects of this project. First, the University thanks the employees of PADEP for their support of this project. In particular, thanks go to:

PADEP Bureau of Mining Programs

- Greg Shuler, Geologist, for his tireless efforts in administering the Act 54 contract, assistance in data collection, and for compiling PADEP's technical review of this report
- Tom Callaghan, Director of the Bureau of Mining Programs, and Keith Brady, Mineral Resource Program Manager (retired), for their oversight and review of this report

PADEP California District Mining Office

- William Plassio, the District Mining Manager during the University's data collection phase, for permitting staff to assist the University in data collection
- Greg Prentice, Compliance Manager, Richard Kormanik, Surface Subsidence Agent Supervisor, and Matt Cavanaugh, Mining Resource Program Specialist, for their help in collecting, interpreting, and reviewing data in the office files
- Surface Subsidence Agents Benjamin Dillie, Anne Hong, Joseph Laslo, and Dan Miles (retired) for arranging field trips for the University to observe impacted and restored features and for sharing their first-hand knowledge of the compliance process.
- Water Pollution Biologists Joel Folman and Stephen Leitkam for training and assessing University personnel in stream sampling techniques
- Greg Ohler, Clerk, for pulling files for the University and assisting with data collection

PADEP Bureau of Point and Nonpoint Source Management

- Dan Bogar, Water Pollution Biologist II (retired), for verification of the University's macroinvertebrate identification

For several mines, the University directly requested digital data from the mine companies. The companies generously supplied AutoCAD or ArcGIS files containing data that had accompanied mine permits to PADEP. The data included precise mining extents and the spatial locations of undermined structures and water supplies. The University thanks the following companies for supplying digital data:

- Consol Energy, Inc.
- Alpha Natural Resources, Inc.
- Mepco Intermediate Holdings, LLC
- Rosebud Mining Co.

From Consol Energy, Inc, the University specifically thanks Joshua Silvis, Manager of Hydrogeology, and Brian Benson, Supervisor of Stream Mitigation, for providing a field trip for the University and students to examine stream impacts and associated mitigation efforts.

Thanks also go to individuals at various organizations around the Pittsburgh area. The University thanks Dr. Timothy Pearce at the Carnegie Museum of Natural History for assistance in identifying mollusk macroinvertebrates. The University thanks Christopher Tracey at Western Pennsylvania Conservancy for sharing his advice and thoughts regarding the effects of land use on stream biota. The University also thanks Jared Pritts, Senior Regulatory Specialist with the U.S. Army Corps of Engineers, Pittsburgh District, for providing information on wetland replacement guidelines.

Lastly, the University thanks a number of people and groups at the University of Pittsburgh whose support was critical to the completion of this project:

- Dr. Paula Grabowski, Chair of the Department of Biological Sciences, Dr.'s Mark Abbott and William Harbert, Chairs of the Department of Geology and Planetary Sciences during preparation of this report, and Dr. Radisav Vidic, Chair of the Department of Civil and Environmental Engineering, for their support of this project
- Lorrie Robbins, Director of the Department of Biological Sciences Central Administration, for her assistance with contractual and budgetary processes
- The Mascaro Center for Sustainable Innovation for support to Robert Wallace (Bevier Scholar) and Angela Anderson (Heinz Endowment Scholar)
- The Department of Biological Sciences for support to Grace Noble (Graduating Senior Fellow) and Kaitlin Piper (HHMI fellow)

EXECUTIVE SUMMARY

Section 18.1 of the Bituminous Mine Subsidence and Land Conservation Act requires PADEP to compile, on an ongoing basis, information from mine permit applications, monitoring reports, and enforcement actions relating to surface impacts of underground bituminous coal mining. It also requires PADEP to report its findings regarding these effects to the Governor, General Assembly and Citizens Advisory Council at five-year intervals. This is the 4th such report and the second completed by a team from the University of Pittsburgh. The team brings together expertise in mine engineering, hydrogeology, and ecology.

Specifically, the University was tasked with:

- Providing a detailed analysis of the effects of underground mining on surface features during the 4th assessment period (21 August 2008 to 20 August 2013).
- Providing data-based recommendations to PADEP on the process by which information concerning the effects of underground mining is obtained and managed.

During the 4th assessment period, 31,234 acres of Pennsylvania land were undermined. This represents an 18% decline in the amount of land undermined from the 3rd Act 54 assessment, reflecting both a reduced demand for coal and the extension of the large Bailey Mine into parts of West Virginia. A total of 46 underground mines were in operation during the 4th assessment. Seven mines utilized longwall mining methods, five mines conducted pillar recovery, and the remaining 34 mines used strictly room-and-pillar mining.

The Bituminous Underground Mining Information System (BUMIS) is used by PADEP to track impacts of these mining operations on surface structures and water supplies. Unfortunately, the University's ability to readily interpret information from this database was significantly hampered by the frequent lack of unique feature identifiers and location information in BUMIS. A total of 389 reported effects on structures were recorded in BUMIS during the 4th assessment period. PADEP determined that the mine operators were liable for 61% of the reported structure effects. For water supplies, BUMIS recorded 855 reported effects on wells, springs, and ponds. The mine operator was found liable for 57% of all reported effects with a final resolution. Interestingly, 25% of these company-liable impacts occurred outside of the PADEP's Rebuttable Presumption Zone. Mine operators utilized private agreements with landowners to settle 70% of the company-liable impacts. The average time to resolution for both structure and water supply reported effects was less than one year (169 and 220 days, respectively). However, when the mine operator was found liable for water supply impacts, the time to resolution exceeded one year (415 days).

For streams, the implementation of a PADEP technical guidance document has greatly improved the ability to quantify and interpret underground mining impacts on surface waters since the 3rd assessment period. In the 4th assessment period, 96 miles of stream were undermined. Of these stream miles, 39 miles belong to streams that experienced mining-induced flow loss or pooling somewhere along their channel. The limited biology data that was available to the University indicates that both mining-induced-flow loss and pooling constitute adverse effects to the macroinvertebrate community. For streams experiencing flow loss, certain mayfly taxa appear to be especially hard hit. Declines in water quality, including increases in conductivity and pH, also accompany mining-induced flow loss impacts. On a positive note, TBS increased over time at sites impacted by flow loss in the 4th assessment period, albeit slowly. Also, gate cut mitigation appears to be successful in restoring pooled streams to their pre-mining condition.

Because BUMIS was not designed to track the complexity of stream impacts, PADEP has struggled to develop a system for recording stream data. During the 3rd assessment period, PADEP utilized stream investigations to track the status and final resolution of all stream impacts. Following implementation of PADEP technical guidance, PADEP changed its tracking system. However, this change has resulted in scattered record keeping that requires hunting for multiple data sources in the hands of individual PADEP staff. These records lack standardization and are sometimes in narrative form without organized data reporting.

Following up on streams that were impacted during the 3rd Act 54 assessment, 51 of the 55 stream investigations from that period have been resolved. For eight of the resolved investigations (involving seven streams), the final resolution by PADEP indicates that the streams have not recovered from the mining-induced impacts. For these and other resolved cases, the University noted a lack of standardization and general inadequacy in flow data used to assess stream recovery.

Wetlands acreage actually showed a slight net increase following undermining at three longwall mines. However, the increases result from a substantial loss of original wetland acreage and creation of new wetland acreage. The original and new wetland acreage often differ functionally and thus the newly emerging and created wetlands do not entirely replace lost wetland functions. For the one mine that exhibited a net decrease in wetland acreage, two wetland mitigation projects have been proposed. However, the proposed projects do not fully replace the function of the lost wetland acreage.

Although the focus of mitigation efforts and citizen concerns is at the ground's surface, the persistent problems with some undermined water supplies, streams, and wetlands appear to be impacted by changes in groundwater flows, driven by fracturing of overburden layers and changes in movement and depth of near-surface waters. This report is the first to consider this issue. Groundwater evaluation relied predominantly on the hydrologic monitoring reports (HMRs) submitted to PADEP, reports on over 750 unique locations, with over 31,000 sampling events reported during the 4th assessment period. This is a rich data set, however it was not necessarily designed to characterize ground water impacts on comprehensive, regional scales. In order to understand how undermining impacts groundwater systems, monitoring and analysis will have to continue to evolve and improve. Such a continued improvement will allow more sophisticated and successful prevention and mitigation of impacts to citizens and to the Commonwealth. The University provides recommendations that if followed will enhance the ability to address important questions regarding the role of groundwater in subsidence-related surface and near-surface effects in the next report.

Since the submission of the 3rd Act 54 report, PADEP has increased its requirements for the submission of a wide variety of data from the mine operators in connection with the permitting and regulation of mining activities. Unfortunately, PADEP struggles with a number of problems associated with what has come to be known as "big data". The use of large amounts of data of diverse kinds requires a modern information system with explicit and enforced standards for data acquisition, submission and management; such an information system and the accompanying data standards and management practices are missing or not enforced. The University found that, while PADEP has enhanced information gathering in a number of areas, it has lost ground since the 3rd Act 54 assessment period in the organization and accessibility of some areas of data necessary for assessing the effects of underground bituminous coal mining in Pennsylvania.

As underground mining continues in the Commonwealth, best practices for managing big data should be utilized to ensure that the land areas above underground mining are managed well. Practices such as data standardization, written protocols, standard electronic data forms and electronic submission, and especially rapid error and standards checking following data submission, can cascade through processes at PADEP and enhance the ability of PADEP to efficiently and effectively serve the Commonwealth.

SECTION I: Introduction

I.A – Overview

This section provides a description of the need for this study and a list of its aims and objectives. It also contains background explanations of certain topics that are relevant to the report and that provide context for subsequent sections.

I.A.1 – Need for this Study

Section 18.1 of the Bituminous Mine Subsidence and Land Conservation Act (BMSLCA) requires the Pennsylvania Department of Environmental Protection (PADEP) to compile, on an ongoing basis, information from mine permit applications, monitoring reports, and enforcement actions. It also requires PADEP to report its findings regarding the effects of underground mining on overlying land, structures, and water resources to the Governor, General Assembly and Citizens Advisory Council at five year intervals.

The Act further stipulates that PADEP is to engage the services of recognized professionals or institutions for purposes of assessing the effects of underground mining and preparing these reports. PADEP initiated a contract with the University of Pittsburgh (hereafter: The University) on 1 September 2012 to fulfill the assessment and reporting requirements for the period from 21 August 2008 to 20 August 2013 (hereafter: 4th assessment period).

I.A.2 – Underground Bituminous Coal Mining's Historical Role in Pennsylvania

Pennsylvania's coal production began with the capture of the sun's energy by ancient plants and the subsequent deposition of layers of undecayed or partially decayed plant matter approximately 300 million years ago. Over the millennia, these layers of plant matter were subjected to low oxygen availability and high pressure and temperature as additional layers of sediment were deposited above the plant layers. The result is the sedimentary (bituminous) or metamorphic (anthracite) rock layers known as coal, which consists mainly of carbon, though it can contain substantial amounts of other elements including hydrogen, sulfur, oxygen and nitrogen. The energy of the sun, stored in the chemical bonds among the materials making coal, represents a substantial treasure that can fuel economic development and prosperity. Coal is the major source of electricity generation worldwide, accounting for 41% of electrical energy production (International Energy Agency 2013). Electricity use scales closely with general metrics of human well-being, measured either by economists as gross domestic productivity or by United Nations as the Human Development Index (Pasternak 2000).

In the Commonwealth of Pennsylvania, the extraction of bituminous coal has a 200 year history and has played a significant role in the state's economic development for over 125 years. Today, coal extraction remains an important industry. In 2012, the U.S. Energy Information Administration reported that Pennsylvania's bituminous underground coal mines directly employed 5,992 workers (U.S. Energy Information Administration 2013a) and produced 44,922,000 tons (short tons) of coal (U.S. Energy Information Administration 2013b), the fourth-largest volume of coal production among the 50 states.

From a national perspective, Pennsylvania's mines represent (U.S. Energy Information Administration 2013b):

- 9.6% of the total number of underground coal mines,
- 10.7% of the total production from underground coal mines,
- 10.6% of the total employment for underground coal mines

While much coal has been mined, there remain approximately 423 million tons of recoverable reserves of bituminous coal in Pennsylvania (U.S. Energy Information Administration 2013c). The coal industry in Pennsylvania directly and indirectly employs approximately 41,577 workers, generates $3.2 billion in economic output and provides tax revenues of approximately $750 million (Pennsylvania Coal Alliance 2012). These data demonstrate the prominent role coal plays in the lives of Commonwealth citizens.

I.A.3 – Environmental Consequences of Mining

The extraction and use of coal in driving the local economy and fueling global development nevertheless has costs. At the global scale, coal contributes disproportionately to global warming relative to other energy sources. Coal has relatively low carbon-use efficiency for the generation of power: In the U.S., coal combustion supplies 39% of total electricity generation but contributes to 75% of the carbon dioxide emissions from the electricity sector (U.S. Environmental Protection Agency 2014). On a local scale, the abundance of coal-related jobs also comes at a cost to both the natural and built environment. Extraction of coal can impact stream ecological health, water and sewer supply systems, roadways and built structures. It is our difficult task as citizens of the Commonwealth to elect lawmakers that will determine the mix of laws and policies that provide energy, jobs, and economic well-being while taking into account the need to maintain healthy lives and a healthy environment for our children and the generations to come. The increasing ability to measure and understand economics, engineering, geology, atmospheric and ecosystem science results from the Industrial Revolution, which has been largely driven by the energy derived from coal. This increased knowledge has resulted in recognition that extraction and use of energy can be accomplished with more sustainable and less harmful techniques. At both state and federal levels, laws and regulations have been adopted and refined toward that end. Today, society demands that the coal mining industry extract this mineral in an environmentally acceptable manner. The outcome of those demands, both in the activities of PADEP as the key regulatory agency concerned with underground mining, and the responses of mine operators, are the subject of this report.

I.B – Environmental Laws and Coal Mining

In the 1940s the Commonwealth began to legislatively recognize the necessity of environmental stewardship to prevent permanent and widespread destruction of its land and water. The Clean Streams Law was amended in 1945 to include acid mine drainage as a pollution source that required regulation. In that same year, the Commonwealth passed the Surface Mining Conservation and Reclamation Act (Act 418), representing its first comprehensive attempt to prevent pollution from surface coal mining. From this point forward, the Commonwealth passed a number of laws that directly addressed environmental issues associated with the deep mining of bituminous coal beds.

I.B.1 – Bituminous Mine Subsidence and Land Conservation Act of 1966 (BMSLCA)

The most significant of these laws was the BMSLCA of 1966. For the first time, certain structures built before April 1966 had to be protected from subsidence regardless of coal ownership rights beneath the structure. This law suggested that coal extraction ratios of less than 50% be used to protect surface properties, but also indicated that specific guidelines could be set by the state.

Gray and Meyers (1970) suggested that the area required underground to minimize subsidence damage on the surface was dependent on the selection of an adequate angle of support (Figure I-1). The angle of support was most dependent on the geologic character of the rocks and, in their report, varied from 15 to 25-degrees. The net result required the support base at the mining level to increase between 53 to 93-ft along its horizontal axis with every 100-ft of overburden. The outcome was a support area for 500-ft of overburden that was equivalent to 3.4 times the support area required at 100-ft of overburden. This method remains the basic support area design for structures requiring damage prevention.

The BMSLCA also established various requirements such as permitting, mapping, protection of certain structures from subsidence damage, repair of subsidence damage to certain structures, and the right of surface owners to purchase support for their structures. Section 4 prohibited subsidence damage to certain structures, homes, public buildings, noncommercial structures, and cemeteries in place on 27 April 1966. Section 6 required operators of underground mines to 1) repair damage within six months and 2) secure a surety bond to cover possible future property damage. Section 15 provided certain owners the right to purchase the coal located beneath their property. This law did not contain any provisions addressing water supplies.

I.B.2 – 1980 amendments to BMSLCA

The BMSLCA was first amended in 1980 to help bring it into compliance with the minimum requirements of the recently passed federal Surface Mining Control and Reclamation Act of 1977 (SMCRA). Section 4, which provided protection to certain structures, was amended to allow the current owner of the structure to consent to subsidence damage, but the damage had to be repaired or the owner compensated. Section 5 was amended to require an operator of an underground mine to adopt measures to prevent subsidence causing material damage to the extent technologically and economically feasible, as well as to maximize mine stability and to maintain the value and reasonably foreseeable use of the surface. These measures were to be described in the permit application. The new language also specifically provided that the new subsection was not to be construed to prohibit planned subsidence or standard room-and-pillar mining.

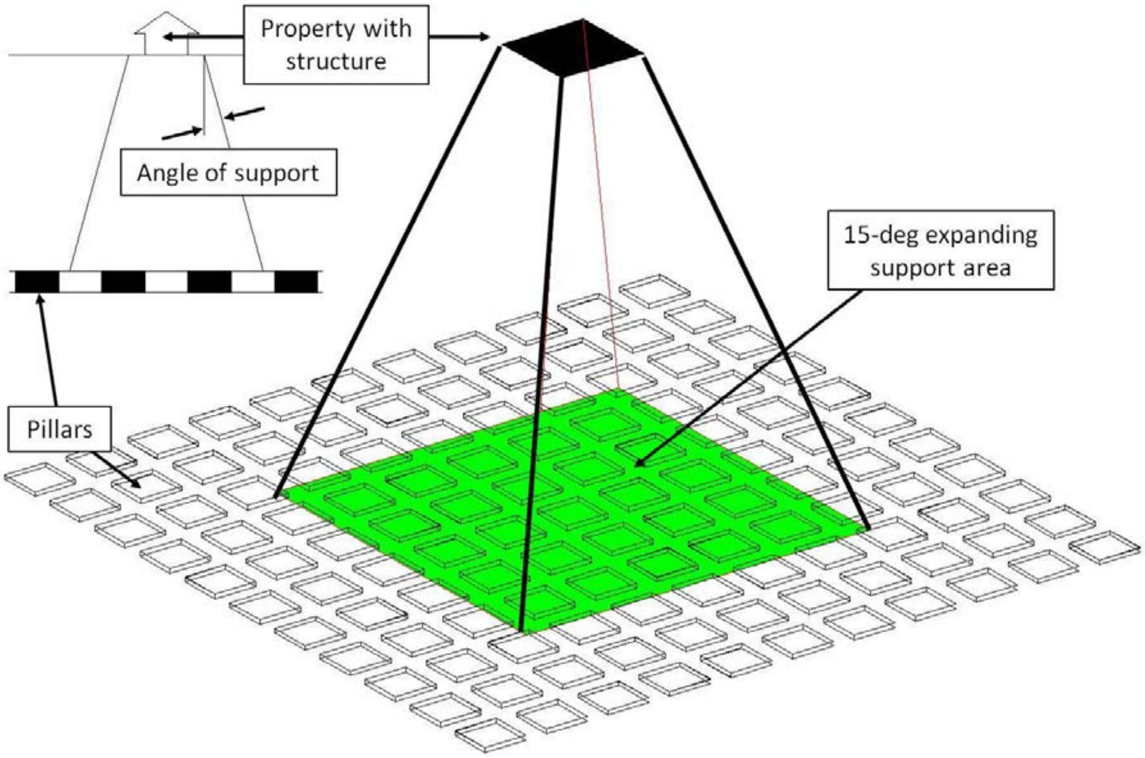

Figure I-1. An interpretation of pillar support required by the BMSLCA (1966) to protect structures from subsidence damage (from Iannacchione et al. 2011).

I.B.3 – Act 54 Amendments

By the mid-1980's, new environmental concerns were being raised about the BMSLCA. In 1986, Arthur Davis, a Professor at the Pennsylvania State University, organized the Deep Mine Mediation Project to bring together the underground bituminous coal industry, agricultural, and non-governmental organizations for the purpose of attaining a consensus position on the BMSLCA.

Ultimately, the state legislature prepared a number of statutory amendments to BMSLCA in 1992. The governor signed the legislation on 22 June 1994 and it became effective on 21 August 1994. This legislation is commonly referred to as Act 54. For the first time the law extended the obligation of coal companies to pay for damage caused to homes and businesses, regardless of when they were constructed. The Act 54 amendments also provided for the replacement of impaired water supplies and provided additional remedies for structural damage:

<u>BMSLCA – revised water supply replacement provisions</u>

- Established a rebuttable presumption zone (RPZ). The RPZ consists of an area above the mine that is determined by projecting a 35-degree line (from vertical) from the edge of mining to the surface. Within this zone, the mine operator is assumed liable for any contamination, diminution or interruption to water supplies.
- Entitled landowners with affected water supplies in the RPZ to a temporary water supply and restoration or replacement of a permanent supply by the mine operator.

- Entitled landowners with affected water supplies outside of the RPZ to permanent water supply restoration or replacement. However, if the operator contests liability in this zone, the burden of proof falls to the landowner or PADEP.
- Established that the RPZ does not apply if a landowner does not allow pre-mining surveys by the mine operator.
- Allowed for voluntary agreements between landowners and mine operators that stipulate the manner in which the water supply is to be restored or an alternate supply provided or that provide fair compensation for the impacts.

BMSLCA – revised structural damage repair provisions

- Mine operators were required to repair or compensate for subsidence damage to any building accessible to the public, non-commercial buildings customarily used by the public, dwellings used for human habitation, permanently affixed appurtenant structures and improvements, and certain agricultural structures.
- Entitled the structure owner or occupant to payments for temporary relocation and other incidental costs.
- Allowed the mine operator to conduct a pre-mining survey of the structure prior to the beginning of mining.
- Voluntary agreements were authorized between mining operators and landowners.
- Allowed underground mining beneath any structure, except a certain limited class of structures and features, as long as the consequential damages are not irreparable and are repaired.
- Stipulated that irreparable damage can only occur with the consent of the owner.

Act 54 imposed certain restrictions and responsibilities on mine operators and on PADEP. Coal operators were responsible for the restoration and/or replacement of a range of features located above, and adjacent to, active underground coal mines. It made PADEP responsible for ensuring the regulations and official mining permits were followed. PADEP was designated to conduct field investigations, examine and approve permits, and report to the general public and industry representatives with their findings.

I.B.4 –Act 54 Reporting Requirements

Act 54 contained a special provision requiring PADEP to produce an assessment of the surface impacts of underground bituminous coal mining every five years. To date three reports have been issued:

- 1st assessment: Submitted by the PADEP in 1999 (PADEP 1999; later amended, PADEP 2001). Covered the period 21 August 1993 to 20 August 1998.
- 2nd assessment: Submitted by California University of Pennsylvania in 2005 (Conte and Moses 2005). Covered the period 21 August 1998 to 20 August 2003.
- 3rd assessment: Submitted by the University of Pittsburgh in 2011 (Iannacchione et al. 2011). Covered the period 21 August 2003 to 20 August 2008.

The University of Pittsburgh was contracted by PADEP again in 2012 to conduct the 4th assessment.

Each report has generated productive discussions between the citizens of the Commonwealth and PADEP regarding desired enhancements to the content of the reports. This in turn has led to modifications of PADEP's reporting requirements associated with mining permits. The University's contract for production of the 4th report (Appendix A) also reflects those discussions. In particular, while mining companies are generally either able to repair, replace, or financially compensate for damages to structures, the ability to repair damage to streams remains largely unknown, as documented in the 3rd assessment. PADEP is therefore seeking a greater scientific understanding of the integrated hydrologic systems that link groundwater and surface water properties. The long-term goal is to better understand the effects of subsidence on the hydrology of undermined areas and thereby improve PADEP's ability to predict sustained damage to streams. To that end, PADEP requested that the University include an analysis of the hydrological impacts of subsidence. In addition, PADEP's task list associated with the contract reflects increased emphasis on comparisons of pre- and post-mining data for streams, both in terms of flow and macroinvertebrate community structure. Prior assessments struggled to make objective determinations of the extent of perturbation and recovery from mining-induced subsidence, highlighting the necessity for the pre-mining data. Also, due to the continuing concern about the length of time necessary for recovery of streams undermined in previous assessment periods, PADEP requested that the University re-visit specific streams from the last assessment that exhibit persistent flow loss problems. Finally, concerns were raised regarding the effects of underground mining on wetlands in response to the previous Act 54 reports. PADEP requested that the University assess pre- and post-mining data on wetland size and type to address these concerns.

I.C – Underground Bituminous Coal Mining Methods in Use in Pennsylvania

The three general methods to extract underground bituminous coal are described below.

I.C.1 – Room-and-Pillar Mining Method

All underground mines use the room-and-pillar mining methods in a similar fashion. Rooms or entries are typically driven 16 to 20-ft wide with continuous mining machines. These rooms outline pillars that are designed to support the overburden weight above the mine and prevent failure of the overlying strata. As long as the pillars are sufficiently sized to support the overburden and the floor rock is strong enough to prevent the pillars from punching or pushing into the bottom, subsidence should not occur with this mining method. Heights of mining range from 3 to 7-ft with some localized areas extending above and below these values. In general, the room-and-pillar mining method relies on two primary components – the main entries and the panels (Figure I-2). Main entries serve as long-standing points of access and egress from the underground and provide the primary means of supplying the underground workings with air, materials and transportation of coal from the working faces. The panels are less permanent and extract the coal in ways that comply with federal and state mining standards and regulations. A production panel begins from the main entries, extending in a series of parallel faces several hundred to several thousand feet into un-mined blocks of coal.

I.C.2 – Pillar Recovery Mining Method

Room-and-pillar mines can use pillar recovery to more fully extract the coal in select production panels (Figure I-2). The areas of pillar recovery mining are of variable shapes and sizes. Figure I-3 shows an example of a partially mined pillar. During pillar recovery, the majority of the pillar is removed, causing the roof strata to collapse into the void created by mining. While commonly employed in past mining operations, this method has seen infrequent use in recent years. When employed, pillar recovery occurs over a relatively small area. Impacts associated with the localized development of a subsidence basin do occur but represent a small fraction of the impacts recorded in PADEP's files (Appendix B).

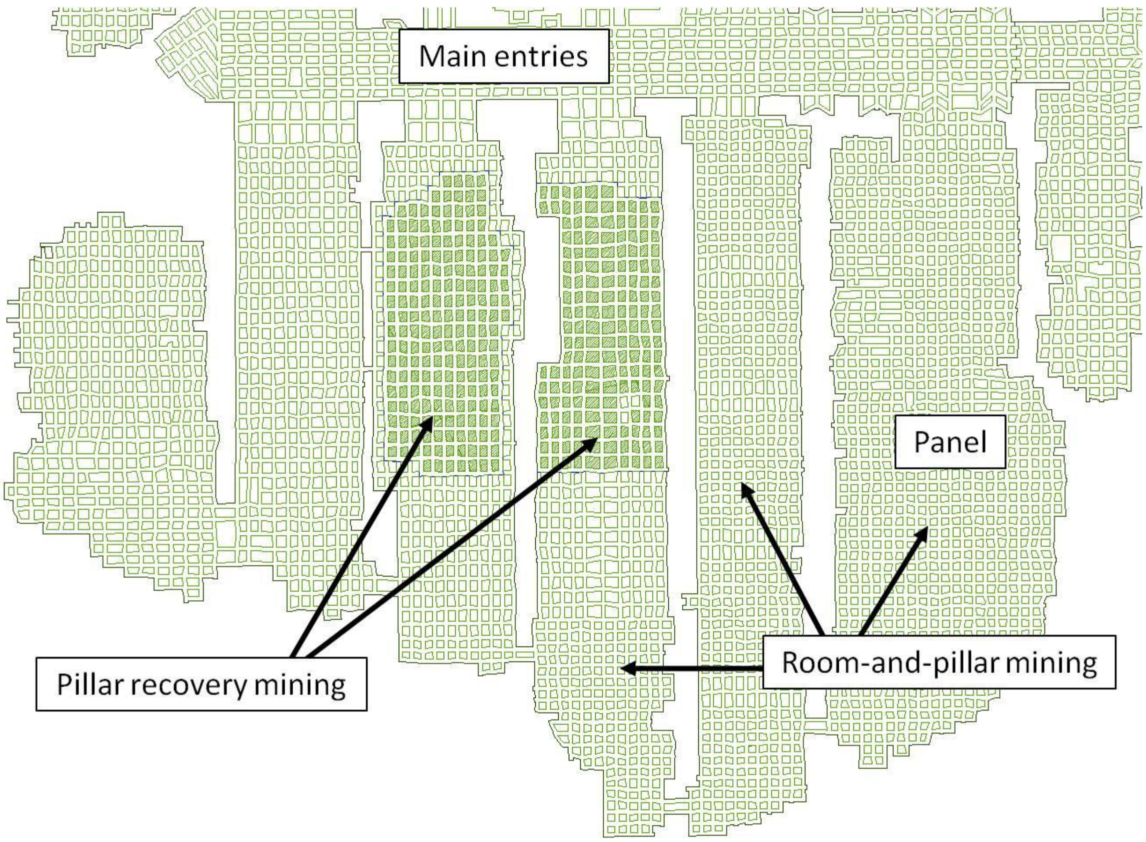

Figure I-2. Example of a room-and-pillar mine where main entries provide long-term access to production panels (from Iannacchione et al. 2011).Green shaded pillars indicate areas where pillar recovery occurred.

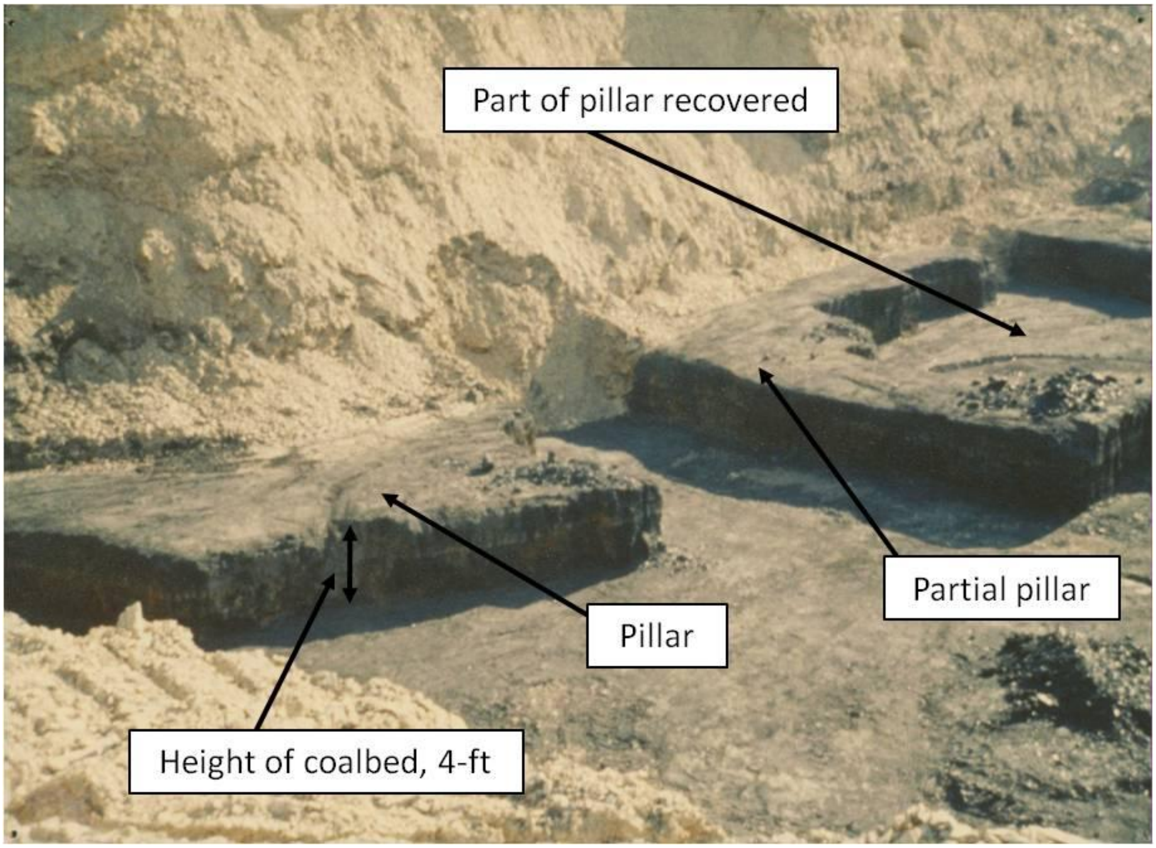

Figure I-3. In this photograph an abandoned mine was uncovered by surface mining revealing a partially mined pillar (from Iannacchione et al. 2011).

I.C.3 – Longwall Mining Method

In the longwall method a high-powered double drum shearer mines the face of the longwall panel. The shearer cuts, on average, 36-in of coal from its short dimension (the width) known as the longwall face (Figure I-4). Longwall operations use room-and-pillar mining methods to develop the main entries and the gate road entries that outline the rectangular panels. At some of the larger longwall mines, one pass of the shearer along a 1,200 to 1,500-ft long face supplies enough coal to fill a unit train. It can take several thousand cuts or slices along the longwall face to completely mine a panel. When a cut is taken, the longwall shield supports move behind the advancing face and allow the strata above the previous position to fall into the void. The entire void area is called the "gob". These longwall gobs are the primary mechanism for subsidence and are a central focus of this study. Six mines employed the longwall method during the 4th assessment period.

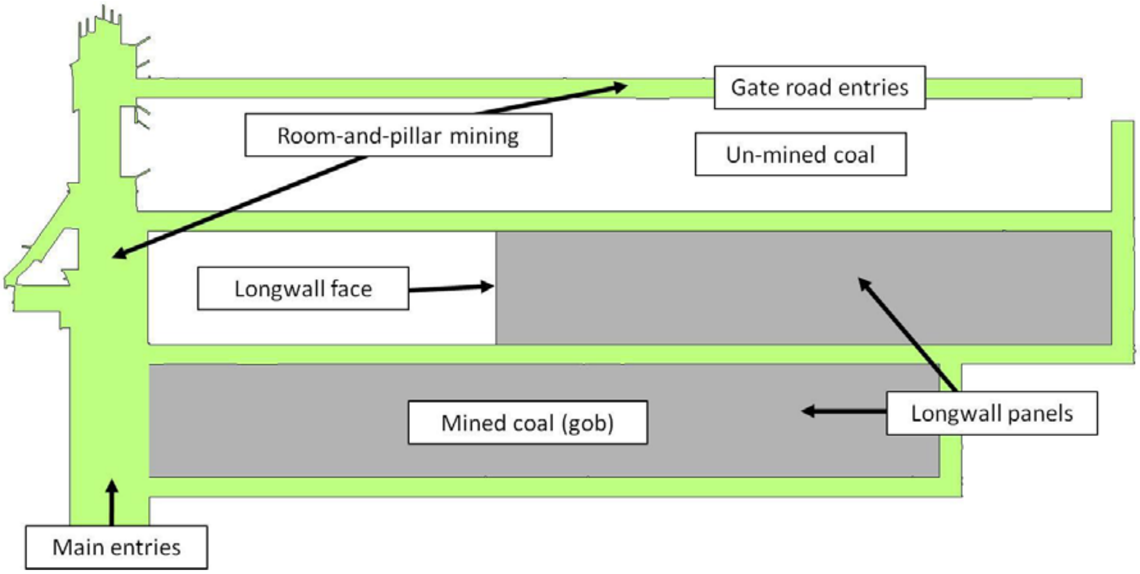

Figure I-4. Example of longwall mining method where longwall panels are developed off main entries and accessed by gate road entries both developed via room-and-pillar mining methods (from Iannacchione et al. 2011).

I.D – Geological Effects of Underground Bituminous Coal Mining

I.D.1 – Geological Effects of Room-and-Pillar Mining

Whenever coal is mined by the underground room-and-pillar mining method, an opening in the rock is created. Groundwater moving through overlying strata can find its way into these openings. Also, under-designed pillars can punch into a softer floor rock and potentially produce subsidence on the surface.

I.D.2 – Geological Effects of Pillar Recovery and Longwall Mining

Both pillar recovery and longwall mining allow the overlying strata to collapse into the mine void, resulting in the formation of a subsidence basin (Figure I-5; Peng 2006). The subsidence immediately above the caved, un-stratified rock layers, creates a zone of extensive fracturing, as much as 20 times the extraction zone height in thickness. In the Pittsburgh Coalbed, where all of Pennsylvania's longwall mining currently occurs, the zone of extensive fracturing can extend over 100-ft above mining. Less extensive, but more persistent fractures can extend over much greater distances and even intercept the surface. Above this zone, the stratum gently bends into the subsidence basin. This bending promotes separations along bedding as the strata moves inward toward the center of the subsidence basin. These fractures and bedding plane separations can affect the water-bearing strata by altering the groundwater flow path and velocity. In addition, the bending stratum introduces complex three-dimensional strain patterns that can stress structures and introduce damage.

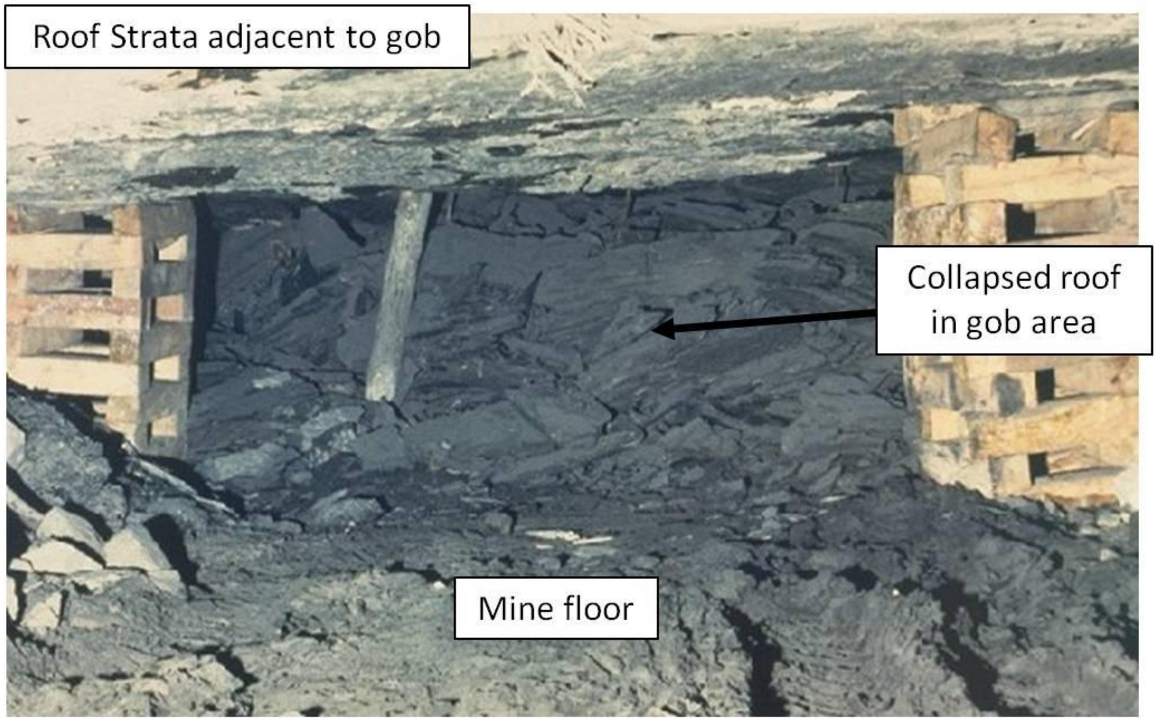

Figure I-5. Example of full extraction mining at the VP No.3 Mine in Virginia. At this mine the roof rock collapses into the void created by the extraction of the longwall panel (from Iannacchione et al. 2011).

I.D.2.1 – Formation of Subsidence Basins

A subsidence basin can be initiated when the extraction zone width-to-overburden ratio exceeds 0.25 (Peng 1992). In longwall mining, the extraction zone width during the 4th assessment period ranged from 1,061 to 1,564-ft (see Table III-8 in Section III). For the average longwall overburden condition of 783-ft (see Table III-11 in Section III), longwall panels have an extraction zone width-to-overburden ratio of 1.3 to 2.0. In pillar recovery mines, full extraction panels are typically 400 to 800-ft wide with overburdens averaging 538-ft (see Table III-11 in Section III), yielding ratios of 0.7 to 1.5. Therefore, a subsidence basin, with significant vertical deformations (> 1-ft), will develop with every longwall and pillar recovery panel mined in Pennsylvania. Furthermore, the maximum vertical subsidence is achieved when the extraction zone width-to-overburden ratio exceeds 1.0. The maximum vertical subsidence is dependent on the thickness of the extraction zone and a subsidence factor that is dependent on overburden, overlying strata properties, and the amount of coal removed.

As the working face of the coal mine advances, the extraction zone increases in size. The composition and thickness of the overlying rock helps determine the subsidence basin that propagates on the surface in advance of the working face underground. The angle between the vertical line at the extraction zone edge and the line connecting the extraction zone edge and point of critical deformation on the surface is called the angle of deformation (Peng and Geng 1982; Figure I-6).

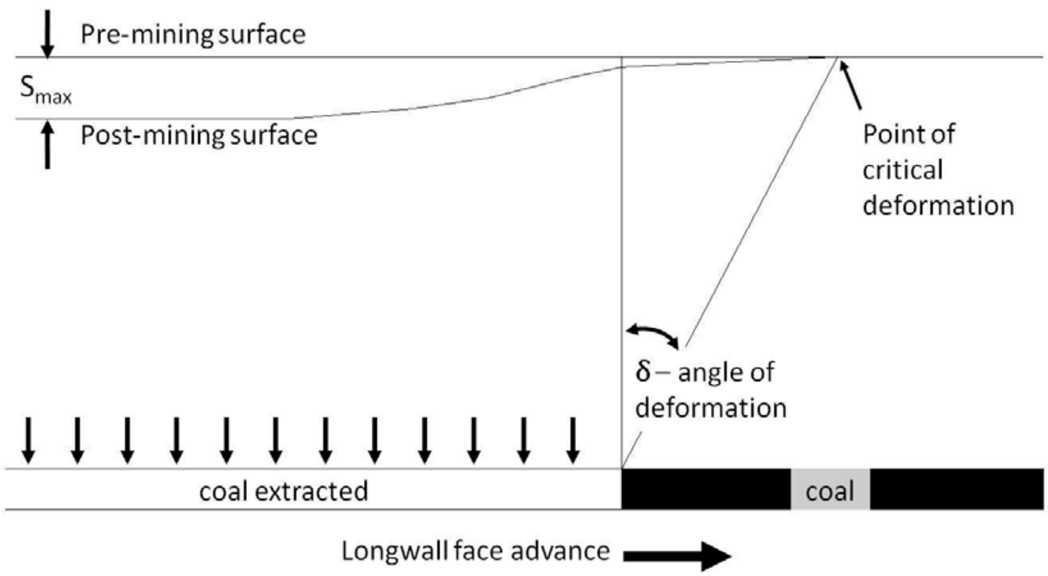

Figure I-6. Generalized model showing how a subsidence basin forms in association with longwall mining (from Iannacchione et al. 2011).

From the point of critical deformation back to the point above the working face, the surface begins to subside even though it is over solid unmined coal. In this zone, the ground surface is extended causing tensional ground strains. Once mining passes under a point on the surface, vertical subsidence accelerates and compression ground strains occur. Tension (extension) in the ground surface can initiate tensile fracturing in structures. Compression (buckling) in the ground surface can initiate shear ruptures and lateral offsets in structures. Finally, as mining moves away, vertical subsidence gradually reduces and movement stops. At this point in time, the maximum subsidence (S_{max}) is achieved and is generally 0.4 to 0.6 times the thickness of the underground extraction zone. In Pennsylvania, the extraction zone generally ranges from 5 to 7-ft, so S_{max} typically ranges between 2 and 5-ft.

I.D.2.2 – The Final Shape and Impact of the Subsidence Basin

Longwall mining subsidence basins are elliptically shaped, three-dimensional surfaces (Figure I-7). The edges of the subsidence basin extend beyond the boundaries of the longwall panel. S_{max} occurs in the center of the basin and subsidence rapidly lessens above the edges of the rectangular longwall panels. The area of the elliptical subsidence basin is significantly larger than the rectangular longwall panel that produces it.

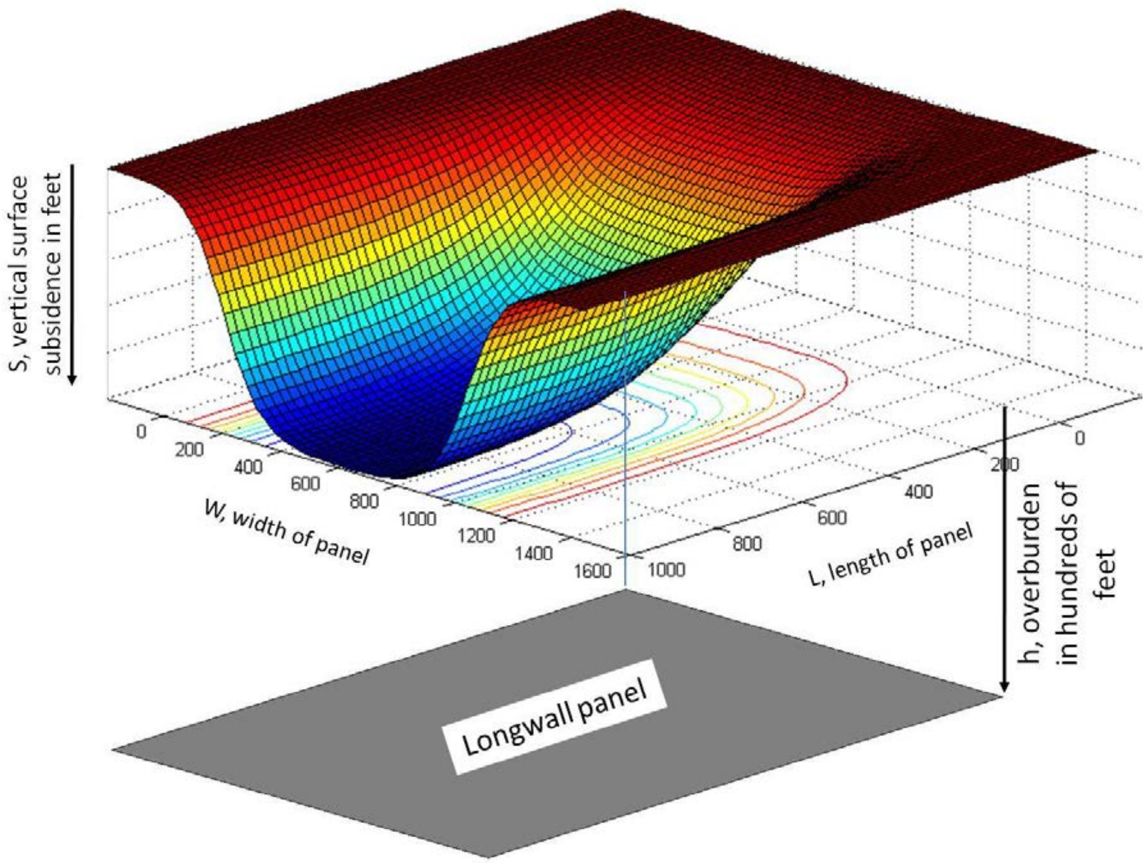

Figure I-7. 3-D view of an idealized subsidence basin overlying a portion of a typical longwall panel in Pennsylvania (from Iannacchione et al. 2011).

I.E. Impacts of Underground Mining on Surface Features and Structures

The majority of possible impacts related to underground mining are associated with mining induced surface subsidence.

I.E.1 – Structures: Impacts of Underground Mining

Any structure that falls within the subsidence basin has the potential to be impacted. The reasons for this are many, including rapidly changing surface slope, curvature, and horizontal strain conditions. Impacts to buildings and structures include shifting of foundations, extensional cracks in walls and floors, and buckling of walls and floors.

I.E.2 – Water supplies: Impacts of Underground Mining

Subsidence-related impacts to water sources can diminish water flow or alter hydrologic flow paths changing water chemistry and sometimes reduce its residential, agricultural and commercial value and use. Impacts to water sources have been occasionally known to extend beyond the subsidence basin (Witkowski 2011).

It should also be noted that room-and-pillar mining may also affect water supplies. The altered groundwater flow paths that can occur under specific conditions may impact the quantity and quality of water produced by wells and springs.

I.E.3 - Hydrology: Impacts of Underground Longwall Mining

Subsidence associated with underground mining has the potential to alter the hydrologic cycle in overlying areas. Changes to surface water flows, either through impedance (i.e. pooling) or routing of surface waters through sub-surface flowpaths (i.e. flow loss), are described below. However, the hydrological impacts to non-stream portions of the landscape are less well characterized. The hydrology of western, and particularly southwestern, Pennsylvania is dominated by interactions between the bedrock, which is composed of extensive strata of sedimentary rock, and the relatively rugged topography, which results from the incision of the surface water drainage network (Figure I-8). This geologic template results in substantial groundwater aquifers that sustain surface water flow during periods without precipitation and provide drinking water for many residents of Pennsylvania living beyond public water distribution networks. Further, these aquifers interact with the surface system in complicated hillslopes with numerous springs that are important for wildlife habitat and livestock watering. The surface disturbances associated with longwall mining have significant implications for these water resources, including the potential "loss" of wells accessing these aquifers (i.e. diminished water yields or water quality from these wells) and the potential loss of flow from springs along the hillslope.

There is a strong emphasis in the standing legislation and technical guidance toward repairing of hydrological impacts to existing water sources. The existence of water sources, by definition, relies heavily on the economic use of the water. However, the simple cycling of water through ground and soil water flow paths provides a wide range of services including provisioning of habitat for trees and various biota and the associated benefits ranging from atmospheric plant respiration inputs to hunting. The widespread diminishment of these processes affects citizens of the Commonwealth beyond individual property owners.

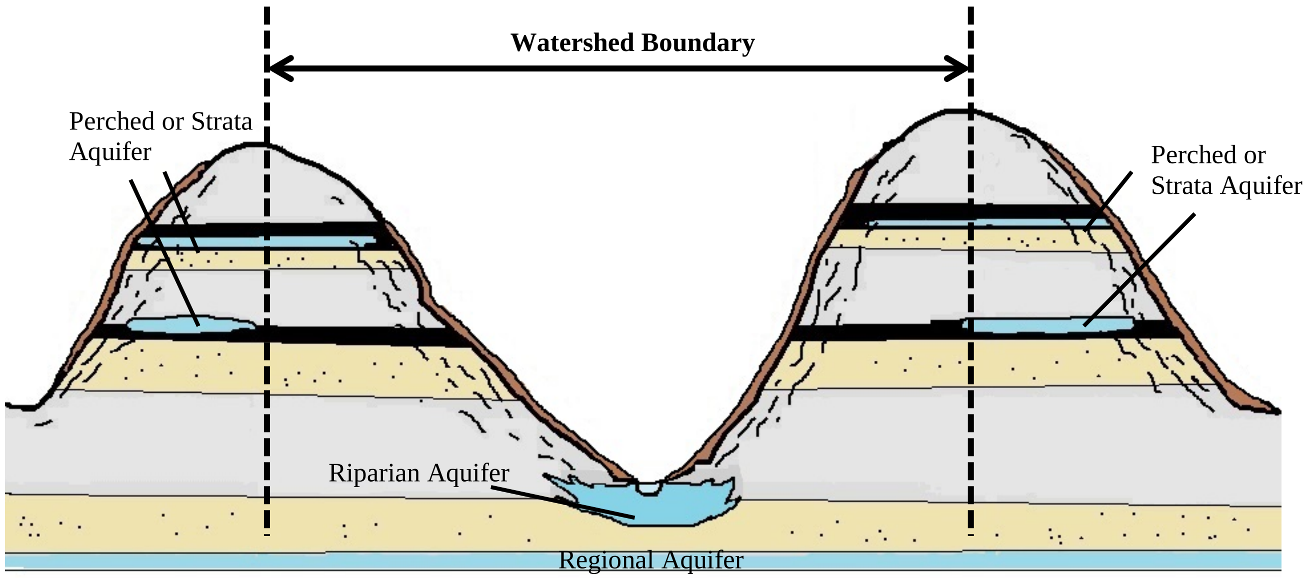

Figure I-8. Conceptual model showing watershed boundaries and ground water aquifer. Source waters and discharge points for ground water drainage patterns are challenging to characterize due to independence from surface topography.

I.E.4. Streams: Ecology and the Impacts of Underground Mining

With over 83,000 miles of streams (U.S. EPA 1998), Pennsylvania is rich in aquatic resources. Pennsylvania has the greatest miles of stream per square mile of land surface of any state in the continental U.S., with three-fold more than Ohio and 1.5-fold that of West Virginia. The total economic benefits derived from rivers and streams are substantial (U.S. National Park Service 2001). For example, angler use and harvest from trout-stocked streams in Pennsylvania generated over $65.7 million across the first eight weeks of the 2005 trout season (Greene et al. 2006). Thus, understanding the impact of underground coal mining on streams and rivers is an especially important issue in the Commonwealth.

In general, subsidence has two geological effects that can impact streams. First, the formation of the subsidence basins above the longwall panels in combination with the un-subsided gate road entries can act as barriers to stream flow. As a result of the uneven subsidence between panels and gate road entries, stream water can pool within the subsidence basin. Second, compressive and tensile forces generated in the bedrock between the mine and the surface can cause bedrock fracturing within and beneath the streambed. The fractures can lead to draining of surface water to deeper strata and loss of stream flow. The fractures can also redirect groundwater to deeper layers, resulting in the loss or reduction of groundwater input to the stream in the immediate area around the fractures.

Disturbances in stream flow and chemistry are widely regarded as the most critical factors influencing stream ecosystems (Resh 1988, Lake 2000, Bunn & Arthington 2002). The effects of pooling disturbances are likely similar to those associated with dams and weirs. Reduction in flow variability and lowered flow rates have been shown elsewhere to result, in some instances, in a number of adverse effects (reviewed in Bunn & Arthington 2002), including excessive stream vegetation growth (Walker et al. 1994), increases in undesirable insect species such as blackflies (De Moor 1986), reduced aquatic insect diversity (Williams and Winget 1979) and ultimately reductions in fish populations (Converse et al. 1998). The effects of subsidence-induced flow loss disturbances are analogous to those of a drought disturbance. During drought, flow loss creates a reduction in habitat space (Lake 2000). As a result, biota can become concentrated into small pools where predation and competition may be intense. Within these small pools, abiotic stressors such as high temperatures and low oxygen can also occur. The continuity of the stream system is broken, as resources that are introduced upstream are no longer carried downstream. Overall, pooling and flow loss result in physiochemical changes that can impact the aquatic life of a stream.

Under the authority of the Pennsylvania Clean Streams Law (35 P.S. §691.1 et seq.) and regulations in PA Code Title 25, including Chapters 86, 89, 93, 96 and 105, the PADEP “will ensure that underground mining activities are designed to protect and maintain the existing and designated uses of perennial and intermittent streams” (PADEP 2005a). In Pennsylvania, four designated uses for streams are identified and required by law (PA Code, Title 25, Chapter 93.3) to be maintained and propagated:

- Cold water fishes – waters containing or suitable for fishes, flora, and fauna that prefer cold water habitats, including fish species of the family Salmonidae (e.g. trout)
- Warm water fishes – waters containing or suitable for fishes, flora, and fauna that prefer warm water habitats
- Migratory fishes – water periodically containing or suitable for fishes that must move through flowing habitats to their breeding ground to complete their life cycle
- Trout stocking – waters stocked with trout and fishes, and the flora and fauna that are indigenous to warm water habitats

In addition, Technical Guidance Document 391-0300-002 (PADEP 2003) specifies criteria for classification as High Quality or Exceptional Value Waters. The ultimate criteria for establishment as Exceptional Value waters, and an important general criterion for establishing designated use category and its attainment, is based on the aquatic macroinvertebrate community the waters contain. Macroinvertebrate community composition generally predicts a stream’s fish community (e.g. Lammert & Allan 1999). In addition, macroinvertebrate taxa span a wide range of trophic levels and pollution tolerance, so macroinvertebrate community composition can reflect the physical and chemical characteristics of the stream (Barbour et al. 1999). Measures of the macroinvertebrate community are therefore appropriate for assessing the influence of mining on local stream stretches.

I.E.5 – Wetlands: Ecology and Impacts of Mine Subsidence

In Pennsylvania, wetlands are defined as “areas that are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions, including swamps, marshes, bogs and similar areas" (PA Code, Title 25, Chapter 105.1; adopted from U.S. Army Corps of Engineers). Wetlands can provide a number of critical ecosystem services for humans, including flood mitigation, storm abatement, groundwater recharge, pollution prevention, and recreation (Mitsch and Gosselink 2007). Wetlands also provide critical habitat for animal and plant species, many of which are threatened or endangered. Indeed, 28% of plants and 68% of birds listed under the U.S. Endangered Species Act occupy wetland habitats (Mitsch and Gosselink 2007). As a result of their importance to both humans and wildlife, wetlands are protected under federal law. The primary regulation guiding wetland protection is Section 404 of the Federal Water Pollution Control Act (commonly known as the Clean Water Act). The U.S. Army Corps of Engineers is responsible for administering Section 404, with assistance from the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and state agencies such as PADEP.

Wetlands are generally characterized by three features – wetland hydrology, hydric soils, and vegetation (Environmental Laboratory 1987). Ultimately, the ecological characteristics of wetlands are dictated by surface and groundwater inputs (Keddy 2000). Changes in water level can simultaneously create and destroy microhabitats within wetlands and affect the size and overall function of the wetland.

Mining-related subsidence can affect water levels in wetlands through three major routes. First, subsidence-induced pooling along streams can result in flooding of riparian wetlands. The excess surface water can increase the duration and extent of wetland saturation, resulting in the conversion of upland habitat to wetland habitat. Generally, these impacts are predicted to result in a net gain of wetland acreage. In contrast, subsidence-induced flow loss in streams can diminish surface water and groundwater inputs to riparian wetlands. Surface and sub-surface cracks in the bedrock can divert water away from wetlands, decreasing the zones of inundation and/or saturation. These impacts are predicted to result in a net loss of wetland acreage. Lastly, migration of springs and seeps down slope following mine subsidence could result in the re-location of slope-side wetlands. The migration of a spring or seep and loss of the groundwater discharge at that location is expected to result in the loss of wetland habitat. If the spring re-appears downslope, then a new wetland may be created at that location. Overall, impacts from underground mining can either increase or decrease wetland acreage. To comply with federal regulations, mine operators much show that no net loss of wetlands occurs.

I.F – Selection of Focal Watersheds for Detailed Case Studies of Mining Impacts

The impacts of subsidence are expected to vary with the geologic and hydrologic characteristics of the watersheds in which they occur. To explore how watershed characteristics influence surface impacts, seven focal watersheds were selected from four active longwall mines for detailed analysis (Figure I-10). The watersheds vary in size, land use, depth to mining (Table I-2) and other hydrogeological characteristics. Several chapters of this report will address the nature of surface feature impacts and mitigation/recovery within these focal watersheds.

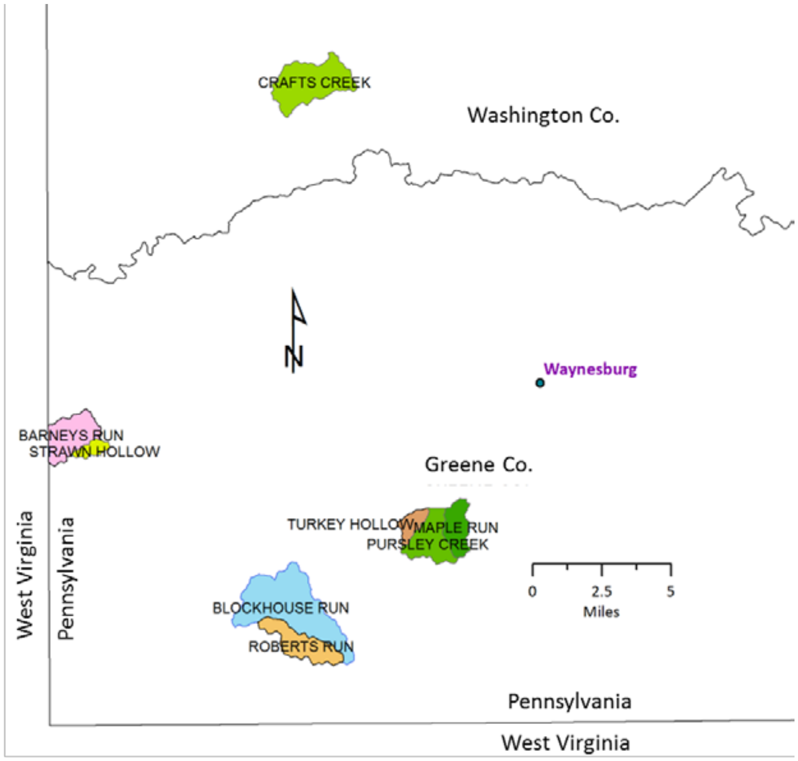

Figure I-10. Location of seven focal watersheds in Greene and Washington Counties.

Table I-2. List of focal watersheds for detailed case studies of mining impacts.

Mine	Focal Watersheds	Watershed Area, Acres	% Forest in Watershed	Average Depth to Mining (ft)	Stream Designated Use
Bailey	Barneys Run	1,506*	77%*	683.3	Trout-stocking fishery
Bailey	Strawn Hollow	349	76%	724.2	Trout-stocking fishery
Blacksville 2	Roberts Run	1,413	91%	955.6	Warm water fishes
Blacksville 2	Blockhouse Run	3,996	77%	964.9	Warm water fishes
Cumberland	Turkey Hollow	472	66%	932.6	High Quality – Warm water fishes
Cumberland	Maple Run	961	91%	852.5	High Quality – Warm water fishes
Cumberland	Pursley Creek	1,692**	80%**	886.7	High Quality – Warm water fishes
Enlow Fork	Crafts Creek	2,388	64%	669.2	Trout-stocking fishery

* - West Virginia portion of Barneys Run watershed not included

** - Includes only portion of Pursley Creek watershed upstream of confluence with Turkey Hollow

I.G. – Current Contract Tasks and Report Structure

The contract that funded this project identified 10 data-related tasks for the University (Appendix A). Listed below are the PADEP's tasks and the sections of this report which address each task.

- Task 1: Review of Information – Section II: Methods: Constructing the Act 54 Geodatabase
- Task 2: Statistical Data – Section III: Underground Bituminous Coal Mining During the 4th Assessment Period
- Task 3: Stream Impacts – Section VII: Effects of Mine Subsidence on Streams During the 4th Act 54 Assessment
- Task 4: Hydrologic Impacts – Section VI: Impacts of Longwall Mining on Groundwater
- Task 5: Stream Impacts - Flow Loss – Section VII: Effects of Mine Subsidence on Streams during the 4th Act 54 Assessment *and* Section VIII: A Follow-Up on the Effects of Mine Subsidence on Streams during the 3rd Act 54 Assessment
- Task 6: Stream Impacts – Pooling – Section VII: Effects of Mine Subsidence on Streams During the 4th Act 54 Assessment
- Task 7: Wetland Impacts – Section IX: Effects of Mine Subsidence on Wetlands
- Task 8: Water Supply Impacts – Section V: Effects of Mining on Water Supplies
- Task 9: Structure Impacts – Section IV: Effects of Mining on Structures
- Task 10: Recommendations/Conclusions – Section X: Recommendations *and* Section XI: Summary and Conclusions

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SECTION II: Methods: Constructing the Act 54 Geodatabase

II.A – Overview

This section provides an overview of the University's methods of data collection and compilation in preparation of the Act 54 report. The construction of the Act 54 Geographic Information System (Act54GIS) is described along with the various sources and software used in its creation and maintenance. The University also outlines the major challenges and limitations encountered in assembling the necessary information and makes recommendations for improving this process.

II.B – Introduction

Determining the impacts of mining is largely a spatial problem. Any impacts on the overburden strata, landscape, structures, streams, and wetlands are limited to an area immediately above and surrounding the area mined. Further, knowing the timing of undermining in relation to the timing of purported damage is crucial to determining the likelihood that the damage was in fact caused by mining. Thus determining the precise locations of all features of interest and areas mined is critical to mining regulation and to Act 54 reporting. Geographic information systems (GIS) are the standard method for working with spatially explicit data. A major part of the Act 54 reporting work involved the construction of the Act54GIS. Much effort was spent collecting available data, transforming and combining the data into user-friendly products for analysis, and updating the database as new spatial data became available.

Two main data collection efforts were made over a period of 14 months. At the outset of the project, 11 months before the end of the 4th reporting period, the University focused on collecting base data, such as the spatial information for roads, streams, bio-monitoring sites, and elevation. The University also collected all data on mining extents and undermined features that were available at that time. After the end of the 4th assessment period, from August 2013 to November 2013, the University focused on updating the mining extents and undermined features so that the spatial data reflected the status of mining as of August 2013 for as many mines as possible.

The overlap between the budgeted time frame for the University's data collection (1 September 2012 through 30 November 2013) and the 4th assessment period (21 August 2008 through 20 August 2013) was the result of discussions following the 2nd and 3rd assessments. In the 2nd assessment, Conte and Moses (2005) specifically indicated that "Such an approach would expedite the completion of the report upon the termination of the assessment period." Thus, a more timely production of the report seemed desirable. However, the overlap in timing presented several unforeseen challenges. The major difficulty created by the overlap was a consequence of PADEP's schedule of due dates for six-month mining maps. The due dates are staggered among the various mines so that the workload of reviewing and processing the maps is spread across time. While in and of itself a wise approach, this had the unfortunate consequence that for some mines the last maps of the reporting period did not arrive at PADEP until well after the University's contract budget and time frame for data collection had ended. While this is inefficient it is not a fatal problem. The remaining six-month maps can be incorporated in the next Act 54 report. Most importantly, their absence is not likely to qualitatively change the conclusions of this report. Table II-1 indicates the last month for which six-month maps were available and incorporated by the University. The challenges with the overlap argue for a middle ground in future reports, e.g. starting perhaps six months prior to the end of the assessment period.

II.B - Data Sources, Software, and Standardization

II.B.1 – Base Data

The first phase in developing the Act54GIS involved populating the database with base data to provide a spatially referenced framework to which all mining related information would be associated. Eighty-five GB of base data was acquired from the Pennsylvania Spatial Data Access (PASDA) geospatial clearinghouse maintained by The Pennsylvania State University (PSU), the Geography Division of the U.S. Census Bureau, and the U.S. Geological Survey:

- Roads:
    - Local roads created by Pennsylvania Department of Transportation (PennDOT): (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaLocalRoads2014_02.xml&dataset=1038)
    - State roads created by PennDOT: (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaStateRoads2014_02.xml&dataset=54)
- Hydrologic features:
    - Networked streams of Pennsylvania created by the Environmental Resources Research Institute (ERRI) at PSU (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=netstreams1998.xml&dataset=16)
    - Small watersheds generated from the USGS Water Resources Division's major watersheds dataset by ERRI at PSU (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=smallsheds.xml&dataset=14)
    - Waterbodies from the National Hydrography Dataset (NHD) created by the US Geological Survey (USGS) (http://nhd.usgs.gov)
- Political boundaries:
    - Statewide Pennsylvania county boundaries created by PennDOT (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PaCounty2014_02.xml&dataset=24)
- Elevation:
    - PAMAP Program LAS: 3.2 ft resolution LiDAR Digital Elevation Models (DEMs) (http://www.pasda.psu.edu/uci/MetadataDisplay.aspx?entry=PASDA&file=PAMAP_DEM.xml&dataset=1247)

II.B.2 – Data on Mining Extents and Undermined Features

Following incorporation of the base data, the University added information on mine locations and undermined features. These data came from three different sources:

- Six-month mining maps submitted by the mine operator to PADEP

- Digital spatial data supplied by the mine operator to the University
- Bituminous Underground Mining Information System (BUMIS) Inventory

II.B.2.1 - Six-Month Mining Maps

Six-month mining maps are submitted by the mine operator to PADEP every six months. The maps depict:
- The location of any mining that occurred during the prior six months
- A prediction of mining during the following six months
- The locations of all surface features such as properties, structures, water supplies and utilities that might be impacted by mining and thus the subject of PADEP mining-related oversight.

Some maps included additional information on coal and surface elevation contours. In general, there was little standardization between maps in what information beyond the bulleted items (above) was included, even within the same operating company.

The University received 565 relevant six-month mining maps (644 GB) as Tagged-Image Format (TIF) or multi-resolution seamless image database (MrSID / SID) format images from the California District Mining Office (CDMO). Approximately 525 of the 565 six-month mining maps were used at some point. However the updates made necessary by the overlap in the reporting period and the University's data collection period, often resulted in more than one map collected for the same area. The University replaced any outdated maps with their newer versions. This resulted in a library of 258 most up-to-date mining maps.

Of the six-month mining maps ultimately used, 106 maps (41%) were received without spatial information, meaning that they lacked an association with a physical location that would allow them to be placed within the geospatial framework of the base GIS described in II.B.1. The University used a process called geo-referencing to assign these maps to the areas that they depicted.

To geo-reference the map images, the University employed two different strategies. In late 2012 and early 2013 during the first round of data collection six-month mining maps were geo-referenced using road intersections from the PennDOT state and local road layers retrieved from the PASDA website. The team would find an intersection on the six-month mining map and match it to the corresponding intersection on the roads layer. If an insufficient number of intersections were available, sharp bends in a road were used. For mines that had some digital information, roads were still used as the primary anchoring points, however, distinct shapes in the mining outline layer were used as second preference over sharp bends in the road. After August 2013, the University used the mining outline shape to geo-reference the new six-month mining maps, having already precisely geo-referenced mining outlines in previous six-month mining maps. Residual error for each map was recorded for each map as the root mean square error (RSME) of the list of control point residuals. In addition, the number of control points for each map was recorded. Since all but one mine employed more than one map, the mean of those numbers was also calculated for each mine. The University recommends that PADEP require electronic submission of all six-month mining maps with standardized geo-referencing.

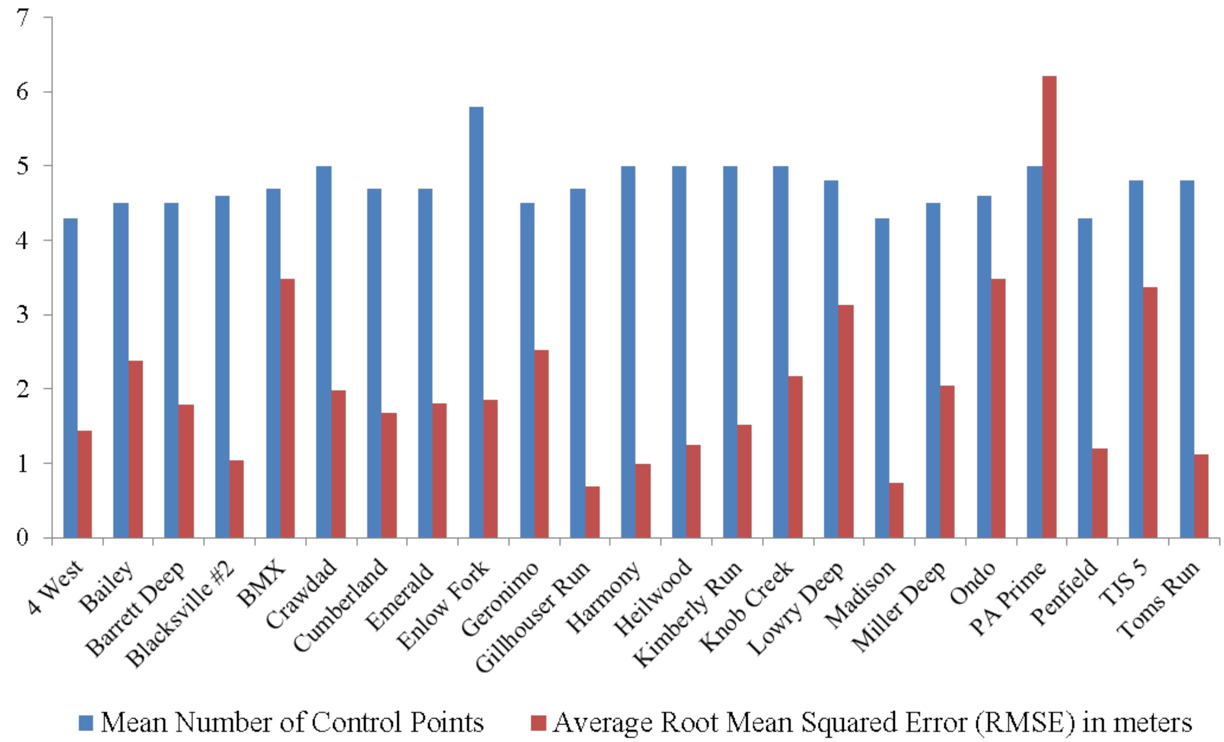

Figure II-1 - The mean number of control points and average root mean square error (in meters) for each mine in the study area for which the University geo-referenced maps. Mines that did not require geo-referencing on the part of the University are not represented in the figure.

For the 152 maps that had accompanying spatial information and were used by the University, the geo-referencing was supplied by PADEP. The legal use constraints on these spatial data require that the University provide the following disclaimer for all maps that follow in the report: "The georeferenced map layer on this product was provided by the Pennsylvania Department of Environmental Protection. This map was georeferenced using information considered to be the best historic data available. It is understood that there is an inherent loss of accuracy in the georeferencing process and the georeferenced map may not align correctly with base maps, real world locations, and/or established coordinate systems. The Department assumes no responsibility for the accuracy or completeness of this information."

II.B.2.2 – Mine Operator Data

University team members contacted and visited mine operator facilities to obtain digital spatial information that would accompany an electronic version of a six-month mining map. Many of the operators agreed to supply us with digital ArcGIS or AutoCAD files (Table II-1) to enhance accuracy by diminishing inherent errors associated with geo-referencing. These data were compared to the six-month mining map records, and were quite accurate. Since the ArcGIS Desktop software produced by the company Esri was the primary tool for the University's analysis, all AutoCAD files were converted into ArcGIS compatible files. The CAD files were initially opened in Autodesk's AutoCAD software and each of the features of interest were then exported individually as a separate CAD file. This suite of new CAD files was then imported one-by-one into ArcMap using Esri CAD-to-geodatabase tools.

II.B.2.3 – Bituminous Underground Mining Information System Inventory

The Bituminous Underground Mining Information System (BUMIS) Inventory is a database established and maintained by PADEP that is intended to track surface impacts related to underground bituminous mining activities. Surface features that may be impacted include structures, water sources (wells and springs), water bodies, streams, and utilities (water and sewer supply systems, power lines, gas lines, and roads). BUMIS is intended by PADEP to not only track impacts on surface features, but also to record corrective actions by the mine operators and regulatory actions by PADEP.

BUMIS cannot be relied upon as the authoritative source of information on undermined surface features, impacts or impact resolution. Spatial coordinates (i.e. longitude and latitude) were rarely provided in BUMIS during the 4th assessment period. As a result, the University had to rely on a feature's unique identification number to determine its spatial location from the six-month mining maps. Unfortunately over 40% of BUMIS features lacked a unique identification number. PADEP corrected approximately 250 errors in BUMIS but insufficiencies in data entry continued through the end of the University's assessment period. The University's final pass through BUMIS revealed that the percentage of features lacking a feature identification number remained around 30 percent. The University also discovered that some six-month mining maps that have feature identification numbers do not have unique feature identification numbers when multiple structures of a given type are present on a single property, a frequent occurrence. In such cases, barns, dwellings, and wells are labeled with a simple B, D, or W respectively. This becomes problematic when attempting to determine exactly which barn, dwelling, or well was impacted by mining. Less commonly, unique identifiers for properties varied between BUMIS and the six-month maps (tax identification numbers in one, tract identification numbers in the other), further complicating efforts to locate undermined and impacted features. Data entry errors are also frequent. For example, damage to wells is sometimes classified as "structure damage". Data entry is often incomplete with a feature lacking, for example, date of impact occurrence and depth to mining. In some cases, impacts are missing altogether. Most of the errors and inaccuracies in BUMIS result from an apparent lack of written protocols for data entry, and lack of quality control and error checking within PADEP.

BUMIS was not accessed by the University directly. Instead BUMIS data was downloaded by PADEP and made available to the University as Microsoft Excel spreadsheets. The University uploaded these spreadsheets into Microsoft Access and linked them to the Act54GIS to determine the locations of impacted features.

Table II - 1. Sources of data on mining extent and undermined features by mine. Information on the received file formats and the most recent month for which six-month mining maps were made available to the University is included. Not all six-month mining maps for the 4th reporting period were submitted in time for inclusion.

Mine	Data Source(s)	Data Format(s)	Month of Most Recent Available Data
Cumberland	Alpha Natural Resources	ArcGIS Shapefiles	Aug-13
Emerald	Alpha Natural Resources	ArcGIS Shapefiles	Aug-13
Barrett Deep	Amfire Mining Co LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Aug-13
Gillhouser Run	Amfire Mining Co LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Madison	Amfire Mining Co LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Mar-13
Nolo	Amfire Mining Co LLC & District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Nov-12
Ondo	Amfire Mining Co LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Aug-13
Dora 8	Amfire Mining Co LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Nov-12
Bailey	Consol PA Coal Co. LLC	AutoCAD file	Aug-13
Enlow Fork	Consol PA Coal Co. LLC	AutoCAD file	Aug-13
Blacksville 2	District Mining Office, California PA	Six-Month Mining Map	Jul-13
Eighty Four	District Mining Office, California PA	Six-Month Mining Map	Nov-11
BMX	Consol PA Coal Co. LLC District Mining Office, California PA	AutoCAD file Six-Month Mining Map	May-13

Mine	Data Source(s)	Data Format(s)	Month of Most Recent Available Data
4 West	MepCo District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jan-13
Prime 1	MepCo District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Crawdad	MepCo District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Titus Deep	Dana / MepCo District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jan-10
TJS 6	Penn View / Rosebud District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Aug-13
Clementine 1	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Dec-12
Lowry	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Penfield	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Apr-13
Toms Run	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Mar-13
Windber 78	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Apr-13
Beaver Valley	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jan-13
Cherry Tree	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Apr-13
Darmac 2	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jun-13
Dutch Run	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jan-13

Mine	Data Source(s)	Data Format(s)	Month of Most Recent Available Data
Harmony	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Heilwood	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Apr-13
Knob Creek	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Apr-13
Little Toby	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Nov-11
Logansport	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jan-13
Long Run	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Mar-13
Rossmoyne 1	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Mar-12
Starford	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Mar-13
TJS 5	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Oct-10
Tracy Lynne	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	May-13
Twin Rocks	Rosebud Mining Co District Mining Office, California PA	AutoCAD file Six-Month Mining Map	Jul-13
Kimberly Run	District Mining Office, California PA	Six-Month Mining Map	Aug-13
Horning Deep	District Mining Office, California PA	Six-Month Mining Map	Apr-13
Geronimo	District Mining Office, California PA	Six-Month Mining Map	Sep-09

Mine	Data Source(s)	Data Format(s)	Month of Most Recent Available Data
Sarah	District Mining Office, California PA	Six-Month Mining Map	Jul-13
Miller Deep	District Mining Office, California PA	Six-Month Mining Map	Feb-13
Quecreek 1	District Mining Office, California PA	Six-Month Mining Map	Mar-13
Roytown	District Mining Office, California PA	Six-Month Mining Map	May-13
Agustus	District Mining Office, California PA	Six-Month Mining Map	Aug-13

II.B.3 – Act 54 2nd and 3rd Assessment Spatial Data

Because the University created the spatial data for the 3rd Act 54 assessment in the form of a GIS database (Iannacchione et al. 2011), the data were readily available for use in the current assessment. Additionally, the University had acquired the spatial data from the California University of Pennsylvania's 2nd Act 54 report (Conte and Moses 2005). Therefore, all of the six-month maps and spatial layers from the 3rd report, and many of the same for the 2nd report were available to the University.

II.B.4 – Standardization of Datum and Coordinate Systems

Once collected, all spatial data sets were converted to a standard datum and coordinate system using the projection tools built into Esri's ArcGIS software. The North American Datum of 1983 (NAD 1983) was used as the earth-shape model for the Act54GIS. This datum associates its geographic coordinate system with the reference ellipsoid of the Geodetic Reference System of 1980. The University employed the Universal Transverse Mercator (UTM) coordinate system because it is an equal area projection that minimizes local distortion. Though the project was limited to Pennsylvania's state boundaries, using a standard projection allows the data to be available for broader use in the future. All mined areas for the 4th Act 54 assessment lie within Zone 17 North of the UTM coordinate system.

II.C – Data Layers Generated by the University

Using the data described above, the University generated relevant data layers for addressing the tasks set forth by PADEP. Specifically, the University generated the following the data layers for each mine, where applicable:

- Mining Extents
- Surface Features
- Overburden
- Buffers
- Stream Observations
- Stream Bio-monitoring Stations
- Topography
- Wetlands

II.C.1 – Mining Extents

In this report "mining extents" is defined as the area within which room-and-pillar, longwall, or pillar recovery mining took place between August 2008 and August 2013. These are represented by ArcGIS feature class polygons, and are separated by mining type. These digital files were compared to the mining extents stored in the 2nd and 3rd period databases. By comparing mining extents across the three reporting periods, the University was able to avoid overlaps and gaps in analysis coverage.

Most mining extents were provided by the mine operators at the outset of the project as digital files (see Section II.B.2.2). Mining extents that could not be collected digitally were traced by the team's GIS specialists using ArcMap's Editor tools and geo-referenced using six-month mining maps. After August 2013, the University team collected final updated digital files from operators employing longwall mining techniques, and traced the updated extents for the remaining room-and-pillar mines from six-month mining maps (Table II-1).

II.C.2 – Surface features

Property parcels, structures, water sources, water bodies, streams and miscellaneous utilities are considered surface features. As with the mining extents, most of the surface features were received digitally from mining companies and compared against six-month mining maps. The University created any missing layers from the six-month mining maps, with the exception of stream and utility layers; these features were obtained from the base data.

Additional information was calculated for the structure, water sources, and water bodies features. These data were added to the feature's attribute table, Esri's term for the tabular data associated with an ArcGIS file. The following fields were added:

- Distance to Mining: the straight line distance between each feature within the layer and the edge of mining; calculated for each mining method (Room-and-Pillar, Longwall, and Pillar Recovery) using ArcMap's Near tool.
- Overburden underneath each feature: the amount of rock between each feature and mining; calculated using the overburden raster values.
- Proximity to Buffer: classification of each feature as inside or outside of that layer's applicable buffer; calculated using ArcMap's Select By Location tool and the University-created buffers (see section II.C.4)
- Topographic Category: whether each feature within a layer is located on a hilltop, a slope, or a valley bottom; calculated using ArcMap's Select By Location tool and University-created topographic categories layer (see section II.C.7)

Lastly, data from BUMIS was also merged with the feature’s attribute data. If the feature was impacted and tracked in BUMIS, then the attribute table includes the following information regarding the status of the impact at PADEP:

- BUMIS Problem I.D.
- Due to Mining? (Yes/No)
- Date Entered in BUMIS
- Date Problem Occurred
- Interim Resolution Date
- Interim Resolution Timespan
- Final Resolution (Yes/No)
- Final Resolution Description
- Final Resolution Date
- Final Resolution Timespan

II.C.3 – Overburden

Overburden is defined as the amount of overlying rock between mining and the surface. Calculating overburden was not an automatic process as the data that the University obtained with respect to coal or surface elevation varied by mine. Depending on the data that were available, the University utilized one of two main protocols to generate overburden layers for each mine.

When overburden data was available, it was largely untouched by the University. Overburden rasters were given directly to the University for some mines. For other mines, overburden rasters were extrapolated from overburden contours using the ArcGIS "Topo to Raster" tool.

When coal and surface elevation contours were the only data layers available, a raster was extrapolated for both using ArcGIS's Topo to Raster tool with 30-m per pixel resolution. The surface elevation raster value was then subtracted from the coal elevation raster value using the ArcGIS Minus tool to get an accurate overburden layer. If a surface elevation contour was not available for a particular mine, the LiDAR DEMs collected for that mine were used as the elevation values.

Because of the varying information collected on overburden, no protocol was put into effect to standardize overburden resolution. The methods employed favored the lowest resolution, leading to a range of resolutions, with the lowest being 30-ft (9-m) per pixel, the highest being 119-ft (36-m) per pixel, and the most frequent value being 98-ft (30-m) per pixel. Metric overburden values were converted to feet.

II.C.4 – Buffers

The University created three buffers to model existing regulatory boundaries. All buffers were created using the combined mining extents for all employed mining methods. For example, if a mine employed both room-and-pillar and longwall mining methods, then the buffer was based on the combined mining extents.

1. A 1,000-ft uniform distance outer buffer was created for each mine to serve as the boundary inside which all features were tracked. Any feature that fell within 1,000-ft of mining was identified and, if possible, linked to the BUMIS inventory.

2. A 200-ft uniform distance outer buffer was applied to all mine maps in the study. This buffer was used as a boundary for the structure and stream feature inventories.

3. The Rebuttable Presumption Zone (RPZ), a variable outer buffer, was generated using overburden raster values (see Section I.B.3 for details on RPZ and Act 54). A buffer was created for each overburden pixel that intersected the mining extent layer using the following equation:

$$RPZ = O * tan(35^\circ * \frac{\Pi}{180})$$

(Where O = the overburden pixel value and RPZ = the buffer distance)

All pixel-buffer boundaries were dissolved, resulting in one RPZ buffer. This buffer was used as a boundary for water sources and water bodies feature inventory.

II.C.5 – Stream Observations

The University was tasked with assessing pre-mining and post-mining Total Biological Scores for five stream sites with flow loss impacts, five sites with pooling impacts, and five sites that were impacted during the 3rd Act 54 assessment. To supplement the data supplied by PADEP for this task, the University assessed the biological health of 19 stream sites. During each stream survey, a DeLorme Earthmate GPS PN-20 handheld unit was used to record the start and end points of the University's sampling locations. The start and end points of any dry stream segments that were observed were also recorded. Data were recorded with an accuracy of at least ±10 meters, with an emphasis on more accurate readings. All coordinates were converted from decimal degree minutes to decimal degrees and manually entered into the Act54GIS.

II.C.6 – Stream Bio-monitoring Stations

PADEP's regulation of mining effects on streams requires that mine operators sample stream macroinvertebrate communities prior to and after mining on all undermined streams. The mine operators or their consultants establish geo-referenced bio-monitoring stations for this purpose. PADEP provided the University with the coordinates of stream bio-monitoring stations established by or on behalf of the mine operators. The records supplied by PADEP were incomplete. The University discovered the coordinates of additional bio-monitoring stations in the paper files at CDMO and added these to the spatial database. All or very close to all bio-monitoring stations reported to PADEP were eventually included in the Act54GIS.

II.C.7 – Topography

Two data layers were created using the LiDAR DEMs from the PASDA website. The first, a hillshade layer, was created with the ArcGIS Hillshade tool and used for visualization purposes. Hillshade layers, when overlaid on an elevation raster, mimic shadows as they would naturally occur, given a particular sun angle. This is useful for distinguishing hilltops from valley bottom with the naked eye. The second layer is the hilltop, slope, and valley bottom or "HSV" data layer which classifies any given elevation value into these three topographic categories based on its surroundings. These data were used to determine if features in particular topographic categories were more or less impacted by underground mining.

To classify areas as sloped, the ArcGIS "Slope" tool was used on all DEMs. The tool was set to highlight any pixel in the DEM that had a greater than 2 percent rise and classify it as "slope". The result was a new raster that effectively separated sloped areas from the flat hilltops and valley bottoms.

To differentiate between hilltops and valley bottoms, the DEM within the 1,000-ft buffer for each mine was sectioned off into 750-m by 750-m blocks, for which the average elevation was calculated. This was done using the ArcGIS Block Statistics tool. Every pixel value that was not categorized as "slope" was then compared to the average of the block in which it was located. If its elevation was greater than the average, it was categorized as hilltop, and if it was less than or equal to the average, it was categorized as valley bottom. These pixel values were then merged into a single shapefile. Pixel values equal to the average were classified as valley bottom due to the topographic characteristics of the focal area that tends toward wide, flat valley bottoms, and sloped, rounded hills. The resulting product was visually checked and corrected for discrepancies.

II.C.8 – Wetlands

To identify the location of wetlands in areas of predicted subsidence associated with longwall mines, data was collected from two sources – the paper files at CDMO and digital files from Alpha Natural Resources, Inc. From the CDMO paper files, 72 maps were geo-referenced with an average of 4.61 control points and 1.73-m RMSE. These wetland maps included few features for geo-referencing, which introduced significant challenges in data creation. For some images, the mining extents were used as the anchor points for geo-referencing. In cases where images did not show significant features from the mining extents, the images were referenced to index maps, which were also geo-referenced using the mining extents. Once all maps were geo-referenced, pre-mining and post-mining wetland areas were traced. In some cases, wetlands were marked by the mining operators as points rather than explicitly delineated in geographic space. The points typically represented test pit locations within the wetlands. In those cases, the exact area of the wetland could not be traced and the test pit location was marked. Data from Alpha Natural Resources, Inc. was received in an Esri ArcGIS format and was incorporated directly into the University's spatial database.

<u>II.D – University GIS Database Structure</u>

For the 4th assessment period, the University team created a hierarchical organization system that employed both digital folders and ArcGIS personal geodatabases. Each mine was given its own parent folder, within which all of the data for that mine alone was stored. This led to a less centralized, but more accessible, data organization. Within the parent folder, each mine was required to have:

- A "personal" geodatabase containing all of the digital ArcGIS-format data layers collected or produced.
    - The ArcGIS personal geodatabase format is the same as that for Microsoft's Access database files (.mdb), allowing us to access the tabular information within the ArcGIS format layers in the more user-friendly setting of Microsoft Access.
- A folder of geo-referenced six-month mining maps
- A "Topography" folder containing rasters relating to elevation
- Original CAD files, if the data was received in Autodesk format
- A map file (.mxd) for ArcMap versions 10.0 and 10.1

While each mine had unique information, all were required to have certain features for analysis. Table II-2 shows the full list of required features.

Table II-2. Required layers, their locations, and origins.

Feature	Type	Location	Origin
Overburden Layer	Raster	Geodatabase	Collected
Mining Extent Layer(s)	Feature Class	Geodatabase	Collected
Structure Layer	Feature Class	Geodatabase	Collected
Water Sources Layer	Feature Class	Geodatabase	Collected
Water Bodies Layer	Feature Class	Geodatabase	Collected
Properties Layer	Feature Class	Geodatabase	Collected
Buffer Layers	Feature Class	Geodatabase	Created
LiDAR DEM	Raster	Topography Folder	Collected
Topographic Categories Layer	Shapefile	Topography Folder	Created
Geo-referenced Six-Month Mining Maps	Geo-TIF Images	Geo-referenced Maps Folder	Collected / Geo-referenced

In addition, each mine was given a two-letter file code that was applied to all of its associated files. For instance, for the first mine in an alphabetical sorting, 4 West Mine, the structures layer is called Fw_structures, and the overburden raster is called Fw_OBraster, because the code for 4 West is "Fw." Refer to Table II-3 for a full list of abbreviations.

Table II-3. Mine file code key.

Mine Name	Mine File Code
4 West	Fw
Agustus	Ag
Bailey	By
Barrett Deep	Br
Beaver Valley	Bv
Blacksville 2	Bk
BMX	Bx
Cherry Tree	Ch
Clementine 1	Cl
Crawdad	Cd
Cumberland	Cu
Darmac 2	Dm
Dora 8	D8
Dutch Run	Dr
Emerald	Em
Enlow Fork	Ef
Geronimo	Gr
Gillhouser Run	Gh
Harmony	Hy

Mine Name	Mine File Code
Heilwood	Hw
Horning Deep	Hr
Kimberly Run	Kr
Knob Creek	Kc
Little Toby	Lt
Logansport	Lg
Long Run	Lr
Lowry Deep	Ly
Madison	Ma
Miller Deep	Ml
Eighty Four	Eg
Nolo	No
Ondo	On
Prime 1	Pr
Penfield	Pf
Quecreek 1	Qc
Rossmoyne 1	Rm
Roytown	Rt
Sarah	Sa
Starford	St
Titus Deep	Tt
TJS 5	T5
TJS 6	T6
Toms Run	Tr
Tracy Lynne	Tl
Twin Rocks	Tw
Windber 78	W7

II.E – Summary

To fulfill the tasks outlined by PADEP, the University constructed the Act 54 Geographic Information System (Act54GIS). Data collection occurred in two main efforts: one before and one after the official end date of the 4th assessment period in August of 2013. The overlap between the University's budgeted data collection time frame and the Act 54 assessment period presented some challenges for data collection. First, the University spent substantial time continually updating the Act54GIS as new data became available. Second, PADEP's staggered schedule for submission of six-month mining maps resulted in some data being unavailable to the University for analysis.

The Act54GIS was populated with base data and data on mining extents and undermined features. The mining data came from three sources: the six-month mining maps, mine operators, and BUMIS. Though the data were received in various formats, all spatial data were converted to Esri ArcGIS files with a NAD 1983 UTM 17N map projection. Ultimately, the University generated a specific suite of data layers for all mines. These features were created using six-month mining maps where they could not be collected directly.

The organization of the University database focused on applying a standard template to each of the individual mines to facilitate data acquisition and identification for users. When looking into a mine's parent folder, the same organization and data layer types are present as those in another mine's parent folder.

References

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SECTION III: Underground Bituminous Coal Mining During the 4th Assessment Period

III.A - Overview

A total of 31,343 acres of Pennsylvania land were undermined by bituminous coal mines between 21 August, 2008 and 20 August, 2013 (4th assessment period). That represents a decrease of ~18% compared to acreage undermined during the 3rd assessment period (38,256 acres). There are two reasons for this reduction in acres mined: 1) In the 4th assessment period a significant portion of the coal mined from the Bailey mine came from lands in West Virginia (Figure III-1); and 2) a reduction in the demand for Pennsylvania coal, especially during 2011 and 2012 where coal production dropped from 59.2 to 54.7 million tons (U.S. Energy Information Administration 2013). The downward trend is further indicated in the total number of mines in operation during the 4th assessment period, reduced from 50 to 46. Longwall mines decreased from eight to seven, room-and-pillar mines from 36 to 34, and pillar recovery mines from six to five.

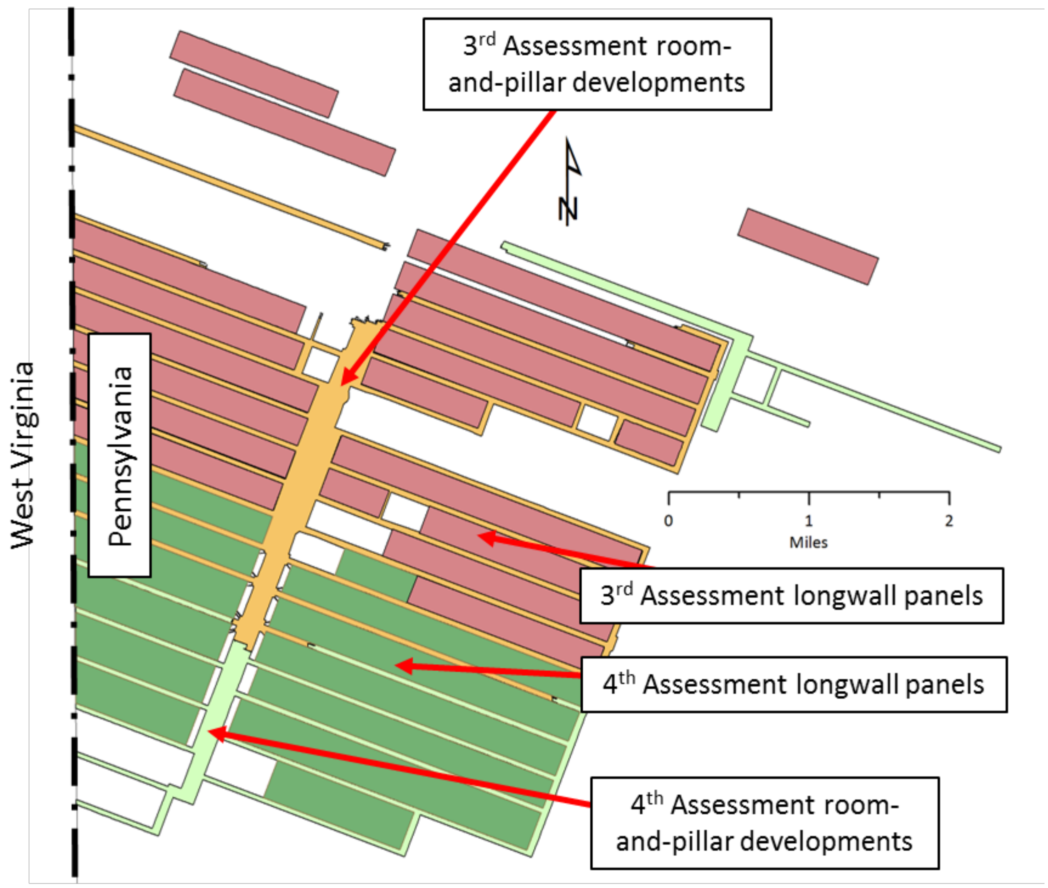


Figure III-1. Aerial distribution of room-and-pillar developments and longwall panels mined during the 3rd and 4th assessment periods at the Bailey Mine in Greene County, Pennsylvania. Note that a significant portion of the 4th assessment period longwall panels on the western side of the Bailey Mine extend into West Virginia, reducing the extent of mining in Pennsylvania. The cyan color indicates longwall panels mined during the 3rd assessment period while green indicates panels mined in the 4th period.

This section contains detailed analysis of 46 mines identified as active during the 4th assessment period and sorted by the type of mine, mining method, coalbed, overburden (depth of mining), size, and location. The University accomplished this by collecting and analyzing both the six-month mining maps that are part of every mine's permit files and company supplied digital maps

III.B – Mines in Operation during the 4th Assessment Period

The identity of the mines that operated during the 4th assessment period were determined with PADEP assistance and by analysis of coal production records contained within the Mine Safety and Health Administrations (MSHA) Mine Data Retrieval System, six-month mine maps collected from the PADEP, and records contained within the Bituminous Underground Mining Information System (BUMIS). Areas within individual mines where active mining operations took place were determined from six-month mining maps and through digital maps obtained from the mine operators (See Section II.B.2). For some mines, it was difficult to determine the exact location of production faces based on available maps. In these cases, the approximated mining location was determined by interpolating between points with known dates. All of the controlling companies with active mining operations (Table III-1) provided digital maps and other information with the exception of Severstal Resources. In many cases, the digital maps included additional details that increased the accuracy of the University's estimates of the extent of mining. A list of all active 4th assessment period mines is provided in Appendix B.

III.B.1 – Companies Operating Mines

Six controlling companies worked 46 underground coal mines during the 4th assessment period (Table III-1). Several of these controlling companies are comprised of subsidiary operating companies. Of the 10 operating companies, only two are independently owned, Rosebud Mining and TJS Mining. Others, for example Consol Energy and Alpha Natural Resources, are among the largest solid fuel energy companies in North America.

Table III-1. Active mines sorted by mining company.

Controlling Company	Operator	Mine	#	Acreage
Alpha Natural Resources	AMFIRE Mining Co.	Barrett, Dora 8, Gillhouser Run, Madison, Nolo, Ondo	6	2,052.2
	Emerald Coal Resources LP	Emerald	1	2,083.0
	Cumberland Coal Resources LP	Cumberland	1	2,652.9
Consol Energy Inc.	Consol Pennsylvania Coal Co. LLC	Bailey, BMX, Enlow Fork	3	10,316.7
	Eighty-Four Mining Co.	Mine 84	1	66.8
	Consolidation Coal Co.	Blacksville 2	1	1,885.9
Mepco Intermediate Holdings LLC	Dana Mining Co.	Crawdad 1, Prime 1, Titus Deep, 4 West	4	1,574.6
Rosebud Mining Co.		Beaver Valley, Cherry Tree, Clementine 1,	20	8,279.6

		Darmac 2, Dutch Run, Harmony, Heilwood, Knob Creek, Little Toby, Logansport, Long Run, Lowry, Penfield, Rossmoyne 1, Starford, TJS 6, Toms Run, Tracy Lynne, Twin Rocks, Windber 78		
Severstal Resources	Rox Coal Inc.	Agustus, Geronimo, Horning Deep, Kimberly Run, Miller Deep, Quecreek No.1, Roytown, Sarah	8	2,422.2
TJS Mining Inc.		TJS 5	1	9.5
		Total	46	31,343

The size of companies mining in Pennsylvania and the scale of their operations varies considerably (Figure III-2). Both Alpha Natural Resources and Consol Energy are comprised of three separate operating companies. The company with the most mines is Rosebud Mining, while the company with the greatest mined acreage is Consol Energy, Inc.

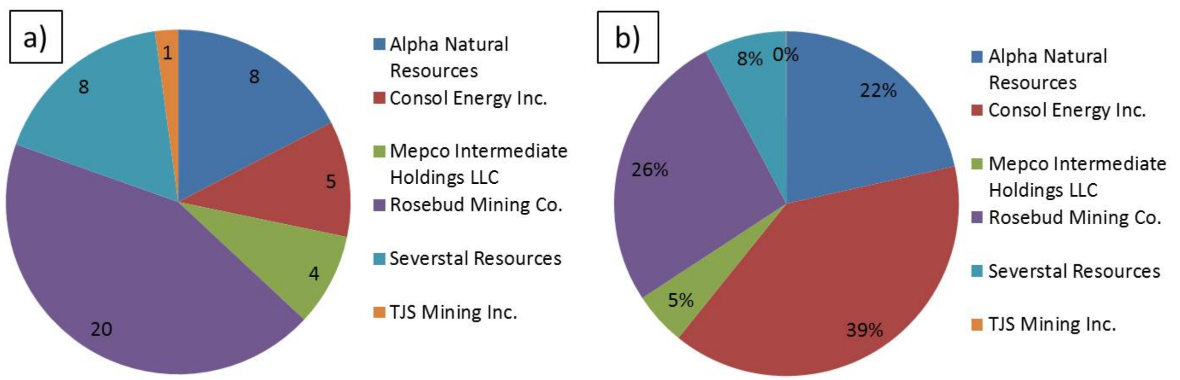


Figure III-2. a) The number of mines operated by each company. b) The percentage of total acres mined by each company. NOTE that Consol Energy has only five mines but 39% of the acreage mined.

III.B.2 – Types of Mining Operations

Three general types of mines are used in Pennsylvania to extract bituminous coal resources: room-and-pillar (RP); room-and-pillar with pillar recovery (PR); and longwall (LW). All three types require room-and-pillar developments where 16 to 20-ft wide entries and cross-cut passages are driven, with interspersed pillars of un-mined coal of varying shapes and sizes. Room-and-pillar mines are comprised exclusively of room-and-pillar developments whereas pillar recovery and longwall mines also utilize full extraction techniques to remove the pillar supports, initiating subsidence of the overburden.

Thirty-four room-and-pillar mines operated during the 4th assessment period (Table III-2). Room-and-pillar mines are found in seven counties: Armstrong, Beaver, Cambria, Elk, Indiana, Jefferson, and Somerset. In these counties, the Freeport and Kittanning Coalbeds are the dominant minable coalbeds.

Table III-2. Thirty-four room-and-pillar mines with operating company, coalbed, county, and Mine Code information.

	Mine	Operating Company	Coalbed	County	Mine Code
1	Agustus	Severstal Resources	Upper Kittanning	Somerset	Ag
2	Barrett Deep	AMFIRE Mining Co. LLC	Lower Kittanning	Indiana	Br
3	Beaver Valley	Rosebud Mining Co.	Upper Freeport	Beaver	Bv
4	Cherry Tree	Rosebud Mining Co.	Upper Freeport	Clearfield	Ch
5	Clementine 1	Rosebud Mining Co.	Lower Kittanning	Armstrong	Cl
6	Darmac 2	Rosebud Mining Co.	Upper Freeport	Indiana	Dm
7	Dora 8	AMFIRE Mining Co. LLC	Lower Kittanning	Jefferson	D8
8	Dutch Run	Rosebud Mining Co.	Upper Freeport	Indiana	Dr
9	Geronimo	Severstal Resources	Lower Kittanning	Somerset	Gr
10	Gillhouser Run	AMFIRE Mining Co. LLC	Lower Freeport	Indiana	Gh
11	Harmony	Rosebud Mining Co.	Upper Kittanning	Clearfield	Hy
12	Heilwood	Rosebud Mining Co.	Lower Kittanning	Indiana	Hw
13	Horning Deep	Severstal Resources	Lower Freeport	Somerset	Hr
14	Kimberly Run	Severstal Resources	Lower Kittanning	Somerset	Kr
15	KnobCreek	Rosebud Mining Co.	Upper Kittanning	Indiana	Kc
16	Little Toby	Rosebud Mining Co.	Lower Kittanning	Elk	Lt
17	Logansport	Rosebud Mining Co.	Lower Kittanning	Armstrong	Lg
18	Long Run	Rosebud Mining Co.	Lower Kittanning	Armstrong	Lr
19	Lowry	Rosebud Mining Co.	Lower Kittanning	Indiana	Ly
20	Madison	AMFIRE Mining Co. LLC	Upper Freeport	Cambria	Ma
21	Miller Deep	Severstal Resources	Upper Freeport	Somerset	Md
22	Ondo	AMFIRE Mining Co. LLC	Lower Kittanning	Indiana	On
23	Penfield	Rosebud Mining Co.	Lower Kittanning	Clearfield	Pf
24	Quecreek 1	Severstal Resources	Upper Kittanning	Somerset	Qc
25	Rossmoyne 1	Rosebud Mining Co.	Upper Freeport	Indiana	Rm
26	Roytown	Severstal Resources	Upper Kittanning	Somerset	Rt
27	Sarah	Severstal Resources	Upper Kittanning	Somerset	Sa
28	Starford	Rosebud Mining Co.	Lower Kittanning	Indiana	St
29	TJS 5	T.J.S. Mining, Inc.	Upper Kittanning	Armstrong	T5
30	TJS 6	Rosebud Mining Co.	Upper Freeport	Armstrong	T6
31	Toms Run	Rosebud Mining Co.	Upper Freeport	Indiana	Tr
32	Tracy Lynne	Rosebud Mining Co.	Lower Kittanning	Armstrong	TL
33	Twin Rocks	Rosebud Mining Co.	Lower Freeport	Cambria	Tw
34	Windber 78	Rosebud Mining Co.	Upper Kittanning	Cambria	W7

Five pillar recovery mines were active during the 4th assessment period (Table III-3). These mines were operated by two companies: AMFIRE and Dana Mining Co. In all five operations, pillar recovery occurred in relatively small mining blocks, typically less than 1,000-ft in length. These areas were mostly within production panels but occasionally occurred along main entries as the mining operations retreated from the mine's reserves.

Table III-3. Five pillar recovery mines with operating company, coalbed, county, and Mine Code information.

	Mine	Operating Company	Coalbed	County	Mine Code
1	4 West	Dana Mining Co.	Sewickley	Greene	Fw
2	Crawdad 1	Dana Mining Co.	Sewickley	Greene	Cd
3	Nolo	AMFIRE Mining Co. LLC	Lower Kittanning	Indiana	No
4	Prime 1	Dana Mining Co.	Sewickley	Greene	Pr
5	Titus Deep	Dana Mining Co.	Sewickley	Greene	Tt

Figure III-3 shows the four Dana Mining operations, all within the Sewickley Coalbed in southern Greene County near the West Virginia state line. In this figure, the room-and-pillar and pillar recovery areas during the 3rd and 4th assessment periods are shown. The small size and sporadic coverage of pillar recovery sections are evident.

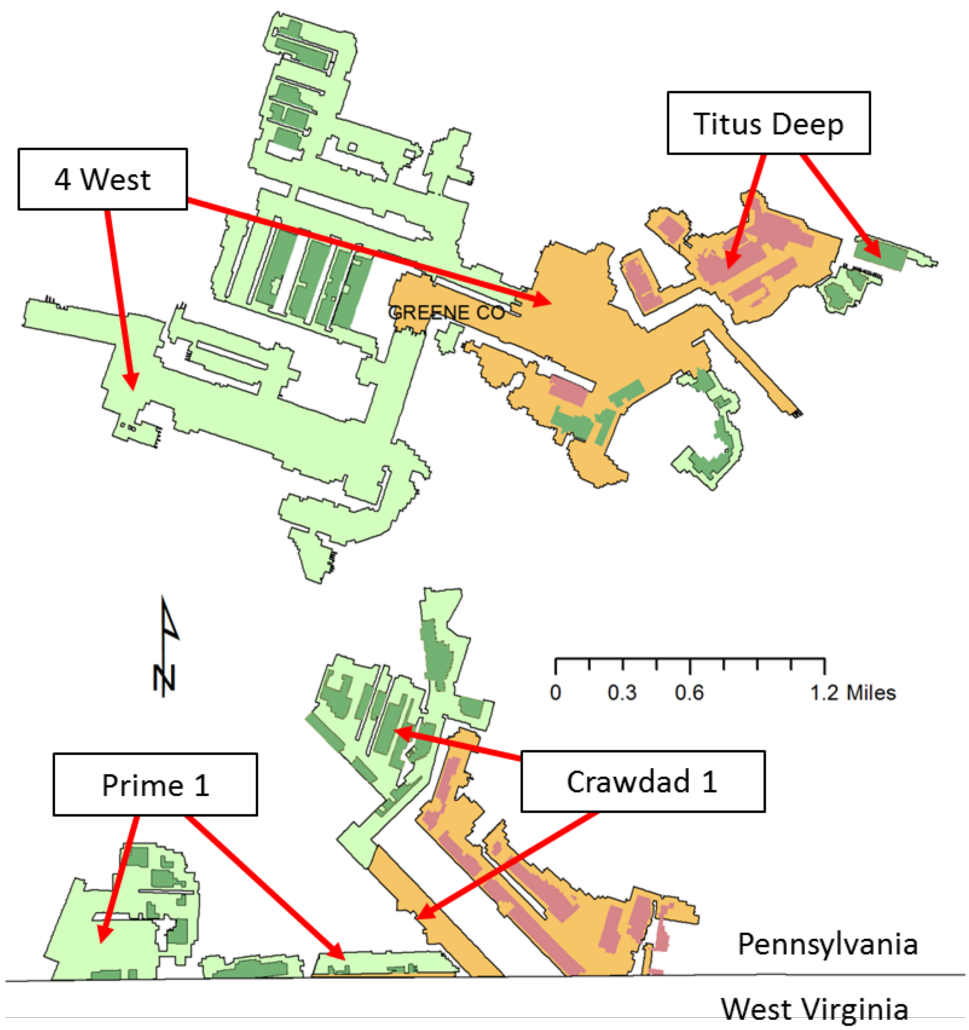


Figure III-3. Four pillar recovery operations in the Sewickley Coalbed of Greene Co. The light green represents room-and-pillar development during the 4th assessment period while the orange shows the 3rd assessment period areas. Dark green and red areas represent pillar recovery sections during the 4th and 3rd assessment periods, respectively.

Seven longwall mines were active during the 4th assessment period (Table III-4). Consol Energy and Alpha Natural Resources managed all seven longwall mines. Many of these operations were among the most productive underground coal mines in the nation (Fiscor 2013). During this period one mine closed, Mine 84, and another opened, BMX.

Table III-4. Seven longwall mines with operating company, coalbed, county, and Mine Code information.

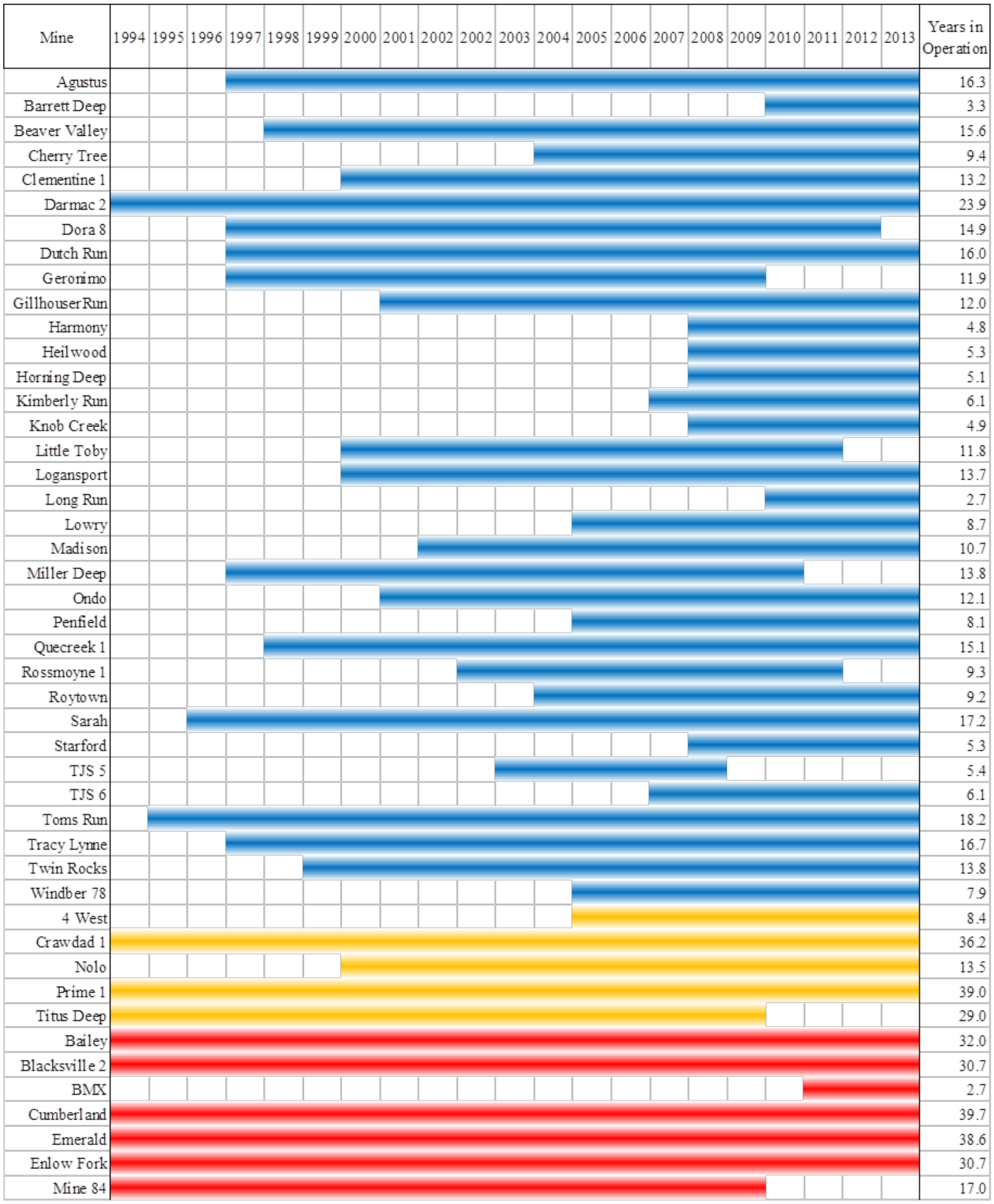
	Mine	Company	Coalbed	County	Mine Code
1	Bailey	Consol Pennsylvania Coal Co. LLC	Pittsburgh	Greene	By
2	Blacksville 2	Consol Coal Co.	Pittsburgh	Greene	Bk
3	BMX*	Consol Pennsylvania Coal Co. LLC	Pittsburgh	Greene	Bx
4	Cumberland	Cumberland Coal Resources LP	Pittsburgh	Greene	Cu
5	Emerald	Emerald Coal Resources LP	Pittsburgh	Greene	Em
6	Enlow Fork	Consol Pennsylvania Coal Co. LLC	Pittsburgh	Washington	Ef
7	Mine 84	Eighty-Four Mining Co.	Pittsburgh	Washington	Eg

* - The BMX mine has yet to commence longwall mining

III.B.3 – Age of Mining Operations

Underground bituminous coal mines operating within the 4th assessment period have been in service for varying lengths of time (Table III-4). Of the 46 mines operating during the 4th assessment period, 11 began and seven ceased operation during this assessment period.

Table III-4. Age of mines operating during the 4th assessment period. NOTE: this analysis only goes back in time to the passage of Act 54 in 1994. Room-and-pillar = blue, pillar recovery = orange, and longwall = red.



III.C – Stratigraphic Influences On Mining

The Commonwealth of Pennsylvania has significant reserves of coal. This resource is arranged in beds contained within the Pennsylvanian and Permian Systems. No Permian Coalbeds were mined in PA using underground methods during the 4th assessment period. Rocks within the Pennsylvanian System range from 299 to 318-million years old (U.S. Geological Survey

Geologic Names Committee 2007) and range in thickness from 1,300 to 1,500-ft (Edmunds et al. 1999). In this region, the Pennsylvanian System contains six formations:

- Uniontown – late Pennsylvanian shales, sandstones, and thin coalbeds
- **Pittsburgh – minable coalbeds,** shales, sandstones, and limestones
- Casselman - claystones, shales, sandstones, and thin limestones
- Glenshaw – claystones, shales, sandstones, and thin limestones
- **Allegheny – minable coalbeds,** shales, claystones, sandstones, and limestones
- Pottsville – early Pennsylvania shales and sandstones

The Casselman and Glenshaw Formations combine to form the Conemaugh Group and the Pittsburgh and Uniontown Formations form the Monongahela Group. The Pottsville Formation and the Conemaugh Group, sometimes referred to as the lower and middle barren formations, are typically void of minable coalbeds. The two prominent coal-bearing formations are the Allegheny and the Pittsburgh. The older Allegheny Formation contains the Freeport and Kittanning Coalbeds while the younger Pittsburgh Formation contains the Pittsburgh and Sewickley Coalbeds (Figure III-5).

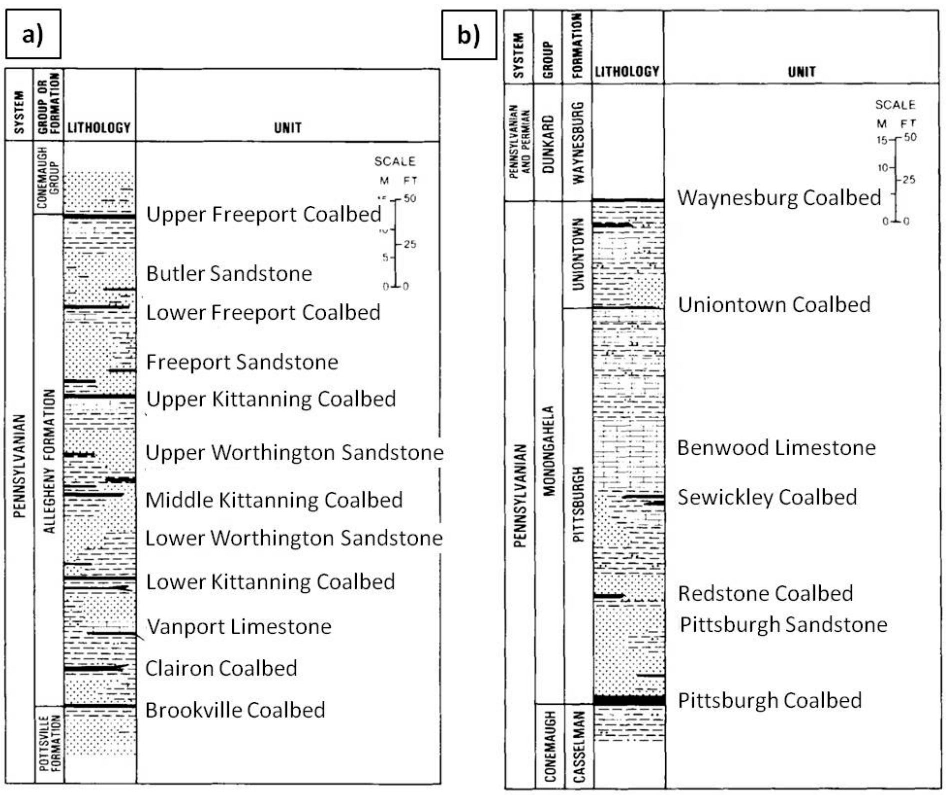


Figure III-5. Generalized stratigraphic sections of the a) Allegheny and b) Pittsburgh Formations of western Pennsylvania (Edmunds et al. 1999).

III.C.1 – Coalbeds Mined

Six coalbeds were mined during the 4th assessment period. Four of the coalbeds are contained within the Allegheny Formation and two within the Pittsburgh Formation (Table III-6). The Allegheny Formation contains 35 mines while the Pittsburgh Formation has 11 mines. The

Allegheny Formation ranges from 270 to 330-ft thick so the distance between the Lower Kittanning and Upper Freeport Coalbeds is relatively moderate (Edmunds et al. 1999). The Pittsburgh Formation averages 240-ft thick with the distance between the Pittsburgh and Sewickley Coalbeds averaging 125-ft. The Allegheny and Pittsburgh Formations are separated by the Conemaugh Group, ranging in thickness from 520-ft in western Washington County to 890-ft in Somerset County (Edmunds et al. 1999). This more significant vertical separation has coalbeds associated with these two formations outcropping in different areas. It is logical, for comparison sake, to group and analyze these coalbeds by formation.

Table III-6. Coalbeds with active mines, listed by number and Formation.

Formation	**Coalbed**	**Number of Mines**	
		3rd Assessment	**4th Assessment**
Pittsburgh	Sewickley	5	4
	Pittsburgh	9	7
Allegheny	Upper Freeport	14	9
	Lower Freeport	2	3
	Upper Kittanning	8	8
	Lower Kittanning	12	15
	Total	50	46

The number of mines that operated in a particular coalbed was not necessarily a good indicator of the total area that was undermined. Figure III-6 shows the relationship between the areas mined in a particular coalbed versus the number of mines operated in this coalbed. For example, five of the seven mines in the Pittsburgh Coalbed were large longwall operations and their corresponding footprint on the surface was equally large. The two Pittsburgh Coalbed mines that did not fit this profile are BMX, a new operation, and Mine 84, closed in 2009. The reason for such a concentration of longwall mines in the Pittsburgh Coalbed is the consistent thickness (5 to 11-ft) extending over large areas. These are near perfect conditions for longwall mining. The thinner, less consistent coalbed of the Allegheny Formation is better suited for the more flexible room-and-pillar mining method. The only other coalbed to show reduced surface areas undermined from the 3rd to the 4th assessment period is the Lower Kittanning (Figure III-6).

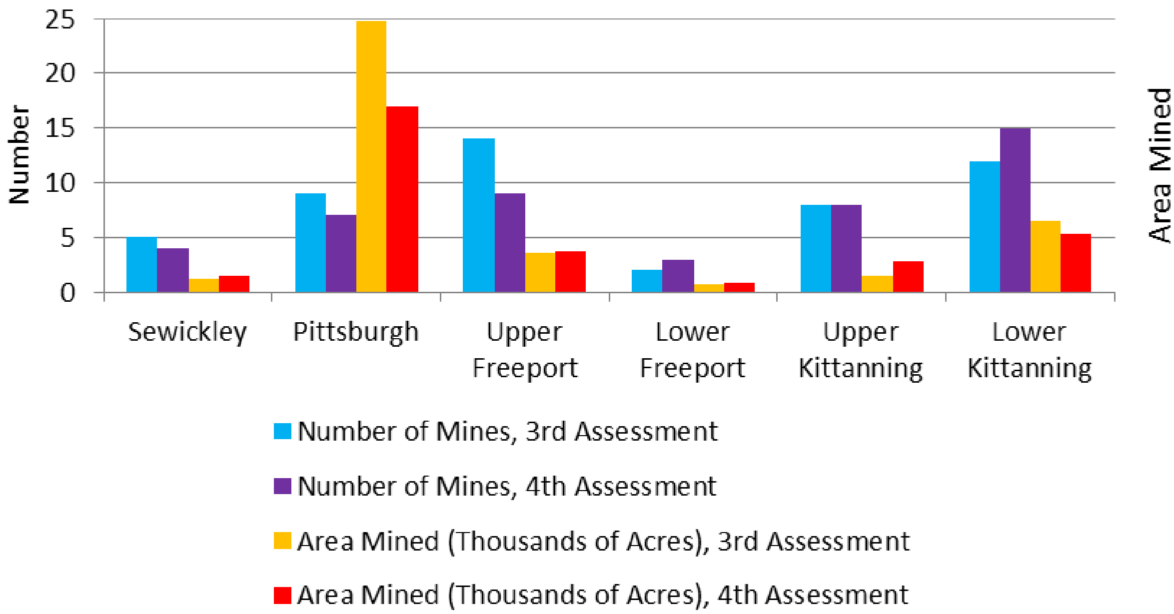


Figure III-6. The distribution of acres undermined between the 3rd and 4th assessment periods based on the coalbed mined. Mining in the Sewickley, Pittsburgh, and Lower Kittanning Coalbed all showed reductions in areas mined while mining in the Upper Freeport, Lower Freeport, and Upper Kittanning Coalbeds showed slight increases. The surface areas undermined by the Pittsburgh Coalbed longwall mines decreased by 31% from the 3rd to 4th assessment period.

III.D –Mining Methods

Three distinct *mining methods* are currently used to extract underground bituminous coal reserves in Pennsylvania: Room-and-Pillar (RP), Pillar Recovery (PR), and Longwall (LW). The room-and pillar development dominates with 59.5% of the total acreage of all methods used (Table III-7).

It is important to distinguish between mining methods in terms of the acreage undermined because the methods vary in expected amount of subsidence. One technique for predicting the degree to which a mining method can cause subsidence is the calculation of the extraction ratio. The extraction ratio, Re, is equal to the extracted area divided by the original area before mining. If all of the coal is mined, Re equals 1.0, conversely, if none of the coal is mined, Re equals zero. The formula for calculating Re is:

$$Re = \frac{Extracted\ area}{Original\ area} = \frac{(pl1 + rw)(pl2 + rw) - (pl1 \times pl2)}{(pl1 + rw)(pl2 + rw)}$$

Where: pl1 = pillar length (Figure III-7)
pl2 = pillar width
rw = room width

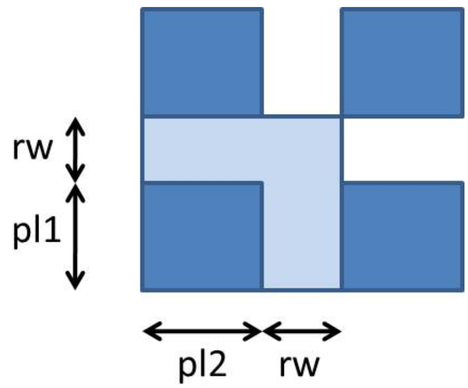


Figure III-7. Parameters, pillar length (pl1), pillar width (pl2), and room width (rw), used to calculate the extraction ratio.

For example, a typical longwall mine has both room-and-pillar developments and longwall panels. Mining these longwall panels, where the extraction ratio is close to 1.0, causes the surface to subside. The subsidence results in the formation of a basin-shaped trough (see Introduction). Longwall panels are surrounded by room-and-pillar sections. The University measured the Re for a wide range of mining methods and found that room-and-pillar developments have Re values between 0.4 and 0.7 (Table III-7). Room-and-pillar developments do not generally directly cause measureable surface subsidence (i.e. subsidence > 0.5-in). However, subsidence impacts can occur above room-and-pillar sections when they are located adjacent to longwall panels or pillar recovery areas. Pillar recovery mining in Pennsylvania extracts on average more than 70% of the coal but, unlike longwall panels, rarely removes all of the supporting pillars. This results in Re values somewhere between 0.7 and 1.0 (Table III-7). Pillar recovery mining does produce a surface subsidence basin and, at low overburdens, can produce subsidence impacts.

Table III-7. Acres mined by mining method and extraction ratio.

Mining Method	**Extraction Ratio, Re**	**Surface Area Undermined**	
		Acres	**%**
Room-and-Pillar Developments	0.4 to 0.7	18,680.5	59.6
Pillar Recovery	0.7 to 1.0	282.8	0.9
Longwall	1.0	12,380.0	39.4
	Total	31,343	100

III.D.1 – Area Undermined by Room-and-Pillar Developments

All 46 mines operated during the 4th assessment period used room-and-pillar developments ranging in size from 1,293.4-acres at Enlow Fork to 9.5-acres at TJS 5 (Figure III-8). The average area underlain by room-and-pillar developments was 406.1-acres with an average mining rate of 6.1 acres/month.

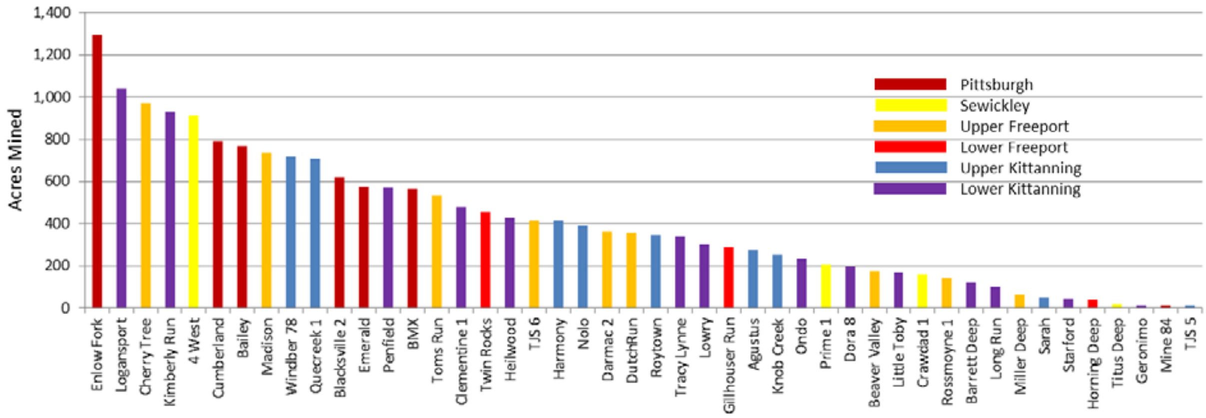


Figure III-8. Areas mined and coalbeds for 46 mines with room-and-pillar developments. It should be noted that areas mined in West Virginia at the Bailey Mine were not considered in this analysis.

Room-and-pillar mining occurred in all six coalbeds. Those in the Pittsburgh and Sewickley Coalbeds should be looked at differently than the others since this is where all the longwall and pillar recovery mining occur. In these areas, room-and-pillar developments can be located near or next-to full extraction mining and subsidence effects can be felt significant distances away. Conversely, for developments in the Kittanning and Freeport Coalbeds, measurable subsidence is unlikely to be observed.

There are two conditions that represent exceptions to the above statements and may result in subsidence impacts with room-and-pillar mining developments:

- <u>Pillar-punching</u> – Typically pillar punching, or floor heaving, occurs when pillars are pressed into claystone layers in the mine's floor. One pillar-punching episode (Figure III-9) was noted during the 3rd assessment period (Iannacchione et al. 2011) but none were documented during the 4th assessment period. It should be noted that the University relies mainly on information contained on six-month mining maps to identify this phenomenon, i.e. written observations contained on the maps.

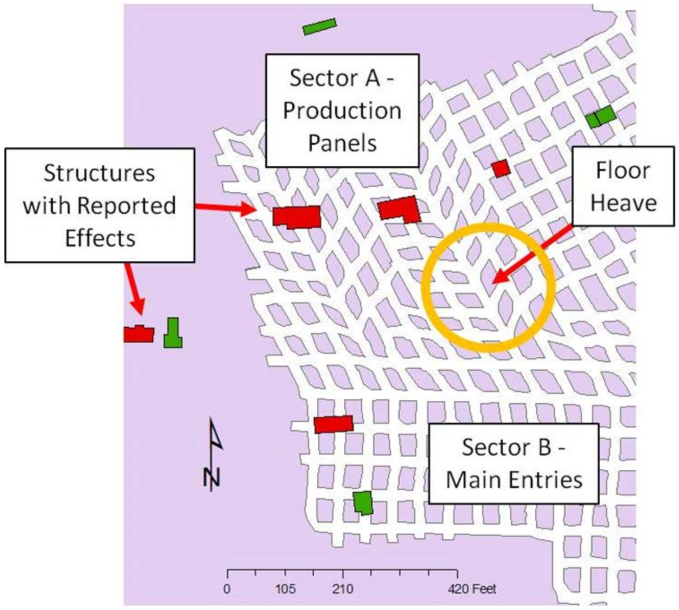


Figure III-9. Area within the Ondo Mine where five structures with reported effects occurred within two distinct pillar layouts, A & B. Note – Red = structures with reported effects, and Green = structures without reported effects (from Iannacchione et al. 2011, Figure V-10).

- Long-term pillar instability – Long-term pillar instability can occur when the strength of the coal pillar (S_p) is exceeded by the overburden pressure (σ_p) applied by the weight of the overburden rock (σ_p).

$$Potential\ for\ pillar\ failure\ or\ Safety\ Factor\ (SF) = \frac{S_p}{\sigma_p}$$

Where: S_p = Strength of coal pillars
σ_p = Overburden pressure on the pillar

The overburden pressure on the pillar is dependent on the weight of the overburden rock (σ_i) and the extraction ratio, Re (Figure III-10).

$$\sigma_p = \frac{\sigma_i}{(1 - Re)} = \sigma_v \times \frac{(pl1 + rw)^2 - (pl2 + rw)^2}{(pl1 \times pl2)^2}$$

Where: $\sigma_v = h \times W \times SG$
h = depth of mining
W = specific weight of water
SG = specific gravity of the overburden

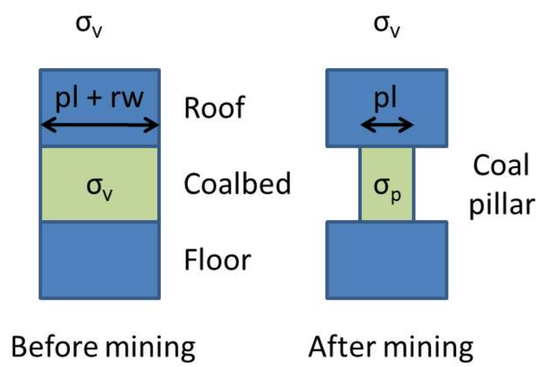


Figure III-10. Parameters important for determining the stability of coal mine pillars used in room-and-pillar developments.

Today in Pennsylvania most room-and -pillar developments are designed with extraction ratios of 0.5 to 0.7 and under 1,000-ft of overburden. If either of these parameters are increased, pillar instabilities could result and subsidence related impacts could occur at the surface.

III.D.2 – Area Undermined by Longwall Panels

Fifty-two longwall panels in six mines extracted coal under 12,380 acres of surface land (Table III-8). The average panel size is 238.1-acres with a standard deviation of 121.6 acres. The largest panels are over 400-acres in size. The average panel width is now 1,290-ft with many of the newest panels approaching 1,500-ft. The average panel length is 8,536-ft. The average length of time to mine a standard size panel is almost 300 days. In general, the panels in the 4th assessment period mined approximately 1-acre/day. In comparison, room-and-pillar developments mine at a much slower rate, i.e. on average five acres/month (see Section III.D.1).

Table III-8. Longwall panel size, shape, and mining history.

Mine	Panel	Start	End	Days	Acreage	Acres /day	Width	Length	Status
Bailey	10I	8/21/2008^	11/3/2008	74	73.5	0.99	1095	10410	C^{+}
	11I	11/18/2008	7/22/2009	246	305.9	1.24	1088	12046	C
	12I	8/4/2009	5/31/2010	300	328	1.09	1163	12066	C
	13I	6/7/2010	3/19/2011	285	328.7	1.15	1164	12023	C
	14I	3/25/2011	12/18/2011	268	304.5	1.14	1089	11900	C
	15I	12/30/2011	2/6/2013	404	416.2	1.03	1480	12084	C
	16I	2/28/2013	8/20/2013*	173	188.8	1.09	1475	5489	Active
	12H**	6/28/2008	1/24/2009		194.7	0.93	1071	7744	C
	13H**	1/25/2009	8/24/2009		183.6	0.87	1085	7255	C
	14H**	9/3/2009	7/6/2010		229.8	0.75	1475	6671	C
	15H**	7/15/2010	4/28/2011		207.1	0.72	1460	6013	C
	16H**	10/31/11	2/27/2012		184.5	1.55	1490	5357	C
	17H**	10/31/12	2/20/13		162.3	1.45	1493	4713	C
Blacksville 2	14-W	9/20/10	5/24/11	246	264.7	1.08	1076	10598	C
	15-W	1/21/10	9/10/10	232	232	1	1081	9142	C
	16-W	3/17/09	1/13/10	302	228.1	0.76	1086	9166	C

Mine	**Panel**	**Start**	**End**	**Days**	**Acreage**	**Acres /day**	**Width**	**Length**	**Status**
	17-W	6/6/11	9/2/12	454	229.8	0.51	1094	11822	C
	18-W	2/29/12	5/30/13	456	298.5	0.65	1066	9257	C
	19-W	6/8/13	8/20/13	73	10	0/14	1100	405	Active
Cumberland	LW54	8/21/2008^			37.1		1355	1183	C
	LW55	10/3/2008	2/22/2009	142	211.8	1.49	1355	6653	C
	LW56	3/16/2009	9/30/2009	198	270.5	1.37	1354	8636	C
	LW57	10/20/2009	4/28/2010	190	258.6	1.36	1390	8101	C
	LW58	6/2/2010	3/24/2011	295	349	1.18	1408	10771	C
	LW59	4/9/2011	12/3/2011	238	354.4	1.49	1397	11007	C
	LW60	12/8/2011	4/19/2012	133	172.3	1.30	1409	5301	C
	LW60 A	5/7/2012	9/2/2012	118	149.3	1.27	1388	4688	C
	LW61	9/18/2012	9/20/2013*	367	58.9	0.16	1564	1640	Active
Emerald	B6	9/15/2008	2/18/2009	156	126.9	0.81	1428	3838	C
	B7	3/18/2009	8/11/2010	511	387.1	0.76	1428	11811	C
	C1	8/21/2008^	6/19/2009	302	170.1	0.35	1231	5998	C
	C2	8/13/2009	5/24/2011	649	372.5	0.57	1436	11277	C
	C3	7/11/2011	8/20/2013	771	312.9	0.41	1246	10721	C
	E1	5/25/2011	3/7/2012	287	106.1	0.37	1433	3202	C
	E2	4/4/2012	8/20/2013*	503	33.2	0.07	1433	832	Active
Enlow Fork	E17	2/10/2008	9/30/2008	233	4.9	0.02	1061	11824	C
	E18	8/21/2008^	3/12/2009	203	305.5	1.50	1068	12245	C
	E19	3/16/2009	10/4/2009	202	305.8	1.51	1091	12227	C
	E20	10/5/2009	6/14/2010	252	304.7	1.21	1086	12207	C
	E21	6/18/2010	3/31/2011	286	415.8	1.45	1487	12232	C
	E22	3/2/2011	2/13/2012	348	407.6	1.17	1484	11981	C
	E23	2/8/2012	2/15/2013	373	411.3	1.10	1487	12085	C
	E24	2/11/2013	8/20/2013*	190	233.8	1.23	1487	12085	Active
	F16	8/21/2008^	10/31/2008	71	78.4	1.10	1087	3144	C
	F17	10/22/2008	6/26/2009	247	303.2	1.23	1091	12142	C
	F18	6/12/2009	1/22/2010	224	303	1.35	1091	12153	C
	F19	1/16/2010	9/10/2010	237	302.4	1.28	1078	12156	C
	F20	9/16/2010	9/17/2011	366	412	1.13	1485	12103	C
	F21	9/14/2011	9/11/2012	363	400	1.10	1502	11750	C
	F22	8/30/2012	8/1/2013	336	387.6	1.15	1490	11381	C
	F23	7/27/2013	8/20/2013*	24	6.4	0.27	1484	188	Active
Mine 84	10B	12/3/2008	3/6/2009	93	56.2	0.6	1153	2144	C

* - Ongoing
^ - Panel started in 3rd assessment period
+ - Panel completed during the 4th assessment period
** - Part of the panel was mined in West Virginia

The 52 longwall panels are all located in Greene and Washington Counties (Figure III-11). This figure illustrates the significant differences in mine layouts. The Enlow Fork is extracting panels in a regular pattern, while the Cumberland and Emerald panels are spread over more irregular blocks of reserves. The shorter panels typically represent mining over the start or end of the assessment period. The lone panel at Mine 84 represents the final segment of mining in late 2008, early 2009. Lastly, please note that all of the panels are oriented approximately N 60 W. This orientation originated in earlier Pittsburgh Coalbed room-and-pillar mines prior to the introduction of longwall mining. Planes of weakness within the coalbed, called face and butt cleat, are oriented parallel and perpendicular to the N 60 W orientation, and allowed for the most efficient and effective means of extracting the coal with conventional mining techniques.

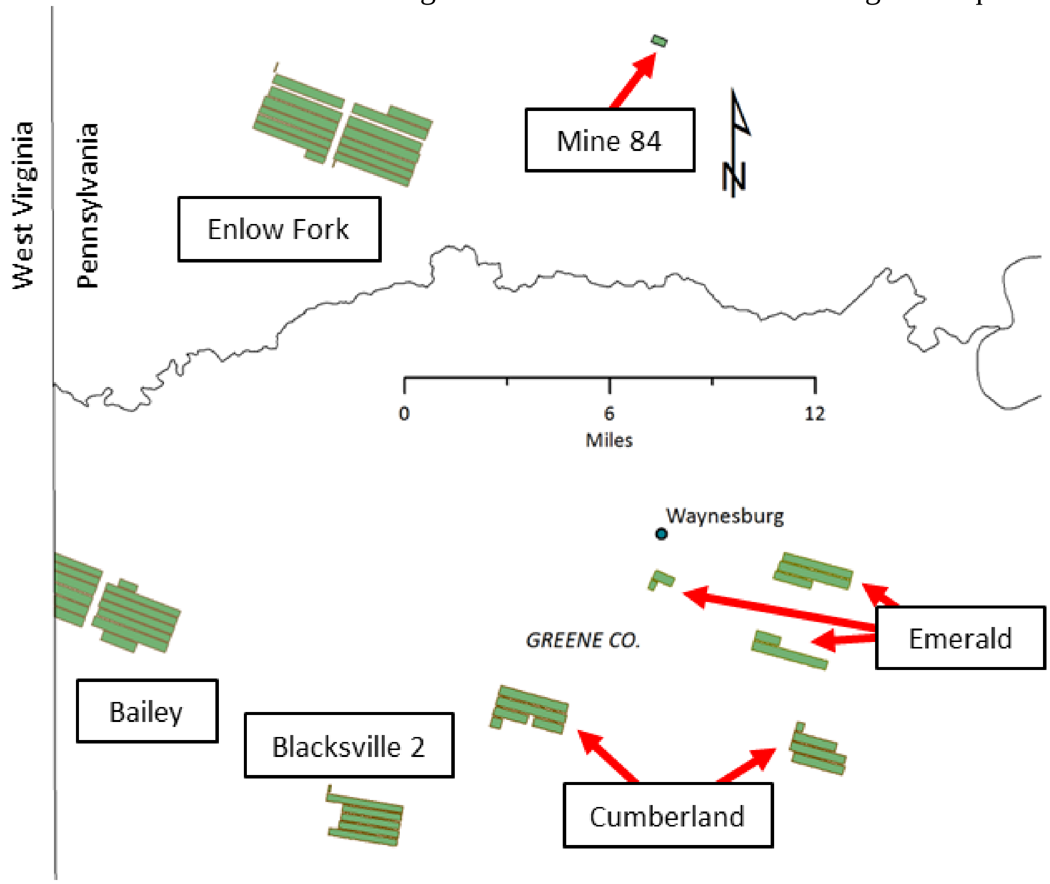


Figure III-11. Six underground coal mines with 52 longwall panels extracted during the 4th assessment period.

III.D.3 – Area Undermined by Pillar Recovery Panels

Five mines used pillar recovery mining methods, mining under 282.8-acres of land (Table III-9). The total areas undermined by this mining method were almost identical to those in the 3rd assessment period (276-acres). In general, pillar recovery is practiced close to West Virginia in the Sewickley Coalbed. The panels containing the pillar recovery areas are typically small (< 20-acres) and occur in rural areas impacting only a few water supplies or structures (see Sections IV and V).

Table III-9. Areas undermined by room-and-pillar mines with pillar recovery, 3rd and 4th assessment period.

Mine Name	**Coalbed**	**Room and Pillar, Acres**		**Pillar Recovery, Acres**	
		3rd	**4th**	**3rd**	**4th**
Nolo	Lower Kittanning	880	388.2	50	22.2
Crawdad 1	Sewickley	326	159.9	86	75.6
4 West	Sewickley	407	928.7	9	127.6
Titus	Sewickley	187	18.9	73	21.6
Prime 1	Sewickley	-	206.4	-	35.8
Dooley Run	Sewickley	21	-	30	-
Dunkard 2	Sewickley	-	-	49	-
Total		1,821	1,702.1	276	282.8

III.E – Mining in Different Counties

As has been noted above, the distribution of mining activity is not uniform across western Pennsylvania. Mining activity in any particular area is connected to three general factors:

1) The occurrence of coal bearing strata, i.e. the Allegheny and Pittsburgh Formations,
2) The coalbed overburden, i.e. at present very little coal greater than 1,000-ft deep is being mined in Pennsylvania, and
3) The economic value of the coalbeds, i.e. coal thickness, quality, accessibility, ownership, etc.

The unique reaction to the three mining factors listed above, produces a wide range of mining activity that is best characterized by county (Figure III-12). Ten counties contained active underground bituminous coal mines during the 4th assessment period. Greene County accounted for 40.3 % of the total area mined and Washington County nearly half that with 19.0%. Armstrong, Cambria, Clearfield, Indiana and Somerset Counties have similar percentages and together accounted for approximately 39.0% of the acreage undermined. Beaver, Jefferson, and Elk have only one relatively small room-and-pillar mine each (Table III-10) and accounted for 1.7% of the total.

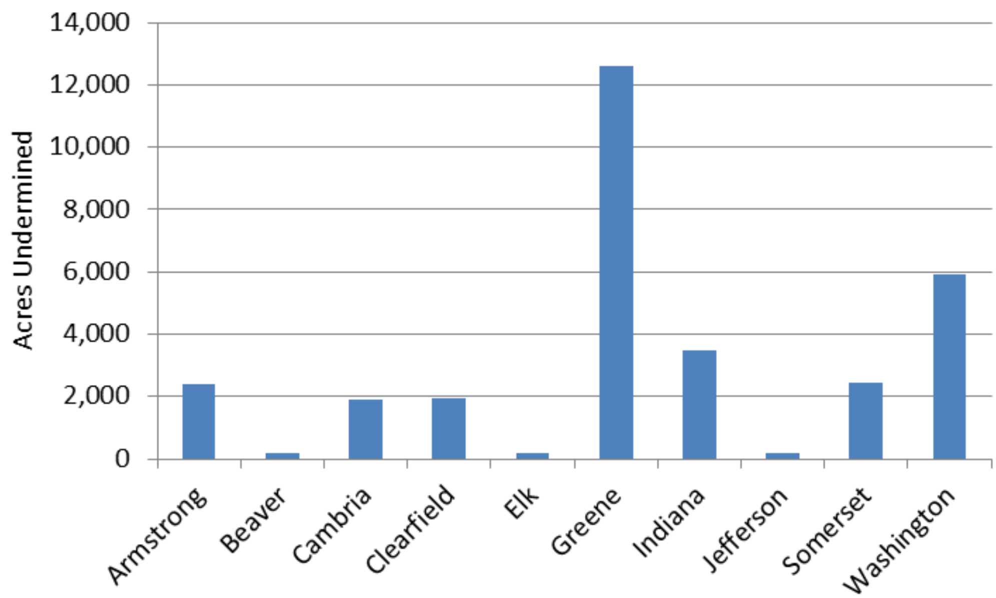


Figure III-12. Areas undermined by county.

Table III-10. Acres undermined in the ten counties producing underground bituminous coal in Pennsylvania.

County	Acres	% of Total Acres
Armstrong	2,400.5	7.7
Beaver	172.7	0.6
Cambria	1,911.0	6.1
Clearfield	1,955.2	6.2
Elk	168.6	0.5
Greene	12,637.1	40.3
Indiana	3,536.8	11.3
Jefferson	196.4	0.6
Somerset	2,422.2	7.7
Washington	5,942.7	19.0
Total	31,343	100

III.F – Variations in Overburden

The variability in the overburden characteristics of the 46 mines studied is significant and important because differences in overburden can affect structures, water supplies, and land in different ways. The shallowest overburden was projected at less than 100-ft in eight room-and-pillar mines; while four mines, all longwall, had maximum overburdens over 1,000-ft.

III.F.1 – Overburden Categories

It is useful to categorize the relative overburden conditions associated with a mine or a mining method. To this end, the University calculated the average, standard deviation, minimum, and maximum overburden conditions for each mine. These conditions were grouped into three distinct overburden categories; shallow, average, and deep and also grouped by mining type. The average overburden category comprised all mines whose values fell within one standard deviation of the mean. This accounted for approximately 2/3 of the mines. The other 1/3 were split between shallow and deep. The category shallow contained mines that had an average overburden greater than one standard deviation below the mean. Conversely, the category deep contains mines that had an average overburden greater than one standard deviation above the mean (Table III-11).

Three categories are determined for each of the three types of mines, yielding nine boundary values. When each of these boundary values for the 3rd and 4th assessment period is analyzed (Table III-11), all show an increase, indicating a measurable rise in the depth of mining occurred between periods.

Table III-11. Definitions of the overburden categories for the three mining types are shown. Ranges were based on the individual average overburdens measured for each mine.

Type of Mine	Overburden Category					
	Shallow, ft		Average, ft		Deep, ft	
	3rd Assessment Period	**4th Assessment Period**	3rd Assessment Period	**4th Assessment Period**	3rd Assessment Period	**4th Assessment Period**
Room-and-Pillar	< 185	**< 200**	185 to 397	**200 to 562**	> 397	**> 562**
RP with Pillar Recovery	< 283	**< 391**	283 to 473	**391 to 685**	> 473	**> 685**
Longwall	< 525	**< 627**	525 to 850	**627 to 939**	> 850	**> 939**

III.F.2 – Longwall Mine Overburden

The seven longwall mines varied in overburden from a minimum of 299-ft at the Emerald Mine to a maximum of 1,230-ft at the BMX Mine (Table III-12). The average longwall overburden was 783-ft with a standard deviation of 156-ft. That is approximately 115-ft greater than the average longwall overburdens during the 3rd assessment period. These data suggest that significant increases in the longwall overburden are occurring. Since there is a relationship between overburden and the maximum amount of vertical subsidence, one could suggest that less dramatic impacts on water supply and structures should be occurring. Using the overburden categories discussed in Section III.F.1, five mines were average with one shallow and one deep (Table III-12).

Table III-12. Overburden characteristics for longwall mines.

Mine	Avg.	Median	SD*	Min.	Max.	Category
Bailey	717	719	127	374	1067	Average
Blacksville 2	920	913	98	699	1155	Average
BMX	971	994	151	548	1230	Deep
Cumberland	867	873	137	565	1185	Average
Emerald	638	633	121	299	959	Average
Enlow Fork	688	696	90	465	919	Average
Mine 84	575	581	78	445	699	Shallow

* SD – Standard Deviation

The spread in the overburden distribution for each of the seven longwall mines is shown in Figure III-13. The range in overburden conditions found within the Bailey and Emerald Mines is the greatest amount these mines. The BMX and Mine 84 had a very small foot-print during the 4th assessment period.

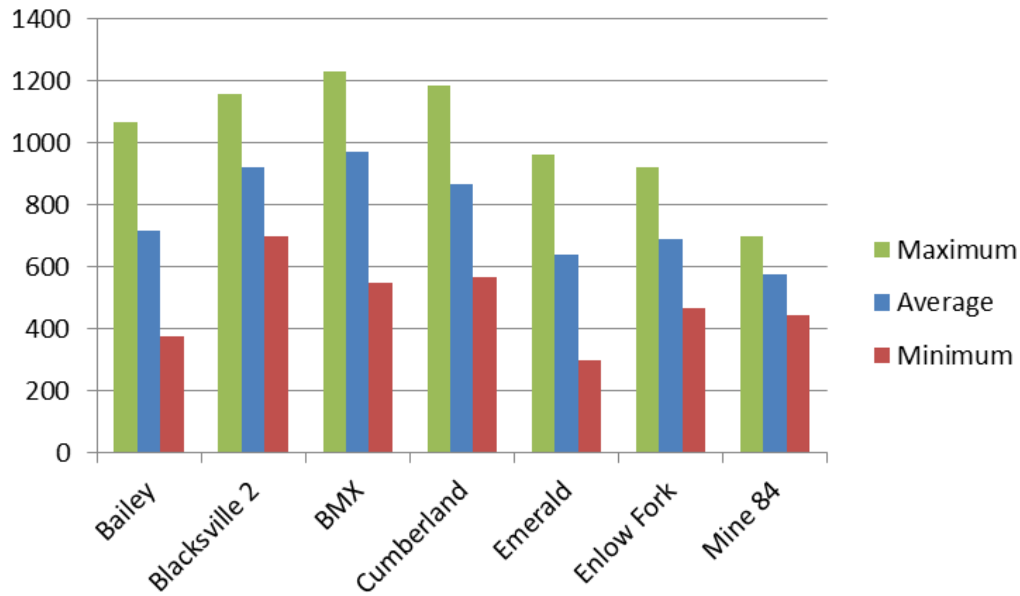


Figure III-13. The distribution in overburden within each of the seven longwall mines.

III.F.3 – Room-and-Pillar Overburden

When compared to the seven longwall mines above, the 34 room-and-pillar mines had less overburden with an average of 381-ft. The lowest overburden occurred at the Lowry Mine, 52-ft, and the highest at Toms Run, 863-ft (Table III-13).

Table III-13. Overburden characteristics for room-and-pillar mines sorted from highest to lowest.

Mine Name	Avg.	Median	SD*	Min.	Max.	Category
TJS 5	643	661.5	56	494	712	Deep
Toms Run	573	615	145	136	863	Deep
Penfield	506	502	82	165	704	Average
Logansport	476	483	65	373	622	Average
Tracy Lynne	470	459	76	305	697	Average
Heilwood	438	449	77	104	575	Average
Clementine	425	443	49	306	518	Average
Windber 78	406	406	59	249	528	Average
Quecreek	395	401	84	227	594	Average
Sarah	381	402	70	209	504	Average
Roytown	377	397	47	225	464	Average
Gillhouser Run	374	382	52	178	509	Average
Darmac 2	372	352	95	188	605	Average
CherryTree	371	376	62	162	561	Average
Lowry	365	365	89	52	516	Average
Harmony	361	375	45	106	415	Average
Ondo	348	374	105	83	508	Average
Starford	335	343.5	66	181	474	Average
Barrett	330	356	83	99	458	Average
Beaver Valley	315	303	48	183	414	Average
Dutch Run	308	298	71	167	500	Average
Horning Deep	287	289	100	121	419	Average
Dora 8	275	208	155	95	538	Average
Twin Rocks	275	271	21	220	334	Average
Long Run	268	267	34	95	327	Average
Madison	262	245	51	181	414	Average
Little Toby	257	265	47	107	340	Average
Agustus	238	236	28	189	304	Average
Knob Creek	236	234	46	129	339	Average
TJS 6	223	222	80	68	491	Average
Kimberly Run	207	208	46	95	317	Average
Geronimo	190	179	34	142	256	Shallow
Miller Deep	175	176	6	150	195	Shallow
Rossmoyne 1	160	165	41	100	300	Shallow
Total	Avg. = 355			Min. = 52	Max. = 863	

* SD – Standard Deviation

The spread in average overburden for each of the 34 room-and-pillar mines is shown in Figure III-14. In this figure, the two deepest mines, TJS 5 and Toms Run, were greater than one standard deviation for the average of all room-and-pillar mines (355-ft), whilst Geronimo, Miller Deep, and Rossmoyne 1 were one standard deviation less than the average. Seven mines had an overburden less than 100-ft. Portions of 17 mines had overburdens greater than 500-ft.

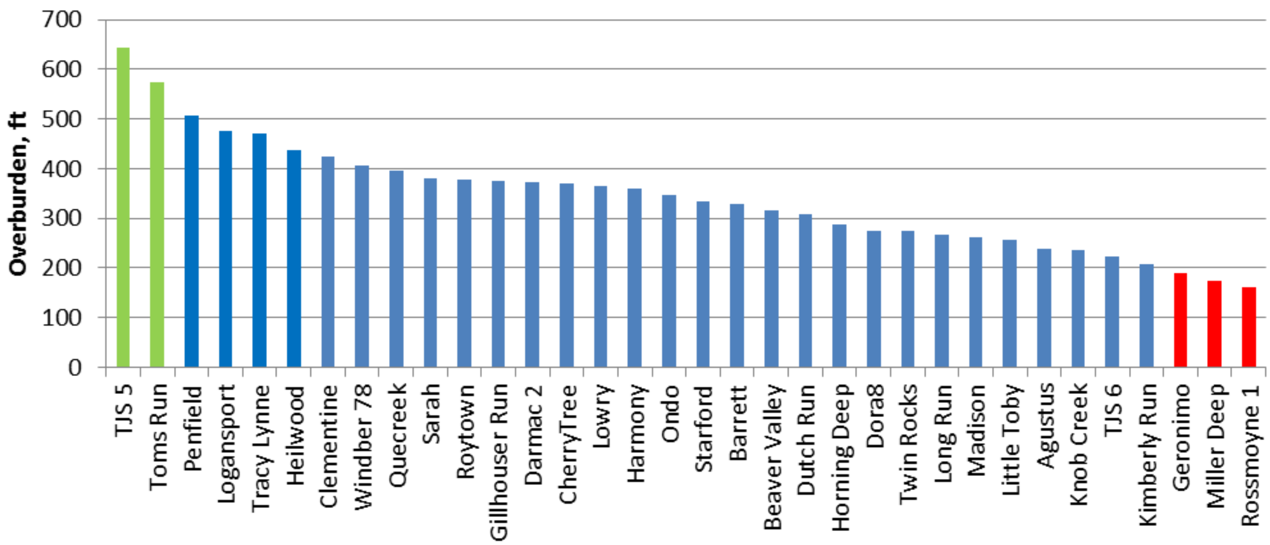


Figure III-14. Distribution of average overburdens for the 34 room-and-pillar mines. Note green mines are classified as deep, blue as average, and red as shallow overburden mines.

III.F.4 – Room-and-Pillar with Pillar Recovery Overburden

When compared to the 34 mines above, the five room-and-pillar mines with pillar recovery were higher in overburden with an average of 540-ft and a standard deviation of 147-ft. The lowest overburdens, 130-ft, occurred at the Titus Deep (Table III-14) a mine that is classified as a shallow overburden pillar recovery mine. The Crawdad mine is classified as deep while the other four mines are classified as average overburden (Table III-14).

Table III-14. Overburden characteristics for room-and-pillar mines with pillar recovery.

Mine	Avg.	Median	SD*	Min.	Max.	Category
4 West	548	566	138	138	845	Average
Crawdad	728	734	25	674	772	Deep
Nolo	405	421	54	229	512	Average
Prime 1	574	564	112	364	846	Average
Titus Deep	304	314	66	130	420	Shallow
Total	540	543	147	130	846	

* SD – Standard Deviation

The overburden distribution for the five room-and-pillar mines with pillar recovery is shown in Figure III-15. The significant spread between minimum and maximum overburdens is evident for all of the mines except Crawdad. The 4 West Mine has the largest variations in overburden.

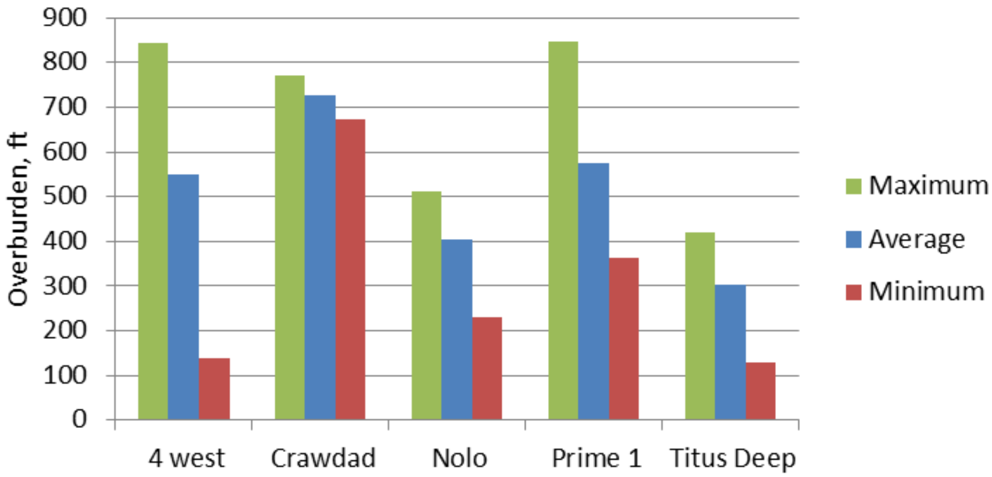


Figure III-15. The distribution in overburden within each of the five pillar recovery room-and-pillar mines.

III.G – Area and Surface Properties Undermined Organized by Mine

Surface properties within 1,000-ft of mining were identified and located by the University within ArcGIS to aid in the location of surface structures and water supplies. Figure III-16 provides an example of surface properties within a 1,000-ft buffer of the Windber 78 Mine. If any part of the property is within the 1,000-ft buffer, information on the acreage and ownership were collected.

Figure III-16. Surface properties (Pink) and the 1,000-ft buffer around the extent of Windber 78 mining.

The number and size of properties that are undermined and/or in the buffer area provide an indirect means to estimate the potential for subsidence related impacts. The average property is 29.1 acres. Properties range from as little as 0.1 acres to as large as 587.4-acres (Table III-15). Each property has the potential for at least one structure and a water supply. Therefore, it is expected that the smaller the average property size over a mine, the more structures and water supplies undermined per acre mined. For example, five mines, Geronimo, Toms Run, Lowry, Heilwood, and Miller Deep, all have an average property size of less than five acres. In comparison, four mines, Titus Deep, Little Toby, Dora 8, and Barrett Deep, all have an average property size greater than 60-acres.

Table III-15. Surface properties within 1,000-ft of mining during the 4th assessment period.

Number of Properties	Total Property Area, Acres	Avg.	SD	Min.	Max.
6,744	131,542	29.1	18.7	0.1	587.4

III.H – Future Mining Trends

Below, the University estimates the amount and character of future underground bituminous coal mining in Pennsylvania. This was accomplished by collecting information on past underground mining within the Pittsburgh Coalbed in Washington and Greene Counties and identifying future areas of mining.

III.H.1 - Trends in Pittsburgh Coalbed Longwall Mining

Since its introduction in 1971 to the Pittsburgh Coalbed of southwestern Pennsylvania, 12 mines have used the longwall mining method (Figure III-17a). In the 1970's, longwall panels were sized to fit within existing production panels commonly used in Pittsburgh Coalbed room-and-pillar mines. These early longwall mines include Blacksville 1, Emerald, Gateway, Humphrey No.7, Maple Creek and Mine 84. In the 1990's the size of longwall panels began a dramatic expansion in size and in layout. Today, Pittsburgh Coalbed mines are designed exclusively around the longwall method. These mines include Bailey, Blacksville 2, Cumberland, Emerald, Enlow Fork, and BMX. The overburden in the remaining unmined portions of the Pittsburgh Coalbed ranges from less than 300-ft in the northwest portion of the basin to as much as 1,433-ft in the southwestern portion of Greene County (Figure III-17b).

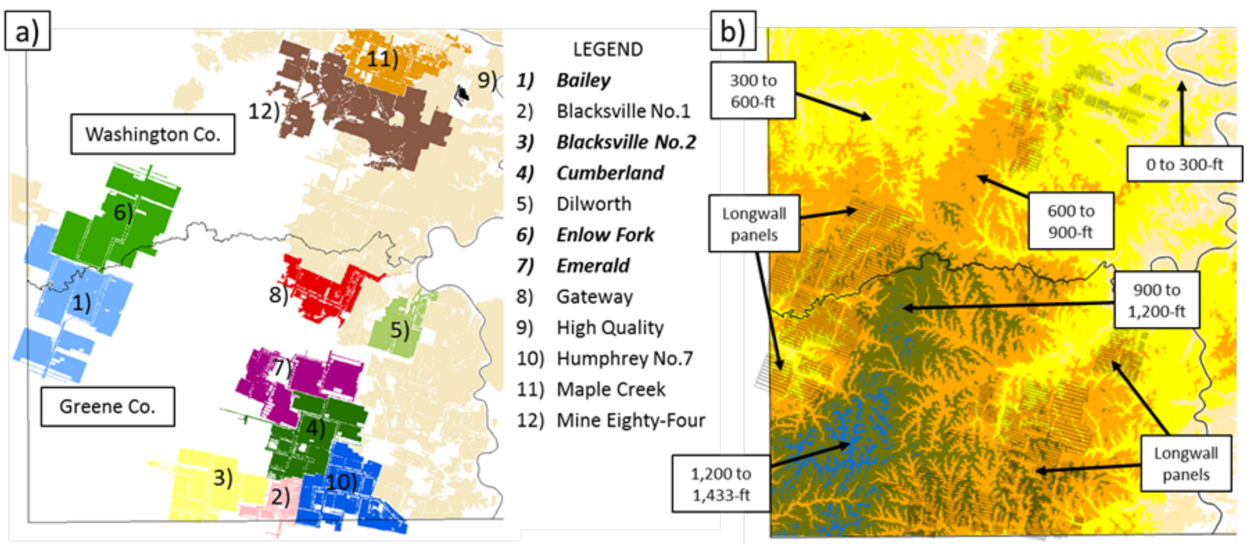


Figure III-17. a) Location and names of the 12 longwall mines (LW) in the Pittsburgh Coalbed of Pennsylvania (The bold & italic are active at the time of the report) and b) Overburden map showing panels mined prior 2013.

By 2008, longwall panels had grown to enormous sizes and now range between 1,200 and 1,500-ft in width and often over 10,000-ft in length (see Table III-8). This change is best illustrated in Figure III-18. When the size of longwall panels are graphed against year of completion, a zone of practical layout size through time is evident. For any given year, technology limitations represent a major restriction above the zone of practical panel layout design. Below this zone, mines are affected by adverse property, geologic or mining conditions (Figure III-18). Adverse property conditions include lease boundaries, gas wells and important surface structures or features. Adverse geologic conditions are mainly associated with localized areas of low, or no, coal but could also be related to any rapid change in the elevation of the coalbed, i.e. rolls, faults, etc.

Adverse mining conditions consist of unstable strata or excessive gas emissions. Clearly, the width of longwall panels is expected to continue to increase. Wider longwall panels would produce fewer gateroad entries, reducing the areas of high strain along the margins of the subsidence basin. In addition, few stream segments would be located above gateroads, reducing the frequency of associated stream pooling above the adjacent panels.

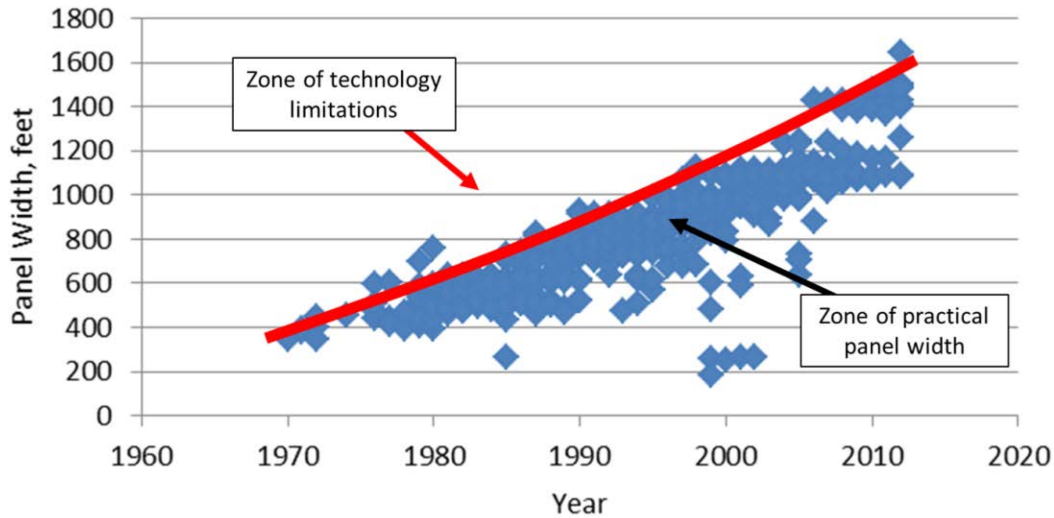


Figure III-18. The graph shows how longwall panel designs have gradually grown through time. Two zones are illustrated: technology limitation and average longwall panel design (delineated by red line).

III.H.1 – Size and Location of Pittsburgh Coalbed Longwall Panels

Past underground coal mine layouts are compiled and displayed in Figure III-19. The location of unmined Pittsburgh Coalbed is calculated to underlay approximately 308,000-acres of surface land. If we assume that all future Pittsburgh Coalbed extraction will be done with the longwall mining method and that 50% will not be mined due to adverse coal thickness or land ownership, then approximately 154,000 acres of coal remain. During the 3rd and 4th assessment period, an average of 4,161-acres were longwall mined every year within Greene and Washington Counties. If this rate of mining continues, it will take approximately 37 years to mine the remaining Pittsburgh Coalbed.

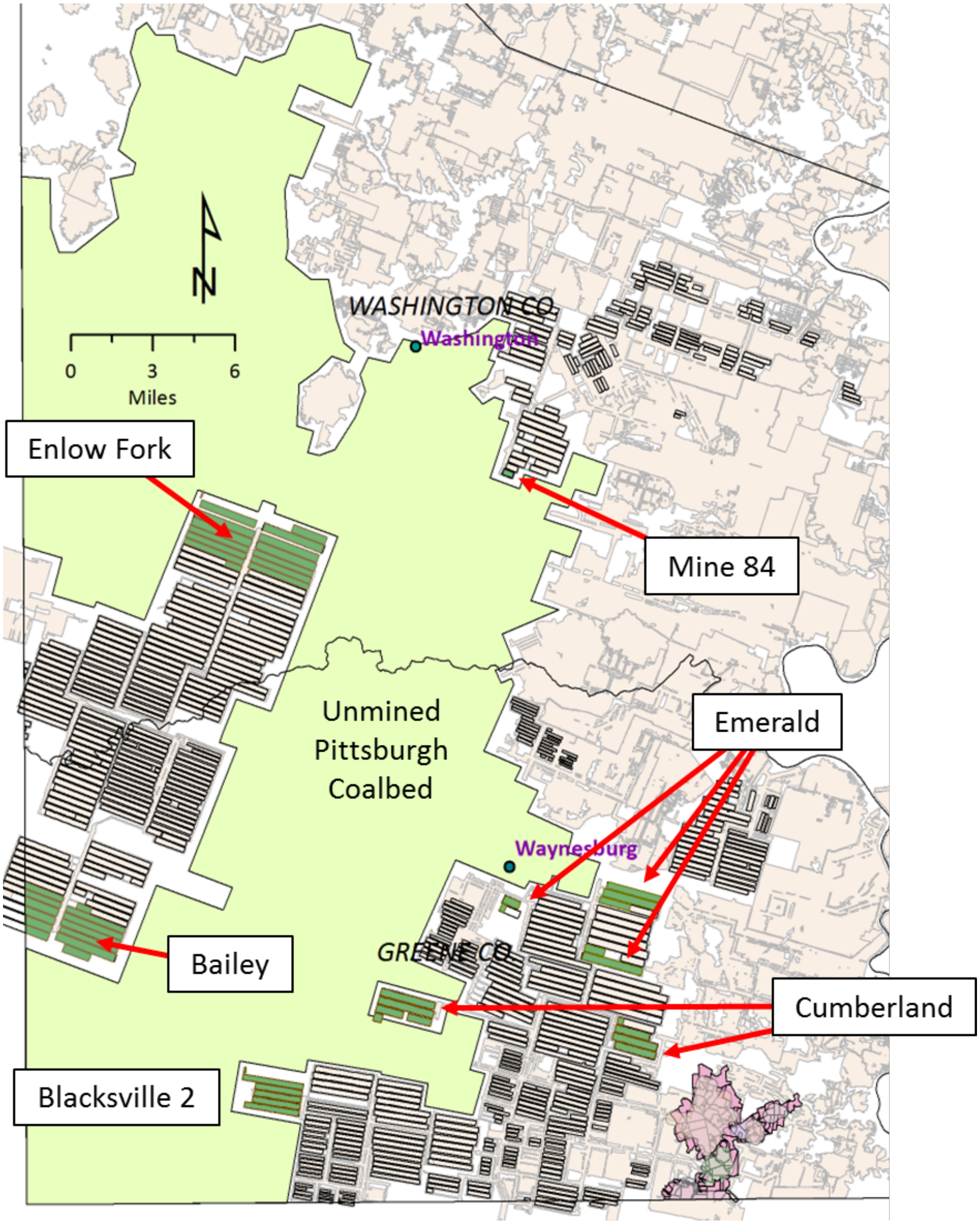


Figure III-19. Longwall panels mined and unmined reserves of the Pittsburgh Coalbed in Washington and Greene Counties, Pennsylvania. Grayed-out areas represent past room-and-pillar mining within the Pittsburgh Coalbed.

III.I – Summary

Forty-six mines operated during the 4th assessment period and are classified as room-and-pillar, room-and-pillar with pillar recovery, or longwall. Six controlling companies owned eleven operating companies and undermined 31,343 acres of surface land. This represents a ~18% decrease in the area mined during the 3rd assessment period. Thirty-four mines are room-and-pillar, seven longwall, and five room-and-pillar with pillar recovery. The following points summarize the findings:

- The decline in areas mined is related to significant portions of the Bailey mine operating in West Virginia and the lower demand for coal to generate electricity.
- The surface areas undermined by the longwall mines reduced 31% from the 3rd to 4th assessment period. Since longwall mining produces the highest numbers of subsidence related impacts, the amount of reported effects was expected to decrease. However, this is not the case (see Section IV and V).
- Consol Energy mined under the most land, 12,269.4-acres, and Rosebud Mining had the most mines, 20.
- Eleven new mines started during the 4th assessment period and seven others ceased operation.
- Six coalbeds, the Sewickley, Pittsburgh, Upper Kittanning, Lower Kittanning, Upper Freeport, and Lower Freeport, are mined in two formations, the Pittsburgh and Allegheny.
- Mining methods are strongly correlated with extraction ratio (Re): longwall panel Re ~ 1.0; room-and-pillar developments Re - 0.4 to 0.7; and pillar recovery Re = 0.7 to 1.0.
- Pillar punching and long term pillar instability are two factors that produce subsidence, impacting surface structures and water supplies, even at low extraction ratios, Re < 0.7.
- Fifty-two longwall panels mined underneath 12,380-acres of surface land.
- The average longwall panel covers 238.1-acres, takes almost 280 days to mine, and extracts surface lands at an average rate of 0.97 acres/day.
- Longwall mining undermines surface lands at almost five times the rate of room-and-pillar development.
- Less than 1% of the coal extracted during the 4th assessment period was mined using the pillar recovery mining method.
- Pillar recovery panels are typically small and irregularly shaped.
- Approximately 40% of the acreage undermined by bituminous coal mining in Pennsylvania is within Greene County; 19% in Washington County; and ~41% in the combined counties of Armstrong, Beaver, Cambria, Clearfield, Elk, Indiana, Jefferson, and Somerset.
- Three overburden categories are established for each mining method; shallow, average, and deep. Shallow and deep categories are defined as differing by one standard deviation from the average overburden for each of the three mining methods.
- In general, longwall mining operations are operating under approximately 100 additional feet of overburden then during the 3rd assessment period.
- The forty-six mines undermined portions of 6,744 surface properties.

- If coal extraction trends over the last ten years continue into the future, there could be only 37-years of longwall mining left within the Pittsburgh Coalbed of southwestern Pennsylvania.

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SECTION IV: Effects of Mining on Structures

IV.A – Overview

The University was tasked with collecting information on structures undermined by bituminous coal mines during the 4th Act 54 assessment period. Overall, the University analyzed a total of 482 reported effects to surface structures that were tracked by PADEP. A total of 389 reported effects occurred during the 4th assessment period with 19 occurring at non-active mining operations. Another 93 reported effects occurred during the 3rd assessment period but were resolved in the current assessment period (Appendix B). The majority of the company liable structure reported effects (230 out of 238) were associated with subsidence from longwall mining. Structure effects are listed by mining type, structure type, time to resolution, and determination of liability. Further analysis examines the relationship between structure effects and several physical characteristics – overburden, horizontal surface distance to mining, and topography.

IV.B – Reported Effects

Subsidence related impacts are tracked within the BUMIS database (see Section II). The University periodically received output from BUMIS and used this information to assist in its analysis. The BUMIS database is meant to track all features, i.e. surface structures (dwellings, barns, etc.), water supplies (wells, springs, etc.), and water resources (streams, wetlands, etc.) undermined by bituminous coal mining operations. In the 3rd assessment report, information was presented on relevant characteristics of these features (Iannacchione et al. 2011a; Iannacchione et al. 2011b). At that time, it was possible to find a physical location for the majority of these features and to match these occurrences with a BUMIS record. This was not the case during the 4th assessment period. BUMIS did not contain enough information to match structures projected on maps with a BUMIS record. Therefore information on the number and kind of structures undermined during the 4th assessment period is not presented.

To help rectify this situation, PADEP agreed to provide adequate location information for only those features known to be a structure or water supply ‘reported effect’. A reported effect occurs when a feature is thought to be impacted by subsidence. Mine operators, residents, or agents of PADEP request that a feature be considered for repair or compensation. A reported effect can be found to be ‘company liable’ or it may be classified as ‘not due to underground mining’.

Two issues occurred when analyzing the reported effects database extracted from BUMIS. First, the ‘feature type’ associated with the reported effect database was not adequately classified. Second, the ‘feature use’ was not always entered into BUMIS, resulting in a large number of ‘unknown’ uses.

The University’s contract with PADEP called for an analysis of subsidence related problems (reported effects) by feature type. In the past, three general feature types were analyzed: structures, water supplies, and land (Figure IV-1). Unfortunately, the BUMIS database contains significant occurrences in which structures were classified as land features and *vice versa*. The same problem was true of BUMIS water supply data analyzed in Section V. Land reported effects, referred to as land damage problems in BUMIS, could not be accurately located and are therefore only reported in the aggregate. Figure IV-1 shows the distribution of the three feature categories used in the University's current analysis: 1) structures, and 2) water supplies, and 3) land (Figure IV-1). The total number of reported effects for the 4th assessment period was slightly higher than that listed in the 3rd assessment period, 1,247 to 1,350. The number of structure reported effects decreased approximately 15% from 456 to 389.

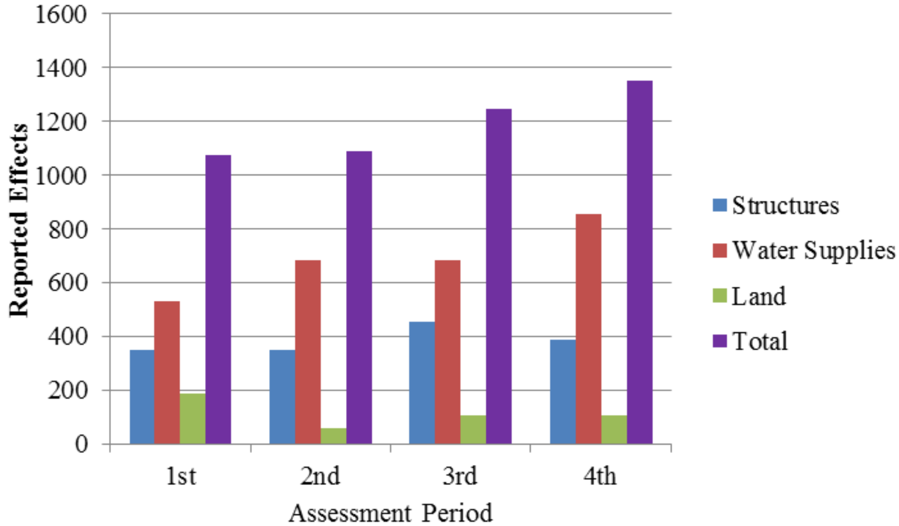

Figure IV-1. Numbers of reported effects over the four Act 54 assessment periods, sorted by feature type.

These two issues 1) failure to locate the exact surface position of features listed in BUMIS and 2) mislabeling of 'feature type' and 'feature use' limited the University's ability to analyze structures, water supply, and land reported effects.

IV.C – Data Sources

The number and characteristics of structures undermined and affected by underground bituminous coal mining were determined by examining the following sources: the BUMIS database, six-month mining maps, paper files at the CDMO, damage reports faxed to the CDMO by mine operators, interviews with technical staff at the CDMO, Surface Subsidence Agent reports, and company-supplied AutoCAD mine maps.

IV.C.1 – Structures Tracked by PADEP

Pennsylvania regulations require that approved subsidence control plans contain information about structures that will be undermined (Pennsylvania Code, Title 25, Chapter 89.142a). The parts of the code of particular relevance to this report are summarized below.

IV.C.1.a – Overburden Less Than 100-ft

§ 89.142a(a) requires the mine to maintain stability beneath structures when mining under overburden less than 100-ft.

IV.C.1.b – Pre-mining Surveys

§ 89.142a(b) requires that the mine operator conduct pre-mining surveys of:

- Dwellings,
- Buildings accessible to the public,
- Noncommercial buildings customarily used by the public, and
- Barns, silos, and certain agricultural structures.

The surveys must be conducted prior to the time the structure lays within a 30-degree angle of the underground mine. Surveys must describe the pre-mining condition of the structure and, if the structure is historically or architecturally significant, the presence of any architectural characteristics that will require special craftsmanship to restore or replace.

IV.C.1.c – Mining Beneath Protected Structures

§ 89.142a(c) sets the default standard for mining beneath structures and features as 50% coal support, although the PADEP may require a greater percentage. This requirement is only for a limited class of structures and features, i.e. public buildings, 20 acre-ft. impoundments, etc. Subsection (c) also clarifies alternatives to the coal support standard including surface measures that may be undertaken in conjunction with planned and controlled subsidence.

IV.C.1.d – Prohibition on Irreparable Damage to Dwellings and Agricultural Structures Greater Than 500-ft^2

§ 89.142a(d) prohibits a mine operator from mining in a manner which would cause irreparable damage to dwellings and permanently affixed appurtenant structures, barns, silos, and certain permanently affixed structures of 500-ft^2 or more used for agricultural purposes. The proposed mining can occur if the mine operator obtains the consent of the structure owner to allow the damage to occur. Alternatively, the proposed mining can proceed if the mine operator, prior to mining, implements measures approved by the Department to minimize or reduce the irreparable damage which would result from subsidence.

IV.C.2 – University's Process for Tracking Structures

To comply with the standards discussed above, the University developed a process to compile and categorize information about structures in the Act54GIS database.

First, the University used a 200-ft buffer zone around all areas mined as a basic criterion for inventorying undermined structures (see Section II.C.4). The buffer starts at the edge of a mining extent and extends outward 200-ft. If a structure fell within the 200-ft buffer, it was considered undermined. All structures that fell outside the 200-ft buffer zone were eliminated with one exception. If a structure was outside the buffer but associated with a reported effect within or prior to the 4th assessment period, it was retained. To further refine the structure inventory to comply with PADEP standards, the size of each structure was calculated within Act54GIS. Those structures that did not meet the minimal square footage requirements ($\geq$ 500-ft^2) as outlined in § 89.142a (f)(1)(v) were eliminated from the inventory. Exceptions to this size restriction were dwellings, garages, barns, silos, public and commercial buildings and towers, churches, and cemeteries.

Next, basic information about each structure was collected and entered into the Act54GIS database. This information consisted of:

- Property owner (name)
- Property ID (number)
- Property number (typically the tax ID)
- County
- Feature ID
- Feature number (number)
- Feature type (three general categories: structures; water supplies; and land)
    - Structures – residence, barn, building, garage, outbuilding, shed, silo, trailer, septic system, etc.
    - water supply -- spring, well, pond, etc.
    - land -- field flooding, soil heave, driveway/road damage, mass wasting, etc.
- Feature use (Residential, Recreational, Agricultural, Community/Institution, Public, Commercial, Industrial, and Unknown)

Following construction of the structure inventory, the University's Act54GIS database was linked to BUMIS to obtain additional information on structures with reported effects. Linking the two databases required the University to construct a common identification number for features that occurred in both datasets. Common identification numbers had to be created because existing identifiers often did not match between the two datasets and BUMIS lacked unique identifiers for many features (see Section II.B.2.3 for additional information on feature identifiers). By linking the two databases, the University determined which structures in the inventory had reported effects. For those with a reported effect, the following characteristics were recorded:

- Reported Effects ID (number)
- Occurrence of Additional Reported Effects (number)
- Claim ID (structure assessment number)
- Cause (mining or other)
- Description of the Reported Effect
- Occurrence Date
- Intermediate Resolution Date
- Final Resolution Date
- Resolution Status

Lastly, ArcGIS tools were utilized to measure the overburden depth (ft.), distance to mining (ft.), and topographic location (i.e. hilltop, hillside, valley bottom) for all structures with reported effects. Analyses were then performed to determine trends associated with structural damage and underground coal mining.

IV.D – Summary Information about Structures Undermined During the 4th Assessment Period

A total of 389 reported effects pertaining to structural damage were reported during the 4th assessment period (Table IV-1). The reports came from the 46 active mines as well as six inactive mines. Approximately 81% of the total reported effects are a result of longwall mining. This is due to the planned subsidence caused by longwall mining.

Table IV-1. Number of reported structural damage effects by mine type.

Mine Type	**Reported Effects**
Room-and-Pillar	48
Pillar Recovery	7
Longwall	315
Mines not in operation during 4th assessment (Not-active)	19
TOTAL	389

Act 54 requires that all structures impacted by underground coal mining be repaired or that the owner compensated. Of the total 389 reported effects, 238 were considered “Company Liable” (Table IV-2), indicating that the damages were related to mining and that the company was responsible for repairs or compensation. Two-hundred-and-thirty or 96.6% of the “Company Liable” effects occurred in association with longwall mining. In contrast, five “Company Liable” effects occurred over room-and-pillar mining, and the remaining three effects occurred over non-active mines. The high number of “Company Liable” effects for longwall mining can be attributed to the formation of the subsidence basin. Generally, impacts occur when coal extraction ratios beneath a structure are above 0.7 (Section III.D). This implies that all of the coal has been removed leaving no support for the overlying rock. An effective means of preventing impacts to structures is the implementation of support pillars with adequate stability to support the roof rock from caving. To increase extraction efficiency, full-extraction mining methods, such as longwall mining and pillar recovery, either do not use or remove those pillars. The result is planned subsidence which can impact structures. Most of the effects over room-and-pillar mining or inactive mines were caused by local subsidence events from old mining.

Table IV-2 lists the final resolution status for the 330 reported effects that were resolved during the 4th assessment period. The average time to resolution for these reported effects was 169 days. Companies can resolve structure effects through a number of routes. BUMIS classifies these final resolutions into the following categories:

- Unspecified agreements
- Company purchased property
- Pre-mining agreements
- MSI
- Repaired
- Resolved
- Landowner negotiations

In the 4th assessment, most structure impacts were mitigated through unspecified agreements, pre-mining agreements, or by the company purchasing the property (Table VI-2).

Table IV-2. Determination of liability based on final resolution status as of 20 August 2013.

Final Resolution		**Number**	**Average Time to Resolution (Days)**
Class	**Category**		
Company Not Liable (Unaffected/No Liability)	Damage Claim Form Not Returned to CDMO	27	184
	No Liability	1	61
	Not Due To Underground Mining	59	74
	Withdrawn	6	414
Company Liable (Assigned/Assumed Liable)	Agreement (Pre Mining)	41	106
	Agreement (Unspecified)	116	279
	Closed/Info Appended to Another Case	1	0
	Company Purchased Property	66	40
	Compensated	2	581
	Landowner Negotiations	1	710
	Repaired	9	284
	Resolved	1	127
TOTAL		330	169

Fifty-nine of the reported structural effects were unresolved as of 20 August 2013. These reports are given an interim resolution status by PADEP until a final resolution can be reached. Table IV-3 lists the unresolved effects and their interim resolution status. The majority of unresolved structure effects are considered to be “Currently Monitoring” by PADEP. This interim resolution status implies that most reported effects require a period of observation before a final resolution can be assigned. It should be noted that nine of these cases occurred during the 3rd assessment period.

Table IV-3. Status of unresolved effects (n = 59) for reported structural effects as of 20 August 2013.

Category	**Number**
Awaiting Additional Info From Operator	1
Currently Monitoring	52
Damage Claim Form Sent To Owner	1
DEP Supported Claim	1
Performing Repairs	1
Under Appeal	1
Unresolved/Pending Investigation	2
TOTAL	59

The time to resolution for the 330 resolved effects for this reporting period is shown in Figure IV-2. The time to resolution was calculated by subtracting the final resolution date from the date the effect was reported. The plot shows that 75% of all reported effects reach a final resolution within 180 days, while the initial third of these reported effects are given a final resolution within the same day. These quick resolution times are likely associated with structures that have pre-mining agreements in association with longwall mining or with structures in close proximity to mining (see below). Ninety-eight percent of all reported effects were resolved within 2 years.

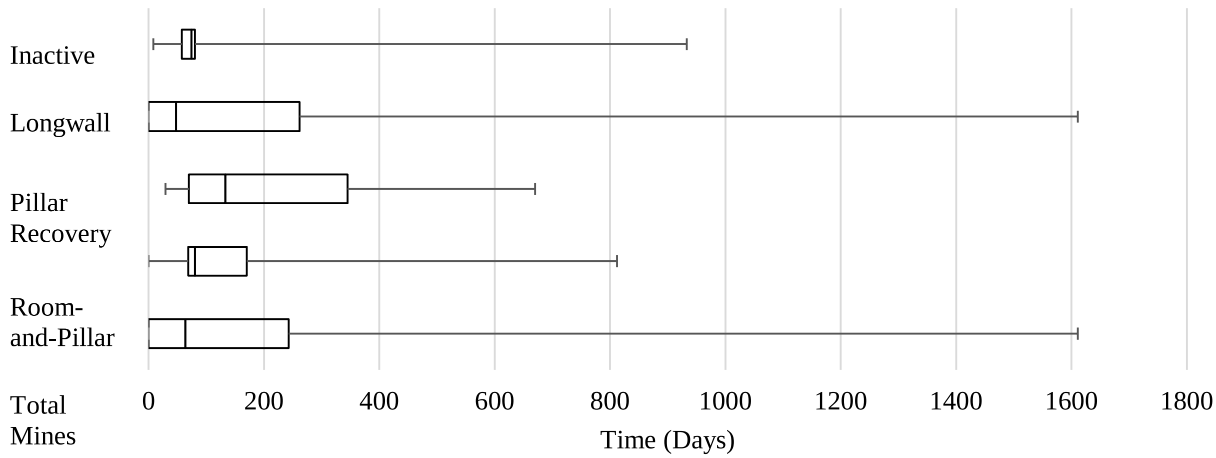

Figure IV-2. Box and whisker plot of the time to resolution of the 330 resolved structure reported effects sorted by mining type as of 20 August 2013.

In general, reported effects with the longest resolution times are those that required repairs from the company (Figure IV-3). Reported effects with the quickest time to resolution are those that are determined to be "No Liability," indicating that mining was not responsible for the impact (Figure IV-3). For these effects, investigations often reveal that mining is distant from the structure and thus unrelated to the effect. When classifying the average time to resolution by mining type, the University found that the longest average time to resolution occurred in inactive mines for structures where an agreement/compensation was required to mitigate the effect. Here, an outlier case that took 933 days to resolution pulled the average higher. This outlier case involved a structure that had been monitored for several years over the inactive Maple Creek longwall mine. The reported effect is resolved and considered "Company Liable" since the monitored ground movements supported a relation to mining activity.

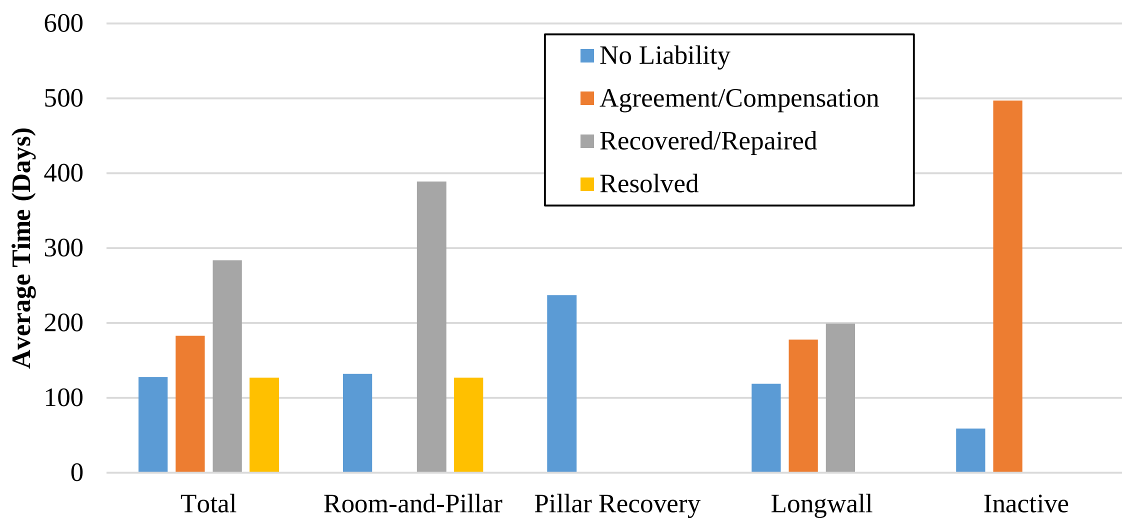

Figure IV-3. The average number of days required to resolve the reported structural effects (N=330) classified by mining type and categorized based on the resolution status as of 20 August 2013.

Figure IV-4 classifies the reported structural effects by structure type. Besides land, barns and dwellings are the next most common structural features with reported effects. Structural features classified as land represent nearly 55% of the total structural reports. The University believes that structures classified as land reported effects in BUMIS may be mislabeled. The University noted that often the reported feature type in BUMIS did not accurately describe the feature that sustained structural damage. For example, a feature listed as a spring sometimes described damage that occurred to a dwelling (Figure IV-4).

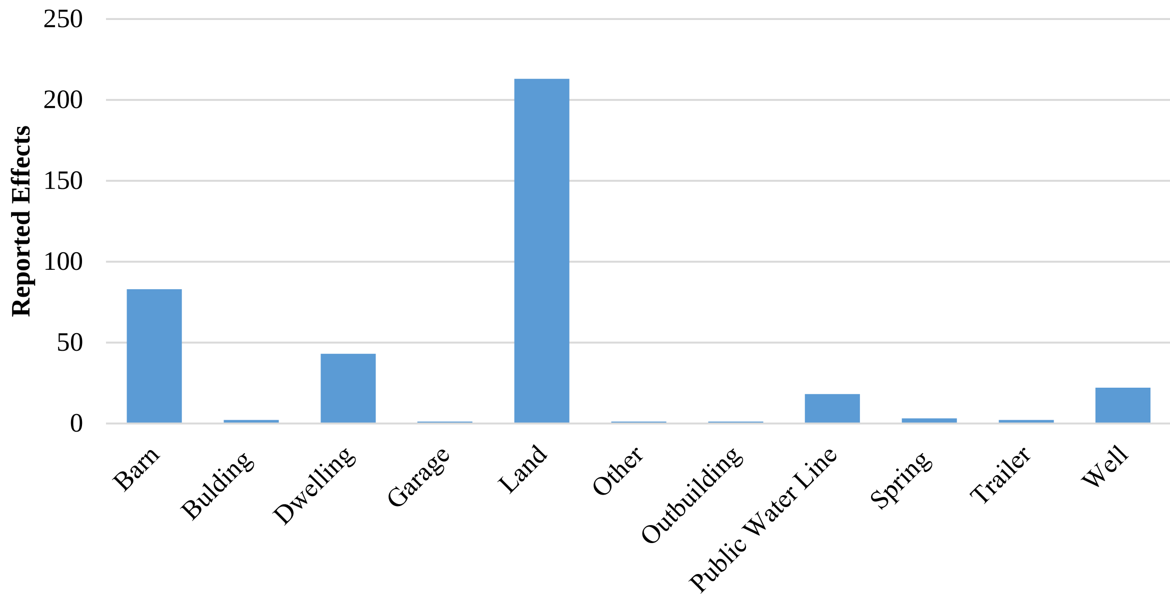

Figure IV-4. Total structure reported (n=389) as of 20 August 2013 classified by feature type.

Structure reported effects can also be classified by use. However, in BUMIS, 46% of all reported structural effects for this assessment period were classified as “Unknown” use (Figure IV-5). The most common uses for structures with reported effects were “Residential” followed closely by “Agricultural”. These two uses represent 47.6% of the total reported structural effects.

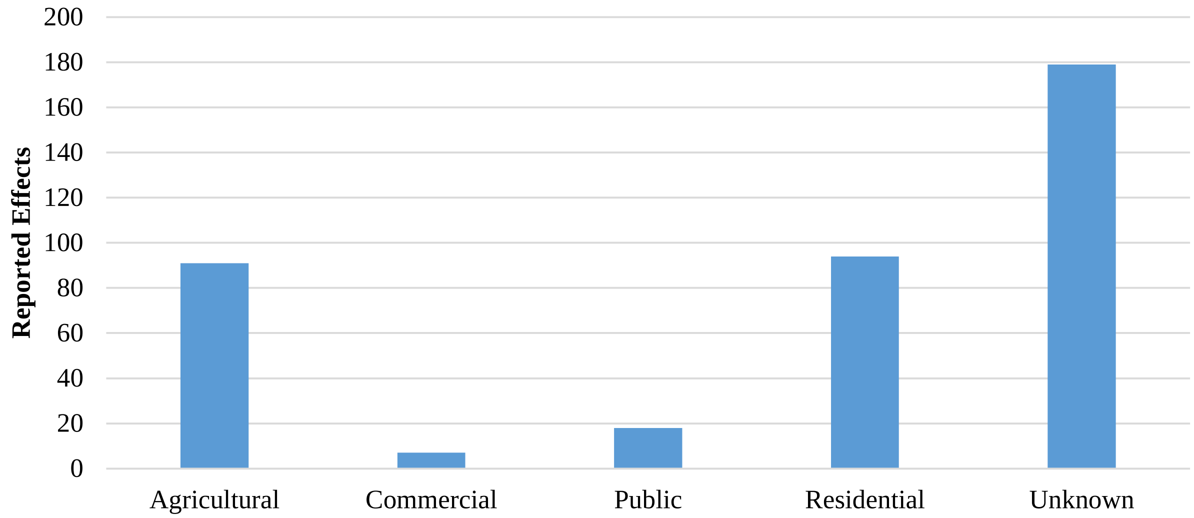

Figure IV-5. Total structure reported effects (n=389) as of 20 August 2013 classified by feature use.

IV.E - Comparison to Previous Act 54 Reports

Since the creation of Act 54, three reports have been submitted regarding the effects of underground bituminous coal mining on surface features. The data collected in these reports allows for comparison with the 4th assessment period.

Figure IV-6 illustrates the total number of structure reported effects for each Act 54 reporting period. The trend is generally upward. However, there is a drop in the number of structure reported effects between the 3rd and 4th assessments. The decrease in mining activity, especially longwall mining, has likely contributed to the decline in structure reported effects.

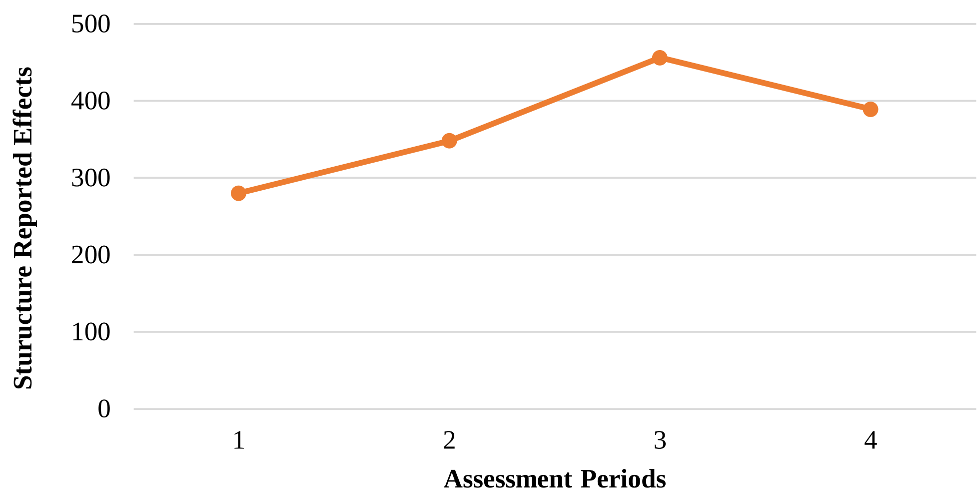

Figure IV-5. Comparison of total structure reported effects from the four Act 54 assessments.

IV.F – Characteristics of Company Liable Structure Effects

The University was able to accurately locate 195 of the 230 company liable structure effects, many with multiple effects, and perform rudimentary analysis. For example, overburden of company liable structure effects clusters about the two unique mine types, longwall and room-and-pillar (Figure IV-6). The data points over longwall mines were far more numerous with much higher overburdens then the room-and-pillar mines.

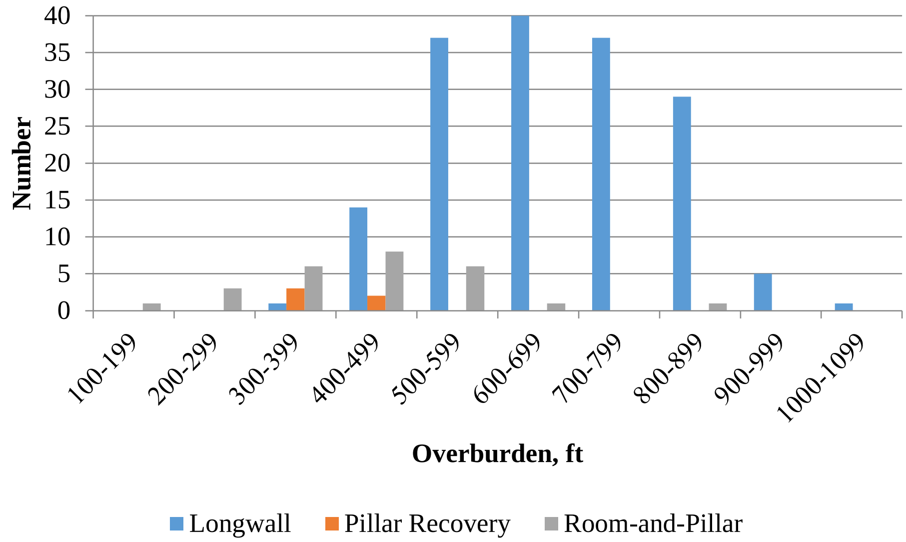

Figure IV-6. Overburden distribution of company liable structure effects. Note that the majority of the occurrences are over longwall mines.

Western Pennsylvania is known for its topographic relief where mass wasting (landslides) commonly occur along hillsides. Under these conditions, the effects of subsidence on structures could be enhanced. One-hundred and seventy-six of the 230 company liable structure effects, some with multiple problems, were accurately located within either the tops of the hills, along the hillside slopes, or within the valley bottoms (Figure IV-7). Sixty-nine percent of all company liable structure effects are located along the hillside. Hillsides should be considered areas of elevated risk for structure affected by subsidence.

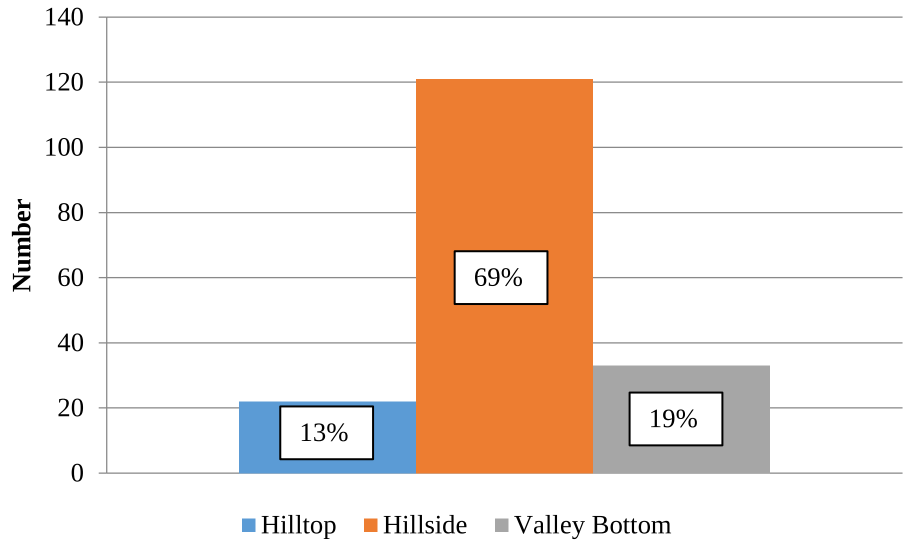

Figure IV-7. Company liable structure effects categorized by their topographic location.

The influence of mining on company liable structure effects was examined by placing the data into one of four categories: 1) above the 'full extraction' panel [longwall or pillar recovery panels], 2) above the room-and-pillar developments, 3) inside the 200-ft buffer but outside the mine, and 4) outside the 200-ft buffer (Figure IV-8). Not surprising, significant numbers of company liable structure effects occur above the longwall panels, but it should also be noted that significant numbers lie outside the 200-ft buffer. Many of these were found to be company liable because they were undermined in early assessment periods or they didn't reach a resolution until the 4th assessment period.

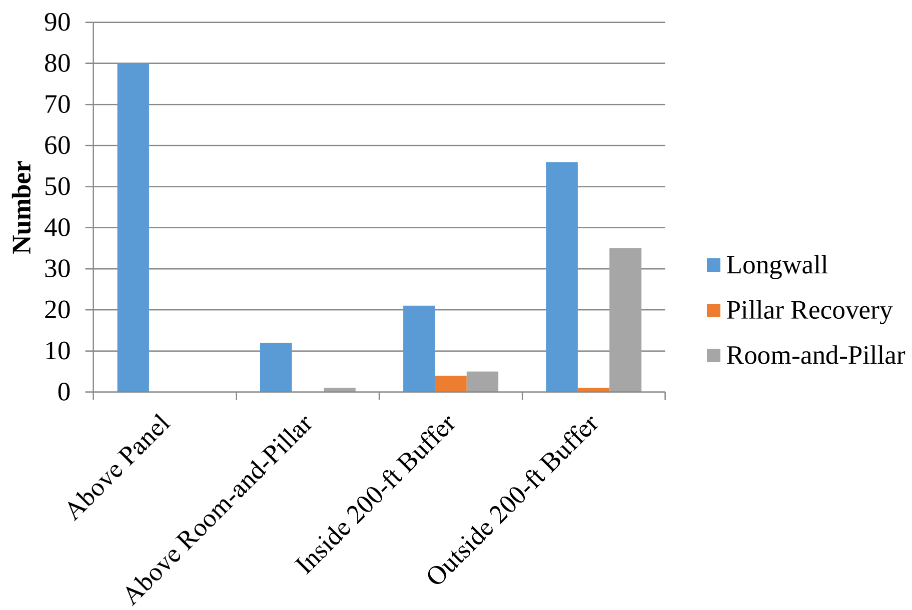

Figure IV-8. Location of the company liable structure effects with respect to the position of key mining zones. These zones were based on mining during the 4th assessment period.

IV.G – Summary Points

Three hundred and eighty-nine structure reported effects occurred during the 4th assessment period. Three hundred and fifteen were from the seven longwall mines, 48 from room-and-pillar mines, and seven from pillar recovery mines. Nineteen were from Non-active neighboring mines (see Appendix B for a list of these mines). An additional 93 effects were carryovers from the 3rd assessment period. Of the 389 structure reported effects, 59 were not resolved at the end of the 4th assessment period. Of the 330 resolved cases, 75% reached a final resolution within 180 days. Of the resolved cases, 238 were found to be company liable structure effects, or 61% of the total. The vast majority of the company liable structure effects occurred over longwall panels (230 out of 238).

The University had difficulty matching feature types shown on six-month mining maps (insufficient labeling information) with reports in BUMIS. In addition, many reported effects in BUMIS were incorrectly labeled by feature type and use.

References

Iannacchione, A., S.J. Tonsor, M. Witkowski, J. Benner, A. Hale, and M. Shendge (2011a) "The Effects of Subsidence Resulting from Underground Bituminous Coal Mining on Surface Structures and Features and on Water Resources, 2003-2008," University of Pittsburgh, http://www.portal.state.pa.us/portal/server.pt/community/act_54/20876.

Iannacchione, A., M. Witkowski, J. Benner, A. Patil, and N. Iannacchione (2011b) "Surface Structures Impacted by Subsidence from Pennsylvania Coal Mines, 2003 to 2008," 30th International Conference on Ground Control in Mining, Morgantown, WV, July 26-28, 2011, pp. 286-295.

SECTION V: Effects of Mining on Water Supplies

V.A – Overview

The University was tasked with assessing water supplies impacted by underground bituminous mining during the 4th Act 54 assessment period. This section includes an inventory of water supplies undermined during the 4th assessment period and evaluates the 855 reported water supply effects from this period. In addition, the University reports on 211 unresolved effects from the 3rd assessment period and provides a brief summary of their current status. Information on water supply reported effects from the 3rd assessment period are discussed by Witkowski (2011). Topics covered in this section include analysis of:

- Actions by the mine operators and PADEP,
- Determinations of liability by the PADEP,
- Development of permanent replacement water supplies, and
- Length of time required to resolve reported effects.

Lastly, the University used statistical analyses and modeling to aid in assessing a water supply's susceptibility to impacts from underground mining.

V.B – Reported Effects

The topic of reported effects was discussed in Section IV.B and should be referred prior to reviewing Section V (see a portion of this discussion below):

> *…'A reported effect occurs when a feature is thought to be impacted by subsidence. Mine operators, residents, or agents of PADEP request a feature be considered for repair or compensation. A reported effect can be found to be 'company liable' or it may be classified as 'not due to underground mining'. …*

Here too, when analyzing the reported effects database extracted from BUMIS, the water supply 'feature type' associated with the reported effect database was not always adequately classified.

The BUMIS database contains significant occurrences where water supplies were classified as land reported effects and vice-versa. The same problem was true of BUMIS structure data analyzed in Section IV. In addition, unresolved water supply reported effects were, for the most part, not given an interim status. The number of water supply reported effects has significantly increased since the 3rd assessment period.

V.C – Data Sources

Information regarding water supplies comes mostly from the PADEP's BUMIS database and company submitted six-month mining maps. Additional information is collected from hydrologic monitoring reports and interviews with field agents.

V.C.1 – Water Supplies Tracked by PADEP

The Act 54 legislation defines a water supply as:

> *"any existing source of water used for domestic, commercial, industrial or recreational purposes or for agricultural uses, including use or consumption of water to maintain the health and productivity of animals used or to be used in agricultural production and the watering of lands on a periodic or permanent basis by a constructed or manufactured system in place on the effective date of this act to provide irrigation for agricultural production of plants and crops at levels of productivity or yield historically experienced by such plants or crops within a particular geographic area, or which serves any public building or any noncommercial structure customarily used by the public, including, but not limited to, churches, schools and hospitals."*

Water supplies must have one of the specified uses in the Act 54 legislation, as stated by the property owner in the pre-mining survey, to be considered in the inventory provided by BUMIS and the six-month mining maps.

V.C.2 – University's Process for Tracking Water Supplies

To comply with the standards discussed above, the University developed a process to compile and categorize information about water supplies in the Act54GIS database.

First, the University calculated a Rebuttable Presumption Zone (RPZ) and used this buffer as a basic criterion for inventorying undermined water supplies (see Section II.C.4). Within the RPZ, any adverse effects on a water supply are initially presumed to be caused by undermining. The mining operator can rebut that assumption by providing evidence to the contrary (see Section V.D below). The RPZ was created by projecting a 35-degree line (from vertical) from the edge of mining to the surface (PADEP, 2008). All structures that fell outside the RPZ were eliminated with one exception. If a water supply was outside the RPZ but associated with a 'reported effect' within or prior to the 4th assessment period, it was retained.

Next, basic information about each water supply was collected and entered into the Act54GIS database. This information consisted of:

- Property owner (name)
- Property ID (number)
- Property number (typically the tax ID)
- County
- Feature ID
- Feature number (number)
- Feature type
- Feature use (Residential, Recreational, Agricultural, Community/Institution, Public, Commercial, Industrial, and Unknown)

Following construction of the water supply inventory, the University's Act54GIS database was linked to BUMIS to obtain additional information on water supplies with reported effects (see Sections IV-B and V-B). By linking the two databases, the University determined which water supplies in the inventory had reported effects. For those with a reported effect, the following characteristics were recorded:

- Reported effects ID (number)
- Occurrence of additional reported effects (number)
- Claim ID (structure assessment number)
- Cause (mining or other)
- Description of the reported effect
- Occurrence date
- Intermediate resolution date
- Final resolution date
- Resolution status

Using these data, reported effects were tracked by mine type, date of occurrence/resolution, type of effect, type of resolution, and actions taken by the DEP and mine operators.

Lastly, ArcGIS tools were utilized to measure the overburden depth (ft), distance to mining (ft), and topographic location (i.e. hilltop, hillside, valley bottom) for all water supplies with reported effects. Analyses were then performed to determine trends associated with water supply impacts and underground coal mining.

V.D – PADEP Determination of Liability

In accordance with ACT 54, mining companies are required to restore or replace water supplies that are contaminated, diminished, or interrupted by their underground mining operations. The Act also requires the mine operator to notify PADEP of any claim made by a landowner or water user. The PADEP tracks the claims from origin to settlement. A mining company and a property owner may settle a claim with a private agreement. Once an agreement has been made between the company and the property owner, the PADEP has no legal authority to intercede and tracking is ended.

The PADEP is responsible for determining liability associated with reported effects. As mentioned above, if a water supply falls within the RPZ the mining company is assumed liable for the impact. The company may rebut the claim if there is data available that shows no relation to mining. If the water supply is located outside of the RPZ, the PADEP is responsible for determining the reason for the impact. Factors used in determination of liability include type of mining, proximity to mining, overburden, seasonality of the claim, pre-mining water supply data, and observed effects on neighboring water supplies. If the PADEP determines that the mining company is responsible for the water supply impact and the property owner is without water, the company must provide the property owner with a temporary water supply until a permanent replacement of pre-mining quality and quantity is in place or an agreement between the water supply owner and the mining company is established. A temporary supply is generally in the form of a storage tank, called a water buffalo, placed on the property in question. The water buffalo is periodically filled with trucked water that is sufficient for the owner's needs. The University was unable to determine the number of temporary water supplies placed during the 4th assessment period because of the many mine operator – property owner agreements established during this period. Permanent water supply replacement actions include, but are not limited to, repairing wells or springs, drilling new wells or springs, or connecting to a public water supply.

In BUMIS, water supply reported effects are noted as either *water loss* or *water contamination.* Seven hundred and twenty-one (84%) of the water supply reported effects were categorized as water loss and 134 (16%) as contamination. Water loss can signify either a reduction of water quantity or a complete loss of the supply while water contamination indicates a reduction in water quality. A reported effect can also have the classification of *not an actual problem;* this describes a reported effect that upon investigation by the mining company or PADEP was determined not to have been impacted by mining. *Not an actual problem* can also be assigned to a reported effect if a mining company provides a temporary water supply as a precaution but no problem developed post-mining.

V.E – Summary Information about Water Supplies Undermined During the 4th Assessment Period

During this assessment period, there were 855 reported effects to wells, springs, and ponds; the effects are tabulated in Table V-1 by mining type. The total number of reported effects included effects from mines that were active during the assessment period as well as effects from mines that ceased operation prior to the 21 August 2008 assessment period start date. Longwall and room-and-pillar mines show the most reported effects while pillar recovery mines show the least. Mines not in operation during this period comprised 6% of the total reported effects. Mines of all types are included in this section.

Table V-1. Number of reported 'water loss/water contamination' effects by mining type.

Mining Type	**Reported Effects**
Room-and-Pillar	384
Pillar Recovery	24
Longwall	393
Mines not in operation during 4th assessment (Non-active)	54
TOTAL	855

When an effect has been resolved, it is given a final resolution status. The final resolution indicates that there is no further impact to the water supply, or the case is closed due to an agreement regardless of whether the water supply is restored. Final resolutions are divided into three categories: 1) *Company Not Liable*, 2) *Company Liable*, and 3) *Unresolved* (see Appendix B). The *Company Not Liable* classification consists of effects that are *Withdrawn, Not An Actual Problem, Not Due To Underground Mining*, etc. The largest category within the *Company Not Liable* class is *Not Due To Underground Mining.* Most of the water supplies in this category have been found to be too distant from mining activity to be the result of mining. The *Company Liable* classification contains *Agreements, Permanent Supplies, Recovered/Repaired, and Resolved* categories. The majority of this class is comprised of agreements between the landowner and the mining company. This class differs greatly from the *Company Not Liable* class when comparing resolution times. *Company Not Liable* resolutions generally are resolved within a few months while a small number of *Company Liable* effects can take years to reach resolution. Table V-2 lists the 29 categories used by the PADEP to classify the resolutions of water supply reported effects and average days required for resolution.

Table V-2. Determination of liability based on final resolution status as of 20 August 2013.

Final Resolution		**Number**	**Average Time to Resolution (Days)**
Class	**Category**		
Company Not Liable (Unaffected/No Liability)	Claim not filed W/in 2 years	1	536
	Damage Not Covered By BMSLCA	1	0
	No Actual Problem	12	26
	No Current Use	5	82
	No Liability	8	7
	Not Due To Underground Mining	224	99
	Owner Failed to Respond to DEP	1	965
	Water Supply Not Covered By BMSLCA	8	5
	Withdrawn	26	66
Company Liable (Assigned/Assumed Liable)	Agreement (Pre Mining)	25	29
	Agreement (Unspecified)	197	355
	Closed/Info Appended to Another Case	1	133
	Company Purchased Property	37	122
	Compensated	0	-
	Landowner Negotiations	1	724
	Perm Water Supply (Public) & O&M Bond	2	1189
	Perm WS (Well/Spring) & O&M Bond	9	764
	Permanent Supply (Public)	3	733
	Permanent Supply (Public) & Agreement	10	298
	Permanent Supply (Unspecified)&Agreement	2	572
	Permanent Supply (Well/Spring)	5	476
	Permanent Supply (Well/Spring)&Agreement	23	730
	Repaired	15	107
	Resolved	11	49
	Stream Recovered	1	183
	Vented - Resolved	0	-
	Water Supply Recovered	29	173
		657 (Total)	220 (Avg.)

A total of 201 water supply reported effects were unresolved at the end of the 4th assessment period. Unresolved effects are given an interim status to indicate the processes occurring in assessing the liability of the effect. However, only three of the unresolved reported effects were given an interim status in BUMIS. The status of the remaining unresolved reported effects could not be determined from the BUMIS database.

Figure V-1 illustrates a status summary of the total water supply reported effects during the 4th assessment period. The *Company Liable* class is further broken into 4 subclasses of *Agreement, Permanent Supply, Recovered/Repaired, and Resolved*. *Agreements* represent 70% of the total company liable effects, *Permanent Supplies* represent 15%, *Recovered/Repaired* 12%, and *Resolved* 3%.

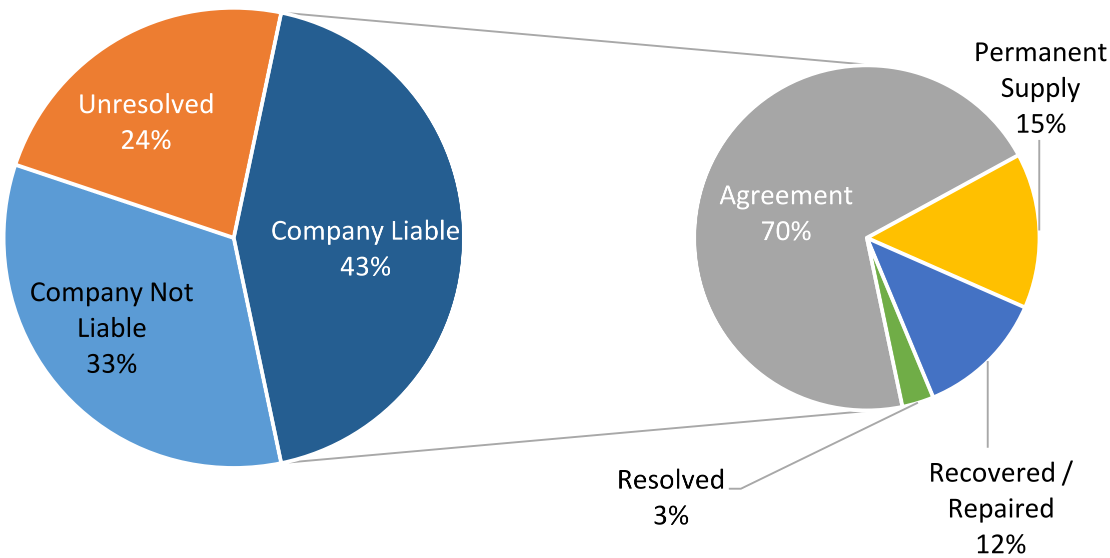

Figure V-1. Final resolution status of the water supply reported effects (n=855) classification as of 20 August 2013. The Company Liable Classification has been separated into four categories: Agreement, Permanent Supply, Recovered / Repaired, and Resolved.

The times to resolution for the 654 resolved effects are shown in Figure V-2 classified by mining type. The time to resolution was calculated by subtracting the resolution date from the date the effect is reported. The plot shows that 25% of total reported effects are resolved within 13 days. A majority of these rapidly resolved effects consisted of agreements that are resolved on the same day as the reported onset of the effect. In fact, more than 25% of all reported longwall effects are resolved on the day of their first reported occurrence. Half of the total reported effects are resolved within about two months, while 75% are resolved within a year. The time to resolution for the remaining 25% of effects is between one and four and one-half years. Many of the effects with prolonged times to resolution are associated with *Permanent Supplies* for which the average times to resolution can exceed two years (Figure V-3). Reported effects that are considered *no liability* or *resolved* had the shortest time to resolution (Figure V-3).

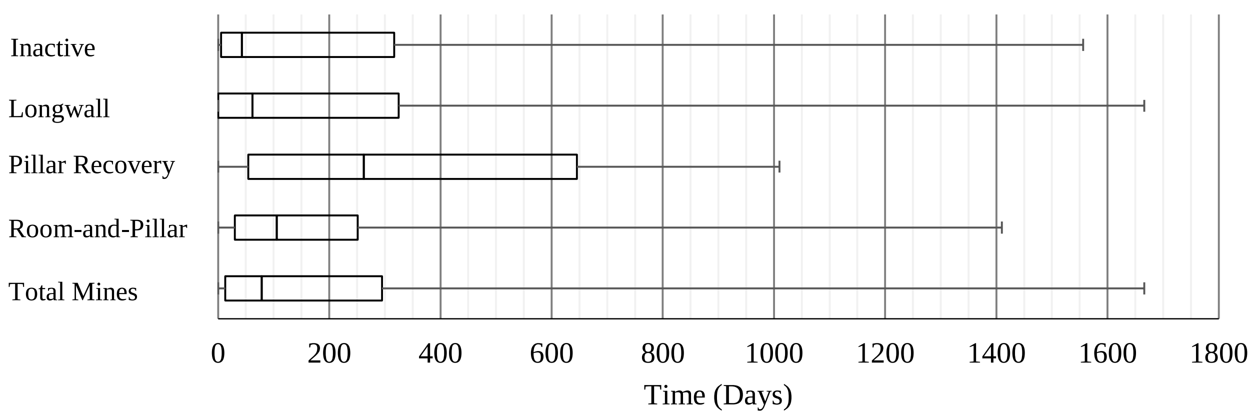

Figure V-2. Box and whisker plot of the time to resolution of the 65 resolved water supply effects sorted by mining type, as of 20 August 2013.

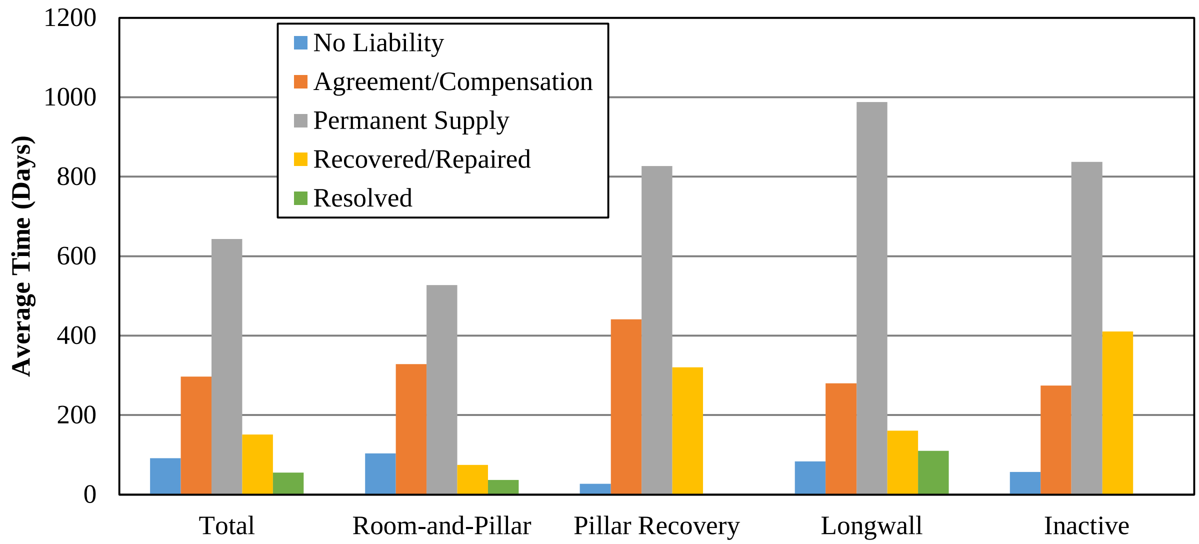

Figure V-3. The average number of days required to resolve the reported effects (n=657) classified by mining type and categorized based on the resolution status as of 20 August 2013.

Figure V-4 represents the total number of reported water supply effects for each mine type by two categories of impact: *water loss* and *water contamination.* Water losses represent the majority of water supply effects, covering 84% of the total. The remaining 16% are categorized as *water contamination* effects. Room-and-pillar mines show the greatest percentage of water contamination effects at 25% while pillar recovery mines show the fewest at 9%.

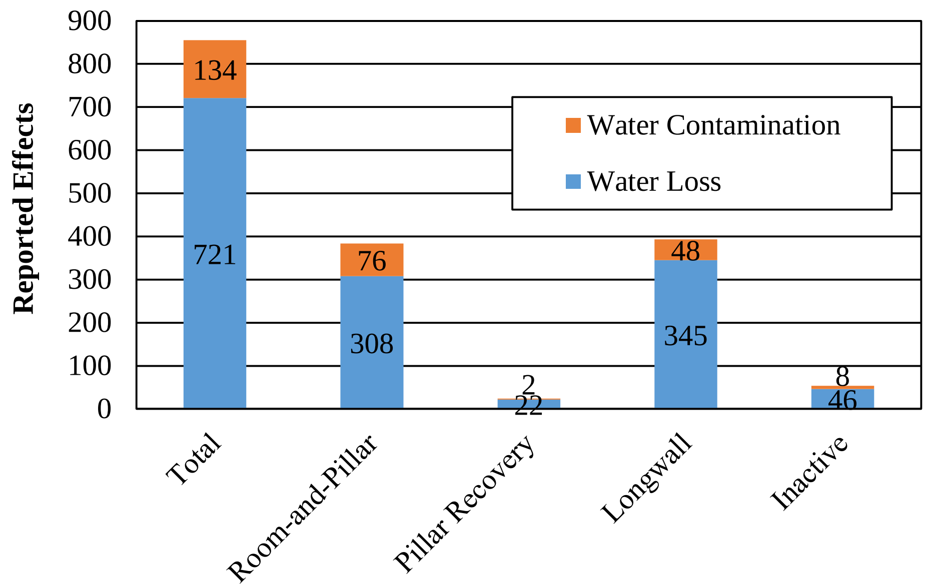

Figure V-4. Total water supply reported effects (n=855) classified by type of impact and organized by mining type as of 20 August 2013.

Reported effects can also be classified by the water supply's use and type. Water supply use can be categorized as *Agricultural*, *Commercial*, *Public*, or *Residential*. Figure V-5 quantifies the reported water supply effects by use. Here, as in structure reported effects (see Section IV), the use of water supplies was not being adequately reported in BUMIS.

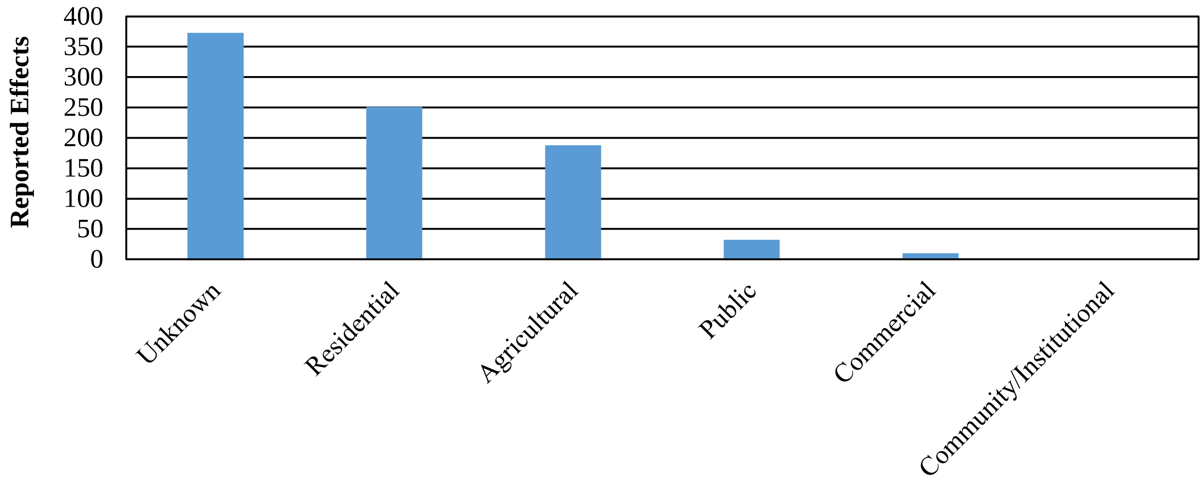

Figure V-5. Total water supply reported effects (n=855) as of 20 August 2013 classified by feature use.

Figure V-6 quantifies the water supply reported effects by type. Water supply types are placed in one of nine categories. The 'land' feature type seem to be a 'catch-all' classification and contains some effects that should be classified as land reported effects, not water supply reported effects.

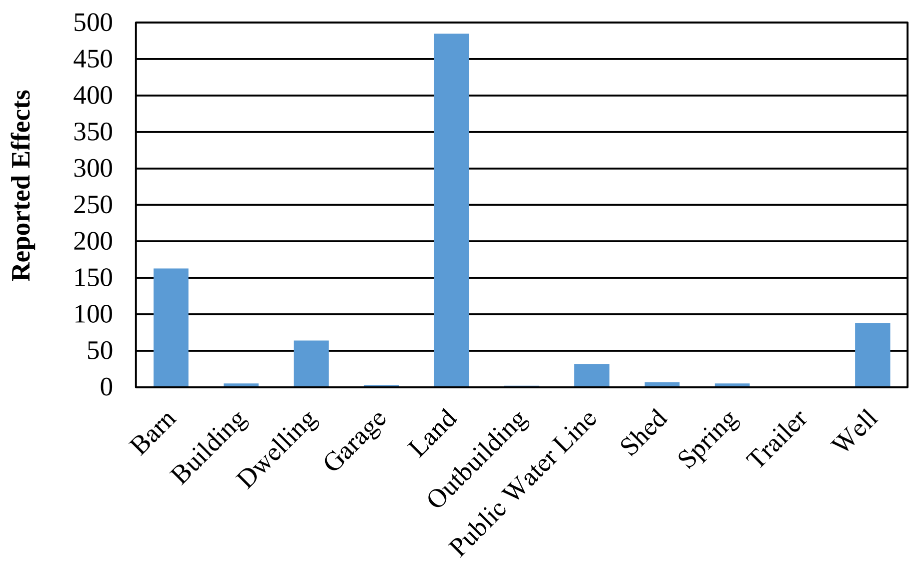

Figure V-6. Total water supply reported effects (n=855) as of 20 August 2013 classified by feature type.

The University analyzed the Company Liable water supply effects to determine the relationship between proximity to mining and determination of company liability. The University calculated the angle from vertical necessary to draw a line from the nearest edge of the mining extent to the reported effect. Figure V-7 illustrates the distribution of the water supply impacts as a function of this angle. 60% of the impacts are within a 10º angle of the edge of mining. About 77% of the water supply impacts are within the RPZ angle used for initial determination of company liability. The remaining 23% outside the RPZ angle are determined to be company liable after further investigation of the reported effect. Of the total 654 resolved reported effects, 57%, or 371, were found to be Company Liable.

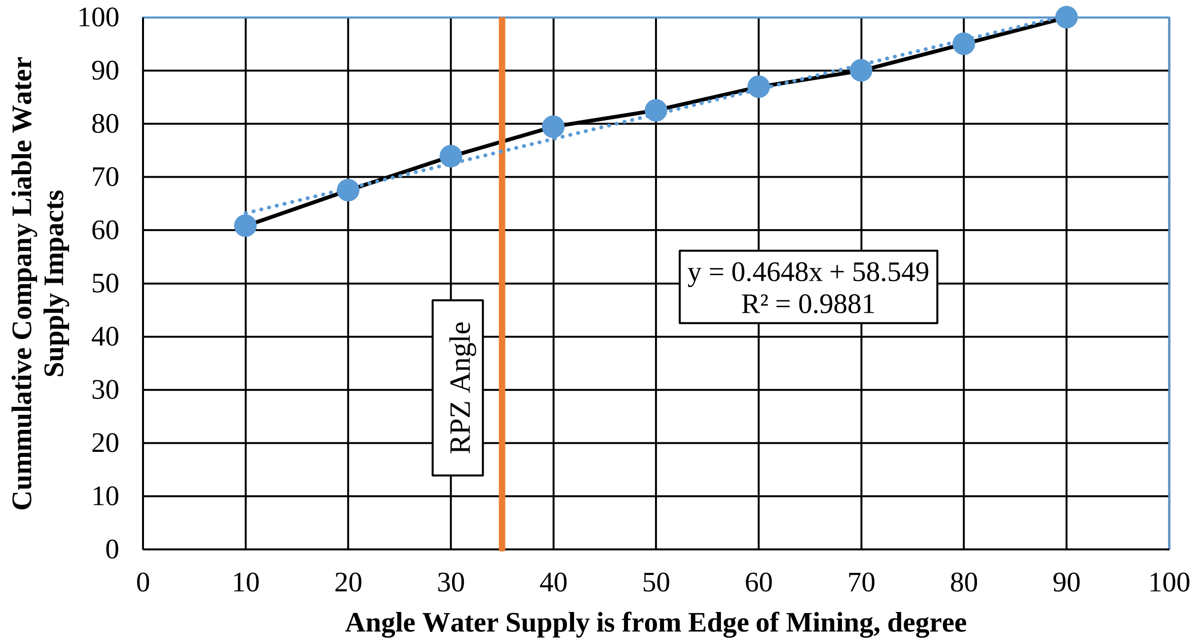

Figure V-7. Distribution of the company liable water supply effects and the angle the water supply is from mining.

V.F – Comparison to Previous Act 54 Reports

Since the creation of Act 54, three reports have been submitted to the Commonwealth regarding the effects of underground bituminous coal mining on surface features. Figure V-8 illustrates a comparison of the total acres mined and total reported water supply effects across these reports and the current Act 54 assessment. Despite an 18% drop in number of acres mined, the number of water supply reported effects has increased by approximately 25% (855 from 683). The increase in reported water supply effects may be attributable to the encroachment of underground mining into more heavily populated areas where the density of water supplies to mining acres is greater than in more rural areas. Another potential cause may be a growing public awareness of Act 54 and its codification of the rights of citizens to redress by the mining company of any adverse effects on water supplies. Lastly, some of the increase could be due to the classification of land reported effects as water supply reported effects.

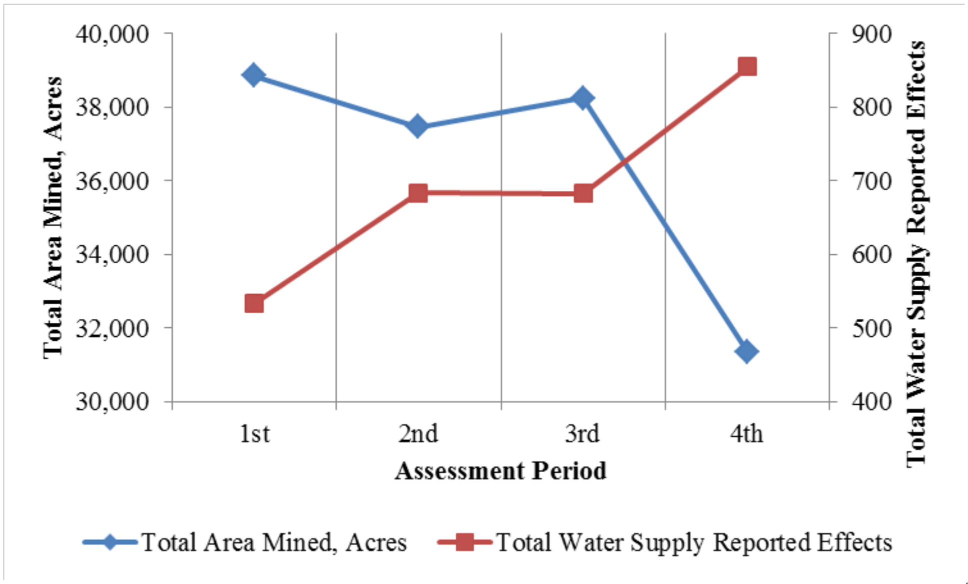

Figure V-8. Comparison of mined acres and total water supply reported effects from the 4th Act 54 assessment with data from previous assessments.

V.G – Characteristics of Company Liable Water Supply Effects

The University was able to accurately locate 367 unique company liable water supply effects, several with multiple effects, and performed rudimentary analysis. Overburden of company liable water supply effects are easily grouped on either side of the 500-ft value (Figure V-9). Room-and-pillar effects clustered between 100 and 500-ft of overburden, while longwall effects clustered between 500 and 900-ft. Three contributing factors for the trends in Figure V-9 are:

- room-and-pillar mines are shallower than longwall mines (averaging 381-ft compared to 783-ft)
- longwall mines undermined more surface lands than room-and-pillar mines (54.3% of the total verses 39.4%), and
- extraction ratios (Re) for room and pillar mines are significantly lower than for longwall mines (RP ranged from Re = 0.4 to 0.7; L ranged from Re = 0.4 to 1.0, see Section III).

The interplay of these three factors in the occurrence of company liable water supply effects is not well understood.

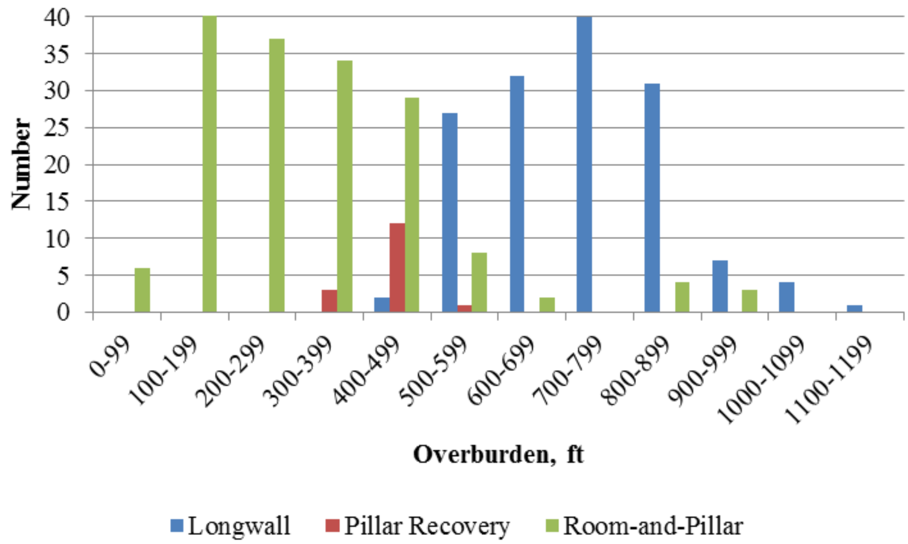

Figure V-9. Overburden distribution of company liable water supply effects. Note that equal numbers of company liable water supply effects between longwall and room-and-pillar mines.

Two hundred and eighty-three company liable water supply effects, some with multiple problems, were located within the tops of the hills, along the hillside slopes, or within the valley bottoms (Figure V-10). The topographic position, i.e. hilltop, hillside, or valley bottom, can be a significant factor in determining the likelihood of company liable water supply effects. Wells are often drilled along the hillside or within the valley bottom as hilltop wells require considerable drilling depth to reach typical groundwater aquifers. Springs are often found on hillsides, especially near the valley bottoms and represent the discharge points for perched aquifers. It is therefore expected to see the distribution of company liable water supply effects as shown in Figure V-10, where effects within hillsides dominate. Few hilltop water supplies are expected, so limited effects are likely. Conversely, water supplies within the valley bottom are least likely to be affected since this area received water from the surrounding hillsides and hilltops as well as the associated streams and wetlands. The data suggests that hillsides water supplies need special attention when planning for subsidence events.

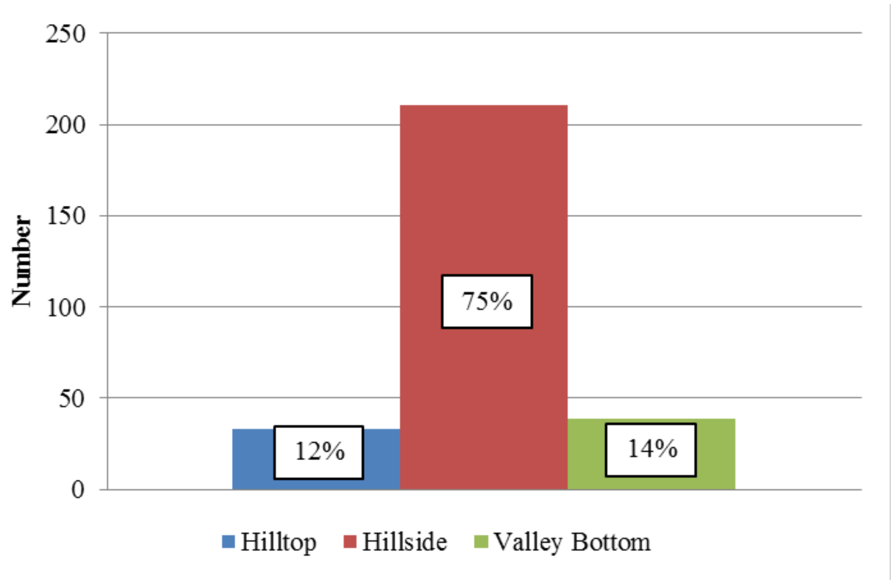

Figure V-10. Company liable water supply effects categorized by their topographic location.

The influence of mining on company liable water supply effects was examined by placing the data into one of four categories: 1) above the 'full extraction' panel [longwall or pillar recovery panels], 2) above the room-and-pillar developments, 3) inside the RPZ buffer but outside the mine, and 4) outside the RPZ buffer (Figure V-11). Three hundred and sixty-three water supplies were accurately located and their positions measured with respect to mining during the 4th assessment period. Seventy (19%) company liable water supply effects occur above the longwall panels. However, 186 (51%) company liable water supply effects lie outside the RPZ buffer. Many of these effects were found to be undermined in early assessment periods or they occurred during the 3rd assessment period but didn't reach a resolution until the 4th assessment period. These data suggest that a company liable water supply can occur when a mine is in a Non-active status and outside the RPZ. This is especially true of room-and-pillar mines.

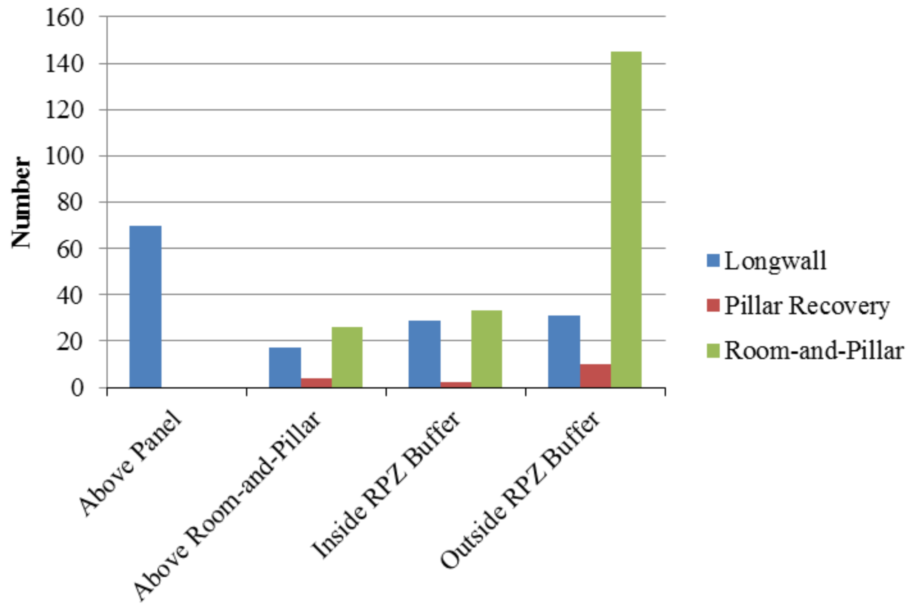

Figure V-11. Location of the company liable water supply effects with respect to the position of key mining zones extracted during the 4th assessment period.

V.H – Summary

Eight hundred and fifty-five water supply reported effects occurred during the 4th assessment period. Three hundred and ninety-three were from the seven longwall mines, 384 from room-and-pillar mines, 24 from pillar recovery mines, and 54 from non-active mines. An additional, 211 water supply reported effects were carryovers, classified as unresolved, from the 3rd assessment period. Of the 654 resolved cases, the average time to reach a final resolution was 220 days with 50% being resolved in the first two months and the final 25% taking between one and 4.5 years.

Three hundred and seventy-one water supply reported effects were found to be company liable, or 43% of the total. Four company liable water supply effects categories were identified: *Agreements* (70% to total company liable water supply effects); *Permanent Supply* (15%); *Recovered/Repaired* (12%), and *Resolved* (3%). The type of agreement was significant in the length of time to a resolution with *Agreements* having the least days and the *Resolved* taking the most days.

Water losses represent the majority of water supply effects, with 84% of the total. Water contamination represents the remaining 16% of the total. Room-and-pillar mines show the greatest percentage of water contamination effects at 25% while pillar recovery mines show the fewest at 9%.

The University was unable to locate all features on six-month mining maps with a corresponding BUMIS report. The feature 'types' and 'uses' were often not classified within BUMIS in a manner consistent with information collected during the 3rd assessment period making comparisons difficult. In addition, unresolved water supply reported effects were, for the most part, not given an interim status.

References

Witkowski, M.N. (2011) “The Effects of Longwall Coal Mining on the Hydrogeology of Southwestern Pennsylvania,” 30th International Conference on Ground Control in Mining, Morgantown, WV, July 26-28, 2011.

SECTION VI: Impacts of Longwall Mining on Groundwater

VI. A – Overview

This section assesses the considerable body of hydrologic data collected during the coal mining permitting process in Pennsylvania, focusing on hydrologic conditions above longwall mining. In particular, the adequacy of the hydrologic data for assessing stream impacts, interactions between ground waters and streams, and the role of hydrologic change in affected supplies is evaluated. This assessment hinges upon an understanding of hydrogeologic conditions in the area. The first portion of the section focuses on the hydrologic and hydrogeologic conditions in southwestern Pennsylvania and summarizes the conceptual understanding of how these conditions interact with underground mining. Next, methods used to collect the hydrologic data and assess the data are outlined. These data are utilized to examine small-scale hydrologic processes, and the limitations of the data, as currently collected and reported, are demonstrated. Finally, the importance of soil water and the current uncertainty regarding hydrologic balance in soil waters is outlined.

VI. B – Regional Hydrology, Geology, Climate

Pennsylvania straddles several physiographic provinces; provinces are defined as regions with consistent topography and landforms. Southwestern Pennsylvania is located in the Waynesburg Hills physiographic sub-province within the Appalachian Plateau Province. The Appalachian plateau was once a relatively flat surface that has been gently and periodically uplifted, allowing incision by streams and rivers and the formation of deep valleys (Wagner et al. 1970). Glaciation also strongly contributed to this incision process as glaciation in the northwestern part of the state directed the drainage of the large Ohio and Beaver paleo-rivers away from what became the Great Lakes region, forcing southwestern Pennsylvania paleo-streams flowing northward to flow south (Wagner et al. 1970). This geologic history is still evident in the modern landscape, particularly the high topographic relief.

VI.B.1 – Geology

The bedrock formations of the Waynesburg Hills physiographic sub-province were deposited during the Pennsylvanian and Permian periods. These formations are composed of sedimentary layers of sandstone, shale, limestone, and coal. These consolidated rock layers generally have low primary permeability. Secondary permeability (fracturing) often facilitates the movement of water through rock layers (Figure VI-1) (Wyrick and Borchers 1981). These permeability features are important to the movement of groundwater.

During the 4th assessment period only rocks from the Pennsylvanian coalbeds were mined. The Pennsylvanian system contains six formations: Uniontown, Pittsburgh, Casselman, Glenshaw, Allegheny, and Pottsville. The two most prominent coal-bearing formations are the Allegheny and the Pittsburgh. The coal geology is covered in more detail in Section III.

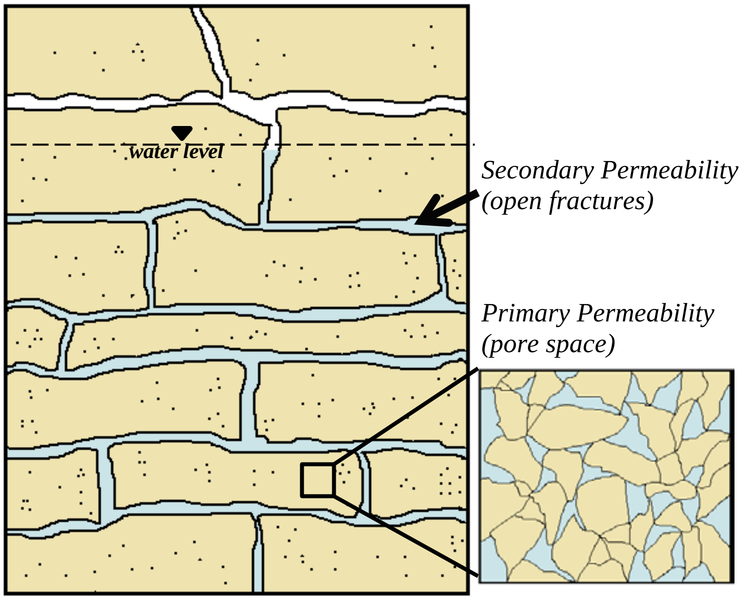

Figure VI-1. Primary and secondary permeability of a rock formation. Figure modified from Wyrick and Borchers (1981).

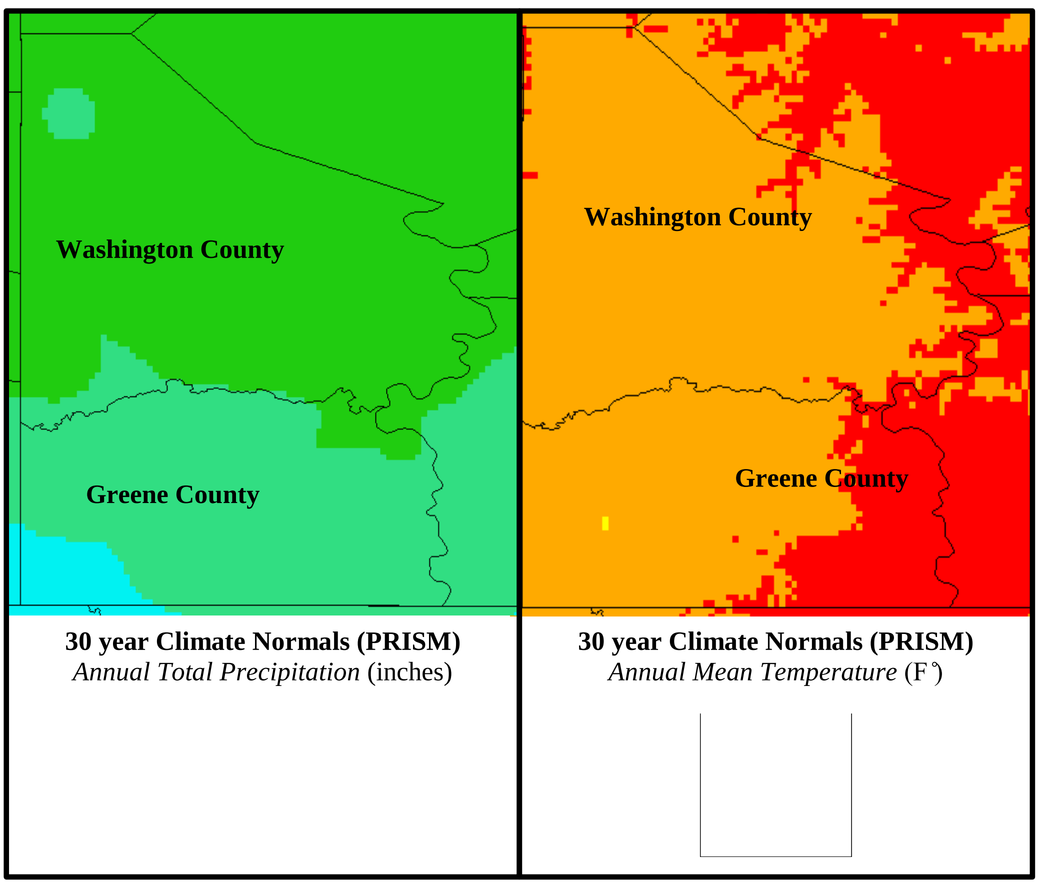

Figure VI-2. Climate data for southwestern Pennsylvania using 30 year normals obtained from http://www.prism.oregonstate.edu/normals/. Climate normals are averages of 30 years of daily data.

VI.B.2 - Climate and Groundwater Hydrology

The climate of southwestern Pennsylvania is humid and moderate. Annual average rainfall ranges between 30 and 49 inches and average temperatures fall between 45 and 54 degrees Fahrenheit (Figure VI-2, http://www.prism.oregonstate.edu/normals/). Drainage basins within southwestern Pennsylvania are typically high relief. The climate and topography results in hydrologic flow paths across scales including: local (perched/strata aquifers), intermediate (riparian aquifers), and regional groundwater systems (Figure VI-3) (Poth 1963).

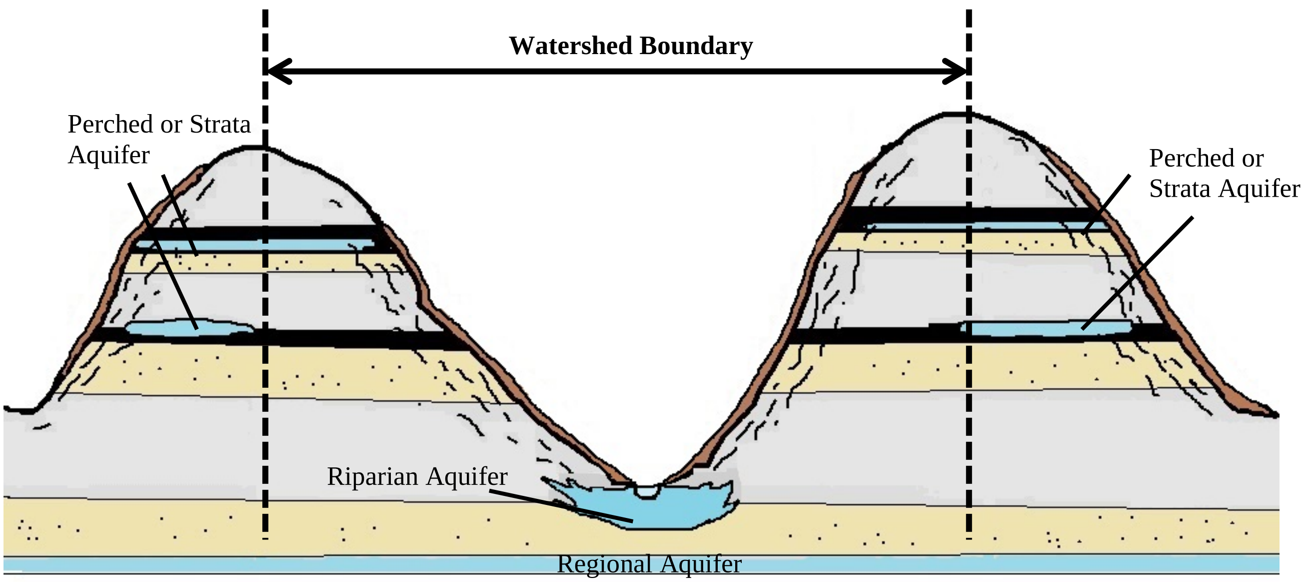

Figure VI-3. Conceptual model showing watershed boundaries and ground water aquifer. Source waters and discharge points for ground water drainage patterns are challenging to characterize due to independence from surface topography.

VI.C - Longwall Mine Subsidence and Hydrologic Impacts

Subsidence due to underground mining interrupts the continuity of rock strata through deformation and fracturing, consequently altering surface topography (Booth 2006, Peng 1992) (Figure VI-4). A subsidence basin typically forms when the ratio of the extraction zone width (width of the longwall panel) to overburden thickness (depth of mine panel) exceeds 0.25 (Iannacchione et al. 2011). Since most recently mined longwall panels are deeper than 500-ft in Pennsylvania (Section III), a subsidence basin is expected to form at panel widths greater that 125-ft. Pennsylvania longwall panels tend to be greater than 1000-ft wide, therefore subsidence basins are expected to form with every mined panel (Iannacchione et al. 2011). Modern longwall mining has been practiced extensively in northern Appalachia for three decades, undermining many surface and subsurface water resources (Peng 2008). Effects on surface and groundwater are dependent on many factors, including overburden thickness and stratigraphy location with respect to longwall mining panels (Peng 2008). It is important to understand how mining subsidence impacts both surface and subsurface landscape processes, particularly hydrological processes.

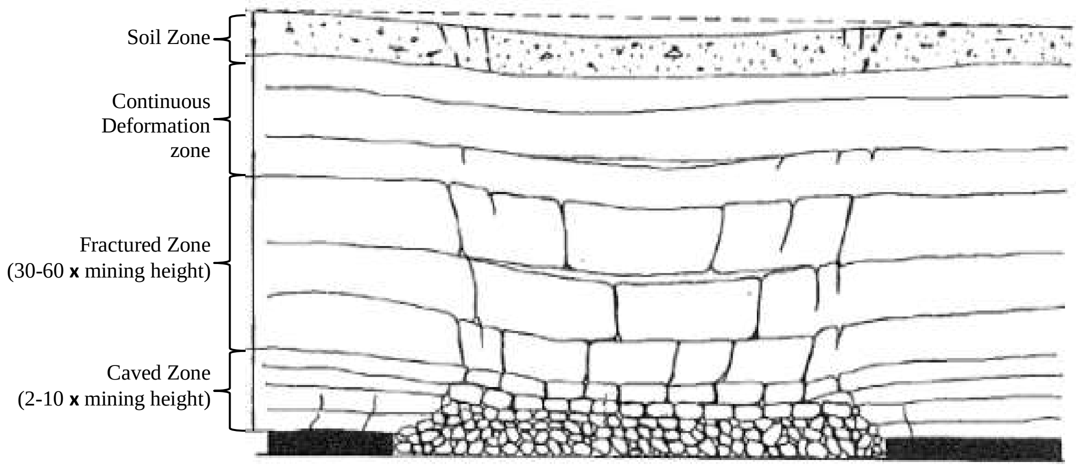

Figure VI-4. Subsidence model showing four subsidence zones as described in Peng (1992).

Many conceptual models have been proposed to describe subsidence processes and resulting alterations to overlying strata. Peng (2006) describes four subsidence zones that are created in the overburden following longwall mine subsidence (Figure VI-4). The immediate zone above the roof of the mine is the **caved zone**, in which the overlying strata fall into the void in irregular platy shapes, expanding to 2 - 10 times the mining height. Above this zone is the **fractured zone**, where strata are broken into blocks by vertical fracturing and by separation of horizontal rock layers resulting in horizontal fractures. The **continuous deformation zone** lies above the fractured zone, but it does not experience major fracturing that extends through the strata. Finally, the **soil zone** varies in depth, with fractures that may extend through the entire soil layer. Cracks can open and close as mining progresses and they may remain persistently open if located near or on the edge of the panel. The properties of these subsidence zones are important when considering impacts to ground and soil water flow. When considering Peng's model, groundwater flow through aquifers located within fractured and caved zones is expected to be persistently altered. Ground water loss located in the overlying continuous deformation zone is not expected to be permanent, but may temporarily be diminished. Water levels in the soil zone may also temporarily drop unless located near the edge of panels, where more persistent cracks may form parallel to the panel edge where soil and ground water rerouting is expected to be more persistent. Depth of mining influences impacts to water sources. The thickness of the fracture zone is generally 325-400-ft. If the depth of mining is less than 400-ft, there is a greater possibility that water loss in streams and wells will occur (Peng 2008).

Kendorski (2006) describes five subsidence zones based on the impacts of mining subsidence to groundwater flow as well as observed changes in rock properties (Figure VI-5). This model was published in 1979 and was the first proposed conceptual model of subsidence that was defensible and could be used to predict changes to a mine's hydrological regime (Kendorski 2006). The five zones, established using observations made by subsidence engineers and hydrogeologists from multiple countries, are similar to Peng's four zones: 1) The caved zone is completely disrupted vertically and horizontally; 2) the fractured zone has high vertical transmissivity due to abundant vertical fractures; 3) the dilated zone contains an upper confining layer unaffected by mining that overlies an impacted zone with increased water storage potential; and 4) the constrained and unaffected zone has no significant effect on transmissivity and storativity of ground water following subsidence. The surface disturbance zone is described by vertical cracks in the surface relative to panel location that temporarily disrupt soil water flow for up to two years (Kendorski 2006).

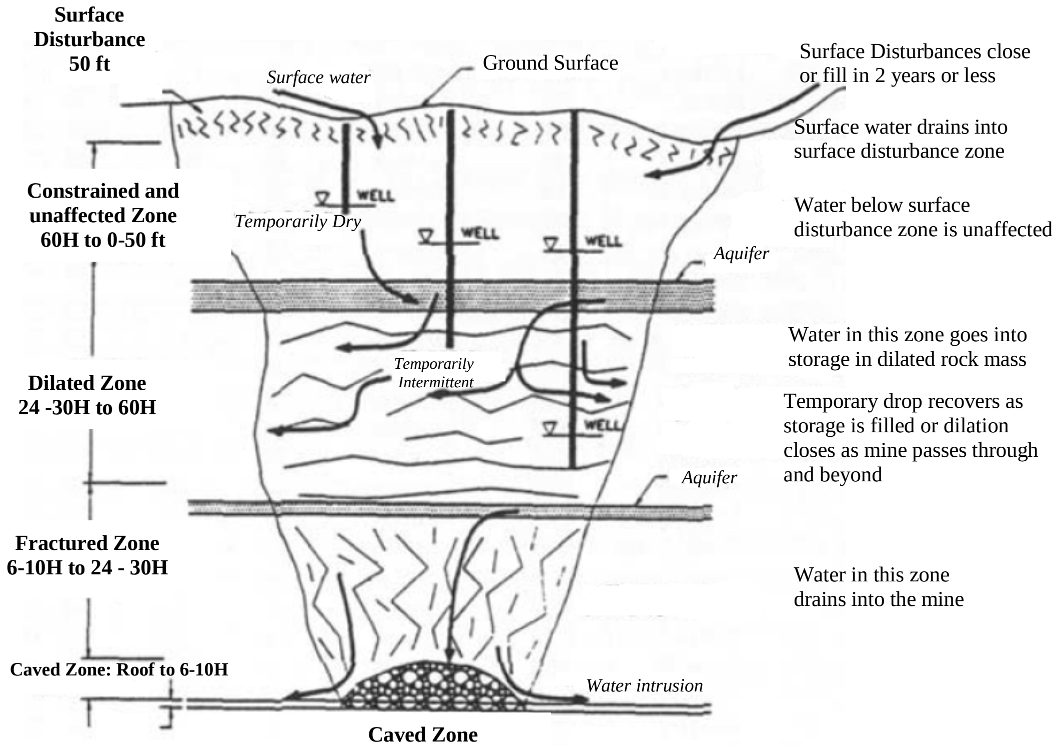

Figure VI-5. Overburden movement resulting from longwall mine subsidence and the 5 zones of overburden strata movement (Kendorski 2006). H = mining height.

VI.C.1 - A Hydrologic Focus on the Eight Factors Impacting Flow Loss

There are many factors that influence the natural flow of groundwater and adequately describing these factors to predict subsidence impacts on surface water hydrology is challenging. As also described in Section VIII, eight factors have been identified as contributing to flow loss impacts on undermined streams (TGD 563-2000-655) and are summarized below along with explanations of how each factor contributes to post mining hydrologic change:

1. Drainage/watershed area: Streams with smaller watersheds are more susceptible to flow loss. During dry periods, "stored" water in a watershed can buffer surface flow. Smaller watersheds collect less water than larger watersheds. They have smaller catchment basins and can also be missed by isolated conductive precipitation systems (thunderstorms). Thus during dry periods, their smaller stored water volume has a diminished flow buffering capacity. Therefore rerouting of water from the basin has a disproportionate effect on water storage and flow buffering capacity in smaller basins leaving them more susceptible to flow loss.

2. Streambed lithology: Streams with a larger percentage of exposed bedrock in the stream channel are more susceptible to flow loss. Brittle, consolidated rock underlying the stream channel or aquifers within a hillslope are more easily fractured and/or existing fractures more easily widened (therefore increasing secondary porosity). Altered fracture networks can re-route flow to deeper flow paths and diminish flow in surface waters and perched/bedrock aquifers. However, this flow loss may be temporary, as particles of weathered rock material can fill the fractures over time.

3. Depth of cover: Streams with shallow overburden depth are more susceptible to flow loss. This is simply due to the depth of the fracture zone that forms following subsidence. Shallow overburden depths increase the potential for fracture zones propagating to surficial zones and compromising confining layers underlying aquifers contained in these strata.

4. Overburden geology: Streams with a greater percentage of “hard rock” in their overburden are more susceptible to flow loss. This factor represents the interaction between mechanisms driving factors 2 and 3, as these interactions can result in positive feedbacks that extend and expand fracture networks.

5. Percent of watershed mined: Streams with a greater percentage of the watershed mined are more susceptible to flow loss. Subsidence impacts are greatest at topographic highs, increasing from valley floors, up the hillslope (Leavitt and Gibbens 1992, Tieman and Rauch 1987). Disrupted hillslope hydrology high in the watershed may lead to diminished flow in streams similarly located. Smaller watersheds that are undermined are, on average, likely to have a larger proportion of the watershed undermined.

6. Stream orientation: Stream orientation with respect to the direction of the maximum principle horizontal stress field can influence the tendency of streams to lose flow as fractures resulting from subsidence will tend to be oriented perpendicular to the least principal stress.

7. Presence of natural fracture zones: Streams already interacting with natural fracture zones (e.g. streams with predominantly straight reaches) are more susceptible to fracture propagation and therefore flow loss.

8. Mining height: As the mining height increases, the likelihood of flow loss on overlying streams also increases, due to the dependence of subsidence effects on coal seam thickness (Figure VI-5).

These eight criteria were identified as factors to aid in predicting flow loss to streams and other water resources post mining. Some of these factors are considered to have greater influence on post mining hydrological outcomes, based on observations and past experience. Those considered primary hydrologic variables are *Drainage/watershed area, streambed lithology,* *depth of cover (overburden), and percent of watershed mined*. The remaining factors, *stream orientation*, *presence of natural fracture zones and overburden lithology*, are considered secondary and can greatly exacerbate impacts of the primary factors.

VI.D – Hydrologic Data and the Evaluation of Hydrologic Impacts

Hydrologic drivers operate across widely varied time scales. Global circulation patterns direct air masses to specific regions, setting the basis for regional climate. The landscape history, ranging from active tectonics to Holocene glaciations, set the terrain and influence the evolution of drainage networks and aquifer systems. Fortunately, most of these dynamics occur so slowly that one can ignore these changes when evaluating the impacts of underground mining. However, beginning with decadal scale drought cycles and continuing through increasingly finer temporal scales, including the dynamics of storm flow generation, a wide variety of time-scales must be incorporated into a coherent and accurate understanding of changes in hydrologic cycling.

Currently, a wide variety of data are reported to PADEP to meet requirements of the permitting and monitoring process. Several of these data series can be used to under hydrologic changes above underground mining, summarized below:

Data this Section Focuses on

1. Hydrologic Monitoring Reports: Mining companies monitor three types of hydrologic responses arising from underground mining: 1) Surface water flow and chemistry are monitored at surface water monitoring stations; 2) Groundwater elevations and chemistry are monitored in selected wells and nests of piezometers (i.e., wells that are “open” at specific depths to examine independent groundwater responses in different aquifers (e.g. shallow, intermediate, and deep), and 3) Spring flow and water chemistry are monitored at selected springs located over mining. In the hydrologic monitoring reports submitted to PADEP during this period, complete flow and chemistry data are generally collected quarterly, though some streams over the Bailey and Enlow Fork Mines included flow monitoring data that varied according to the relative position of undermining (see section VII.D.1 for relevant portions of permit requirements). Water chemistry is very rarely reported in cases where sampling is more frequent than monthly.

Data Described in Detail in the Section VII

2. Stream Biological Monitoring: Transitions in hydrologic conditions are one of the stressors that can alter benthic macroinvertebrate communities and therefore are reflected at least in part in the changes in Total Biological Scores reported for stream reaches.

3. Flow loss maps: The maps showing reaches without flow can be used to understand areas of substantial hydrologic impact.

Data Described in the Section V

4. Water Loss Claims: In water loss claim rebuttals, data on particular water sources is sometimes extensive, particularly pump test data from water wells. These data are reported on a frequent time interval basis, generally one to fifteen minute intervals. However, the intervals between sets of measures are variable and sometimes long and the data is not organized into a single source. Furthermore, the data is not directly connected to the other hydrologic and geologic and mining related data, making utilization difficult, largely due to difficulties in discovery.

Other Data

5. Permit Data: As part of the permitting process, a wide range of data are collected and reported to the DEP. Most useful in the present context are two data types:

   - borehole logs showing the local overburden stratigraphy and
   - surveys of water availability and quality in sources above the undermined areas.

   In both cases these data are generally reported once, in the original permit or in a revision to the permit.

VI.D.1 - Hydrologic Data Collection Methods

In Pennsylvania, underground coal mining permits require a flow monitoring plan (5600-PM-BMP0324, 8.9 (PADEP, 2012)) that includes:

i. Weekly measurements commencing six (6) months prior to undermining the area of concern.
ii. Daily measurements commencing two weeks prior to undermining the area of concern and continuing until the potential for mining induced flow loss becomes negligible. (In the case of longwall mining daily measurements should continue until the longwall face has progressed a distance equal to the cover thickness beyond the area of concern.)
iii. Detect and report all occurrences of flow loss to the district mining office within 24 hours of observation.
iv. If flow loss occurs, daily observations or measurements commencing from the date of the observed loss and continuing until flow fully recovers or is fully restored or until underground mining operations are determined not to be the cause of the problem.
v. Weekly measurements continuing six months after the conclusion of daily monitoring.
vi. Corresponding measurements of flows in control streams (if applicable). [5600-PM-BMP0324, p. 8-3 to 8-4]

In addition, 5600-PM-BMP0324, 8.15 (PADEP 2012) requires a hydrologic monitoring plan that includes:

a. Complete Form 8.15A (Monitoring Program Summary) identifying the points which will be used in the monitoring program, the parameters to be measured at each point, and the period and frequency of sampling at each point.

b. Attach a narrative describing how the proposed monitoring points relate to the detection and mitigation of impacts discussed under Modules 8.9, 8.10 and 8.14.
c. Provide plans and describe procedures to compute accurate discharge flow rates from springs, streams, drains, pipes, sediment/treatment ponds, and mine discharge points. The field system as well as the calculation method must be usable by monitoring personnel and PADEP mine inspectors.
d. Describe how samples will be taken, preserved, and shipped to the laboratory.
e. Indicate the name and address of the laboratory that will perform analyses.
f. Provide the name and credentials of individual(s) performing well pumping tests.
g. Address the scope, location, and frequency of postmining monitoring (e.g. mine pool level monitoring). [5600-PM-BMP0324, p. 8-8]

These sampling guidelines and the reporting of results from pre-mining monitoring are contained in the permitting instructions; however, requirements for reporting during mining are not clearly specified. Hydrologic monitoring reports (HMRs), reports including flow, water elevation, and water chemistry data are submitted on a quarterly basis to PADEP. Yet, within these reports, there is substantial variability in what is reported (e.g. some mine operators report high frequency flow monitoring during the undermining period, some do not). There are distinct differences in report formats among companies. Further the reporting formats often evolve over the course of the reporting period. Even more problematically, format changes occur within a single report for most of the mines. The reporting process seems to be improving in that, beginning in the second quarter of 2013, these data were provided to PADEP on digital media (e.g. digital video discs) and stored with the paper copies.

Compilation and organization of this data required a substantial amount of effort, and largely precluded the time necessary to clearly document the informal processes of information exchange between the coal companies and PADEP. Some data that is collected to meet permitting process requirements is not reported to PADEP in the HMRs. For example, of HMR data gathered, there were no points in Blacksville 2, Emerald, or Cumberland with more than 40 observations (i.e., all reported data from these mines on average captured less than 2 observations every quarter). These areas were all undermined, meaning the required high frequency flow data was not reported in the HMR.

The heterogeneity in the data reported and the reporting format necessitates making decisions to allow for comparison of the data among the mined areas. For this report, the University relied solely upon the hydrologic monitoring reports submitted to the PADEP and stored in the permit files at CDMO. The University did not anticipate that the more extensive data collected to meet permit requirements would not be reported. Therefore resources necessary to determine exactly how information informally flows between PADEP and the mining companies were not available. Most importantly, focusing on the materials readily available in the HMRs is a more reasonable approximation of the data available to citizens of the Commonwealth during file reviews.

This variability in format required substantial data gathering and organization (Figure VI-6). In general, the process was conducted as follows:

1. All available HMRs were gathered from the relevant portion of the permit file. Data quality was assessed during this step by examining files for temporal continuity, etc.
2. If digital files were not available, HMR's were made digital as follows:
   a. HMR hard copies were scanned at 300 dpi resolution
   b. Scanned copies were processed with optical character recognition software, converting the digital image to spreadsheets
   c. Spreadsheets were compared with scanned images copies to check data accuracy.
3. Digital files required substantial reorganization for even rudimentary analyses (e.g. time series plotting). All files were reorganized into tables such that each sampling event was in its own row, identified by mine, station name, and date. All reported monitoring data was included in this row in the appropriate column. A separate table with all hydrologic monitoring stations reported in a single row along with appropriate geographic coordinates was also generated.
4. Both tables were stored in a database management system.

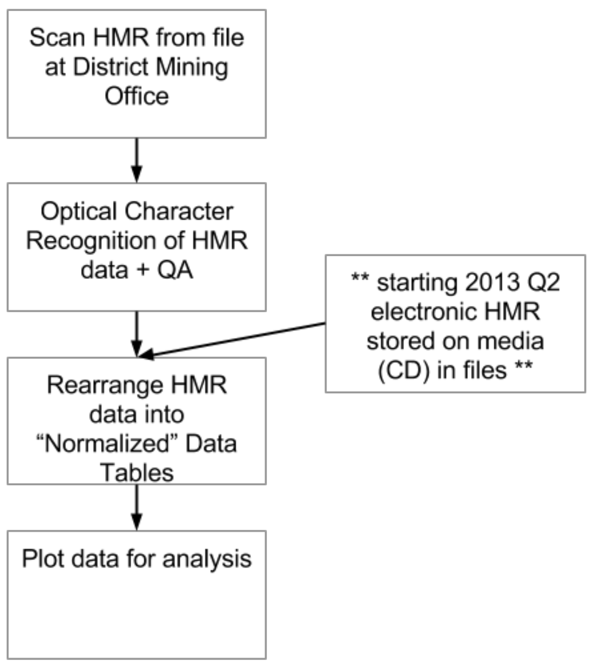

Figure VI-6. Flow chart showing processes involved in HMR data collection

This process was time and labor intensive. Moreover, given the relative timing of the assessment period, the last several quarters of hydrological monitoring arrived late during the University's working period. The University worked to compile complete records for the active mines (i.e., Bailey, Enlow Fork, Blacksville 2, Cumberland and Emerald), but there is inconsistency in the final quarter included in this analysis. In addition, several of the HMRs included data from earlier periods reported in current HMR. Table 1 shows the extent of time included in the database for each mine active during the 4th assessment period. For all analyses described below observations outside of the 4th assessment period were not included.

Table VI-1. Time period included in collected HMR data

Mine	Earliest Data Included	Latest Data Included
Bailey	Q1 2002	Q3 2013
Blacksville	Q4 2005	Q2 2013
Cumberland	Q4 2008	Q3 2013
Enlow Fork	Q3 2002	Q3 2013
Emerald	Q1 2009	Q3 2013

During the data gathering and organization process, HMR points without spatial coordinates listed in the HMR for at least some point during the assessment period were not included in the database. This decision was made early in the process. However, this process precludes quantification of the number of monitoring observations where observations are not usable. Counting of these instances would be a useful tool in future evaluation of the hydrologic data.

VI.E - Evaluation of HMR Data

The resulting HMR database contains 756 hydrologic monitoring stations and more than 31,000 distinct sampling visits among these stations. The number of hydrologic monitoring points may be inflated as naming conventions are not always clear. For example, in the Enlow Fork HMR data, there are two stations named alternatively, “SW 35” and “SW-35”. Identical coordinates were provided for each station, however the stations were sampled on a unique set of dates. In cases like these, the University preserved both stations. This may result in an over-count of stations due to duplicative station names, but should not cause an over-count of unique sampling events.

In some cases, variable units for pertinent data were reported. Most importantly discharge was reported both as cubic feet per second and gallons per minute. Similarly water level elevations in wells were reported both as the actual elevation above sea level and the depth from the land surface elevation at the well. This inconsistency was problematic as in some cases units/datums were switched within a single HMR, requiring substantial vigilance to not misclassify gallons per minute or feet below land surface observations. Data were converted to a consistent format. Gallons per minute were converted to cubic feet per second by multiplying by 0.00223. Depths to groundwater were converted to elevation above sea level by subtracting the depth to groundwater from the reported land surface elevation at the well location. If no elevation data were provided (roughly 86 sampling events during the 4^{th} assessment period), the groundwater elevations were not determined.

VI.E.1 - Evaluation of HMR Data Quality – Mass Balance

During the data organization process, problems in the reported data were evident. For example, water level elevation/flow data were reported in date format. In other cases, things like pH were reported in the wrong data row or column. In order to evaluate the general data quality in the HMRs, the University compared some of the simple chemical characteristics. Direct comparison of chemistry data with independent measurements is far beyond the scope of this reporting effort.

However, comparison of chemistry potentially allows examination of the rate of keystroke errors, misclassification errors, etc. The relationship of reported major anions (i.e., alkalinity (the sum of carbonate masses) and sulfate) and reported total dissolved solids were the primary data used in comparison. The comparison was based on the fact that surface waters remain neutrally charged. Therefore, the sum of anion mass must be less than total dissolved solid mass, as sufficient cations must present to offset the anion's negative charge. It is true that the cation mass can be minimal in acidic waters as the positively charged hydronium ion (i.e., H+) has a mass of 1. In the sampling period only 5 water samples were reported to have pH's below 6, indicating the contribution of hydronium ions appears largely negligible (i.e., less than 1-ppm). Therefore, as hydronium ions were not contributing to the total dissolved solids, the ratio of anions to total dissolved solids depends on the relative masses of the cations and anions. The maximum ratio, in most surface waters, is by definition less than 0.8. This would be the ratio in a pure magnesium sulfate solution, and the ratio would necessarily diminish with changes in the cation or anion mixture. In the 1,111 water samples in which total dissolved solids were reported, 563 had the ratio of the sum of alkalinity and sulfates to total dissolved solids exceeding 0.8. While this may result from common issues (e.g. reported pH's are in error and hydronium ions do contribute substantially, the waters have high dissolved organic acid content, or samples were not filtered) these explanations cannot be confirmed without a complete chemical characterization of the waters. However, the large proportion of the data in which water chemistry is substantially dominated by anions suggests the HMR data should be used with caution. This is particularly important as the water chemistry may provide useful information in future efforts to understand hydrologic changes associated with underground mining.

In addition, the University examined the relationship between total dissolved solids and specific conductivity to further evaluate the proportion of anions in samples where total dissolved solid concentrations were not reported. These total dissolved solids and specific conductivity were related as expected, with total dissolved solids (mg/L) 0.59 times the specific conductivity (µmho/cm). This relationship was applied to the 6,878 water samples where a specific conductivity was measured. Of these samples, 2,595 (38%) of the samples had a sum of sulfates and alkalinity that represented more than 80% of the measured or estimated TDS, a better rate than the direct comparison with total dissolved solids. However, three percent of these 6,878 samples (198 samples) had a sum of alkalinity and sulfates that was greater than the reported TDS or the TDS estimated from the reported specific conductivity, violating mass/charge balance. Where mass and charge balance are not preserved, it seems data should be rejected and amended data submission required. This may occur, but it is not reflected in the HMR file.

The chemistry data assessment suggests the HMR data quality should be more carefully evaluated. While the chemistry data does not control the flow, it provides a means to assess processes of dilution, changes in reduction/oxidation conditions, etc. These changes can inform our understanding of source flow paths in impacted water bodies. There are non-trivial issues with mass balance in the reported data. Confirmation of a problem and identification of the source of the problem are beyond the scope of this reporting, but something that should be addressed in the long term.

VI.E.2 - Evaluation of HMR Data Adequacy – Variability in Hydrologic Conditions

In general, the measurement of flow and water elevation is less prone to data quality issues due to the relative simplicity of the measurement. Water samples were collected by the field technician and transferred to the lab technician necessarily creating a gap in context. In contrast, water flows and elevations were generally measured by a few technicians and their experience with the sampling site can make small errors in math, transposition errors, etc. easier to catch and correct. However, while the redundancy in the chemistry data allows comparisons for consistency, flow and elevation data cannot be compared systematically with other reported data. Therefore systematic assessment of flow and elevation data quality was not completed.

Instead, the variability in hydrologic conditions was assessed with the HMR data. There were several instances in which flow for the same station was reported in separate parts of the HMR for the same day (Table VII-2). Most of these observations were not likely conducted at the same time, as the technicians would compare notes and minimize effort. In cases where both observations are identical (e.g. surface water stations with a difference factor of 1) it is likely these are the same data used in multiple reports to PADEP. However, in the remaining cases, the University assumes that the measurements are likely independent. In some cases, this is likely not true, as some differences seem to result from conversion errors (e.g. ST05-244 from Emerald on 12/12/2011 is similar to the conversion factor between gallons per minute and cubic feet per second (448.8)). However, the remaining data seem to be independent measurements over the course of the day. Most pairs resulted from cases where both daily hydrological monitoring and quarterly hydrological/chemical monitoring overlapped. In these cases, there is substantial variability in the flow levels (20-100%) measured within 24-hr of each other. In addition, groundwater elevations vary on average 9 inches over the 24 hour period. Data allowing attribution of this variability to measurement error, natural variability in flow/water table, etc. does not exist. However, the resulting implied level of uncertainty impacts the ability to detect changes in stream flow or water table due to mining impacts. A 20% change may be larger than changes arising from mining impacts. These data allowing comparison of measurements within a day are limited, however they indicate daily variability in hydrologic conditions could exceed potential hydrological impacts of mining. Therefore it is not clear that HMR are sufficient to detect and characterize these changes.

Table VII-2. Multiple observations of hydrologic conditions in a single day. The difference factor is the ratio of the larger observation to the smaller observation.

Ground water Elevations					
Mine	**Monitoring Point**	**Date**	**Measurement 1 (feet - MSL)**	**Measurement 2 (feet - MSL)**	**Difference (feet)**
By	PZ-H-I	15 October 2008	999.99	1000.91	0.92
By	PZ-H-S	15 October 2008	1022.31	1021.56	0.75
By	PZ-H-S	15 May 2009	1022.52	1021.79	0.73
By	PZ-H-S	14 July 2009	1021.53	1022.29	0.76
By	PZ-H-S	9 October 2009	1021.99	1022.34	0.35
By	PZ-H-I	18 January 2011	1001.26	1002.19	0.93
By	PZ-H-S	18 January 2011	1021.29	1022.12	0.83
By	PZ-F-S	3 December 2012	942.9	941.84	1.06
Ef	27-18-4.01-PZ-HI	8 September 2012	1157.7	1159.34	1.64
Surface Water Flows					
Mine	**Monitoring Point**	**Date**	**Measurement 1 (cubic feet per second)**	**Measurement 2 (cubic feet per second)**	**Factor of Difference (Max/Min)**
By	SW-17	17 September 2008	0.5	0.5	1
By	SW-17	9 June 2009	2.9	2.9	1
By	SW-17	2 December 2009	1.1	1.1	1
By	SW-17	2 March 2010	2	2	1
By	SW-17	20 October 2010	0.16	0.2	1.25
By	Strn H-02	10 February 2011	0.293	0.15	1.98
By	SW-17	14 February 2011	5	5	1
By	Strn H-02	7 November 2011	0.122	0.00022	546
By	Strn H-02	13 February 2012	0.158	0.217	1.37
By	SW-19	6 December 2012	0.001	0.47	470
By	SW-19	14 February 2013	5.4	5.4	1
Cu	S-81	26 April 2012	0.04	0.0397	1.01
Cu	S-82	26 April 2012	0.017	0.0172	1.02
Ef	SW28	6 March 2012	0.83	0.91	1.1
Ef	SW42	15 August 2013	0.08	0.11	1.38
Em	ST05-244	12 December 2011	0.014	6.36	454

Agencies such as the U.S. Geological Survey typically measure discharge/water table elevations at fifteen or thirty minute intervals and average these readings to report daily average discharges/water level elevations, smoothing this variability and collecting that data that allow detection of changes at shorter time scales. Examination of continuous stream flow measurements from such regional networks demonstrates the importance of more frequent measurements in the evaluation of hydrologic change. The U.S. Geological Survey (USGS) constantly measures stream flow in streams across the United States and stores these data in the National Water Information System (NWIS). Several gauging stations that record flow in streams draining areas lying over active and historical longwall panels are available for analysis: South Fork Tenmile Creek at Jefferson, Pennsylvania (USGS 03073000), Wheeling Creek at Elm Grove, WV (USGS 03112000), Chartiers Creek at Carnegie, Pennsylvania (USGS 03085500), and Dunkard Creek at Shannopin, Pennsylvania (USGS 03072000) (Figure VI-7). In addition, USGS groundwater monitoring network water level elevations were collected from the Greene (USGS 394655080014301) and Washington (USGS 400233080261301) County observation wells. These wells are further from the longwall mining activity (Figure VI-7), but the groundwater monitoring network is decidedly sparser than the surface water observation network and continuous records closer to underground mining activity do not exist.

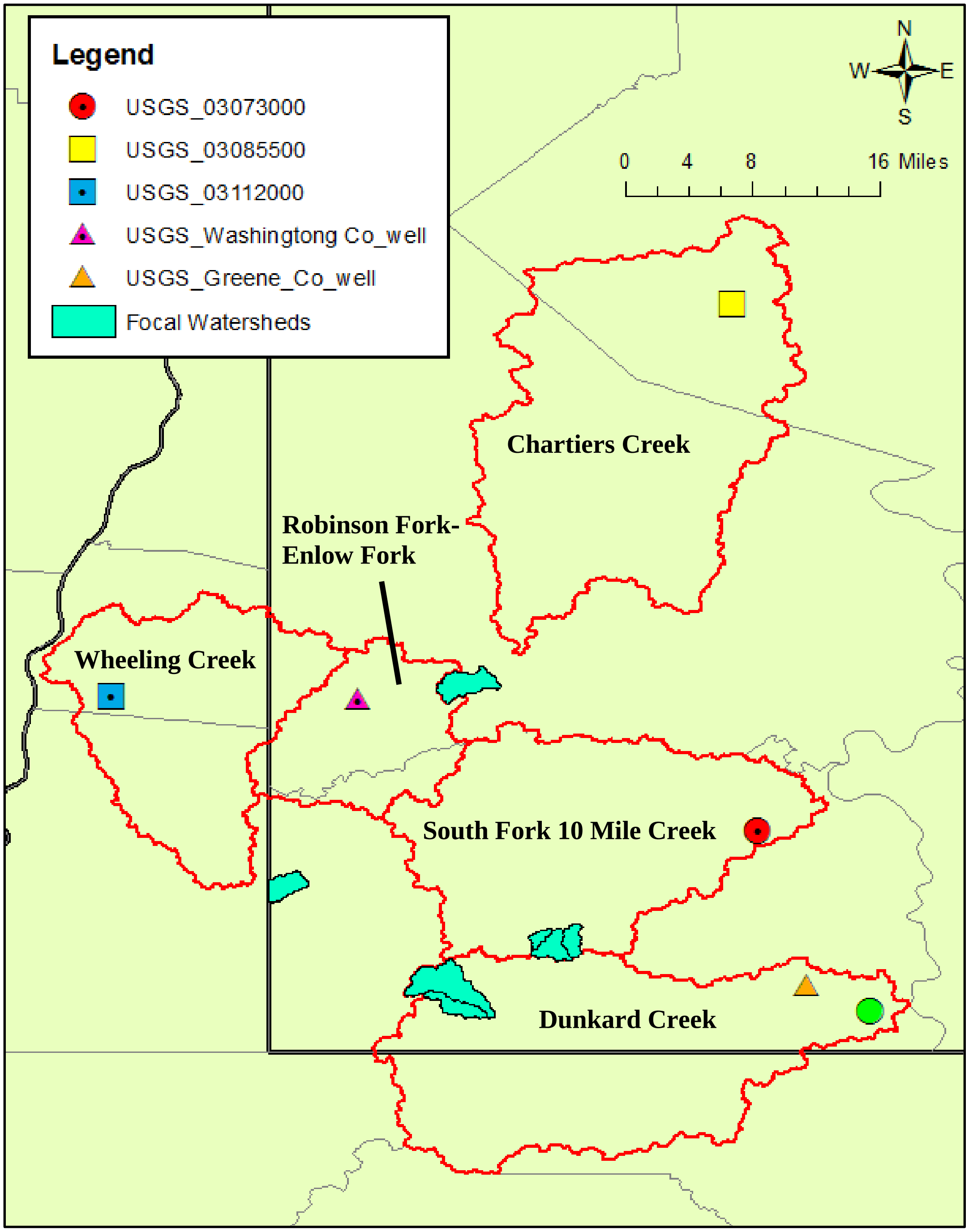

Figure VI-7. Locations of USGS stream gauges and groundwater monitoring wells relative to watersheds overlying areas of active mining. Red outlined areas are major HUC 10 watersheds in which the USGS monitoring points are located (http://datagateway.nrcs.usda.gov/).

Using the record from Wheeling Creek as an example, the variability in daily discharge over the course of the assessment period is considerable (Figure VI-8). The average daily flows range over two to three orders of magnitude in a typical year. This variability is even wider if the finer time interval (e.g. average thirty minute discharge) data is examined. The sparse nature of water flow from Crafts Creek (reported for Enlow Fork point SW36), is challenging to interpret given this variability. The low discharges measured during 2010 and 2011 could conceivably be a function of timing and it is therefore challenging to attribute "changes" observed in the record to underground mining activities.

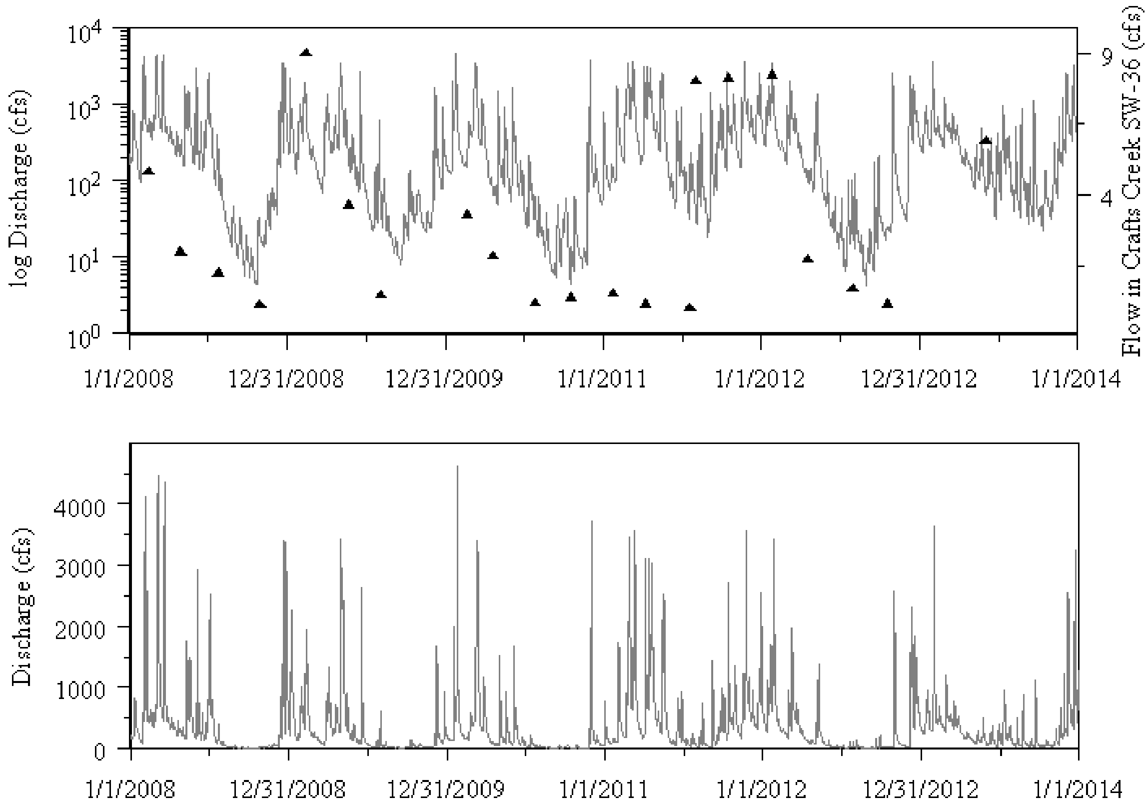

Figure VI-8. Average daily flow at Wheeling Creek at Elm Grove, WV (USGS 03112000) over the course of the assessment period. Upper panel shows log transformed discharge and the discharges recorded at SW-36, a hydrologic monitoring point located on Crafts Creek above the Enlow Fork Mine (SW-36 discharges shown as triangles and depicted on right hand scale). Lower panel shows Wheeling Creek discharge data on an untransformed basis.

Groundwater elevations do not vary over as large a range as stream flow. However, groundwater elevations are clearly influenced by the local hydrologic conditions at depth (Figure VI-9). In general, very limited hydrogeologic information is provided in module 8, in particular, logs of stratigraphic materials for these piezometers and groundwater wells are lacking. Therefore attribution of the wide variance in piezometers such as Bar R-PZ-1 and Bar R-PZ-2 (Figure VI-9) to shallow overburden or to an actual difference in hydrogeologic materials is not possible. In addition, the HMR data are more variable than the USGS data, likely due to the difference between a daily average and a single measurement during the day, particularly when reported data indicate that ground water elevations vary over an average range of 9 inches/day. Fundamentally, even the USGS monitoring wells are radically different, despite the fact that they are meant to represent hydrogeologic conditions in adjacent counties. Given these data limitations, only groundwater data in close proximity to impacted areas of interest are appropriate for detailed analysis.

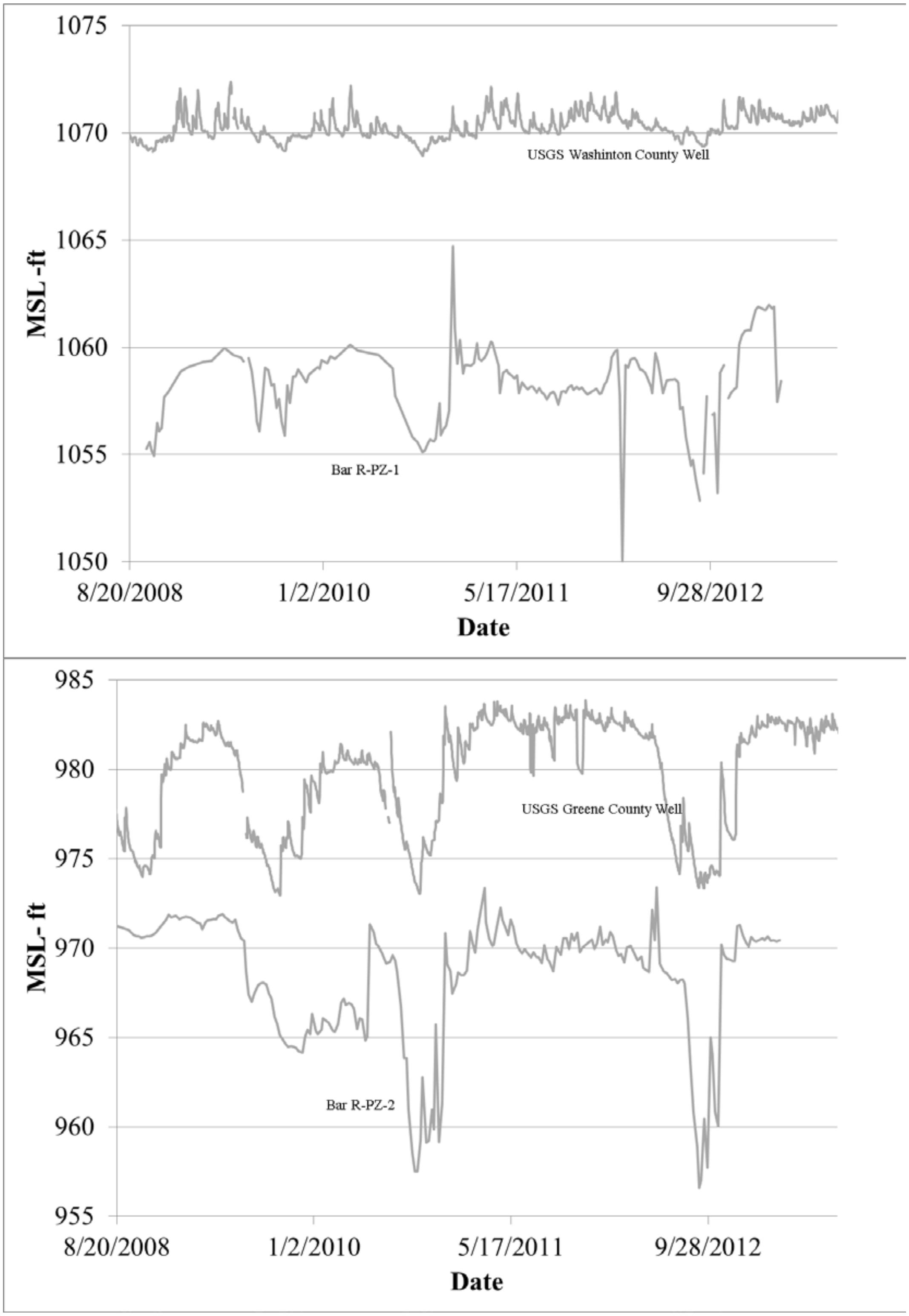

Figure VI-9. Average daily water level elevation in the USGS Groundwater Monitoring Network wells for Washington and Greene County, Pennsylvania, plotted with observations made at Bar R PZ-1 and Bar R PZ-2, two piezometers located in Barneys Run, over the Bailey Mine.

VI.E.2 - Evaluation of HMR Data Adequacy – How much precision is necessary?

The impacts of underground mining to hydrologic systems depend, at least in part, on the changes in variability in flow and therefore the changes in local shallow water table elevations. The most acute impact is the complete loss of flow in the stream. Intermittent flow is a natural occurrence in low order streams, as these streams are generally situated at elevations above regional ground water aquifers and diminished moisture status during summer months cannot be buffered by subsidies from these deeper ground water reservoirs. In low order streams, the timing and duration of periods without flow are controlled by relatively consistent processes (e.g. transpiration via local vegetation and evaporation due to climate) and the biota of those streams are generally adapted in ways that synchronize with these predictable patterns (Lytle and Poff 2004). Changes to either timing or duration of no-flow periods can interfere with strategies developed by in-stream organisms to survive dry periods. In general, the regional hydrologic observations (i.e., the USGS NWIS data) are made on larger streams that intercept regional aquifers. Therefore, these long-term records of flow generally do not include intermittent periods of no flow and characterization of these "natural" periods of flow loss is not clearly quantified. Impacts to in-stream macroinvertebrate communities can be inferred from the measurement of these communities. However, these measurements do not clearly allow assessment of other no-flow impacts. For example, nutrient buffering capacity of smaller streams is likely compromised or diminished during extended no flow periods, contributing to aquatic impacts further downstream. Mechanistic prediction of diminished buffering is not possible without clearer characterization of the flow regime changes following undermining.

The changes in water balance resulting in flow loss can be approximated by comparing the water augmentation data (described in Section VII) with annual average precipitation and used to estimate the relative amount of precipitation that is "lost" in dry streams following subsidence. For example, all weekly augmentation reported for Barneys Run (the focal watershed over Bailey Mine) during 2012 were converted to gallons by multiplying average gallons per minute values by the number of minutes in a week. The resulting gallons were summed to arrive at an approximate number of gallons augmented in 2012 (38.3 million gallons). Converting these gallons to cubic feet (5.12 million cubic feet/year) and dividing by the number of square feet that Barneys Run drains (81 million square feet) results in a depth of 0.063 feet or roughly 0.75 inches. This depth is analogous to a single precipitation event in the region, the proverbial 1-inch storm. Therefore, the augmentation done in Barneys Run in 2012 is equivalent to a climatically minor event. Given an annual rainfall of 42 inches (Figure VI-2), that means the impacts necessitating augmentation result from a relatively minor change in water balance.

The collection and reporting of more frequent hydrologic data is necessary to evaluate the impacts of underground mining. The limited data collection event at its maximum (once per day) still is substantially variable, variability that seems to be on par or greater in relative magnitude than the water losses causing impacts. If augmentation is equivalent to a single storm over the course of a year, the 20-100% variability in flow measurement / nine-inch variability in water level elevation seems to be large enough to obscure detectable changes in the hydrologic record. The collection of additional higher frequency data (i.e., at 15 or 30 minute intervals) should allow characterization of this variability and an accounting for it in the assessment of impacts. Most importantly, collection of hydrologic data at these shorter time intervals seemingly is already occurring. Multiple cases of equipment deployed in groundwater wells to measure groundwater elevations were observed during field visits made as part of the assessment process. Formalization of these activities and communication of the result in a systematic format would enhance the PADEP's ability to assess the potential hydrologic impacts of underground mining.

Further, hydrologic system health depends on the storm flow responses. Storm flow hydrographs generally peak over relatively short periods (Figure VI-8). The magnitude of peak flow determines the characteristics of a wide variety of important factors ranging from the amount of scour disturbance to the timing of floods in lower reaches. The observations of mining-induced lengthening of no-flow periods coupled with the predominant conceptual models suggest that if anything, storm flow hydrographs will likely be diminished. However this expectation cannot be evaluated with currently reported data.

VI.E.3 – Incremental Reporting of Hydrological Data

One of the challenges in reconstructing hydrologic changes following undermining is synthesizing the baseline information provided in module 8 of the mining permit, particularly given the incremental nature of changes made as part of the revisions to the permit.

To illustrate, the University selected a number of module 8 sections from recent permit revisions for comparison. These revisions were all submitted to the Enlow Fork permit as revisions allowing additional activities associated with mining and not covered in the original permit. All of the revisions selected have versions available in Microsoft Word format, enabling whole text comparison of the content. The relevant revisions are listed below:

- Revision 92, **Enlow Fork Mine Overland Conveyor - Phase 1 (Dec 2010)**
- Revision 97, **Enlow Fork Mine F23 Bleeder shaft**
- Revision 99, **Enlow Fork Mine Overland Conveyor - Phase 2**
- Revision 102, **Enlow Fork Mine 3 North No. 6 Airshaft**

In each case the University utilized the Microsoft Word Document Compare tool to detect changes made from one revision to the next. The complete set of changes in the module 8 text from revisions 92 to 97 are shown below:

Section 8.1.a: a paragraph on shallow groundwater removed,

Section 8.1.b: the list of wells and well depths was altered to reflect local conditions.

Section 8.1.c:

> "**Ground water from the hilltops and valley sides move toward the ground water discharge zone of Rocky Run or Long Run. Topographic relief in the area of the permit ranges from a high of approximately 1400 feet MSL to a low of approximately 1090 feet MSL along Rocky Run.**"

Changed to:

> "**Ground water from the hilltops and valley sides move toward the ground water discharge zone of Sawhill Run and tributaries of Sawhill Run.**"

Section 8.1.f: number of wells in the inventory changed.

Section 8.1.g:

> "**There are no impacts associated with previous mining at the Enlow Fork Mine known to exist within the proposed surface activity permit boundary. No impacts are expected on the quality or quantity of local water resources as a result of the proposed overland conveyor belt installation. It is expected that surface flows, water levels, seasonal recharge characteristics, and water quality will be consistent with pre-existing conditions.**"

Changed to:

> "**No impacts on the quality and quantity of local resources have been noted as a result of past shaft installations. CPCC has monitored water supplies and resources before and after shaft installations. Results of the monitoring at these stations indicate that flows, water levels, seasonal recharge characteristics, and water quality are consistent with pre-mining conditions.**"

Section 8.1.h: "overland conveyer system" replaced with "shaft"

Section 8.2: exhibit numbering changed.

Section 8.5: "1000feet" changed to "1,000 feet of the permit area"

Section 8.6: documentation of pond presence was removed due to change in locale

Section 8.7.b: rewording of language stating that no public water supplies exist in the permit area.

Section 8.13.a: Changes in exhibit numbering

Section 8.14.a.ii: added

> "**Ground water elevations will return to their pre-mining condition because the temporary, artificial gradient caused by mining will be eliminated as the mine voids fill with water. The pool within the Enlow Fork Mine will be about 660 feet msl, or just above. The highest coal elevation in the Enlow Fork Mine will be about 660 feet msl. No discharges to the land surface upon site completion is expected because the lowest land surface elevation at the proposed openings is approximately 1332 feet msl.**"

Section 8.14.a.iv.(1): added

> "**No post-mining discharge is predicted because the coal elevation does not exceed the surface elevation. The lowest surface elevation of the proposed openings is 1332 feet msl. As discussed above, the predicated post-mining pool elevation and maximum elevation of the Pittsburgh coal in the Enlow Fork Mine is 660 feet msl. No mine water will be pumped to the surface. Thus, no discharges to the land**

> **surface are predicted from the operations proposed in this application.**"

Section 8.14.a.iv.(4): language describing hazardous materials associated with belt operations removed from shaft application

Section 8.14.a.iv.(6):

> **"There will be no storage of coal or spoil within the proposed overland conveyor system permit boundary. The proposed overland belt will be installed entirely on the ground surface with limited subsurface activity. The conveyor system will contain spill prevention trays and be monitored to limit other possible sources of contamination to water resources associated with the transportation of coal and spoil through the proposed permit area. It is expected that no adverse hydrologic effects will result from activities associated with this surface facility."**

Changed to

> **"No coal or spoil removal storage are proposed for this surface activity. The proposed shaft will be constructed with steel casing and be grouted. Refer to Module 23 for construction details."**

Section 8.15.a: presence of springs added along with note specifying collection before treatment where possible.

Section 8.15.b: List of monitoring points changed to reflect locale.

Changes from Revsion 92 → Revision 99 and Revision 92 → Revision 102 were similar or even less dramatic than those summarized above.

Each permit revision's module 8 was roughly fifteen pages long. In each revision that the University analyzed, the actual change in wording amounts to less than a page of actual content changes. Further, these changes mostly arise from specific characteristics of the permit area (addition or subtraction of spring monitoring, etc.). While this similarity in module 8 content is not unexpected given the relatively small distance separating permit areas, the usefulness of simply repeating the same content in these submissions is questionable, as the variability in things like hydrogeologic conditions are likely large (e.g. Figure VI-9). However, even if this additional site-specific information is not useful/feasible, by surrounding the relevant, incremental changes in the much larger, unchanged documents, the ability to comprehensively evaluate water resource changes is diminished.

For example, consider the case where an interested party wants to catalog the hydrologic monitoring points in an area and understand the hydrologic component (e.g. spring, well, surface water) these points monitor. The process shown in Figure VI-10 would have to be repeated four times for the permits above.

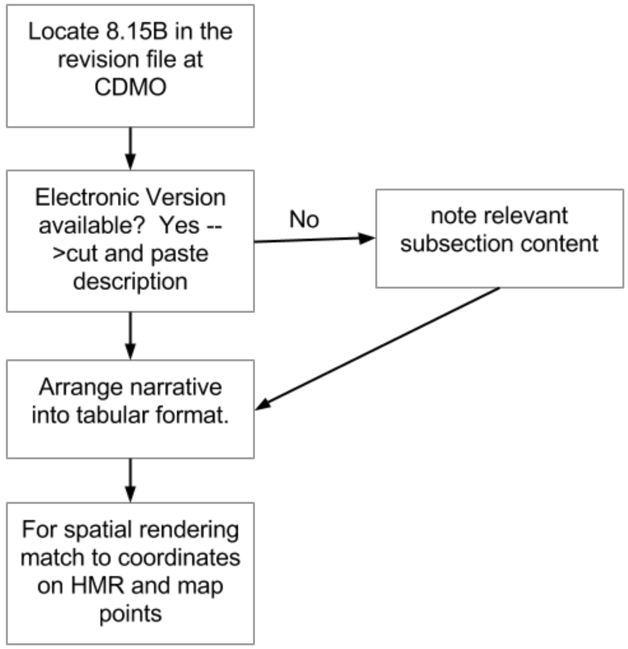

Figure VI-10. Process necessary to summarize module 8.15 (list of hydrologic monitoring points) data across permit revisions.

The adoption of content management tools could simplify both the reporting and evaluation process. Electronic versions of the permits could be maintained and revisions to each of the module subsections recorded and associated with the relevant section. Then, if a particular module sub-section were of interest, the original material and revisions could be viewed in the larger context. For example, Figure VI-11 illustrates the potential for such a system when reviewing Module 15.B. In this hypothetical case, the purposes of all of the hydrologic monitoring points could be accessed in single interface, allowing rapid evaluation of available information. Moreover, in such systems linkages to geographic information systems and other visualization tools would facilitate more and better evaluation of monitoring planning.

The state already implements similar tools in complicated data management systems, for example the PA*IRIS well data system (http://www.dcnr.state.pa.us/topogeo/econresource/oilandgas/pa_iris_home/). Similarly, a system like the BUMIS database could be adapted to allow this sort of content management. Permit revision information linked to other relevant data would allow more effective understanding of the hydrologic impacts of underground mining.

8.15.B. Attach a narrative describing how the proposed monitoring points relate to the detection and mitigation of impacts discussed under Modules 8.9, 8.10 and 8.14.

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. **<other revisions not shown for this example>**

Revision 92 **There are 4 total long-term surface water monitoring points on Rocky Run and Long Run. Stream flows and water quality will be monitored quarterly at these points to determine if any changes occur. A surface water monitoring point is located upstream and downstream of the permit area on both Rocky Run and Long Run.**

Three springs (27-25-2.0 S2, S3, S4) and one well (27-24-15 W1) will be monitored quarterly to determine if any changes in ground water quality or quantity occur. The proposed overland belt will be installed entirely on the ground surface with limited subsurface activity. The conveyor will contain spill prevention trays and be monitored to limit other possible sources of contamination to water resources associated with the transportation of coal and spoil through the proposed permit area. It is expected that no adverse hydrologic effects will result from activities associated with this surface facility.

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Revision 102 **There are 4 long-term surface water monitoring points on tributaries to Buffalo Creek. Stream flows and water quality will be monitored quarterly at these points to determine if any changes occur during or after shaft construction. Surface water points 32994 BC-U1 and 32994 BC-D1 are located upstream and downstream, respectively, of the permit area. Unnamed tributary EF T3D will be monitored at the mouth and EF T1 will be monitored downstream of the permit area.**

Monitoring points 27-3-16 S1 and 27-3-6 S1 will be monitored to determine any changes in ground water quantity or quality.

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Figure VI-11. Mock-up of a possible management information system interface allowing the review of permit module revisions in the context of other revisions.

VI.F – Focal Watershed Analysis

Assessing the impact of longwall mining on groundwater is complicated, particularly due to the variation in groundwater response across physiography. Wells in the region tap a variety of aquifer types, including perched aquifers, strata aquifers (both fractured and un-fractured), and riparian aquifers. In general, the economics of well drilling dictate that the shallowest aquifer providing a reliable water yield is tapped. This minimizes labor and casing costs, and further avoids deeper water's tendency to have increasing levels of dissolved solids due to longer water-rock contact times. However, given the geometry of aquifer systems (Figure VI-3), losses of water from the topographically higher aquifers can be rerouted to the alluvial aquifers lying under the valley soils. In some cases these changes in hydrologic flow paths can result in interactions with other groundwater sources, such as chemically reduced groundwaters (i.e., high in soluble iron) that would impact water quality when mixing with existing groundwater. As a result, longwall mining may diminish well production/water quantity at higher aquifers and diminish water quality in wells situated in lower aquifers.

Further, observations of groundwater are limited to relatively few and spatially limited points (i.e., wells). In general, HMR data is collected from a subset of existing wells and nests of piezometers (i.e., wells that are "open" at specific depths to examine independent groundwater responses in different aquifers (e.g. shallow, intermediate, and deep)).

Given the wide range of available data and the complexity of the hydrologic system, small (0.5 - 6 square mile) watersheds located over areas of active mining during the 4th assessment period were selected for intensive analysis (Table VI-3 and Figure VI-12).

Table VI-3. Hydrological characteristics of focal watersheds.

Focal Watersheds	Associated Mine	Watershed Area (acres)	# of Water Supplies	# of Affected Water Supplies	# of HMR Points in the watersheds			
					X	□	●	▲
Barneys Run	Bailey	1856	110	8	3	1	9	-
Roberts Run	Blacksville 2	1414	3	0	-	-	9	-
Blockhouse Run	Blacksville 2	4000	50	5	5	1	9	-
Turkey Hollow	Cumberland	474	21	4	3	1	5	-
Maple Run	Cumberland	960	25	0	2	2	13	1
Pursley Creek	Cumberland	5267	86	11	4	5	8	-
Crafts Creek	Enlow Fork	2387	119	4	2	-	9	1
Symbol Key: X = Piezometer, □= Well, ●= Stream, ▲= Spring								

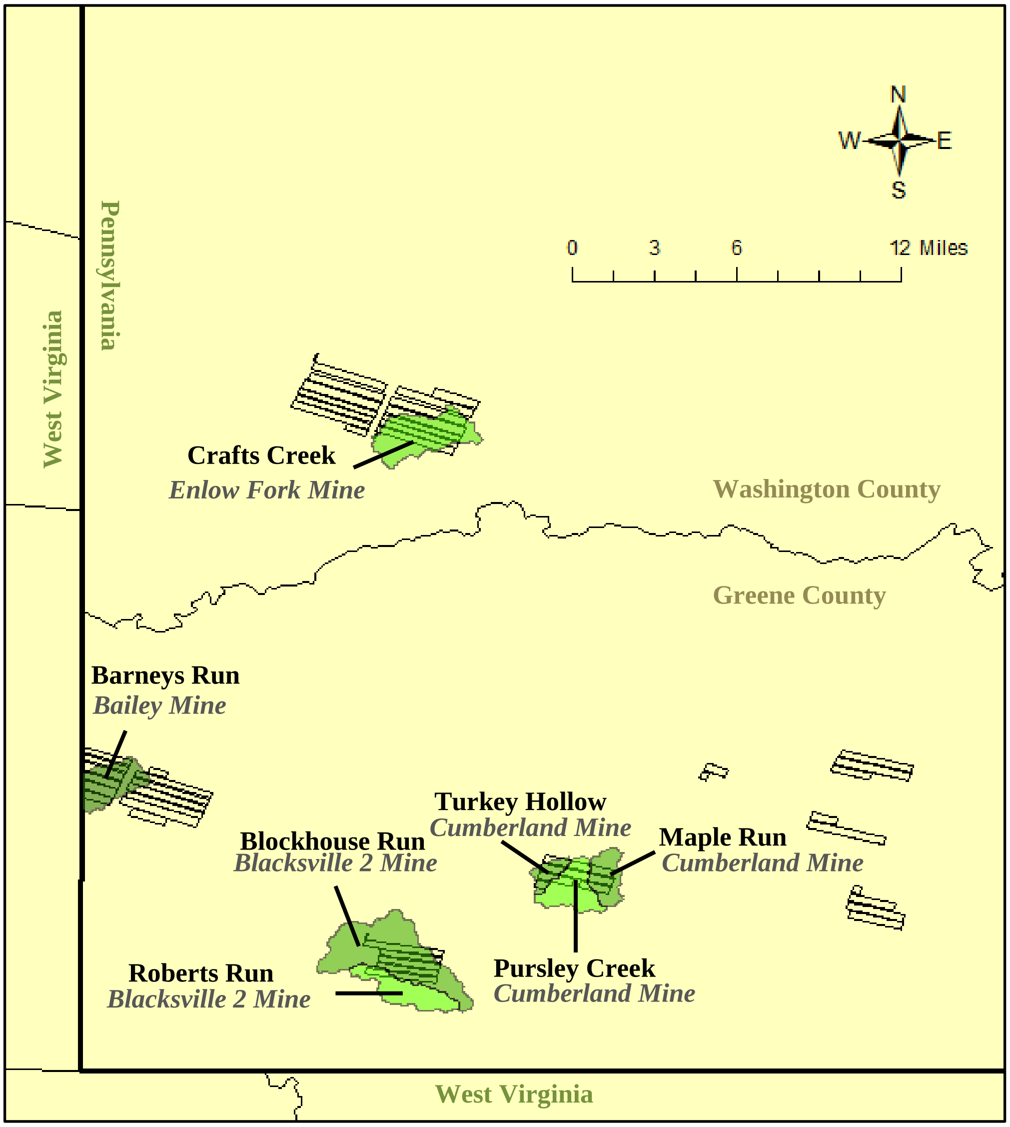

Figure VI-12. Locations of focal watersheds relative to active longwall mining during the 4th assessment period.

VI.F.1 - Affected Water Supplies

Analysis of affected water supplies relative to lowered water tables is challenging given the existing data is limited in spatial and temporal density. There are few HMR points within each of the focal watersheds (Table VI-3). For the seven focal watersheds there are 42 reported effects for water supplies. Unfortunately, only nine of these reported effects can be compared to HMR data, as the other sampling points are too distant from HMR sampling points to make clear comparisons. Reported affected water supplies were compared with HMR data from specific sub drainage areas where the effects occurred (i.e. the same tributary or stream branch). These sub-drainages were selected as the analysis unit as they provide a means to assess water balance and the interactions among ground and surface water determining this balance. Few piezometer, spring, or well HMR points were in close proximity to most of the reported effects. Further, one reported water supply effect was near both a well and a piezometer, but the well data was mostly missing and the piezometer water elevation data reported in two different formats (MSL-ft and depth from surface) that were uncomparable due to missing elevation data for the HMR point.

The remaining reported effects to water supplies were located in drainages without HMR points in close proximity and cannot be assessed with HMR data. Overall, data necessary to determine if these reported effects are related to mining-induced fluctuation in groundwaters has not been reported in the HMRs.

VI.F.2 - Crafts Creek

Of the four reported effects to water supplies in the Crafts Creek watershed, there is one water supply problem that is close enough to an existing HMR point to allow direct comparison (Figure VI-13*)*. A spring 0.1-mi upstream of the stream monitoring point UNT 40939-U1 is reported in BUMIS to have lost flow and to have eventually gone dry (Figure VI-14). Both the initial diminution of the spring and loss of the spring occur during periods of low flow in the stream. However, it is not clear if the low flow periods are due to mining or natural fluctuations due to seasonal climate. When HMR data from surrounding points are compared, they all have similar flow patterns, suggesting the quarterly HMR data is capturing natural seasonal fluctuations (Figure VI-15). It is also important to note that at the time the water supply problem was first reported, the area had not yet been undermined (Figure VI-14). However, sections of a panel downstream of the water supply problem were mined in July and August of 2010, a period during which Washington and Greene Counties were under a drought warning. There is a drop in flow during that time period for HMR point UNT 40939-U1, but a similar drop occurs at the same time at other points within the watershed suggesting a seasonal fluctuation instead of a mining effect (Figure VI-15). As of 11 May 2011, the affected water supply has a resolution status of “unspecified agreement”

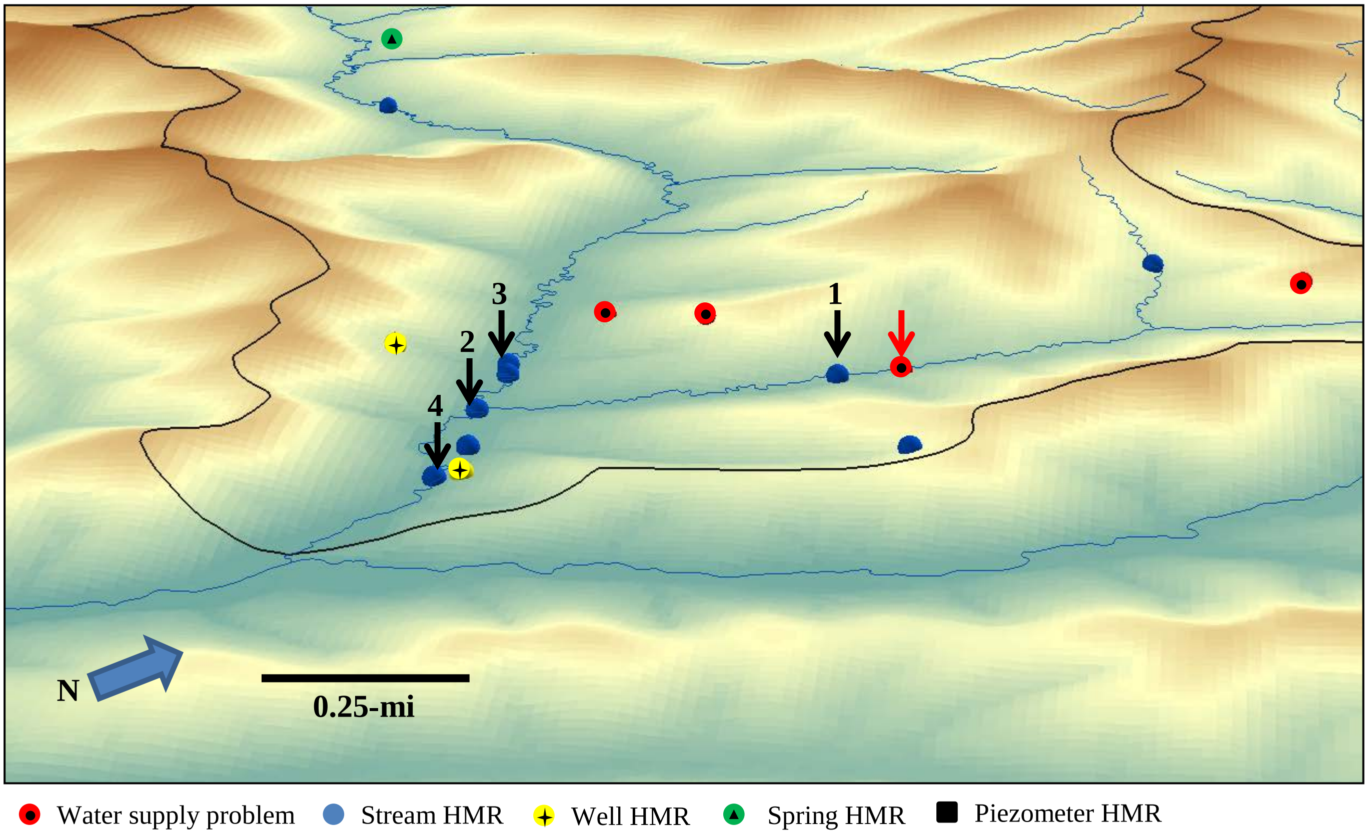

Figure VI-13. Crafts Creek watershed showing HMR points and water supply problems. Numbered points on the map correspond to the plots below and are as follows: ***1****) UNT 40939-U1,* ***2****) UNT 40939-D1,* ***3****) SW 36,* ***4****) 40938 D-1*

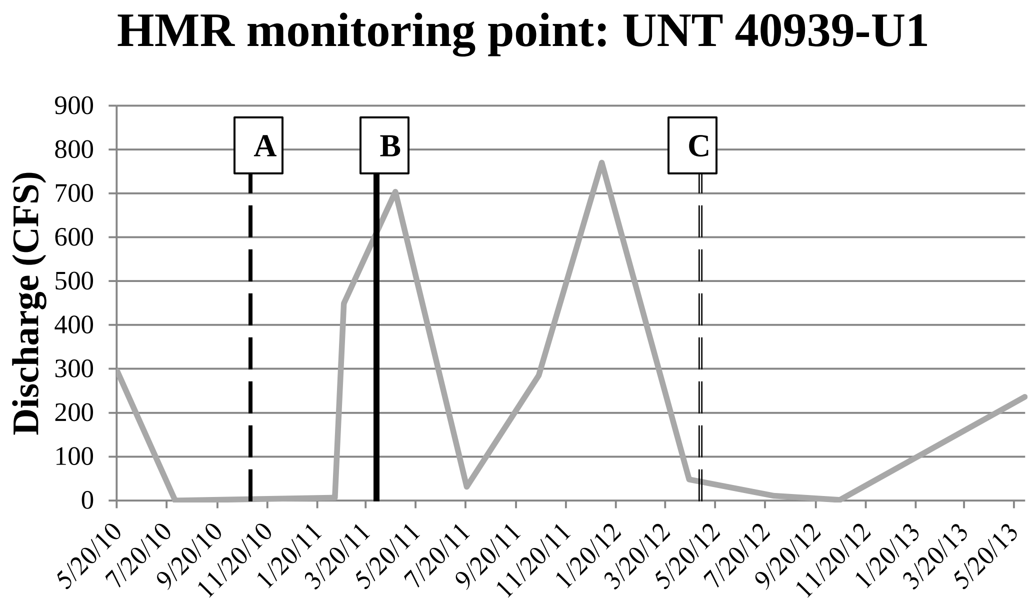

Figure VI-14. HMR monitoring point near Crafts Creek water supply problem. The first dashed line (A) represents the date the supply problem was first reported (4 November 2010). The solid line (B) indicates the date the water supply was undermined (25 April 2011). The final dashed line (C) indicates the date that "total loss of spring" was recorded in the BUMIS (11 May 2011).

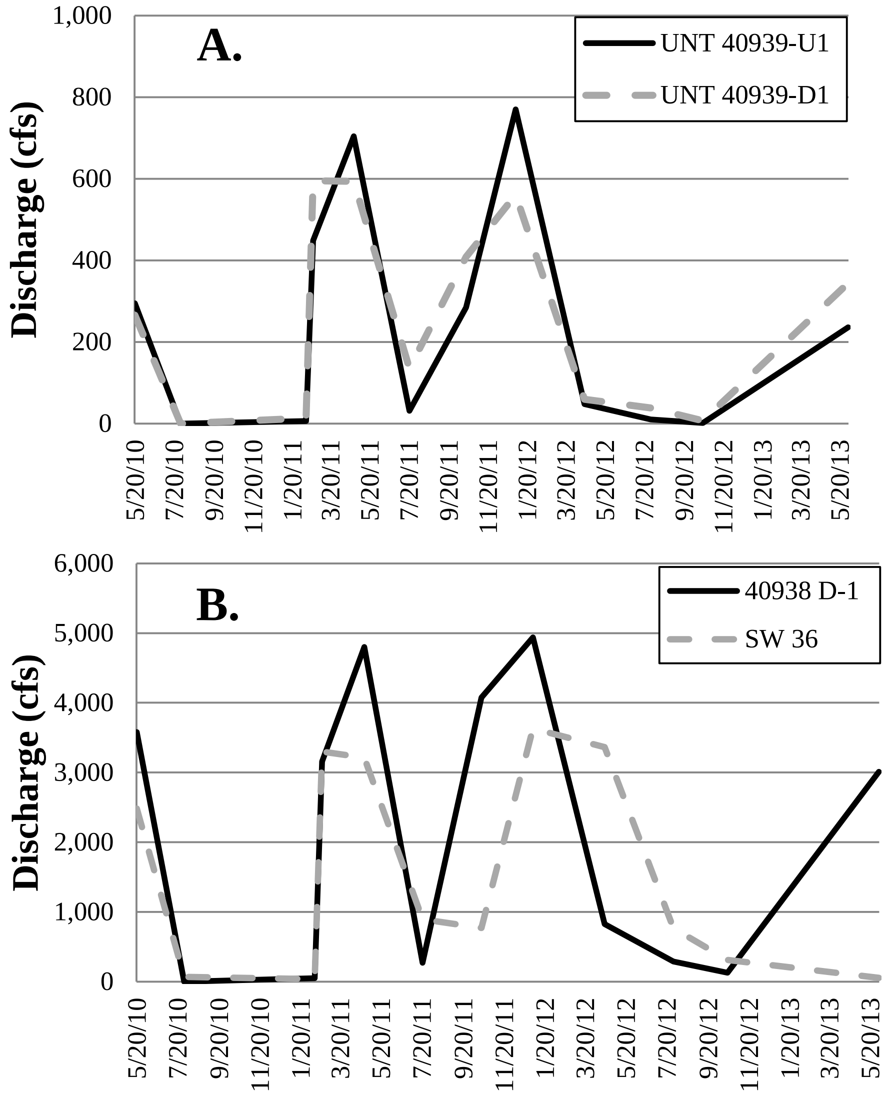

*Figure VI-15. Comparison of HMR data between two tributary monitoring points (**A**) and two main stem Crafts Creek monitoring points points (**B**) within the Crafts Creek watershed.*

VI.F.3 - Barneys Run

Barneys Run, lying over the Bailey Mine, has eight reported effects to water supplies that have been recorded in BUMIS. Two of these may be hydrologically related to HMR point Bar-R3-02. Both water supply problems are within 0.1 and 0.2 miles of the HMR point:

- Reported Effect #1: Indicated by a #1 in *Figures VI-16 and 17*, SPRING108 experienced water loss according to BUMIS records on 29 June 2012. No final resolution indicated.

- Reported Effect #2: Indicated by a #2 in *Figures VI-16 and 17*, SPRING110 was noted in BUMIS to be dry. No final resolution has yet been indicated.

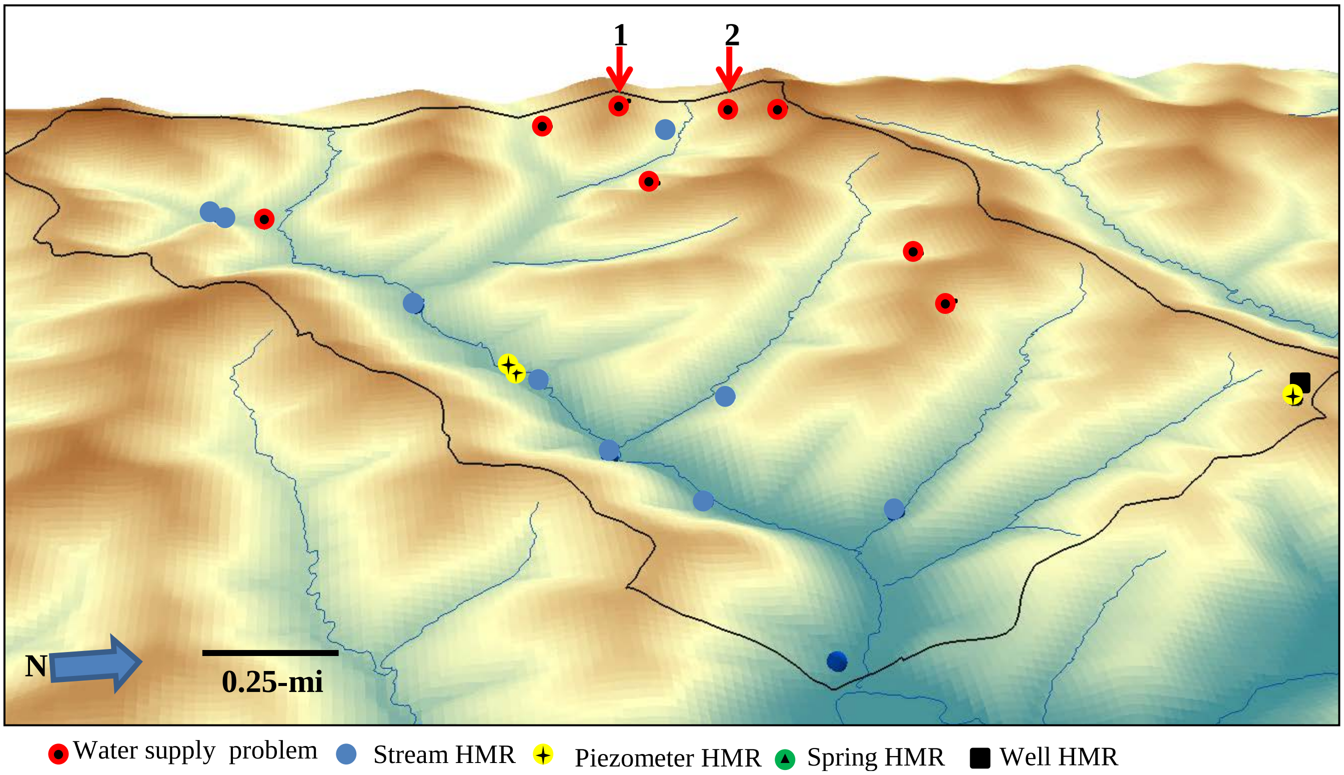

Figure VI-16. Barneys Run watershed showing HMR points and water supply problems. Red arrows are the two water supply problems discussed in the text.

Time since mining for both points is indicated in Figure VI-17. Both water supply problems were reported 29 June 2012, during time periods where low flow for the HMR point is typical and may represent seasonal fluctuations. The groundwater levels relative to these springs are challenging to determine from stream flow data.

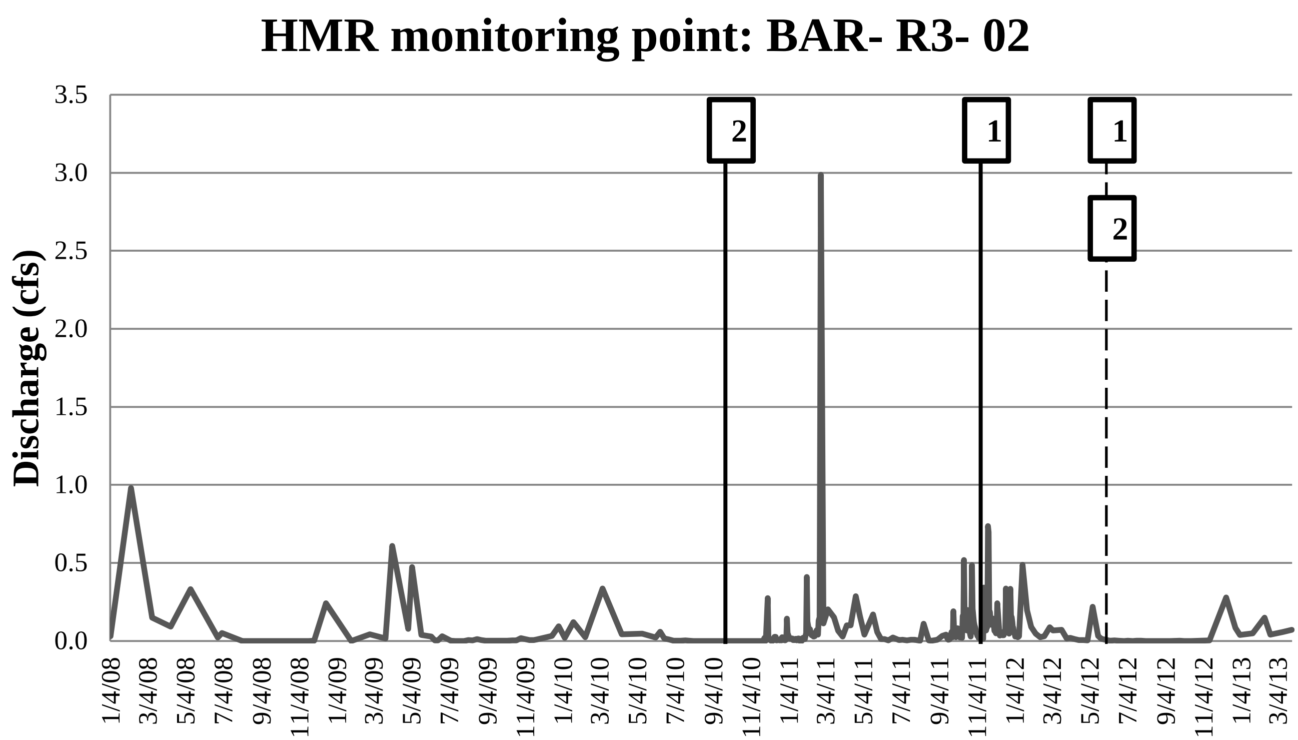

Figure VI-17. HMR monitoring point near the two Barney's Run water supply problems. The solid line with a number one indicates the date SPRING 108 was undermined (24 Oct 2011). The second solid line with a number two indicates the date SPRING 110 was undermined (27 Dec 2010). The dashed line represents the date given in BUMIS that both water supply issues were reported (29 June 2012).

VI.F.4 - Blockhouse Run

There are two water supplies reported to be affected in Blockhouse Run that are close to HMR points. In the northern region of the Blockhouse Run watershed, an affected water supply is located 0.3-mi upstream from HMR piezometer 1305-105 PZ DS and 0.2-mi from a stream HMR point SW-15 (Figure VI-18). The affected water supply is labeled as both a spring and a well in BUMIS and the problem was reported as water loss to the spring on 29 Aug 2009. The nearby HMR spring data record begins on 14 Aug 2009 and has no recorded flow until March 2010 (Figure VI-19). Because there is only one HMR datum available before the reported effects, attribution to mining or seasonal water balance fluctuations is not possible. The nearby piezometer HMR data does not begin until one month after the reported effects and is not useful for assessing mining impacts on the nearby water supply. Also, based on available data, at the time of reporting the water supply had not yet been undermined. The closest mined panel to this point is 0.25-mi away and occurred 2-3 years after the reported problem. The BUMIS record indicates a final resolution status of "unspecified agreement" on 1 Nov 2010.

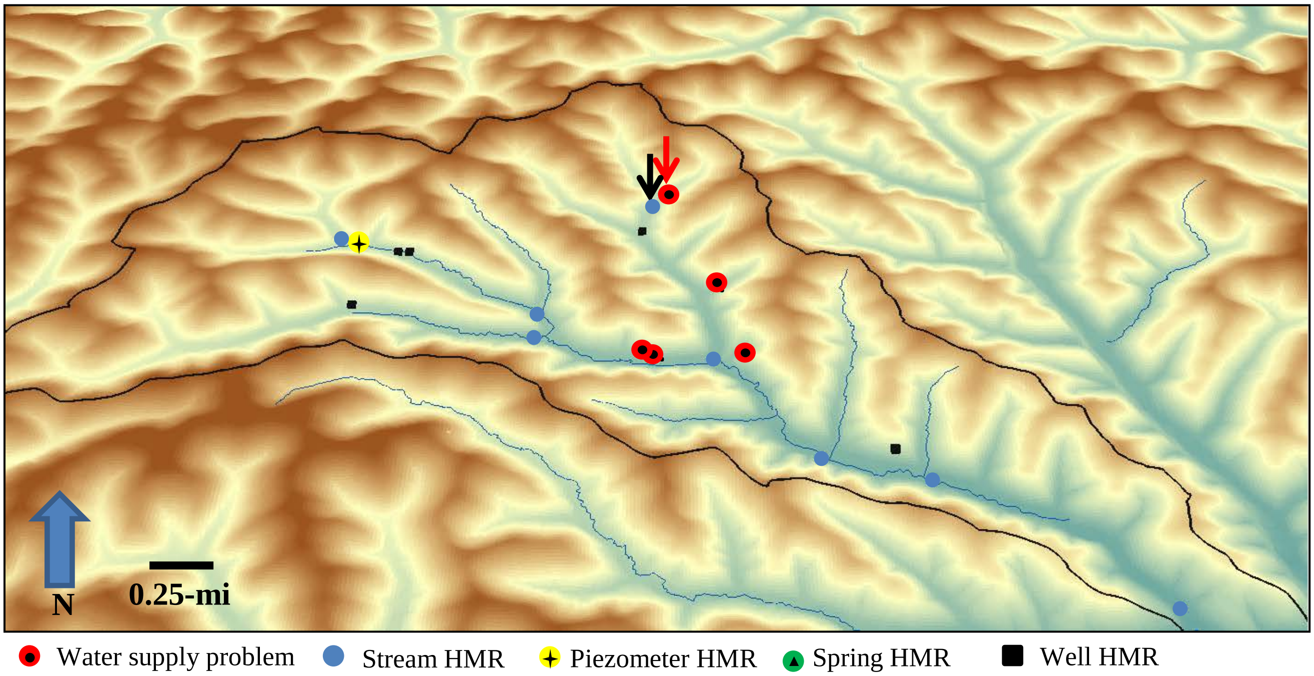

Figure VI-18. Blockhouse Run watershed showing HMR points and water supply problems. The red arrow is the water supply problem discussed in the text. The black arrow over the blue dot is the comparative stream HMR point SW-15.

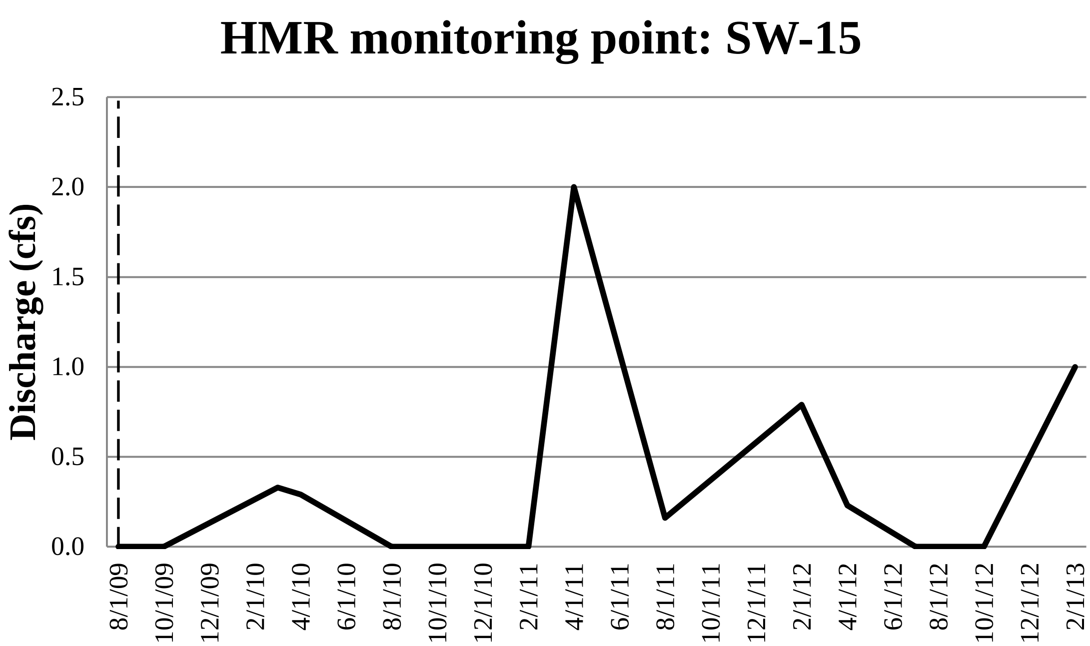

Figure VI-19. HMR monitoring point near a Blockhouse Run water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (29 Aug 2009). The HMR point has not yet been undermined.

VI.F.5 - Pursley Creek

There are five water supplies with reported effects that are near HMR locations in the Pursley Creek watershed. The first impacted water supply is located in the southeastern part of the watershed and labeled “1” in Figure VI-20. It is 0.05-mi upstream from the stream HMR monitoring point S-77. The water supply type was not recorded in BUMIS, but is described as having diminished flow and therefore may be a spring. The diminishment in flow follows a peak in the flow data of S-77 (Figure VI-21). It is not clear if these two events are connected and are due to changes in the water table. No final resolution is indicated in BUMIS.

Three impacted water supplies are upstream from stream HMR point S-49 (Figure VI-22). The closest is 0.08-mi upstream, and the other two are 0.25-mi above the HMR point. The water supply problems are labeled “2”, “3”, and “4” in Figure IV-22. For two of the water supplies (#’s 2 and 3) the problem is described in BUMIS as “cloudy water” and recorded as contaminated with no known cause. Existing chemistry data for the HMR point indicates a large increase in total suspended solids, near the dates of the reported effects for the impacted water supplies (Figure VI-23). The final resolution of water supply issue #2 according to the BUMIS database was “No actual problem”, on 20 August 2013. A third water supply (#4) 0.25-mi upstream of HMR point S-49, is a well that experienced water loss on 7 July 2013 and coincides with a decrease in flow (Figure VI-24). Water supply problems #3 and #4 have no final resolution date.

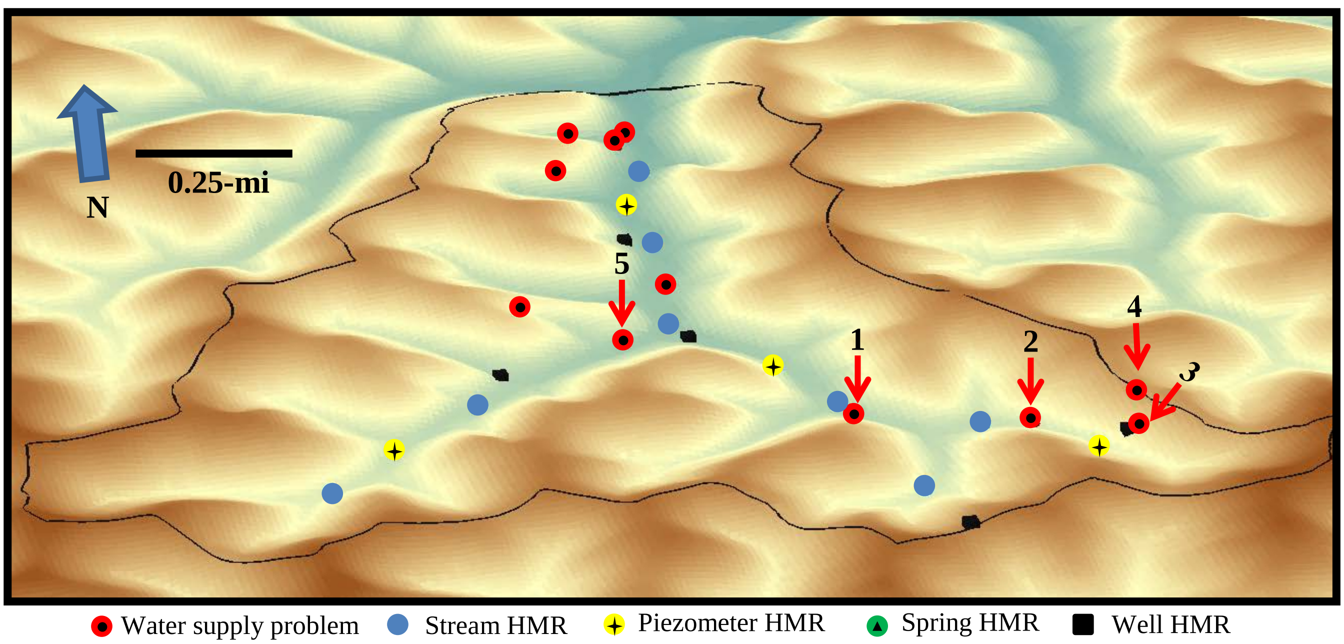

Figure VI-20. Pursley Creek watershed showing HMR points and water supply problems. The red arrows are the water supply problems discussed in the text.

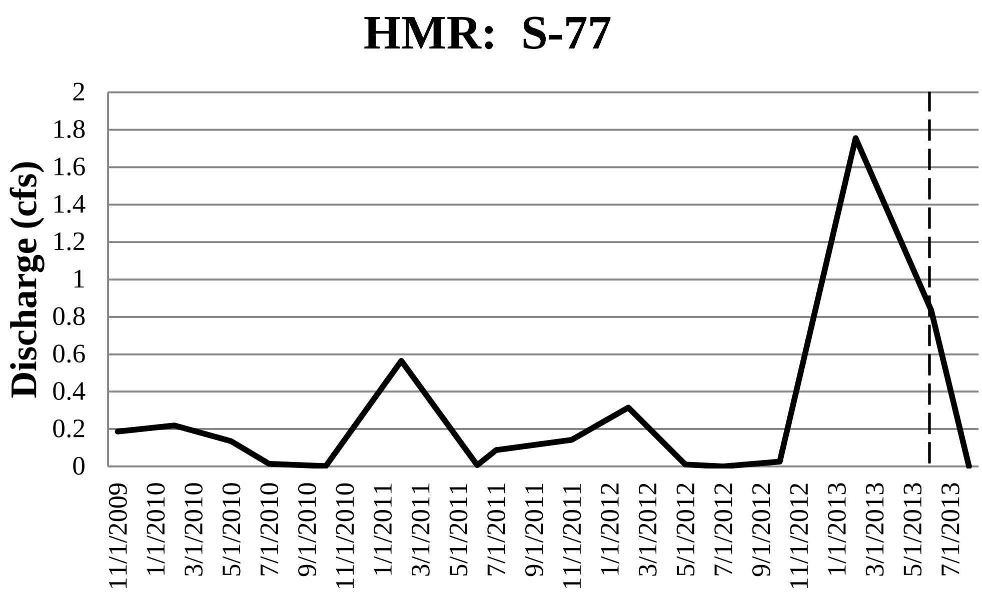

Figure VI-21. HMR monitoring point near a Pursley Creek water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (24 May 2013).

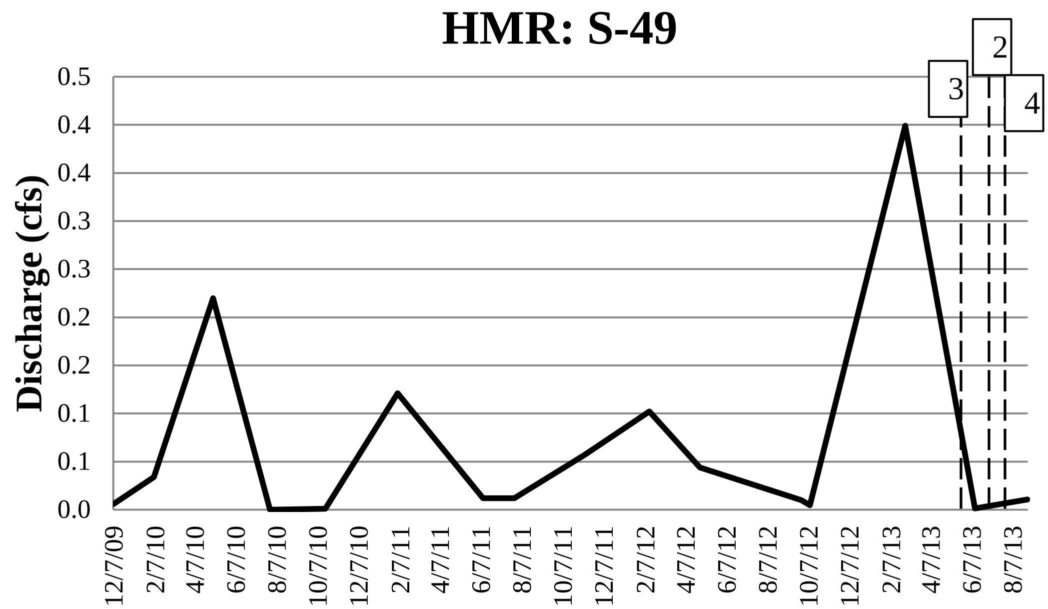

*Figure VI-22. HMR monitoring point near a Pursley Creek water supply reported effects. The dashed lines represent the dates given in BUMIS that the water supply issues were reported: **2-** 27 June 2013, **3-** 17 July 2013, **4-** 31 May 2013.*

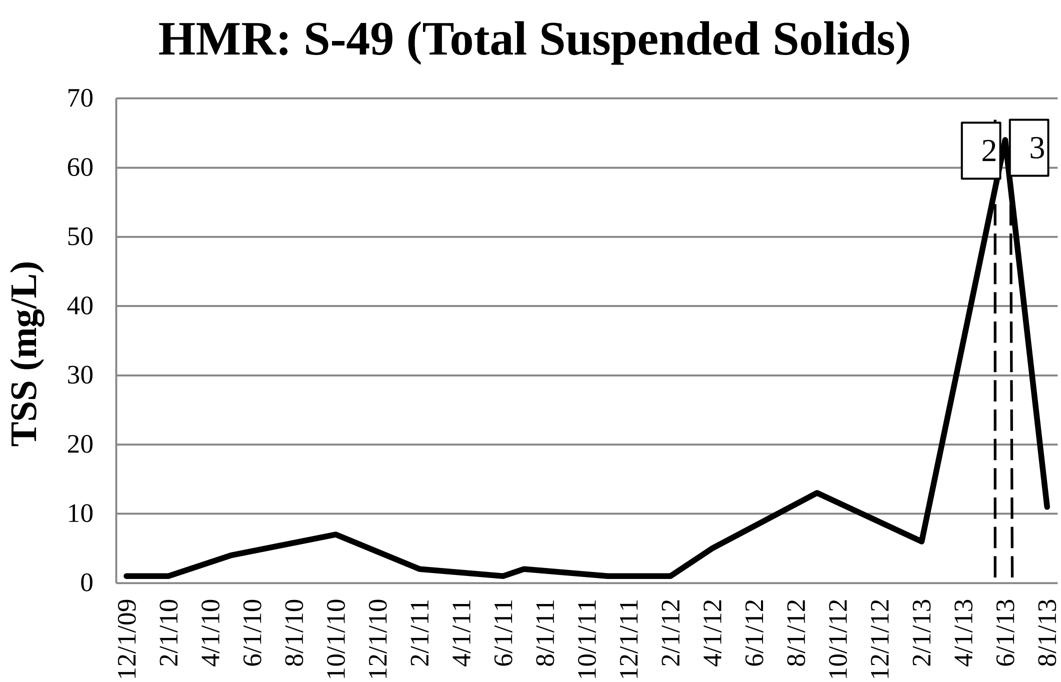

*Figure VI-23. HMR monitoring point near a Pursley Creek water supply reported effects, displaying total suspended solids data. The dashed lines represent the dates given in BUMIS that the water supply issues (water contamination) were reported: **2-** 27 June 2013, **3-** 17 July 2013.*

A fifth reported effect on a water supply is located in the southwest region of the watershed and is labeled “5” in Figure VI-20. It is 0.10-mi upstream of stream HMR point S-75. The affected water supply was reported on 1 December 2011 by the property owner (Figure VI-24) as having a funny taste and is labeled in BUMIS as contaminated. There is an increase in flow near the date the water supply reported effect occurred, but it is unclear whether the increase in flow is related to hydrologic changes due to mining in a nearby panel. HMR chemistry data for S-75 would help to elucidate changes to water taste in the impacted well, but does not exist until 26 April 2012. The final resolution was an unspecified agreement on 19 March 2013.

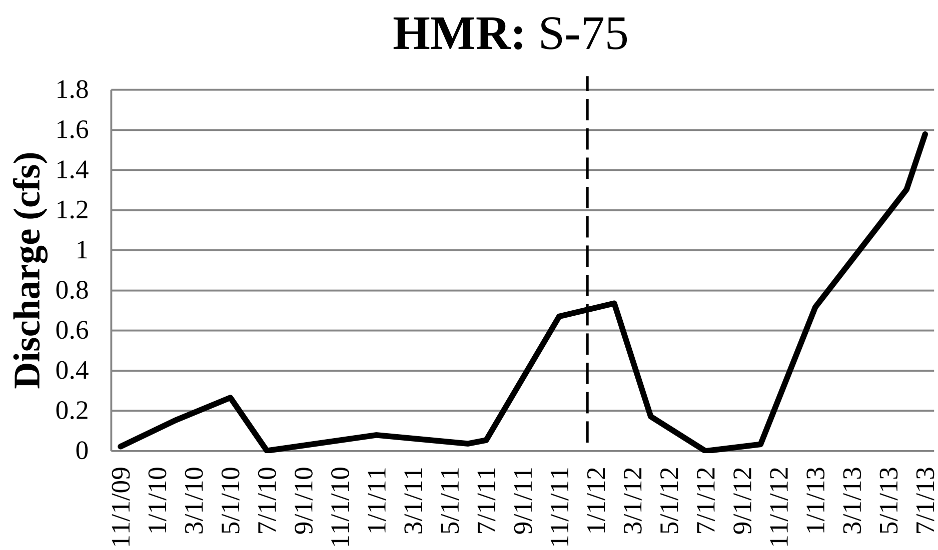

Figure VI-24. HMR monitoring point near a Pursley Creek water supply problem #4. The dashed line represents the date given in BUMIS that the water supply issue was reported (1 December 2011).

The Pursley HMR points and water supplies discussed in this section were not directly undermined via longwall mining during the 4th assessment period.

VI.F.6 - Turkey Hollow

There is one impacted water supply in Turkey Hollow that is 0.05-mi downstream of HMR point S-70 (Figure VI-25), reported on 14 June 2011. The reported effects in BUMIS are water loss and black specs in the water. There is a decrease in flow near the time of the reported effects and this may be related to diminished flow due to mining, as longwall mining took place in the underlying panel between 9 April 2011 and 3 December 2011 (Figure VI-26). However, there is also a similar dip in flow data at the same time in 2010 and 2012, potentially indicating seasonal effects. The final resolution is pre-mining agreement, with a resolution date the same as the date the problem was reported.

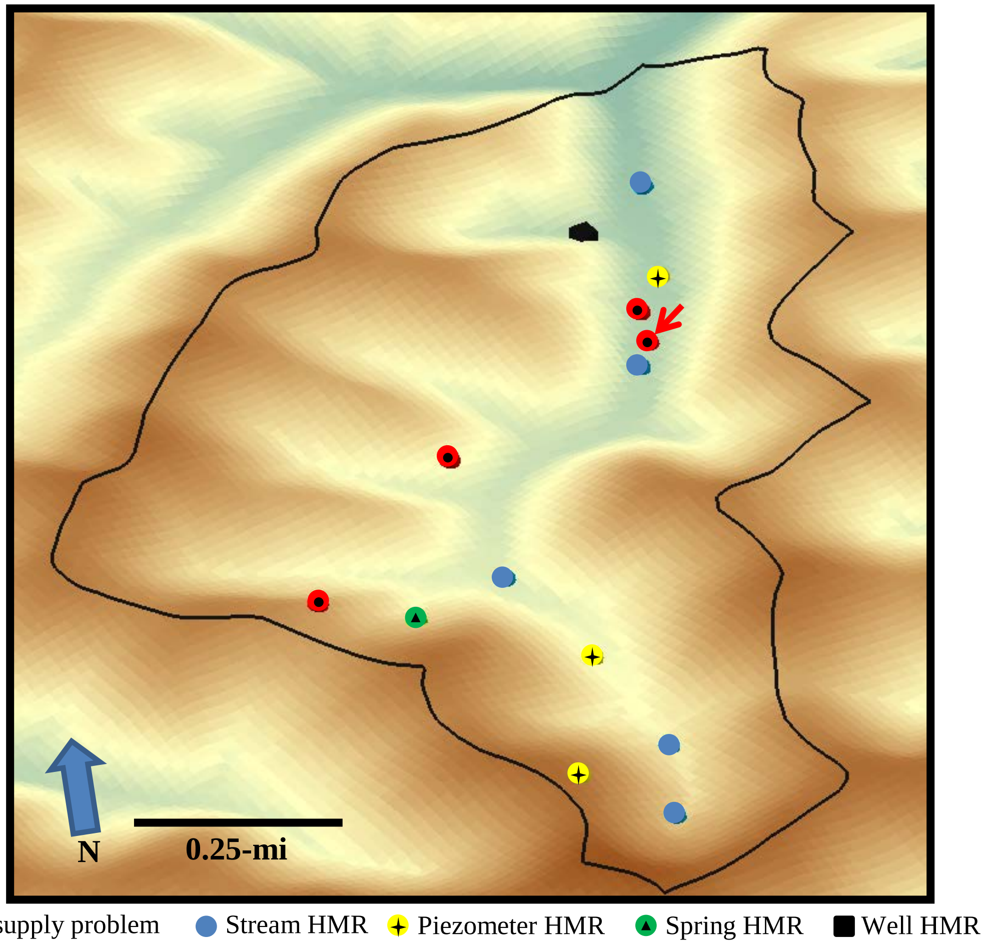

Figure VI-25. Turkey Hollow watershed showing HMR points and water supply problems. The red arrow is the water supply problem discussed in the text.

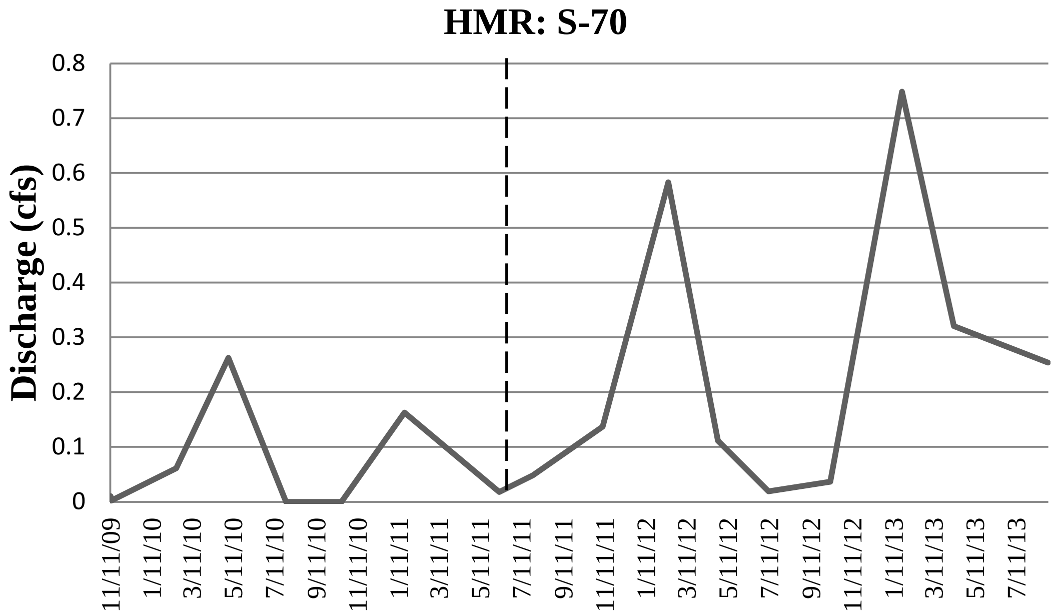

Figure VI-26. HMR monitoring point near a Turkey Hollow water supply problem. The dashed line represents the date given in BUMIS that the water supply issue was reported (24 June 2011).

VI.F.7 - Roberts Run and Maple Run

According to the BUMIS database, these watersheds do not contain any reported effects of mining on water supplies.

VI.F.8 - Summary of Water Losses in Focal Watersheds

Overall, the analysis of affected water supplies relative to lowered water tables is challenging given the existing data. HMR data is spatial and temporally sparse. There are limited numbers of HMR points within each of the focal watersheds (Table VI-3). These watersheds were chosen in part due to their representativeness; therefore this is not likely a function of unlucky selection of study areas. Moreover, most HMR points with data are relatively distant from impacted water sources. Further, the low frequency of reported HMR data collection results in limited ability to garner insight as it is unclear from the reported quarterly HMR data whether the observed pattern of flow represents natural fluctuations or mining impacts to water supplies. A clear understanding of the role of groundwater in reported effects requires changes in the data collection regime.

<u>VI.G – Understanding Hydrologic Changes in the Hillslopes</u>

Mining induced subsidence impacts vary with catchment size, so streams and aquifers located at relatively higher elevations (i.e., more headwaters environments) may be disproportionately impacted. Some have found valley bottoms to be relatively less impacted and hilltops more impacted (Leavitt and Gibbens 1992, Tieman and Rauch 1987). Even though impacts are potentially greater on the hillslopes, mining subsidence impacts on hillslope hydrology are poorly characterized compared to stream flow and ground water dynamics. For example, consider springs, hillslope locations where ground water flowing through the hillslope discharges to the land surface (Springer and Stevens 2008). Longwall mine subsidence can impair spring flow and may also result in the re-emergence of springs further down the slope (Figure VI-27). The redistribution of ground and soil water has the potential to impact human interactions with water beyond simple availability.

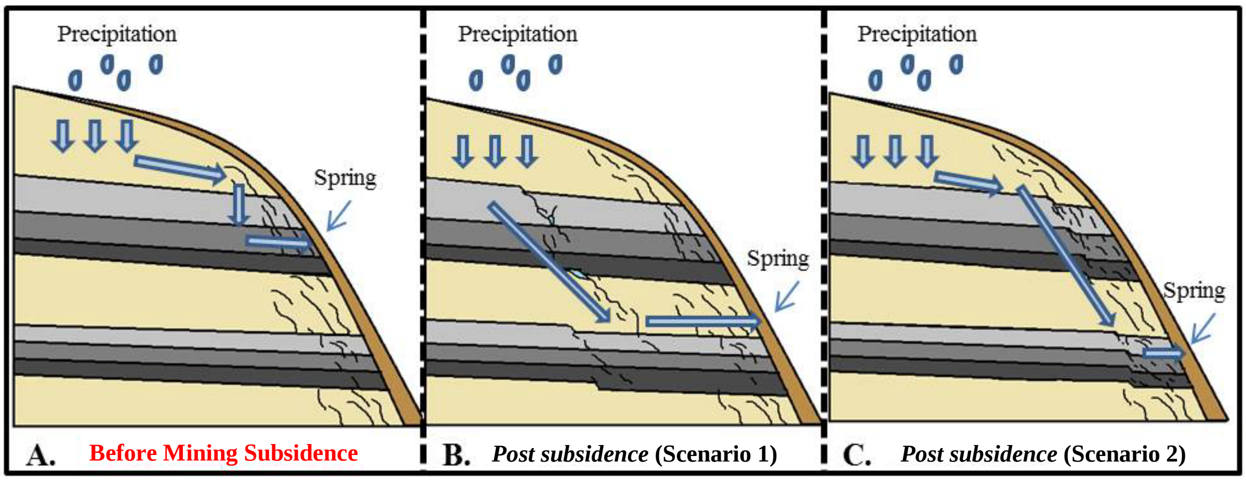

Figure VI-27. Potential impacts of longwall mining subsidence on spring flow. ***A.)*** *An original, un-impacted spring on a hillslope. Ground water drains in a step pattern down the hillslope.* ***B.)*** *In this first scenario a deep fracture alters hillslope drainage and changes the location of the spring further down the hillslope.* ***C.)*** *In a second scenario increased shallow fracturing of the hillslope surface diverts the spring further down the hillslope.*

The hillslope springs of southwestern Pennsylvania are numerous and support ecosystem components that are considered globally rare and threatened, as they provide a specific type of habitat for a diversity of organisms (Springer and Stevens 2008). Changes in spring hydrology can impact biota dependent in these spring systems. The diversion of shallow ground water away from the hilltops and hillslope shoulders can also result in reduced water availability to the surrounding forest through reduced soil moisture and reduced ground water access if levels drop below the rooting zones of trees (Figure VI-28). This increased dryness of the hillslope may reduce forest health and potentially magnify potential climate change impacts to forest ecosystems (Allen et al. 2010, Iverson and Prasad 2002).

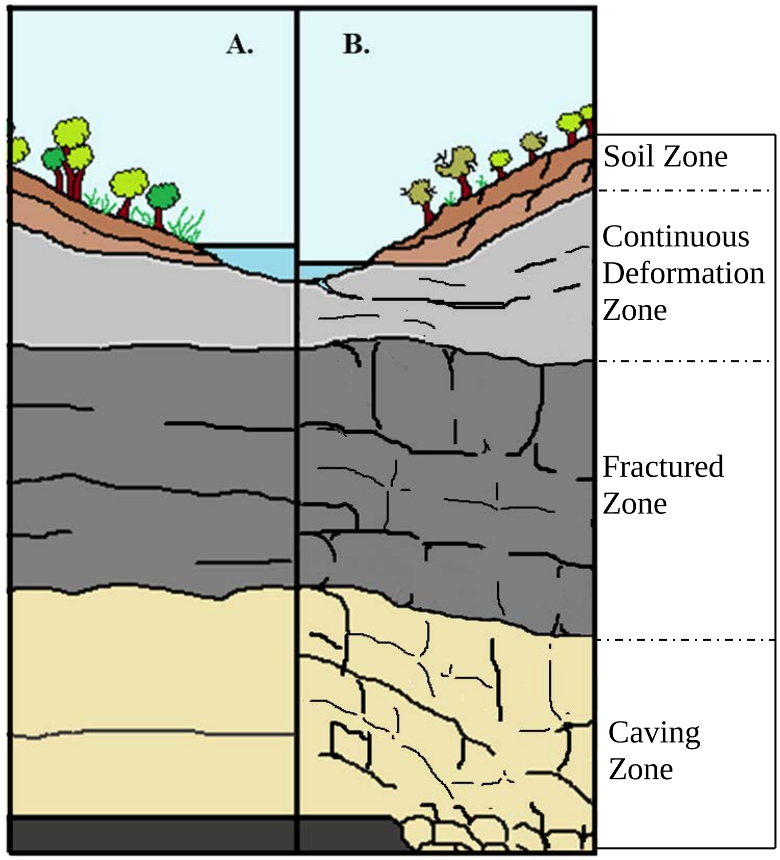

Figure VI-28. Modified Peng (2008) subsidence model before (A) and after mining (B), demonstrating how longwall subsidence impacts surface water and through surface water impacts potentially impacts forest ecosystems as well.

VI.G.1 – Number of Monitored Springs vs. Actual Springs

Despite the potential importance of hillslope hydrological changes, very few springs are established as hydrologic monitoring points (Table VI-4). For the five longwall mines included in this assessment period, only 41 springs were monitored, and only five of these were actually undermined during this assessment period (Table VI-4). Moreover, these points are likely a small sampling of total number of springs present over longwall mining. For example, at an undisclosed mine in the northern Appalachian coalfield, monthly discharge data were examined for 77 undermined springs 12 months before and 12 months after the subsidence event (Silvis 2009). This study was able to identify significant impacts to the undermined springs, with 40% considered significantly impaired (Silvis 2009). Comparable data is not reported for the 4th Act 54 assessment period. Additional data collection is necessary to understand impacts to hillslope hydrology.

Table VI-4. Number of total spring hydrologic monitoring points vs. number of spring hydrologic monitoring points undermined in the 4th assessment period.

Mine	Total # of spring HMR points	Total # of spring HMR points undermined during the 4th assessment period
Enlow Fork	15	2
Bailey	6	0
Blacksville 2	1	0
Emerald	17	2
Cumberland	2	1
TOTAL	**41**	**5**

VI.H – Summary

The amount of data collected regarding hydrologic conditions as part of the coal mining permitting process is substantial (over 750 sampling stations and over 30 thousand samples collected from these stations). However, given the hydrologic complexity of the region and the resulting complexity in hydrologic response, the data, as reported, is insufficient to allow clear assessment of hydrologic impacts. With relatively minor changes in practice, the ability to apply data that is being collected can dramatically improve. Documentation of what should be reported and how it should be reported will make assessment easier and more accurate. Construction of data structures able to handle the variety and volume of data are essential to the actual use of the data. Adoption of simple quality assurance evaluation (e.g. is mass balance reasonable) would also make the hydrologic data better and therefore more useful. In addition to data improvements, data collection frequency and the spatial density of sampling both need to increase. The normal hydrologic variability in the region requires substantial data to allow clear separation of signal and noise and close spatial proximity to detect changes. Finally, the hydrologic balance of soil moisture, particularly in hillslopes overlying underground mining, is not sufficiently characterized to understand hydrologic changes following under mining.

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SECTION VII: Effects of Mine Subsidence on Streams during the 4th Act 54 Assessment

VII.A – Overview

This section assesses the impact of mine subsidence on the flow and biological health of streams in Pennsylvania. The University begins by comparing PADEP's multi-metric index for stream biology to other state and regional indices. There has been much discussion in recent years regarding the suitability and accuracy of PADEP's index, so here the University statistically evaluates its utility relative to similar indices. The University also recognizes that isolating the effect of mine subsidence on streams is a challenging task because many factors outside of mining influence stream ecosystems. Therefore, this section includes a discussion of the factors that cause natural variation in stream flow and biology, and highlights approaches to control for these factors in subsequent analyses. Following this discussion, the University reports the length of streams undermined and impacted during the 4th assessment period. PADEP's methodology for tracking stream impacts is discussed and the University highlights how the tracking procedures have changed since the 3rd assessment. The University then analyzes the effects of mining-induced flow loss and pooling on stream macroinvertebrate communities. The mitigation techniques that are utilized to restore impacted streams are described and the University reports the degree to which these were employed during the reporting period. The University also analyzes the effectiveness of mitigation in restoring communities to their pre-mining state. This section concludes with a comparison of pre- and post-mining Total Biological Scores for sites within the University's focal watersheds.

VII.B – PADEP Metric for Determining the Effects of Mining on Stream Biology

To determine if a stream is attaining its designated aquatic life status (Section I.E.4), the PADEP developed a macroinvertebrate community index known as the Total Biological Score (TBS; PADEP 2005a). This index serves as an indicator of stream biological integrity. The protocol for collecting macroinvertebrate samples and generating a stream reach's TBS is contained in Technical Guidance Document 563-2000-655 (hereafter TGD 563-2000-655; PADEP 2005a). TGD 563-2000-655 is based on recommended approaches in Barbour et al. (1999), the U.S. Environmental Protection Agency's (U.S. EPA) report on best methods for bioassessments. The two key elements of this approach are the development of a standardized sampling approach and the construction of an index that reliably reflects a stream's biological condition. To construct the index, scientists identify attributes (i.e. metrics) of the macroinvertebrate community that are ecologically relevant and reflect the community's response to pollution or other stressors. Typically, there is considerable redundancy among these metrics, i.e. many are highly correlated with each other. While multivariate statistics, such as principal components analysis, can remove redundancy and maximize the use of the information contained in all metrics, most states have settled on the use of indices that combine a small number of core metrics. The core metrics that jointly capture much of the necessary information are aggregated into a multi-metric index of stream health.

PADEP's development of the TBS index is recorded in an unpublished draft document (PADEP 2005b). Therein, the PADEP research that established the suitability of the TBS as a metric is documented. In addition, this study established a TBS benchmark above which the TBS is thought to indicate aquatic life use attainment and below which streams are deemed to be not attaining use. The benchmark for southwestern Pennsylvania is 50.1 (PADEP 2005b). While this document is unpublished, it is widely used by mine operators for comparing samples to the benchmarks that the document recommends for attainment. Nearly nine years after the draft version was produced, a final document has yet to be approved and disseminated to the public.

Since the development of the TBS, questions have been raised regarding its suitability for accurately assessing stream health and use attainment in southwestern Pennsylvania streams. These questions likely stem in part from the lack of a rigorous published report on the methodology used to develop and test the TBS. To partially assess the utility of TBS in measuring stream health, the University compared TBS to another metric developed for use in Pennsylvania - the Macroinvertebrate Biotic Integrity Index (MBII; Klemm et al. 2003). The large-scale analyses and careful testing of the MBII make it an ideal index for comparison with TBS. Strong similarity between the two indices would indicate that they convey much the same information, while substantial differences would indicate a need for re-evaluation of the TBS.

The MBII was developed by the U.S. EPA's Environmental Monitoring and Assessment Program. The program evaluated 574 first, second, and third order stream reaches in a region known as the Mid-Atlantic Highlands (Klemm et al. 2003). The Mid-Atlantic Highlands include Pennsylvania, Maryland, Virginia, West Virginia, parts of Delaware outside the coastal Plains, and the Catskill Mountains of New York. Importantly, the region includes southwestern Pennsylvania and samples from southwestern Pennsylvania streams were included in the study. Klemm et al. (2003) evaluated more than 100 macroinvertebrate metrics that are commonly used in the published literature, testing signal to noise ratio, responsiveness to disturbance gradients, and redundancy (i.e. correlation) among the metrics. The resulting multi-metric MBII was intended, like the PADEP's TBS, to indicate the extent to which disturbances have impacted a stream reach.

The University further assessed the effectiveness of PADEP's TBS index by comparing it to the indices developed for three nearby states whose ecosystems are similar to the ecosystem in which the majority of underground bituminous coal mining occurs in PA: Maryland's Index of Biological Integrity (IBI; Stribling et al. 1998), the Virginia Stream Condition Index (VASCI; Burton and Gerrisen 2003) and the West Virginia Stream Condition Index (WVSCI; Gerritsen et al. 2000). Finally, the University calculated the first principle component (PC1) of the aggregate set of 22 metrics used in these five indices (see Table VII-1 for a list of the metrics used in each index). Percent Tanytarsini of the Chironomidae, a metric used in the VASCI, could not be used because mine operators in Pennsylvania are only required to report Chironomidae without tribe or genus identification; this metric was therefore omitted from both the Principal Component analysis and the VASCI calculations.

Table VII-1. Comparison of PADEP Total Biological Score component metrics and of the index itself to four other indices and their component metrics: The Mid-Atlantic Highlands Macroinvertebrate Biological Integrity Index (MBII) of Klemm et al. (2003), The Maryland Index of Biological Integrity (IBI) of Stribling et al. (1998), The Virgina Stream Condition Index (SCI) of Burton and Gerrisen (2003) and the West Virgina Stream Condition Index (SCI) of Gerritsen et al. (2000). All correlations reported are based on pre-normalized metrics. The average correlations do not change significantly when normalized metrics are used.

Macroinvertebrate Metric	PADEP TBS	Mid-Atlantic Highlands MBII	Maryland IBI	Virgina SCI	West Virginia SCI	PC1
Taxonomic Richness	✔		✔	✔	✔	✔
% of Individuals in 5 Most Dominant Taxa		✔				✔
% of Individuals in 2 Most Dominant Taxa				✔	✔	✔
Trichoptera Taxa Richness	✔	✔				✔
Ephemeroptera Taxa richness		✔	✔			✔
Plecoptera Taxa Richness		✔				✔
Diptera Taxa Richness			✔			✔
Filterer-Collector + Predator Taxa Richness	✔					✔
Filterer-Collector index		✔				✔
EPT (Ephemeroptera + Trichoptera + Plecoptera) Taxa Richness			✔	✔	✔	✔
Intolerant Taxa Richness	✔		✔			✔
Macroinvertebrate Intolerance Index (MTI)		✔				✔
% (Plecoptera + Trichoptera - Hydropsychidae)				✔		✔
% EPT Richness	✔					✔
% Non-Insect Individuals		✔				✔
% Ephemeroptera			✔	✔		✔
% Chironomidae				✔	✔	✔
% Tanytarsini of Chironomidae[1]			✔			
% Tolerant Individuals			✔			✔
% Collectors			✔			✔
% Scrapers				✔		✔
HBI - Hilsenhoff Biotic Index, Family Level*				✔	✔	✔
Correlation with TBS	-	0.83	0.39	0.66	0.87	0.85
Probability of a larger r^2	-	< 0.0001	0.0003	< 0.0001	< 0.0001	< 0.0001
Mean	66.9	48.9	3.9	67.9	73.9	22.46
Standard Deviation	19.3	15.6	0.66	14.7	14.2	20.95

*Abundance-weighted avg tolerance (Family taxonomic level)

[1]Not included - see Sec. VIIB.

To compare the macroinvertebrate indices, the University calculated TBS, MBII, IBI, VASCI, WVSCI and PC1 for 90 stream samples with data in the PADEP paper files. For stream samples to be usable for this analysis, the data on individual taxa abundance had to be included. As recommended by Barbour et al. (1999), all of the metrics used for calculating each state's indices are normalized according to the regional distribution of metric values. This is done by dividing individual sampling station metrics by percentiles of the regional distributions of metric values to put all metrics on scales of 0 – 100 (except for the IBI; it is scaled 0 – 10). The University did not use the PADEP TGD percentiles for the metrics, but instead used the percentiles of the metric distribution for the 90 samples in this analysis. This was done so that all five of the indices being compared were scaled to the same distribution. Interestingly, the mean value of the TBS for the 90 samples calculated by this method (67.0 +/- 2.0 SE) fall within two standard errors, i.e. not detectably different, from the two pre-mining mean TBS the University reported in Section VII.H.2 (71.2 +/- 1.5 SE; 67.7 +/- 2.9 SE), indicating that the use of any of those distributions' percentiles will give nearly identical values. The University wrote a Statistical Analysis System (SAS 2013) macro language program (available on request from the University research team) that estimated the percentiles of the distribution of values across the 90 stream samples and used those percentiles to norm the metrics according to the methods outlined by PADEP (2005b) and the developers of the other indices cited above. The program then calculated the TBS and other indices from their respective normalized metrics. Finally, the program calculated the correlations among the five measures. The results are shown at the bottom of Table VII-1.

PADEP's TBS is significantly correlated with all five tested metrics and highly correlated with all but Maryland's IBI. In particular, the high correlation of the TBS with PC1 and MBII (r^2 = 0.85 and 0.83, respectively), the most comprehensive of the indices tested, shows that the TBS captures the vast majority of information on macroinvertebrate community integrity available from the methods commonly used across this region for bioassessment. The University is confident in stating that the PADEP TBS is an accurate indicator of changes in the biotic community associated with disturbance and pollution.

VII.C – Isolating the Effect of Mine Subsidence: Controlling for Non-Mining Related Influences on Stream Flow and Biology

Stream flow and biology are naturally variable and influenced by a number of factors unrelated to mining. Below is a discussion of the degree to which climate, catchment and reach-scale characteristics as well as sampling season influence stream flow and biology above longwall mines in Pennsylvania. The University's efforts to control for these factors while investigating subsidence impacts are also described.

VII.C.1 – Effect of Climate on Stream Flow

Flow regimes are strongly affected by many factors, including catchment size, geology, topography, surrounding vegetation, local temperatures and precipitation (Poff et al. 1997). While all of these factors influence a stream's flow pattern, it is the latter climatic factors of temperature and precipitation that drive seasonal and annual variation in stream flow. Periods of high and low stream flows are common in Pennsylvania due to the seasonal climate (Section VI). During periods of low flows, streams can even experience flow loss if the climatic conditions are dry enough. However, flow loss is also a common impact of mine subsidence. Thus, to understand the effect of subsidence on flow loss, it is critical to first understand the effect of climate on stream flow loss.

The relationship between climatic conditions and stream flow loss was assessed by first determining periods of drought during the 4th Act 54 assessment period. Drought conditions are regularly monitored by PADEP using a composite metric that combines data from four drought indicators – groundwater percentiles, surface water percentiles, precipitation departures, and the Palmer Drought Severity Index (Pennsylvania Water Science Center 2014). Using this composite metric, counties are placed into one of three drought categories: drought watch, drought warning, and drought emergency (Pennsylvania Water Science Center 2014). Greene and Washington counties, where all active longwall mines from the 4th assessment period are located, experienced three drought watches and one drought warning during the reporting period (Table VII-2).

Table VII-2. Periods of drought conditions during the 4th Act 54 assessment in areas with active longwall mines.

Start Date	**End Date**	**Status**
11/7/2008	1/26/2009	Drought watch
9/16/2010	11/10/2010	Drought warning
11/10/2010	12/17/2010	Drought watch
7/19/2012	8/31/2012	Drought watch

Next, the average percent flow loss (defined as: (the length of the stream with no flow) / (total length of the stream observed)*100) was calculated for streams (N = 18) during a non-drought (March 2010) and drought period (October 2010). The selected streams are located in the permit area for Bailey Mine, but had not yet been undermined at the time of the March and October 2010 surveys. Many of these streams exhibited substantial flow losses during the drought period (Figure VII-1). Large flow losses were particularly common on first order streams. In the non-drought period, only 5 of the 18 streams experienced flow loss, and all flow losses were minimal (<11% of stream dry; Figure VII-1). Clearly, climate must be accounted for when evaluating the effect of mine subsidence on stream flow loss.

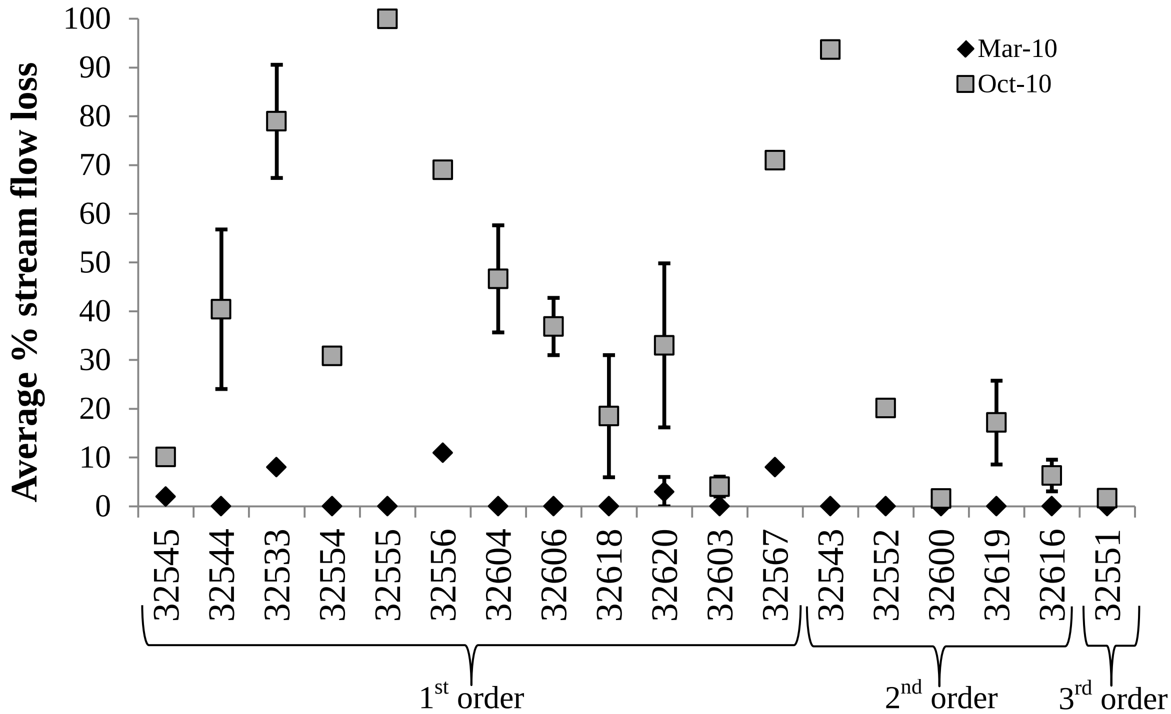

Figure VII-1. Average percent stream flow loss on streams outside of mining under non-drought (March 2010) and drought conditions (October 2010). Data are means +/- one standard error. Streams without error bars were either monitored only one week out of the month or exhibited no variation from one week to another.

To that end, mine operators with approval from PADEP recently established a "wet" and "dry" season for Pennsylvania (Consol Pennsylvania Coal Company 2010). The wet season is December-May, while the dry season is June-November. The University adopted this classification system in the assessment of stream flow loss to avoid confounding the impact of climatic conditions with mine subsidence. Below, maximum and minimum stream flow losses are reported for both the wet and dry seasons (Section VII-E; Appendix F).

VII.C.2 – Effect of Catchment and Reach-Scale Characteristics on Stream Biology

In stream ecosystems, the distribution and abundance of macroinvertebrates is determined by a spatial hierarchy of habitat filters (sensu Poff 1997; Vinson and Hawkins 1998, Heino 2009). The abiotic and biotic filters range from broad-scale controls at the stream catchment basin to local factors operating within the stream reach. At the catchment scale, land use is one factor that is known to influence macroinvertebrate communities (reviewed by Johnson and Gage 1997, Allan 2004, Hughes et al. 2006, Johnson and Host 2010). The conversion of land to agricultural and developed areas impacts stream communities by changing both the physical and chemical makeup of aquatic environments (Allan 2004). Specifically, human dominated landscapes can increase stream sedimentation rates, introduce contaminants, alter runoff and groundwater flows, and reduce the amount of riparian vegetation and large woody debris (Allan 2004). These physiochemical changes scale up and affect the diversity of life streams are able to support. The loss of riparian vegetation can reduce detrital food inputs for macroinvertebrates while the loss of coarse woody debris can eliminate refuges from predation for fish and invertebrates (Everett and Ruiz 1993). When evaluating the magnitude of land use impacts, it is important to consider the spatial arrangement of land use in a watershed (Kearns et al. 2005). For example, a large agricultural field adjacent to a stream is likely to exert very different effects on the stream ecosystem relative to several small fields scattered throughout an otherwise forested watershed. While land use patterns in the catchment can influence macroinvertebrate diversity, the relative importance of land use vs. factors operating at the reach-scale remains the subject of much investigation (Johnson and Host 2010). Reach-scale factors include channel morphology, stream habitat, and water quality. Clearly, the environmental conditions at the reach-scale are regulated to some degree by factors operating at the catchment scale (Poff 1997). However, in some areas – particularly those that are largely undisturbed – reach-scale factors can outweigh the importance of catchment factors and play a dominant role in structuring macroinvertebrate communities (Weigel et al. 2003, Johnson et al. 2007)

The complex nature of interactions between stream ecosystems and their surrounding landscapes required that the University develop a method to control for this complexity before assessing the impacts of mine subsidence (Section VII.H) and restoration on stream macroinvertebrate communities (Section VII.J). Land cover information was obtained from the National Land Cover Database (NLCD) 2006 Land Cover data layer (Fry et al. 2011) for 16 stream catchments over areas of active and planned longwall mining (Bailey, Enlow Fork, Cumberland, and Emerald Mines). Within each catchment, subwatersheds were delineated for each stream bio-monitoring station (N = 201 stations; Figure VII-2) using a flow accumulation layer and the "Watershed" tool in ArcGIS. The NLCD layer was clipped to the resulting subwatersheds and then FragStats version 4.1 (University of Massachusetts, Amherst, Massachusetts, USA) was used to calculate land use and landscape pattern metrics (i.e. largest patch index, edge density, shape index, contiguity, patch richness, Simpson's landscape diversity index, Simpson's landscape evenness; see McGarigal et al. 2012 for definitions). Lastly, the landscape data was merged with information on reach-scale characteristics for each of the bio-monitoring stations. Reach-scale data were collected by the mine operator prior to undermining the stream. Measures of water quality included conductivity, pH, and dissolved oxygen. Measures of stream habitat and channel morphology were based on the U.S. Environmental Protection Agency low-gradient habitat assessment score for each station. The assessment evaluates 10 habitat parameters, such as channel sinuosity, bank stability, and riparian zone vegetation, to generate a composite score. Scores range from 0-200, with scores in the 156-200 range representing optimal habitat, 106-155 suboptimal, 56-105 marginal, and 0-55 indicating poor habitat.

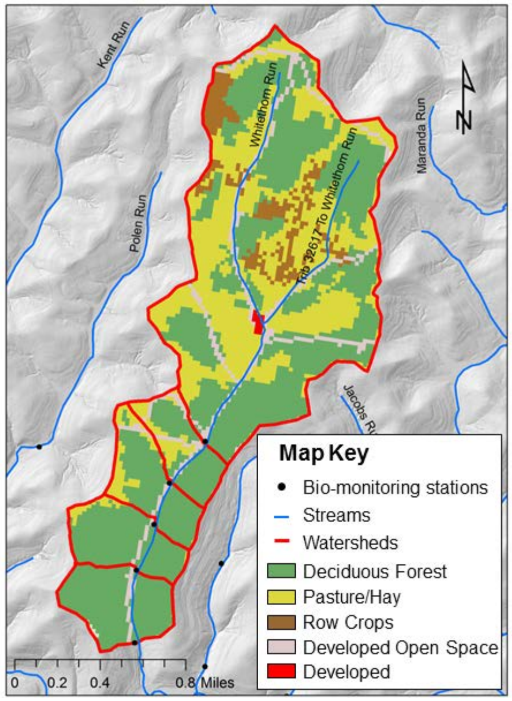

Figure VII-2. An example of land use within Whitethorn Run, a focal catchment in a planned expansion area of Bailey Mine. The red lines indicate the delineated subwatersheds for each bio-monitoring station (black point) within the catchment. The subwatersheds in this catchment are dominated by forest and pasture/hay land use types.

Data from large spatial scales can be challenging to statistically analyze for several reasons (Allan and Johnson 1997, King et al. 2005). One problem is that stream sites that are close together are likely to be more similar in terms of land use and biology than sites that are distant from each other (i.e. spatial autocorrelation; King et al. 2005). Due to the close proximity and sharing of water flows between many of the bio-monitoring stations in these 16 catchments, spatial autocorrelation was assessed prior to further analysis. Using ArcGIS, the stream course distance between stations that were hydrologically connected (a "station pair") was measured. Stations were considered to be connected if water flowed downstream from one site to another (i.e. "flow-connected", sensu Peterson and Ver Hoef 2010). This method does not consider stations from adjacent tributaries to be "connected". This approach is appropriate for sites in Appalachia because lateral dispersal of macroinvertebrates between adjacent watersheds via adult flights is rare (Griffith et al. 1998). Based on the distribution of the distances between stations, the station pairs were organized into 10 bins and the average correlation in Total Biological Score was calculated for each bin (N = 29-95 station pairs/ bin). A bootstrapping procedure was used to generate 95% confidence intervals for each correlation estimate. The analysis indicated that stations within 1,673-ft of each other had significantly correlated Total Biological Scores. To eliminate spatially autocorrelated stations from the data set, all upstream stations that were hydrologically connected to the most downstream station and within the determined distance were eliminated. This procedure was applied to each station until the entire watershed had been examined. This analysis removed 50 stations from the data set, leaving 151 stations that can be considered statistically independent of each other.

A second statistical problem is that catchment and reach-scale variables are often not independent predictors of biological communities because they can be correlated with each other. For this data set, a Spearman correlation analysis revealed significant correlations among many of the catchment-scale variables (Appendix E). While land use was also expected to be highly correlated with water quality, there were few highly significant relationships (Appendix E). The lack of strong correlations suggests that stream pH, conductivity, and dissolved oxygen in southwestern Pennsylvania may be affected to a larger degree by the area's underlying geology than land use practices. Prior to further analysis, bio-monitoring stations that were missing data for one or more of the predictor variables were dropped (7 stations dropped; N = 144).

A partial least squares (PLS) regression was used to analyze the relationship between Total Biological Score and the catchment and reach-scale variables. PLS regression is a multivariate statistical technique that is well-suited for ecological datasets with correlated predictor variables (Carrascal et al. 2009). PLS regression extracts a series of orthogonal factors from the predictor variables. The factors are extracted in such a way as to maximize the variance explained among the predictors and in the response variable (SAS Institute Inc. 2008). While this technique initially extracts as many factors as there are predictors in the dataset (in this case, 17 factors), the number of relevant factors can be determined by looking at the explanatory power of each factor. In the analysis, the first two factors explained 32.8% of the variation in Total Biological Score (Table VII-3). The remaining factors only explained an additional 3.1% of the variance in Total Biological Score, suggesting that the bulk of the explanatory power is contained within these first two factors. The meaning of the two factors can be determined by evaluating the weights of each predictor variable on the factors (Table VII-3). For factor 1, negative values are associated with bio-monitoring stations that have diverse catchments with pasture/hay and reaches with high pH and low habitat scores. In contrast, stations with positive values of factor 1 have catchments that are dominated by large, intact patches of deciduous forest and reaches with neutral pH and high habitat scores. Like factor 1, factor 2 is largely a function of a station's habitat assessment scores. However, factor 2 is also a function of the % developed land in the catchment and landscape contiguity. Bio-monitoring stations with negative values of factor 2 generally have contiguous landscapes in their catchment but low habitat scores at the reach scale. Stations with positive values of factor 2 have catchments that are somewhat fragmented by development and reaches with high habitat scores.

Table VII-3. Weights for each of the catchment and reach-scale variables on factors 1 and 2 from the partial least squares regression. The four largest weights for each factor are in bold.

Predictor	**Weights**	
Catchment scale	**Factor 1**	**Factor 2**
% Pasture	**-0.397**	0.016
% Deciduous Forest	0.360	-0.184
% Developed Open Space	-0.045	0.342
% Row Crops	-0.120	0.189
% Developed	0.145	**0.428**
Largest Patch Index	**0.382**	-0.135
Edge Density	-0.265	**0.348**
Shape Index (AM)	-0.249	-0.132
Contiguity (AM)	0.130	**-0.379**
Patch Richness	-0.263	-0.049
Simpson's Diversity Index	-0.327	0.277
Simpson's Evenness Index	-0.301	0.266
Watershed Area	-0.171	-0.128
Reach scale		
US EPA Low-Gradient Habitat Assessment	**0.465**	**0.483**
pH	**-0.396**	-0.281
Conductivity	-0.182	-0.019
Dissolved oxygen	-0.044	-0.130
R^2 for Y-variable	0.189	0.140
R^2 for X-variables	0.334	0.128

Using Spearman correlation analysis, the University found that both factors from the PLS regression have a significant positive correlation with TBS (factor 1: $r_s = 0.47$, $P < 0.0001$; factor 2: $r_s = 0.34$, $P < 0.0001$; Figure VII-3). The positive correlation between TBS and factor 1 (Figure VII-3a) indicates that larger TBS are associated with forested catchments and reaches with neutral pH and pristine habitat. Low TBS are associated with pasture/hay land use in the catchment, alkaline pH, and poor reach habitat. The University is aware of only one other study that has assessed the relationship between agricultural land use and stream biology in Pennsylvania (Genito et al. 2002). The study found that Ephemeroptera, Trichoptera, and overall taxonomic richness decreased as agriculture increased in a subwatershed of a tributary to the Susquehanna River (Genito et al. 2002). The University's results generally confirm those of Genito et al. (2002) and indicate that agricultural land use reduces the quality of macroinvertebrate communities in Pennsylvania.

The positive correlation between TBS and factor 2 (Figure VII-3b) indicates that larger TBS are also associated with catchments with developed land and reaches with high habitat scores. Development and/or urbanization is generally associated with declines in macroinvertebrate community metrics (e.g. Roy et al. 2003, Urban et al. 2006). However, Allan (2004) notes that declines are often only apparent once a threshold level of development or urbanization (~10-20%) has been reached. In the University's dataset, the average percent developed land in a catchment was 0.25% and the maximum percent developed was 7.1%. Thus, it is likely that the degree of development in this region is not large enough to significantly impair macroinvertebrate community health. In fact, the slight increases in light, nutrients, and water temperature that accompany small amounts of development may actually result in increases in apparent stream biotic integrity up to a point.

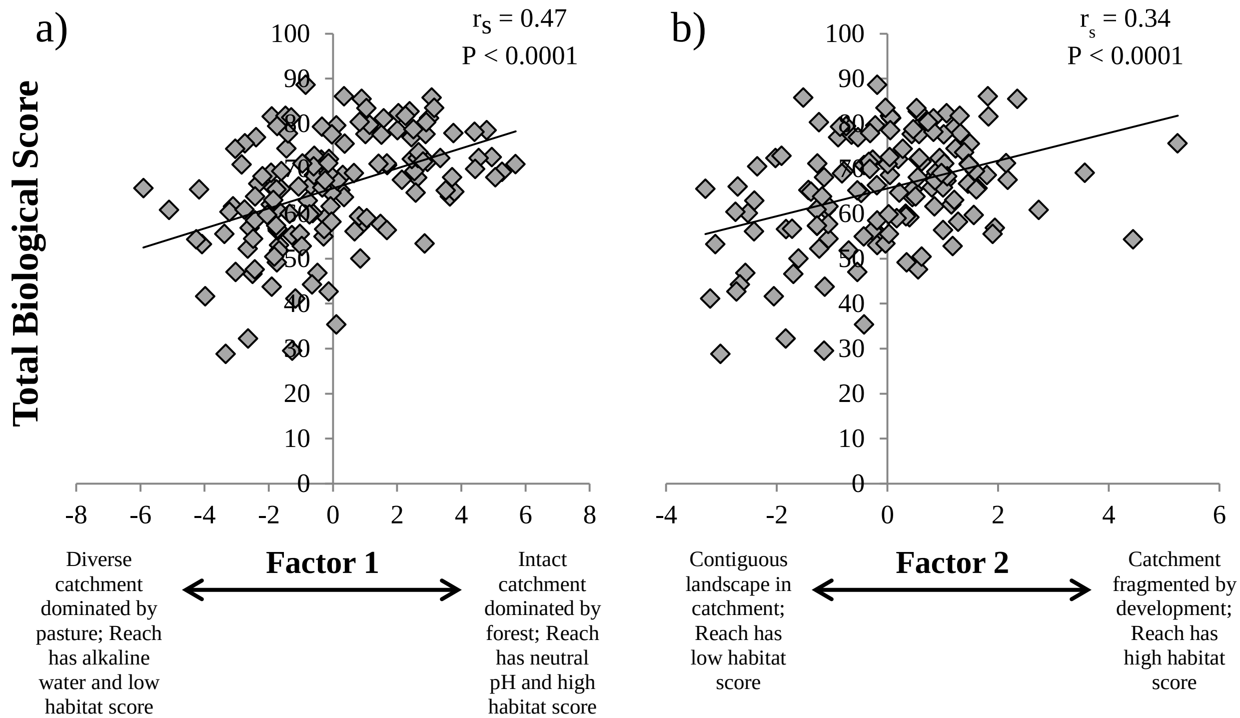

Figure VII-3. Correlation between Total Biological Score and factors 1 and 2 from the PLS regression (N = 144 bio-monitoring stations).

Lastly, the variable importance for projection (VIP) value was calculated for each predictor variable. The VIP value indicates the importance of a variable for fitting the overall PLS regression model (SAS Institute Inc. 2008). Variables with VIP values less than 0.8 are generally unimportant for model fitting and prediction (SAS Institute Inc. 2008). In this analysis, two reach-scale predictors – the U.S. EPA low gradient habitat assessment score and stream pH – were the most important variables for modelling TBS (Table VII-4). Descriptions of landscape fragmentation (i.e. Simpson's diversity index and edge density) and the % developed land in the catchment were also highly important.

The results of this analysis were used by the University to control for the effect of land use while investigating subsidence impacts on stream biology (Section VII.H). For each station, the scores for factors 1 and 2 were multiplied by the regression slope for TBS v. factor 1 or TBS v. factor 2. This product was then subtracted from the station's TBS. The resulting "adjusted TBS" puts all streams on a level playing field during assessment of mining impacts (e.g. TBS from forested sites are adjusted downwards while TBS from agricultural sites are adjusted upwards) and allows for biological comparisons across sites.

Table VII-4. Variable importance for projection (VIP) values for each predictor variable in the PLS regression model. Values greater than 0.8 are in bold and indicate predictors that are important for describing TBS.

Predictor	**VIP Value**
Catchment scale	
% Pasture	**1.079**
% Deciduous Forest	**1.080**
% Developed Open Space	**0.861**
% Row Crops	0.573
% Developed	**1.135**
Largest Patch Index	**1.092**
Edge Density	**1.126**
Shape Index (AM)	0.751
Contiguity (AM)	**1.008**
Patch Richness	0.724
Simpson’s Diversity Index	**1.125**
Simpson’s Evenness Index	**1.053**
Watershed Area	0.564
Reach scale	
US EPA Low-Gradient Habitat Assessment	**1.744**
pH	**1.283**
Conductivity	0.496
Dissolved oxygen	0.345

VII.C.3 – Effect of Month of Sampling on Stream Biology

Temporal variation in stream macroinvertebrate communities can result from differences in macroinvertebrate life histories as well as seasonal and annual changes in habitat availability, temperature, and flow (Linke et al. 1999). One particularly strong example of seasonal variation in macroinvertebrate abundance comes from the family Capniidae (Plecoptera). Due to their life cycle, Capniidae larvae are very abundant in Pennsylvania streams across the winter months, but are rare in the summer months (Walsh et al. 2007), earning them the common name of “winter stoneflies”. Summer and winter months are known to consistently vary in terms of taxa richness and diversity (e.g. Linke et al. 1999, Riley et al. 2007). As a result, many bio-monitoring programs select an index period, or a temporal constraint, for sampling (e.g. West Virginia Stream Condition Index, Gerritsen et al. 2000; Virginia Stream Condition Index, Burton and Gerritsen 2003). In Pennsylvania, TGD 563-2000-655 requires that all Total Biological Scores (TBS) be collected between October and May (PADEP 2005a). However, even within an index period, biological metrics can vary with time (Gerritsen et al. 2000).

To determine the degree of both seasonal and annual variation in TBS, the University analyzed data on stream TBS and sampling date that were collected prior to mining by mine operators (N = 1,328 samples). Analysis of variance (ANOVA) was used to test the following model: TBS = month + year + station. Because multiple samples were collected at a single station, station was included to account for the sample variation that was due to site level differences. Overall, the ANOVA model was highly significant ($P < 0.0001$) and accounted for a significant amount of the variation in TBS ($R^2 = 0.72$). TBS varies significantly with month of sampling across the October-May index period (month, $F_{7,805}= 5.30$; $P < 0.0001$). Samples collected during the beginning and end of the index period tend to have lower TBS than samples collected in the middle of the period (Figure VII-4). Samples collected in October and November have particularly low TBS, scoring on average 10-11 points lower than samples collected in December-March. TBS for samples collected in April and May are also lower than those from December-March, although to a lesser degree (3-4 points lower on average). May scores are actually not significantly different from those collected in December-February (Figure VII-4). The observed variation in TBS across the index period may be a function of macroinvertebrate life history events (Figure VII-4), although additional studies are needed to test this idea. Interestingly, year was not a significant predictor of TBS ($F_{6,805}= 1.42$; $P = 0.20$) suggesting that year-to-year fluctuations in abiotic conditions play little to no role in explaining macroinvertebrate community variation.

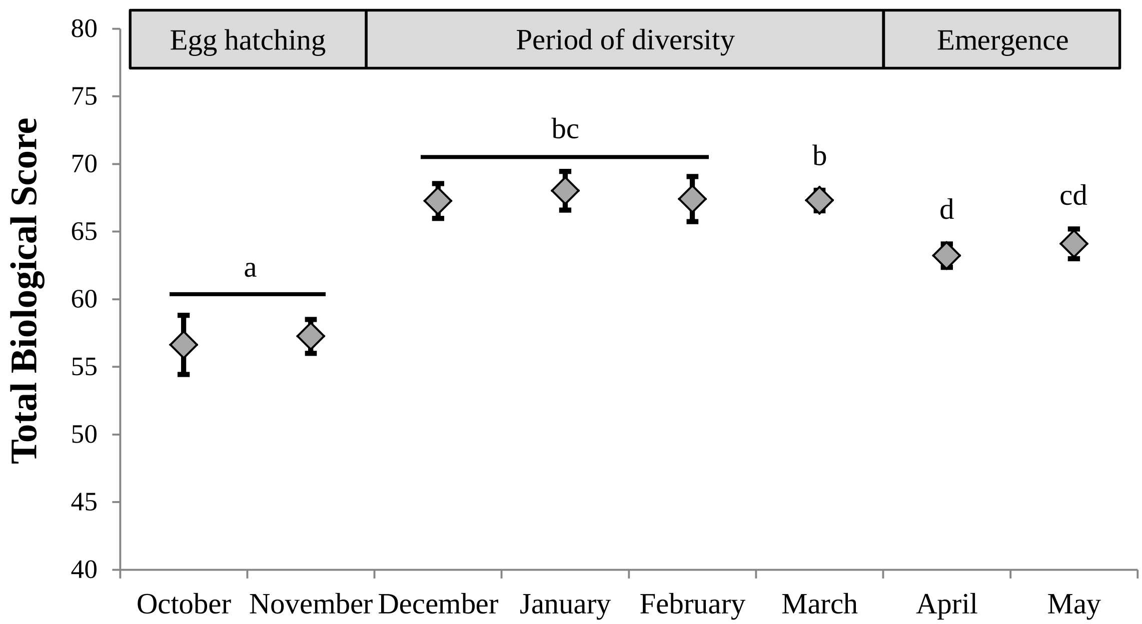

Figure VII-4. Relationship between Total Biological Score and month of sampling across PADEP's sampling index period (N = 1,328 samples). Data are monthly mean TBS +/- 1 standard error. Points that share a letter are not significantly different from each other (P > 0.05, Tukey-Kramer HSD test). Gray boxes represent possible biological mechanisms underlying differences in scores over time.

An ideal index period will balance the need to minimize temporal variability with the goal of maximizing sampling of targeted assemblages (Barbour et al. 1999). Due to the strong reduction in average TBS that occurs in October and November sampling events, the University suggests that PADEP shorten its index period for TBS sampling to December-May. Greater than 50% of the pre-mining samples in this dataset were collected in March and April, suggesting that mine operators are already focusing their sampling efforts in the early spring months.

To control for temporal variation while analyzing the effect of subsidence on stream biology (Section VII.H), each station's TBS was adjusted based on the month in which it was collected. A standard adjustment value was created for each month by subtracting the average TBS for each month from the overall average TBS. This correction value was then subtracted from each bio-monitoring station's TBS. As with the land use adjustment described above, the goal was to equalize all samples in terms on sampling month.

VII.D – Length of Streams Undermined During the 4th Assessment

PADEP tasked the University with determining the miles of streams undermined during the 4th Act 54 assessment period. To accomplish this task, ArcGIS was used to clip the "Networked Streams of PA" (see Section II.B.1 for description) to the longwall, room-and-pillar, and pillar recovery extents (where applicable). The advantage to using the "Networked Streams of PA" in this analysis is that it was used by two previous Act 54 reports (Conte and Moses 2005, Iannacchione et al. 2011), so results are directly comparable with those reports. The drawback to using this streams layer is that it does not include many of the smaller tributaries in Pennsylvania (hereafter referred to as zero-order tributaries). As a result, the analysis may underestimate the actual miles of stream undermined. The streams layer was also clipped to the 200-ft buffer surrounding each mine, as streams in this area are considered by PADEP to be potentially impacted by mining.

A total of 96.05 miles of streams were undermined during the 4th assessment period (Table VII-5). Of these, 50.59 miles of streams were undermined by longwall mining methods, while 45.04 miles were undermined by room-and-pillar methods (Table VII-5). Less than 0.5% of the streams undermined during the assessment period were undermined by pillar recovery techniques (Table VII-5). Overall, the 4th assessment period experienced a 16% decrease in stream lengths undermined relative to the 3rd Act 54 assessment period, during which a total of 113.7 miles of streams were undermined (Iannacchione et al. 2011). Miles of undermined stream declined in both the longwall and room-and-pillar categories (longwall – 3rd assessment: 63.81; room-and-pillar – 3rd assessment: 49.7; Iannacchione et al. 2011).

Table VII-5. Lengths of streams undermined in miles by mine and mining method.

Mine	**Mining Method**				**Total w/o Buffer (mi)**	**Total Length (mi)**
	Room-and-Pillar	**Long Wall**	**Pillar Recovery**	**Buffer Zone**		
	Length (mi)	Length (mi)	Length (mi)	Length (mi)		
4 West	3.12	0.00	0.43	2.89	**3.55**	**6.44**
Agustus	0.77	0.00	0.00	0.38	**0.77**	**1.15**
Bailey	2.86	14.36	0.00	3.37	**17.22**	**20.59**
Barrett Deep	0.11	0.00	0.00	0.20	**0.11**	**0.31**
Beaver Valley	0.22	0.00	0.00	0.38	**0.22**	**0.61**
Blacksville 2	2.56	5.81	0.00	1.91	**8.37**	**10.28**
BMX	2.46	0.00	0.00	2.40	**2.46**	**4.86**
Cherry Tree	2.05	0.00	0.00	2.07	**2.05**	**4.12**
Clementine 1	1.19	0.00	0.00	1.79	**1.19**	**2.98**
Crawdad	0.37	0.00	0.00	0.38	**0.37**	**0.75**
Cumberland	2.37	7.62	0.00	2.88	**9.99**	**12.86**
Darmac 2	0.81	0.00	0.00	1.88	**0.81**	**2.69**
Dora 8	0.41	0.00	0.00	0.59	**0.41**	**1.00**

Mine	Mining Method				Total w/o Buffer (mi)	Total Length (mi)
	Room-and-Pillar	Long Wall	Pillar Recovery	Buffer Zone		
	Length (mi)	Length (mi)	Length (mi)	Length (mi)		
Dutch Run	0.48	0.00	0.00	0.58	**0.48**	**1.06**
Emerald	2.16	6.04	0.00	4.38	**8.21**	**12.59**
Enlow Fork	5.00	16.59	0.00	4.23	**21.59**	**25.82**
Geronimo	0.00	0.00	0.00	0.03	**0.00**	**0.03**
Gillhouser Run	0.65	0.00	0.00	0.39	**0.65**	**1.04**
Harmony	0.20	0.00	0.00	0.22	**0.20**	**0.42**
Heilwood	0.67	0.00	0.00	1.19	**0.67**	**1.86**
Horning Deep	0.05	0.00	0.00	0.10	**0.05**	**0.15**
Kimberly Run	0.83	0.00	0.00	0.75	**0.83**	**1.58**
Knob Creek	0.51	0.00	0.00	0.36	**0.51**	**0.86**
Little Toby	0.09	0.00	0.00	0.52	**0.09**	**0.61**
Logansport	2.75	0.00	0.00	3.17	**2.75**	**5.91**
Long Run	0.03	0.00	0.00	0.04	**0.03**	**0.08**
Lowry Deep	0.21	0.00	0.00	0.53	**0.21**	**0.73**
Madison	0.83	0.00	0.00	0.16	**0.83**	**0.99**
Miller Deep	0.19	0.00	0.00	0.08	**0.19**	**0.27**
Mine 84	0.08	0.17	0.00	0.11	**0.25**	**0.36**
Nolo	0.28	0.00	0.00	0.38	**0.28**	**0.67**
Ondo	0.25	0.00	0.00	0.89	**0.25**	**1.14**
Prime 1	0.05	0.00	0.00	0.58	**0.05**	**0.64**
Penfield	0.33	0.00	0.00	0.33	**0.33**	**0.66**
Quecreek 1	2.31	0.00	0.00	1.64	**2.31**	**3.95**
Rossmoyne 1	0.13	0.00	0.00	0.55	**0.13**	**0.68**
Roytown	0.89	0.00	0.00	0.58	**0.89**	**1.47**
Sarah	0.22	0.00	0.00	0.67	**0.22**	**0.89**
Starford	0.16	0.00	0.00	0.48	**0.16**	**0.64**
Titus Deep	0.22	0.00	0.00	0.17	**0.22**	**0.39**
TJS 5	0.00	0.00	0.00	0.07	**0.00**	**0.07**
TJS 6	0.98	0.00	0.00	1.20	**0.98**	**2.19**
Toms Run	1.57	0.00	0.00	1.70	**1.57**	**3.27**
Tracy Lynne	1.02	0.00	0.00	1.67	**1.02**	**2.68**
Twin Rocks	0.58	0.00	0.00	0.60	**0.58**	**1.18**
Windber 78	2.01	0.00	0.00	1.54	**2.01**	**3.55**
	45.04	**50.59**	**0.43**	**51.01**	**96.05**	**147.06**

Using data from the Pennsylvania Aquatic Community Classification System, it was determined that many of the streams that were undermined are located in watersheds of high conservation concern for this region of Pennsylvania (Table VII-6; Walsh et al. 2007). Streams in these watersheds meet specific criteria for high quality community habitats, including macroinvertebrate diversity and trophic structure, fish metrics and the number of stream reaches designated as “Least Disturbed Streams” (i.e. having little to no human influence; Walsh et al. 2007). Scientists with the Pennsylvania Natural Heritage Program and the Western Pennsylvania Conservancy recommend that “…monitoring agencies and programs…scale their efforts and funding for conservation and restoration based on the regional prioritization” (Walsh et al. 2007).

Protection of streams in these high quality watersheds is thus an important conservation objective.

*Table VII-6. Watersheds that were undermined during the 4th assessment and are classified as high conservation priorities in the Waynesburg Hills region (Walsh et al. 2007). * = Tier 1 – highest quality watersheds in the region, Tier 2 - second highest quality watersheds.*

Mine	Watershed Name	Conservation Priority Tier*
Bailey	Dunkard Fork	1
Bailey	South Fork of Dunkard Fork	1
Cumberland	Whiteley Creek	2
Emerald	Whiteley Creek	2
Emerald	South Fork of Tenmile Creek	2
Enlow	Templeton Fork	2

VII.E – Length of Streams Impacted During the 4th Assessment

In addition to determining the total miles of streams undermined, PADEP also requested that the University quantify the length of stream impacts. Specifically, the University was tasked with the following:

> **Task 1.** Calculate the lengths of undermined streams (organized by mining method) that fall into one of the following categories – a) streams with no reported effects, b) streams with mining-induced pooling, and c) streams with mining-induced flow loss.
> **Task 2.** Identify the location of each reported incident of stream flow loss. Provide a GIS layer of each mine showing the location of all reported incidents of flow loss that were longer than two weeks or required augmentation and a table that lists the latitude and longitude of the center of the flow loss and the minimum and maximum lengths.
> **Task 3.** Identify the location of each reported incident of pooling. Provide a GIS layer of each mine showing the location of all reported incidents of stream pooling and a table that lists the latitude and longitude of the center of the pooling and minimum and maximum lengths.

To complete these tasks, all undermined streams had to be classified as unaffected, impacted by mining-induced flow loss, impacted by mining-induced pooling, or impacted by both flow loss and pooling. To categorize the undermined streams, the University used data from PADEP monthly stream flow map database and the mine permit revisions. The monthly stream flow map database is a recent addition to the data files at CDMO, so it is briefly described here. The database is stored in a Microsoft Outlook folder on PADEP servers. Each month, mine operators submit stream hydrologic assessments to the CDMO database via email. Because there is no standardized format for these data submissions, stream flow maps and data files from different mine operators vary in content. For mines operated by Consol Energy, Inc., maps and Microsoft Excel files identify the location and length of flow loss on a weekly basis. The Excel files also report which streams received augmentation each week, including the number of active augmentation wells per stream and the augmentation rate. Maps identify the location of all augmentation wells. For mines operated by Alpha Natural Resources, Inc., maps identify the location of flow losses on a weekly basis, but there are no accompanying Excel files that quantify the length of flow loss or that describe patterns of augmentation. Because the files from Alpha Natural Resources, Inc. did not include data on stream augmentation, the University asked CDMO to request these data from the mine operator. CDMO requested the data and additional maps were supplied to the University on a cd. The maps that were received are known as "straight line" maps. The stream of interest is depicted as a straight line with sections of flow loss/pooling and dates of augmentation color-coded (Figure VII-5).

Streams were classified using the above data. Streams that received augmentation during the 4^{th} assessment period (see Table VII-13) were classified as experiencing mining-induced flow loss. While the contract also asked the University to consider flow losses that lasted longer than two weeks, many intermittent streams commonly lose flow for two weeks or more during the dry season, especially during drought periods (Figure VII-1). Thus, it seems inappropriate to attribute flow losses of two weeks or more to mining-induced impacts. It should be noted that augmentation is likely not a perfect indicator of mining-induced impacts either. Mine operators sometimes augment streams during the dry season to demonstrate good stewardship of the land that they have mined (J. Silvis, Consol Energy, Inc., pers. comm.). For pooling, all streams that received a gate cut (see Table VII-11) or have a proposed future gate cut (Table VII-12) were classified as experiencing mining-induced pooling. Streams receiving both augmentation and gate cuts were considered to have had both mining-induced flow loss and pooling. Because streams from room-and-pillar mines did not receive augmentation or gate cuts, this analysis focuses exclusively on streams from longwall mines.

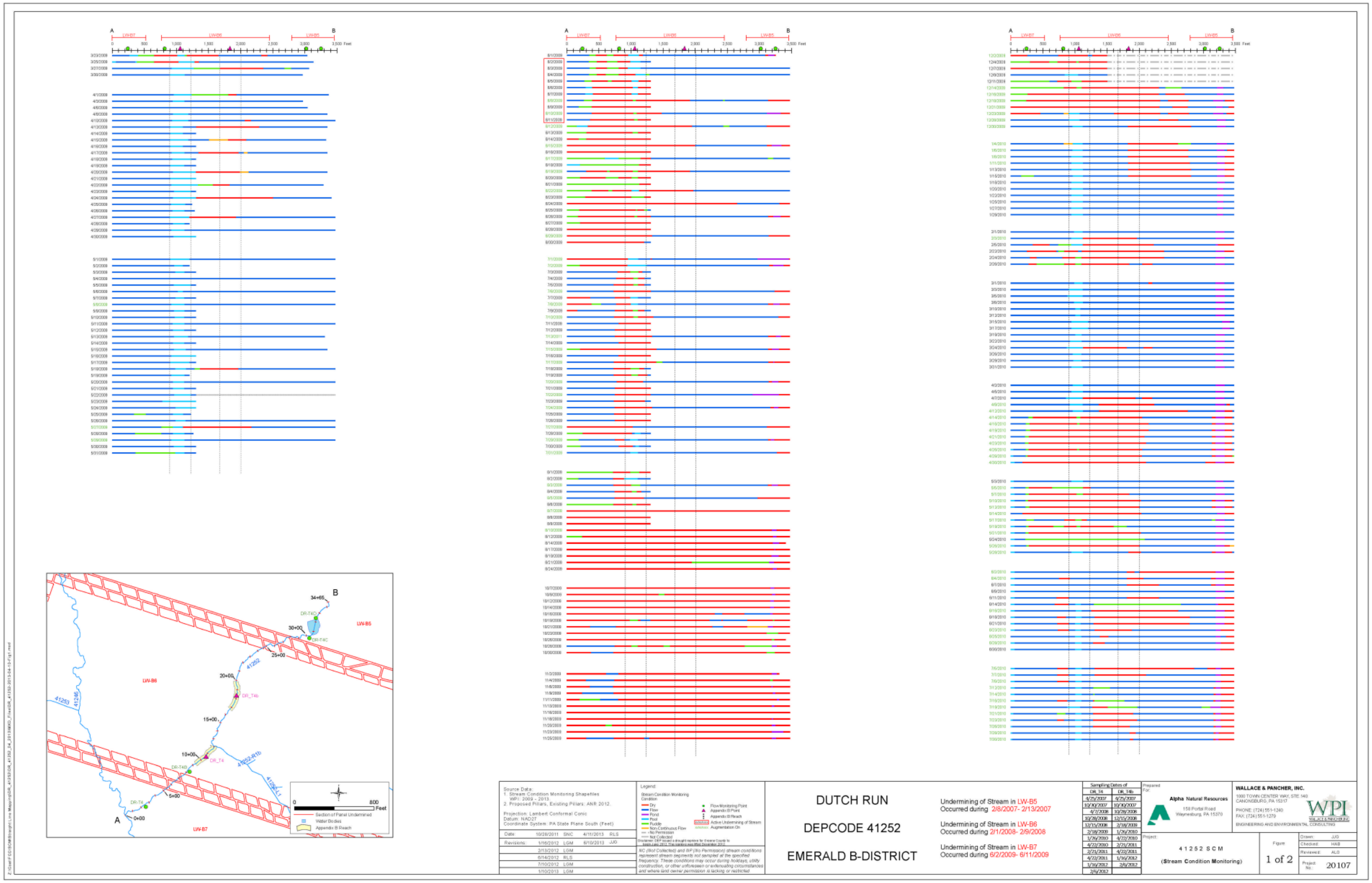

Figure VII-5. An example of a "straight-line" flow map from Alpha Natural Resources, Inc. Each line represents the dry and flowing lengths on a particular date for unnamed tributary 41252 to Dutch Run in Emerald Mine. Dates with augmentation are highlighted in green.

For Task 1, ArcGIS was used to clip the undermined streams in each category to the longwall, room-and-pillar, and 200-ft buffer extents. The “Networked Streams of PA” layer was used for this task. It is important to note that the results of Task 1 do not represent the length of stream *actually* experiencing flow loss or pooling. The lengths reported represent the miles of undermined stream belonging to a stream channel that experienced flow loss, pooling, or both somewhere along its extent.

Streams experiencing flow loss, pooling or both comprised 39.2 miles (Table VII-7) – or roughly 77% – of the total miles of streams undermined by longwall techniques (50.59 miles, Tables VII-5). Thus, only 23% of the total miles undermined by longwall techniques belonged to streams that did not experience mining-induced flow-loss or pooling. In contrast, streams experiencing flow loss, pooling, or both comprised just 44% (6.55 miles; Table VII-7) of the total miles of stream undermined by room-and-pillar techniques (14.95 miles from the five longwall mines, Table VII-5). For the stream lengths located in the 200-ft buffer zone, these lengths were most likely to be associated with streams that were unaffected by mining (10.82 unaffected miles, Table VII-7, of the total 16.77 buffer miles for the five longwall mines, Table VII-5). Overall, these data indicate that streams that are undermined by longwall mining techniques have a high probability of being impacted by either flow loss or pooling. There is variation across mines, with streams in Cumberland and Emerald Mines each having < 1 mile of their undermined streams belonging to streams impacted by flow loss (Table VII-7). This result could be an artifact of how the University categorized streams using data from PADEP. Recall that streams were categorized as experiencing mining-induced flow loss only if they received augmentation. Differences in mitigation approaches or even reporting practices across mine operators could account for the variation in miles of streams experiencing flow loss. Alternatively, the variation could represent natural differences in the geologic and hydrologic conditions between mines.

For Task 2, data from the PADEP monthly flow map database was used to identify the locations of maximum and minimum flow losses in both the wet and dry seasons. Due to the differences in reporting by Consol Energy, Inc. and Alpha Natural Resources, Inc., different approaches were adopted to complete this task for each operator.

Table VII-7. Undermined stream lengths categorized as belonging to streams with mining-induced flow loss, mining-induced pooling, mining-induced flow loss and pooling, or unaffected. Lengths do not represent length of impact but lengths of undermined stream segments that contain a reported impact.

	Flow Loss			**Pooling**			**Flow Loss and Pooling**			**Unaffected**		
Mine	**Longwall Length (mi)**	**Room-and-Pillar Length (mi)**	**Buffer Length (mi)**	**Longwall Length (mi)**	**Room-and-Pillar Length (mi)**	**Buffer Length (mi)**	**Longwall Length (mi)**	**Room-and-Pillar Length (mi)**	**Buffer Length (mi)**	**Longwall Length (mi)**	**Room-and-Pillar Length (mi)**	**Buffer Length (mi)**
Bailey	8.01	0.76	1.18	0.00	0.00	0.00	5.62	0.68	0.60	0.74	1.42	1.60
Blacksville	2.56	0.85	0.35	0.73	0.23	0.21	2.34	0.60	0.21	0.18	0.89	1.14
Cumberland	0.74	0.09	0.19	2.34	0.42	0.84	0.00	0.00	0.00	4.54	1.85	1.85
Emerald	0.09	0.00	0.04	1.39	0.00	0.25	0.77	0.09	0.09	3.80	2.08	4.00
Enlow Fork	8.29	1.83	0.82	2.08	0.38	0.46	4.25	0.63	0.71	1.97	2.16	2.24
TOTAL	**19.68**	**3.52**	**2.59**	**6.54**	**1.03**	**1.76**	**12.97**	**2.00**	**1.60**	**11.23**	**8.40**	**10.82**

For Consol-operated mines, Microsoft Excel files from the monthly flow map database were used to tabulate the flow loss lengths for all streams receiving augmentation during the 4th assessment period. It should be noted that Excel files for Blacksville 2 Mine were only submitted beginning in July 2011 so files for the beginning of the assessment period were not available. Statistical software was used to identify the dates of maximum and minimum post-mining flow loss in both the wet and dry seasons (SAS Institute Inc. 2013). For minimum flow losses, dates where the stream experienced 0-ft flow loss were excluded because 0-ft of flow loss cannot technically be considered a loss. Flow loss locations were identified by geo-referencing all monthly flow maps and digitizing the maximum and minimum flow loss areas. The monthly stream flow maps submitted by the mine operator do not use the “Networked Streams of PA” stream layer. Instead, these maps use a detailed stream layer that shows the locations of the smaller, zero-order tributaries that are not identified on the “Networked Streams of PA” layer. To accurately display both the stream and the flow loss segments reported by the mine operator, the University traced the mine operator’s stream layer in ArcGIS and used it to map maximum and minimum flow loss.

For mines operated by Alpha Natural Resources, the “straight-line” maps for all augmented streams were visually inspected to identify the dates of maximum and minimum flow loss for both the wet and dry seasons. The lengths of the flow loss segments were quantified using the Analysis feature of Adobe Photoshop (Adobe Photoshop CS5, Adobe Systems Incorporated, San Jose, CA). Using the scale bar provided on each map, the measurement scale was customized to convert from pixel lengths to length in feet. The flow loss lengths were then recorded using the Ruler tool. To identify the flow loss locations, the flow loss lengths were carefully matched to the streams layer provided by Alpha Natural Resources in ArcGIS. Like the stream layers utilized by Consol-operated mines, the Alpha streams layer is more detailed than the “Networked Streams of PA” stream layer and displays zero-order tributaries. Flow losses on two streams in Cumberland Mine (unnamed tributaries 41264 and 41267 to Dyers Fork) could not be mapped because these streams did not appear on the Alpha streams layer as they were undermined during the 3rd assessment period.

Maximum post-mining flow loss lengths in the dry season ranged from 936-ft to 10,883-ft (Appendix F). Summing the maximum flow loss lengths in the dry season for all streams indicates that maximum flow losses totaled 52.2 miles of undermined streams (Appendix F). Because the dry season flow loss lengths are influenced to a large degree by climatic conditions (Section VII-C.1), the maximum flow loss length in the wet season is likely a more precise indicator of mining-induced flow loss impacts. Maximum post-mining flow loss lengths in the wet season ranged from 96-ft to 8,106-ft (Appendix F). Maximum flow losses summed across all streams for the wet season totaled 23.7 miles of undermined streams (Appendix F). Maps identifying the locations of all maximum and minimum flow losses are located in Appendix C. Separate maps were created for streams undermined in the 2nd and 3rd Act 54 assessment periods that continue to exhibit mining-induced flow loss impacts. Because these streams continued to receive augmentation during the 4th assessment, they were identified as still exhibiting flow loss.

Unfortunately, the University was unable to complete Task 3 because the paper files that were made available at the CDMO did not contain maps for the vast majority of pooling impacts. Technical drawings of pooling were available in the plans for gate cut mitigation; however, these technical drawings cannot be spatially geo-referenced to identify the pooling location. Furthermore, because they are focused on the gate cut restoration area, they often do not show the entire length of pooling, making it impossible to quantify the maximum/minimum pooling lengths. According to PADEP, maps of pooling are not required because pooling is predicted up front in the permit application. While the location and lengths of pooling could not be determined, the location and lengths of gate cut restoration areas are described below (Section VII.I.2). Gate cuts are generally necessitated by pooling and thus give some indication of pooling frequency and location.

VII.F – PADEP System for Tracking Stream Impacts

The above data and previous Act 54 reports (Conte and Moses 2005, Iannacchione et al. 2011) demonstrate that longwall mining can cause flow loss and pooling impacts to undermined streams. PADEP is responsible for “documenting observations regarding mining-induced changes” and “determining when a stream has recovered” (PADEP 2005a). Here, the system for tracking stream impacts during the 3rd Act 54 assessment period is described along with the changes that were made to that system during the 4th assessment.

During the 3rd Act 54 assessment period and prior to the adoption of TGD 563-2000-655, a “stream investigation” was initiated each time a stream impact was reported by a mining company, a property owner, or a PADEP surface subsidence agent (SSA). Each stream investigation was given a unique identifier (e.g. ST0501 represents the first (01) stream (ST) impact that occurred in 2005 (05)) that could be tracked in both BUMIS and the paper files at CDMO. Once a stream investigation was filed, PADEP would determine if the impacts were mining-related or the result of seasonal variations in climate. If the changes were determined to be mining-induced, then the mine operator was granted a period of time to perform mitigation. The operator would later submit data to PADEP for determination of stream recovery. If the stream had recovered, PADEP would release the stream from further monitoring. If the stream had not recovered, PADEP would require additional mitigation. This stream tracking procedure is summarized in Figure VII-6a.

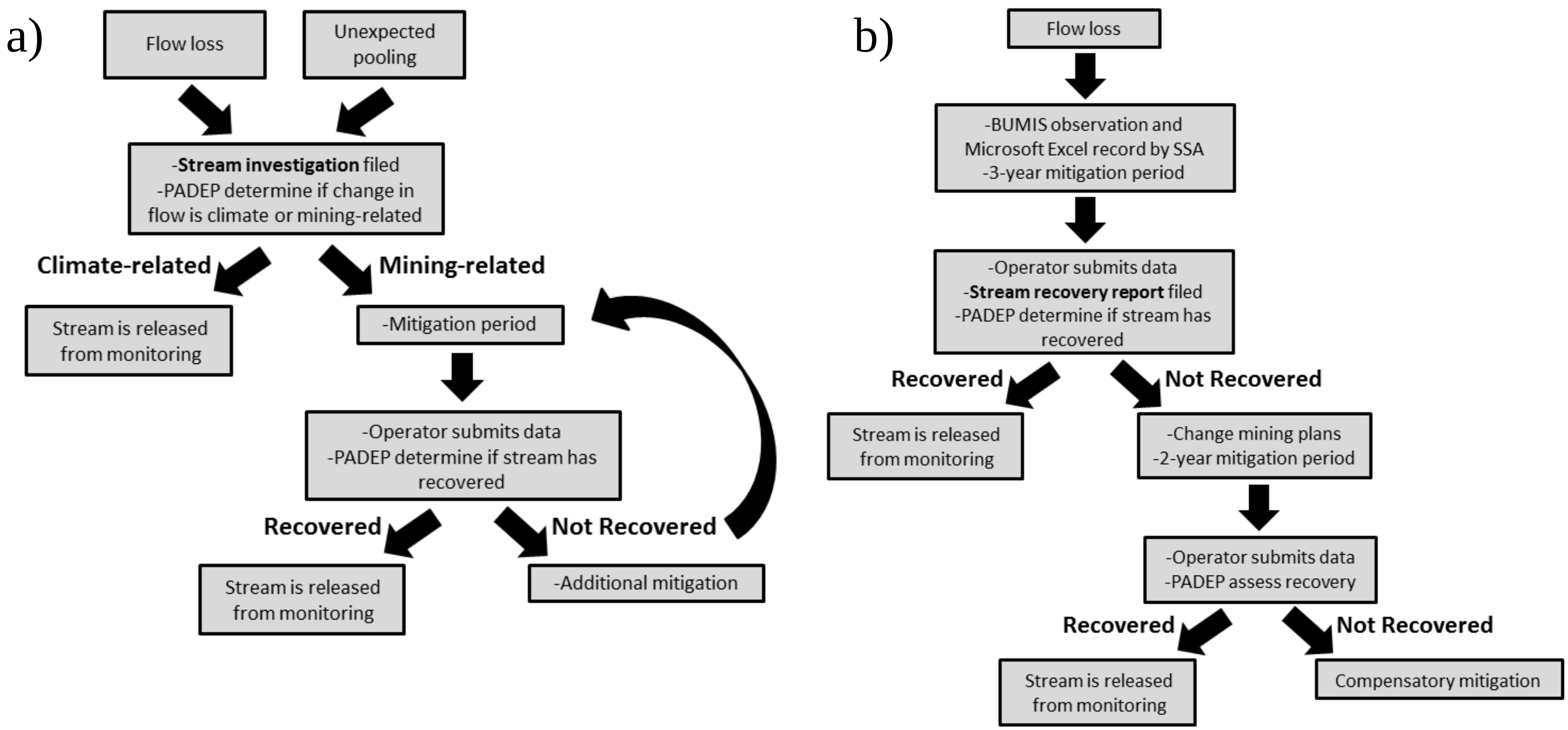

Figure VII-6. PADEP methodology for tracking stream impacts during the a) 3rd and b) 4th Act 54 assessment periods.

According to PADEP, stream investigations are still used to track impacts that occurred prior to mine operators coming into compliance with TGD 563-2000-655. However, the procedure for tracking stream impacts after this time point is quite different (Figure VII-6b). PADEP no longer has a stream investigation period in which they determine if changes in flow are related to mining or climate. Instead, changes in flow that occur at the time of mining are automatically assumed to be mining-related. If a change in stream flow is observed by a PADEP SSA, a record of the impact is made in the BUMIS agent observation files and in the SSA's stream data logs. Stream data logs are Microsoft Excel files that are stored on PADEP servers. The SSA then notifies the mine operator of the impact, and the operator has three years from the date of impact to repair the reported stream damages. Over this period, the SSA monitors the stream and tracks any mitigation work that is performed. Records of mitigation are stored in the stream data logs. If PADEP finds that stream flow and biology have not recovered after three years, then they require a change in future mining plans to avoid mining under similar settings. At this point, the operator has two more years to perform additional mitigation work. Once the operator submits the final flow and biological data to PADEP, a "stream recovery report" is generated. Stream recovery reports are paper files at CDMO that contain the data from the mine operator and reviews by PADEP hydrologists and biologists. If the flow and biology match pre-mining conditions or those of an approved control stream, the stream recovery report is closed. However, if a stream cannot be restored after a total of five years, then the operator may be required to perform compensatory mitigation. (PADEP 2005a). Compensatory mitigation generally refers to "restoration or enhancement of an equivalent length of another stream in the same watershed or a nearby watershed." (PADEP 2005a). It should be noted that the timeframe outlined here applies to flow loss impacts only – the three year recovery period outlined by TGD 563-2000-655 does not apply to unexpected pooling impacts.

Comparison of figures VII-6a and b reveals significant differences in PADEP's approach to tracking stream impacts between the 3rd and 4th Act 54 assessment periods. The 4th assessment protocol makes two significant improvements over the 3rd assessment protocol – operators are automatically assumed liable for changes in stream flow that occur at the time of mining and streams are no longer mitigated for an indefinite period of time. In terms of mitigation, TGD 563-2000-655 makes it clear that "if a stream cannot be fully restored within five years", then compensatory mitigation may be required (PADEP 2005a). While the University recognizes the advances made by PADEP in tracking stream impacts, there are several drawbacks to the 4th assessment protocols. First, tracking the occurrence and resolution of stream impacts is no longer a simple matter of tallying the number of stream investigations and their final resolution statuses. Currently, impacts are tracked by two different systems – BUMIS observation files and SSA stream data logs. The BUMIS observation files are standardized across agents and can be quite informative. However, they are written as narratives that makes extraction of relevant data difficult and time-consuming. PADEP acknowledge that BUMIS was never intended for tracking stream impacts. As a result, the SSA stream data logs were created. These logs are also a wealth of information, but there is no standardized format for the logs across the agents. Furthermore, because there is no record of these files in the filing system at CDMO, it would be difficult for citizens of the Commonwealth to request and/or obtain these data. The University was not aware that these files existed until one year after the start of the contract period. Once it was discovered that PADEP was internally tracking stream impacts on Microsoft Excel spreadsheets, the University had to specifically request them from PADEP. The University suggests that PADEP develop a centralized and standardized information system for tracking stream impacts. Maps, photos, narratives, and raw data that the SSAs are already collecting could be integrated into a system under a unique identifier for each stream. Such a system would increase PADEP efficiency and transparency to the public. The second drawback to the 4th assessment protocol is that after mitigation, PADEP relies on the mine operator to submit flow and biology data. The University suggests that PADEP specifically request these data after mitigation to ensure a timely assessment of recovery. The University further suggests that all flow and biology data collected by the mine operators during the mitigation period be required for submission to avoid any perception of selective data submission. The University is not suggesting that mine operators are engaging in such practices, only that the current practice leaves both the operators and PADEP susceptible to such suspicions. Lastly, while TGD 563-2000-655 allows for three years of restoration before requiring a change in the mining plans, it is possible that similar streams may be undermined during this time period and impacted in a similar manner. While the University has no suggestions for avoiding this inherent lag time in protecting similar streams from the impacts of mining, this situation does highlight the importance of understanding factors that contribute to stream impacts so that operators can better predict them before they even occur.

It is important to note that the PADEP approaches to tracking and record-keeping outlined above have no formal documentation associated with them (G. Shuler, PADEP, email comm.) They are not therefore policy, but only practice promulgated by word of mouth. The University recommends that a written policy be developed.

VII.G – Stream investigation and recovery reports initiated during the 4th assessment

The stream investigation and recovery reports initiated during the 4th Act 54 assessment period are described below. The number of cases, their time to resolution, and final resolution status are compared to data from previous assessments. Lastly, several case studies are highlighted to detail the current methods utilized by PADEP to assess stream recovery.

VII.G.1 – Stream investigation and recovery report data collection

Stream investigations were tracked using BUMIS and paper files at CDMO. The University collected information on the date the impact occurred, the final resolution status, and the final resolution date. Using these data, the time to resolution in days was calculated for each stream investigation.

During the course of data collection, the University discovered that BUMIS is incomplete. Two of the nine stream investigations from this period were not tracked in BUMIS – only in paper files at CDMO. For data on stream recovery reports, the University had to rely exclusively on the paper files at CDMO which are assumed to be complete.

VII.G.2 – Stream Investigations: Resolution status and time to resolution

A total of nine stream investigations were filed during the 4th assessment period (Appendix G1). Of these, five had a final resolution as of 20 August 2013 (Table VII-8). Considering that the 3rd Act 54 assessment period had a total of 55 stream investigations (Iannacchione et al. 2011), stream investigations at PADEP have declined by 84%. The decline is largely a result of the shift in methodology for tracking stream impacts (Figure VII-6). Stream impacts are now tracked in BUMIS and SSA stream data logs.

Table VII-8. Resolution status of stream investigations initiated in the 4th assessment period.

Resolution Status	Number
Final: Not recovered: compensatory mitigation required	1
Final: No actual problem	1
Final: Not due to underground mining	2
Final: Stream Recovered	1
Interim: Not Yet Resolved	4
Total	9

The small number of resolved cases from this assessment period, coupled with the wide variation in time to resolution, resulted in a large standard deviation around the mean time to resolution (776 days +/- 1050 days). Thus, any comparison with the average time to resolution from the 3rd Act 54 assessment is difficult to interpret and relatively meaningless. However, it should be noted that three of the five stream investigations were resolved within one year of the stream impact (Appendix G1).

For these five resolved stream investigations, PADEP first determined if the changes in stream flow were climate or mining-related (Figure VII-6a). For two cases during the 4th assessment, PADEP attributed flow losses to climatic conditions (i.e. drought, seasonal intermittent flow). These two cases have a final resolution of “Not due to underground mining”. Close observation however revealed that inadequate data and observations served as the basis for these determinations. For case ST0902, PADEP relied on just six months of pre-mining flow data to establish the normal range of conditions for an unnamed tributary to Whiteley Creek (stream 41257) rather than using a control stream. It should be noted that this stream was undermined between 20 April and 4 May 2009 and experienced flow loss well after the mine operator was in compliance with TGD 563-2000-655. It is unclear why this case was not handled using the newer methodology developed by PADEP (Figure VII-6b) and held to the strict recovery standards set forth by TGD 563-2000-655. For case ST0903, flow loss was observed on Cessna Run (stream 46501) in TJS 6, a room-and-pillar mine. While stream flow losses are rare in room-and-pillar mines, pillar failure can occur and cause fracturing of the aboveground rock strata. The initial flow loss was reported by a property owner on 11 September 2009. A site visit was made a year later in September 2010 by PADEP. At that time, Pennsylvania was experiencing a severe drought (Table VII-2). PADEP noted that the stream was dry at this time, but that subsequent stream visits showed flow in the stream channel. Because there is no evidence that the site was visited by PADEP prior to the drought event, the cause of the 2009 flow loss – a year in which the state did not experience drought conditions – is unknown. PADEP did not request that the mine operator select a control stream and post-mining flow data was not available in the stream investigation file. Because PADEP observations indicated that flow returned following the 2010 drought, the case was closed on 9 June 2011.

PADEP also determined for one stream investigation during the 4th assessment that there was "no actual problem" (Table VII-8). In this case (ST1102), comparisons of flow data from a control stream and stream 32736, an unnamed tributary to Templeton Fork, revealed no difference in the average percentage of stream dry. Interestingly, in these analyses, only flow data from the uppermost reaches of the control stream were utilized because these reaches were most similar in drainage area to Stream 32736.

Only two cases in the 4th assessment were ruled to be related to mining. For case ST1201, PADEP determined that stream 41250, an unnamed tributary to Dutch Run, had recovered to a normal range of conditions based on flow data from the mine operator. However, closer inspection of the data again indicates that the PADEP's decision was based on inadequate flow data. A control stream was not used to establish the normal range of flow conditions. A field visit was conducted on 3 February 2012 during which the stream was flowing and according to PADEP agents, "appears to be restored to support or sustain its uses." For the other case (ST1203), the PADEP ruled that stream 32596, an unnamed tributary to North Fork of Dunkard Fork, is not recovered and that compensatory mitigation is required. This stream investigation combined three previous claims for stream 32596, including ST0428, ST0502, and ST0512. See Section VIII for more information on PADEP's decision on this and other streams in Bailey Mine.

As for the four stream investigations that remain open, pre-mining flow data or control stream flow data have been submitted for three of the cases (ST0901, ST1001, and ST1101). PADEP hydrologists are currently reviewing these data to make a final decision regarding the stream status. However, for two of the three cases the flow data that is currently available is inadequate. For case ST1001, only eight months of pre-mining flow data is available. A control stream has not yet been proposed to more thoroughly establish baseline conditions. For case ST1101, flow data from the control stream were collected between September 2008 and May 2010. The mine operator compared these data to post-mining data on the impacted stream that was collected between September 2007 and December 2008. The time periods for comparison do not align, thus negating the usefulness of the control stream comparison. The final unresolved case, ST1202, involves stream 32719, an unnamed tributary to Rocky Run. According to the stream investigation file, the PADEP required the mine operator to perform mitigation work to restore flow conditions to the stream. The mine operator submitted restoration plans in July 2010 to perform shallow grouting and remove any alluvial bedload material that was impeding stream flow. Unfortunately, there was no additional information available on this stream investigation in the paper files at CDMO. As a result, the University could not determine if the mitigation work had ever been completed and if so, if it was successful.

VII.G.3 – Stream Recovery Reports: Resolution status and time to resolution

A total of 14 stream recovery reports were submitted by mine operators to PADEP during the 4th assessment period (Table VII-9; Appendix G2). PADEP has reached a final resolution on 11 of these cases, with only three reports remaining in review by PADEP agents (Table VII-9). Of the resolved cases, nine were released from monitoring. However, two cases from Bailey Mine require compensatory mitigation (stream 32511, an unnamed tributary to Dunkard Fork, and Crow's Nest, an unnamed tributary to North Fork of Dunkard Fork; see Section VIII for more information on the PADEP's decision on this and other streams in Bailey Mine).

Table VII-9. Resolution status of stream recovery reports from the 4th assessment period.

Resolution Status	Number
Final: Not recovered: compensatory mitigation required	2
Final: Released	9
Interim: Not Yet Resolved	3
Total	14

Inspection of the flow and biological data that were submitted by the mine operator and used by the PADEP to assess stream status revealed that data were largely collected in accordance with TGD 563-2000-655. The University noted only two problems with the data submissions. First, in several cases, just one post-mining TBS was submitted and compared to control stream biology to determine recovery (e.g. SR0901, SR0905, SR1001). Often the lone post-mining TBS was collected by PADEP biologists. TGD 563-2000-655 clearly states that recovery must be based on a *mean* post-mining TBS that is generated from at least two TBS samples that are within 16% of each other (PADEP 2005a). Second, pre-mining flow measurements in one case were not made on a weekly basis for 6 months prior to mining. A control stream should have been used for comparison with post-mining flow conditions, but there was no evidence that a control stream was used (SR1001). Overall, the data associated with the stream recovery reports appears to be much more detailed and more in line with PADEP policy than that found in the stream investigation files. However, biological recovery assessments must be based on two post-mining samples – not just one. The University also suggests that the mine operators, rather than PADEP agents, should be responsible for generating these post-mining scores.

VII.H – Biological Assessment of Streams Impacted by Flow Loss and Pooling

To determine the biological impacts of flow loss and pooling impacts, PADEP tasked the University with assessing pre- and post-mining Total Biological Scores (TBS) for at least five stream segments that experienced mining-induced flow loss and at least five stream segments that experienced mining-induced pooling. The University's findings are presented below.

VII.H.1 – Stream Biology Data Collection and Analysis

Data on stream biology is stored exclusively in the paper files at CDMO. While the University found an abundance of pre-mining biology data in the paper files, post-mining biology data was generally scarce and difficult to find.

For mining-induced flow loss impacts, the University was only able to locate pre- and post-mining TBS for streams from one longwall mine – Bailey Mine. During the permitting of the Bailey Mine South Expansion, PADEP developed a compliance schedule that listed dates for the submission of pre- and post-mining stream and wetland data. These data submissions were located in a folder labelled "Bailey Mine TGD" at CDMO. To the University's knowledge, no other longwall mine has been placed under a compliance schedule by PADEP and therefore similar data were largely unavailable from other mine operators (see below). In addition to the data located in this file, additional pre- and post-mining TBS data were located in the stream recovery files. In total, the University identified 24 stream bio-monitoring stations in Bailey Mine that had experienced mining-induced flow loss impacts (i.e. received augmentation and/or grouting) and had both pre- and post-mining TBS data. While these data are likely not representative of flow loss impacts at all longwall mines, pre- and post-mining TBS from other mines were not made available to the University.

For mining-induced pooling impacts, biology data is available in the stream restoration reports that are submitted annually to PADEP following the gate cut. However, most of the TBS data in these reports is collected either pre-mining or post-restoration. It seems that in general, very few TBS are collected after mining, but before the gate cut occurs. TGD 563-2000-655 stipulates that mitigation plans for pooling should be designed to address mining induced changes before they result in adverse effects on streams and wetlands (PADEP 2005a). The short time to gate cut mitigation in several mines (Figure VII-13) suggests that gate cuts are being performed rapidly to prevent such adverse effects from occurring. As a result, pre- and post-mining (pre-mitigation) TBS data were limited to eight stream bio-monitoring stations in two longwall mines – Bailey and Enlow Fork Mine.

Prior to analysis, datasets were corrected for spatial and temporal correlations among the observations. An important assumption of statistical analysis is that observations are uncorrelated and independent of one another. To correct for spatial correlation among the bio-monitoring stations, the University eliminated all stations that were within 1,673-ft of another station (see Section VII.C.2 for methodology). This correction removed three stations from the flow loss dataset and four stations from the pooling dataset. While it might seem that repeated measures analysis should be used to correct for temporal correlations since the data are longitudinal in nature (i.e. a single bio-monitoring station is sampled at multiple time points and samples that are collected closer in time may be more similar than samples collected over distant time points), samples were not taken at equally spaced time points across sampling stations. The equal spacing of time points across sampling stations is a requirement of repeated measures. Thus a repeated measures approach was precluded. This analysis does not distinguish among the different pre- and post-mining time points – instead it tests how, on average, post-mining TBS differ from pre-mining TBS. The University analyzed raw pre- and post-mining TBS and as well as adjusted TBS that were corrected for the influence of catchment and reach-scale characteristics as well as month of sampling (see Sections VII.C.2 and VII.C.3). For mining-induced flow loss impacts, the final dataset was large enough ($N = 21$ stations with 125 TBS samples) to use analysis of variance (ANOVA) to statistically test the difference between pre- and post-mining scores (model: raw or adjusted TBS = mining (pre-mining vs. post-mining) + station). For mining-induced pooling impacts, the remaining dataset was not large enough to meet the assumptions of a statistical analysis ($N = 4$ stations with 20 TBS samples). Instead, the average pre- and post-mining scores and their standard errors are reported.

Regarding the lack of post-mining biology data, PADEP asserts that data was requested from Cumberland and Emerald Mines in April 2013. Data were submitted by the mine operator on 7

August 2013. However, PADEP did not start review of the data at this time or notify the University of its existence because the data were misplaced in CDMO following submission (G. Prentice, PADEP, email comm.). Once the data had been found, PADEP begin its review in February 2014. At this time, the University was still not made aware of the data and did not discover it until April 2014. Upon reviewing the data in April, it became evident that the Cumberland and Emerald stream biology data lacks compliance with TGD 563-2000-655. First, very few stations had pre-mining TBS. Of the 52 bio-monitoring stations in the report, only 11 had at least two pre-mining TBS, a requirement of the TGD. While stations undermined shortly after the TGD's implementation may be expected to lack sufficient data, stations undermined as recently as 2010 in both Cumberland and Emerald Mines reported just a single pre-mining TBS. As a result, the bulk of the post-mining biology data for Cumberland and Emerald Mines are compared to data from control streams that were chosen post-mining. Second, the pre-mining data that is available suggests that the consultants employed by Alpha Natural Resources, Inc. are not following the sampling protocols required by Appendix B of TGD 563-2000-655. The pre-mining scores are highly variable – of the 11 sites with two pre-mining TBS, just five sites had scores that met the TGD 563-2000-655 requirement of being within 16% of each other. PADEP discovered that consultants were not using 200 organisms +/- 20% to generate TBS. PADEP agents have trained consultants on TGD 563-2000-655 protocols both in the field and in the lab (PADEP, pers. comm.). Lastly, the month of sampling (as well as data on water quality and macroinvertebrate community composition) was only reported for samples collected on control streams. Without this information, scores cannot be corrected for temporal variation in sampling date. Due to uncertainty regarding the validity of the data for the reasons outlined above, the University did not include any stations from Cumberland or Emerald Mine in the assessment of mining-induced flow loss and pooling impacts on stream biology. The problems encountered suggest that the PADEP would be well served to require certification of consultants' abilities at sampling according to protocols and competency at macroinvertebrate identification. Furthermore, the University recommends that PADEP closely evaluate the data submissions that are made available before and after mining.

PADEP also acknowledges that post-mining TBS were requested from Enlow Fork Mine in February 2014. Data were submitted by the mine operator in March 2014 (G. Prentice, PADEP, email comm.), however these data were never made available to the University.

VII.H.2 – Pre- and Post-Mining Total Biological Scores from Streams Impacted by Mining-Induced Flow Loss and Pooling

On average, mining-induced flow loss reduces a stream's Total Biological Score by 9 points (Figure VII-7). Despite a small sample size, this result is highly significant (effect of mining on raw TBS, $F_{1,103} = 16.44$; $P < 0.0001$; effect of mining on adjusted TBS, $F_{1,103} = 15.84$; $P = 0.0001$). The reduction in TBS is greater than 12% of the pre-mining average, indicating that, on average, mining-induced flow loss has an adverse effect on stream biological communities (PADEP 2005a).

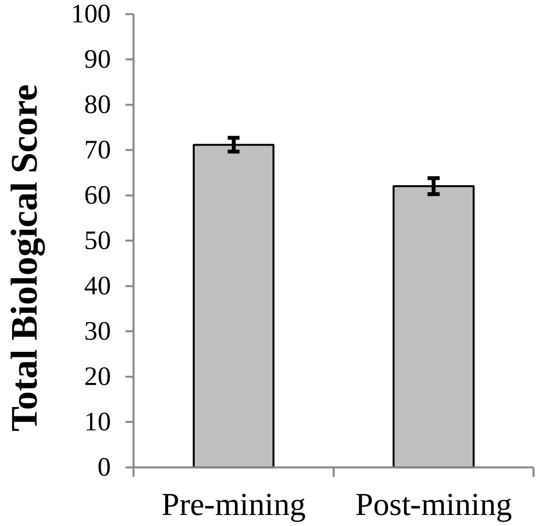

Figure VII-7. Comparison of pre- and post-mining Total Biological Scores for streams impacted by mining-induced flow loss. Data are least squares means +/- 1 standard error.

A similar pattern was found for streams impacted by mining-induced pooling. On average, pooling reduces a stream's adjusted TBS by 7 points (pre-mining adjusted TBS: 67.7 +/- 2.9 vs. post-mining adjusted TBS: 60.5 +/- 6.2; means +/- 1 standard error). When looking at the unadjusted scores, pooling reduces raw TBS by 5 points (pre-mining raw TBS: 63.5 +/- 2.3 vs. post-mining raw TBS: 58.4 +/- 5.9). As with flow loss, the reduction in adjusted TBS is greater than 12% of the pre-mining average. However, the reduction in raw TBS is within 12% of the pre-mining average. While these results suggest that adverse effects are occurring on pooled segments before gate cut mitigation work begins, additional data would allow a more definitive conclusion.

Overall, these two analyses demonstrate that mining-induced flow loss and to a lesser degree, mining-induced pooling, have significant detrimental effects on stream communities. While the data came from a limited number of longwall mines, the results are concordant with reported reductions in macroinvertebrate taxa richness following longwall mining reported elsewhere (Stout 2003).

VII.H.3 – Changes in Macroinvertebrate Community Composition for Streams Impacted by Mining-Induced Flow Loss

Total Biological Score is a multi-metric index of stream community health (PADEP 2005a). While it is useful in measuring overall changes in community status, it does not explain how the community changes functionally or taxonomically in response to disturbance. To understand how mining affects macroinvertebrate communities in terms of taxa and function, the University investigated changes in community composition. Unfortunately, data on community composition are not always reported to PADEP. Often, mine operators submit just the TBS and its five associated metrics to describe pre- or post-mining stream samples. Within the flow loss dataset, only 16 stations had samples that reported pre- and post-mining macroinvertebrate sample composition (N = 28 pre-mining samples, N = 34 post-mining samples). For these samples, the

University calculated the relative frequency of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa occurrences. The University focused on these macroinvertebrate orders because EPT taxa are often thought to be more sensitive to disturbance (although this is not always true; Rosenberg et al. 2008) and EPT richness or % EPT is a commonly used metric in many multi-metric stream indices (e.g. Gerritsen et al. 2000, Burton and Gerritsen 2003), including the Total Biological Score (PADEP 2005a). Non-metric multi-dimensional scaling (NMDS) was also used to visualize community similarity across pre- and post-mining samples (R, version 3.0.2; R Core Team 2014). NMDS is a type of ordination analysis. Ordination reduces multivariate data, such as species abundances, to a smaller number of composite variables. Each sample receives a score for these new composite variables and the samples can then be plotted in multi-dimensional space. The scores preserve the degree of differentiation between the samples so that samples that are far apart in graphical space differ from each other, while samples that cluster together in graphical space are similar to each other. Data were log-transformed ($\log_{10}(x) + 1$) prior to ordination. Following the ordination, permutation tests were used to determine if time of sampling (pre- vs. post-mining) was a significant predictor of community composition.

The majority of Ephemeroptera taxa declined in frequency following mining-induced flow loss (Figure VII-8). Many taxa experienced dramatic declines, with eight genera showing a ~50% reduction in their occurrence (Figure VII-8). The most striking reductions are found in *Ephemerella*, *Eurylophella*, and *Epeorus*. These taxa were relatively common prior to mining, occurring in 50-60% of all samples. After the flow loss disturbance created by mine subsidence, these taxa became quite rare and were found in 26% or less of the samples. In general, the families Ephemerellidae and Heptageniidae appear to be highly sensitive to flow loss, with all genera in these families experiencing declines following mining (Figure VII-8; exception: *Nixe* in Heptageniidae).

In contrast, Plecoptera and Trichoptera appear to be quite robust to mining-induced flow loss, as few taxa experienced strong declines in frequency following mining (Appendix H1). Many taxa remained at a similar frequency or even increased in frequency. For example, the Trichoptera genus *Ironoquia* occurred at just 5% of sites prior to mining but was present at nearly 50% of sites after mining-induced flow loss occurred (Appendix H1). Similarly, the genus *Isoperla* doubled in frequency following mining-induced flow loss (Appendix H1). In general, taxa from these orders appear to be more tolerant of mining-induced flow loss.

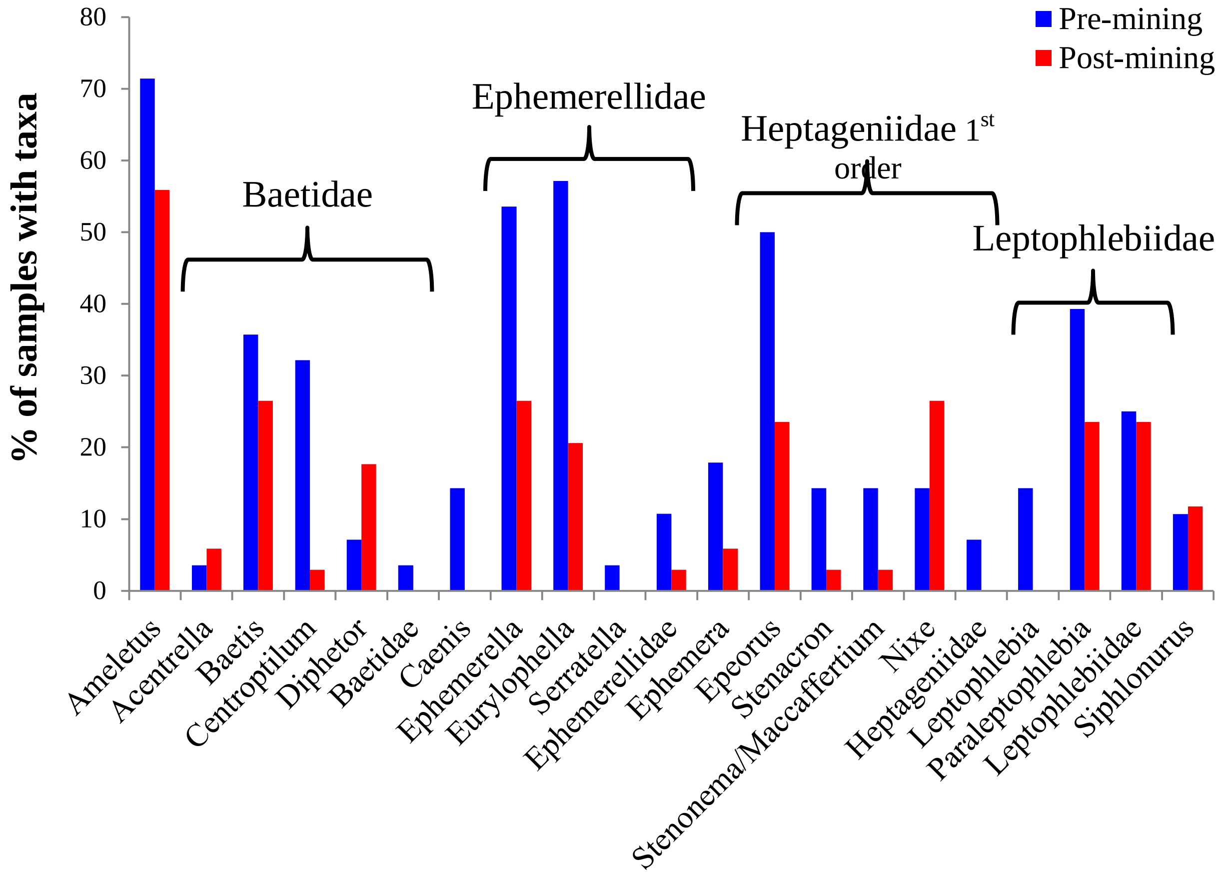

Figure VII-8. Relative frequency (%) of Ephemeroptera taxa occurrences in pre- (N = 28) and post-mining (N =34) samples. While the bulk of the samples were identified to the genus level, consultants were at times only able to identify to the family level. For families with more than one genus represented, a bracket is used to group all genera belonging to that family.

NMDS shows that community composition differs between pre- and post-mining samples (ordination stress = 0.23; Figure VII-9). Permutation tests confirm this difference, as time of sampling was a highly significant predictor of community composition (R^2 = 0.15; P = 0.001). Month of sampling was also a significant predictor of community composition (R^2 = 0.62; P = 0.001), but station id was not. The post-mining communities are shifted towards the top of Figure VII-9 compared to the pre-mining communities. Functionally, this reflects a shift away from scraper and collector-gatherer taxa, such as the Ephemeroptera discussed above, towards the shredder and predator taxa of the Plecoptera and Trichoptera. Stress tolerant Diptera taxa, including *Ormosia*, *Simulium*, and *Clinocera*, also appear to be more highly correlated with post-mining communities than pre-mining communities.

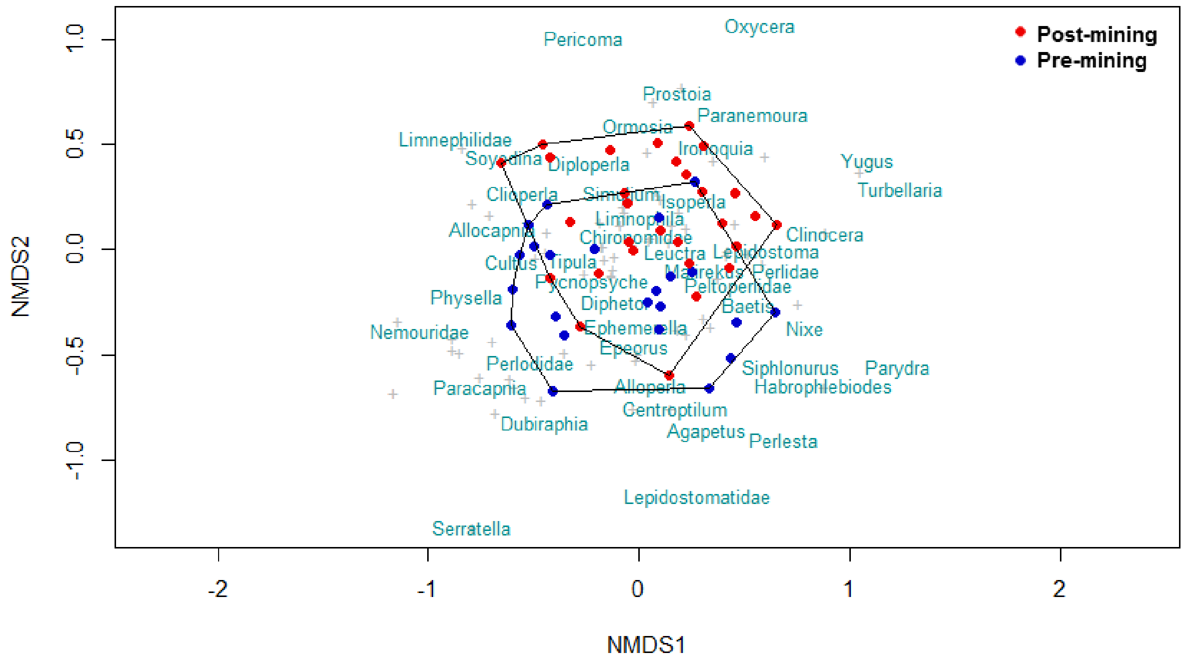

Figure VII-9. Non-metric multi-dimensional scaling ordination for community composition of pre- (N = 28) and post-mining (N = 34) samples. Gray plus signs represent additional taxa whose names are not displayed. When taxa overlap, only the name of the more abundant taxa is displayed.

These results are similar, although less dramatic, to the effects of mountaintop coal mining on stream communities (Pond et al. 2008). In mountaintop coal mining, layers of overburden are placed in valleys near the surface mine. The valley fills not only affect the physical habitat of intermittent and perennial streams in the valleys, but they can also affect the quality of groundwater and surface runoff entering the streams. Mountaintop coal mining is not currently practiced in Pennsylvania, but is used in other parts of Appalachia (Kentucky, Tennessee, Virginia, and West Virginia).

Pond et al. (2008) found that stream communities of mined sites in West Virginia were distinctly different from those of unmined sites. In particular, the community level differences were strongly linked to the loss of taxa from the families Ephemerellidae and Heptageniidae in mined sites (Pond et al. 2008). While the physical disturbance of mountaintop mining (i.e. stream burial) is dramatically different from the disturbance associated with longwall mining (i.e. streambed fracturing), it appears that the two mining methods can have similar impacts on aquatic communities. However, the complete loss of many Ephemeroptera taxa from mountaintop mined sites in the Pond et al. (2008) study indicates that the effects of mountaintop mining on stream biology are much stronger than those of longwall mining.

The loss of Ephemeroptera at mountaintop mining sites has been linked to increases in specific conductivity (hereafter, conductivity; Pond et al. 2008, Pond 2010). Conductivity is defined as the ability of a material to conduct an electrical current (µS/cm) at a standardized temperature (25°C). For streams, conductivity reflects the concentration of charged particles in the water. Because conductivity has been associated with declines in macroinvertebrate health in the Western Allegheny Plateau ecoregion, the U.S. EPA recently established a conductivity benchmark for aquatic life in this area (U.S. EPA 2011). A benchmark of 300 µS/cm was selected because analyses indicate that 95% of aquatic taxa can persist at this level. While the benchmark was not derived using data from Pennsylvania, it is expected to be applicable to sites in Greene and Washington counties because they are part of the Western Allegheny Plateau ecoregion. To determine if the changes in Ephemeroptera frequency following longwall mining (Figure VII-9) are similarly related to changes in conductivity, the University analyzed pre- and post-mining chemistry data. Within the flow loss dataset, 17 stations had samples that reported pre- and post-mining conductivity, pH, dissolved oxygen, and stream flow. The data were collected concurrently with biological sampling. Using these parameters, flux was also calculated. Because surface runoff can dilute the concentration of charged particles in the stream, flux adjusts the conductivity measures by flow rate (flux = conductivity*flow). All metrics were first analyzed using a multivariate analysis of variance (MANOVA; model: conductivity pH dissolved oxygen flow flux = mining station) to assess the overall effect of mining on stream physiochemistry. Following a significant MANOVA, individual two-way ANOVAs were used to test the effect of mining and station identity on each metric. Metrics were log-transformed when necessary to meet assumptions of normality and homoscedasticity. One post-mining conductivity measure was dropped from analyses because studentized residuals indicated that it was a significant outlier (947 µS/cm).

Stream physiochemistry is significantly affected by mining (MANOVA, Roy's greatest root = 1.50, F = 28.82, numerator degrees of freedom = 4, denominator degrees of freedom = 76, $P < 0.0001$). This result was driven in large part by significant increases in conductivity ($F_{1,80}$ = 106.21, $P < 0.0001$) and pH ($F_{1,81}$ = 67.60, $P < 0.0001$) following mining (Table VII-10). Unfortunately, data for flow and flux could not be analyzed using individual ANOVAs because despite transformation, the residuals violated test assumptions. However, the mean post-mining flux is ~3 times larger than the pre-mining value (Table VII-10), indicating that even after adjusting for large flows during storm events, post-mining streams had elevated levels of dissolved materials in the water. In contrast, the level of dissolved oxygen did not differ between pre- and post-mining samples (Table VII-10).

*Table VII-10. Pre- and post-mining physiochemical parameters for streams experiencing flow loss. Following a significant MANOVA, each parameter was analyzed using a two-way ANOVA to test the effect of mining and station identity. * = significant effect of mining, P < 0.05. N = sample size, DO = dissolved oxygen. Flux = conductivity*flow.*

	Pre-mining				**Post-mining**			
	Mean	Std. Error	Range	N	Mean	Std. Error	Range	N
Conductivity*	169.1	9.1	58-416	61	329.9	12.3	148-462	37
pH*	7.30	0.04	6.55-8.1	61	7.88	0.07	6.7-8.69	38
DO	10.9	0.3	7.1-15.9	61	10.7	0.3	5.62-13.84	38
Flow	0.18	0.03	0.001-1.1	61	0.28	0.07	0.01-2.99	45
Flux	26.9	4.7	0.11-180	61	80.2	19.5	1.57-442	37

Elevated conductivity and alkalinity levels have previously been observed in streams over longwall mining (Stout 2003). These changes were attributed to increased retention time underground (Stout 2003). Extra time spent in underground rock layers could increase contact time between the water and the rock and allow more dissolved solids to enter the water.

However, at sites experiencing flow loss, grout mitigation (see Section VII.I.3) and subsequent weathering of the grout material could also lead to increases in conductivity and pH. Unfortunately, the available data cannot be used to determine the exact mechanisms underlying the increases in conductivity and pH observed here. It is also unclear if the increased conductivity is directly responsible for declines in Ephemeroptera frequency at longwall mined sites. Indeed, the nature of the relationship between conductivity and biotic integrity remains the subject of much investigation (U.S. EPA 2011). However, longwall mining clearly pushes stream conductivity levels over the U.S. EPA benchmark for aquatic life (Table VII-10). The University suggests that PADEP and future Act 54 reports further investigate the impacts of longwall mining on stream water quality in the Commonwealth.

Changes in community composition could not be assessed for streams with mining-induced pooling impacts because the available data only had two stations that reported pre- and post-mining macroinvertebrate taxa abundance. This sample size is not sufficient to draw conclusions regarding the impact of subsidence related pooling on stream macroinvertebrate community structure.

VII.I – Stream Mitigation

Following subsidence-induced impacts, mine operators employ a variety of techniques to repair streams. For pooling impacts, TGD 563-2000-655 requires that mitigation be performed when the pool depth increases exceed 1-foot or more, or when other adverse conditions are created (e.g. loss of riffle habitat, sedimentation, nuisance to property owners; PADEP 2005a). For predicted flow loss impacts, the mine operator must have mitigation measures in place to restore flow to the stream within 24 hours (PADEP 2005a). If the flow loss was unpredicted, then the mine operator has 15 days to restore flow (PADEP 2005a). The mitigation plan for flow loss impacts should also include measures that are designed to restore natural stream flow “within one year or within a specified time period” (PADEP 2005a). Below, the techniques that are commonly used by mine operators to mitigate stream impacts are described. The number of streams receiving mitigation during the 4th assessment is also reported along with the time to mitigation.

VII.I.1 – Gate cut and stream channel restoration methods

To mitigate pooling impacts, gate cuts lower the stream bed elevation and establish a new stream gradient to promote flow across the gate area (Figure VII-10). Gate cutting is a multi-step process that involves design, permitting, construction, and monitoring. Because models are used to predict where pooling will occur, gate cut designs are typically drawn up and submitted to the PADEP along with the mine permit application before mining even begins. Following mining, the mine operator must meet with a DEP biologist and mining engineer to investigate any pooling impacts and determine if the existing mitigation plans are adequate (PADEP 2005a). If the existing mitigation plans require modification or if the pooling occurred in unpredicted areas, a permit revision must be filed with the DEP. In addition to the mine permit, a Chapter 105 permit is also required for gate cut mitigation. Because gate cuts alter the course, current, and/or cross section of a stream, the mitigation constitutes encroachment on a body of water, a process that is regulated by PA Code, Title 25, Chapter 105. The Chapter 105 permit must be approved by both the PADEP and the U.S. Army Corps of Engineers. Once all permits are in place, construction can begin.

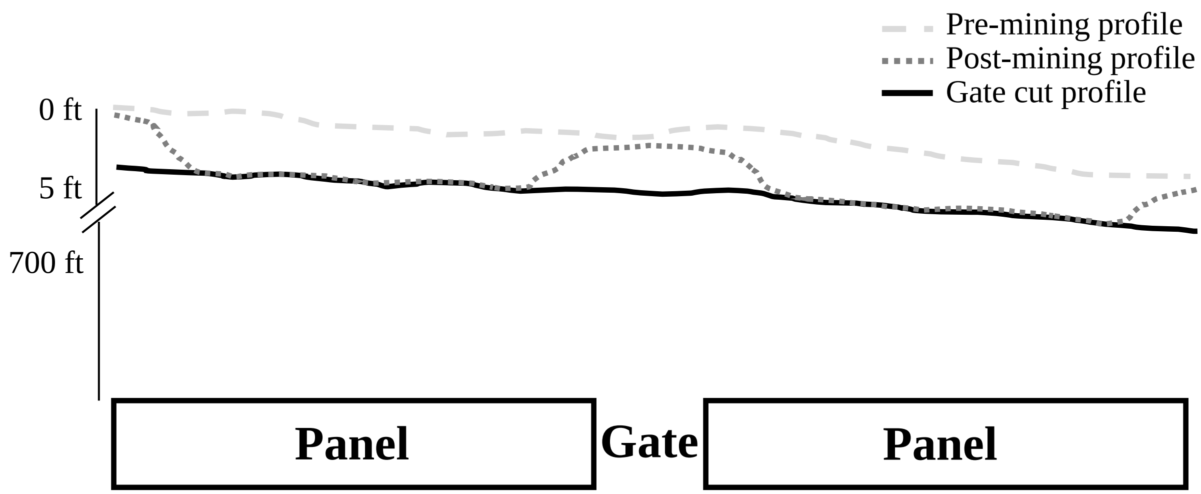

Figure VII-10. Conceptual drawing of a cross sectional stream profile before mining, after mining, and following gate cut mitigation.

To prepare the construction site, a rock construction entrance is built and silt fence is erected around equipment and staging areas to prevent sedimentation to the stream. These measures are required erosion and sedimentation controls and are outlined in Technical Guidance Document 363-2134-008 (PADEP 2012). Stream flow is routed around the restoration area using a pump and hose, commonly known as a “pump-around”. To minimize the volume of water that must be re-routed, the majority of gate cuts (~85% in this assessment period) are conducted during the dry season (June-November). Fish that are observed in the stream channel are netted and moved outside of the restoration area. Once the stream bed is clear, excavation work begins at the downstream end and proceeds in an upstream direction. The alluvial material that is excavated from the stream is stockpiled nearby, and following the gate cut, some of it is placed back in the bottom of the stream to provide habitat and cover for macroinvertebrate and fish species. The remaining alluvial material is removed to a permanent disposal site.

As the channel is excavated, hydraulic control structures are installed to prevent bank erosion and promote in-stream habitat diversity. These structures include rock vanes, log vanes, and J-hook vanes, which are designed to reduce shear stress on the near bank and promote stream flow through the center of the channel (Rosgen 2001). These structures also create pools immediately downstream that provide fish habitat. Other structures, such as boulders and root wads, are also used to stabilize banks and create habitat for fish and macroinvertebrates.

Finally, the banks are re-graded to provide stability and prevent further erosion. Cut banks are typically re-graded with a minimum 2H:1V slope (i.e. 2 horizontal feet for every 1 vertical foot; PADEP 2012). Steeper slopes, which would increase flow velocity and the likelihood of erosion, are only permitted in rare cases (e.g. to preserve trees along the stream banks inside East Finley Park, Templeton Fork F10 panel gate cut; B. Dillie, PADEP, pers. comm.). Following bank regrading (Figure VII-11), live plant cuttings and previously potted vegetation are installed and the banks are seeded and mulched. The banks are further stabilized using a combination of biodegradable mats, coir logs, and other materials.

Figure VII-11. Photograph of the recently completed E20 gate cut on Crafts Creek. Banks had been re-shaped, but vegetation had not yet been planted. (Photo courtesy of A. Iannacchione).

To assess the performance and success of the gate cut, the site is monitored for a period of five years following mitigation as a condition of the Chapter 105 permit. Each year, an annual stream restoration monitoring report is submitted to PADEP. During the five year period, the mine operator must demonstrate that the post-restoration Total Biological Scores fall within 88% of the pre-mining or control stream scores (PADEP 2005a). Once the community has recovered, biological monitoring ceases. However, stream enhancement structures and vegetation are assessed on an annual basis for the full five years. The stream enhancement structures are monitored for stability, and if any have become unstable, dislodged or removed, corrective measures must be performed. For vegetation, percent cover on the banks must reach 75-85% by the end of the third year, and no planted species should comprise more than 35% of the area (CEC 2012a, CEC 2012b, WPI 2012).

VII.I.2 – Gate cut and stream channel restoration during the 4th assessment

Based on data in the permit revisions and conversations with PADEP SSA, the University determined that 28 gate cuts were performed across 4.21 miles of stream during the 4th assessment period (Table VII-11). Enlow Fork Mine had the greatest number of stream segments with gate cuts (N = 12), while Blacksville 2 Mine had the fewest (N = 0). Many streams received multiple gate cuts over this period. South Fork of Dunkard Fork in Bailey Mine and Templeton Fork in Enlow Fork Mine each had six gate cut mitigation projects totaling 7,030-ft and 4,001-ft of stream length, respectively. The single longest gate cut mitigation project occurred on Dyers Fork in Cumberland Mine (Table VII-8). Nearly 4,000-ft of stream were mitigated over the 53-54 gate road area. Prior to the gate cut, pooling along this stretch of Dyers Fork was severe with increases in natural stream depth of up to 6.1-ft along the southern edge of panel 53 (Cumberland Permit Revision 96). Several factors likely contributed to the significant amount of restoration work required on this stretch of Dyers Fork. First, Dyer's Fork has an extremely low gradient (0.015%; WPI 2012). Second, the gate road length between the 53-54 panels is nearly three times larger than typical gate roads in Cumberland Mine (686-ft vs. 216-ft), meaning that an unusually large area between the panels did not subside (Figure VII-12). Lastly, the stream runs nearly parallel to the 53-54 gate road (Figure VII-12). For all of these reasons, long stretches of stream had to be cut to reach a lower stream bed elevation and alleviate the pooling. Similarly, South Fork of Dunkard Fork in Bailey Mine runs nearly parallel to the 11I-12I gate road area and this area also required a substantial gate cut restoration project following mining (Table VII-11).

TGD 563-2000-655 indicates that mitigation of mining-induced pooling impacts should be performed before the pooling results in adverse effects on streams (PADEP 2005a). Therefore, the University predicted that gate cut mitigation would occur rapidly after mining and subsidence of the stream. The University used data from stream restoration files and SSA BUMIS observations to determine the date that each gate cut project began. The PADEP monthly flow map database was also used to roughly determine the date when each stream was undermined. A stream segment was determined to be undermined when the longwall face was completely past the stream. The difference between these two dates represented the time to restoration.

On average, it takes 682 +/- 100 (mean +/- 1 standard error) days once mining has occurred for restoration work to begin on pooling impacts. However, there is significant variation across mines (Figure VII-13). Gate cuts in Bailey and Enlow Fork Mines occur, on average, less than two years following undermining of the stream while the average gate cut in Cumberland and Emerald Mines is not initiated until nearly three years after mining (Figure VII-13).

Table VII-11. List of all stream segments receiving gate cuts during the 4th assessment period.

Mine	PA WRDS Stream Code	Stream Name	Panel	Length of Restoration (ft)
Bailey	32540	Barneys Run	12I	200
Bailey	32536	South Fork of Dunkard Fork	10I	1,100
Bailey	32536	South Fork of Dunkard Fork	11I	1,960
Bailey	32536	South Fork of Dunkard Fork	12I	1,070
Bailey	32536	South Fork of Dunkard Fork	13I	1,320
Bailey	32536	South Fork of Dunkard Fork	14I	1,180
Bailey	32536	South Fork of Dunkard Fork	15I	460
Cumberland	41261	Dyers Fork	52-53	1,007
Cumberland	41261	Dyers Fork	53-54	3,962
Cumberland	41246	Dutch Run	52	700
Cumberland	41246	Dutch Run	53	667
Cumberland	41246	Dutch Run	54	300
Cumberland	40592	Pursley Creek	58	No data
Cumberland	41178	Whiteley Creek	55-56	536
Emerald	41268	Mount Phoebe Run	B7	814
Emerald	41269	UNT to Mount Phoebe Run	B7	137
Enlow Fork	40938	Crafts Creek	E17	No data
Enlow Fork	40938	Crafts Creek	E18	600
Enlow Fork	40938	Crafts Creek	E19	837
Enlow Fork	40938	Crafts Creek	E20	977
Enlow Fork	32708	Templeton Fork	F13	950
Enlow Fork	32708	Templeton Fork	F14	600
Enlow Fork	32708	Templeton Fork	F15	600
Enlow Fork	32708	Templeton Fork	F16	700
Enlow Fork	32708	Templeton Fork	F17	626
Enlow Fork	32708	Templeton Fork	F18	525
Enlow Fork	32738	UNT to Templeton Fork	F17	375
Enlow Fork	32739	UNT to Templeton Fork	F17	50
TOTAL:				**4.21 miles**

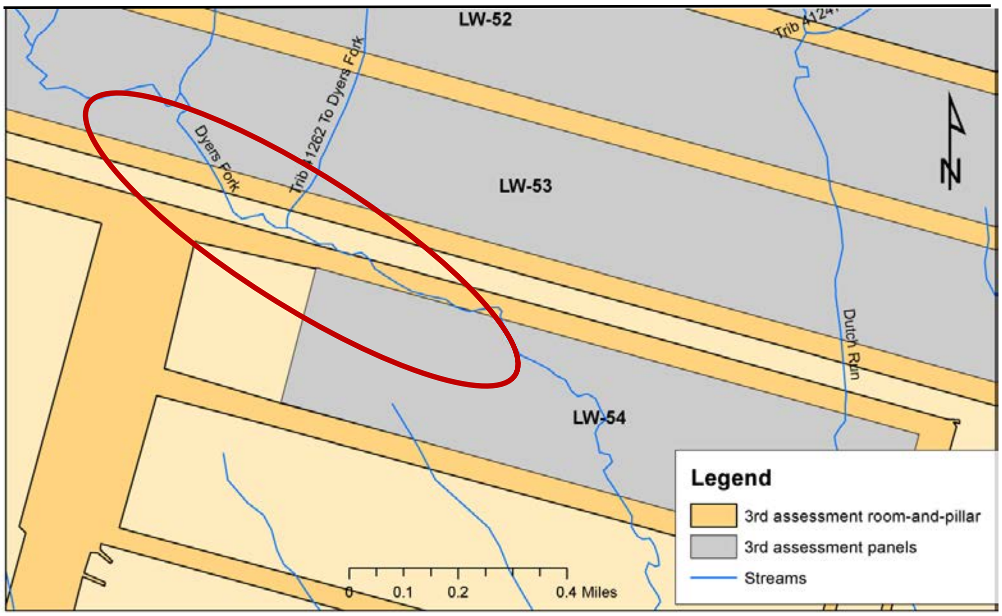

Figure VII-12. Approximate area of the Dyers Fork 53-54 gate cut is circled in red. A long gate cut was required here because the stream runs nearly parallel to the gate and the gate is wider than normal.

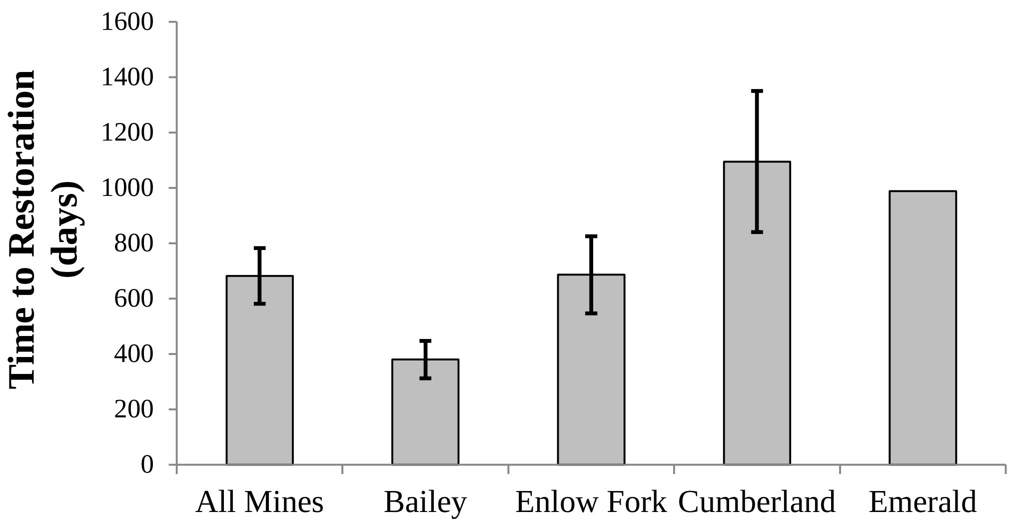

Figure VII-13. Time to gate cut and channel restoration for streams impacted by pooling during the 4th assessment. Data are means +/- 1 standard error.

Several factors may have contributed to the increased time to restoration in Cumberland Mine. First, two gate cuts involved restoration work under major bridges and thus required an additional set of approvals from PennDOT. For the Whiteley Creek 55-56 gate cut, which occurred near the I-79 bridge, confusion over the culvert type at the bridge between PennDOT and the mine operator delayed restoration for over four years after mining had occurred. For the Dyers Fork 52-53 gate cut, PennDOT expressed concern that gate cutting activities could affect the stability of the Route 19 bridge abutments and alter the hydraulic capacity of the bridge (WPI 2012). The agency had recently completed a reconstruction of the Route 19 bridge in 2006.

Ultimately, the mine operator and PennDOT reached an agreement to complete the gate cut in two phases: Phase 1 included a partial gate cut downstream of the bridge, while phase 2 finished the gate cut under the bridge and installed rip-rap along the stream bank and crossvanes in the stream channel (WPI 2012). Phase 1 was initiated roughly 336 days after mining, but phase 2 was not completed until nearly 4 ½ years after mining took place. For the analysis in Figure VII-13, the University considered the time to restoration for this gate cut to be 336 days. In addition to the complications introduced by PennDOT, two other gate cut projects in Cumberland Mine involved impacting an existing wetland. The design for gate cuts 52 and 53 over Dutch Run called for the excavation of 0.88 acres of wetland DR-27. To mitigate this wetland loss, the gate cut designs had to incorporate a wetland mitigation site. The time required to design the wetland mitigation site and obtain approvals for impacting an existing wetland may have increased the time to mitigation for these two sites as well. Overall, it appears that working with additional agencies and general design challenges may have hampered the restoration efforts in Cumberland Mine.

Gate cuts are also proposed for a number of additional sites that experienced pooling impacts during the 4th assessment period (Table VII-12). While Blacksville 2 Mine did not have any gate cuts during the 4th assessment, several are planned and awaiting approval by the PADEP. These gate cuts were initially planned in the mine permit, but the original plans were not sufficient to mitigate the extensive pooling that resulted following subsidence. A permit revision was therefore required to amend the restoration plans. The Muddy Creek gate cut in Emerald Mine is also awaiting approval by PADEP. All other gate cuts listed in Table VII-12 have been approved and await action by the mine operator.

Table VII-12. List of all stream segments with proposed gate cuts during the 4th assessment. Gate cuts had not been initiated as of 20 August 2013.

Mine	PA WRDS Stream Code	Stream Name	Panel
Bailey	32551	Mudlick Fork	15I
Bailey	32551	Mudlick Fork	16I
Blacksville 2	41812	Blockhouse Run	13-14W
Blacksville 2	41812	Blockhouse Run	13-14W
Blacksville 2	41812	Blockhouse Run	14-15W
Blacksville 2	41812	Blockhouse Run	15-16W
Blacksville 2	41821	UNT to Blockhouse Run	17W
Blacksville 2	41821	UNT to Blockhouse Run	18W
Emerald	41268	Mount Phoebe Run	B6
Emerald	41014	Muddy Creek	C2
Emerald	41246	Dutch Run	B7
Enlow Fork	32777	Buffalo Creek	F22
Enlow Fork	40285	Ten Mile Creek	E23
Enlow Fork	40285	Ten Mile Creek	E24

VII.I.3 – Augmentation, grouting, and stream liner methods

When a flow loss impact occurs following mining, augmentation is used to restore flow to the stream within 24 hours (if flow loss was predicted) or within 15 days (if flow loss was unpredicted; PADEP 2005a). Augmentation restores flow by drawing on water from nearby wells, water tanks, or from other streams. The water is carried above and belowground via a system of pipelines from these sources to the augmentation discharge points (Figure VII-14). Depending on the severity of the impact, multiple augmentation points may be necessary to sustain stream flow across the impacted area. At the discharge point, the water is either released directly into the stream or released into a rock lined valley that was constructed along the stream bank. The rock valley aerates the water, which can remove certain pollutants, and prevents bank erosion. It has been suggested that the augmentation process may wash alluvial material into small surface cracks and allow the stream to "self-heal". However, the University could not identify any clear cases of "self-healing", suggesting that for many streams, additional mitigation work is required to repair the flow loss impacts.

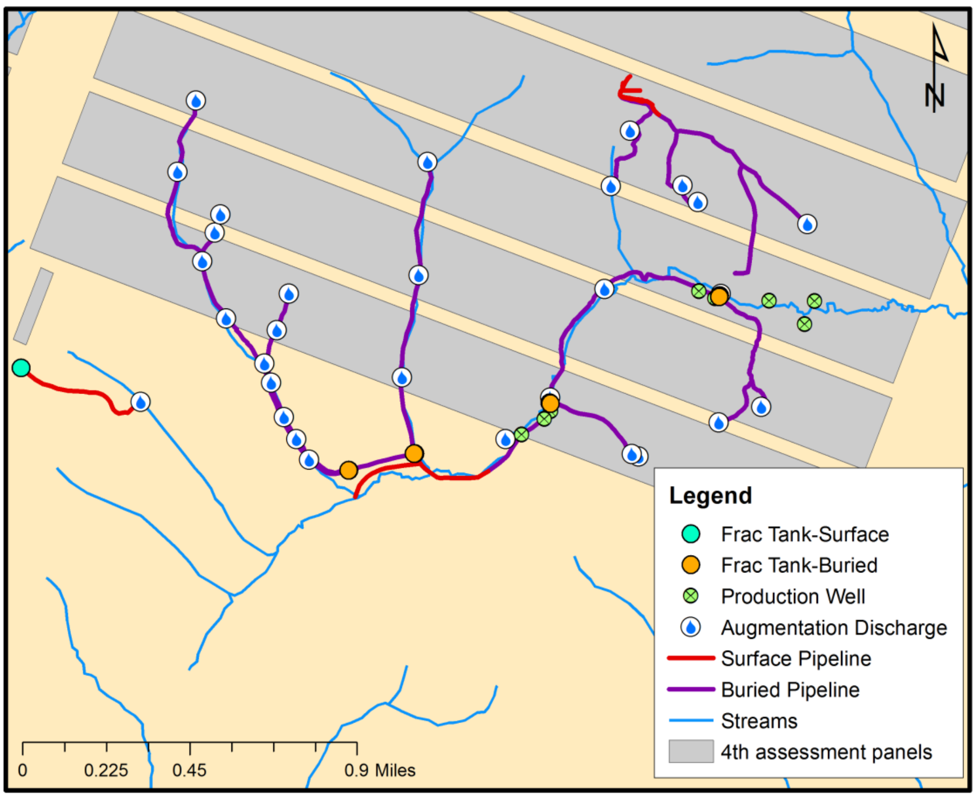

Figure VII-14. The augmentation system in the Crafts Creek watershed over Enlow Fork Mine. It is one of the larger augmentation systems developed by mine operators during the 4th assessment period. Map does not show zero-order tributaries, many of which also received augmentation (see right side of map).

To mitigate flow loss impacts, mine operators typically turn to a technique known as grouting. Depending on the severity of the impact, one of two grouting methods may be applied – surficial grouting or closure grouting (Haibach et al. 2012). For both methods, a pump-around system is set up to divert stream flow and dry the stream bed. Bedrock heaves and excess alluvial material are then removed. For impacts requiring surficial grouting, fractures in the bedrock are identified and sealed using a cement mixture containing roughly 3% bentonite clay. The clay provides flexibility to the cement mixture and prevents the cement from shrinking once it hardens in the cracks (B. Benson, Consol Energy, Inc., pers. comm.). Once the surface cracks are filled, the stream banks are stabilized and in-streams habitats are restored (Haibach et al. 2012). If surficial grouting is not successful in restoring flow, then closure grouting may be used. In closure grouting, a series of 2-in diameter, 6-ft deep boreholes are drilled at 10-ft intervals across the impacted area. The cement/bentonite clay mixture's viscosity is finely tuned to a thin watery paste, and pumped into the boreholes at a low steady velocity that is designed to fill in even very small cracks in the underlying bedrock. If this first "pass" is not successful in restoring stream flow, then a second pass will drill and fill boreholes at 5-ft intervals across the impacted area. Eventually, the rock fissures will not take any more grout, and grouting mitigation will cease.

While grouting is the preferred method for mitigating flow loss on streams with bedrock bottoms, it is ineffective on streams where the alluvial thickness is greater than 3-ft (Haibach et al. 2012). In these cases, the mine operator may opt to install a channel lining to seal the cracks. Channel lining is also used as a last resort on bedrock dominated streams when grouting has proven to be ineffective. Channel linings come in two forms – a synthetic liner and an alluvial amendment (Haibach et al. 2012). While channel linings have been in use for several years (e.g. the Laurel Run channel lining installed in 2007 above Emerald Mine), the technology for this mitigation method is continually evolving. In the past, channel linings consisted exclusively of synthetic liners. Here, the most recent innovations in channel linings are described.

To install a channel lining, the vegetation surrounding the construction site is first cleared and the necessary erosion and sedimentation controls are set up. The alluvium in the stream channel is then excavated and stockpiled nearby. For synthetic liners, a geosynthetic clay fabric is laid across the stream channel and the fabric is topped with a cellular confinement system (Figure VII-15a). This honeycomb-shaped system of cells is anchored into the ground and filled with gravel (Figure VII-15b). Once the stream enhancement structures are in place, the cells are topped with a thick layer (i.e. minimum of 6-in) of the stockpiled alluvium.

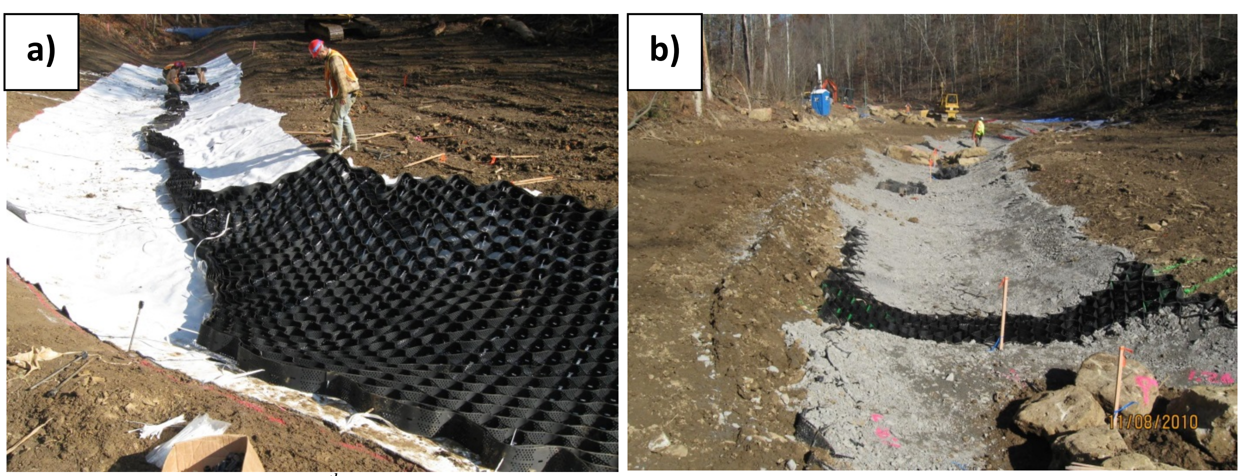

Figure VII-15. During the 4th assessment the installation of a synthetic liner consisted of a) a geosynthetic clay liner and a cellular confinement system and b) gravel fill (Photo from PADEP files).

In contrast, for an alluvial amendment, the stockpiled alluvium is mixed with bentonite clay. Typically, 100-ft^3 of alluvium and soil material are mixed with 200-lbs of bentonite to form a slurry (B. Benson, Consol Energy, Inc., pers. comm.). The slurry is laid down in the excavated stream channel and compacted to create a channel lining (Figure VII-16). Following installation of either the synthetic liner or alluvial amendment, the stream banks are re-graded, stabilized, and planted in a similar fashion to a gate cut mitigation project.

Figure VII-16. Placement of alluvial amendment liner into stream channel in E18 panel of Crafts Creek (Photo from PADEP files).

VII.I.4 – Augmentation, grouting, and stream liners during the 4th assessment

To determine the number of streams receiving augmentation during the 4th assessment period, the University collected data from the PADEP monthly flow map database. For mines operated by Consol Energy, Inc., Microsoft Excel files describe both the number of augmentation discharge points that are installed on a stream (i.e. available for use) and the number of augmentation points that are active on a stream in a particular month. The University compiled data for all months and used SAS (SAS Institute Inc. 2013) to identify the maximum number of discharges installed on each stream and the maximum number that were active at one time. Unfortunately, for Enlow Fork and Blacksville 2 Mines, data on augmentation was not submitted to the PADEP monthly flow map database prior to June 2011. Thus, the analysis of total augmentation in these mines is conservative and only represents augmentation that occurred from June 2011 until the end of the reporting period. For mines operated by Alpha Natural Resources, the University used the "straight-line" maps to identify streams receiving augmentation. Unfortunately, the "straight-line" maps do not provide information on the number of augmentation discharges that are installed or active on a stream and the University could locate this information in any of the files at CDMO.

Augmentation discharge points were installed on 95 streams during the 4th assessment period (Table VII-13). Augmentation discharges were active at 74 of these streams (Table VII-13).

Table VII-13. Streams receiving augmentation during the 4th assessment period.

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Max # of Augmentation Discharges Installed	Max # of Augmentation Discharges Active At One Time
Bailey	32540	Barneys Run	BarR	6	5
Bailey	NA	UNT to Barneys Run	BarR-2R	3	1
Bailey	NA	UNT to UNT of Barneys Run	BarR-2R-1L	1	1
Bailey	32541	UNT to Barneys Run	BarR-3R	2	2
Bailey	32542	UNT to Barneys Run	BarR-5R	4	3
Bailey	NA	UNT to UNT of Barneys Run	BarR-5R-4R	1	1
Bailey	32544	UNT to Barneys Run	BarR-8R	3	4
Bailey	NA	UNT to UNT of Barneys Run	BarR-8R-1R	3	2
Bailey	32543	UNT to Barneys Run	BarR-8R_BarR-8R-2R	3	3
Bailey	32532	UNT to Dunkard Fork	DF-19R	10	4
Bailey	32533	UNT to UNT of Dunkard Fork	DF-19R-1R	3	2
Bailey	32534	UNT to UNT of Dunkard Fork	DF-19R-2R	3	3
Bailey	NA	UNT to UNT of Dunkard Fork	DF-19R-2R-1R	3	3
Bailey	32535	UNT to UNT of Dunkard Fork	DF-19R-5R	1	0
Bailey	NA	UNT to UNT of Dunkard Fork	DF-19R-7R	2	2
Bailey	32511	UNT to Dunkard Fork	DF-9L	3	3
Bailey	32553	UNT to Hewitt Run	HewR-2R	3	3
Bailey	32551	Mudlick Fork	MdlkF	2	2
Bailey	NA	Crow's Nest	NoF-1L	3	2
Bailey	32595	UNT to North Fork of Dunkard Fork	NoF-3L	5	4
Bailey	32597	UNT to North Fork of Dunkard Fork	NoF-3R	2	1
Bailey	32596	UNT to North Fork of Dunkard Fork	NoF-5L	10	7
Bailey	32598	Polly Hollow	PlyH	1	1
Bailey	32536	South Fork of Dunkard Fork	SoF	22	10
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-11L	4	3

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Max # of Augmentation Discharges Installed	Max # of Augmentation Discharges Active At One Time
Bailey	32566	UNT to South Fork of Dunkard Fork	SoF-12L	3	3
Bailey	32567	UNT to South Fork of Dunkard Fork	SoF-16R	2	0
Bailey	32537	UNT to South Fork of Dunkard Fork	SoF-1R	1	1
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-2R	2	1
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-3R	1	0
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-4R	1	1
Bailey	32539	UNT to South Fork of Dunkard Fork	SoF-5L	5	4
Bailey	32546	UNT to South Fork of Dunkard Fork	SoF-6L	5	3
Bailey	32549	UNT to South Fork of Dunkard Fork	SoF-8L	4	3
Bailey	32550	UNT to UNT of South Fork of Dunkard Fork	SoF-8L-2L	2	2
Bailey	32565	UNT to South Fork of Dunkard Fork	SoF-9L	7	3
Bailey	32547	Strawn Hollow	StrnH	4	3
Bailey	NA	UNT to Strawn Hollow	StrnH-1R	1	0
Bailey	32548	UNT to Strawn Hollow	StrnH-2R	3	2
Bailey	32504	Wharton Run	WhrtnR	3	2
Bailey	NA	UNT to Wharton Run	WhrtnR-7L	2	1
Bailey	32508	UNT to Wharton Run	WhrtnR-8R	1	1
Blacksville 2	41812	Blockhouse Run	BlkhR	8	6
Blacksville 2	41826	UNT to Blockhouse Run	BlkhR-15R	4	3
Blacksville 2	41820	UNT to Blockhouse Run	BlkhR-1L	3	3
Blacksville 2	41824	UNT to Blockhouse Run	BlkhR-2L	2	2
Blacksville 2	41818	UNT to Blockhouse Run	BlkhR-2R	4	4
Blacksville 2	41819	UNT to Blockhouse Run	BlkhR-3R	3	3
Blacksville 2	41821	UNT to Blockhouse Run	BlkhR-9R	1	0
Blacksville 2	41813	Roberts Run	RbtsR	1	1

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Max # of Augmentation Discharges Installed	Max # of Augmentation Discharges Active At One Time
Blacksville 2	41806	Toms Run	TmsR	1	0
Blacksville 2	41809	UNT to Toms Run	TmsR-4R	1	0
Blacksville 2	41833	UNT to Toms Run	TmsR-8R	1	1
Cumberland	41282	UNT to Whiteley Creek	WC_41282	No data	No data
Cumberland	40614	UNT to Pursley Creek	PC_40614	No data	No data
Cumberland	NA	UNT to Pursley Creek	PC_40592-L7	No data	No data
Cumberland	41264	UNT to Dyers Fork	DF_41264	No data	No data
Cumberland	41267	UNT to Dyers Fork	DF_41267	No data	No data
Emerald	41014	Muddy Creek	MC_41014	No data	No data
Emerald	41252	UNT to Dutch Run	DR_41252	No data	No data
Enlow Fork	32777	Buffalo Creek	BufC	5	0
Enlow Fork	32998	UNT to Buffalo Creek	BufC-11R	2	0
Enlow Fork	32999	UNT to Buffalo Creek	BufC-12R	3	2
Enlow Fork	33000	UNT to Buffalo Creek	BufC-13R	1	1
Enlow Fork	32996	UNT to Buffalo Creek	BufC-9L	2	2
Enlow Fork	40938	Crafts Creek	CrC	10	5
Enlow Fork	NA	UNT to Crafts Creek	CrC-1.5R	1	0
Enlow Fork	NA	UNT to Crafts Creek	CrC-1.7R	2	2
Enlow Fork	40939	UNT to Crafts Creek	CrC-1R	2	2
Enlow Fork	40940	UNT to UNT of Crafts Creek	CrC-1R,2R	3	2
Enlow Fork	40941	UNT to Crafts Creek	CrC-2R	2	2
Enlow Fork	40942	UNT to Crafts Creek	CrC-3R	5	4
Enlow Fork	40943	UNT to UNT of Crafts Creek	CrC-3R,1R	2	1
Enlow Fork	40944	UNT to Crafts Creek	CrC-4R	10	5
Enlow Fork	NA	UNT to UNT of Crafts Creek	CrC-4R,2R	2	2

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Max # of Augmentation Discharges Installed	Max # of Augmentation Discharges Active At One Time
Enlow Fork	NA	UNT to UNT of Crafts Creek	CrC-4R,3R	2	0
Enlow Fork	40945	UNT to Crafts Creek	CrC-5R	1	0
Enlow Fork	NA	UNT to Crafts Creek	CrC-6L	2	0
Enlow Fork	NA	UNT to UNT of Crafts Creek	CrC-6L,1L	1	0
Enlow Fork	NA	UNT to Crafts Creek	CrC-9L	2	0
Enlow Fork	32719	UNT to Rocky Run	RkyR-9L	5	0
Enlow Fork	32708	Templeton Fork	TemF	6	3
Enlow Fork	32738	UNT to Templeton Fork	TemF-21L	1	0
Enlow Fork	NA	UNT to UNT of Templeton Fork	TemF-21L,0.9L	2	0
Enlow Fork	32739	UNT to UNT of Templeton Fork	TemF-21L,1L	1	0
Enlow Fork	32740	UNT to Templeton Fork	TemF-23L	6	0
Enlow Fork	32742	UNT to Templeton Fork	TemF-25L	3	1
Enlow Fork	NA	UNT to UNT of Templeton Fork	TemF-25L,1L	3	0
Enlow Fork	32743	UNT to Templeton Fork	TemF-26L	2	1
Enlow Fork	32744	UNT to Templeton Fork	TemF-27L	2	2
Enlow Fork	32745	UNT to Templeton Fork	TemF-28L	2	1
Enlow Fork	40285	Ten Mile Creek	TenC	2	1
Enlow Fork	40949	UNT to Ten Mile Creek	TenC-8L	3	2
Enlow Fork	40951	UNT to UNT of Ten Mile Creek	TenC-8L,1L	3	3
Enlow Fork	40950	UNT to UNT of Ten Mile Creek	TenC-8L,2R	2	2

[1]NA = Zero order tributary

Bailey Mine had the greatest number of streams with installed and active augmentation discharge points (Figure VII-17). While Enlow Fork Mine undermined more miles of stream than Bailey Mine (Table VII-5), this mine installed fewer augmentation discharges and activated only half as many discharges (Figure VII-17). The analysis accounts for augmentation on streams that currently have an augmentation reprieve from PADEP so reprieves do not explain the differences between the two mines. The University expects that the differences are the result of either fewer flow loss impacts in Enlow Fork Mine or an artifact of the incomplete dataset for Enlow Fork. What is clear from Figure VII-17 is that the number of streams receiving active augmentation in Bailey Mine was nearly 5-times that of Blacksville 2 Mine, 8-times that of Cumberland Mine, and nearly 20-times that of Emerald Mine. These differences are due in part to the fact that these mines undermined fewer miles of stream than Bailey Mine (Table VII-5). The differences may also reflect variation in the mine operators' approaches to stream mitigation and/or dissimilarities in the geologic and hydrologic conditions between the mines.

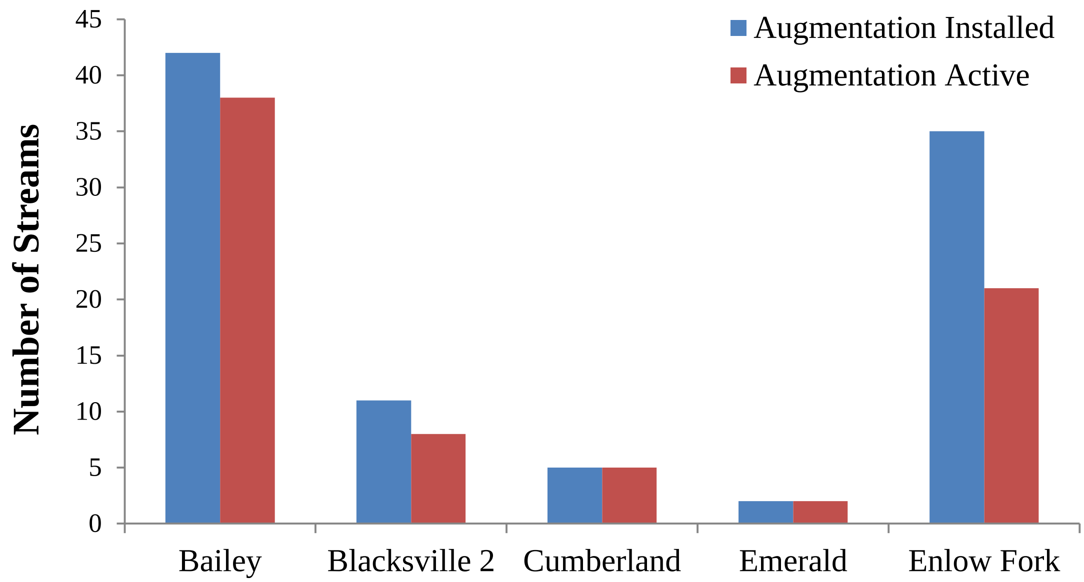

Figure VII-17. Number of streams with augmentation installed and active during the 4th assessment period by mine.

On average, a stream receiving augmentation had 3.20 +/- 0.31 augmentation discharges installed along its length, but only a maximum of 1.94 +/- 0.19 discharges were active at any one time (mean +/- 1 standard error). South Fork of Dunkard Fork in Bailey Mine had the greatest number of augmentation points installed with 22 discharges along its length (Table VII-13). During the drought period of August 2010, up to 10 augmentation points were actively discharging over 600-gpm into South Fork of Dunkard Fork. Other streams with significant numbers of augmentation points installed include: an unnamed tributary to Dunkard Fork (Stream 32532), an unnamed tributary to the North Fork of Dunkard Fork (Stream 32596), Crafts Creek, and an unnamed tributary to Crafts Creek (Stream 40944) (Table VII-13).

To determine the number of streams receiving grouting during the 4th assessment period, the University compiled data from two major sources: the BUMIS agent observation files and the

SSA stream data logs (see Section VII.F for description). The extent of grouting on each stream was approximated by recording the panels in which grouting occurred.

The University found that 57 streams received grouting during the 4th assessment period (Table VII-14). Of these, 40% received grouting in multiple panels. PADEP does not currently require mine operators to report the length of stream grouted, but the University suggests that these data would be useful in assessing the actual extent of stream mitigation following mining. The University was able to locate one report describing stream grouting in Bailey Mine for the 3rd and 4th quarters of 2008 (Consol Energy Inc. 2009). The report was in a folder labelled "Bailey Mine Special Conditions" in the CDMO paper files. According to the report, ~5,941-ft and ~2,758-ft of streams were grouted in the 3rd and 4th quarters of 2008, respectively. It is unclear from the report if the amount of grouting in these two quarters is representative of the grouting extents in a typical year. However, if these lengths are extrapolated across the five-year reporting period, it would be predicted that over 8 miles of stream received grouting during the summers and falls of 2008-2013 in Bailey Mine. Considering that 16.75 miles of stream were undermined by Bailey Mine during this assessment period (Table VII-1), if this estimate of the grouting extent is even reasonably close, then ~50% of the stream length undermined in Bailey Mine was likely grouted. The University suspects that this estimate of grouting in Bailey is highly conservative. First, the University does not have an estimate of grouted stream lengths for the 1st and 2nd quarters of 2008, so the amount of stream that may have been grouted during the winter and spring months of the reporting period is unknown. Second, the report indicates that between December 2006 and September 2008, ~35,935-ft of stream were grouted in Bailey Mine (Consol Energy Inc., 2009). This indicates that in less than two years, nearly 7 miles of stream received grouting, and suggests that the estimate of 8 miles of grouting over a 5 year period is likely too low. Unfortunately, the University could not locate similar data from other mines for comparison with this analysis on Bailey Mine.

Overall, these data suggest that bedrock fracturing is a widespread accompaniment to longwall mining, at least in Bailey Mine. Bedrock fracturing is likely a common feature of undermined landscapes in areas with geological profiles that are similar to those in Bailey Mine. The extent of bedrock fracturing in such mines, and its influence on shallow groundwater flow, necessitates an extensive grouting mitigation program, perhaps to a much greater degree than has previously been recognized.

Table VII-14. Streams receiving grouting in the 4th assessment period.

Mine	**PA WRDS Stream Code[1]**	**Stream Name**	**Company Code**	**Panels with Grouting**
Bailey	32540	Barneys Run	BarR	11I, 12I, 16H, 17H
Bailey	NA	UNT to Barneys Run	BarR-2R	11I
Bailey	32542	UNT to Barneys Run	BarR-5R	14H
Bailey	32544	UNT to Barneys Run	BarR-8R	16H
Bailey	32543	UNT to Barneys Run	BarR-8R and BarR-8R-2R	16H

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Panels with Grouting
Bailey	NA	UNT to Barneys Run	BarR-8R-1R	15H
Bailey	32532	UNT to Dunkard Fork	DF-19R	10H, 11H, 12H, 13H
Bailey	NA	UNT to Dunkard Fork	DF-19R-7R	13H
Bailey	32511	UNT to Dunkard Fork	DF-9L	16C
Bailey	32553	UNT to Hewitt Run	HewR-2R	15I, 16I
Bailey	NA	UNT to Mudlick Fork	MdlkF-1L	16I
Bailey	NA	Crow's Nest	NoF-1L	5I
Bailey	32595	UNT to North Fork of Dunkard Fork	NoF-3L	2I, 3I, 4I
Bailey	32596	UNT to North Fork of Dunkard Fork	NoF-5L	2I, 4I
Bailey	32598	Polly Hollow	PlyH	4I
Bailey	32536	South Fork of Dunkard Fork	SoF	8I, 12I
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-11L	14I
Bailey	32566	UNT to South Fork of Dunkard Fork	SoF-12L	14I, 15I
Bailey	32567	UNT to South Fork of Dunkard Fork	SoF-16R	15I
Bailey	32539	UNT to South Fork of Dunkard Fork	SoF-5L	10I, 11I
Bailey	32546	UNT to South Fork of Dunkard Fork	SoF-6L	11I
Bailey	32549	UNT to South Fork of Dunkard Fork	SoF-8L	10I, 11I, 12I
Bailey	32550	UNT to South Fork of Dunkard Fork	SoF-8L-2L	10I, 11I
Bailey	32565	UNT to South Fork of Dunkard Fork	SoF-9L	12I, 13I
Bailey	32547	Strawn Hollow	StrnH	14I
Bailey	32548	UNT to Strawn Hollow	StrnH-2R	13I
Blacksville 2	41812	Blockhouse Run	BlkhR	15W, 16W
Blacksville 2	41826	UNT to Blockhouse Run	BlkhR-15R	18W
Blacksville 2	41820	UNT to Blockhouse Run	BlkhR-1L	15W
Blacksville 2	41818	UNT to Blockhouse Run	BlkhR-2R	14W, 15W
Blacksville 2	41819	UNT to Blockhouse Run	BlkhR-3R	15W, 16W, 17W
Blacksville 2	41813	Roberts Run	RbtsR	14W
Blacksville 2	41833	UNT to Tom's Run	TmsR-8R	21M
Cumberland	41261	Dyers Fork	DF_41261	52, 53, 54
Cumberland	41264	UNT to Dyers Fork	DF_41264	50, 51, 52, 53
Cumberland	41267	UNT to Dyers Fork	DF_41267	51
Cumberland	41246	Dutch Run	DR_41246	51-52 gate, 53
Cumberland	NA	UNT to Pursley Creek	PC_40592-L7	60
Cumberland	40614	UNT to Pursley Creek	PC_40614	60
Cumberland	NA	UNT to Turkey Hollow	TH_40611-L2	60

Mine	PA WRDS Stream Code[1]	Stream Name	Company Code	Panels with Grouting
Cumberland	41282	UNT to Whiteley Creek	WC_41282	55
Emerald	41252	UNT to Dutch Run	DR_41252	B6
Emerald	41014	Muddy Creek	MC_41014	C1
Emerald	40465	UNT to Smith Creek	SC_40465	E2
Enlow Fork	40938	Crafts Creek	CrC	E18, E19, E20
Enlow Fork	NA	UNT to Crafts Creek	CrC-1.5R	E20
Enlow Fork	NA	UNT to Crafts Creek	CrC-1.7R	E20
Enlow Fork	40941	UNT to Crafts Creek	CrC-2R	E20
Enlow Fork	NA	UNT to Crafts Creek	CrC-3L	E20
Enlow Fork	40942	UNT to Crafts Creek	CrC-3R	E20
Enlow Fork	40943	UNT to Crafts Creek	CrC-3R,1R	E20, E21
Enlow Fork	40944	UNT to Crafts Creek	CrC-4R	E17
Enlow Fork	32742	UNT to Templeton Fork	TemF-25L	F17, F18
Enlow Fork	32744	UNT to Templeton Fork	TemF-27L	F18, F19
Enlow Fork	40949	UNT to Ten Mile Creek	TenC-8L	E22, E23
Enlow Fork	40951	UNT to Ten Mile Creek	TenC-8L,1L	E22, E23
Enlow Fork	NA	UNT to Templeton Fork	TF21L-0.5L	F16

[1]NA = Zero order tributary

Lastly, the University investigated the number of stream impacts requiring liners and the time to restoration. Based on data from the permit revisions and conversations with the SSAs and mine operators, the University found that three streams had liners installed during the 4th assessment period (Table VII-15). The time to restoration for each liner project was calculated as the date the liner project began minus the date of undermining. Dates were determined from SSA observation records in BUMIS. Details regarding the liner installations are provided below.

Table VII-15. Streams with liners installed during the 4th assessment period.

Mine	PA WRDS Stream Code	Stream Name	Panel	Time to Restoration (days)	Liner Type: Length (ft)
Bailey	32596	UNT to North Fork of Dunkard Fork	3I	2074	synthetic: 1,150
Enlow Fork	40938	Crafts Creek	E18	674	synthetic: 607 alluvial: 450
Mine 84	40824	Brush Run	6B	2673	alluvial: 750

In Bailey Mine, Stream 32596 (an unnamed tributary to North Fork of Dunkard Fork) exhibited extensive flow loss following subsidence of the 1-4I panels. The flow loss in the 3I panel was tracked by the PADEP in stream investigation ST0502 and ST1203 (see Section VIII.B.4). A total of 10 augmentation points were installed along this stream to maintain flow (Table VII-13) and by the end of December 2008, nearly 75% of the stream length had been grouted (Consol Energy Inc. 2009). Despite these mitigation efforts, stream flow did not recover in the 3I panel and the mine operator began working with property owners as early as July 2009 to obtain access for additional restoration work, such as liner installation or additional grouting (Consol Pennsylvania Coal Company, LLC 2009). Installation of an 1,150-ft strip of synthetic liner occurred during the fall of 2010 over the 3I panel. The following spring the liner experienced damage during high flow events. The SSA noted that water had seeped in underneath the synthetic liner, the cellular confinement system had become exposed, and the banks were eroding in some places. BUMIS records indicate that liner repair did not begin until 20 August 2012, over a year after the damages occurred. Observations from the fall of 2013 noted that the cellular confinement system was still visible in places but that no new bank erosion had occurred. Following a period of monitoring, PADEP ultimately ruled that this stream had not been restored to its pre-mining condition in the 3I panel or any other panel (ST1203).

Crafts Creek was impacted by flow loss in the E18 panel almost immediately after longwall mining passed under the stream. BUMIS records indicate that on 12 November 2008 a “during mining” survey of the E18 panel revealed a 1,400-ft section of flow loss and ~200 dead fish. PADEP ordered immediate augmentation and issued a compliance order as a result of the infraction. The augmentation system in the Crafts Creek watershed is extensive (Figure VII-14) and was used to maintain flow until restoration work could begin. Grouting approaches were not effective in sealing the fractures beneath the stream. PADEP approved a permit revision for the installation of a 1,050-ft liner on 3 August 2010. Rather than line the entire restoration area with a synthetic liner, the operator split the restoration area in half to compare the effectiveness of a synthetic liner against the new alluvial amendment approach. Restoration work was completed in the fall of 2010. However, as with the liner for stream 32596, the SSA noted damage to the synthetic liner the following spring. The cellular confinement system was exposed and groundwater was pushing up from beneath the stream channel against the liner, causing the liner to balloon up in the stream. No significant problems were noted in the area of the alluvial amendment. During the fall of 2011, French drains were installed to relieve the groundwater pressure around the synthetic liner. The drains discharge directly into Crafts Creek. When the University observed the restoration area in July 2013, the synthetic liner and cellular confinement systems were not exposed, suggesting that the French drains have been effective in allowing the liner to settle. Recovery of the biological community over the E18 liner has not yet been assessed. However, biological data collected following the E18 gate cut indicates that the Total Biological Score at the bio-monitoring station in the E18 panel (BSW16) has returned to pre-mining levels (pre-mining average TBS: 49.4 vs. a single post-gate cut TBS: 45.8; CEC 2010). It should be noted that the pre-mining scores for this site did not meet the requirements of TGD 563-2000-655 – the relative percent difference among the pre-mining scores was greater than 16%.

The last liner installed during the 4th assessment was on Brush Run in Mine 84. This stream was undermined by the 6B panel between 20 March and 11 April 2006. BUMIS records indicate that on 26 April 2006, the stream was pooling near the 6B-7B gate but was dry in the center of the 6B panel. The 6B-7B gate was cut in March 2007 to alleviate the pooling, however, the flow loss problems remained. The shallow overburden at this site (380-ft) coupled with the unique location of the stream on the edge of the panel may have contributed to the flow loss. At least three augmentation wells were drilled in panel 6B to sustain flow over the impacted area. The mine operator began negotiating with surrounding landowners in June 2009 to gain access to the stream for restoration. An agreement between the operator and landowner was reached in May 2011. It was decided that grout mitigation would be ineffective in Brush Run because the bedload is greater than 6-ft deep in some places. The mine operator proposed to utilize either a synthetic liner or alluvial amendment to mitigate the flow loss. Once the access agreement was in place, the operator requested an extension from PADEP to wait to begin restoration work until spring 2012. During the summer of 2012, the operator applied for and received an Army Corps of Engineers permit for the stream work. The operator opted to use an alluvial amendment on Brush Run, likely due in part to the reduced number of problems associated with this type of liner installation at Crafts Creek. Restoration work in the Brush Run stream channel finally began on 5 August 2013. Overall, the time to restoration for this stream segment was >7 years. While obtaining landowner access clearly played a part in delaying the mitigation process, it is unclear why the operator did not immediately apply for the required permits after gaining access. It is also interesting to note that this flow loss did not trigger a stream investigation during the 3rd Act 54 assessment period at the PADEP, and as result, no information was reported on this impact in the last Act 54 report (Iannacchione et al. 2011). Unfortunately, the effectiveness of this liner installation could not be evaluated by the University because the mitigation work occurred so close to the end of the current assessment period. The University suggests that future studies follow up on this stream restoration project.

VII.I.5 – Construction of Access Roads to Support Mitigation Activities

Many undermined streams are surrounded by forest or other habitats that are difficult to navigate with the heavy construction equipment that is required for mitigation. As a result, mine operators build roads along impacted streams to facilitate the movement of equipment between existing roads and the mitigation site. Road construction is an ecological disturbance that is generally associated with declines in biodiversity in both terrestrial and aquatic communities (Trombulak and Frissell 2000). Roads affect communities through multiple mechanisms, including vegetation removal during construction, modification of animal behavior, alteration of both the physical and chemical environment, spread of invasive species, and increasing the use of the area by humans (Trombulak and Frissell 2000). While road construction is not a direct result of subsidence, it is an indirect effect of mitigating subsidence-related stream impacts. To fully understand the impacts of subsidence and subsequent restoration on stream ecosystems, it is important to consider the effect of road construction.

VII.I.6 – Access Road Construction during the 4th Assessment

While access road construction can be quantified through careful, time-consuming measurements of the erosion and sedimentation control plans submitted to PADEP, mine operators are not required to formally report this information in the mitigation plans. However, the University was able to locate one report for Bailey Mine that detailed access road construction during the 3rd and 4th quarters of 2008 (Consol Energy Inc. 2009). No access roads were built during the 3rd quarter of 2008. However, ~7,913-ft of access roads were built in the 4th quarter (Consol Energy Inc.

2009). Overall, the report states that between December 2006 and December 2008, access road construction in Bailey Mine totaled 79,426-ft, or 15 miles (Figure VII-18; Consol Energy Inc. 2009). Because data from other time periods and other mines was not available, it is unknown if this amount of road construction is representative of conditions at all longwall mines. The University suggests that PADEP request that mine operators specifically quantify and report the length of access road construction as this would provide valuable information regarding the degree of disturbance to terrestrial and aquatic ecosystems during mitigation.

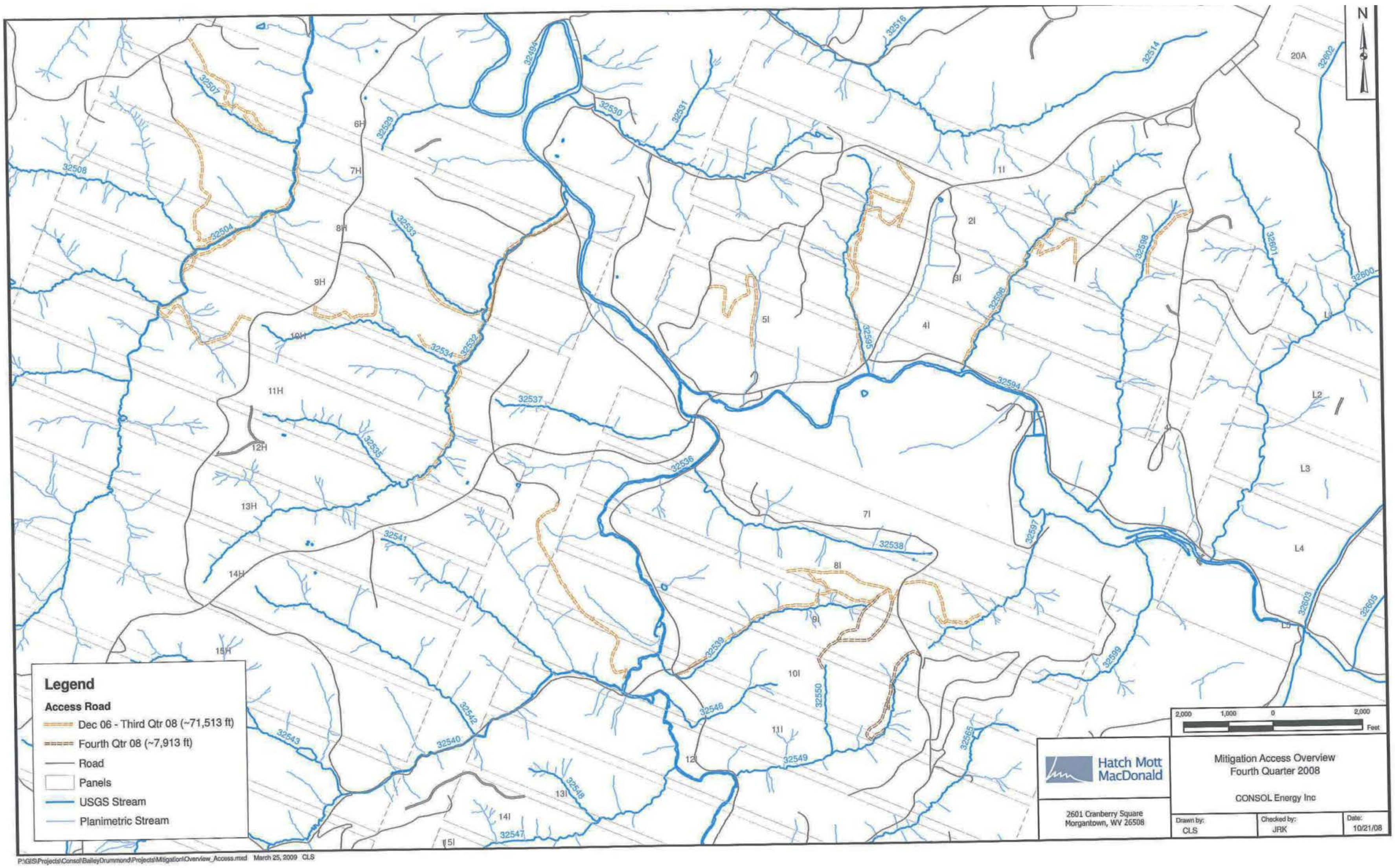

Figure VII-18. Map from mine operator showing access road construction (orange lines) in Bailey Mine between December 2006 and December 2008 (Consol Energy Inc. 2009).

VII.J – Biological Assessment of Streams Following Mitigation

While stream macroinvertebrates communities are affected by mining-induced flow loss and pooling, it is unknown if the mitigation measures (i.e. augmentation, grouting, liners, gate cuts) utilized by mining companies are effective in restoring the communities. PADEP tasked the University with evaluating at least five stream segments that had gate cut mitigation work completed during the 4th assessment period. While the University was not specifically tasked with evaluating stream segments that had grout mitigation, it is clear that far more stream segments receive grouting than gate cuts (Table VII-14 vs. Table VII-13). Thus, the University was also interested in determining the biological recovery of streams that receive grouting.

VII.J.1 – Stream Biology Data Collection and Analysis

The University could not identify any TBS that were specifically identified as being collected "post-grouting". The TBS collected after mining at sites that are known to have received grouting are identified as simply "post-mining". Because the date of grouting is unknown, it is uncertain if these "post-mining" TBS were collected before or after grout mitigation. It is possible that some of the post-mining TBS data in the flow loss analysis (Figure VII-7) were collected after grouting took place. The University suggests that PADEP require mine operators to label samples collected after grout mitigation as "post-grouting" as this would allow for PADEP to assess the effectiveness of this mitigation technique.

While the University could not look at the effect of grouting per se, it was possible to investigate changes in TBS and stream chemistry over time at sites experiencing flow loss. The University predicted that if grouting is effective in restoring stream biology and chemistry to pre-mining levels, then TBS would increase and pH and conductivity would decrease with time since mining. To test this prediction, the University used the flow loss dataset described above (see Section VII.H.1). To determine the time since mining, the University first geo-referenced the monthly longwall face positions for Bailey Mine to estimate the date when each bio-monitoring station was undermined. The date of undermining was considered to be the date at which the face had passed the station. For all post-mining biological and chemical samples, the time since mining was then calculated by subtracting the date of undermining from the date of sampling. Regression analyses were used to test the relationship between time since mining and TBS (raw and adjusted), conductivity, and pH. Analyses controlled for the effects of station on biology and chemistry.

For streams with gate cut mitigation, pre-mining and post-restoration TBS are located in the annual stream restoration reports that are submitted to PADEP. The University identified a total of 18 bio-monitoring stations with post-restoration biology data. The stations are located near gate cuts in Bailey Mine, Enlow Fork Mine, and Cumberland Mine. The three stations in Cumberland Mine however, are located ~1200-ft upstream and/or downstream from the actual restoration areas. Samples from these stations may not reflect the conditions of the biological community with the actual restoration area. It is unclear why bio-monitoring stations were not established inside the gate cuts at Cumberland Mine. Therefore, data from Cumberland Mine are presented separately. For the data from Bailey and Enlow Fork Mine, bio-monitoring stations were located directly within the restoration area. The data were corrected for spatial autocorrelation by eliminating stations that were within 1,673-ft of another station (see Section VII.C.2 for methodology). Correction for temporal correlation was not possible due to the timing of the sampling events. The corrected dataset contained pre-mining and post-restoration TBS data from 10 bio-monitoring stations (N = 67 samples). The University tested for the difference between pre-mining and post-restoration raw and adjusted TBS using an ANOVA (model: raw or adjusted TBS = mining (pre-mining vs. post-restoration) + station). Adjusted TBS were corrected for the effects of surrounding land use and month of sampling (as described in Sections VII.C.2 and VII.C.3).

VII.J.2 – Relationship between Time since Mining and Total Biological Score, Conductivity, and pH for Streams Impacted by Mining-Induced Flow Loss

On average, TBS collected at bio-monitoring stations with mining-induced flow loss increase over time (effect of time since mining on raw TBS: $F_{1,51}$ = 10.36, P = 0.0022; effect of time since mining on adjusted TBS $F_{1,51}$ = 11.23, P = 0.0015). However, the rate of increase in TBS is slow, with TBS increasing ~0.01 points/day on average following mining (slope from raw TBS model: 0.012; slope from adjusted TBS model: 0.0135). Recall that post-mining TBS at these sites are, on average, nine points lower than the pre-mining TBS (Figure VII-7). The regression equations from the current analysis indicate that it would take nearly three and half years for a station's TBS to increase by nine points and recover to roughly pre-mining levels (raw TBS model: 1291 days or 3.5 years; adjusted TBS model: 1209 days or 3.3 years). This time to recovery is slightly longer than the three years that the PADEP currently allows for stream mitigation and recovery (Figure VII-6b; PADEP 2005a). For streams experiencing larger reductions in TBS following mining (> 9 points), recovery may take even longer.

Interestingly, the biological recovery does not appear to be a function of recovery in stream chemistry. There was no significant relationship between time since mining and conductivity ($F_{1,35}$ = 0.04, P =0.8401) or pH ($F_{1,36}$ = 1.68, P = 0.20), indicating that water quality does not return to pre-mining levels following mining.

VII.J.3 – Pre- and Post-Restoration Total Biological Scores for Streams with Gate Cut Mitigation

For streams with gate cuts in Bailey and Enlow Fork Mine, the average post-restoration TBS is identical to the average pre-mining score (Figure VII-19). Statistically, there is no significant difference in pre- and post-restoration scores (effect of restoration on raw TBS, $F_{1,58}$ = 0.01, P = 0.94; effect of restoration on adjusted TBS, $F_{1,58}$ = 0.32, P = 0.57). These results confirm those of a recent analysis by the mine operator and their consultants, which also found that post-restoration TBS did not differ from pre-mining TBS (Nuttle et al. 2014). Gate cut mitigation appears to be effective in restoring the macroinvertebrate community following mining-induced pooling.

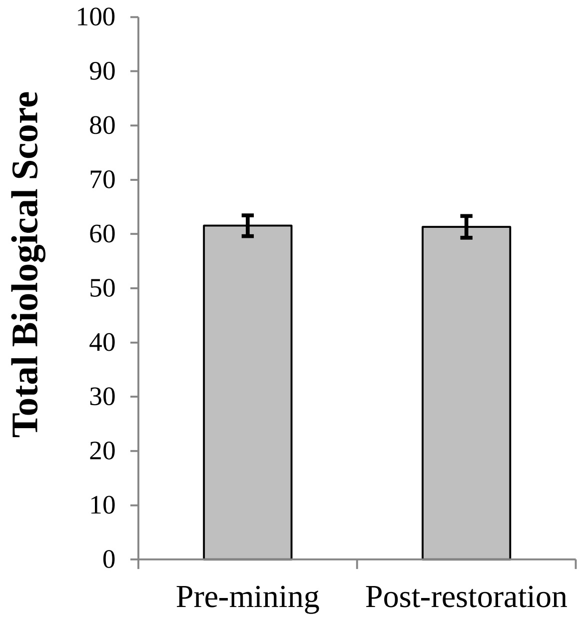

Figure VII-19. Comparison of pre-mining and post-restoration Total Biological Scores for streams with gate cut mitigation in Bailey and Enlow Fork Mines. Data are least squares means +/- 1 standard error.

Similar trends were observed for Cumberland Mine. On average, the raw post-restoration TBS are equal to or greater than the mean control stream score (Figure VII-20). However, it is unclear how indicative these scores are of conditions inside the restoration site due to the distance between the restoration sites and the bio-monitoring stations. It should also be noted that stations DF STA 2 and DF STA 21 have not yet been released from monitoring by PADEP because the post-restoration scores are not within 16% of each other. Post-restoration scores from Bailey and Enlow Fork Mines indicate that two years' worth of monitoring (i.e. roughly four samples) are often required to obtain two samples that score within 16% of each other.

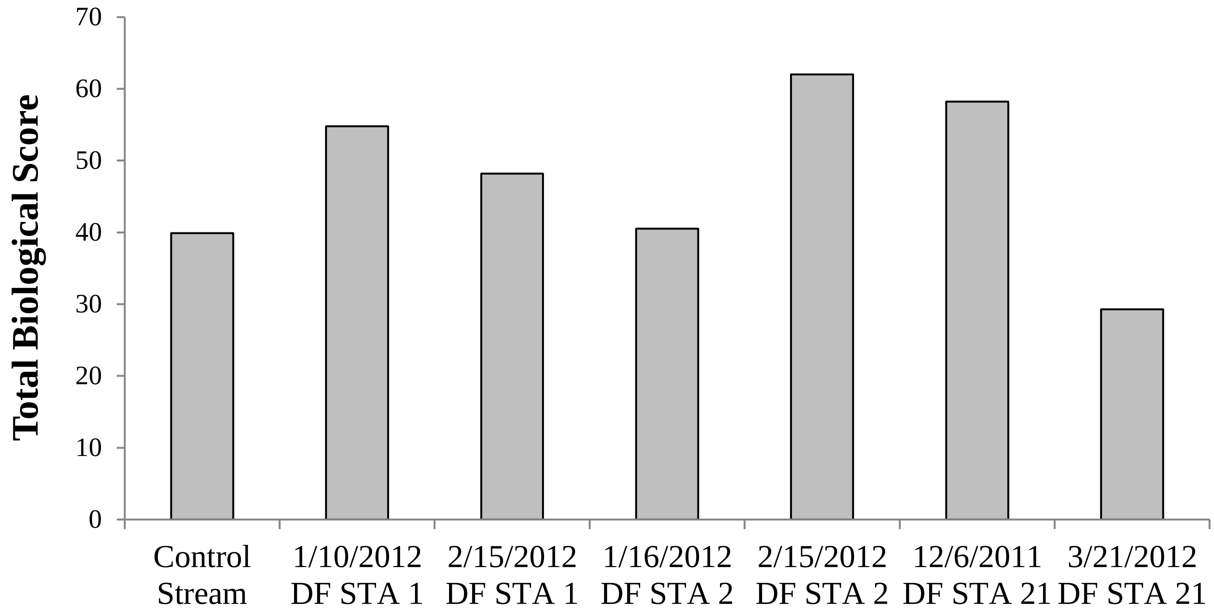

Figure VII-20. Post-restoration Total Biological Scores for three bio-monitoring stations on Dyers Fork in Cumberland Mine. Scores are compared to the mean score from control stream station GAR4. Bio-monitoring stations are ~1,200-ft outside the restoration areas.

VII.J.3 – Verifying TBS Reported by Mine Operators Following Gate Cut Mitigation

To verify the accuracy of the data used in the above analyses and graphs, the University re-sampled four stations where restoration work had been performed and compared the scores to post-restoration scores from the mine operators (Table VII-16). All macroinvertebrate samples were collected in accordance with TGD 563-2000-655 Appendix B methodology. University personnel were trained by a PADEP biologist in TGD sampling methods and certified as being competent (Appendix I1) and a subsample of macroinvertebrate samples were submitted to PADEP for verification of ids (Appendix I2). Data for all University-collected samples can be found in Appendix D2.

Table VII-16. Stations with gate cut restoration that were sampled by the University and compared to samples from the mine operator.

Mine	PA WRDS Stream Code	Stream Name	Station Name	Sampling Date	Within the range of scores reported by mine operator?
Cumberland	41261	Dyers Fork	DF STA 1	3-May-2013	No
Cumberland	41261	Dyers Fork	DF STA 21	3-May-2013	Yes
Enlow Fork	40938	Crafts Creek	BSW20	5-Apr-2013	No
Enlow Fork	32708	Templeton Fork	BSW19	9-May-2013	Yes

Two of the four sites scored within the range of post-restoration scores reported by the mine operator (Table VII-16). The sample for station BSW19 on Templeton Fork scored 41.3, which is similar to post-restoration scores collected by the mine operator in the spring months at this site (44.4 and 41.9; CEC 2012c). The sample for DF STA 21 on Dyers Fork scored 38.6. The mine operator reported scores at this site of 58.2 in December 2011 and 29.3 in March 2012 (Figure VII-20). While the University's score falls within this range, the range is relatively large and reflects a high degree of variability in the scores reported by the consultants.

In contrast, scores for the other two sites fell outside and below the range of scores reported by the mine operator (Table VII-16). The sample from station BSW20 on Crafts Creek scored 34.7. The mine operator has sampled this station three times following restoration, with the following results: 39.2 on 24 May 2011, 51.2 on 1 November 2011, and 60 on 9 April 2012. The University's score is most similar to the first score collected by the mine operator following gate cut mitigation. Differences in the sampling locations may account for the observed differences in TBS. Following restoration, the mine operator re-located station BSW20 slightly downstream so that the station was located directly inside the restoration area (BSW20A; CEC 2012d). The University was unaware of this shift in station location at the time of sampling. Such shifts in sampling location also occurred at Templeton Fork following restoration (BSW19A; CEC 2012c), however, the location change did not affect the score for that site. For DF STA 1, the post-restoration TBS was also lower than the scores reported by the mine operator. Samples collected by the mine operator in January and February 2012 scored 54.8 and 48.2, respectively (Figure VII-20) while the University's sample had a TBS of 32.6. Differences in month of sampling may account for the differences observed at this site.

While a much greater sample size would be needed to draw conclusions regarding the accuracy of data submitted to PADEP as well as the repeatability of TGD 563-2000-655, the University can conclude that sampling location and month of sampling likely play a significant role in determining a station's TBS. The University suggests that PADEP agents continue to monitor sampling efforts by the mine operator and also perform their own spot-checking of the data from time to time, with careful consideration of these factors.

VII.J.4 – Changes in Macroinvertebrate Community Composition for Streams with Gate Cut Mitigation

To determine if gate cut mitigation affects community composition, the University identified nine stations from Bailey and Enlow Fork Mines that reported pre- (N = 14) and post-restoration (N = 21) macroinvertebrate taxa abundance. As in Section VII.H.3, the University focused on taxa in the Ephemeroptera, Plecoptera, and Trichoptera orders and calculated the relative frequency of taxa occurrences among pre- and post-restoration samples. NMDS and permutation tests were also used to determine if restoration significantly affected overall community composition.

While the TBS is nearly identical between pre- and post-restoration samples, there are subtle changes in community composition as a result of restoration. For Ephemeroptera, two moderately common genera (present at more than 50% of sites pre-mining) experienced declines in relative frequency that were >50% (*Ephemerella* and *Ephemera*). Most other Ephemeroptera taxa remained at similar frequencies following restoration (Appendix H2).

For Plecoptera, the University observed a slight shift away from taxa in the families Capniidae and Chloroperlidae but strong increases in genera such as *Perlesta* and *Isoperla* (Appendix H2). It should be noted that genera in the family Chloroperlidae were not common prior to restoration, so the reduction in relative frequency may simply be due to the general rarity of these taxa. However, the genus *Allocapnia* in the family Capniidae was quite common prior to restoration with a relative frequency across sites of 57.1%. Yet, after gate cut mitigation, it was found at less than 25% of sites. *Isoperla*, a widespread genus, showed the opposite trend and nearly doubled following restoration. This genus appears to be highly tolerant of disturbance as it also experienced significant increases following mining-induced flow loss.

Following restoration, the majority of Trichoptera increased in relative frequency across sites (Figure VII-21). In fact, four new genera that were not present prior to mining were identified following gate cut mitigation. Two of these genera, *Ceratopsyche* and *Diplectrona* belong to the family Hydropsychidae.

While there are subtle shifts in EPT taxa occurrences, the NMDS and permutation tests indicate that restoration does not significantly alter community composition (ordination stress = 0.19; time of sampling, P = 0.30; Figure VII-22). Month of sampling was a significant predictor of community composition (R^2 = 0.63, P = 0.001), but station id was not.

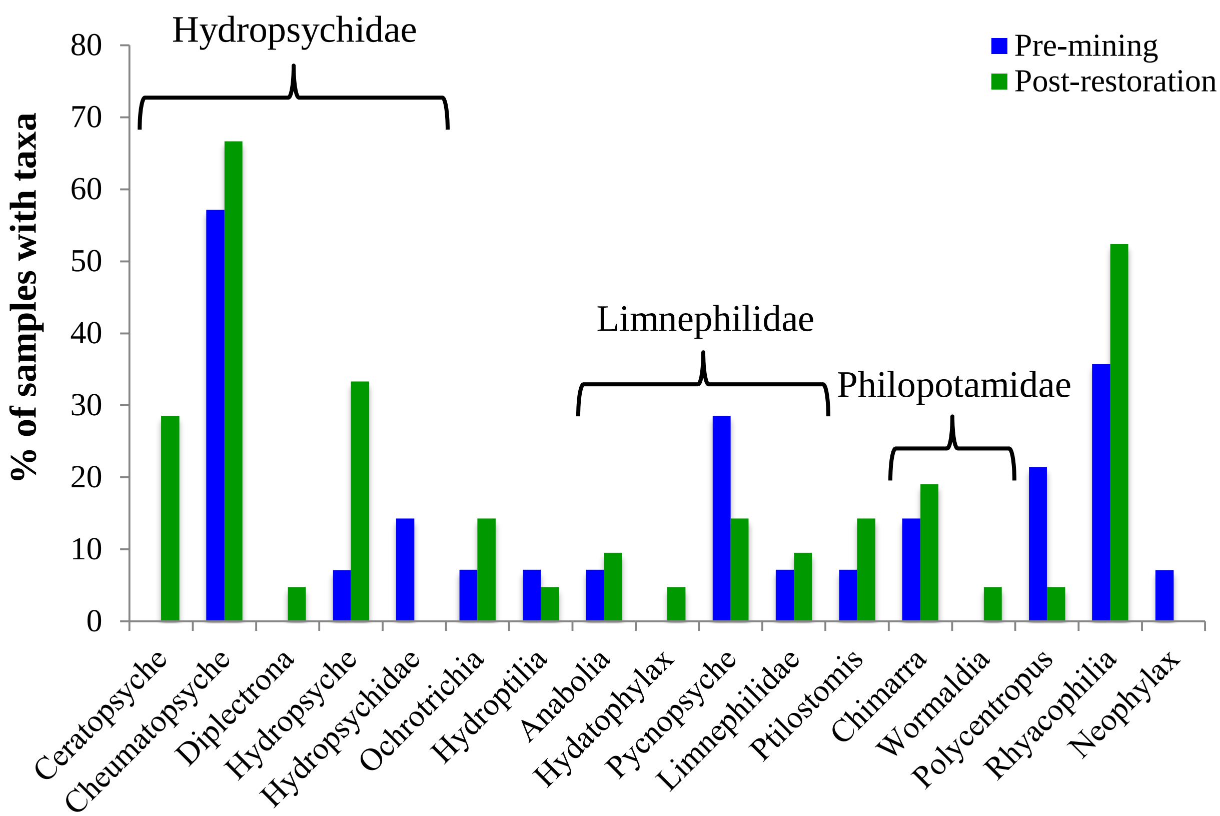

Figure VII-21. Relative frequency (%) of Trichoptera taxa occurrences in pre- (N = 14) and post-restoration (N =21) samples. While the bulk of the samples were identified to the genus level, consultants were at times only able to identify to the family level. For families with more than one genus represented, a bracket is used to group all genera in that family.

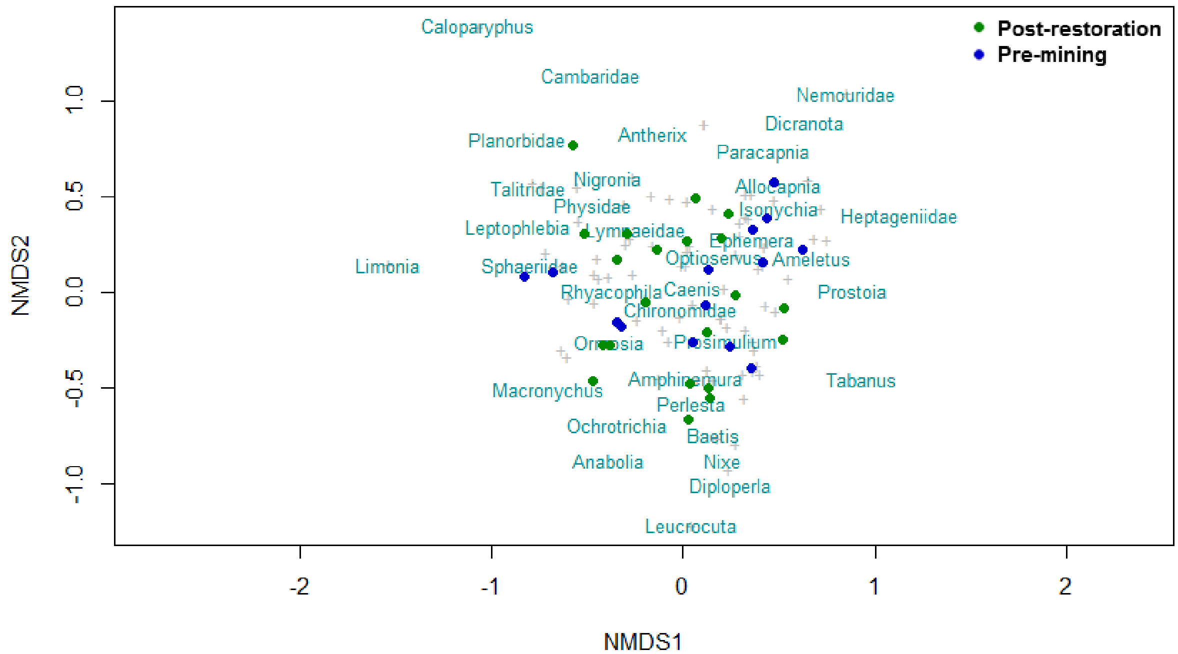

Figure VII-22. Non-metric multi-dimensional scaling ordination for community composition of pre-mining (N = 14) and post-restoration (N = 21) samples for sites with gate cut mitigation. Gray plus signs represent additional taxa whose names are not displayed. When taxa overlap, only the name of the more abundant taxa is displayed.

VII.K – Pre- and Post-Mining Biology in Focal Watersheds

Up to this point, the University's analyses of subsidence impacts on stream biology have utilized data from just one or two mines. Nearly all of the post-mining biology data that was available at PADEP was from Bailey Mine. Similarly, the bulk of the post-restoration data came from just two mines – Bailey and Enlow Fork Mine. To determine if mining-induced flow loss, mining-induced pooling, and restoration work have similar impacts on stream biology at other mines, the University sampled 10 bio-monitoring stations within the Act 54 focal watersheds (Table VII-17). All samples were collected in accordance with TGD 563-2000-655. University personnel were trained and observed by a PADEP biologist in the TGD sampling methodology (Appendix I1) and a subsample of the macroinvertebrate samples were submitted to a PADEP biologist for verification of ids (Appendix I2). Data for all University-collected samples can be found in Appendix D2.

Overall, the University observed a diversity of responses across the sites. Below, a more detailed description of the impacts at each site is provided along with graphs that compare the mine operator's pre-mining scores to the University's post-mining scores.

Table VII-17. Bio-monitoring stations from focal watersheds that were sampled for biology to supplement data from PADEP. Latitudes and longitudes for stations are available in Appendix D2.

Mine	PA WRDS Stream Code	Stream Name	Station Name	Impacted by Mining?
Sites impacted by flow loss and grout mitigation				
Bailey	32547	Strawn Hollow	BSW39	Yes*
Blacksville 2	41813	Roberts Run	BSW22	No
Cumberland	40608	UNT to Maple Run	MRT12	Yes
Enlow Fork	40941	UNT to Crafts Creek	BSW24	Yes
Sites impacted by flow loss but not requiring grout mitigation				
Enlow Fork	40944	UNT to Crafts Creek	BSW13	No*
Sites impacted by pooling				
Blacksville 2	41812	Blockhouse Run	BSW23	Yes
Emerald	41014	Muddy Creek	MC B2	Yes
Sites with gate cut mitigation				
Emerald	41268	Mount Phoebe Run	MP STA 1	Yes
Unaffected sites				
Cumberland	40607	Maple Run	MR4	No
Cumberland	40607	Maple Run	MR5	No

* Augmentation was on at time of sampling or during month prior to sampling

VII.K.1 – Pre- and Post-Mining Biology in Bailey Mine

Because Barneys Run, the focal watershed in Bailey Mine, was already heavily represented in the University's analysis of the effects of mining-induced flow loss, the University opted to sample biology in a similar, but much smaller watershed of Bailey Mine. Strawn Hollow, a tributary to the South Fork of Dunkard Fork, is located over the 12-15I panels of Bailey Mine. Station BSW39 is located in the middle of the Strawn Hollow watershed in the 14I panel, and the drainage area upstream of this station is characterized by dense forest. Based on the land use, field observations, and the pre-mining TBS data, the station appears to have had little human disturbance prior to mining. Following mining, flow loss and bedrock heaving were observed in the 14I panel. Four augmentation points were installed throughout the watershed to maintain flow across the impacted area. The 14I panel was grouted in 2012. The University sampled station BSW39 on 18 April 2013 and found that grout mitigation has not yet been effective in restoring the biological community to pre-mining levels (Figure VII-23). Relative to the pre-mining data, declines were observed in three of the five TBS metrics, including taxa richness, % EPT richness, and intolerant taxa richness (Appendix D2). The TBS for this site was 59.4, which is less than 88% of the mean pre-mining score. These results reinforce the University's findings from Figure VII-7 and further implicate mining-induced flow loss as a significant contributor to adverse effects on stream communities. It should be noted that one augmentation well was on during the University's sampling and was discharging ~10gpm, so this sample does not reflect the natural biological conditions over the 14I panel. The University suggests that future studies follow-up on the flow and biological recovery of Strawn Hollow.

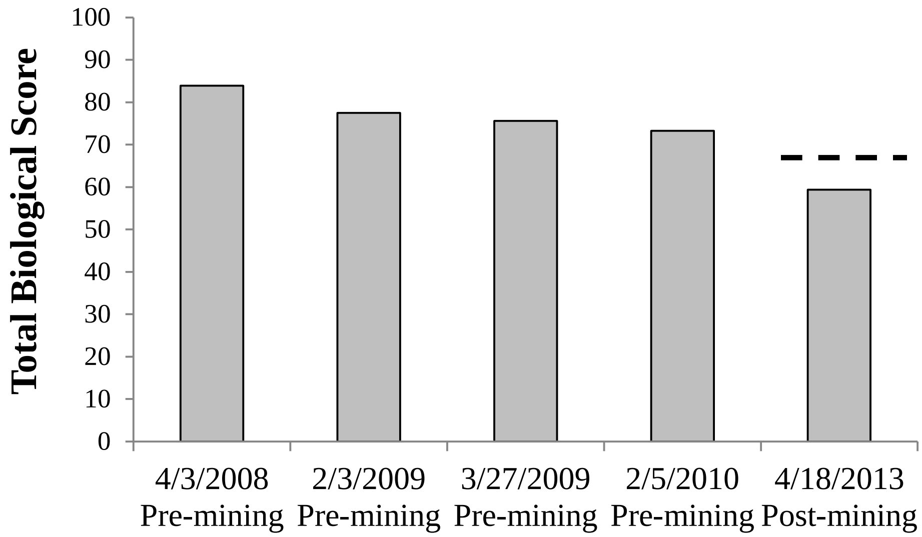

Figure VII-23. Total Biological Scores for bio-monitoring station BSW39 on Strawn Hollow, a tributary to the South Fork of Dunkard Fork, in Bailey Mine. Pre-mining scores were collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VII.K.2 – Pre- and Post-Mining Biology in Blacksville 2 Mine Focal Watersheds

The Blockhouse Run watershed runs over the 14-18W panels of Blacksville 2 Mine. It is likely this watershed will continue to be undermined by additional panels in the future due to its relatively large size. Station BSW23 is located in the 15W panel, and while the bulk of the drainage area upstream of this station is forested, there is a small patch of pasture/hay just upstream of the bio-monitoring station. While the pasture/hay has the potential to create human-induced disturbances to the station's biological community, the one pre-mining score that was available suggests that the community was quite healthy prior to mining (Figure VII-24). Following mining, pooling was observed at this station and several other locations along Blockhouse Run. A gate cut is planned for the 14-15W gate area, which should eventually alleviate the pooling at this station. The gate cut had not been performed at the time of this report. The University sampled this station on 25 April 2013 and found that the pooling at the site was having an adverse effect on the biological community (Figure VII-24). The University's sample had 12 fewer species than the pre-mining sample and the number of intolerant taxa and filterer-collector/ predators was reduced by 50%. These data add weight to the analysis which suggested that mining-induced pooling impacts adversely affects stream biology communities (Section VII.H.2). However, the decline in TBS observed here is more dramatic than the average declines following pooling that were reported in the analysis. The significant decline in TBS on Blockhouse Run may be a result of the prolonged pooling at this site. Because mining of this station was complete by 26 October 2009, pooling had likely been present on site for > 3 years at the time of the University's sampling.

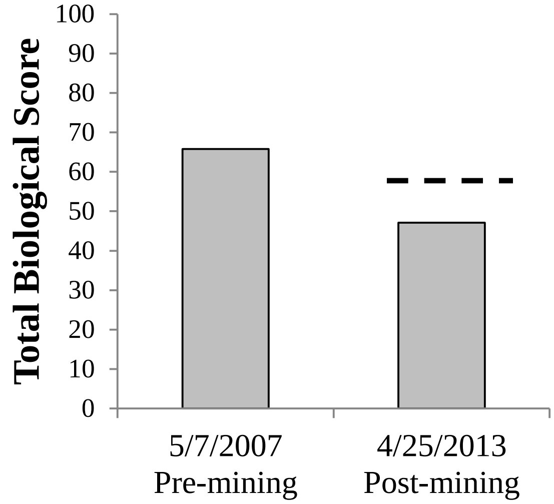

Figure VII-24. Total Biological Scores for bio-monitoring station BSW23 on Blockhouse Run in Blacksville 2 Mine. The pre-mining score was collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

The Roberts Run watershed is the second focal watershed for Blacksville 2 Mine. During the 4th assessment period, Roberts Run was mined by the 14W panel. Station BSW22 is located roughly 4,000-ft downstream from the headwaters, near the 13-14W gate area. The drainage area upstream of this site is almost entirely forested, with one road running alongside the stream. Again, field observations and the pre-mining data (Figure VII-25) for this site suggest that human-disturbances to the stream biological community are minimal. While no mining-induced changes to the stream channel were noted during mining in fall 2010, a small no-flow section increased in size week by week as the panel undermined the stream. A single augmentation was established to maintain flow over the 14W panel. The stream was grouted in 2012. The University sampled station BSW22 on 25 April 2013 and found that the post-grouting scores were equivalent to the pre-mining scores (Figure VII-25). While these data suggest that grouting may be an effective restoration technique, it should be noted that station BSW22 is ~300-ft downstream from the impacted area. The status of the biological community in the area directly impacted by flow loss is unknown. The University suggests that PADEP continue to monitor this site and while awaiting flow and biology data from the mine operator.

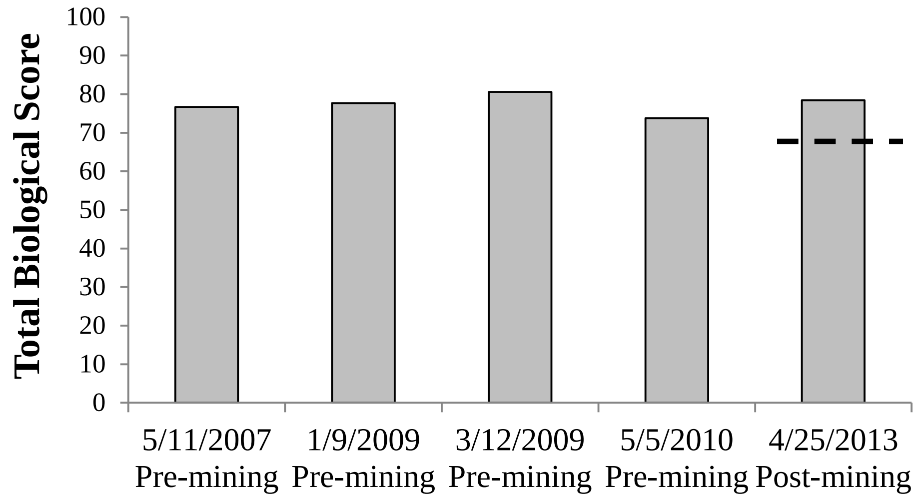

Figure VII-25. Total Biological Scores for bio-monitoring station BSW22 on Roberts Run in Blacksville 2 Mine. Pre-mining scores were collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VII.K.3 – Pre- and Post-Mining Biology in Cumberland Mine Focal Watershed

The Maple Run watershed is located in the Cumberland West district over longwall panels 58-61. Within this watershed, the University selected three bio-monitoring stations for sampling – MR4, MR5, and MRT12. MR4 and MR5 are both located along Maple Run, while MRT12 is located on stream 40608, an unnamed tributary to Maple Run. The NLCD classifies the land surrounding Maple Run and stream 40608 as forest (Fry et al. 2011), however during field observations, the University noted that stations MR4 and MR5 were surrounded by pasture/hay, with a residence also very close to the stream. While all streams within this watershed are classified as high quality-warm water fisheries (Table I-2), it is possible that human impacts may explain the moderate to low pre-mining TBS at MR4 and MR5 (Figure VII-26). Following mining, PADEP agents noted that there were no mining-induced changes to Maple Run. Indeed, when the University sampled MR4 and MR5 on 30 April 2013, the post-mining samples were well within the range of pre-mining scores for the two sites (Figure VII-26). It should be noted that the two pre-mining scores for MR4 are not within 16% of each other as required by TGD 563-2000-655. However, these data suggest that macroinvertebrate communities are largely undisturbed at sites where no mining-induced changes are observed.

Station MRT12 is surrounded by forest and the pre-mining scores for this station suggest that the site experiences little human disturbance and had a healthy macroinvertebrate community prior to mining (Figure VII-27). Following mining, bedrock fractures and compression heaves were noted in stream 40608, just downstream of station MRT12. These mining-induced changes resulted in a flow loss impact. Bentonite clay was used to fill the fractures and mitigate the damages. To the University's knowledge, augmentation was not used at this site. The University sampled MRT12 on 8 March 2013 and the sample indicates that the site is experiencing an adverse effect from mining. The sample score is less than 88% of the pre-mining average (Figure VII-27). While pre-mining samples always identified $\geq$ 25 taxa at this site, the University's sample only identified 19 unique taxa. Data from this site confirm the analysis from Figure VII-7 and indicate that mining-induced flow loss generally reduces stream TBS.

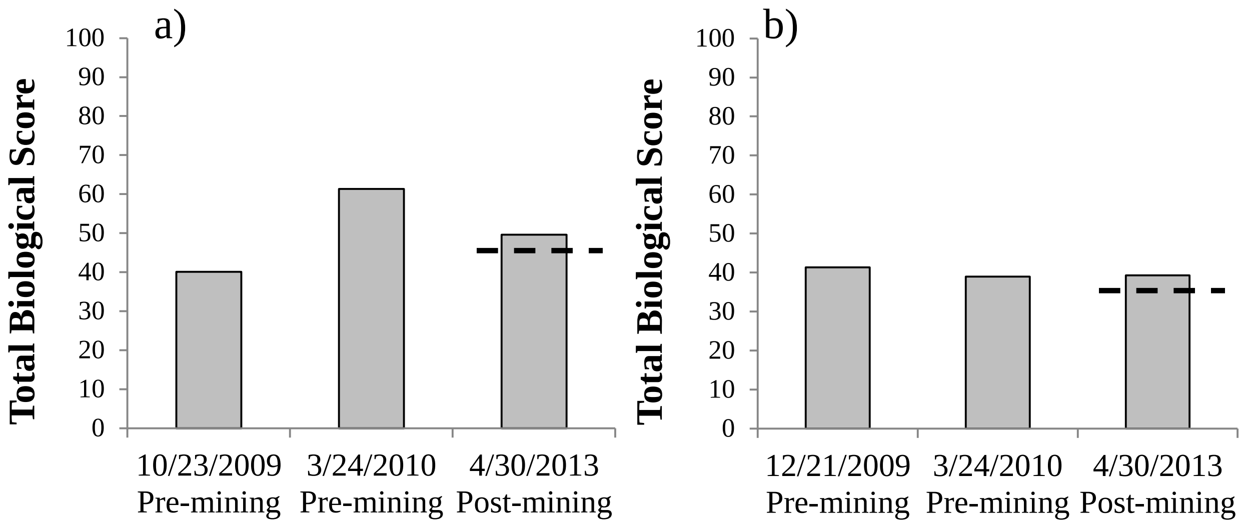

Figure VII-26. Total Biological Scores for a) bio-monitoring station MR4 and b) station MR5 on Maple Run in Cumberland Mine. Pre-mining scores were collected by the mine operator while post-mining scores were collected by the University. Dashed lines indicate the minimum Total Biological Score required for stream to be considered recovered.

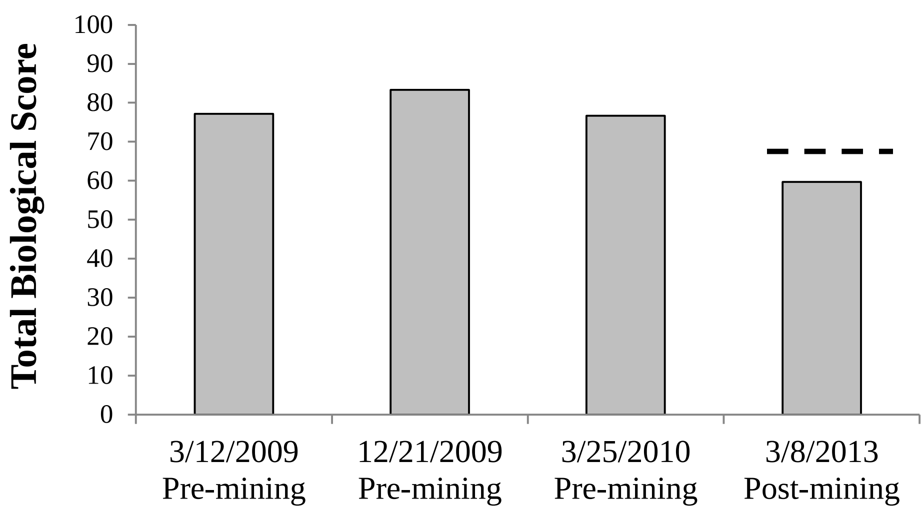

Figure VII-27. Total Biological Scores for bio-monitoring station MRT12 on stream 40608, an unnamed tributary to Maple Run, in Cumberland Mine. Pre-mining scores were collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VII.K.4 – Pre- and Post-Mining Biology in Emerald Mine

The University did not select any focal watersheds in Emerald Mine, however, it is important to sample sites across all longwall mines in an equal manner. During the 4th assessment period, the

Mount Phoebe Run watershed was undermined by panels B6 and B7 in Emerald Mine. Bio-monitoring station MP STA 1 is located ~1,200-ft south of the B7 panel on Mount Phoebe Run. Field observations revealed that at this site the stream is bounded on the left side by forest and on the right side by a residence. The banks of the stream near the residence are lined with tall herbaceous cover although some large pieces of equipment are also piled nearby. Further upstream, the drainage area becomes characterized by a mix of forest and pasture/hay. The direct adjacency of station MP STA 1 to a residence suggests that there is likely some degree of human disturbance on the stream site. Unfortunately, pre-mining data are not available to confirm this. The pre-mining scores for MP STA 1 were not within 16% of each other and thus were not provided by the mine operator to PADEP. Following mining of the B7 panel in March 2010, pooling in excess of 1-ft developed near the southern end of the B7 panel. The pooling had not been predicted by subsidence modeling, so a permit revision was required for the gate cut mitigation project. The gate cut was completed in November 2012. The University sampled station MP STA 1 on 8 November 2013 to evaluate the recovery of the biological community at this site. While pre-mining scores were not available, the mine operator proposed using pre-mining scores from MP 3, a nearby station upstream of the gate cut mitigation area, as a restoration target for MP STA 1. The University's sample shows that the post-restoration TBS from MP STA 1 is much lower than the pre-mining scores at MP 3 (Figure VII-28). This difference may reflect an unrecovered macroinvertebrate community, differences in month of sampling, or a poor choice of "restoration target" scores. However, it should be noted that as with the bio-monitoring stations along Dyers Fork, MP STA 1 is located some distance away from the restoration area. It is unclear how well conditions at MP STA 1 reflect biological recovery in the mitigated area. The University strongly suggests that the mine operator establish bio-monitoring stations within future gate cut mitigation sites.

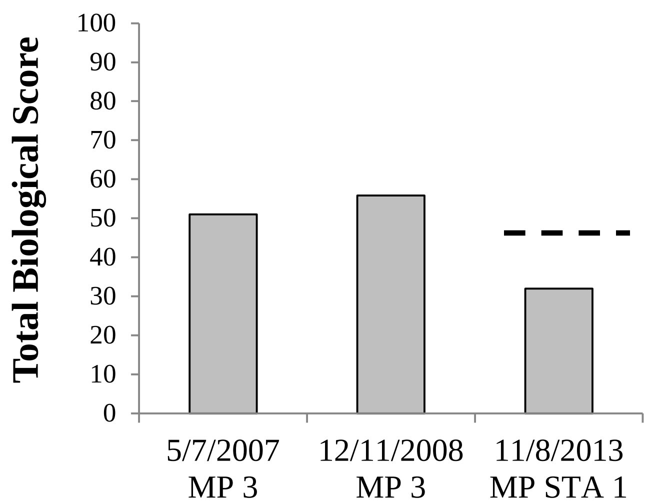

Figure VII-28. Total Biological Scores for bio-monitoring stations MP 3 and MP STA 1 on Mount Phoebe Run in Emerald Mine. Pre-mining scores for MP 3 were collected by the mine operator while post-restoration scores for MP STA 1 were collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

The Muddy Creek watershed was undermined by panels C2-C3 of Emerald Mine during the 4th assessment period. Station MC B2 is located on Muddy Creek in the C2 panel, near the mouth of stream 41085 (an unnamed tributary to Muddy Creek). The drainage area above MC B2 contains a mix of forest, pasture/hay and row crops. The area directly adjacent to the station is largely pasture/hay. The moderate pre-mining scores at this site suggest that land use practices were impacting the stream community before mining began (Figure VII-29). Following mining of the C2 panel, pooling was observed by PADEP agents near station MC B2. Mitigation measures have not yet been taken to alleviate the pooling. The University sampled station MC B2 on 15 November 2013 and the sample scored a TBS of just 31.1. This score is not within 88% of the pre-mining scores, and it is much lower than post-mining scores collected by the mine operator. The differences between the University's post-mining score and those of the mine operator may be due to differences in month of sampling. The University's score was collected in November, a month during which samples score on average 10-11 points lower than samples collected during spring months (Figure VII-4).

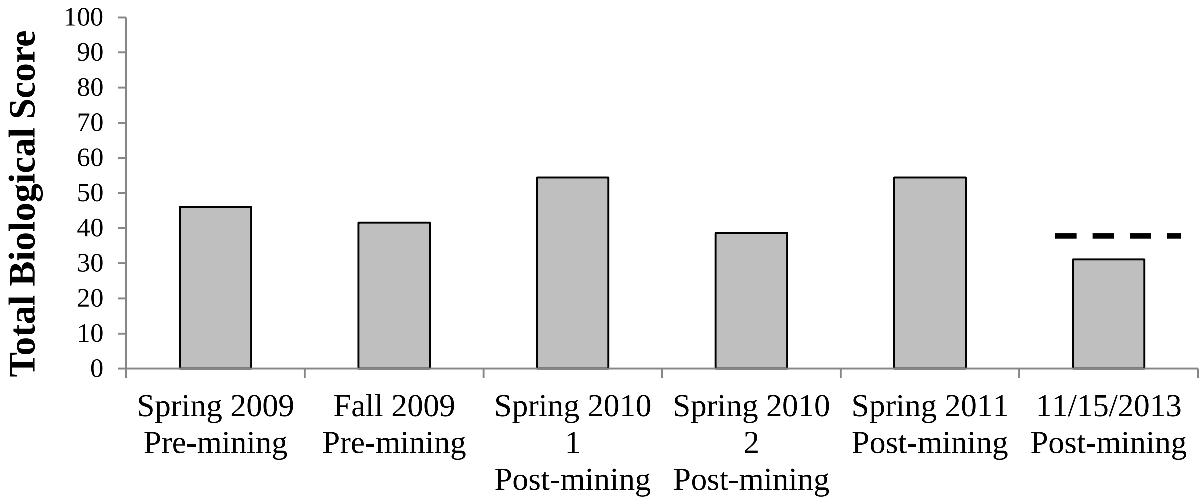

Figure VII-29. Total Biological Scores for bio-monitoring station MC B2 on Muddy Creek in Emerald Mine. Pre and post-mining scores for MC B2 were collected by the mine operator and a single post-mining score was collected by the University in November 2013. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VII.K.5 – Pre- and Post-Mining Biology in Enlow Fork Mine Focal Watershed

The Crafts Creek watershed in Enlow Fork Mine was undermined by longwall panels E15 through E23 during the 3rd and 4th Act 54 assessment periods. The University selected two bio-monitoring stations for sampling within this watershed. Station BSW24 is on stream 40941, a relatively short first order tributary over panels E20 and E21. Station BSW13 is on stream 40944, another first order tributary that crosses panels E16-E19. Station BSW13 is located in the E18 panel. The Crafts Creek watershed contains a mosaic of three major land use types – forest, pasture/hay, and row crops. While the drainage basins for these stations are largely forested, the area upstream of station BSW13 on stream 40944 contains ~20% pasture/hay land use. These land use practices, along with the many residences and recreational activities in the watershed, suggest that the Crafts Creek watershed experiences more human influences than any of the other focal watersheds. The moderate pre-mining scores (Figure VII-30, Figure VII-31) also indicate that this watershed had some degree of human disturbance prior to mining.

Stream 40941 experienced mining-induced flow loss impacts in January 2010 after mining of the E20 panel. An augmentation discharge point was established at the E20/E21 gate to maintain flow and the affected area was grouted in November 2010. The University sampled station BSW24 on 5 April 2013 and found that this station was adversely affected by flow loss. The post-mining TBS of 47.2 is much lower than the pre-mining score of 64.9 (Figure VII-30). Interestingly, the sample was dominated by amphipods of the genus *Crangonyx* (112 *Crangonyx* individuals out of 170 total individuals; Appendix D2). This finding is somewhat unusual and further indicates that the community structure at this site has been significantly altered by mining, as amphipods were not present in the pre-mining sample. Because augmentation has not been used at this site since fall 2011 (based on augmentation submitted by the mine operator), the University is confident that this sample represents the natural biological conditions on stream 40941.

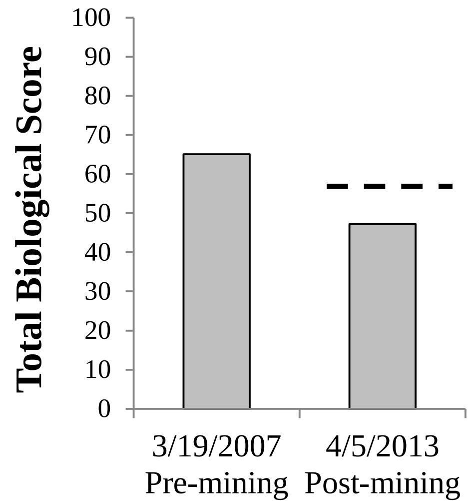

Figure VII-30. Total Biological Scores for bio-monitoring station BSW24 on stream 40941, an unnamed tributary to Crafts Creek. The pre-mining score was collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

Stream 40944 and bio-monitoring station BSW13 were undermined by panel E18 in January-February 2009. While some flow loss issues have been noted in the stream section above this panel, the most significant flow losses on stream 40944 occurred downstream over panel E17. Augmentation in the E18 panel has been instrumental in maintaining flow through the heavily impacted E17 panel area. The section over the E18 panel itself however has never received grouting or any mitigation other than augmentation. The University sampled station BSW13 on 29 March 2013 and the post-mining TBS fell well within the range of the pre-mining scores collected at this site (Figure VII-31). While this is encouraging, it should be noted that augmentation was used extensively on this stream in fall 2012 through February 2013. While augmentation was not on during the University's sampling, the sample may not accurately reflect the natural biological conditions on site.

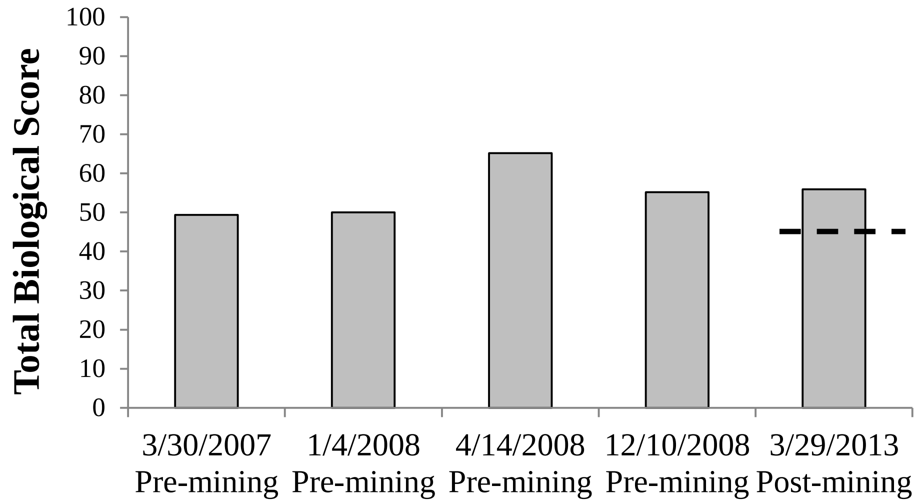

Figure VII-31. Total Biological Scores for bio-monitoring station BSW13 on stream 40944, an unnamed tributary to Crafts Creek, in Enlow Fork Mine. Pre-mining scores were collected by the mine operator while the post-mining score was collected by the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VII.L – Summary

To isolate the effect of mining on stream flow and biology, it is critical to account for factors that cause natural variation in stream ecosystems. Stream flow can be influenced by climate, so in this assessment, stream flow losses are reported for both the wet (December – May) and dry (June-November) seasons. Stream biology can be influenced by watershed and reach-level characteristics as well as month of sampling. Low TBS are generally associated with watersheds with pasture/hay land use and reaches with poor habitat scores and alkaline pH. TBS are also lower when stream samples are collected in early fall (i.e. October and November). In this assessment, variation in watershed and reach characteristics as well as month of sampling are controlled for when analyzing the impacts of mining on stream macroinvertebrate communities.

During the 4th Act 54 assessment, 96.05 miles of stream were undermined, which represents a 16% decline from the 3rd assessment. Longwall mining accounted for the undermining of 50.59 miles of stream undermining. Of the stream miles undermined by longwall techniques, 39.2 miles, 77%, belong to streams that experienced mining-induced flow loss, pooling, or both somewhere along their channel. On these streams, the maximum length of post-mining flow loss ranged from 936-ft to 10,883-ft in the dry season and from 96-ft to 8,106-ft in the wet season. The length of mining-induced pooling on individual streams could not be estimated due to a lack of data.

PADEP no longer has a stream investigation period in which they determine if changes in flow are related to mining or climate. Instead, changes in flow that occur at the time of mining are automatically assumed to be mining-related.

PADEP is responsible for tracking all mining-induced impacts on stream flow and biology. PADEP's methodology for tracking stream impacts changed between the 3rd and 4th Act 54 assessments as a result of the implementation of TGD 563-2000-655. Currently, stream investigations are only used by PADEP to track impacts that occurred before TGD 563-2000-655. For impacts occurring after this point, PADEP no longer requires a formal investigation to determine if the changes in flow are climate or mining-related - instead, the mine operator is automatically assumed liable for impacts occurring at the time of undermining. Once an impact occurs, a record is made in BUMIS and in the SSA stream data logs and the operator is given three years to mitigate the impact and submit data to PADEP for review. The data submission initiates a stream recovery report at PADEP. If the data in the stream recovery report indicates recovery, then the stream is released. If the stream is not recovered, then PADEP can request a change in future mining plans. At this time, the mine operator has two more years to perform additional mitigation work before PADEP will require compensatory mitigation. Thus five years of mining can continue under the existing permit before a final determination of recovery or lack thereof is made. In the University's assessment, this time period may prevent the PADEP from taking action to prevent permanent stream flow loss on additional streams when mining conditions, overburden depth and composition and other factors are similar to those leading to unrecoverable stream loss in the first instance.

As a result of these changes, the 4th assessment period saw just nine stream investigations by PADEP. Of these, four were unresolved at the end of the assessment period. For many of the stream investigations, flow data from the mine operator was inadequate to assess recovery. Fourteen stream recovery reports were filed during the 4th assessment. PADEP has released nine of these from further monitoring, while two cases require compensatory mitigation, and three cases are still under review. In the resolved cases, the University noted that PADEP would occasionally use one post-mining TBS rather than two to assess biological recovery on a stream.

PADEP tasked the University with assessing pre- and post-mining Total Biological Scores (TBS) for at least five stream segments that experienced mining-induced flow loss and at least five stream segments that experienced mining-induced pooling. For the flow loss investigation, Bailey Mine was the only mine with both pre- and post-mining biology data that met the requirements of TGD 563-2000-655. In this mine, mining-induced flow loss significantly reduces TBS and the decrease constitutes an adverse effect under the definition given in TGD 563-2000-655. Mining-induced flow loss drives declines in Ephemeroptera and taxa in the families Ephemerellidae and Heptageniidae appear to be especially sensitive. Post-mining macroinvertebrate communities are characterized by a shift to shredder and predator taxa and stress-tolerant Dipteran taxa. The changes in biology are accompanied by changes in water quality, with conductivity and pH significantly increasing at sites with mining-induced flow loss. On average, the increases in conductivity exceed the U.S. EPA's benchmark for aquatic life in the Western Allegheny Plateau ecoregion. For the pooling investigation, data from Bailey and Enlow Fork Mines indicate that mining-induced pooling reduces TBS. When adjusting TBS for the effects of watershed and reach-level characteristics and month of sampling, pooling impacts also constituted an adverse effect to streams.

As the first Act 54 report to quantitatively track stream mitigation, the University found that:

- 28 stream segments received gate cuts to alleviate mining-induced pooling (Total miles mitigated: 4.21 miles).
- 95 streams had augmentation discharges installed along their channel and augmentation was active at 74 of these streams to maintain flow during or after mining.
- 57 streams received grouting to mitigate mining-induced flow loss. Estimates for one longwall mine suggest that ~50% of the stream miles undermined received grouting.
- Three stream segments had liners placed in their channels to restore flow following mining-induced flow loss.
- At one longwall mine, ~7,913-ft of access roads were constructed immediately adjacent to streams in just a three month period to support mitigation activities.

In assessing the effectiveness of stream mitigation techniques, the University found that TBS increases over time at sites experiencing mining-induced flow loss. The rate of recovery is slow though, and analyses suggest that on average, 3 ½ years are required to restore the macroinvertebrate community to its pre-mining condition. In contrast, water quality does not recover over time and pH and conductivity at flow loss sites remain elevated following mitigation. For streams with pooling impacts and gate cut mitigation, restoration is effective in restoring TBS to pre-mining levels. Macroinvertebrate community composition following gate cuts is indistinguishable from the pre-mining community composition.

Data from the focal watershed analyses generally supports the conclusions above, but also highlight the site-specific nature of mining impacts. Stream characteristics and mitigation measures differ from site to site. In general, for sites that were unaffected by mining, post-mining TBS matched pre-mining TBS.

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SECTION VIII: A Follow-Up on the Effects of Mine Subsidence on Streams during the 3rd Act 54 Assessment

VIII.A – Overview

During the 3rd Act 54 assessment period (2003-2008), a total of 55 stream investigations were initiated by the PADEP. At the end of that period, 35 investigations were considered "Unresolved", indicating that the streams had not yet recovered to pre-mining conditions (Iannacchione et al. 2011). Here, the University re-visits the investigations from the 3rd assessment period to determine the status and time to resolution of those unresolved cases. Additionally, the University was tasked with evaluating the status of five streams that were undermined prior to the implementation of TGD 563-2000-655. Unfortunately, streams undermined prior to TGD 563-2000-655 lack sufficient assessments of pre-mining flow and biological integrity to properly measure recovery. Therefore, the University selected five streams that were undermined prior to the implementation of TGD 563-2000-655, were sampled during the 3rd assessment, and were the subject of an unresolved investigation from the 3rd assessment. If the sites have recovered, the Total Biological Score (TBS) is expected to either remain the same or improve from the last assessment. Where appropriate, the TBS for these sites is also compared to control streams as suggested in TGD 563-2000-655.

VIII.B – Stream Investigations from the 3rd Assessment Period

VIII.B.1 – Stream investigation data collection

While BUMIS was not designed to track stream impacts, it is used by PADEP to store basic details on stream investigations including the date of impact, investigation assignment, and the interim and final resolution statuses. The paper files at CDMO can contain additional information, including mitigation plans, flow data, and relevant correspondence. The University utilized these two sources to determine the following for all stream investigations recorded in the 3rd assessment report by Iannacchione et al. 2011: the date the impact occurred, the final resolution status, and the final resolution date. The date the impact occurred was subtracted from the final resolution date to determine the time to resolution in days for each stream investigation.

The University was able to track the outcome of 41 of the 55 stream investigations from the 3rd assessment period using BUMIS. However, 25% of the stream impacts from this period are not identified in the BUMIS database. Nine impacts are documented only in the paper files at CDMO. These impacts have received a formal stream investigation claim number, so it is unclear why they were not entered into BUMIS. An additional five stream impacts were never assigned stream investigation claim numbers and thus could not be tracked in BUMIS or the paper files. The University was only aware of these impacts because they were recorded in an Excel file that was given to the University by PADEP. For these impacts, the University relied on the Excel file to determine the time to resolution and final resolution status. Because the University could not identify the rationale behind omission from BUMIS, omission from the paper files, or inclusion in the afore-mentioned Excel file, it remains unclear if additional impacts occurred that are unaccounted for in any of these places.

VIII.B.2 – Resolution status

Of the 55 stream investigations that were initiated during the 3rd assessment period, 51 had a final resolution by the end of the 4th assessment period (Table VIII-1). The final resolution status can fall into a variety of categories. Three cases were determined by PADEP to be "not due to underground mining". In these cases, PADEP has ruled that the stream impacts can be attributed to factors such as drought, surrounding land use practices, or other non-mining related issues. For cases with mining-related stream impacts, the majority of streams recovered to pre-mining flow conditions, either on their own or following mitigation work. This includes the thirty-eight cases with a final resolution status of "repaired", "resolved", and "stream recovered". It should be noted that the University and PADEP could not determine the distinction between these three final resolution statuses.

Table VIII-1. Number of stream investigations that were initiated in the 3rd assessment period and their resolution status at the end of the 3rd and 4th assessment periods.

Resolution Status	Number as of 3rd Assessment	Number as of 4th Assessment
Final: Closed due to federal court settlement	0	1
Final: Closed/Info appended to another case	0	1
Final: Compensatory mitigation required	0	7
Final: Not due to underground mining	3	3
Final: Repaired	1	1
Final: Resolved	15	35
Final: Stream recovered	0	2
Final: Withdrawn	1	1
Interim: Not Yet Resolved	35	4
Total	**55**	**55**

A single case was "withdrawn" from consideration by PADEP. ST0434 involved a reported flow loss in the 2I panel of stream 32596 (an unnamed tributary to the North Fork of Dunkard Fork), a stream that was the focus of three other stream investigations during the 3rd assessment period. According to BUMIS, the mining company requested an extension for development of a mitigation plan. The investigation was closed one day later. Because BUMIS does not provide any additional information on this investigation, the reason for the withdrawal is unknown. While the other three stream investigations on stream 32596 were eventually merged into a single case (ST1203), there is no evidence that this case was merged with another investigation.

The final resolution status for one case from the 3rd assessment period clearly indicates that the case was appended to another investigation. ST0701, which tracked flow loss impacts to stream 32719 (an unnamed tributary to Rocky Run) in the F6, F7, and F8 panels of Enlow Fork Mine, is now considered "closed/info appended to another case". The case was appended to ST1202, which currently remains unresolved (Appendix G2). Biology data suggests that this stream was significantly impacted by mining. A post-mining sample collected by the mine operator in the F7 panel on 4 December 2007 had a TBS of 24. However, flow recovery is the only compliance required for this stream because it was undermined prior to TGD 563-2000-655. Mitigation plans were submitted in the summer 2010 for grouting and bedload removal in the stream. No additional information was available regarding this stream's current status.

Four investigations initiated in the latter half of the 3rd assessment remain open (Table VIII-2). The investigations in Bailey and Enlow Fork Mines are awaiting final decisions by PADEP hydrologists who will determine if flow conditions have returned to pre-mining levels. Biological recovery has already been documented for the investigation at Bailey Mine. An email from a PADEP biologist dated 22 November 2010 indicates that the TBS for an unnamed tributary to the South Fork of Dunkard Fork was 70.28. This score is well within 16% of 76.3, the TBS for the approved control stream. The investigations in Cumberland Mine required Chapter 105 permits from the U.S. Army Corps of Engineers before mitigation work could begin. According to BUMIS, the permit for both projects was received by CDMO on 27 May 2010. Cumberland Mine permit revision 112 was approved on 26 July 2011 and allows for stream restoration work on stream 41267, an unnamed tributary to Dyers Fork. However, the University could not identify a permit revision that approved restoration work on Stream 41264, another unnamed tributary to Dyers Fork.

Table VIII-2. Unresolved stream investigations initiated in the 3rd assessment period.

Panels	PA WRDS Stream Code[1]	Stream Name	Claim #	Stream Designated Use	Date Problem Occurred	Final Resolution Status
Bailey Mine						
8I	NA	UNT South Fork of Dunkard Fork (SoF-2R)	NOT IN BUMIS	Trout-stocked fishery	6/1/2007	Not yet resolved
Cumberland Mine						
51, 52	41264	UNT Dyers Fork	ST0603	Trout-stocked fishery	5/30/2006	Not yet resolved
50, 51	41267	UNT Dyers Fork	ST0607	Trout-stocked fishery	11/13/2006	Not yet resolved
Enlow Fork Mine						
E13, E14	32724	UNT Rocky Run	ST0710	Trout-stocked fishery	5/1/2007	Not yet resolved

[1] = Zero order tributary

Despite mitigation efforts by the mining companies, PADEP has ruled that some streams have not recovered to pre-mining conditions (Table VIII-1). Below, Section VIII.B.4 provides a discussion of the mining and environmental conditions at these streams.

VIII.B.3 – Time to resolution

The average time to resolution for stream impacts occurring in the 3rd assessment was 1,313 days, or just over 3 ½ years (median: 1,253 days). However, there was significant variation in the time to resolution, reflected in both the large standard deviation of the mean (+/- 761 days, or just over 2 years) and in Figure VIII-1. While a case of flow loss to Dyers Fork in Cumberland

Mine was resolved within just 136 days (the minimum time to resolution), a case of flow loss on stream 32596, an unnamed tributary to the North Fork of Dunkard Fork, took 3,170 days to reach a final resolution (the maximum time to resolution). Of the 10 cases in the 3rd assessment period that took over five years to resolve, eight of these cases involve streams that PADEP ruled have not recovered from mining (Figure VIII-1; one case closed due to federal court settlement, seven cases require compensatory mitigation). With TGD 563-2000-655, it is anticipated that the time to resolution will drop, even for irrecoverable streams, as the TGD clearly states that recovery must occur within 5 years or compensatory mitigation will be required.

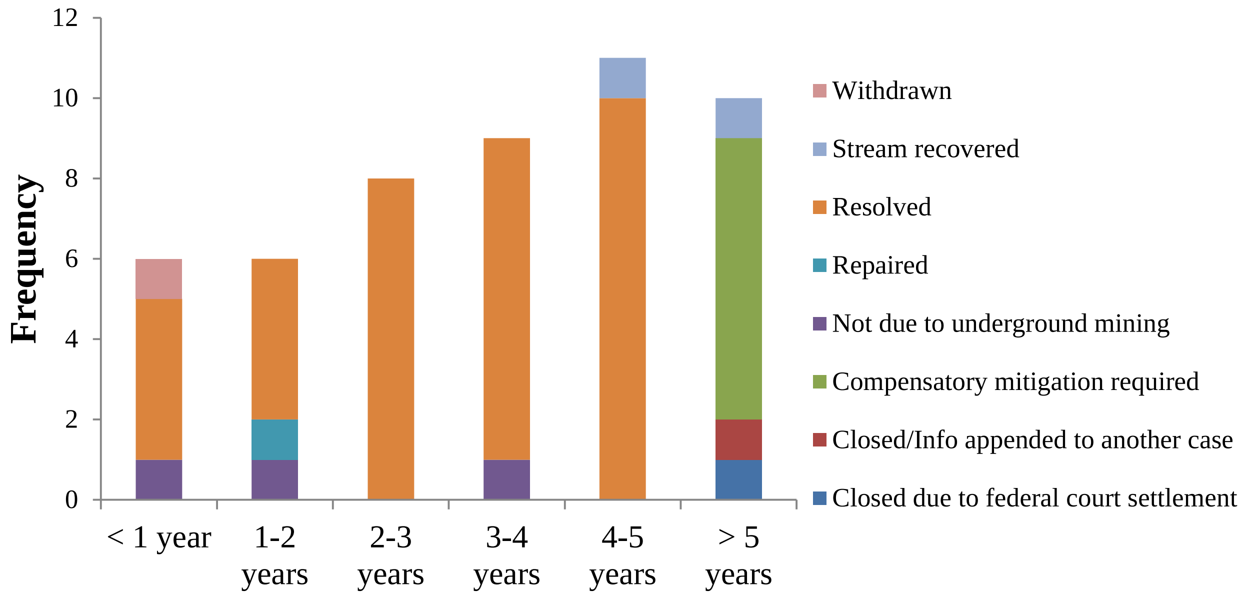

Figure VIII-1. Histogram showing the number of stream investigations that were initiated in the 3rd assessment period according to their time to resolution and final resolution status.

VIII.B.4 – Streams that have not recovered from mining-induced impacts

A single stream investigation was "Closed due to federal court settlement" and seven stream investigations had a final resolution status of "Not recoverable: compensatory mitigation required". In total, eight cases involved streams that have not recovered from mining-induced flow impacts. These eight investigations can be separated into two case studies. The first case study has already been described in some detail in the 3rd assessment report (Iannacchione et al. 2011), but it is briefly re-visited here due to its significance. Stream 39816, an unnamed tributary to Maple Creek, was undermined by the 4 and 5 East panels of High Quality Mine in 2004. Overburden depths for the stream ranged from 255-320 feet in the 4 East panel and 225-255 feet in the 5 East panel (EHB Docket 2004-245-L). Following longwall mining, stream sections overlying these panels experienced flow loss, and despite augmentation and grouting mitigation efforts, PADEP determined that stream flow did not recover to pre-mining conditions. As a result, PADEP issued an order on 12 November 2004 restricting the mine operator to room-and-pillar mining within the 6 East panel to prevent what it predicted would be similar damage to another unnamed tributary to Maple Creek. This order was challenged by the operator and brought before an Environmental Hearing Board (EHB). The EHB ruled in favor of the

PADEP's order (EHB Docket 2004-245-L) and despite an appeal, the Commonwealth Court of Pennsylvania upheld the EHB's ruling (No. 724 C.D. 2007). The PADEP now considers the stream investigation for 39816 "closed due to federal court settlement" (Table VIII-1).

The case from High Quality Mine is interesting for two reasons. First, the mining conditions at High Quality were unique. As the EHB pointed out in its report "…there are no other mines in Pennsylvania where an operator has attempted to longwall coal using modern methods with such shallow cover." (EHB Docket 2004-245-L). Indeed, average overburden depths at other mines currently operating in Pennsylvania are typically at least twice as large as those found in High Quality Mine (see Section III.F.2). There is little doubt that the extremely shallow overburden profiles for the High Quality Mine contributed to the significant stream impacts. Indeed, when the overburden depth is less than 50 times the coal seam thickness plus 100 feet (i.e. $OB < 50t + 100$, where OB = overburden and t = coal seam thickness in feet), it is considered a "rule of thumb" that a stream protection pillar should be left in place to prevent subsidence underneath the stream (Karmis et al. 2012). In streams with such shallow overburdens, the fracture zone that develops above the mine following subsidence can intercept the drainage zone of the stream and result in flow loss (Karmis et al. 2012). At High Quality Mine, the coal seam ranged in height from 7 to 10-ft in the 6 East panel (EHB Docket 2004-245-L). Plugging these values into the rule of Karmis et al. (2012), it can be seen that the overburden depth at High Quality Mine was far less than the 450-600-ft that would be required for full extraction longwall mining. Even the less conservative model by Kendorski (2006; i.e. $OB < 30t + 50$) would require at least 260-350-ft of overburden for full extraction. The second interesting and challenging aspect of the High Quality Mine case is that as the EHB notes, "The absence of sufficient baseline data will make it difficult to determine whether the 4E/5E Stream has ever fully recovered." (EHB Docket 2004-245-L). The streams in High Quality Mine were undermined prior to the passage and implementation of the PADEP's TGD 563-2000-655. As a result, there was insufficient data to fully assess both the extent of the flow loss and the potential for recovery. TGD 563-2000-655 stipulates that mining companies must now submit flow measurements and observations collected over a 24-month period prior to undermining (PADEP 2005). However, TGD 563-2000-655 also notes that such pre-mining flow data may be extrapolated from "control" streams when necessary. It is unclear why a control stream was not utilized in this case. Overall, the stream losses at High Quality Mine were instructive for both the mining industry and the PADEP – not only did this case highlight the limitations to longwall mining but it also emphasized the shortcomings in previous data collection methods.

The second case study in which PADEP ruled that streams have not recovered from longwall mining involves a group of six streams from Bailey Mine (Table VIII-3). Together, these streams were the focus of 13 of the 24 streams investigations from Bailey Mine during the 3rd assessment period (Iannacchione et al. 2011), indicating that they were heavily impacted by mining. Because these streams were undermined before the mine operator came into compliance with TGD 563-2000-655, PADEP determined that recovery should be based on flow only. Two separate consent order and agreements (CO&A) detailed the recovery conditions agreed upon by PADEP and the mine operator for this group of streams. Stream 32596 was the subject of a CO&A that was filed on 19 September 2007 and amended on 24 April 2008 (Docket # 066008 and 076010). The other five streams were included under CO&A Docket # 086003 which was filed on 11 June 2008 and amended on 8 September 2008. The latter CO&A is commonly referred to as the “Bailey Mine Global CO&A”. PADEP delivered separate rulings for each CO&A on 27 December 2012.

Table VIII-3. Streams from Bailey Mine that PADEP has determined are not recovered. Panels listed indicate locations of irreparable impacts.

PA WRDS Stream Code[1]	Stream Name	Panels
32598	Polly Hollow	1-4I
32511	UNT to Dunkard Fork	16C
32595	UNT to North Fork of Dunkard Fork	2-5I
NA	Crow's Nest	2-4I
32534	UNT to UNT of Dunkard Fork	9-10H
32596	UNT to North Fork of Dunkard Fork	1-4I

[1] NA = Zero order tributary

For stream 32596, undermining occurred from February 2004 to September 2005 by the 1-4I panels of Bailey Mine. The stream is oriented perpendicular to the longwall panels and was mined in a downstream direction. The streambed is characterized by a large amount of exposed bedrock (26%) as well as cobble, gravel, and silt (ST1203). Overburden depths range from 330-570 feet across the four panels, and are near the lower end of this range across the 3 and 4I panels (ST1203). The thickness of the coal seam being mined in this area is unknown, although a recent permit revision indicates that the mining height in Bailey Mine is generally 6.5-ft (Bailey Mine, Permit Revision 150). Following mining, the stream experienced flow loss impacts. The impacts were particularly severe over the 3I-4I panels, where zero flows (i.e. 0-gpm) were recorded at surface water monitoring station HSW02 from April 2005 to February 2007 (see ST1203). PADEP initiated separate stream investigations for the flow loss impacts over each panel, resulting in four stream investigations for stream 32596 during the 3rd assessment period (Iannacchione et al. 2011). As discussed above, one investigation was withdrawn while the other three were combined into ST1203 during the 4th assessment. To maintain flow at least 10 augmentation discharge points were installed, seven of which were active during the 4th assessment (Table VII-13). Additionally, maps from Consol indicate that approximately 75% of the stream’s 5,500-ft had been grouted by December 2008 (Consol Energy Inc. 2009). Grouting has occurred within each panel with varying effectiveness. Due to continued flow loss in the 3I panel, a synthetic stream liner was installed (Table VII-15). In the 4I panel, cement grouting did not repair the flow loss impacts, so the mine operator applied additional grouting using a polyurethane mixture. To evaluate recovery of the stream for the CO&A, PADEP used data from surface water monitoring stations (i.e. volumetric flow rates), augmentation discharges, and precipitation through May 2012. Augmentation was turned off in early 2011 to evaluate natural stream flow conditions. During this augmentation reprieve, only the two most upstream surface water monitoring stations experienced zero flows. These zero flows occurred during the dry season. However, precipitation was well above average during the augmentation reprieve. The period prior to the undermining of stream 32596 was also characterized by above-average precipitation and so, using pre-mining data from the surface water monitoring stations, PADEP determined that “the stream, post-mining, does not flow to the same degree after similar precipitation amounts as it did pre-mining”.

For the streams covered under the Bailey Mine Global CO&A, the mining and mitigation conditions vary. Stream 32511 was actually undermined by the 16C panel in Bailey Mine at the end of the 2nd Act 54 assessment period, between 19 February 2003 and 2 March 2003 (see ST0318). This stream runs in a northeast to southwest direction across the panel. Mining started at the headwaters and progressed in a downstream direction. Overburden depths for this stream segment range from 546-ft at the 16C tailgate to 523-ft at the 16C headgate (see ST0318). After mining, heaving was observed in the stream channel and flow loss occurred. At least 3 augmentation wells have been used to sustain flow (Table VII-13) to this stream during the 4th assessment period. Additionally, “the majority of the 16C panel section of this tributary has been mitigated” (Consol Pennsylvania Coal Company 2010) using grouting techniques. Consol attempted to negotiate with the landowner to purchase the property and perform additional mitigation work; however, these negotiations were described by PADEP as “tentative” (ST1203).

Streams 32595, 32598, and Crow’s Nest are located in the same area of Bailey Mine as stream 32596 and generally share many characteristics with that stream. These streams were undermined between 2004 and 2006. The streams run perpendicular to the panels in many places. All watersheds were mined in a downstream direction. Overburden depths are within the range of those observed at 32596. For example, overburden depths on stream 32595 are 510-ft in the 2I panel, 462-ft in the 3I panel, 390-ft in the 4I panel, and 345-ft in the 5I panel (see ST0519). Following mining, compression heaves and bedrock fracturing resulted in mining-induced flow loss impacts on each of these streams. For stream 32595, at least five augmentation wells were installed to maintain flow across the 2I-5I panels (Table VII-13) and the stream channel was grouted in areas throughout these panels. The Crow’s Nest tributary, which runs across the 4I and 5I panels of Bailey Mine, had at least three augmentation points installed in the 5I panel (Table VII-13). The entire length of the stream within this panel was mitigated using grouting (~1,200-ft). Stream 32598 was undermined and experienced flow loss in the 1-4I panels. Due to landowner access issues in the 2I and 3I panels, mitigation work was only performed in the 1I and 4I panels. As for the un-mitigated 2I/3I panels, PADEP observations from March 2012 indicate that flow loss impacts remain and that mitigation in surrounding panels has not restored flow to these sections (Figure VIII-2).

The mining conditions at stream 32534 differ in several interesting ways from those at the other Bailey Mine Global CO&A streams. First, this stream was undermined later than the others, from December 2006 through August 2007, by the 9H and 10H panels of Bailey Mine. Second, rather than perpendicular, roughly 2/3 of the stream length runs nearly parallel to the panels. The headwaters of stream 32534 begin in the 10H panel and flow in a northeasterly direction, crossing just briefly into the 9H panel. In the 9H panel, the stream orientation changes and the stream flows in a southeasterly direction until it empties into stream 32532. Due to this unique orientation, the stream was not mined from its headwaters to its mouth. Instead, the mid-section was first undermined by the 9H panel, with the headwaters being undermined later by the 10H panel. While this stream differs in orientation and direction of mining, in terms of overburden and natural characteristics it is quite similar to the other Bailey Mine Global CO&A streams.

Overburden depths range from 437-ft to 607-ft and the stream is characterized by large amounts of exposed bedrock. As in stream 32598, landowner access issues prevented mitigation in the 10H panel. In the 9H panel, at least three augmentation wells were installed to maintain flow (Table VII-13) and grouting was used to mitigate bedrock cracks.

Figure VIII-2. Portion of 600-ft no flow section across the 2I/3I panel of Polly Hollow (Stream 32598) in March 2012, approximately seven years after mining. Landowner access issues have prevented mitigation on this stream segment. (Photo courtesy of PADEP)

To determine the recovery status of the Bailey Mine Global CO&A streams, PADEP compared the average percent of non-flowing stream length (hereafter, average percent flow loss) in the wet and dry seasons to data from a set of four control streams (Figure VIII-3). Originally, five control streams were named in the CO&A – streams 32553, 32604, 32606, 32619, and 32620. However, PADEP hydrologists determined that data from control stream 32553, an unnamed tributary to Hewitt Run, were significantly different from that of the other four control streams. Specifically, stream 32553 had larger average percent flow loss relative to the other control streams. As a result of these differences, stream 32553 was excluded from the analysis. For the remaining control streams, the PADEP examined the range of average percent flow loss in the wet and dry seasons (range = minimum average percent flow loss on a control stream - maximum average percent flow loss on a control stream). The average percent flow loss for the streams covered under the Bailey Global CO&A were then compared to this range. If the average percent flow loss fell outside the control stream maximum, then the stream was determined to be impacted.

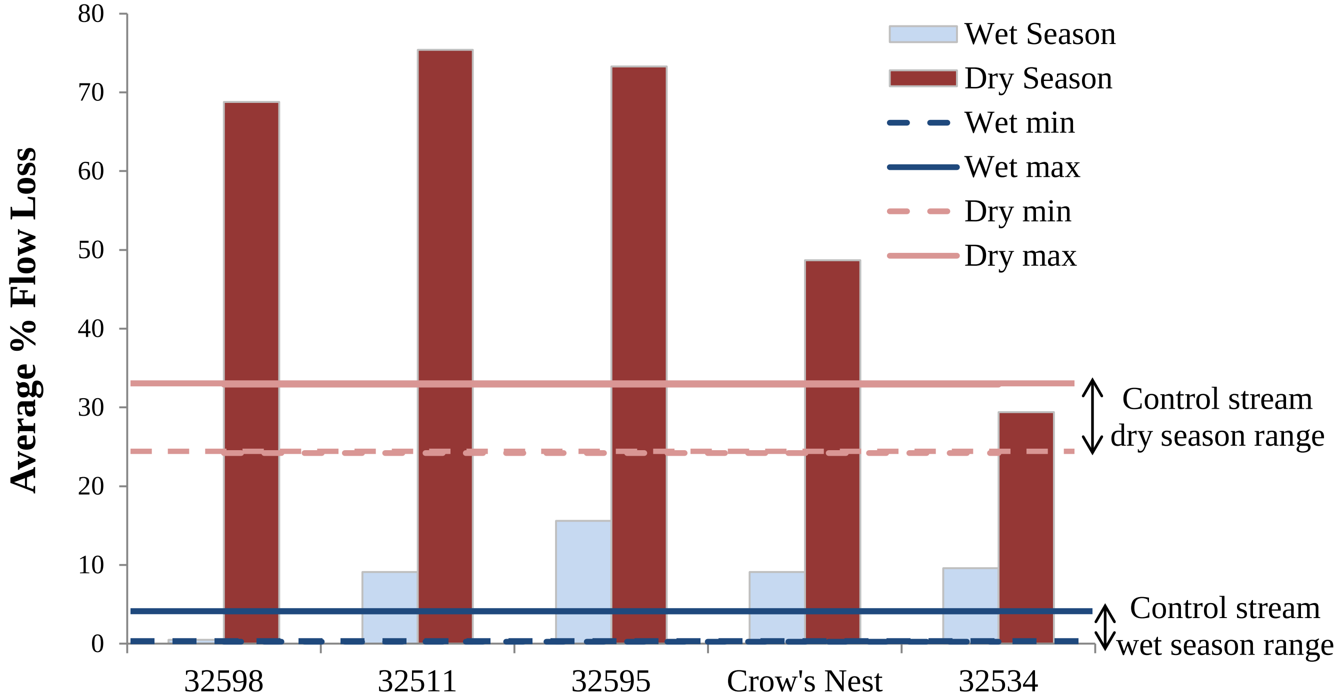

Figure VIII-3. Average percent non-flowing stream lengths in the wet and dry season for streams from the Bailey Mine Global CO&A (bars). Maximum and minimum average percent non-flowing stream lengths for control streams are shown for comparison (lines).

The PADEP determined that during the August 2010-August 2011 period, the average percent flow loss for four of the five undermined streams during the wet season exceeded the range of flow loss in control streams (Figure VIII-3). In fact, the average percent flow loss was two to three times that experienced by control streams. Similar trends were found in the dry season, with four of the five streams again experiencing flow losses outside the control stream range (Figure VIII-3). For streams 32598 and 32511, analysis of data from August 2010-August 2012 revealed the same patterns. On the basis of these data, the PADEP determined that streams 32511, 32598, 32595, Crow's Nest, and 32534 have not recovered from mining-induced flow loss impacts

When comparing the rulings for the two CO&A's in Bailey Mine, two major differences stand out. First, the type of data used to measure flow recovery differs between the two CO&A's. For stream 32596, data on post-mining volumetric flow rates (in gallons per minute) was matched with precipitation and augmentation patterns. For the five streams in the Bailey Mine Global CO&A, the average percent flow loss was compared to the range of average flow loss in multiple control streams (Figure VIII-3). Second, the use of control streams differs between the two CO&A's. For stream 32596, the data from surface water monitoring stations were not compared to control stream data. In contrast, the average percent flow loss for the five Bailey Mine Global CO&A streams was compared to data from four other control streams. The lack of control stream data for stream 32596 may be due to the availability of pre-mining data at the surface water monitoring stations. However, for some of the stations, less than a year's worth of pre-mining data (N = 10 observations) was used in the assessment, which is inadequate for establishing a "normal range of conditions".

Using data from these case studies, the mine operators and PADEP have begun to address a critical question – namely, what factors contribute to extreme mining-induced flow loss impacts? The ability to predict which streams are likely to experience flow loss is critically important, as TGD 563-2000-655 stipulates that "Underground mining operations should be planned and conducted to prevent adverse effects". TGD 563-2000-655 suggests several factors that are likely to be associated with flow loss (PADEP 2005). Consol Energy, Inc. has further classified the factors into two classes - primary and secondary indicators of flow loss (Bailey Mine, Permit Revision 150). They include the following:

PRIMARY FACTORS

1. Drainage/watershed area: Streams with smaller watersheds are more susceptible to flow loss.
2. Streambed lithology: Streams with a larger percentage of exposed bedrock in the stream channel are more susceptible to flow loss.
3. Depth of cover: Streams with shallow overburden depth are more susceptible to flow loss.
4. Percent of watershed mined: Streams with a greater percentage of the watershed mined are more susceptible flow loss.

SECONDARY FACTORS

5. Overburden geology: Streams with a greater percentage of "hard rock" in their overburden are more susceptible to flow loss.
6. Stream orientation: Streams with extensive lengths overlying the tensional zone of the panels are more susceptible to flow loss.
7. Presence of natural fracture zones: Streams with natural fracture zones are more susceptible to flow loss.
8. Mining height: As the mining height (i.e. coal seam thickness) increases, the likelihood of flow loss on above streams also increases.

The University recommends that PADEP and mine operators move beyond these general rules and use data from the case studies above to create more detailed predictions regarding mining-induced flow loss impacts.

VIII.C – Status of Streams Sampled for Biology during 3rd Assessment

Of the five streams that were undermined prior to the implementation of TGD 563-2000-655 but evaluated by the University of Pittsburgh in both the 3rd and 4th assessment periods, two streams have improved in TBS since the 3rd assessment, while three streams have declined (Figure VIII-4). Below, a detailed evaluation of the current status of each of these streams is provided.

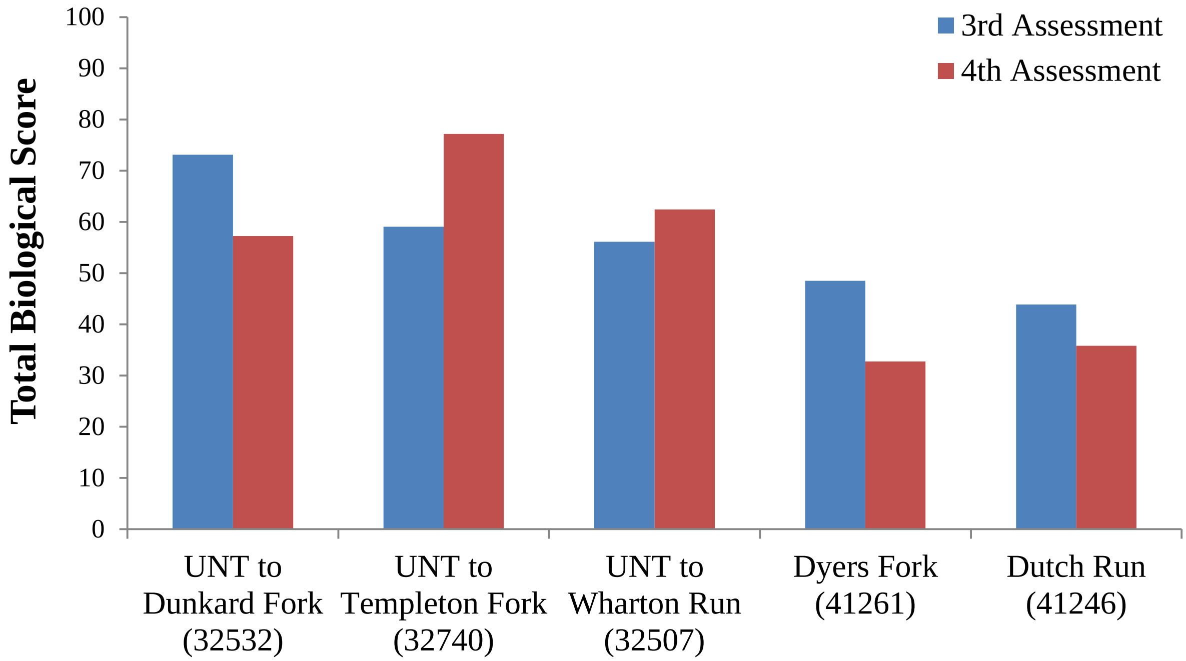

Figure VIII-4. Comparison of Total Biological Scores from the 3rd vs. 4th assessment for five streams undermined prior to compliance with TGD 563-2000-655.

VIII.C.1 – Stream 32532, unnamed tributary to Dunkard Fork

Stream 32532 was undermined by a total of eight panels in Bailey Mine (7H-14H panels). The only portion of the stream that was not undermined is a ~1,000-ft section near the mouth. The stream is a second-order tributary and classified as a warm water fishery. The mining of the 8H panel resulted in significant heaves and subsequent flow loss to the stream across both the 7H and 8H panels in June 2006. The length of flow loss regularly met or exceeded 4,000-ft. According to BUMIS, the mine operator immediately initiated heave removal and grouting in July 2006. On 4 August 2006, CDMO opened a formal stream investigation for this stream (ST0606). In an email dated 22 November 2010, a PADEP biologist indicated that samples collected in the 7H and 8H panels of stream 32532 generated TBS of 83.5 and 72, respectively. According to the email, these scores exceeded the pre-mining TBS of 63, indicating that this section of the stream had recovered biologically (Figure VIII-5). The investigation was closed by PADEP on 1 September 2010.

In the 3rd assessment, the University's macroinvertebrate sample from the 7H/8H gate area scored a 73.1, which is similar to the PADEP's TBS for the 8H panel. During the 4th assessment, the University sampled the same area on 23 April 2013 and this sample had a TBS of just 57.3. This score represents a strong decline from the 3rd assessment and the scores reported by PADEP (Figure VIII-5). Specifically, decreases were observed for four of the five biological metrics, including a loss of six taxa – four of which were Trichoptera (See Appendix D1).

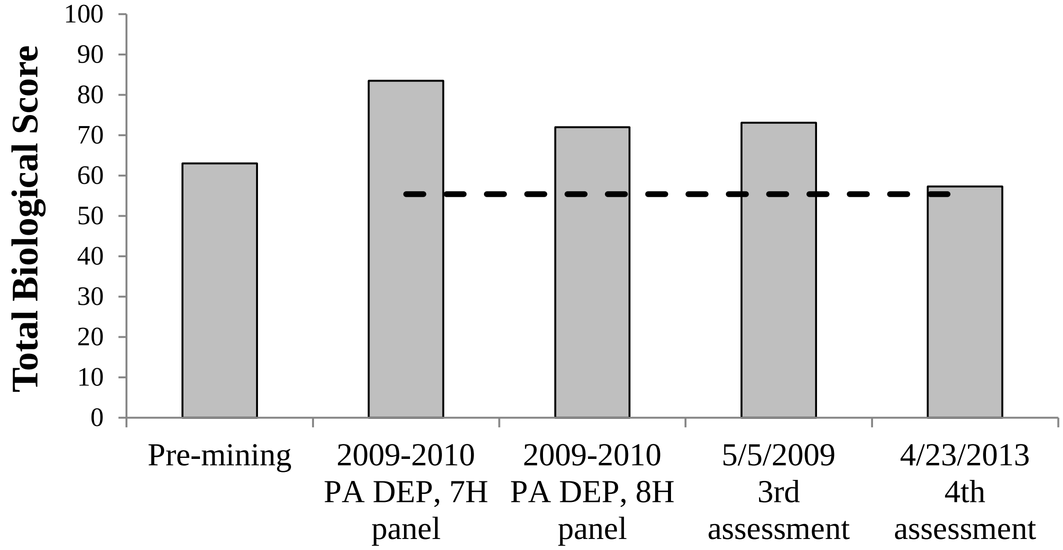

Figure VIII-5. Total Biological Scores for stream 32532, an unnamed tributary to Dunkard Fork, collected by the mine operator, PADEP and the University. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

While it appears that the score for this stream has declined over time, augmentation may be partially responsible for the inflation of TBS during the 2009 and 2010 samplings. Augmentation data from the mine operator shows that this stream received augmentation through January 2011 (Figure VIII-6). While the source of the augmentation may not have been directly within the 7H or 8H panels, augmentation in upstream panels could still influence downstream flow conditions and thus, the macroinvertebrate community. Augmentation was particularly abundant during the falls of 2008 and 2009, just before the spring samplings of 2009 and 2010 (Figure VIII-6). Because many aquatic macroinvertebrates lay their eggs during the late fall (Wallace and Anderson 1996), augmentation during this period may have allowed the egg and larval stages of certain taxa to persist until the spring when the samplings were conducted. Without augmentation, taxa that are sensitive to low flow or flow loss conditions may be unable to survive. It is likely that on-going augmentation prohibited proper evaluation of flow and biological recovery by the PADEP and by the University in the 3rd assessment period. Since this time, the PADEP has created an "augmentation reprieve" period for mine operators during which augmentation is turned off to evaluate natural flow and biology. This new policy should prevent augmentation from affecting measures of recovery on streams mined after TGD 563-2000-655.

Lastly, it is important to note that the University's score of 57.3 is greater than 88% of the pre-mining TBS of 63. This indicates that despite the lower score when augmentation is not present, the macroinvertebrate community is meeting the pre-mining conditions.

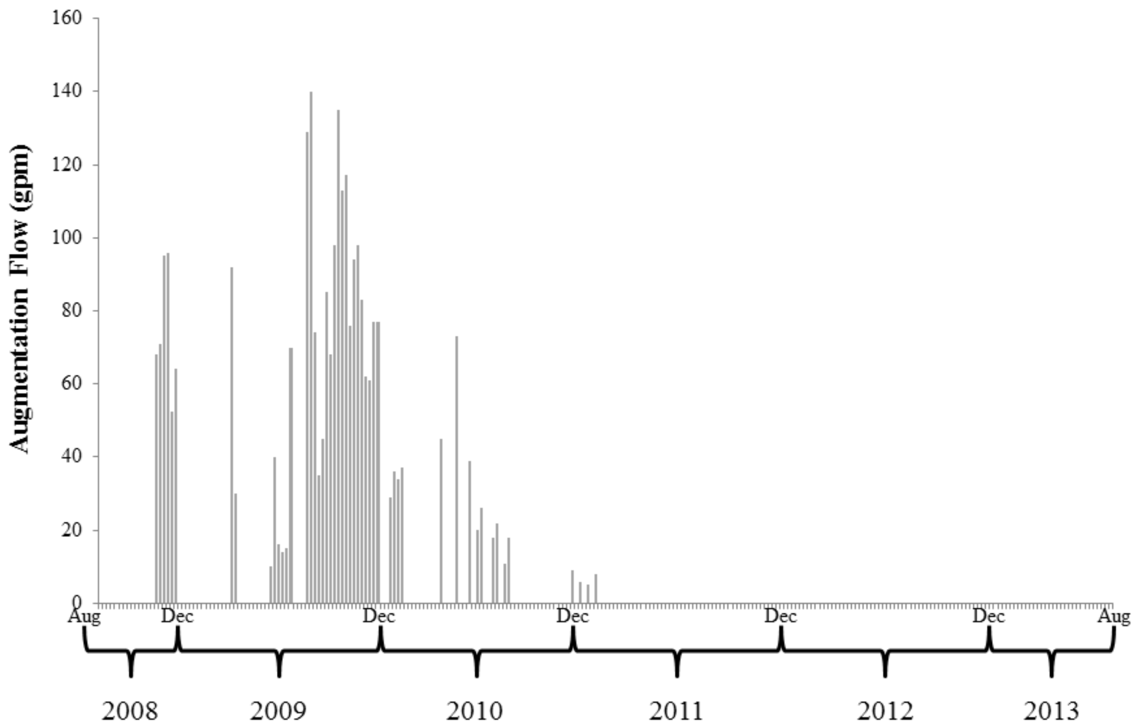

Figure VIII-6. Augmentation flow (in gpm) for stream 32532, an unnamed tributary to Dunkard Fork, during the 4th assessment period (Provided by the mine operator to PADEP). Mining of the 8H panel occurred in June 2006.

VIII.C.2 – Stream 32740, unnamed tributary to Templeton Fork

Stream 32740 is a first order stream with a trout-stocking fishery use designation. This stream was completely undermined by four successive panels (F13-F16) in Enlow Fork Mine during the 3rd assessment. Compression heaves and cracks were noted on 20 September 2006 in the F13 panel by PADEP. Augmentation was used to maintain flow until grouting could begin in the spring of 2007. Despite subsequent heaving and flow loss issues in the F14 panel as well, a formal stream investigation was never opened on this stream during the 3rd assessment period. It was not until 2009 that a stream recovery report (SR0901) was submitted by the mine operator for stream 32740.

The PADEP determined that both flow and biological recovery were required for this stream because the bulk of the undermining occurred after the implementation of TGD 563-2000-655. Pre-mining flow data from 2004 and 2005 indicated that in wet years such as 2004 (Table VIII-4), the stream flowed continuously. In 2005 when precipitation levels were similar to the 30-year average (Table VIII-4), the stream exhibited significant drying from August through October. For example, on 14 August 2005, 52% of the observed stream length was found to be dry (2,967 of 5,679-ft). Despite having two years of pre-mining data for stream 32740, the mine operator contended that the two very wet years of 2003 and 2004 (Table VIII-4) resulted in skewed pre-mining data for both 2004 and 2005. Thus, PADEP approved 40939, an unnamed tributary to Crafts Creek, as a control stream for use in determining both flow and biological recovery.

Table VIII-4. Monthly and yearly precipitation totals for Waynesburg, PA from 2003-2005 as well as the 30-year average (Provided by the mine operator to PADEP).

	30 year average	**2003**	**2004**	**2005**
Jan	2.93	3.33	3.67	6.42
Feb	2.52	5.40	2.40	1.85
Mar	3.51	1.45	3.72	4.04
Apr	3.25	2.40	4.46	2.69
May	4.18	7.17	4.42	3.36
Jun	3.64	7.15	6.33	2.10
Jul	4.01	7.60	4.22	4.41
Aug	3.94	7.66	5.96	3.59
Sept	3.20	3.50	8.33	0.93
Oct	2.48	3.50	4.01	4.16
Nov	3.21	6.70	3.64	3.59
Dec	2.70	2.63	2.53	1.88
Total	**39.57**	**58.49**	**53.69**	**39.02**

To evaluate flow recovery, PADEP reviewed detailed flow data that was submitted by the mine operator on 29 October 2009. The data reveal that the post-mining percentage of non-flowing stream lengths is consistently greater than the pre-mining percentage in all panels (Table VIII-5). However, because the mine operator contended that the pre-mining data were skewed by abnormal precipitation (Table VIII-4), the critical comparison is the post-mining percentage of stream dry vs. the control stream percentage of stream dry. The post-mining percentage of stream dry for stream 32740 is more than twice that of the control stream (38% vs. 16%), suggesting that flow has not recovered in stream 32740. However, PADEP agents determined that this stream had met the requirements for flow recovery and released the case.

In terms of biological recovery, the PADEP sampled this stream in 2009 and found that the TBS for the F13 panel was higher than the score for the control stream (Figure VIII-7). As a result, the PADEP ruled that the stream's biological community had recovered. With both the flow and biological assessments in hand, the stream recovery report was closed on 5 February 2010.

During the 3rd assessment, the University sampled this stream on 29 May 2009, just 3 weeks after the PADEP's sampling effort, and the University's TBS matched PADEP's score (Figure VIII-7). For the 4th assessment, the University re-sampled the same area on 9 May 2013. This sample had a TBS of 77.2, suggesting that the macroinvertebrate community has continued to improve over the past four years. Indeed, four of the five metrics showed strong increases since the last assessment (See Appendix D1). The significant recovery of the biological community over the past several years calls into question the appropriateness of the control stream TBS as an accurate benchmark for measuring recovery of this stream.

Table VIII-5. Flow loss data for stream 32740, an unnamed tributary to Templeton Fork, and control stream 40939, an unnamed tributary to Crafts Creek (Provided by the mine operator to PADEP in October 2009). Bold numbers indicate the key comparison for assessing flow recovery.

Stream	Location	Timing	Average Dry Length, ft	Average Percentage of Monitored Length Dry
32740	Overall	Pre-mining	331	7%
32740	Overall	Post-mining*	1,479	**38%**
32740	F-13 Panel	Pre-mining	128	10%
32740	F-13 Panel	Post-mining	229	17%
32740	F-14 Panel	Pre-mining	31	2%
32740	F-14 Panel	Post-mining	293	19%
32740	F-15 Panel	Pre-mining	148	10%
32740	F-15 Panel	Post-mining	506	33%
32740	F-16 Panel	Pre-mining	20	2%
32740	F-16 Panel	Post-mining	136	10%
40939	Overall	Control*	1,174	**16%**

*For period after mining of F-16 panel

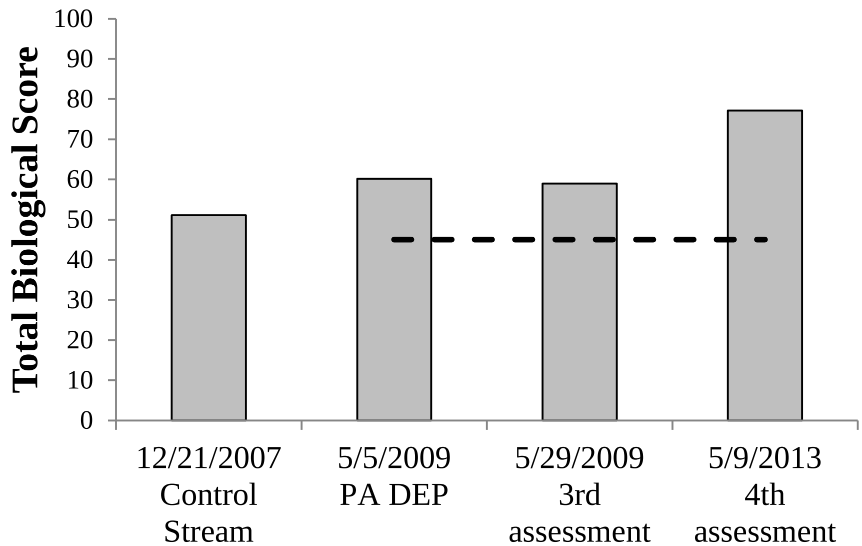

Figure VIII-7. Total Biological Scores for stream 32740, an unnamed tributary to Templeton Fork, collected by the PADEP and the University and compared to the score for control stream 40939, an unnamed tributary to Crafts Creek. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VIII.C.3 – Stream 32507, unnamed tributary to Wharton Run

This warm water fishery was undermined by the 7H panel of Bailey Mine in 2005. On 24 August 2005, flow loss and fractures were noted by PADEP. These impacts triggered stream investigation ST0511 on 1 September 2005. The PADEP approved a monitoring plan for this stream on 5 May 2006 that would "consist of monthly stream flow measurements, location of flowing and non-flowing segments, and biological sampling on two separate occasions." The mine operator submitted monitoring reports in 2007 and 2010. Two years of pre-mining flow data - from 2003 and 2004 - were present for this stream. However, as with stream 32740, the mine operator contended that the data came from years with unusually large amounts of precipitation (Table VIII-5). In contrast to the investigation on stream 32740, PADEP did not require selection of a control stream for comparison. The University could not determine the reason for the inconsistencies between these two cases.

As stipulated in the monitoring plan, the final 2010 report contained two types of flow data: pre- and post-mining lengths of non-flowing segments (Table VIII-6) and graphs of precipitation vs. pre- and post-mining volumetric surface flow (Figure VIII-8). However, without control stream data for comparison, the datasets provide little insight on flow recovery and if anything, indicate a lack of recovery. For example, the post-mining non-flowing lengths are 58 times those recorded prior to mining (Table VIII-6). Even after grouting, on average ~50% of the stream length remained dry (Table VIII-6).

Table VIII-6. Flow loss data for stream 32507, an unnamed tributary to Wharton Run (Provided by the mine operator to PADEP).

Timing	Average Dry Length, ft	Average Percentage of Monitored Length Dry
Pre-mining	8.1	0.29%
Post-mining	1,629.1	58.43%
Post-grouting	1,377.3	49.40%

These differences in the length of non-flowing segments may be a function of the variation in precipitation over time. Therefore, the mine operator graphed precipitation vs. volumetric flow in an attempt to control for precipitation. Unfortunately, the analysis suffers from two major problems. First, precipitation should be plotted on the x-axis and flow should be plotted on the y-axis because flow varies as a function of precipitation. Second, the most meaningful interpretation of such a graph would be to fit separate regressions to the pre- and post-mining data to determine if the slope of the relationship changes after mining. One would predict that after mining, if precipitation is quickly lost to cracks in the bedrock, then stream flow would be low even after significant precipitation events. This would lead to a lower slope in the post-mining regression. Instead, the mine operator plotted a single regression for both the pre- and post-mining data (Figure VIII-8). While this relationship is largely meaningless, the graph does reveal that volumetric flow rates were reduced nearly 100-fold following mining. The PADEP ruled that flow had recovered despite these extreme inadequacies in the flow data.

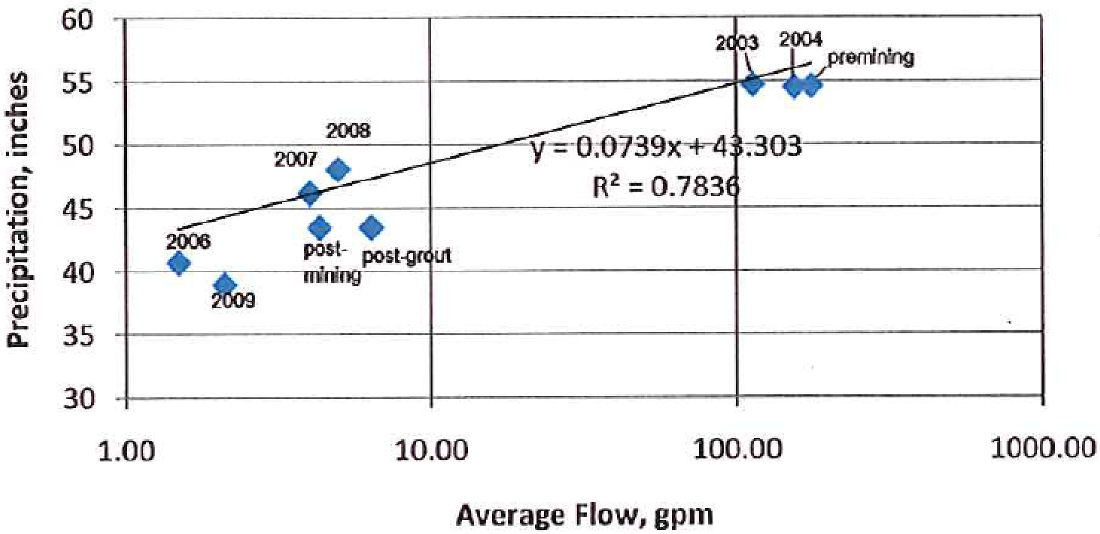

Figure VIII-8. Graph of precipitation vs. volumetric flow rates as recorded at a surface water monitoring station at the mouth of stream 32507, an unnamed tributary to Wharton Run (Provided by the mine operator to PADEP).

In terms of biological recovery, the mine operator's 2010 report contained TGD 563-2000-655 Appendix A sampling that showed the stream was supporting a biologically diverse macroinvertebrate community after mining. Because the stream was undermined prior to the implementation of TGD 563-2000-655, it was not subject to more rigorous biological monitoring. The stream investigation was closed on 19 May 2010.

On 16 April 2013, the University visited the exact location that had been sampled during the 3rd assessment to collect another macroinvertebrate sample. The TBS increased from 56.1 during the 3rd assessment to 62.4 in the 4th assessment (Figure VIII-4). The increase in TBS can be attributed in large part to the presence of six additional taxa in the sample from this period (See Appendix D1).

Despite this increase in TBS, the lack of both pre-mining biological data and a control stream prohibits an assessment of stream biological recovery. Because the 4th assessment score is within 16% of the 3rd assessment post-mining score (PADEP 2005), the diversity of the macroinvertebrate community in stream 32507 appears to be relatively stable following mining.

VIII.C.4 – Stream 41261, Dyers Fork

Dyers Fork is a third order stream with designated uses that include trout-stocked fishery and wildlife water supply. Dyers Fork runs across Cumberland Mine, and during the last assessment period, the downstream half was undermined by panels 51-55. While flow loss has occasionally occurred as a result of mining under Dyers Fork (see ST0323), pooling has become an increasing problem as the mining progresses downstream. The extremely low gradient of this stream (0.015%) and its parallel orientation to the panel in many places make it highly susceptible to subsidence induced pooling (WPI 2012a). The pooling issues have never triggered stream investigations though – this is because the mine operator acknowledged that the pools would result from mining and submitted mitigation plans to the PADEP in advance of mining. Once mining was complete and property access issues were resolved, the mine operator commenced stream restoration work. As a result, gate cuts have been performed throughout Dyers Fork (at gates 46/47, 51/52, 52/53, and 53/54).

During the 3rd assessment, the University sampled the biological community in panel 52 of Dyers Fork on 12 May 2009. The sample scored 48.5 (Note: This TBS differs slightly from that reported in the 3rd assessment. The 3rd assessment score included counts of Coleoptera taxa that are not approved for use with the Total Biological Score metric, according to TGD 563-2000-655 (PADEP 2005)). At the time of sampling, the 51/52 gate cut had been completed, but significant pooling still existed at the tailgate of panel 52. The gate cut across the 52/53 gate (Figure VIII-9) was extremely complex as it required restoration activities under the Route 19 bridge. As a result, the gate cut took place in two distinct phases (see discussion in Section VII.I.2).

Figure VIII-9. Looking downstream toward the Route 19 bridge at the completed gate cut on Dyers Fork at the 52/53 gate in Cumberland Mine on 7 May 2013. (Photo by A. Hale)

Following Phase 1, the mine operator established biological monitoring stations along Dyers Fork, including a site known as DF STA 2 in panel 52. Because the stations lacked appropriate pre-mining data, a station on Garner Run (stream 40643; station GAR 4) was approved by PADEP as a control stream (WPI 2012b). TBS for GAR 4 and DF STA 2 following Phase 1 restoration are shown in Figure VIII-10.

While the mean of the two scores collected by Wallace & Pancher, Inc. (WPI) is higher than the mean of the two control stream scores, the WPI scores were not within 16% of each other, and thus do not satisfy the requirements of TGD 563-2000-655 for recovery.

During the 4th assessment, the University sampled station DF STA 2 to compare findings with those of WPI. The University's sample generated a score of 32.7, which is the lowest TBS on record for this station. It is unclear why this sample scored so much lower than those from WPI. It is possible that the subsequent restoration work during Phase 2 impacted the biological community at this station. However, DF STA 2 is located upstream of the 52/53 gate cut area, and thus the only impacts from the gate cut on this site should have been an improvement in flow conditions. The generally low scores observed on this stream may be due in part to the surrounding land use practices and the low stream gradient. Hay and alfalfa fields surround Dyers Fork and the land use analysis in Section VII.C.2 indicates that this land use type is typically associated with low Total Biological Scores.

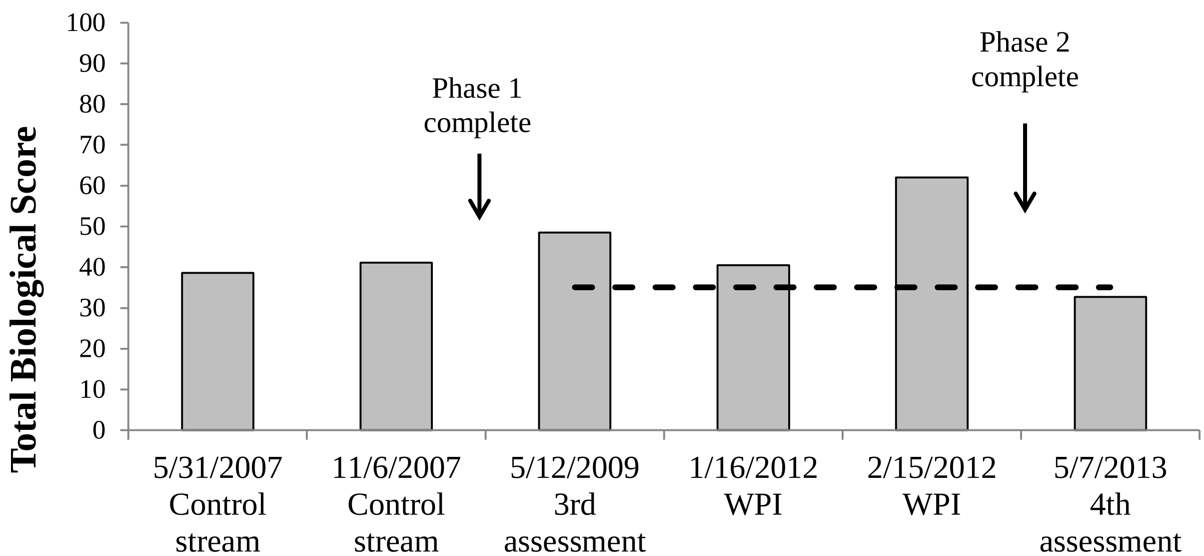

Figure VIII-10. Total Biological Scores for stream 41261, Dyers Fork, in panel 52 collected by Wallace & Pancher, Inc. (WPI) and the University and compared to scores from control stream 40643, Garner Run. Arrows indicate roughly when the two restoration phases were completed. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

Because WPI scores do not meet TGD requirements and the University's 4th assessment score was extremely low, further biological monitoring of Dyers Fork is warranted. While this stream is not currently trout-stocked (WPI 2012a), it is designated as a trout-stocked fishery and this use depends on a healthy macroinvertebrate population.

VIII.C.5 – Stream 41246, Dutch Run

Dutch Run is a second order stream in Cumberland Mine with designated uses as a trout-stocked fishery and wildlife water supply. During the 3rd assessment, the stream was undermined by six successive panels (panels 49-54). Records indicate that every gate road has been cut along this stream to alleviate pooling problems. Like Dyers Fork, stream investigations were not initiated for these stream impacts because the company had predicted the impacts prior to mining and submitted mitigation plans in advance.

During the 3rd assessment, the University sampled the macroinvertebrate community inside panel 53, just south of the 52/53 gate. The area was experiencing pooling at the time of sampling, and generated a TBS of 43.9 (Note: This TBS differs slightly from that reported in the 3rd assessment. The 3rd assessment score included counts of Coleoptera taxa that are not approved for use with the Total Biological Score metric, according to TGD 563-2000-655 (PADEP 2005)). While panel 53 was mined in March 2008, the gate cut for this area (i.e. Restoration Area #7) was not started until January 2012. This was due in part to the addition of a wetland restoration area adjacent to the gate cut (Section X.F). The addition of the wetlands required another permit revision (Cumberland Mine, Permit Revision 105), which was approved by PADEP on 24 January 2011.

When the University re-visited the Dutch Run sampling area on 1 May 2013, the gate cut was completed and the wetlands were in place. However, the wetland plantings had just been installed and as a result, the right stream bank was devoid of mature vegetation (Figure VIII-11). The University's sample generated a TBS of 35.8. The largest difference between the 3rd and 4th assessment samples was found in the taxa richness metric – during the 3rd assessment 20 taxa were collected while the 4th assessment sample only captured 11 taxa (see Appendix D1). It seems probable that these differences are due to the on-going wetland construction project near the sampling site.

Figure VIII-11. Wetlands are being constructed to the right of stream 41246, Dutch Run, in panel 53. (Photo by A. Hale)

While Dutch Run lacked pre-mining data, the PADEP approved a station on Garner Run (stream 40643; station GAR 4) for use as a control stream (WPI 2012b). GAR 4 is the same station that is used as a control for sites on Dyers Fork. Dutch Run's 4th assessment score is greater than 88% of the mean TBS for GAR 4 (mean = 39.85), indicating that despite the reduction in score from the 3rd assessment period, Dutch Run is maintaining a biological community that is comparable to the approved control stream (Figure VIII-12).

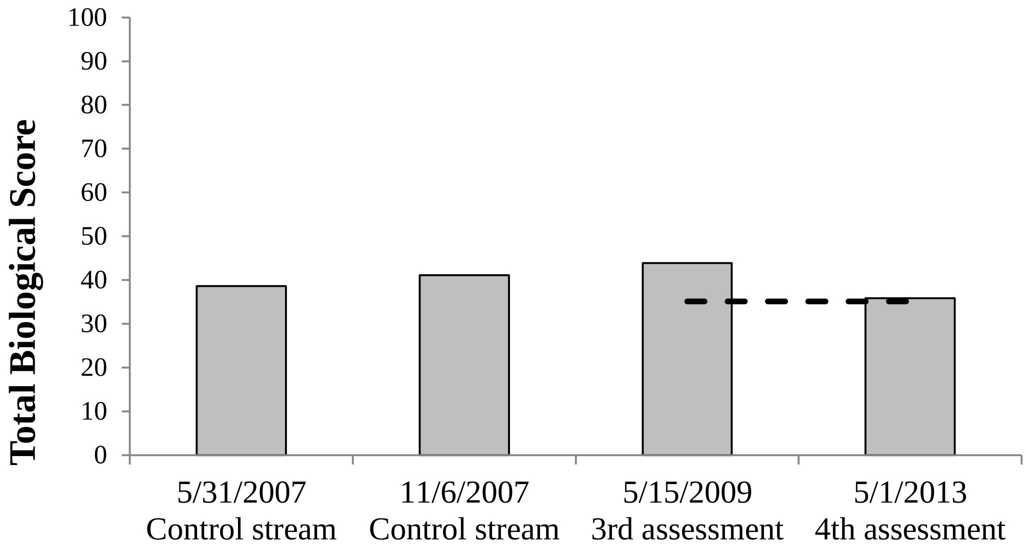

Figure VIII-12. Total Biological Scores for stream 41246, Dutch Run, collected by the University and compared to scores for control stream 40643, Garner Run. Dashed line indicates the minimum Total Biological Score required for stream to be considered recovered.

VIII.D – Summary Points

Of the 55 stream investigations that were initiated in the 3rd Act 54 assessment, 51 reached a final resolution by the end of the 4th assessment period. The average time to resolution for these cases was 1,313 days or just over 3 ½ years.

Four stream investigations from the 3rd Act 54 assessment remain unresolved. These cases have been open for 7-8 years. PADEP is currently reviewing flow data for two of the cases, yet there is little information in BUMIS or the paper files at CDMO regarding the status of flow recovery for the other two cases.

Of the 51 resolved stream investigations, seven cases were ruled by PADEP to be "Not recoverable: compensatory mitigation required". A single case was "Closed due to federal court settlement". Overall, these eight cases represent stream impacts that have not recovered following mining-induced flow loss. A number of mitigation techniques were utilized in an attempt to restore flow, including augmentation, cement grouting, polyurethane grouting, and the installation of stream liners. The University examined the mining and natural conditions at these sites in an attempt to arrive at some general characteristics that may act as predictors of severe stream flow loss. In general, the stream segments in these cases are characterized by shallow depths to mining, with impacts occurring in areas with overburdens less than or approximately equal to 500-ft.

The University also re-sampled the biological communities for five streams that were impacted and studied during the 3rd Act 54 assessment. Of these five streams, two showed improvements in TBS from the 3rd assessment while three experienced declines. Despite the decline in TBS for stream 32532, an unnamed tributary to Dunkard Fork, the 4th assessment score was greater than 88% of the pre-mining score. The apparent decline in TBS between the 3rd and 4th assessment periods may be due to the inflation of TBS during the 3rd assessment period when augmentation on this stream was still on-going. Declines in TBS were also observed on Dyers Fork and Dutch Run, two streams which were impacted by pooling impacts in the 3rd assessment. For Dutch Run, the 4th assessment score was greater than 88% of the approved control stream TBS, indicating that despite the decline from the 3rd assessment, the biological community has recovered. For Dyers Fork, the 4th assessment score is less than 88% of the approved control stream score. Further monitoring of this site will be necessary to ensure biological recovery.

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SECTION IX: Effects of Mine Subsidence on Wetlands

IX.A – Overview

PADEP tasked the University with assessing the impact of mining related subsidence on wetlands in the Commonwealth. Specifically, the University reports on the acreage of wetlands undermined, the change in wetland acreage following mining, and the acreage of wetland replacements conducted during the 4th assessment period. The University also investigates two major issues that are pertinent to wetland management and restoration – natural variation in wetland size over time and the effectiveness of wetland restoration projects.

IX.B – Data Collection and Analysis

IX.B.1 – Determining Total Acreage of Wetlands Undermined and Change in Wetland Acreage Post-Mining

The University collected data on wetland acreage from the paper files at CDMO. TGD 563-2000-655 requires that permit applications include an inventory of all wetlands above areas of planned longwall mining and room-and-pillar mining where depth of cover is < 100-ft (PADEP 2005). Therefore, the University expected to find extensive wetland inventories in files permitting longwall mine expansions. However, locating such data was a challenge. Many of the areas mined during the 4th assessment period were permitted prior to full compliance with TGD 563-2000-655. While TGD 563-2000-655 was approved in October 2005, full compliance was only required for permit applications received 24 months after TGD 563-2000-655's implementation (i.e. October 2007; PADEP 2005). During this two year window, major expansions were permitted by PADEP, including the Cumberland Mine West Expansion (permitted on 31 July 2007, revision 74) and the Enlow Fork Mine North Expansion (permitted on 18 January 2008, revision 70 – the permit application was received prior to the two year deadline). For these expansions, wetland inventories were only required in areas of surface mining activity (Form 15A). Today, the mine permit application has been revised to reflect TGD 563-2000-655 requirements. Section 8.12 now requires an inventory of all wetlands in areas above underground mining (unless room and pillar depth of cover exceeds 100-ft, as per TGD 563-2000-655).

The University found that the most reliable and complete source of wetland data was located in the permit renewal files for the longwall mines (Appendix J). Mine permits must be renewed every five years, and TGD 563-2000-655 requires that the renewal include an evaluation of wetland gains and losses over the prior five year period (PADEP 2005). Unfortunately, the Act 54 five year assessment period does not perfectly align with the permit renewal timeframe for most longwall mines. As a result, data tables from permit renewals that were submitted prior to August 2013 included data on wetlands that were undermined in the 3rd Act 54 assessment period. They also lacked data on many wetlands that were undermined during the 4th assessment period. Indeed, the data from the Cumberland and Emerald Mine permit renewals is almost exclusively for wetlands undermined during the 3rd assessment period (see maps in Appendix C). For the assessments and analyses below, the University included data on all wetlands that were inventoried in the permit renewals, regardless of whether they were undermined in the 3rd or 4th assessment periods. By using all of the available data, the University provides a complete analysis of mining impacts on wetland acreage. For Cumberland and Emerald Mines, the University supplemented the permit renewal data with data from the ArcGIS files supplied by Alpha Natural Resources, Inc. to the University (Appendix J3 and J4). However, the University kept these data distinct from that reported in the permit renewals. Comparisons across mines are made using only the data in the permit renewals. This allows for comparison of acres undermined and wetland gains/losses during a five year period at each longwall mine.

Blacksville 2 Mine stands out as an exception, as this longwall mine did not submit a permit renewal during the Act 54 assessment period. The Blacksville 2 Mine expansion permit (permitted on 16 March 2009, revision 67) contains data on pre-mining wetland acreage for the expansion area as required by the new mine application. However, without a permit renewal, the University did not have a five-year assessment of wetland acreage undermined or wetland gain/loss for comparison with the other longwall mines. To approximate the wetland acreage undermined in a five year period, the University identified all of the wetlands in the Blacksville 2 expansion and then determined which wetlands were undermined during the 4th Act 54 assessment period. The total acreage of these wetlands was calculated using data from the expansion permit. Thus, the undermined wetland acreage reported for Blacksville 2 Mine actually spans the 4th Act 54 assessment period in contrast to the data from other mines.

Wetland acreage was not assessed at Mine 84 due to the minimal amount of longwall mining that occurred there during the 4th assessment period (~56 acres).

In addition to reporting on wetland acreage, PADEP also requested that the University report on the number of wetlands undermined. However, during identification of wetland locations (Section IX.B.2), the University discovered that many individual wetlands on the maps were being grouped together and identified as a single wetland by the mine operator in the permit renewal data tables. For example, wetland Enlow-53F is listed as a single wetland on the permit renewal data tables for Enlow Fork Mine (Appendix J5), yet maps reveal that this wetland is composed of five separate wetland patches (Figure IX-1). The grouping may have been less problematic if the University could have identified the method behind the wetland grouping. However, it is unclear why Enlow-53F was treated as a group of 5 wetland patches while Enlow-98D was treated a single wetland within that larger group (Figure IX-1). The University also detected wetland grouping in Bailey Mine. Here, 100 pre-mining wetlands were listed in the permit renewal data table but 190 wetland patches were mapped in the field. The University feels that any report on the number of wetlands undermined would be biased and largely inaccurate as a result of the wetland grouping. Therefore, here the University reports only statistics on the acreage of wetlands undermined.

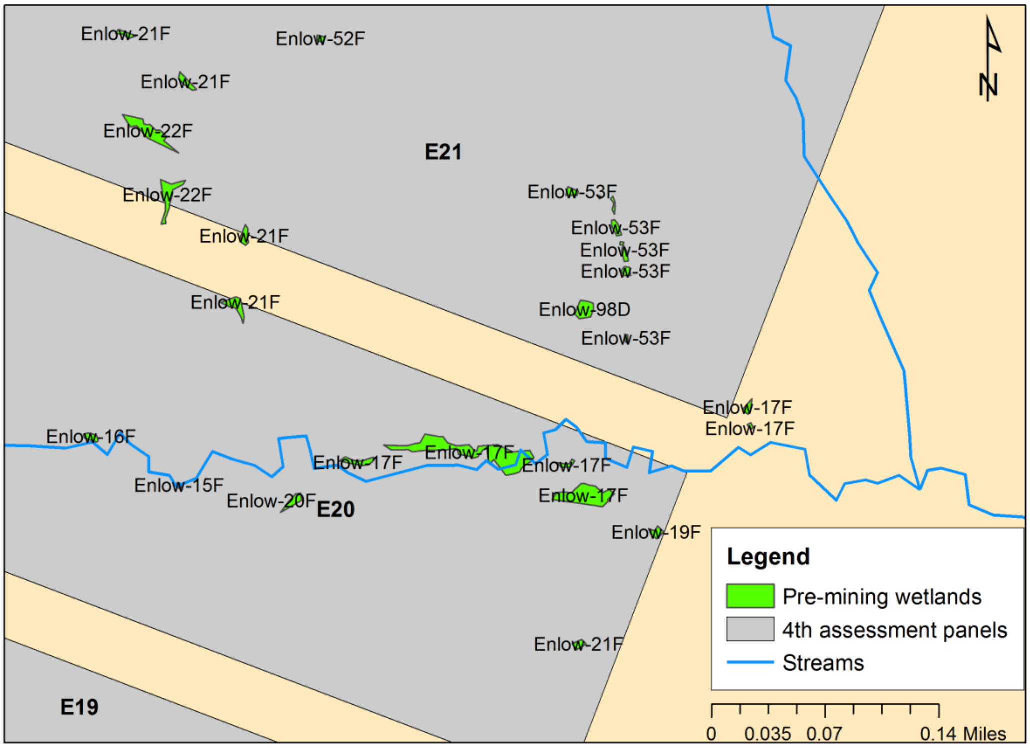

Figure IX-1. Map of Enlow Fork Mine pre-mining wetland delineations. Multiple wetlands are grouped together and identified as a single wetland (e.g. Enlow 53-F). This creates challenges in reporting the number of wetlands undermined using the data from the permit renewals.

IX.B.2 – Identifying Wetland Locations

For a full discussion of the methods used to identify wetland locations, see Section II.C.8. Wetland maps are located in Appendix C.

IX.C – Pre-Mining Wetland Acreage and Type

Across five longwall mines, a total of 236.9 wetland acres were inventoried by mine operators prior to mining. Enlow Fork Mine reported the largest pre-mining wetland acreage, with 150.8 acres of wetlands being identified in the E11-E21 and F10-F19 longwall panels (Table IX-1). However, Cumberland Mine actually had the greatest density of wetlands prior to mining, with 2.92 wetland acres for every 100 acres of proposed longwall mining (Table IX-1). Blacksville 2 and Emerald Mines had similar densities of pre-mining wetlands (~0.60 acres/100 acres of proposed mining), while Bailey Mine had the lowest density with just 0.28 wetland acres for every 100 acres of mining (Table IX-1). The average overburden for these wetlands varied across mines. On average, wetlands at Blacksville 2 Mine had the greatest depth to mining while wetlands at Emerald Mine had < 600-ft of cover (Table IX-1).

Table IX-1. Pre-mining wetland acreage for five longwall mines. Wetlands included in this analysis are located over areas of room-and-pillar or longwall mining. Wetlands outside of mining but within the permit area are not included. Data are from permit renewals and the Blacksville 2 expansion permit.

Mine	Panels Included in Inventory	Acreage Mined by Panels	Pre-Mining Wetland Acreage	Pre-Mining Wetland Acres/ 100 Acres Mined	Average Overburden for Pre-Mining Wetlands
Bailey	9H-14H; 8I-12I	2,645	7.4	0.3	638.1
Blacksville 2	14-18W; part of 19W	1,263	8.6	0.7	843.2
Cumberland	48-53	2,167	63.2	2.9	617.1
Emerald	B1-B2; part of B4	1,139	6.8	0.6	591.6
Enlow Fork	E11-E21; F10-F19	6,159	150.8	2.4	648.9
Total			236.9		

Comparing these data with the 3rd Act 54 assessment, pre-mining wetland acreage more than doubled (3rd assessment acreage: 93.9; Iannacchione et al. 2011). While this assessment includes data on some wetlands that were undermined during the 3rd assessment (Section IX.B.1), there is very little overlap between the data used in the two Act 54 reports. Using the information on wetland acreage and panel location in Appendix G1 of the 3rd Act 54 report, the University determined that only 16.4 wetland acres could potentially be considered redundant between the two reports. Therefore, it is safe to say that the pre-mining acreage reported to PADEP by the mine operators has doubled over the last five years.

The increase in reported pre-mining acreage is likely a direct result of the changes that were required by TGD 563-2000-655. During the 3rd Act 54 report, wetland data were largely unavailable in the paper files at CDMO. As a result, the 3rd Act 54 report, as well as the 2nd Act 54 report, relied on the National Wetlands Inventory (NWI; U.S. Fish and Wildlife Service 2014b) to determine pre-mining wetland acreage. There are two reasons why the NWI alone is inadequate for inventories of pre-mining wetlands. First, the images used by the NWI to delineate wetlands in Greene and Washington counties are from 1982-1985 (NWI Pennsylvania metadata). Landscape and climatic changes over the past 30 years may have resulted in the loss or gain of wetlands that could not be observed using NWI data. Second, NWI wetlands are identified based on vegetation, visible hydrology, and geography using high altitude imagery (U.S. Fish and Wildlife Service 2014b). Errors in wetland boundaries and classification are inherent in this system. Field work is required to ground-truth the NWI and to identify additional wetlands that may not have been detected.

Today, TGD 563-2000-655 requires that multiple sources - including NWI maps, Natural Resource Conservation soil surveys, aerial imagery, and local mapping - be used to identify areas of potential wetlands (PADEP 2005). Field surveys must follow to identify the precise location and limits of each wetland using the Routine Method described in the Army Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). During the field surveys, at least one sampling area/test site is established for each wetland (Bailey Mine, Permit Revision 161; Cumberland Mine, Permit Revision 115; WPI 2010; Enlow Fork Mine, Permit Revision

105). At the test site, dominant plant species, hydrologic characteristics, and a soil profile description are recorded. Wetland boundaries are then delineated and recorded using GPS and sketch maps. In addition to providing more precise boundaries, this method also identifies very small wetlands that are often missed in the NWI delineations. This intensive method of identifying wetlands has likely played a significant role in the increase in reported wetland acreage prior to mining.

Approximately 84% of the pre-mining wetland acreage was composed of palustrine emergent (PEM) wetlands (Table IX-2). Palustrine describes the wetland system, and includes all non-tidal wetlands that are dominated by trees, shrubs, persistent emergent vegetation, or emergent mosses or lichens (Cowardin et al. 1979). Emergent describes the wetland class, and refers to wetlands with greater than 30% cover by erect, rooted, herbaceous, hydrophytic vegetation (Cowardin et al. 1979). PEM wetlands are commonly referred to as freshwater marshes, meadows, or fens. The primary function of most of these PEM wetlands is to provide habitat for wetland species, but many PEM wetlands also provide important flood storage during storm events and pollution prevention (based on functional inventories provided in permit renewals).

The emergent vegetation of PEM wetlands can often transition into scrub/shrub vegetation (PSS). Scrub/shrub vegetation is defined as woody vegetation that is less than 20-ft tall, and includes shrubs and small trees. Wetlands with both emergent and shrubby vegetation are considered PEM/PSS, and these wetlands composed 29.07 acres of the pre-mining wetland acreage for the 4th assessment period (Table IX-2). PEM wetlands can also transition into areas with forested vegetation (PFO), or woody vegetation that is more than 20-ft tall. Wetlands composed of both PEM and PFO areas made up 4.14 acres of the pre-mining wetland acreage (Table IX-2). All other wetland types combined made up less than 4 acres of the total pre-mining wetland acreage (Table IX-2).

Table IX-2. Pre-mining wetland acreage by wetland type for five longwall mines. Data are from permit renewals and the Blacksville 2 expansion permit. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014a).

	Wetland Type (acres)							
Mine	PEM	PEM/PFO	PEM/PSS	PEM1	PFO	PFO1/PEM1	PSS	PSS/PFO
Bailey	6.9	0.3	0.1	0.0	0.0	0.0	0.1	0.0
Blacksville 2	6.5	0.2	2.0	0.0	0.0	0.0	0.0	0.0
Cumberland	54.2	1.0	8.1	0.0	0.0	0.0	0.0	0.0
Emerald	6.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Enlow Fork	125.8	2.7	18.7	0.1	0.4	0.8	2.0	0.4
TOTAL	199.9	4.1	29.1	0.1	0.4	0.8	2.0	0.4

IX.D – Change in Wetland Acreage Following Mining

Bailey, Emerald, and Enlow Fork Mines each reported net gains in wetland acreage following mining-related subsidence (Table IX-3). The largest gains were reported in Enlow Fork Mine, with the addition of three wetland acres. However, the largest overall change in wetland acreage was a net loss of 4.84 wetland acres in Cumberland Mine (Table IX-3). Wetland mitigation is required to offset these wetland losses. The Cumberland Mine wetland mitigation projects are described below (Section IX.F). As for Blacksville 2 Mine, post-mining wetland surveys were not completed by the end of the Act 54 reporting period, so the net change in wetland acreage for this mine could not be assessed.

Table IX-3. Net change in wetland acreage following mining for five longwall mines. Data are from permit renewals and the Blacksville 2 expansion permit.

Mine	Pre-Mining Wetland Acreage	Post-Mining Wetland Acreage	Net Change in Wetland Acreage
Bailey	7.40	7.97	0.57
Blacksville 2	7.45	No data	No data
Cumberland	63.23	58.39	-4.84
Emerald	6.85	8.98	2.14
Enlow Fork	66.12[1]	69.12	3.01

[1] = Includes only those wetlands for which post-mining surveys have been conducted.

While three of the longwall mines reported net gains in wetland acreage, this does not indicate that the pre-mining wetland acreage was unaffected by subsidence. In fact, large losses in pre-mining wetland acreage (~33-41% pre-mining acres lost; Figure IX-2) were offset by significant gains in new wetland acreage for these three mines (Figure IX-2). Interestingly, Cumberland Mine – the only mine reporting a net loss in wetland acreage – actually had the smallest percent loss of pre-mining wetland acreage (Figure IX-2). The minimal gains in wetland acreage following subsidence were not enough however to offset even these small losses.

The question becomes – is the newly created wetland acreage functionally equivalent to the wetland acreage that was lost as a result of mine subsidence? To address this question, the University investigated changes in wetland acreage by wetland type (Table IX-4). In Cumberland Mine, 24 acres of wetlands that were classified as strictly PEM prior to mining were lost following subsidence (Table IX-4). Many wetlands that were considered strictly PEM prior to mining had developed some scrub/shrub vegetation after mining. The PEM wetland acreage was thus re-classified as PEM/PSS during post-mining surveys. There are two possible explanations for this shift from strictly PEM to PEM/PSS wetland types. First, mine subsidence may have lowered the water table, reducing groundwater discharge to the PEM wetlands. Second, variation in precipitation between the pre- and post-mining surveys may have reduced surface water inputs to the PEM wetland. Either of these mechanisms could have reduced the degree of inundation within the PEM wetlands and allowed for the encroachment of facultative wetland (FACW) woody species, such as black willow (*Salix nigra*). Within the PEM/PSS wetlands, the scrub/shrub vegetation is a relatively minor percentage of the total wetland acreage (median percentage of scrub/shrub vegetation = 11%). Thus, the conversion of PEM wetlands to PEM/PSS has not resulted in a total loss of the functions associated with the original PEM wetlands.

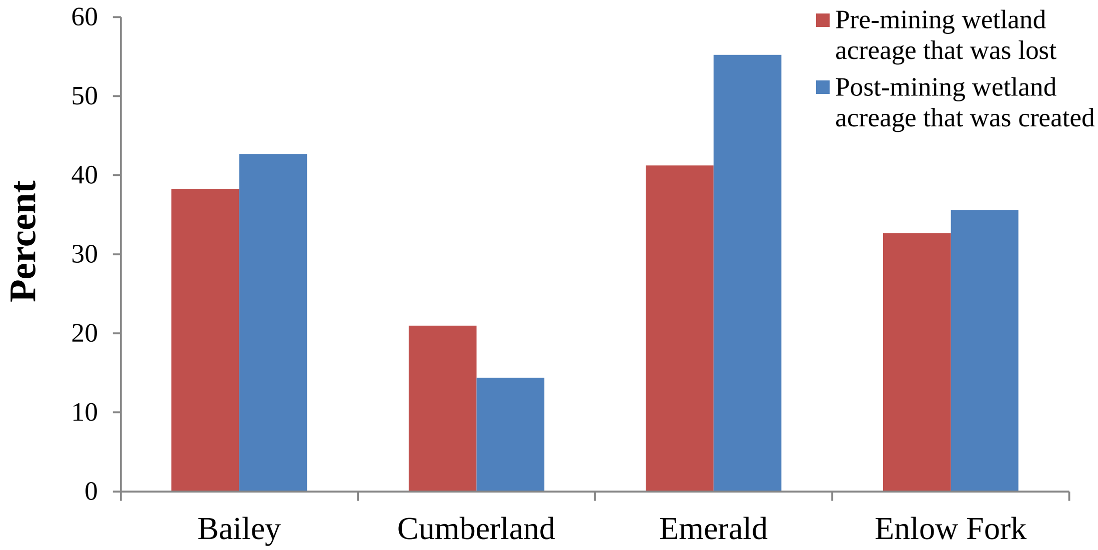

Figure IX-2. Percent of pre-mining wetland acreage that was lost following mine subsidence (red). Percent of post-mining wetland acreage that was created through mine subsidence (blue).

Table IX-4. Change in wetland acreage following mine subsidence by wetland type for five longwall mines. Data are from permit renewals. Blacksville 2 Mine is not included because there is no post-mining data for this mine. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014a).

	Wetland Type (acres)								
Mine	PEM	PEM/PFO	PEM/PSS	PEM1	PFO1/ PEM1	PSS	PSS/PFO	PEM/PSS/ PFO	PEM1B/ PUBHh
Bailey	0.6	-0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Cumberland	-24.0	-0.1	15.8	0.0	0.0	0.0	0.0	3.4	0.0
Emerald	1.8	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Enlow Fork	8.9	1.0	-3.1	-0.01	-0.3	0.5	-0.1	0.0	0.0
TOTAL	-12.7	0.9	12.9	-0.01	-0.3	0.5	-0.1	3.4	0.2

In contrast, the losses in PEM/PSS wetland acreage at Enlow Fork Mine and PEM/PFO acreage at Bailey Mine may be harder to functionally offset with gains via subsidence (Table IX-4). The gains in PEM wetland acreage at both of these mines (Table IX-4) cannot fully replace the habitats and resources that were available in the more complex PEM/PSS and PEM/PFO wetland types. Eventually, the new PEM wetland acreage may develop into PEM/PSS and/or PEM/PFO, however, the slow growth of woody vegetation means that the conversion process will require years to decades.

Interestingly, Bailey Mine also gained acreage of an entirely new wetland type following mining. Post-mining surveys recorded 0.17 acres of palustrine emergent/palustrine unconsolidated bottom (PEM1B/PUBHh) wetlands along stream 32537, an unnamed tributary to the South Fork of Dunkard Fork. The modifiers on the wetland code for these areas indicate that the wetlands are saturated (B) and/or permanently flooded (H) due to a dike or impoundment (h, U.S. Fish and

Wildlife 2014). The last modifier suggests that the new wetland acreage is not due to mine subsidence and rather is a result of changes in land use.

IX.E – Non-Mining Related Influences on Change in Wetland Size

While the PADEP attributes changes in wetland size to mine subsidence, it is important to recognize that climatic variation can cause natural changes in wetland size. Climate influences the water level in freshwater wetlands, and it is the water level that dictates wetland type and size (Keddy 2000). Wetland water levels are largely a function of the balance between precipitation and evapotranspiration (Mitsch et al. 2009). Because precipitation and temperature vary both seasonally and annually, wetland size can vary across multiple time scales. To assess the degree of natural variation in wetland size, multiple pre-mining delineations would need to be performed on a given wetland. While this approach is not economically feasible for all wetlands that will be undermined, targeting a group of wetlands that are representative of the larger set could be useful in interpreting the impacts of subsidence on wetland size. Currently, mine operators only submit a single pre-mining delineation for each wetland to PADEP. However, ArcGIS data from Alpha Natural Resources, Inc. indicate that multiple pre-mining delineations are performed on at least a subset of wetlands. In panel C-2 of Emerald Mine, pre-mining wetland delineations were conducted along Muddy Creek and two of its unnamed tributaries (streams 41086 and 41084) in September 2004 and July 2009. Eight wetlands were identified in the 2004 delineations. In 2009, nine wetlands were identified. A new wetland had been created, but over half of the existing wetlands had decreased in size (Table IX-5). Overall, the area experienced a net loss of 0.816 wetland acres between the two pre-mining delineations (Table IX-5). These losses may be driven by differences in precipitation between the two delineation periods. The University calculated the total precipitation for 12 months prior to each of the delineations and found that the period prior to the 2004 survey was much wetter than the period leading up to the 2009 survey. There were 16 additional inches of precipitation in the period before the 2004 survey, suggesting that the decreases in wetland size in 2009 may have been related to climatic variation. For those wetlands that showed little change in size between the two delineations, it is possible that their primary source of water input may be groundwater, as water levels in groundwater-fed wetlands tend to fluctuate to a lesser degree than water levels in wetlands fed primarily by precipitation and run-off (Mitsch et al. 2009).

Additional data is clearly needed to fully assess the link between climate and change in wetland size. However, based on the case study in Emerald Mine, the University suggests that climatic variation warrants consideration by PADEP when evaluating the impacts of subsidence on wetland acreage. Multiple pre-mining delineations on a focal group of wetlands may provide PADEP and mine operators with a natural standard deviation in wetland size that can be applied to evaluate post-mining delineations. However, the University recognizes that choosing a representative group of wetlands for monitoring may be a significant challenge.

Table IX-5. Comparison of wetland acreage from two different pre-mining delineations (2004, 2009) for wetlands near Muddy Creek over Emerald Mine C-2 panel. Data are from Alpha Natural Resources, Inc.

Wetland ID	Pre-mining 2004 Acreage	Pre-mining 2009 Acreage	Net Change
CBMC-4	0.470	0.319	-0.151
CBMC-3	0.198	0.015	-0.183
CBMC-2	0.423	0.058	-0.365
CBMC-5	0.055	0.088	0.033
CBMC-5A	0.000	0.020	0.020
CBMC-6	0.143	0.100	-0.043
CBMC-7	0.040	0.006	-0.034
CBMC-8	0.011	0.013	0.002
CBMC-9	0.075	0.085	0.009
TOTAL	**1.416**	**0.600**	**-0.816**

IX.F – Wetland Mitigation during the 4th Assessment

Cumberland Mine was the only longwall mine with a subsidence-related net loss of wetland acreage during the 4th assessment period. Because the net loss was greater than 0.5 acres, (Table IX-3), the permittee was required to perform compensatory mitigation. If the loss had been less than 0.5 acres, the mine operator could have made a monetary contribution to the Pennsylvania Wetland Replacement Project which is administered by PADEP and the National Fish and Wildlife Foundation (PADEP 1996). The money from this fund is used to support projects that restore or create wetlands and riparian buffer zones. All losses greater than 0.5 acres however require wetland replacement.

Guidelines for wetland replacement are described in a PADEP Technical Guidance Document entitled “Design Criteria – Wetland Replacement/Monitoring” (hereafter TGD 363-0300-001; PADEP 1997). In general, PADEP requires a 1:1 replacement ratio in area and wetland type for all impacted wetlands (e.g. if 1.1 acres of PEM wetlands are impacted, then 1.1 acres of PEM wetlands must be constructed). Additionally, the guidance stipulates that the replacement wetlands must be located adjacent to the impact site unless an alternative location is approved. When the impacted wetlands share a “significant nexus” with a navigable waterway, the U.S. Army Corps of Engineers wetland replacement guidelines apply (Rapanos v. United States). Unlike PADEP, the U.S. Army Corps of Engineers’ area replacement ratios can vary with wetland type. In the Pittsburgh district, the Army Corps generally recommends PEM replacement ratios of 1:1, PSS ratios of 2:1, and PFO ratios of 3:1 (U.S. Army Corps of Engineers, pers. comm.), however the agency reserves the right to alter the ratios to meet the requirements of the Final Compensatory Mitigation Rule (U.S. Army Corps of Engineers and U.S. Environmental Protection Agency 2008).

To mitigate the wetland losses at Cumberland Mine, the mine operator proposed projects at two different sites. The first mitigation site is located along Dutch Run near the 52 and 53 gate cut areas. During the gate cuts, re-contouring of the stream banks and channel slope modifications impacted 0.88 acres of wetland DR-27. The wetland mitigation project along Dutch Run was designed to offset the losses to wetland DR-27 and to create wetland "credits" (i.e. acres) that could be applied to other projects that required wetland replacement. A total of 2.22 wetlands acres of various types, including PFO, PSS, PEM and POW (Palustrine Open Water; Table IX-6) were created at this site. The wetland impacts to DR-27 claimed 0.88 credits in the new restoration site, while impacts from another restoration project claimed 0.14 credits. As a result, 1.28 credits or acres were left over for application to the wetland losses that resulted from subsidence.

Table IX-6. Breakdown of wetland cover type at the Dutch Run wetland mitigation site. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014a) except as noted. Data are from Cumberland Mine, Permit Revision 105.

Cover Type	Acreage	% of Total Area
POW[1]	0.7	32%
PFO	0.37	16%
PSS	0.93	42%
PEM	0.22	10%
TOTAL	**2.22**	**100%**

[1] = Palustrine open water

The Dutch Run wetland replacement enhanced and expanded portions of DR-27 and also added a large open water area (Figure IX-3). The open water zone is located over an area that was classified as PEM wetland acreage prior to mining but was lost as a result of subsidence. The open water zone is fed by both groundwater inputs and a surface water inlet channel from Dutch Run. An outlet channel leads away from the open water zone and back into Dutch Run to maintain proper water levels in this area. The design was approved by PADEP on 24 January 2011. The Dutch Run stream gate cuts were initiated in January 2012 and wetland excavation for the open water zone began in May 2012.

The University surveyed the Dutch Run wetland mitigation site with PADEP agents on 1 May 2013. At that time, the trees and shrubs had just been planted (Figure IX-4a) and some emergent vegetation was present on the edges of the open zone (Figure IX-4b). Several structures were also present in the open water zone, such as hummocks and root wads, which will provide habitat for wetland animals. Unfortunately, the University cannot assess the effectiveness of the Dutch Run wetland mitigation project in this report. Because the wetland plantings were completed just four months before the end of the University's reporting period, the first monitoring report was not available for us to review. The mine operator is responsible for submitting reports to the PADEP every six months for the first two years following mitigation and annually for the next three years. These reports should contain an inventory of vegetation survival and percent cover, general information on the site conditions, photographs, and plans for correcting any identified problems.

While the Dutch Run mitigation site is replacing 1.28 of the 4.84 wetland acres lost via subsidence in Cumberland Mine, it is unclear if the new wetland at this site will serve the same function as the lost wetland area. The majority of the wetland acres lost via subsidence were of the PEM wetland type (Table IX-4), but just 10% of the Dutch Run site contains PEM wetland cover type (Table IX-6). The bulk of the site (74%) will be composed of PSS wetlands and palustrine open water (POW) wetlands (Table IX-6). It should be noted that POW wetlands were not detected in the pre-mining surveys over Cumberland Mine. Open water wetlands are the easiest to construct and make excellent habitat for waterfowl (Zedler 2000), however, the addition of this novel wetland type does not functionally replace the loss of PEM wetlands. The Dutch Run site does not appear to fulfill the 1:1 wetland type replacement criteria as described in TGD 363-0300-001 (PADEP 1997).

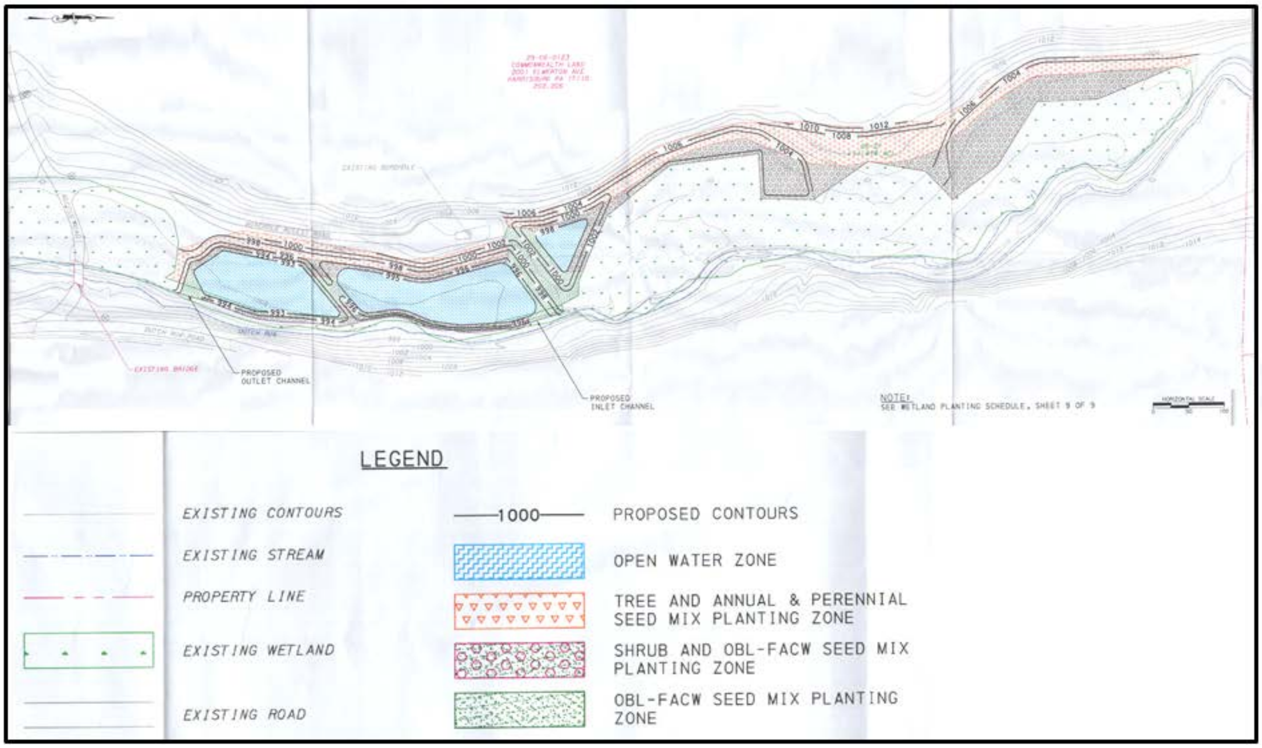

Figure IX-3. Design for the Dutch Run wetland mitigation site. Design is from Cumberland Mine, Permit Revision 105.

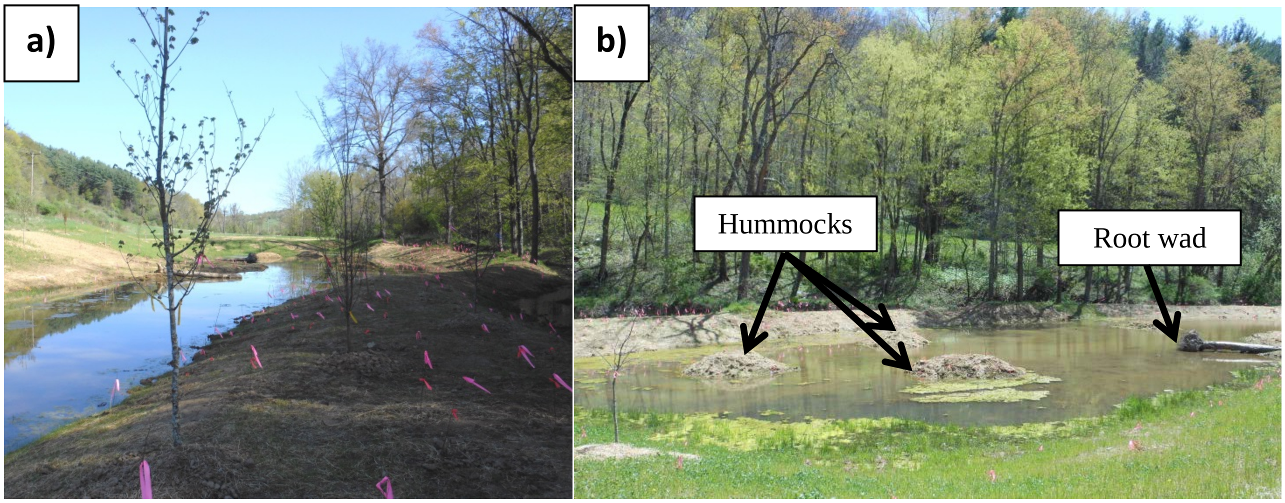

Figure IX-4. Photos from the University survey of the Dutch Run mitigation site in May 2013. a) Trees and shrubs (with pink flags) had just been planted. B) Hummocks and root wads in the open water zone provide habitat for wetland animals.

The remaining 3.56 wetland acres that were lost via subsidence will be mitigated at a second site that is situated along Whiteley Creek over the 56-57 gate area in Cumberland Mine. Work on this mitigation site had not begun by the end of the Act 54 reporting period, but designs indicate that the wetland replacement at this site will create 3.97 acres of wetland (Table IX-7). The original permit for this work was approved by PADEP on 12 January 2012 (Revision 115). However, the permit was approved before post-mining wetland surveys had been conducted at the site. The mine operator performed post-mining wetland surveys in July 2012 and discovered that three new wetlands had been created by subsidence in areas that overlapped that the proposed mitigation site (Wetlands WC-11101, WC-11102, WC-11104; Figure IX-5). Additionally, wetland WC-8, which existed prior to mining and was supposed to abut the proposed mitigation site, increased in size by 0.046 acres (Data from Alpha ArcGIS files). As a result, the mitigation designs had to be modified to accommodate the new wetlands that had been created following subsidence. Revised mitigation plans were submitted to PADEP and approved on 5 December 2012 (Revision 128). However, these plans were revised again on 30 September 2013 (Revision 134) and on 6 November 2013 (Revision 135) for unknown reasons.

Table IX-7. Breakdown of wetland cover type at the Whiteley Creek wetland mitigation site. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014a). Data are from Cumberland Mine, Permit Revision 135.

Cover Type	Acreage	% of Total Area
PFO	1.09	27%
PSS	0.79	20%
PEM	2.09	53%
TOTAL	**3.97**	**100%**

While the final mitigation plans were submitted outside of the Act 54 4th assessment period, a brief description of the plans is included here. Two gas lines criss-cross the mitigation site

(Figure IX-5) such that the proposed wetlands will be installed in five separate cells. Two inlet channels, one from Whiteley Creek and one from stream 41284 (an unnamed tributary to Whiteley Creek), will provide surface water flow to wetland cells 4 and 5 (Figure IX-5). The wetlands will also receive some groundwater input, as data from five wells drilled at the mitigation site indicate that average groundwater levels are within 0.5-ft of the bottom of the wetland cells (Revision 134). Over half of the wetland acreage is designed to be PEM wetlands (Table IX-7). The PEM areas will be seeded with an obligate wetland seed mix that is dominated by sedge and reed species (Revision 135) and sweetflag (*Acorus calamus*) seed. The PFO and PSS wetland areas will be planted with wetland trees (*Platanus occidentalis*, *Quercus bicolor*, *Nyssa sylvatica*; N = 25/species) and shrubs (*Cornus amomum*, *Cephalanthus occidentalis*, *Alnus incana*; N = 108/species), respectively.

The Dutch Run and Whiteley Creek mitigation sites are fully replacing the acreage that was lost via subsidence in Cumberland Mine. However, they may not be fully replacing the function of the lost wetland acreage. Between the two sites, 2.31 acres of PEM wetlands will be created. However, subsidence at Cumberland Mine created a net loss of 4.84 wetland acres, most of which were of the PEM wetland type. Overall, there appears to be a net loss of emergent wetland vegetation and its associated functions in Cumberland Mine, despite mitigation at the Dutch Run and Whiteley Creek sites. While the gains in PSS and PFO wetland types are valuable for wildlife, the loss of PEM wetlands could affect plant species diversity, detrital input, and nutrient cycling.

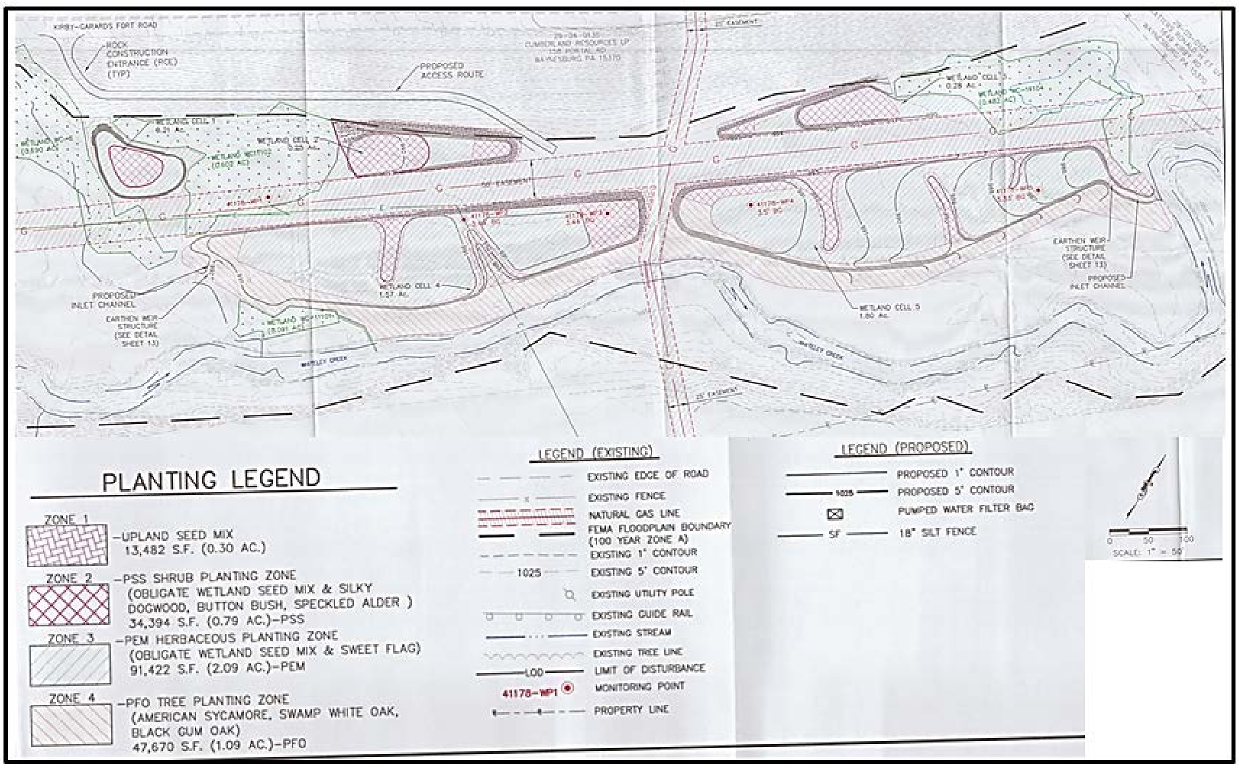

Figure IX-5. Design for the Whiteley Creek wetland mitigation site. Design is from Cumberland Mine, Permit Revision 135. Green stipple represents pre-mining wetlands.

IX.G – Challenges in Ensuring Wetland Mitigation Effectiveness

A general concern with any restoration project, including wetland replacements, is the effectiveness of the mitigation. Monitoring programs that assess the function of wetland mitigation sites are used to determine restoration “success”. Monitoring requirements in Pennsylvania TGD 363-0300-001 call for the permittee to monitor wetland mitigation sites for five years following construction (PADEP 1997). Some argue though that it can take closer to 15-20 years to determine the success of mitigation projects involving freshwater marshes, and even longer for other wetland types (Mitsch and Wilson 1996). Unfortunately, there are few published studies tracking the long-term development of wetland restoration projects (Zedler 2000).

In Pennsylvania, at least three past studies have indicated challenges in achieving functional success in wetland mitigation projects. For example, a survey of 69 mitigation wetlands between 1992 and 1995 indicated a mitigation success rate of 68.7% (PADEP 2001). In this survey, wetlands were rated on a simple scale of 1-4 with 1 indicating a “success” (i.e. presence of a wetland on the mitigation site) and all other numbers indicating some type of failure (2 = hydrology present, but poor vegetation, 3 = no hydrology, vegetation is stressed, 4 = not a wetland; PADEP 2001). It should be noted that wetland age was not documented in this study, so it is unclear if lack of function can be attributed to lack of maturity in the mitigated sites. In 2002, a comparative study found that created wetlands in Pennsylvania had reduced organic matter, lower plant species richness and lower total plant cover relative to natural wetlands (Campbell et al. 2002). These authors broadly addressed the contribution of wetland age to these differences by dividing created wetlands into two groups – those created more than 10 years ago and those created less than 10 years ago. While soil characteristics of older created wetlands more closely approximated those of natural wetlands, plant species richness was lowest in the created wetlands that were > 10 years old. In these sites clonal species such as the broad-leaved cattail (*Typha latifolia*) had become dominant. Reference sites also contained large patches of cattail but other plant species were able to co-exist with the cattails at these sites. In a more recent comparative study, wetland mitigation sites in Pennsylvania were found to have a lower functional capacity than natural wetlands (Gebo and Brooks 2012). Functional capacity scores were based on a suite of 10 wetland functions, including functions related to hydrology, biogeochemistry, and biodiversity. Specifically, floodplain mitigation sites, such as those at Dutch Run and Whiteley Creek, exhibited significantly lower short-term surface water storage and retention of inorganic particulates on average than reference sites (Gebo and Brooks 2012). Interestingly, this study found no effect of wetland age or size on the function of mitigation wetlands. Overall, these studies suggest that wetland mitigation projects in Pennsylvania have historically not been completely successful in replacing the function of lost wetland acreage.

Many of the mitigation sites that were evaluated in the studies cited above were constructed in the 1980s and 1990s. Wetland mitigation design has improved substantially since that time to overcome many of the environmental constraints that can stand in the way of an effective wetland replacement. For example, the absence of a seed bank and/or lack of opportunity for seed dispersal posed a significant challenge for early restoration sites that were constructed on areas with degraded seed banks or far away from natural wetlands (Zedler 2000). The construction of the Dutch Run and Whiteley Creek mitigation sites immediately adjacent to existing wetlands ensures that these mitigation sites will receive vegetative propagules.

Similarly, the inclusion of wells on the Whiteley Creek mitigation site to monitor groundwater levels for two years prior to restoration will help inform the establishment of an appropriate hydrologic regime, a factor with which many early wetland restoration projects struggled (Zedler 2000). However, building resilience (i.e. long-term stability, ability to withstand change while retaining similar function) into restoration projects remains a significant challenge (Suding 2011). For instance, initial successes in restored wetlands in Illinois were compromised later due to invasions by non-native species (Matthews and Spyreas 2010). In Pennsylvania, the permittee is only required to monitor the mitigation site for five years (PADEP 1997), so restoration cannot require on-going remediation and intervention to ensure their long-term success. Because the Whiteley Creek mitigation site is on property owned by the mine operator, the site will need to be self-sufficient after the five year monitoring period. In contrast, the Dutch Run mitigation site is on property owned by the Pennsylvania Game Commission. Thus, the state agency will likely be able to provide remediation measures on an as-needed basis if necessary after the five monitoring period. While this is not an ideal solution to the problem of designing wetland resilience, it does ensure that measures are in place to protect the mitigation site over time. As the science of wetland restoration continues to progress, wetland mitigation is expected to continue to improve in terms of effectiveness. Indeed, it is critical that the wetland mitigation projects have a high probability of success because they must replace the wetlands that have already been lost via subsidence.

IX.H – Summary

Because much of the active mining during the 4th assessment occurred in areas that were permitted prior to the deadline for compliance with TGD 563-2000-655, the University could not rely on permit applications for wetland data. Instead, the University found that permit renewals were the most reliable source of wetland data. Permit renewals contain information on pre- and post-mining data for all wetlands undermined during a given five year period.

Relative to the 3rd assessment, reports of pre-mining wetland acreage more than doubled, with five longwall mines reporting a combined total of 235.7 wetland acres prior to mining. This is likely a direct result of TGD 563-2000-655, which requires that multiple sources - including NWI maps, Natural Resource Conservation soil surveys, aerial imagery, and local mapping - be used to identify areas of potential wetlands. Of the five longwall mines, Cumberland Mine had the greatest density of pre-mining wetlands, with 2.92 wetland acres for every 100 acres of planned longwall mining. The majority of all pre-mining wetlands (84%) were classified as palustrine emergent wetlands, meaning that they were freshwater systems dominated by erect, rooted, herbaceous vegetation.

Of the four longwall mines with available post-mining data, three reported net gains in wetland acreage following mining. Despite these net gains, 33-41% of the original wetland acreage was lost after subsidence. The losses of original wetland acreage were offset by the creation of new wetland acreage. The new wetlands were generally palustrine emergent, while the lost wetlands had a mix of emergent and scrub/shrub or forest vegetation. The emergent wetlands may eventually develop woody vegetation, but this could take decades. Currently, the new wetlands do not functionally replace the complexity and resources that were provided by the original wetlands.

Cumberland Mine was the only mine with a net loss of wetlands totaling 4.84 acres. The bulk of these losses occurred in palustrine emergent wetlands. To replace the losses, the mine operator proposed two mitigation sites, one along Dutch Run and the other next to Whiteley Creek. Together, these sites will create 6.19 wetland acres. However, just 2.31 acres of palustrine emergent wetlands will be created. Thus, the mitigation does not provide a 1:1 functional replacement of the lost wetlands. Furthermore, the University could not evaluate the effectiveness of either mitigation project as the Dutch Run site was planted just months before the end of the reporting period and work on the Whiteley Creek site had not even begun. Past studies of wetland mitigation projects in Pennsylvania suggest that mitigation sites have lower functionality relative to natural wetlands. Clearly, close study of the Dutch Run and Whiteley Creek mitigation sites is warranted to ensure that these sites achieve their proposed function and that they are maintained for years to come.

Lastly, it should be noted that evaluation of subsidence-related changes in wetland acreage is complicated by natural variation in wetland size due to seasonal and annual fluctuations in temperature and precipitation. Currently, PADEP requires one pre-mining and one post-mining delineation for each wetland. Multiple delineations on a focal group of wetlands may provide PADEP with a standard deviation for wetland size over time. Such information would allow agents to control for climatic variation while assessing the impacts of subsidence.

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SECTION X: Recommendations

X.A – Overview

PADEP tasked the University with providing data-based recommendations on how to improve the implementation of Act 54. Below, the University first provides general recommendations for improving data submission and storage at PADEP. Second, the University makes specific suggestions based on the results from previous sections. The aim of these recommendations is to enhance PADEP's regulatory efficiency and their ability to more effectively evaluate the impacts of mine subsidence.

X.B – General Recommendations

1. Lack of uniformity in data submitted by the mine operators in fulfillment of permit requirements strongly hampers both enforcement of regulations and required Act 54 reporting. To enhance the efficacies of the regulatory and reporting processes, all data should be usable in spatially-explicit formats and/or readable by standard analytic software. The following recommendations address aspects of non-uniformity in data submission that were found by the University to hinder consistent regulation and reporting:
    - **a.** *All information should be submitted in electronic form*
    - **b.** *A protocol for submission of each type of data should be developed and disseminated. These protocols would specify:*
        - **i.** *File type (e.g. spreadsheet, geospatial format, etc.)*
        - **ii.** *Required metadata*
        - **iii.** *Required data, standard units of measurement for the data, and required precision of the data*
        - **iv.** *File formatting requirements (e.g. content and order of columns)*
        - **v.** *Time window in which data must be submitted*
    - **c.** *A protocol for PADEP's rapid checking of the incoming data and returning it if non-compliant should be developed and implemented.*

2. The University's efforts at data discovery were quite difficult, for both the data received by the PADEP from the mine operators and the data generated internally by PADEP. This was true in the 3rd Act 54 assessment as well. Some data was in BUMIS, although a significant amount of that was incomplete or in error (e.g. 25% of stream investigations from 3rd assessment were still not in BUMIS and 30% of features with a reported effect in the 4th assessment lack a unique identifier; Section II. B.2.3). Some data was in paper files at the CDMO. Some data was in paper files on PADEP personnel desks with no record that it had ever been submitted and/or removed from the file system. Some data was in spreadsheets on the computers of individual DEP personnel or PADEP servers but not readily available to the University or the general public. These last two types of locations were the most challenging since the University was dependent on PADEP personnel to volunteer the information. The University therefore makes the following recommendations to improve data storage:
    - **a.** *BUMIS:*
        - **i.** *Written protocols for data entry should be developed and implemented.*

   ii. *Quality control and quality checking protocols should be developed and implemented.*
   iii. *ALL information that can be georeferenced and is pertinent to permitting, regulation, and reporting should be included in BUMIS to create a true information system where all relevant information can be accessed.*
   iv. *Requiring submission of information from the mining operators and from DEP field agents in standardized formats (see Section X.B.1 above) will greatly facilitate the efficiency with which the above steps can be implemented.*
 - **b.** *For both spatial and non-spatial information, it is possible to link all pertinent information in a single electronic system. For example, the construction industry is rapidly implementing such systems and finding that they reduce liability, increase enforceability of contracts and generally greatly improve operating efficiency. Mining operations are likely to move in this direction as well. The PADEP would be wise to anticipate this and develop standards for data and record submission and tracking that can used by mining operators as they develop/implement such software. Planning those requirements in advance of the mine operator's adoption of such management systems will be far less expensive and frustrating to the operators than the development of conversion methods from their system to the DEP's system a posteriori.*

3. Analysis of the reported effects entered in the BUMIS database was challenging for the University. The largest of these challenges was comparing the features in BUMIS to the features labelled on the six-month mine maps. Features on the six-month maps are not labelled as specified in the PA Code, which requires a numerical identifier for structures and other surface features (PA Code, Title 25 Chapter 89.154b). Subsequently, the features cannot be matched with the information in BUMIS. All reported effects required additional information to be located. Again, the University notes that ~30% of reported effects listed in BUMIS could not be located from the six-month mine maps. The following recommendations will aid future analyses:
   - **a.** *Six-month mine maps:*
     - **i.** *Structures and surface features should be labelled with a unique numerical identifier whereby that feature can be identified solely by its numerical identification for a given mine*.
     - **ii.** *All structures and surface features required to be identified should be identified within at least 200-ft of previous and active mining*.
   - **b.** *BUMIS*:
     - **i.** *All features should be input in BUMIS with geographic coordinates from either field GPS devices or computer geographic information system software. The coordinates should be given to the tenth of a second or to the ten-thousandths of a degree. Less than 1% of the reported effects were given coordinates*.
     - **ii.** *Feature identification should match that of the six-month mine maps. Features should be able to be identified by feature number alone. Features should be identified by type, use, or property parcel*.

iii. *Information for a particular feature should be checked for accuracy before the case is closed. Information found in the BUMIS comments section suggests that many of the features are inaccurately labelled from initial inputs.*

4. The overlap between the 4th Act 54 assessment period and the University's budgeted time frame for data collection presented unforeseen challenges. PADEP's schedule for submission of six-month mining maps and hydrologic monitoring reports resulted in the arrival of some maps and hydrologic monitoring data at CDMO well after the University's collection period. Additionally much time and effort was spent continually updating the Act54GIS database as new data became available.

   The University recommends that future reports avoid significant overlap between the assessment period and the report preparation time period. The University suggests that PADEP aim for six months of overlap between the two periods to facilitate a timely report yet avoid unnecessary data updates.

X.C – Recommendations for Act 54: Structures

1. PA Code requires that all "dwellings, public buildings and facilities, churches, schools, hospitals and impoundments with a storage capacity of 20 acre-feet" be labelled with an identifying number on the six-month mining maps (PA Code, Title 25, Chapter 89.154b). However, the University found that many structures on the maps were not adequately labelled. Dwellings and barns are often labelled as simply D or B, respectively, which complicates efforts to determine the location of the impacted structure and its relation to mining. As a result of the inadequate labelling on the maps, the structure information in BUMIS also lacked unique ids. BUMIS also commonly misclassified structural features. For example, the feature type for structural impacts was sometimes listed as land or spring but further review of information and comments revealed the feature to be a dwelling or a garage.

   The University recommends that PADEP enforce proper labelling of features on six-month mining maps with identifying numbers to facilitate the tracking of undermined structures and mining-related impacts. The University recommends that PADEP adopt the quality checking protocols suggested above to ensure BUMIS accuracy.

X.D – Recommendations for Act 54: Water Supplies

1. PA Code also requires that all water supplies be labelled with an identifying number on the six-month mining maps (PA Code, Title 25, Chapter 89.154b). The University found that water supplies are often simply listed as W1 (i.e. well 1 on property) or S1 (i.e. spring 1 on property) but several W1 or S1 designations exist on a single map because most properties have at least one water supply. This compromised the linking of

information between the six-month mine maps and the BUMIS database for effective analysis.

The University recommends that PADEP adopt a numerical ID preceding the W1 or S1 identifier to allow more efficient tracking of undermined water supplies.

X.F – Recommendations for Act 54: Groundwater

1. TGD 563-2000-655 specifies the frequency of stream flow monitoring that is required before, during, and after mining (PADEP 2005). These monitoring guidelines are distinct from the "Hydrologic Monitoring Plan" required as part of module 8 in permit applications (section 8.15) which outlines the sampling of water quality and quantity at a set of surface water stations, wells, piezometers, and springs (PADEP 2012). While technical guidance specifies measurement of flow and groundwater elevations on a daily basis during periods of undermining, it is not clear that all of these data are consistently reported in the hydrologic monitoring reports. The majority of the reported data is quarterly sampling. In general, we found a quarterly sampling frequency inadequate to characterize impacts to system hydrology. However, even daily sampling frequency cannot necessarily capture rapid changes occurring during subsidence.

   The University recommends that the frequency of sampling be increased to sub-daily time increments (e.g., hourly or at 15 min intervals), particularly during periods just before, during, and just after undermining.

2. The "Hydrologic Monitoring Plan" required in the mine permit application offers a great deal of flexibility in the selection of the locations of sampling locations (PADEP 2012). However, the hydrogeology of the region, particularly the hydrologic response to the disturbances associated with undermining, seems to occur across a continuum from the hilltop to the valley bottom. Using the hydrologic monitoring points provided, the University found it difficult, if not impossible, to reconstruct the processes occurring from hilltop to valley bottom.

   The University recommends that review of hydrologic monitoring plans be designed so that hydrologic monitoring points are arranged along at least one continuous transect from hilltop to valley bottom.

3. The reporting of monitoring results has undergone substantial change over the course of this assessment period. Hydrologic monitoring reports (HMRs) were submitted electronically beginning in the second quarter of 2012. However, these data arrive in an inconsistent format requiring substantial time and effort to reorganize and analyze the data.

   The University strongly recommends that electronic submission continue and be expanded wherever possible. Moreover, the University recommends a consistent, organized format be established for electronic submission of hydrologic monitoring *results, allowing seamless synthesis of these data for comprehensive analysis of water balance.*

4. The HMRs are stored in a separate portion of the permit files, isolated from both the permitting data and the water loss investigations. In addition, these HMR data are also isolated from other relevant data in other modules such as overburden stratigraphy. The simple comparison among these data sets that is necessary for assessment of water losses, inference of hydrologic change, etc. requires substantial logistical overhead to gather and synthesize the data on an *ad hoc* basis. This cost in time and energy is exacerbated by the incremental revisioning of permits.

   The University recommends that HMR data be stored as part of a larger information system, either incorporated into existing systems (e.g. BUMIS) or preferably, the next generation data systems with spatial querying capabilities described above (Section X.B.2.b). This data system would ideally allow direct appending of revisions to existing permit module text, providing examination of permit revisions in context. This data organization would enhance the ability of the PADEP and citizens of the Commonwealth to comprehensively evaluate the changes in water balance occurring above underground mining.

5. Understanding the processes causing losses of water sources following underground mining is challenging given the limited understanding of the well stratigraphy or how they are completed. Supplemental data sources were consulted to determine local aquifer stratigraphy, though with limited success. This data gap results from the legacy of decisions made about well completion reporting in the Commonwealth and retrospective change is not likely. However, future data, if available, would enhance the ability to understand and potentially prevent water loss.

   The University recommends that stratigraphic logs of all wells or piezometers completed as part of the underground mining permitting process be submitted to existing state data bases such as the Pennsylvania Ground Water Information System (PAGWIS). The University recognizes that such reporting is not required by existing regulations, but the addition of these new data to the existing data resources would benefit the citizens of the Commonwealth in general and should be encouraged. Moreover, it would allow more rapid and effective assessment of water loss in undermined areas.

6. The maturation of hydrologic monitoring of surface water systems and mitigation strategies to address surface water impacts has highlighted the limited understanding of hydrologic processes on the hillslopes. Hydrologic monitoring of changes in spring flow is the smallest HMR data set. Hydrologic changes occurring in hillslopes cannot be characterized as data simply do not exist to evaluate changes in hillslope hydrology.

   The University recommends that additional monitoring of changes to hillslope moisture status be added to the technical guidance allowing the assessment of changes in hillslope soil moisture patterns. These data may be more sensitive to long term changes and the *potential "healing" of hydrologic system following mining. Ideally, these data would be collected as part of the transects mentioned above.*

X.G – Recommendations for Act 54: Streams

1. In general, standardized, electronic formats for flow and biology data submission are lacking. Stream flow maps and accompanying data are currently submitted to PADEP on a monthly basis by mine operators (Section VII.D). While these data are not required by the mine permit application, they are extremely useful in determining the nature and severity of stream impacts. Unfortunately, it is difficult to use these data to draw general conclusions about the impacts of mining on stream flow due to a lack of standardization across mines. As for the biology data, module 8 of the mine permit application provides forms for the submission of pre- and post-mining biological data (Forms 8.8C and 8.8D). However, mine operators do not typically use these forms and instead create their own. One consequence is that data on macroinvertebrate community composition, which is required by Form 8.8C, is only occasionally submitted.

   The University recommends that submission of monthly stream flow maps and data continue. To maximize the utility of these data, the University also recommends that PADEP develop a standardized electronic format for submission. The University encourages the display of active and inactive augmentation wells on maps to aid in identifying streams experiencing flow loss and the severity of the impact. The University also encourages the use of spreadsheets to explicitly quantify the lengths of flow loss. Maps are useful in identifying the locations of flow loss, but spreadsheets would facilitate statistical analysis of flow loss lengths.

   The University also recommends that PADEP re-work Forms 8.8C and 8.8D for biological data submission. Mine operators have developed significant improvements over these forms that allow data to be readily exported to statistical programs for analysis. PADEP biologists should also request and store all macroinvertebrate taxon-level data associated with a particular TBS. Evaluation of TBS and its associated metrics can provide insight into the degree of impact and/or recovery, but data on community composition can explain how *a community is affected by subsidence and/or mitigation.*

2. TGD 563-2000-655 currently requires that all Total Biological Scores (TBS) be collected between October and May (PADEP 2005). The University found that even within this index period, TBS varies significantly with month of sampling. On average, TBS collected in October and November were 10 points lower than TBS collected in December-March (Figure VII-5).

   The University recommends that the PADEP's index period be shortened to December-May and that PADEP encourage operators to concentrate TBS sampling efforts in December-March. The shorter index period would eliminate the need to consider month of sampling when assessing the impact of mining and degree of recovery for stream macroinvertebrate communities.

3. PADEP's methodology for tracking stream impacts changed between the 3rd and 4th Act 54 assessment periods following implementation of TGD 563-2000-655 (Figure VII-7). Determining the number of stream impacts and their final resolution now requires consultation of BUMIS agent observation files and SSA stream data logs. The BUMIS observations are written in a narrative style that makes extraction of relevant data challenging while the SSA stream data logs lack a standardized format and they are not stored in place that is readily accessible to citizens of the Commonwealth.

   The University recommends that PADEP develop a written policy for tracking stream impacts along with a centralized and standardized database system that incorporates all relevant data, including maps, photos, narratives, and raw data. Because BUMIS was not designed to track the complex nature of stream impacts, a novel information system may be required. The University also recommends that PADEP request and store all flow and biology data collected by the mine operator following mitigation to avoid the perception of selective data submission.

4. TGD 563-2000-655 requires that stream flow must return to a "normal range of conditions" following mining-induced impacts (PADEP 2005). The normal range of conditions is to be based on a minimum of two years of flow data. However, the University found that PADEP determinations of flow recovery were typically based on inadequate flow measurements and idiosyncratic methods of analysis (Section VII.G.2).

   Additionally, it was discovered that the PADEP flow assessments utilize two different measures of stream flow (Section VIII.B.4). One measure is the percent of the stream length experiencing flow loss. The other measure is a volumetric flow rate, typically measured as gallons of water passing a fixed point on the stream per unit time.

   The University recommends that PADEP establish a more rigorous protocol for assessing impacts on stream flow. PADEP must first establish a standard measure of stream flow. The University suggests that volumetric flow rates be selected as the standard, as these measures precisely quantify stream flow while percent flow loss simply reflects the presence or absence of water. Following mining, it is possible that flow may return, but at a lower volume than was present prior to mining. Volumetric flow rate measures would capture this variation, but percent flow loss would not. Once a standard measure is in place, PADEP must ensure that mine operators comply with TGD 563-2000-655 and submit at least two years of pre-mining stream flow data. Finally, PADEP should establish quantitative guidelines for determining what degree of variation indicates an adverse effect of mining on stream flow.

5. TGD 563-2000-655 requires that flow loss mitigation plans "should provide for surveys of the macroinvertebrate community…as soon as practicable after flow has recovered or been restored" (PADEP 2005). However, Bailey Mine is the only longwall mine submitting post-mining macroinvertebrate data in a timely fashion following mining-induced flow loss. After the University's data collection period had ended, the University learned that PADEP had received biology data from Cumberland and Emerald Mines in

August 2013 but that the data had been misplaced for several months. As a result, the data were not available to the University until April 2014 – well after the data collection period. PADEP also asserts that data from Enlow Fork Mine was requested in February 2014 and received in March 2014. These data were received well after the University's data collection period and were never made available to the University.

The University recommends that PADEP establish strict schedules for the submission of biology data following flow loss mitigation and flow recovery.

The University also recommends that biological samples collected after grout mitigation at sites experiencing flow loss impacts be explicitly labelled as "post-grouting" to facilitate determination of the effectiveness of this technique.

6. TGD 563-2000-655 allows for the use of control streams to determine whether changes in undermined streams are related to mining. Control streams must match the undermined streams in the following ways (PADEP 2005):
    a. Drainage area and yield
    b. Stream gradient
    c. Habitat and canopy cover
    d. Watershed topography
    e. Watershed land use
    f. Surface geology
    g. Streambed substrate
    h. Physical and chemical parameters

    The University's assessment of the available data suggests that control sites are not selected in the rigorous manner required by TGD 563-2000-655. When the University could locate the rationales underlying control stream selection in the paper files at CDMO, selections were based almost exclusively on watershed land use and watershed size. Indeed, the rationale from one mine operator indicates that CDMO has identified these two characteristics as the most important parameters for comparing undermined and control sites (Wallace & Pancher, Inc. 2013). However, the University knows of no analysis by PADEP that has formally tested this idea. The University's analysis in Section VII.C.2 indicates that stream habitat and pH are actually more important predictors of stream biology than watershed land use or size (Table VII-4). It should be noted that the University could not test the importance of other factors, such as surface geology and streambed substrate, due to a lack of available data.

    Even with careful selection of control streams, these streams may not accurately reflect the pre-mining conditions of undermined streams. Following restoration, the University noted that Total Biological Scores on undermined streams were occasionally much higher than those observed on the control streams (e.g. Section VIII.C.2). Such cases suggest that either restoration is enhancing stream habitat above and beyond pre-mining conditions or control streams are an inadequate comparison.

The University recommends that PADEP and mine operators utilize control streams only in extreme circumstances to evaluate recovery of undermined streams. While this assessment saw the lingering effects of mines moving into compliance with TGD 563-2000-655, with all active mine permits now having been issued or renewed after implementation of TGD 563-2000-655, two years of pre-mining flow data and TGD compliant pre-mining Total Biological Scores should be required of all mining operators.

7. An important function of the Clean Streams Law of Pennsylvania (Act of 1937, P.L. 1987, No. 394) is "regulating the impact of mining upon water quality, supply, and quantity". While TGD 563-2000-655 and the mine permit application provide for an assessment of stream flow and biological recovery, it does not currently assess impacts to stream water quality. Using data from one mine, the University found that streams affected by mining-induced flow loss have significantly elevated conductivity and pH (Table VII-10). On average, the increase in conductivity following mining exceeds the U.S. EPA's benchmark for aquatic life in the Western Allegheny Plateau ecoregion (U.S. EPA 2011). Furthermore, the University found that these chemical parameters show no sign of returning to pre-mining levels over time (Section VII.J.2).

   The University recommends that PADEP closely monitor data on stream physiochemistry to determine if the changes in water quality detected by the University are a general trend associated with mining-induced flow loss. The University also suggests that future Act 54 reports follow up on this finding and assess the nature of the relationship between water quality and macroinvertebrate community composition at mined sites.

8. Grouting is a commonly utilized by mine operators to mitigate flow loss impacts to streams (Table VII-14). However, PADEP does not require mine operators to report the length of streams that are grouted. Because many of the sites that require grout mitigation are in highly forested areas that are inaccessible to heavy equipment, access roads are often built to move equipment to the restoration area (Section VII.I.5-6). PADEP does not require formal quantification of access road lengths.

   The University recommends that PADEP require mine operators to formally quantify the length of grouting and access road construction. This information would aid in monitoring the extent of mitigation and in evaluating the ecological impact of stream mitigation on surrounding terrestrial ecosystems.

X.H – Recommendations for Act 54: Wetlands

1. PADEP requested that the University report on the number of wetlands undermined. However, the University discovered that individual wetland patches identified on the maps were grouped together as a single wetland for evaluation of gains and losses in the mine operator's data tables (Section IX.B.1). The method underlying the decision to group certain wetland patches could not be identified. The seemingly random grouping prohibited numeration of undermined wetlands and also made it impossible to determine the relationship between wetland gains/losses and geological parameters, such as overburden depth, slope position, etc.

The University recommends that PADEP identify the mechanism underlying wetland grouping. If the grouping is a result of hydrological and biological connectivity between wetland patches, then the practice of grouping may be relevant to assessments of mining-induced gains and losses. However, if the grouping reflects data collection methods or other factors unrelated to wetland ecology, then PADEP should request that mine operators discontinue the practice.

2. TGD 363-0300-001 requires a wetland replacement ratio of 1:1 in terms of area and function for all impacted wetlands (PADEP 1997). In this assessment, Cumberland Mine experienced a net loss of 4.84 wetland acres, the bulk of which were palustrine emergent wetlands. While the two mitigation sites created a total of 5.25 wetland acres to offset these losses, just 2.31 acres were designed to be palustrine emergent wetlands.

   The University recommends that PADEP provide greater oversight of the 1:1 replacement ratio for both wetland acreage and wetland function/type. Palustrine emergent wetlands in particular provide plant habitat, detrital inputs, and can influence nutrient cycling (Mitsch et al. 2009) and take less time to establish relative to scrub-shrub and forested wetlands.

References

Mitsch, W.J., J.G. Gosselink, C.J. Anderson, and L. Zhang. (2009) *Wetland ecosystems*, Hoboken, New Jersey, John Wiley & Sons.

PADEP. (1997) “Design Criteria – Wetland Replacement/Monitoring,” Technical Guidance Document 363-0300-001, February 11, 1997, 11p.

PADEP. (2005) “Surface Water Protection – Underground Bituminous Coal Mining Operations,” Technical Guidance Document 563-2000-655, October 8, 2005, 43 p.

PA DEP (2012) “Instructions for Completing the Application for Bituminous Underground Mine, Coal Preparation Plant and / or Coal Refuse Disposal Area” Document 5600-PM-BMP0324, February 2012, 148 p.

U.S. EPA (2011) “A field-based aquatic life benchmark for conductivity in Central Appalachian streams. EPA/600/R-10/023F”, Washington D.C.

Wallace & Pancher, Inc. (2013) “Post-Mining Compliance per TGD #563-2000-655, Alpha Natural Resources, Cumberland Mine Panels 52-57, Emerald Mine Panels B5-B7 and C1-C2, Control Stream Proposal”. August 7, 2013.

SECTION XI: Summary and Conclusions

XI.A - Overview

Section 18.1 of the Bituminous Mine Subsidence and Land Conservation Act requires PADEP to compile, on an ongoing basis, information from mine permit applications, monitoring reports, and enforcement actions. It also requires PADEP to report its findings regarding the effects of underground coal mining on overlying land, structures, and water resources to the Governor, General Assembly and Citizens Advisory Council at five year intervals. This is the 4th such report and the second completed by a team from the University of Pittsburgh. The team brings together expertise in mine engineering, hydrogeology, and ecology.

The University team saw its goal as one of providing the best unbiased information possible. To accomplish that, the team made impartiality a central operating value. Virtually everyone that will read this report makes constant small decisions to turn on a light, or use a home appliance. Because coal supplies more than 40% of all electricity (U. S. Energy Information Administration 2013), we are all dependent on coal in the United States. This report addresses the costs of coal on very local scales, costs that are not necessarily reflected in coal's price or coal workers' paychecks. With clear knowledge we can make decisions about how to best manage our immediate and future needs for energy as well as our need for healthy ecosystems and vibrant communities. Coal is a natural treasure, a legacy passed down through the ages by the ecosystem that was on earth 300 million years ago. The University's intention with this report is to aid the people of the Commonwealth in the wise extraction and use of coal, thereby ensuring that coal's energy is used to build the natural and human legacy for the millennia yet to come.

In the 3rd assessment, PADEP asked only for a reporting of the effects of underground bituminous coal mining. In the contract leading to this 4th report, the University was also tasked with evaluating PADEP's effectiveness in implementing Act 54. The University has therefore focused on producing a report that provides both a detailed analysis of the effects of mining as well as data-based recommendations to PADEP on the process by which information concerning the effects of underground mining is obtained and managed.

XI.B - Summary

Data collection, error checking, and incorporation in the Act 54 Geographic Information System (Act54GIS) collectively represented by far the largest proportion of total University effort on this project. Once completed, this system contained spatially explicit information on all features for which the effects of underground coal mining are regulated by PADEP. Mining data came primarily from three sources – six-month mining maps provided by PADEP, mining maps and other spatial data provided by mine operators, and PADEP's Bituminous Underground Mining Information System (BUMIS). However, data for some undermined features (e.g. stream bio-monitoring stations and wetlands) came from additional paper documents the University discovered within the permit files and in the files of PADEP individuals working on specific permit issues. The data were received in various formats; all data was converted to Esri ArcGIS files with a NAD 1983 UTM 17N map projection. The Act54GIS also contained base layers that relate the extent of mining and its impacts to a larger landscape framework, including all roads, rivers and topographic features. The Act54GIS makes possible analysis and reporting of information required by the 4th assessment period contract between the University and PADEP, including comparisons with past assessment periods. Further, it provides a useful basis for organizing the information necessary for future reports.

The cost to the Commonwealth and the difficulty of constructing the GIS database could have been greatly reduced. Given difficulties encountered in attempting to extract necessary information from BUMIS, it is clear that the mining information system is not linked to a geographic information system. Records in BUMIS are sometimes missing altogether and frequently lack sufficient information to accurately determine their locations and feature type or to link them to other sources of information regarding that particular feature and effect. Furthermore, it was unclear whether or not the California District Mining Office (CDMO) of PADEP had a GIS database in place during the 4th assessment period. Although the Master Agreement between PADEP and the University states "The University shall make maximum use of information contained in relevant data layers maintained on the PADEP's geographic information systems," PADEP did not provide access to a PADEP geographic information system. In the 3rd assessment period, the University explicitly requested access to PADEP's geographic information system and was denied. During the 4th assessment period it remained unclear if a GIS system existed containing mining regulatory information; if it does exist, the University was not given access.

In this report, the University is able to provide the most detailed information yet produced for Act 54. The University's contract from PADEP placed a strong emphasis on reporting on the effects of underground mining on streams and wetlands, since these are the effects that have been of greatest concern for both the mining industry and many citizens of the Commonwealth. For the first time, the University was able to assess a number of aspects of the relationship between underground mining and stream and wetland impacts with statistical estimates of certainty regarding the results. For the first time, PADEP also requested an assessment of underground mining effects on groundwater.

A total of 31,343 acres of Pennsylvania land were undermined by 46 underground bituminous coal mines during the 4th assessment period. This represents an 18% drop in bituminous coal production from underground mines in Pennsylvania compared to the previous 5-year reporting period. This drop results in part from a decrease in demand for coal and partly from the movement of mining activity in the large longwall Bailey Mine to the west, shifting increasingly into West Virginia. Six companies operated these 46 mines . The number of mines operated per company ranged from 1 to 20 and the percentage of all acreage mined per mining company ranged from <1 to 39%. Thirty-four of the 46 active mines used exclusively room-and-pillar methods, seven were longwall operations, and five were pillar recovery operations. Thirty-five of the 46 mines worked Kittanning and Freeport Coalbeds of the Allegheny Formations while the remaining 11 worked the Pittsburgh and Sewickley Coalbeds of the Pittsburgh Formation. Forty percent of the total area mined was in Greene County, 19% in Washington County with the remaining 39% spread over Armstrong, Beaver, Cambria, Clearfield, Elk, Indiana, Jefferson, and Somerset Counties. The average size of longwall panels has increased nearly four-fold since the method's introduction in Pennsylvania around 1970, from about 400-ft in width originally to as much as 1,560-ft currently. The University estimates that about 154,000 acres of minable coal remain in the Pittsburgh Coalbed, given current mining methods. At the current rate of mining (during the 3rd and 4th assessment period, an average of 4,161 acres were undermined per year) it will take approximately 37 years to mine the remaining coal in the Pittsburgh Coalbed. No estimates of remaining minable coal for the Kittanning and Freeport Coalbeds are made.

Subsidence is strongly associated with mining method with the vast majority of subsidence resulting from longwall mining. Subsidence from longwall mining is influenced by the depth of overburden; the deeper the overburden the smaller the magnitude of subsidence. Longwall panels are on average operating under deeper overburden in the 4th assessment period relative to the 3rd reporting period. Subsidence also occurs in room-and-pillar mines that practice pillar recovery. In general, room-and-pillar mines don't produce subsidence, although pillar punching or pillar instabilities can, on rare occasions, cause subsidence related impacts on the surface.

During the 4th assessment period, 389 effects on structures were reported. Of these, 315 (81%) were associated with longwall mines. For 238 (61%) of the reported effects, the damage was determined to be due to undermining and thus the mining company was deemed liable. All but 59 (15%) were resolved during this assessment period. For the 330 effects with a final resolution, the average time to reach a decision was 169 days. Of those cases determined to involve mining company liability, 157 (66%) were resolved by agreement between the property owner and the mining company. Legally, PADEP is not privy to the details of these private agreements, so the extent to which the damage was repaired or the structure was replaced is unknown. Relative to the 3rd assessment, the number of effects on structures dropped by approximately 14%, while the number of acres mined dropped by 18%. The challenge of identifying and tracking all structure effects was greatly increased by the frequent lack of unique structure identifiers in BUMIS.

During the 4th assessment period, there were 855 reported effects to wells, springs, and ponds. These effects were nearly evenly split between room-and-pillar and longwall mining operations. Of these, 201 (23%) remained unresolved at the end of the 4th reporting period. Among those that were resolved, the average time to resolution was 220 days. Of the 654 resolved effects, 57% were determined by PADEP to be due to underground mining. The mine operator was held responsible for the resolution of those cases. For those resolved effects for which the operator was held responsible the average time to resolution was 415 days. Seventy percent of all company-liable effects, representing 31% of all reported effects on water supplies, were settled through an agreement between the mining company and the property owner. For these effects, there was no way to know if the water supply was impacted and, if so, restored, replaced or abandoned.

Approximately three-fourths of the company-liable water supply effects lay within PADEP's Rebuttable Presumptive Zone (RPZ), determined by a line at 35 degrees from vertical extending upward and away from the closest edge of the extent of mining to the surface. Within the RPZ effects are assumed to be due to mining unless the mining company can show otherwise. Thus, 25% of effects lie outside of the RPZ, as much as 85 degrees outward and upward from the edge of mining. Despite an 18% drop in number of acres mined, the number of reported water supply effects has increased by approximately 25%. The increase in reported water supply effects may be attributable to the encroachment of underground mining on more heavily populated areas in the 4th period and to increased public awareness of mining company responsibility for addressing any mining-related impacts on water supplies.

The ability to identify and track underground coal mining's effects on water supplies suffered from the same problems in BUMIS as did the tracking of reported effects on structures. The University makes specific recommendations regarding best practices in data management in this report.

The University organized available data to comprehensively understand the hydrologic changes following underground mining, particularly changes to groundwater. The hydrologic monitoring data is an additional body of data requiring substantial effort to organize and link to other existing PADEP data sources. There are over 750 distinct water quantity and quality sampling locations over longwall mines reported to PADEP during the 4th assessment period. Reported sampling of these locations include over 31,000 sampling events. This considerable data set does not seem to include substantial flow monitoring required as part of relevant permits but not included in regular hydrologic monitoring reporting. In general, due to the typical frequency and variability in reported monitoring and the complicated nature of local hydrology, pertinent questions are challenging to address. These shortcomings are demonstrated in efforts to clarify the causes of reported water supply effects in the focal watersheds using hydrologic monitoring data. Looking forward, with relatively minor changes to sampling and reporting, these hydrologic systems can be clarified and potential impacts from future mining more effectively mitigated.

During the 4th Act 54 assessment, 96 miles of stream were undermined. Longwall mining accounted for the undermining of 51 miles of stream, which represents a ~20% decline from the 3rd assessment, reasonably commensurate with the 18% decline in acres mined during this period. Nearly all reported stream impacts result from subsidence associated with longwall mining. Of the stream miles undermined by longwall techniques, 39 miles belong to streams that experienced mining-induced flow loss, pooling, or both, somewhere along their channel. On these streams, the maximum length of post-mining flow loss ranged from 936-ft to 10,883-ft in the dry season and from 96-ft to 8,106-ft in the wet season. Flow loss during the dry season may, in part, be a function of seasonal variations in water balance, so the University expects that wet season flow losses more accurately reflect the impact of mining. The locations and lengths of mining-induced pooling on individual streams could not be determined due to a lack of data. Maps in the Chapter 105 permits for gate cut mitigation either lack sufficient detail for georeferencing or focus on the restoration area and do not show the entire extent of pooling.

The procedure for tracking stream impacts at PADEP changed between the 3rd and 4th assessment periods due to the implementation of TGD 563-2000-655. Stream investigations are now only used by PADEP for streams undermined prior to TGD 563-2000-655. For streams undermined after TGD 563-2000-655, a period of investigation is no longer required to determine the cause of changes in stream flow. Instead, any change in flow that occurs at the time of mining is automatically assumed to be a mining-induced impact. A record of the impact is made in the BUMIS observation files and in the SSA stream data logs. The mine operator then has three years to mitigate the impact and submit data to PADEP for review. The data submission initiates a stream recovery report in the paper files at CDMO. If the review indicates stream recovery, then the stream is released. If the stream has not recovered after three years, PADEP can require a change in future mining plans. The mine operator then has two years to perform additional mitigation. If the final attempts at stream restoration are unsuccessful then PADEP will require compensatory mitigation. The new protocol at PADEP makes significant improvements over the 3rd assessment protocol in that changes in the stream at the time of mining are automatically assumed to be mining-related and streams can no longer be mitigated indefinitely. However, this protocol also makes it challenging to rapidly quantify the number of impacts and their final resolution status as one must now consult multiple data sources that either lack standardization or are written as narrative without organized data reporting.

Due to the changes in tracking stream impacts, just nine stream investigations were initiated during the 4th Act 54 assessment. Of these, four were unresolved at the end of the assessment period. For many of the stream investigations, flow data submitted by the mine operator and utilized by PADEP was inadequate to assess recovery. Fourteen stream recovery reports were filed during the 4th assessment. PADEP has released nine of these from further monitoring, while two cases require compensatory mitigation, and three cases are still under review. In the resolved cases, the University noted that PADEP would occasionally use one post-mining TBS rather than requiring the mine operator to submit two scores to assess biological recovery on a stream.

During the 4th reporting period the University was able to quantify aspects of stream mitigation efforts for the first time. In all, 95 streams had augmentation discharges installed along their channel and augmentation was active at 74 of these streams to maintain flow during or after mining. In all, 57 streams received grouting to mitigate mining-induced flow loss. Grouting involves the injection of bentonite, urethane or other mixes into stream bedrock fractures in an attempt to prevent surface water from flowing underground through the fractures. Estimates for one longwall mine suggest that ~50% of the stream lengths undermined received grouting. Three stream segments had liners placed in their channels to restore flow following mining-induced flow loss. Many miles of access road are constructed along streams as a part of the mitigation process. Over one longwall mine, nearly 8,000-ft of access roads were constructed to support mitigation activities in just a three month period.

For one mine, Bailey, the operator submitted a sufficient number of stream samples before and after mining that the University could compare pre- and post-mining TBS. On average, mining-induced flow loss significantly reduced TBS, resulting in an average drop in TBS of 13%. PADEP's policy states that a 12% or greater drop in TBS for any one stream indicates an adverse effect. This analysis suggests that on average streams are adversely affected. Mining-induced stream effects cause especially large reductions in two mayfly families, Ephemerellidae and Heptageniidae. The post-mining communities shift away from collector-gatherer and scraper macroinvertebrate taxa that are normally important components of healthy stream macroinvertebrate communities. Water quality is also affected by mining-induced flow loss. Conductivity and pH increase significantly at impacted sites, and the increases in conductivity push levels above the U.S. EPA's benchmark for aquatic life in this ecoregion. The ability of grout mitigation to restore streams to their pre-mining condition remains somewhat unclear. TBS appear to increase over time but slowly. Analyses indicate that on average, three and a half years are required for TBS to return to pre-mining levels. However, conductivity and pH remain elevated following mining and mitigation.

During the 4th reporting period 28 stream segments received gate cuts to alleviate mining-induced pooling (total miles mitigated: 4.2 miles). Data from Bailey and Enlow Fork Mines (the only usable data available) indicate that mining-induced pooling reduces TBS and is thus an adverse effect to streams. However, gate cut restoration is effective in restoring TBS to pre-mining levels. Macroinvertebrate community composition after gate cut restoration is statistically indistinguishable from pre-mining macroinvertebrate community composition. Based on the available data, the University views gate-cutting mitigation methods as successful in restoring stream ecology.

The University also carried forward the history of stream investigations from the 3rd assessment period. Of the 55 stream investigations that were initiated in the 3rd assessment, 51 reached a final resolution by the end of the 4th assessment period. The average time to resolution for these cases was 1,313 days or just over three and half years. Four stream investigations from the 3rd Act 54 assessment remain unresolved. These cases have been open for seven to eight years. PADEP is currently reviewing flow data for two of the cases, yet there is little information in BUMIS or the paper files at CDMO regarding the status of flow recovery for the other two cases.

Eight of the 51 or 16% of resolved investigations were resolved not because of recovery but because they have been deemed not recoverable. One of these involves a federal court settlement. Overall, these cases represent impacted streams that have not recovered from mining-induced flow loss, despite a variety of mitigation techniques. In general, the stream segments in these cases are characterized by shallow depths to mining, with impacts occurring in areas with overburdens less than approximately 500-ft.

The analysis and reporting on underground mining effects on wetlands is still in its infancy. Many of the active mining operations during the 4th assessment received their permits prior to the deadline for compliance with TGD 563-2000-655. The permit applications therefore do not contain sufficiently detailed wetlands inventories, if any wetland information is present at all. The University therefore relied instead on permit renewals, containing information on pre- and post-mining data for all wetlands undermined in a five year period. Of the five longwall mines, Cumberland Mine had the greatest density of pre-mining wetlands, with 2.92 wetland acres for every 100 acres of planned longwall mining. The majority of all pre-mining wetlands (84%) were classified as palustrine emergent wetlands, meaning that they were freshwater systems dominated by erect, rooted, herbaceous vegetation.

In three of the longwall mines, there was a slight net gain of wetland acreage. However, among these mines, 33-41% of the original wetland acreage was lost after subsidence. The losses of original wetland acreage were offset by the emergence of new wetland acreage, mostly palustrine emergent, while the lost wetlands had a mix of emergent and scrub/shrub or forest vegetation. The emergent wetlands may eventually develop woody vegetation, but this could take decades. Currently, the new wetlands do not functionally replace the complexity and resources that were provided by the original wetlands.

Cumberland Mine was the only mine with a net loss (4.84 acres) of wetlands. The bulk of these losses occurred in palustrine emergent wetlands. Proposed mitigation along two streams, Dutch

Run and Whiteley Creek, will create 6.19 wetland acres but just 2.31 acres of palustrine emergent wetlands. Thus, the mitigation does not provide a 1:1 functional replacement of the lost wetlands. Past studies of wetland mitigation projects in Pennsylvania suggest that mitigation sites have lower functionality relative to natural wetlands. Clearly, close study of the Dutch Run and Whiteley Creek mitigation sites is warranted to ensure that these sites achieve their proposed function and that they are maintained for years to come; they are just now being established and so it is too early to make any assessment at this time.

Evaluation of subsidence-related changes in wetlands is complicated by natural variation in wetland size due to seasonal and annual fluctuations in temperature and precipitation. Multiple delineations on a focal group of control wetlands would allow agents to assess the extent of variation in wetland size due to natural factors and compare this to the observed changes after mining. This would provide a more objective means of determining the effects of subsidence on wetland size.

PADEP tasked the University with providing data-based recommendations on how to improve the implementation of Act 54. The aim of these recommendations is to enhance PADEP's regulatory efficiency and their ability to more effectively evaluate the impacts of mine subsidence. In summary, the recommendations fall into three broad categories:

1. Standardization of data acquisition and submission to PADEP.
    a. Further thought needs to be given to frequency and timing of certain kinds of field data acquisition, such as stream flow measures, macroinvertebrate sampling, and well and piezometer data. Details are given in the full report.
    b. PADEP should establish written requirements for the specific contents, formats and file types for the data required from the mine operators. All submissions should be in electronic form. File submission requirements would facilitate comparison across mines as well as rapid and accurate incorporation in both PADEP's information system and standard statistical software. Suggestions are provided in the report.
2. Quality control and quality checking in PADEP's data management process.
    a. Written quality assurance and quality control protocols should be developed and implemented; they are presently largely lacking.
    b. Quality assurance and quality control methods should also be applied to past data entries to correct errors.
    c. All submitted data should be checked for adherence to technical guidance documents and general policy soon after submission and rejected if standards are not met.
3. Determination and tracking of impacts and standards for determining resolution.
    a. Link BUMIS to a geographic information system.
    b. Develop a single centralized and standardized database for tracking stream impacts and their resolutions.
    c. Implement more rigorous methods for determining impacts and recovery of stream flow. These should be based on volumetric flow rather than presence or absence.

d. Develop data on regional temporal variation in wetland size for testing putative mining effects as compared to natural variation in wetland size. In addition, more rigorous assessment of changes in wetland function and of equivalent wetland function replacement is advised.

XI.C – Conclusions

In implementing Act 54, the Pennsylvania General Assembly declared the following:

1) "The protection of surface structures and better land utilization are of the utmost importance to Pennsylvania.
2) Damage to surface structures and the land supporting them caused by mine subsidence is against the public interest and may adversely affect the health, safety and welfare of our citizens.
3) The prevention or restoration of damage from mine subsidence is recognized as being related to the economic future and well-being of Pennsylvania.
4) The preservation within the Commonwealth of surface structures and the land supporting them is necessary for the safety and welfare of the people.
5) It is the intent of this act to harmonize the protection of surface structures and the land supporting them and the continued growth and development of the bituminous coal industry in the Commonwealth.
6) It is necessary to provide for the protection of those presently existing structures which are or may be damaged due to mine subsidence. It is necessary to develop an adequate remedy for the restoration and replacement of water supplies affected by underground mining.
7) It is necessary to develop a remedy for the restoration or replacement of or compensation for surface structures damaged by underground mining.
8) It is necessary to provide a method whereby surface structures erected after the effective date of this act may be protected from damage arising from mine subsidence." (Act 54).

Importantly, the Act further stipulated that "Nothing in this act shall be construed to amend, modify, or otherwise supersede standards related to prevailing hydrologic balance contained in the Surface Mining Control and Reclamation Act of 1977… nor any standard contained in the act of June 22, 1937 known as the "The Clean Streams Law," or any regulation promulgated thereunder by the Environmental Quality Board." (Act 54).

The successful management of land during periods of repetitive subsidence disturbance requires the collection, organization, and analysis of a wide variety of data. The growth of computing power and automated sensors has created challenges in many fields, challenges that are loosely grouped into what is called "big data". The term big data refers to a situation where the data collection exceeds one's ability to manage the data, precluding the data from being included in decision making frameworks. The management of land above underground coal mining is at the cusp of such challenges.

Early implementation of Act 54 focused on challenges facing citizens of the Commonwealth who reside over undermined areas. Since that time, processes for protecting residents have become standardized. There are clear best management practices to mitigate and repair subsidence effects to structures and water supplies. If properly implemented, the hindrance to local residents can be minimized.

However, as more attention is focused on undermined surface water systems, the path forward is not as clear. When a wall is cracked, the crack is repaired. When a well is obstructed, a new well is drilled. However, when a stream runs dry, how do we “put it back?” It is in protection and mitigation of surface and ground water effects where data needs grow quickly. How much flow should be in a stream at a given point in the year? What if it’s a dry year? This question requires the collection of data before, during, and after undermining. The question also requires the collection of data tailored to a specific location. When we fix a wall, the blocks are a standard size. When we drill a well, the casing is a standard diameter. Natural waters do not come in standard sizes or configurations, requiring an iterative, data- intensive approach to “putting things back.” We must examine management practices to ensure they work “best” in any single system.

Recent guidance from PADEP has improved the ability to interpret and mitigate the impacts of underground mining on surface and ground waters (PADEP 2005). Data presented in this report indicate that certain mitigation measures (e.g. gate cuts) are effective in restoring stream systems across a number of sites that vary in mining and environmental conditions. However, big data challenges limit evaluation of other mitigation techniques (e.g. grouting) and other impacts (e.g. hillside springs). As underground mining continues in the Commonwealth, best practices for managing big data should be utilized to ensure that the land areas above underground mining are managed well. Practices such as data standardization, electronic submission, and rapid error and standards checking for data submission can cascade through processes that have evolved for data gathering, enhancing the ability of all who rely on the data to protect the Commonwealth.

XI.D – References

PADEP. (2005) “Surface Water Protection – Underground Bituminous Coal Mining Operations,” Technical Guidance Document 563-2000-655, October 8, 2005, 43 p.

U.S. Energy Information Administration (2013). “Electric Power Annual 2012,” http://www.eia.gov/electricity/annual/

Appendix A: Master Agreement between PADEP and the University

Attachment 1

The University of Pittsburgh Master Agreement
Contract No. 4400004037
Project Template

Project Name:

The Effects of Subsidence Resulting from Underground Bituminous Coal Mining on Surface Structures and Features and on Water Resources: Fourth Act 54 Five-year Report

Objective:

The objective of the project is to prepare a report that summarizes all structure damage, land damage, stream impacts, and water supply impacts that have occurred during from the period of August 21, 2008 through August 21, 2013. The information contained in the report is derived from various sources including permit applications, map records, inspectors' observations, investigation files, mine subsidence insurance records, geographic data layers, and surveys of mine operators and property owners.

Problem Statement:

In 1994, the Pennsylvania General Assembly amended the Bituminous Mine Subsidence and Land Conservation Act by removing the absolute protection afforded to dwellings in place on April 27, 1966 and by adding new requirements relating to the repair of subsidence damage and the replacement of water supplies affected by underground mining operations. The amendments provided remedies for damages to more types of structures than the previous law and introduced, for the first time in Pennsylvania, remedies for effects on private water supplies. Recognizing that the amendments represented a major change in the way structures and water supplies were protected, the General Assembly included a statutory section requiring the PADEP to compile information regarding the effects of underground mining on surface structures and features and on water resources, including sources of public and private water supplies. The General Assembly further directed the PADEP to utilize the service of professionals or institutions recognized in the field in preparing this assessment.

Performance Site (please list location where work will be performed):

University of Pittsburgh
Swanson School of Engineering
Department of Civil & Environmental Engineering
949 Benedum Hall
Pittsburgh, PA 15261

Will the University be accessing any state facilities or computer systems to complete any tasks? If so, please describe:

Pennsylvania Department of Environmental Protection
California District Mining Office
25 Technology Drive
California Technology Park
Coal Center, PA 15423

Attachment 1

The University of Pittsburgh Master Agreement
Contract No. 4400004037
Project Template

The information the University will be accessing at the California District Mining Office is as follows:

1. The University shall make the maximum use of information contained in the PADEP's Bituminous Mine Information System (BUMIS) database. The BUMIS contains information on mines that operated during the assessment period; properties, structures and water supplies undermined during the assessment period, land, structure, and water supply impacts that occurred during the assessment period, claim resolutions, and the observations of PADEP field agents.

2. The University shall make the maximum use of information contained in relevant data layers maintained on the PADEP's geographic information systems. The California District Office maintains GIS data layers containing mine boundaries, longwall panels developed during the assessment period, and stream attributes. The PADEP's Emap system contains various data layers that may be useful in gathering supplemental details.

Tasks:

Task 1: Review of Information

1.1 The University will collect basic information from the Bituminous Underground Mine Impact System (BUMIS) and the permit applications on structures, wells, streams, wetlands, etc. undermined during the fourth assessment period. They will then provide an inventory of land, structures, wells, streams, and wetlands undermined that are pertinent to the report. The PADEP will supply a (Excel or Access) database with the BUMIS information.

1.2 The University will assemble 6-month mining maps and enter them into a GIS data base to obtain mine permit boundary's, water supplies, spring's, and structures locations and other pertinent surface information in relationship to the mine company's mining operations. Construct a GIS database containing the limits of the undermined area during the fourth assessment period and the location of structures, wells, streams, wetlands, etc. as located on 6-month mining maps or collected from BUMIS and permit files. The PADEP will supply digital copies of all 6-month mining maps active during the fourth assessment period. The PADEP will supply all electronic permit files that were submitted during the fourth assessment period.

Task 2: Statistical Data

2.1 The University will determine the total acreage of coal mined by mine name and mining method and submit to the PADEP a table with the acreage of coal mined sorted by mining method, mine name, and county.

2.2 The University is to consolidate all electronic relevant data used during the fourth assessment period. The University is to provide this information to the PADEP in ArcGIS, and Microsoft 10 format. The University will also provide the PADEP a copy of all publications, theses, and conference presentations that contain information gathered in conjunction with the fourth assessment period.

Task: 3.0 Stream Impacts

3.1 Identify the location of each reported incident of stream flow loss. Provide a GIS Layer of each mine showing the location of all reported incidents of stream flow loss that was longer than two-weeks or required augmentation and a table that lists the latitude and longitude of the center of the flow loss and the minimum and maximum lengths.

3.2 Identify the location of each reported incident of pooling. Provide a GIS Layer of each mine showing the location of all reported incidents of stream pooling and a table that lists the latitude and longitude of the center of the pooling and the minimum and maximum lengths.

3.3 Calculate the lengths of undermined streams (organized by mining method) that fall within one of the following categories: a) streams with no reported effects; b) streams affected by mining induced pooling; and c) streams affected by mining induced flow loss. Tables and maps listing the lengths of streams undermined (organized by mining method) that fall within one of the following categories: a) streams with no reported effects; b) streams affected by mining induced pooling; and c) streams affected by mining induced flow loss. Totals for each category as well as a cumulative total for all categories should be included with the tables. Data shall be made available to the PADEP in ArcGIS, and Microsoft 10 formats.

Task: 4.0 Hydrologic Impacts

4.1 The University will examine the hydrological monitoring data, the stream flow measurements and piezometer data, submitted to the PADEP to determine the adequacy of information submitted concerning stream impacts. They will then provide the PADEP an evaluation of the submitted hydrological monitoring data, stream flow measurements, and piezometer data for stream impacts for accuracy, quality, quantity, and sufficiency.

4.2 The University will review the methods and frequency of collecting flow measurements and piezometer data. They will then provide the PADEP with an evaluation of the methods and frequencies being used to collect the flow measurements and piezometer data, and whether the submitted data is adequate to assess stream impacts from flow loss and pooling.

4.3 The University will determine if any "affected" water supplies within the five (5) pre-selected streams were due to the lowering of the water table. The evaluation for each stream section should include information on stream flow, piezometer and pump test data, geological conditions, overburden thicknesses, topography, stream morphology and any other relevant geological characteristics.

4.4 The University will review the pre - and post-mining stream hydrology conditions of five (5) selected streams that lost flow, including at least two (2) streams where flow loss has exceeded the predicted recovery period (two to three years) as outlined in the Technical Guidance Document 560-2000-655. The evaluation for each stream section should include information on stream flow, piezometer and pump test data, geological conditions, overburden thicknesses, topography, stream morphology and any other relevant geological characteristics The University will provide an evaluation on the potential causes of the changes in hydrologic conditions between the pre - and post-mining steam flow conditions. Emphasis should be placed on streams with long-term flow loss (greater than three years) with the goals of assessing the likelihood of near-term flow recovery and identifying any mitigating factors that are preventing or delaying recovery.

Task: 5.0 Stream Impacts – Flow Loss

5.1 The University will include an assessment of the pre- and post-mining "total biological scores" for segments of five (5) streams that experienced flow loss in accordance PADEP Technical Guidance 563-2000-655. Provide an assessment of the pre- and post-mining "total biological scores" for selected reported incident of stream flow loss.

5.2 The University will review and evaluate five (5) selected sections of streams that were undermined prior to the implementation of the Technical Guidance Document 560-2000-655. Provide an evaluation of the existing conditions of streams that were undermined prior to the implementation of the guidance document. The evaluation should include information areas of pooling, stream loss, and biological assessments.

Task: 6.0 Stream Impacts – Pooling

6.1 The University will conduct an evaluation five (5) selected sections of streams that had stream mitigation work completed during the fourth assessment period. The evaluation for each pooled section should include information on stream flow, piezometer and pump test data, geological conditions, overburden thicknesses, topography, stream morphology and any other relevant geological characteristics. They will provide to the PADEP a written section that evaluates the effectiveness how well the stream pooling mitigation is working, (ex. have the pooling issues been resolved, were there access issues, and are the biological scores returning after the pooling area was removed.) during the fourth assessment period in terms of flow restoration and biological community changes. The evaluation of each pooled section should include information on stream flow, piezometer and pump test data, geological conditions, overburden thicknesses, topography, stream morphology and any other relevant geological characteristics.

6.2 The University will determine the status of five (5) selected reported incidents of pooling and include an assessment of the pre- and post-mining "total biological score" calculated in accordance PADEP Technical Guidance 563-2000-655. Provide a section listing the locations and status of five (5) selected reported occurrences of stream pooling. The section should include an assessment of the pre- and post-mining "total biological scores" submitted to and collected by the PADEP as well as any recent fieldwork conducted by the University. The PADEP will supply the existing pre- and post-mining "total biological scores" for evaluation.

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Task: 7.0 Wetland Impacts

7.1 The University will determine the number of wetlands (identified in permit applications and renewals, and the NWI database) by type (e.g., vernal, emergent, palustrine, etc.) that were exposed to the effects of underground mining operations. Include information on whether these wetlands are in areas of planned subsidence and the depth of cover for wetlands. Provide a table listing the number of wetlands (identified in permit applications and renewals after the adoption of the TGS in 2007/2008, and the NWI database) by type (e.g., vernal, emergent, palustrine, etc.) that were exposed to the effects of underground mining operations. Provide tables or other means to show effects of mining on wetlands in areas of planned subsidence and depth to mining.

7.2 The University will determine the number and acreage of the wetlands that were restored or replaced during the fourth assessment period. A table and or other means (charts, graphs, etc.,) listing the number and acreage of wetlands restored or replaced during the fourth assessment period and after adoption of the TGS in 2007/2008.

7.3 The University will calculate the net gain or loss in wetland area resulting from mining-induced changes from existing data. A table and or other means (charts, graphs, etc.,) listing the net gain or loss in wetland area resulting from mining induced changes will be developed and provided to the PADEP.

7.4 The University will evaluate the effectiveness of the wetland replacements and provide a written section that includes the information on the effectiveness of restoring species, diversity, and hydrology.

Task: 8.0 Water Supply Impacts

8.1 The University needs to determine within 35-degrees (angle of influence) of the mine permit boundary the number of water supplies undermined and affected by the underground mining operations. A table or other means (charts, graphs, etc.,) identifying the number of water supplies undermined during the fourth assessment period must be submitted sorted by the following information:

a) Supply type (i.e. well, springs, or public water connection);

b) Use (i.e. domestic, agricultural, industrial);

c) Mining type (i.e. longwall, room & pillar and pillar retreat); and

d) Type of impact (i.e. contamination, diminution, or damage to physical components)

8.2 The University will evaluate and outline the processes involved with water supply replacements and the amount of time that is required to resolve the permanent water replacement.

8.3 The University will evaluate the resolution times and status of water supply replacements that occurred during the fourth assessment period. The University will submit to the PADEP a table that is based on the PADEP water supply replacement process that evaluates the amount of time required to resolve the impacts.

Task: 9.0 Structure Impacts

9.1 The University will determine the overburden thicknesses for longwall mining operations that were active during the fourth assessment period and provide a GIS layer with 100-ft overburden contours.

9.2 The University will determine where available data exists, the overburden thickness for room and pillar mining operations that were active during the fourth assessment period, and provide a GIS layer with 100-ft overburden contours for any room and pillar mining operations that were active during the fourth assessment period and has existing overburden thickness data.

9.3 The University will define within a 200-foot buffer from the edge of the edge of the mining operations the total number of impacts to structures during the fourth assessment period due to undermining. Provide a table or other means (charts, graphs, etc.,) identifying the number of structures undermined during the fourth assessment period sorted by: a) structure type, (i.e. residential, public etc.), b) mining type (i.e. longwall, room & pillar and pillar retreat), and c) type of impact.

9.4 The University will determine the status and resolution times of structure repairs that occurred during the fourth assessment period. Provide a table or other means (charts, graphs, etc.,) that evaluates the status and resolution times of the structure impacts that occurred during the fourth assessment period.

9.5 The University will review the processes involved with structure repairs and the amount of time that is required to resolve the damage issues. A description of the structure repair process and the time required to resolve the structure repairs will be provided to the PADEP.

Task: 10.0 Recommendations / Conclusions

10.1 The University will submit an evaluation of the compiled data with conclusions concerning the effectiveness of PADEP's implementation of Act 54, and policies.

10.2 The University will provide recommendations based on the analysis of the data to the on how to improve the implementation of Act 54s.

Task: 11.0 Draft of Report

11.1 The University will write a draft report and submit it to the PADEP for comments by April 30, 2014.

Task: 12.0 Final Report

12.1 The University will address the PADEP comments on the draft report and deliver a final report on August 31, 2014. The University will provide the PADEP ten (10) printed copies of the final report, and one (1) electronic copy of the final report in Microsoft Word format.

Task: 13.0 Additional Deliverables

13.1 The University will provide the PADEP with all relevant data used in the report. Provide the PADEP with all raw, manipulated, and computed data used in the, evaluations, interpretation and conclusions used in the assembly of the report in Word, Excel and ArcGIS format.

Confidential Information:

The following confidential information of the Agency will be part of the scope of work.

The UNIVERSITY agrees to protect the confidentiality of the COMMONWEALTH'S information. The COMMONWEALTH agrees to protect the confidentiality of UNIVERSITY'S confidential information. In order for information to be deemed confidential, the party claiming confidentiality must designate the information as "confidential" in such a way as to give notice to the other party. The parties agree that such confidential information shall not be copied, in whole or in part, except when essential for authorized use under this Contract. Each copy of such confidential information shall be marked by the party making the copy with all notices appearing in the original. Upon termination or cancellation of this Contract or any license granted hereunder, the receiving party will return to the disclosing party all copies of the confidential information in the receiving party's possession, (other than one copy of copyrighted works, which may be maintained for archival purposes only). Both parties agree that a material breach of these requirements may, after failure to cure within the period specified in this Contract, and at the discretion of the non-breaching party, result in termination for default.

Project Meeting Requirements:

A project meeting will be held face to face or electronically among the Principal Investigator and Agency project manager, or their designees, within ten working days of the issuance of the Purchase Order, to discuss the scope of implementation for the completion of the project. Subsequent project meetings will be held at the request of the Principal Investigator and Agency project manager, or their designees. Written minutes of, and action items resulting from, project meetings will be provided electronically by the Principal Investigator to the Agency project manager and all meeting participants within 10 working days of the meeting.

Communications and Reporting:

Oral or written communications that may affect the scope of the research project or services, budget, or period of the project shall be documented and relayed to the Agency project manager by telephone, e-mail, or memo for the Agency's consideration. Any changes shall only be effective through approval of the Agency and execution of a modification to the purchase order. If the increase totals the project to be greater than $100,000, Department of General Services approval shall be received.

Attachment 1

The University of Pittsburgh Master Agreement
Contract No. 4400004037
Project Template

The Principal Investigator will provide the following information to the Agency as shown in the chart below:

Task	Description	Due Date
11	Draft Report	April 30, 2014
12	Final Report	August 31, 2014
13	Additional Deliverables	August 31, 2014

Management Plan and Staffing:

Biology Personal Services:

Steven Tonsor, PhD (PI)

Post-doctoral Researcher

Graduate Student Researcher

Research Specialist

Undergraduate Student

Engineering Personal Services:

Anthony Iannachione, PhD (PI)

Graduate Student Researcher

Graduate Student Researcher

Undergraduate Student Researcher

Geological Personal Services:

Daniel Bain, PhD (PI)

Graduate Student Researcher

Work team members who have not yet been named shall be identified when they join the team. When a new team member is named, the Principal Investigator will notify the Agency in writing prior to charging the person's time to the project.

Overall Performance Time Frame: (For The University of Pittsburgh to fill out)

Attachment 1

The University of Pittsburgh Master Agreement
Contract No. 4400004037
Project Template

This research project or services will be completed 24 months from the date of issuance of the Purchase Order.

September 01, 2012 – Project begins

March 12, 2013 – Progress meeting

September 18, 2013 – Progress meeting

February 11, 2014 - Progress meeting

April 30, 2014 – Draft of final report submitted to the Department

May 31, 2014 – Department returns comments on final report to the University

August 31, 2014 – Final report provided to Department

Appendix B: Summary of mining activity and reported effects during the 4th assessment period.

Mine Name	Type of Mine*	Mining Method (Acres)			Total (Acres)	Structures**				Water Supplies**				Land Reported Effects	Streams Undermined (Miles)
		Room and Pillar	Pillar Recovery	Longwall		Reported Effects	Company Liable	Company Not Liable	Unresolved	Reported Effects	Company Liable	Company Not Liable	Unresolved		
Agustus	RP	274.4			274.4	0	0	0	0	6	3	1	2	0	0.77
Barrett Deep	RP	120.8			120.8	0	0	0	0	4	2	2	0	0	0.11
Beaver Valley	RP	172.7			172.7	0	0	0	0	10	2	4	4	0	0.22
Cherry Tree	RP	970.9			970.9	0	0	0	0	19	2	11	6	0	2.05
Clementine 1	RP	476.3			476.3	16	3	10	3	62	33	26	3	0	1.19
Darmac 2	RP	362.4			362.4	0	0	0	0	14	8	4	2	0	0.81
Dora 8	RP	196.4			196.4	1	0	0	1	4	1	1	2	0	0.41
Dutch Run	RP	356.6			356.6	1	0	1	0	7	4	2	1	0	0.48
Geronimo	RP	13.8			13.8	0	0	0	0	3	3	0	0	0	0
Gillhouser Run	RP	288.5			288.5	1	0	1	0	3	1	1	1	0	0.65
Harmony	RP	413.7			413.7	0	0	0	0	2	0	1	1	0	0.2
Heilwood	RP	427.3			427.3	4	0	3	1	10	0	8	2	0	0.67
Horning Deep	RP	41.1			41.1	1	0	1	0	2	0	2	0	0	0.05
Kimberly Run	RP	931			931	0	0	0	0	31	2	16	13	0	0.83
Knob Creek	RP	251.5			251.5	0	0	0	0	4	0	3	1	0	0.51
Little Toby	RP	168.6			168.6	0	0	0	0	8	2	6	0	0	0.09
Logansport	RP	1,058.8			1,058.8	1	0	1	0	30	8	14	8	0	2.75
Long Run	RP	101.3			101.3	0	0	0	0	4	3	1	0	0	0.03
Lowry	RP	300.4			300.4	0	0	0	0	0	0	0	0	0	0.21
Madison	RP	735.6			735.6	1	0	1	0	5	2	3	0	1	0.83
Miller Deep	RP	63.5			63.5	1	1	0	0	0	0	0	0	1	0.19
Ondo	RP	300.5			300.5	3	0	3	0	28	18	7	3	1	0.25
Penfield	RP	570.6			570.6	0	0	0	0	1	1	0	0	0	0.05
Quecreek 1	RP	708.1			708.1	0	0	0	0	15	5	6	4	0	2.31
Rossmoyne 1	RP	139.7			139.7	2	0	2	0	40	28	7	5	0	0.13
Roytown	RP	342.9			342.9	0	0	0	0	16	8	6	2	0	0.89
Sarah	RP	47.6			47.6	2	0	2	0	1	0	1	0	0	0.22

Mine Name	Type of Mine*	Mining Method (Acres)			Total (Acres)	Structures**				Water Supplies**				Land Reported Effects	Streams Undermined (Miles)
		Room and Pillar	Pillar Recovery	Longwall		Reported Effects	Company Liable	Company Not Liable	Unresolved	Reported Effects	Company Liable	Company Not Liable	Unresolved		
Starford	RP	46.6			46.6	0	0	0	0	8	0	7	1	0	0.16
TJS 5	RP	9.5			9.5	1	0	1	0	0	0	0	0	0	0
TJS 6	RP	413.9			413.9	0	0	0	0	20	7	11	2	0	0.98
Toms Run	RP	532.1			532.1	3	0	3	0	2	0	2	0	0	1.57
Tracy Lynne	RP	340.7			340.7	10	1	3	6	19	9	4	6	1	1.02
Twin Rocks	RP	453.3			453.3	0	0	0	0	3	0	3	0	0	0.58
Windber 78	RP	722.1			722.1	0	0	0	0	3	0	3	0	1	2.01
Subtotal	RP	*12,353.2*			*12,353.2*	*48*	*5*	*32*	*11*	*384*	*152*	*163*	*69*	*5*	*23.22*
4 West	PR	928.7	127.6		1,056.3	2	0	2	0	1	0	0	1	2	3.55
Crawdad	PR	159.9	75.6		235.5	0	0	0	0	0	0	0	0	0	0.37
Nolo	PR	388.2	22.2		410.4	2	0	2	0	22	13	5	4	0	0.28
Prime 1	PR	206.3	35.8		242.1	3	0	3	0	1	0	0	1	0	0.33
Titus Deep	PR	18.9	21.6		40.5	0	0	0	0	0	0	0	0	0	0.22
Subtotal	*PR*	*1,702*	*282.8*		*1,984.8*	*7*	*0*	*7*	*0*	*24*	*13*	*5*	*6*	*2*	*4.75*
Bailey	L	766.5		3,107.6	3,874.1	53	42	7	4	70	18	21	31	10	17.2
Blacksville 2	L	622.8		1,263.1	1,885.9	11	6	1	4	28	15	6	7	8	8.37
BMX	L	566.7		0	566.7	0	0	0	0	0	0	0	0	0	2.46
Cumberland	L	791.1		1,861.8	2,652.9	47	24	7	16	61	27	20	14	20	9.99
Emerald	L	574.2		1,508.8	2083	46	25	18	3	54	30	11	13	30	8.21
Enlow Fork	L	1,293.4		4,582.5	5,875.9	145	131	3	11	156	95	19	42	22	21.6
Mine 84	L	10.6		56.2	66.8	13	2	10	1	24	8	11	5	4	0.25
Subtotal	*L*	*4,625.3*		*12,380.0*	*17,005.3*	*315*	*230*	*46*	*39*	*393*	*193*	*88*	*112*	*94*	*68.08*
Non-Active Mines during the 4th assessment period***						19	3	7	9	54	13	27	14	5	
Total		**18,681**	**283**	**12,380**	**31,343**	**389**	**238**	**92**	**59**	**855**	**371**	**283**	**201**	**106**	**96.05**
Unresolved Reported Effects from the 3rd Assessment Period						**93**				**211**					

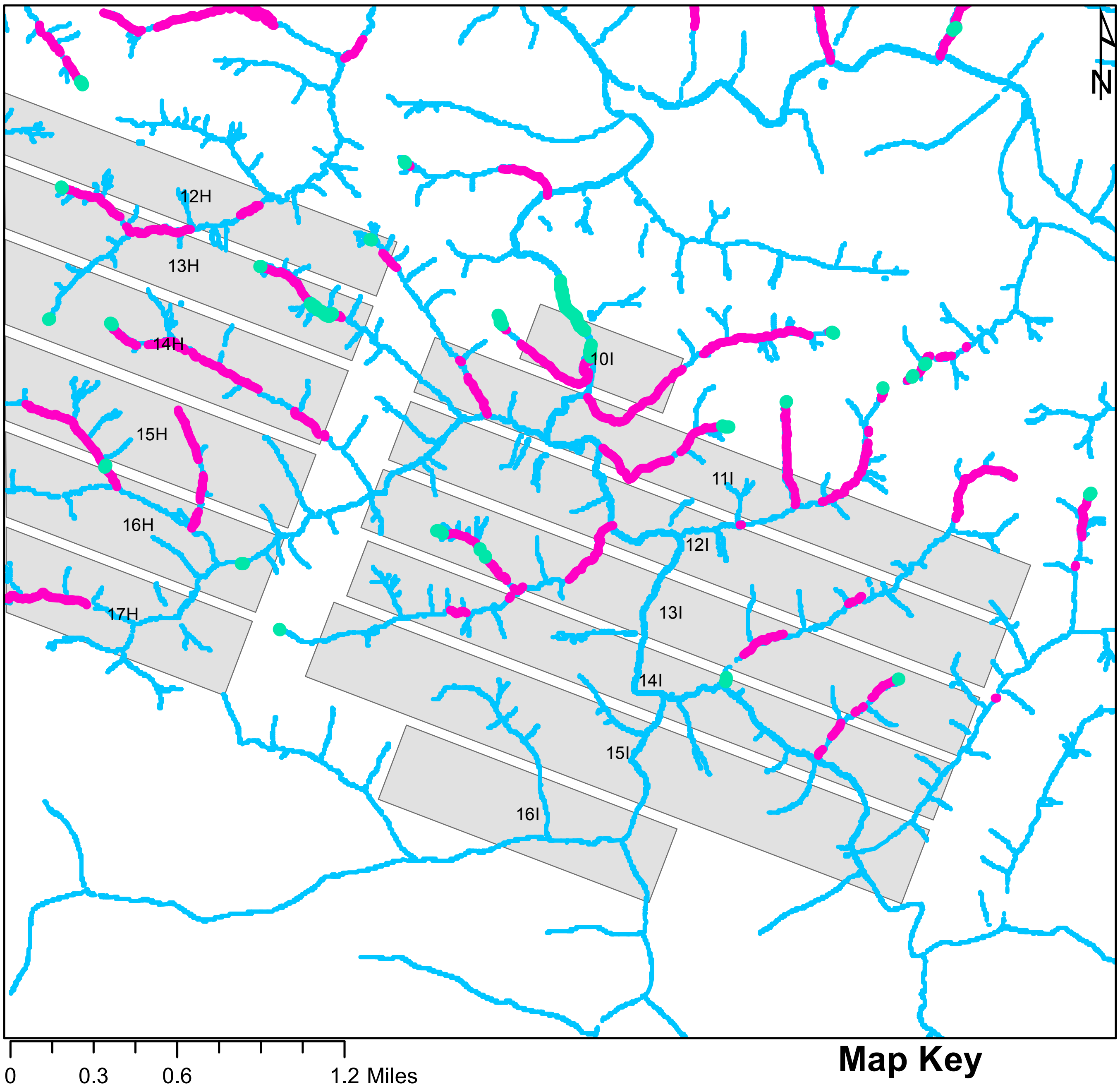
* - RP = Room-and-pillar mining, PR = Room-and-pillar with pillar recovery, and L = Longwall mining.

** - Some features types may have been misclassified.

*** - Non-active mines include: Barbara 1 & 2, Brubaker, Darmac 3, David Dianne, Dilworth, Emilie 1 & 2, Foundation, Genesis 17, High Quality, Homer City Deep, Humphrey 7, Lucerne 9, Maple Creek, Mathies, No. 3 Deep, Parkwood, Ridge, Roaring Run, Stitt, Solar 7, TJS 1 Deep, Triple K 1, Urling 1 & 3 Deep

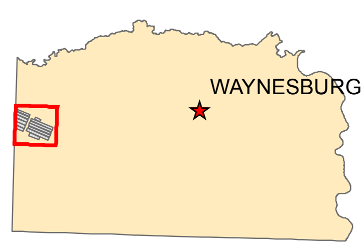
Appendix C: Maps of Maximum and Minimum Stream Flow Loss and Wetlands

Bailey Mine,
Minimum and Maximum Stream Flow Loss,
Wet Season



Map Key

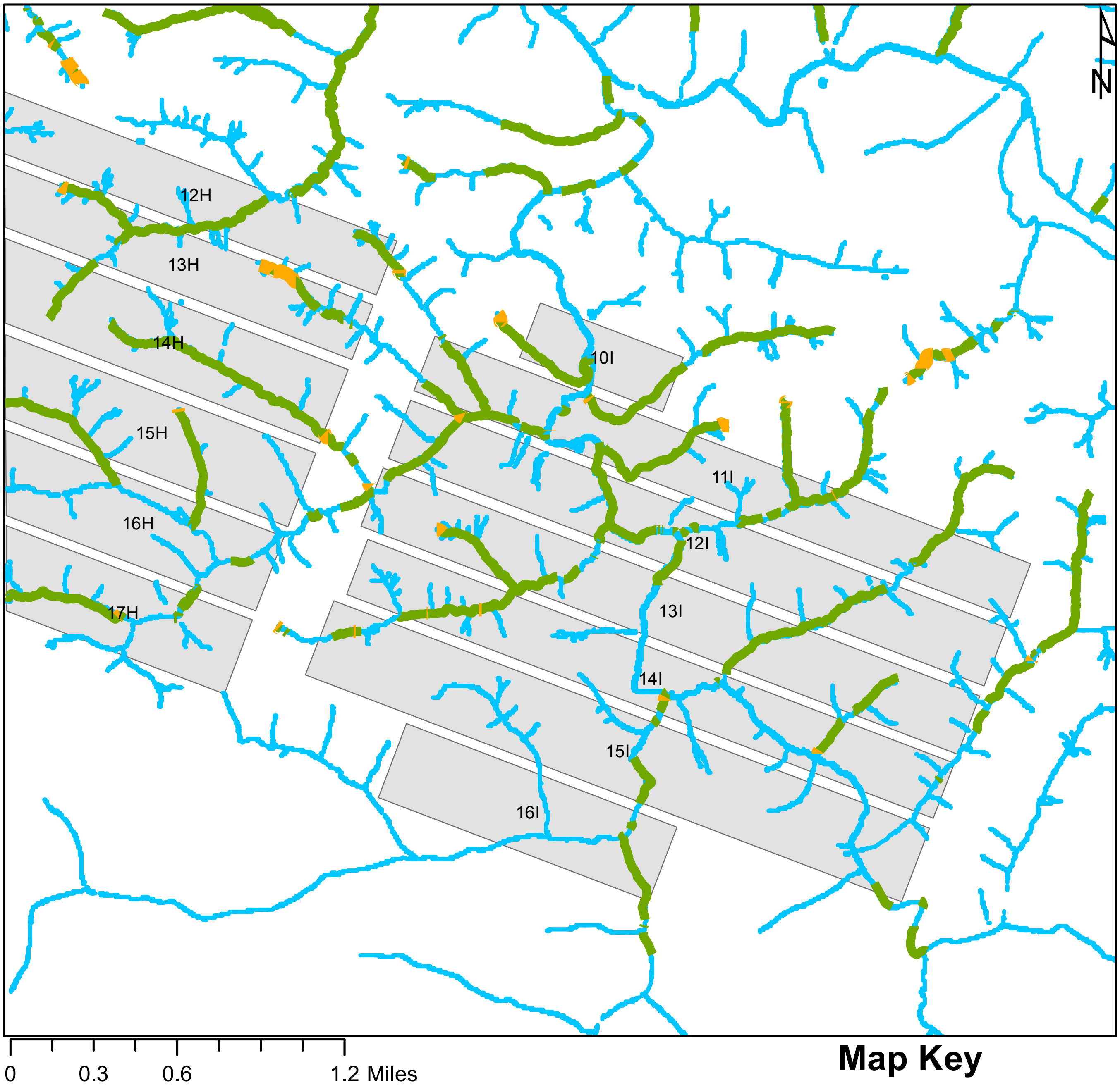
- Minimum Length (Wet Season)
- Maximum Length (Wet Season)
- Streams
- Longwall Panel (4th)



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Bailey Mine,
Minimum and Maximum Stream Flow Loss,
Dry Season



Map Key

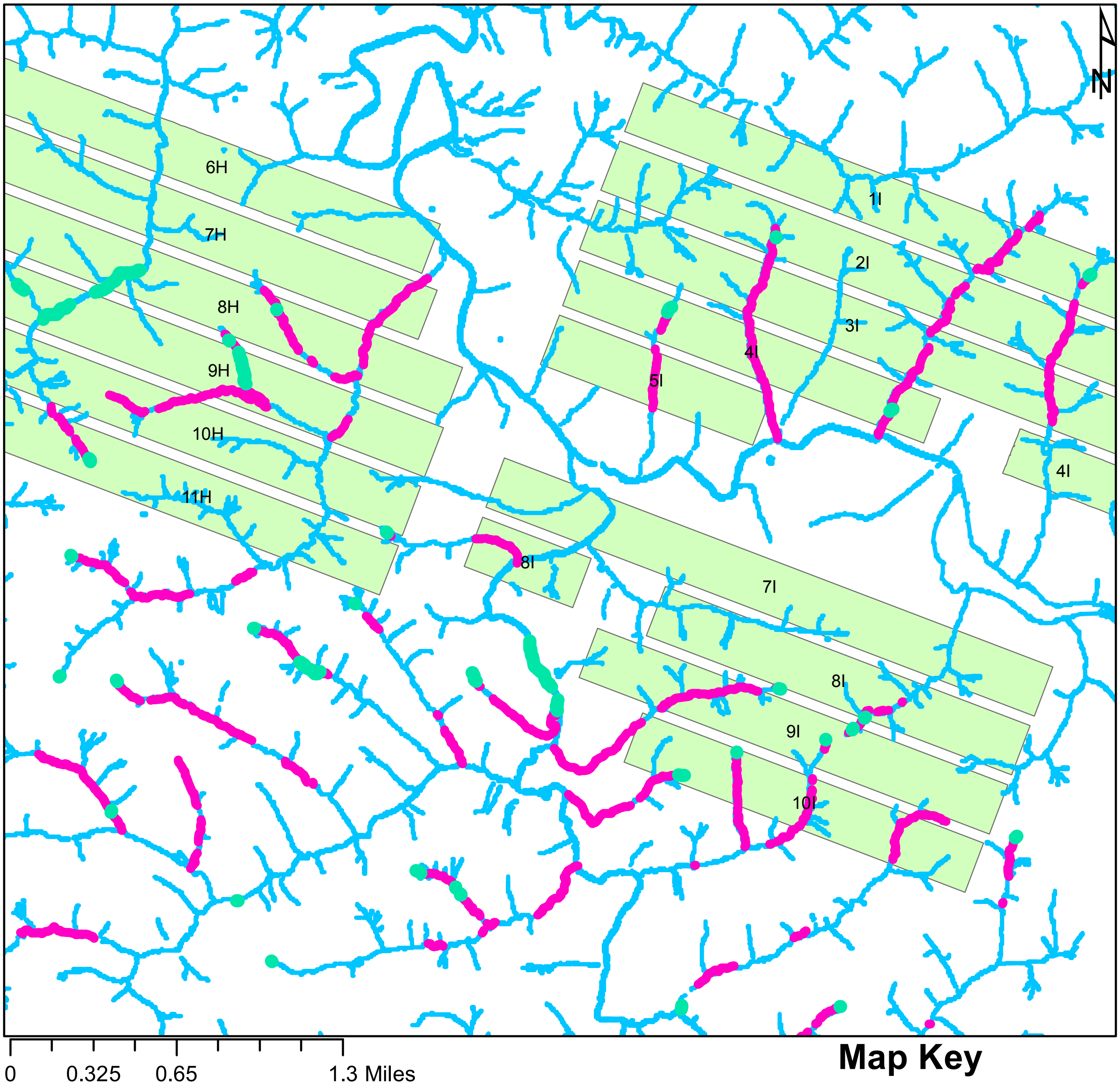
- Minimum Length (Dry Season)
- Maximum Length (Dry Season)
- Streams
- Longwall Panel (4th)

Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

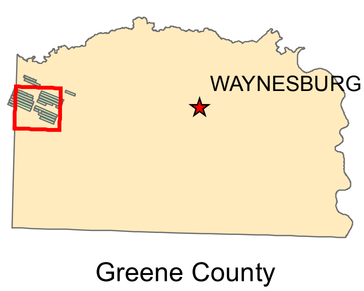
Prepared by:
University of Pittsburgh

Bailey Mine,
Minimum and Maximum Stream Flow Loss,
Wet Season



Map Key

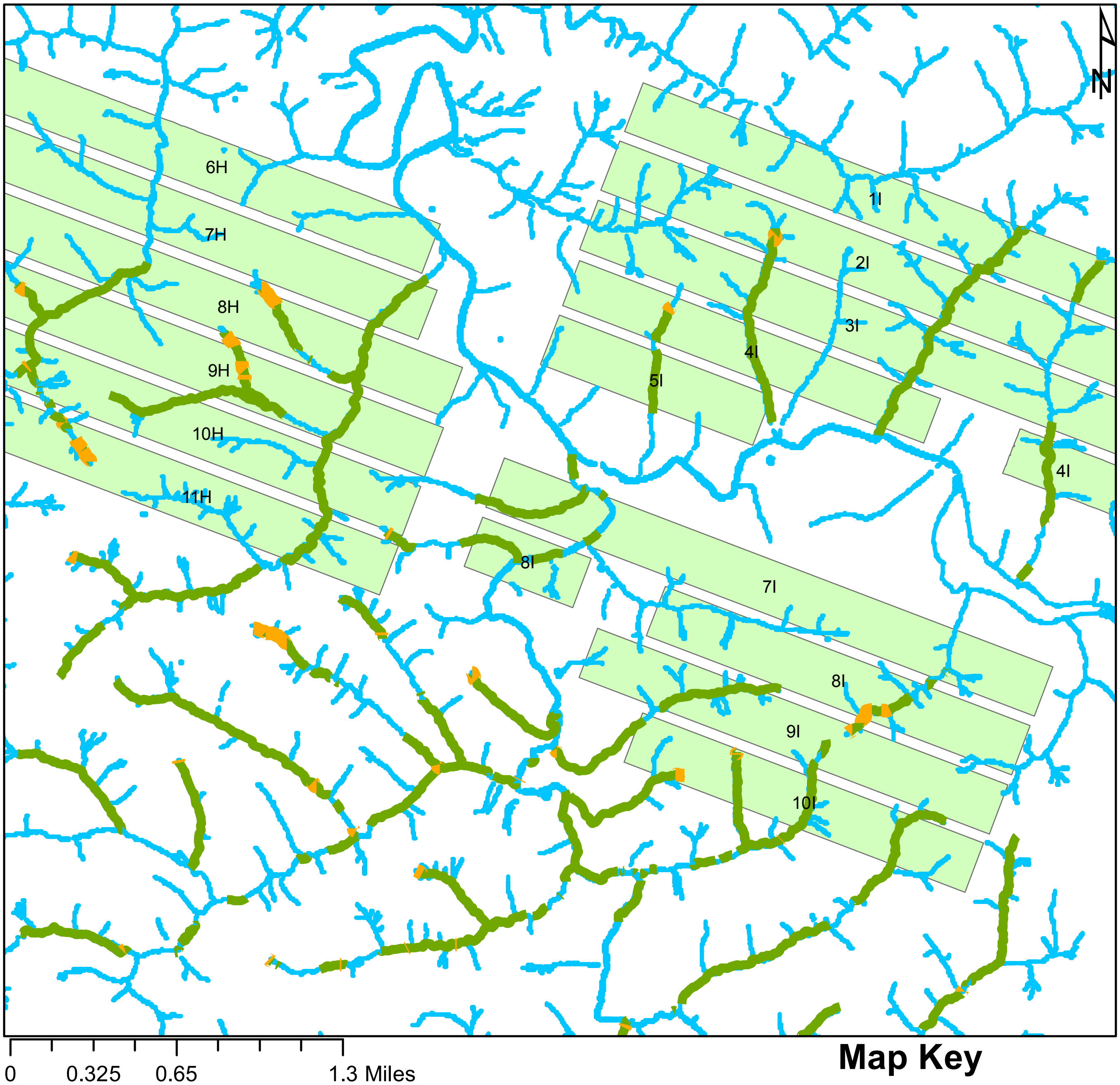
- Minimum Length (Wet Season)
- Maximum Length (Wet Season)
- Streams
- Longwall Panel (3rd)



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

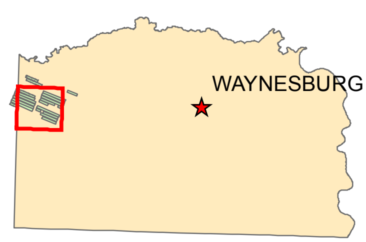
Prepared by:
University of Pittsburgh

Bailey Mine, Minimum and Maximum Stream Flow Loss, Dry Season



Map Key

- Minimum Length (Dry Season)
- Maximum Length (Dry Season)
- Streams
- Longwall Panel (3rd)

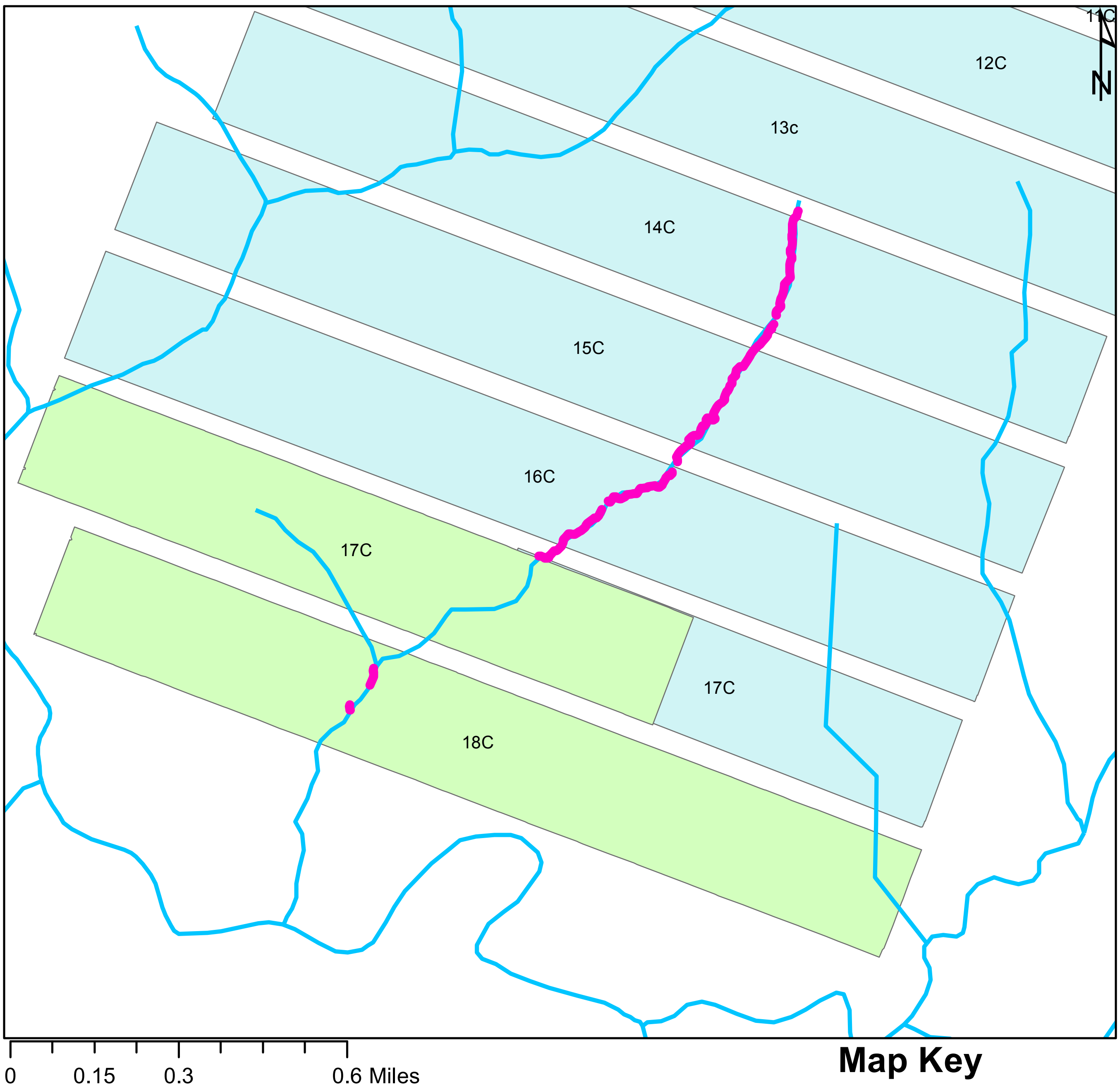


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Bailey Mine, Minimum and Maximum Stream Flow Loss, Wet Season



Map Key

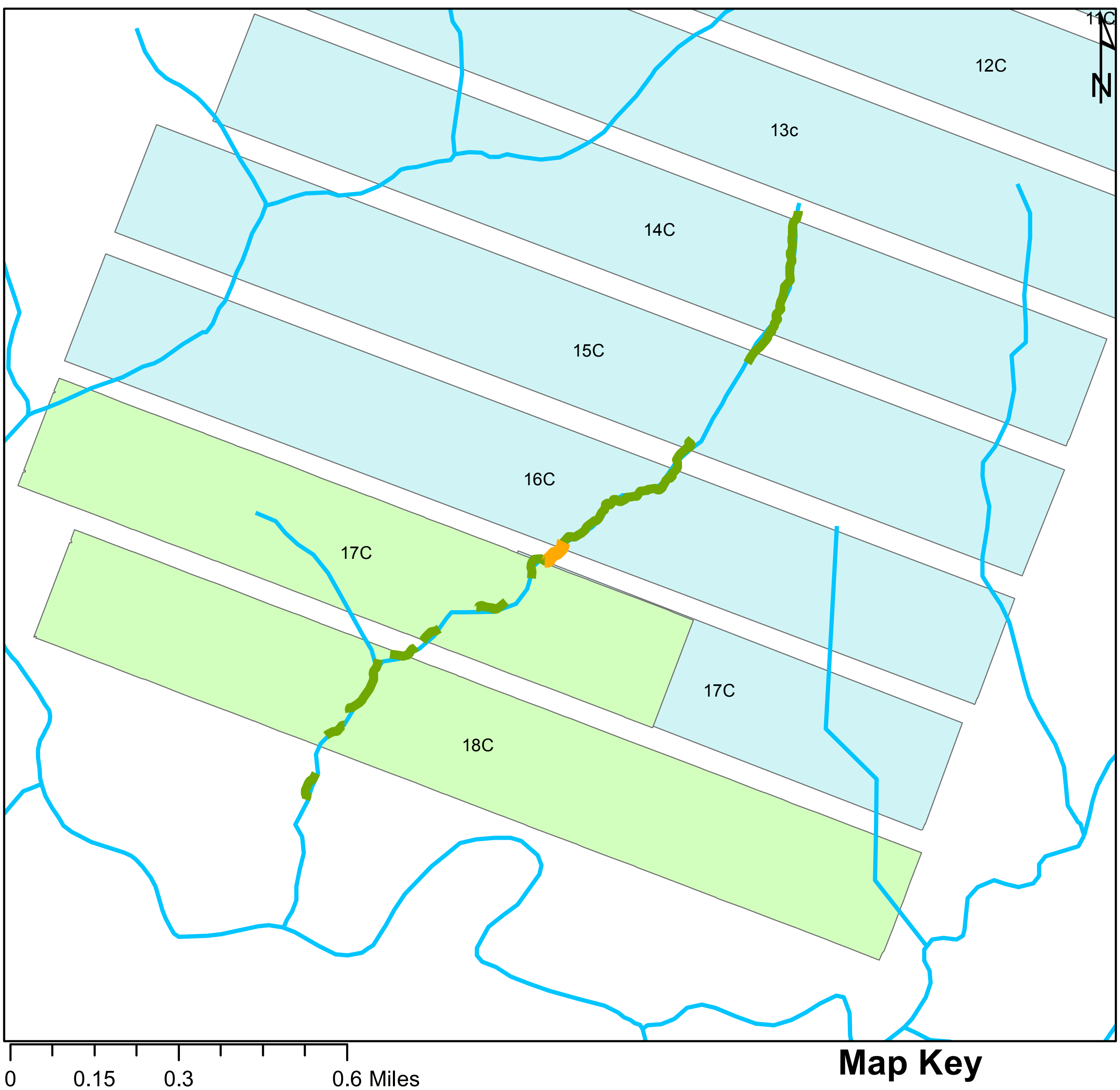
- Minimum Length (Wet Season)
- Maximum Length (Wet Season)
- Streams
- Longwall Panel (3rd)
- Longwall Panel (2nd)

Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

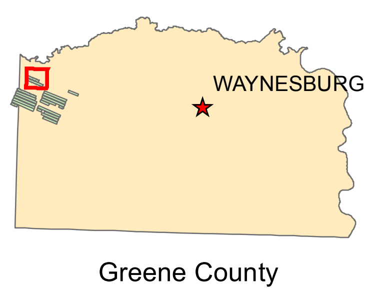
Prepared by:
University of Pittsburgh

Bailey Mine,
Minimum and Maximum Stream Flow Loss,
Dry Season



Map Key

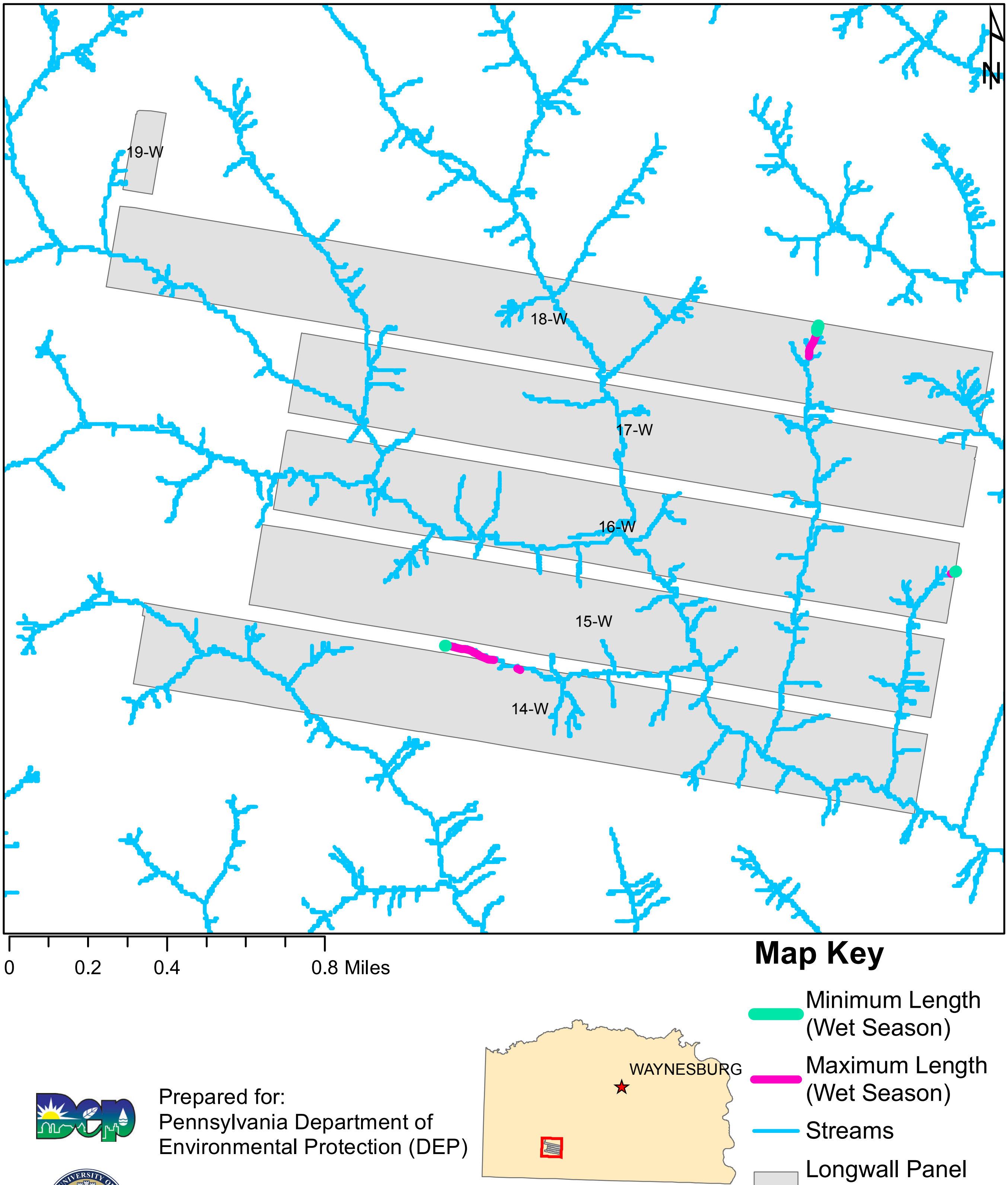
- Minimum Length (Dry Season)
- Maximum Length (Dry Season)
- Streams
- Longwall Panel (3rd)
- Longwall Panel (2nd)



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

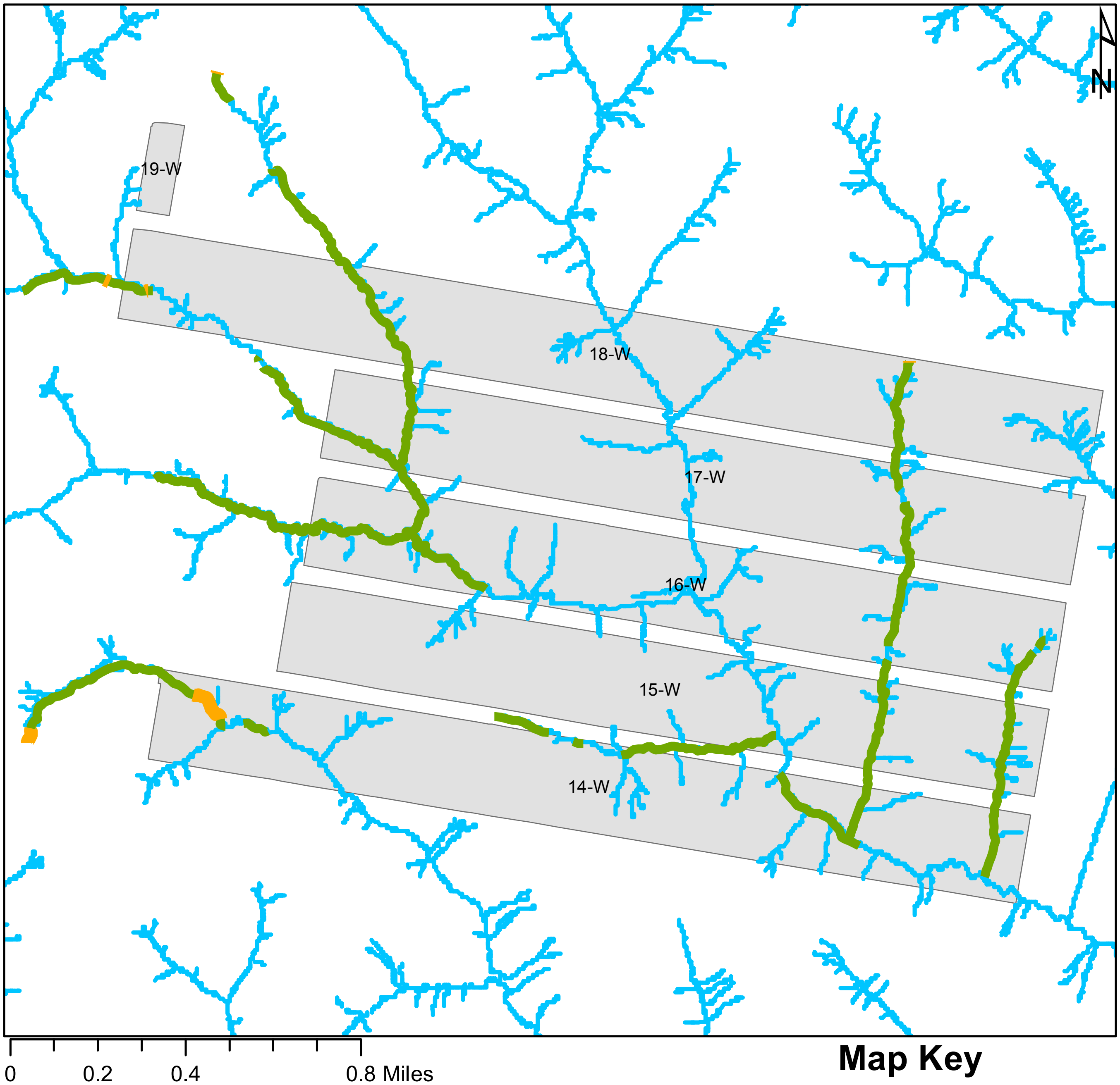
Blacksville 2 Mine, Minimum and Maximum Stream Flow Loss, Wet Season



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

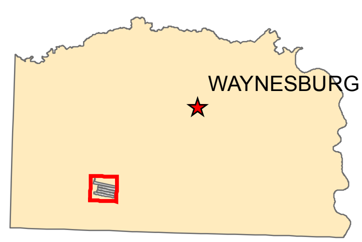
Prepared by:
University of Pittsburgh

Blacksville 2 Mine,
Minimum and Maximum Stream Flow Loss,
Dry Season



Map Key

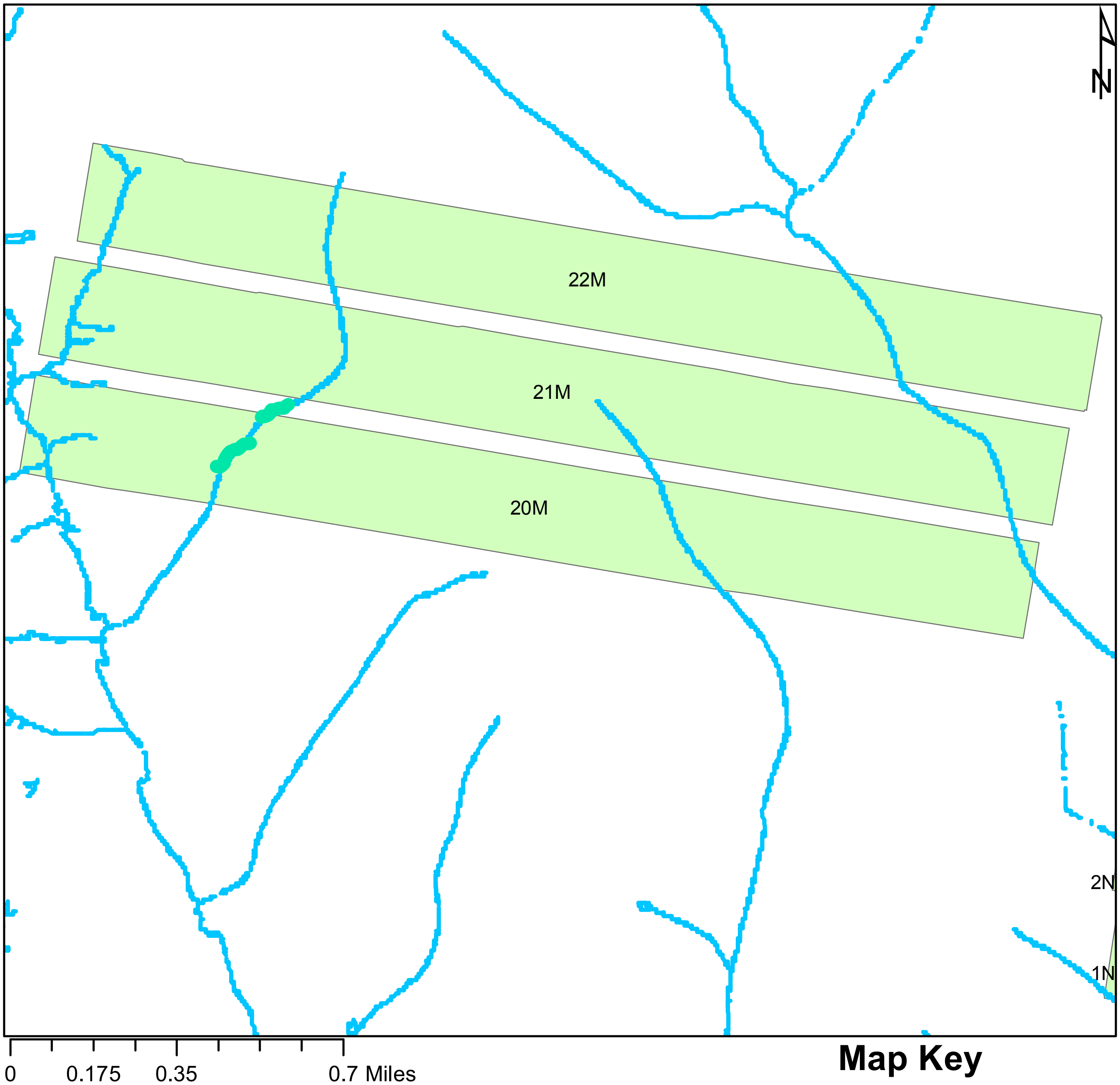
- Minimum Length (Dry Season)
- Maximum Length (Dry Season)
- Streams
- Longwall Panel (4th)



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Blacksville 2 Mine, Minimum and Maximum Stream Flow Loss, Wet Season



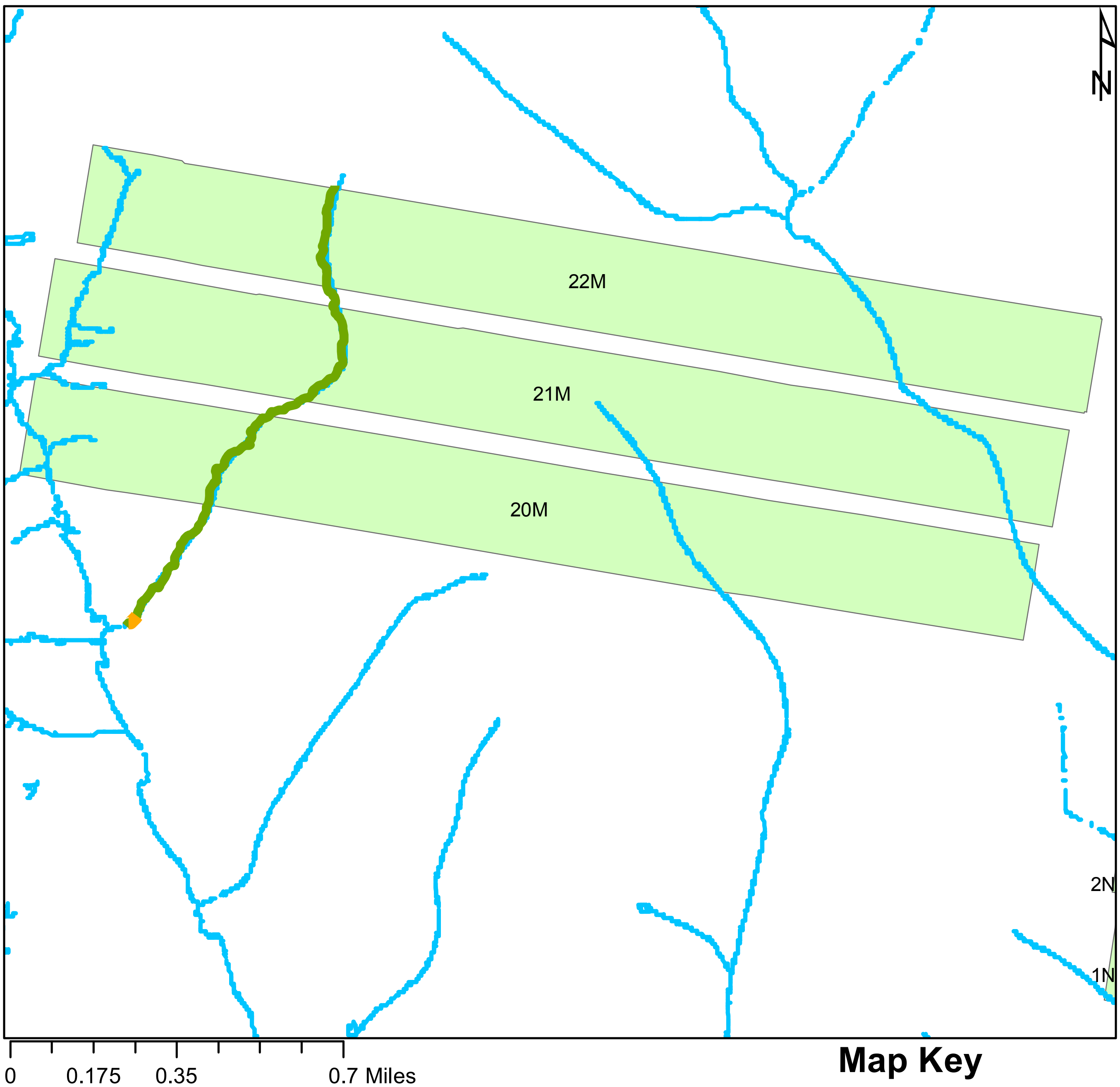
Map Key

- Minimum Length (Wet Season)
- Maximum Length (Wet Season)
- Streams
- Longwall Panel (3rd)

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Blacksville 2 Mine, Minimum and Maximum Stream Flow Loss, Dry Season



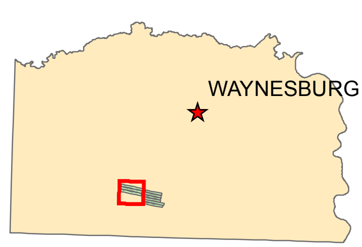
Map Key

Minimum Length (Dry Season)

Maximum Length (Dry Season)

Streams

Longwall Panel (3rd)

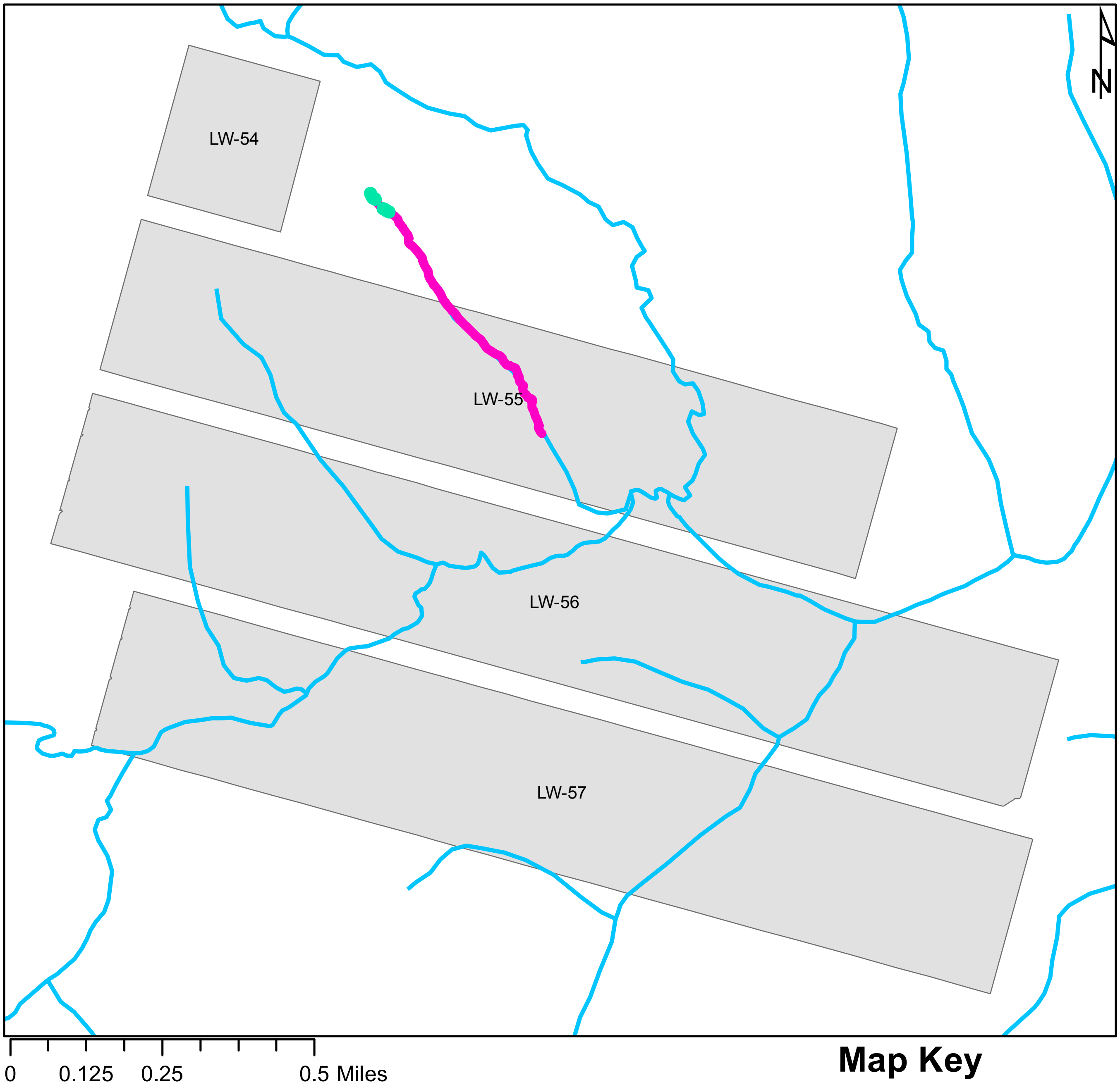


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Cumberland Mine, Minimum and Maximum Stream Flow Loss, Wet Season



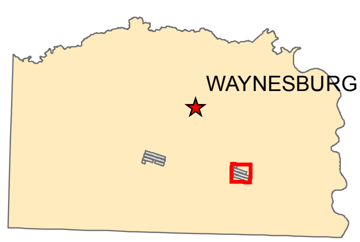
Map Key

Minimum Length (Wet Season)

Maximum Length (Wet Season)

Streams

Longwall Panel (4th)

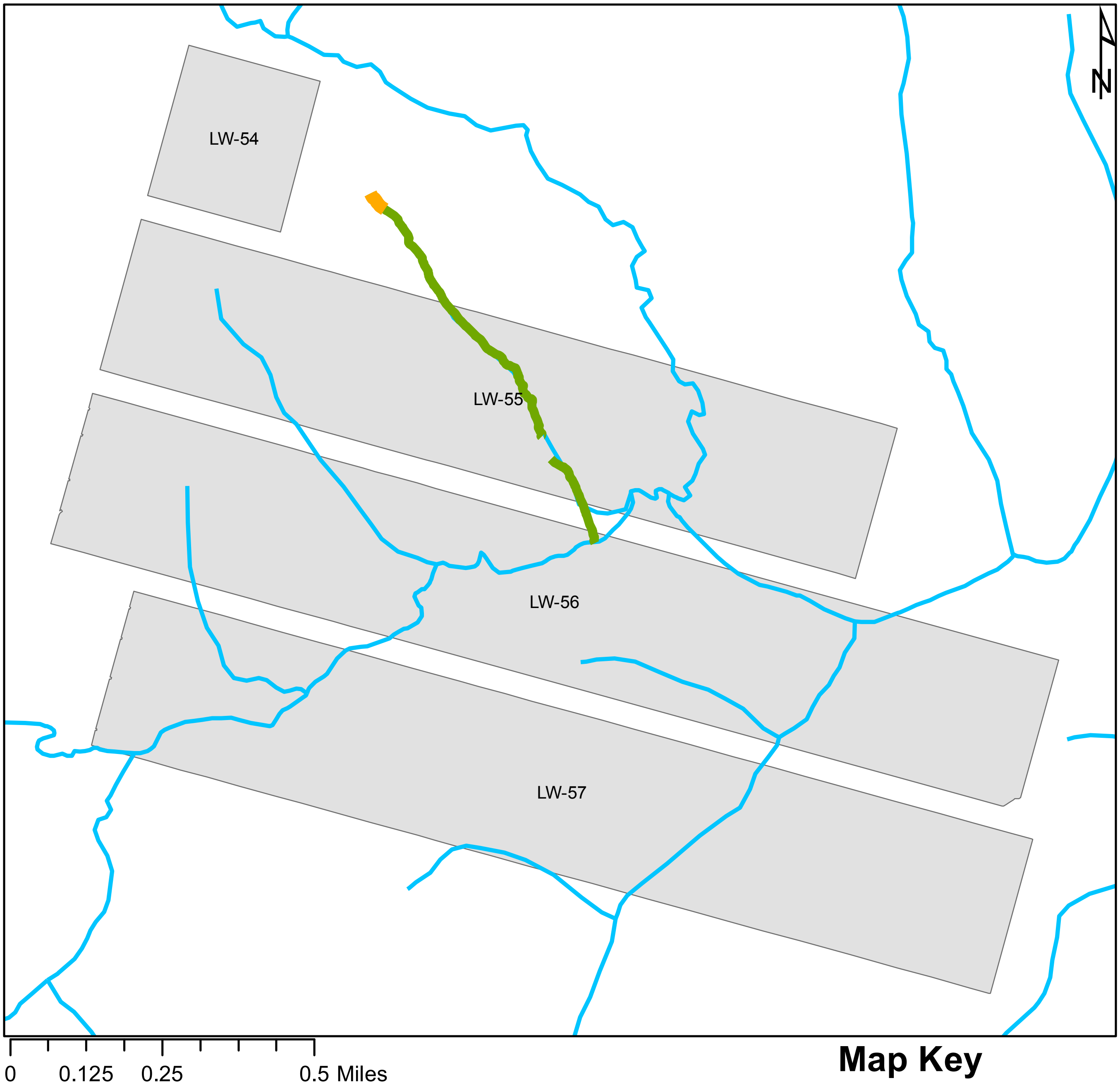


Greene County

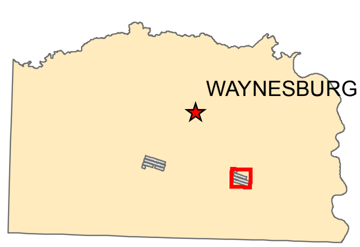
Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Cumberland Mine, Minimum and Maximum Stream Flow Loss, Dry Season



Map Key

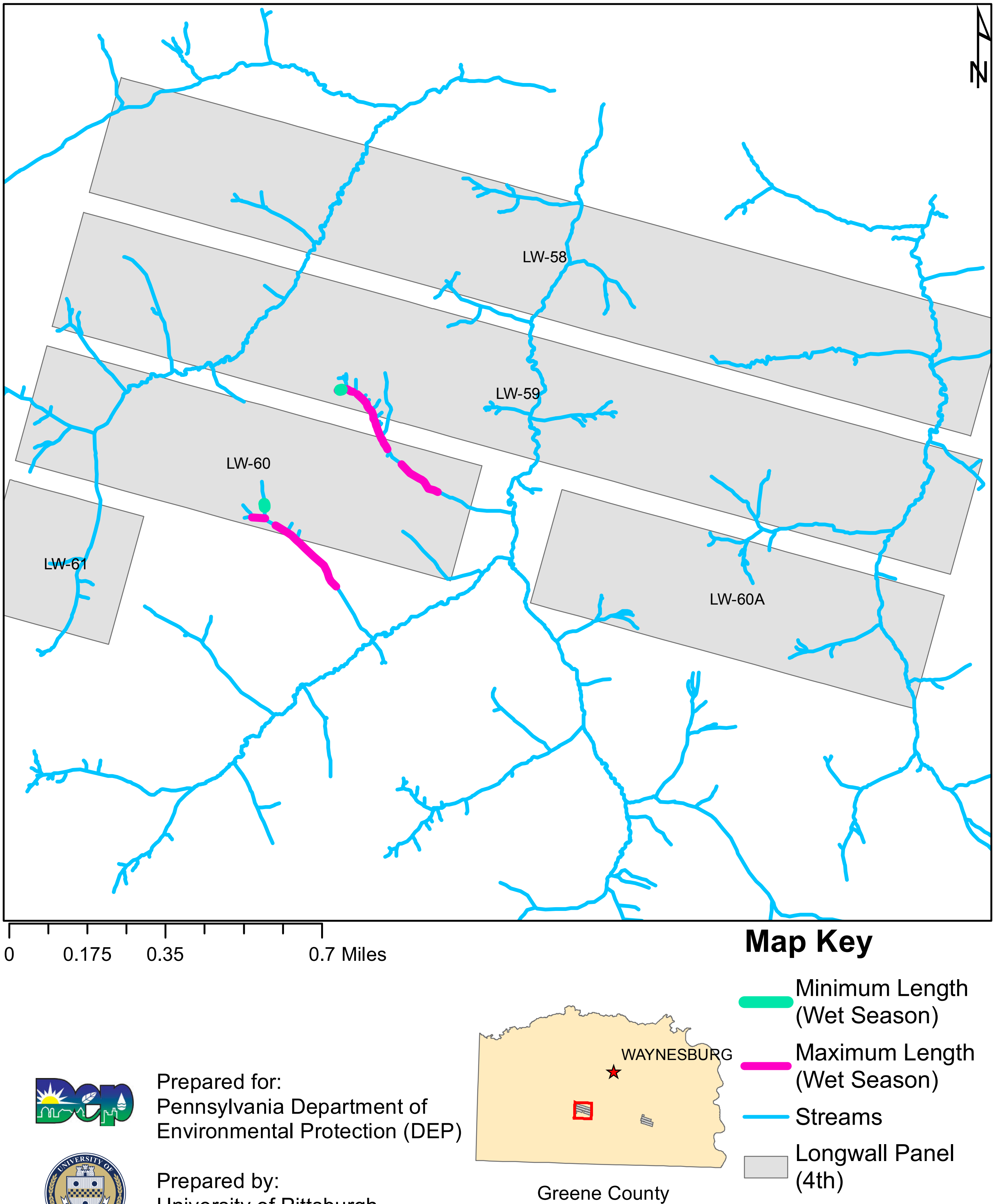


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

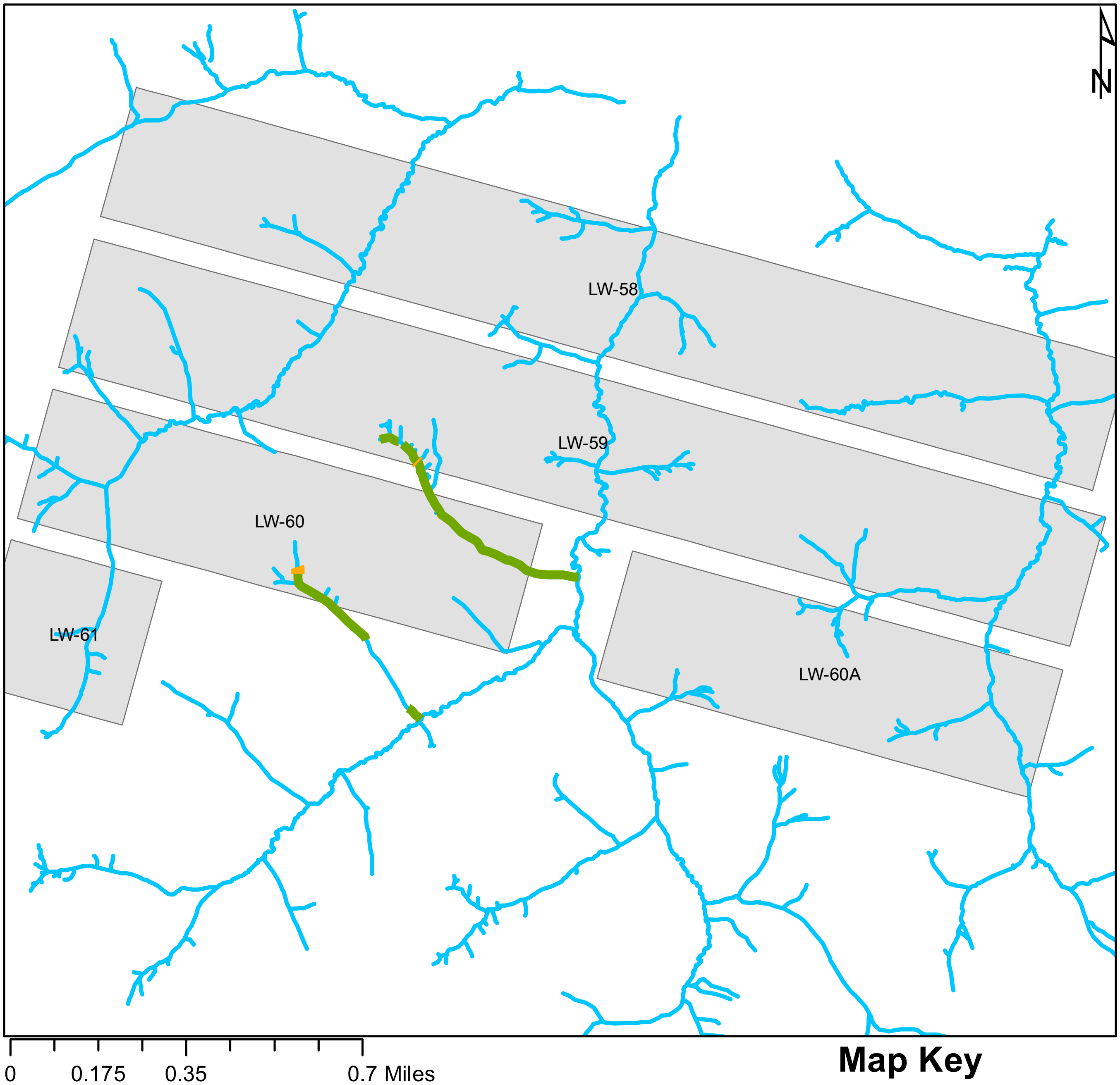
Cumberland Mine, Minimum and Maximum Stream Flow Loss, Wet Season



Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

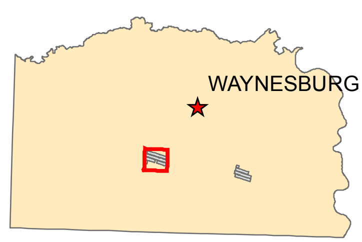
Prepared by:
University of Pittsburgh

Cumberland Mine,
Minimum and Maximum Stream Flow Loss,
Dry Season



Map Key

- Minimum Length (Dry Season)
- Maximum Length (Dry Season)
- Streams
- Longwall Panel (4th)

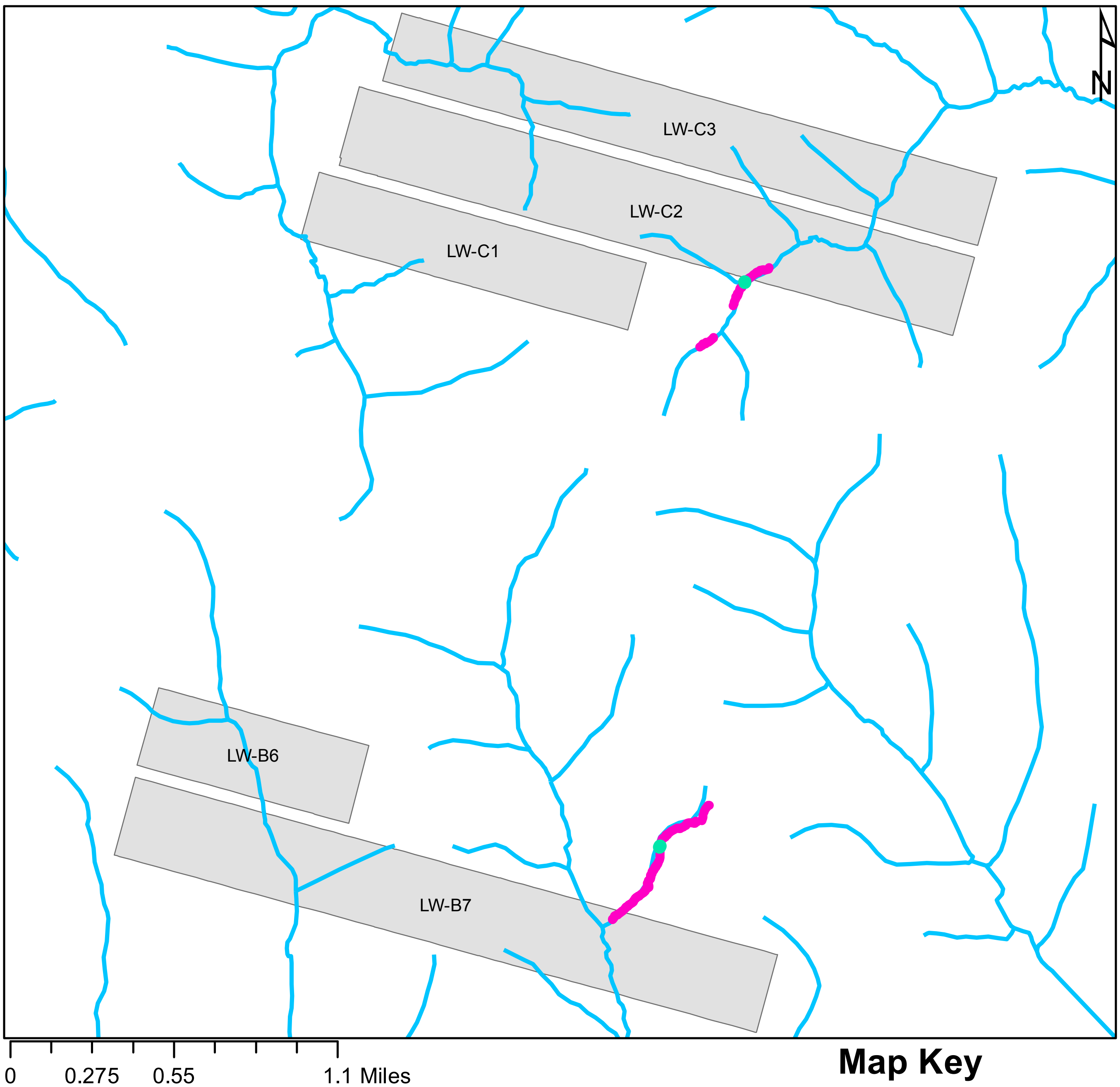


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Emerald Mine,
Minimum and Maximum Stream Flow Loss,
Dry Season



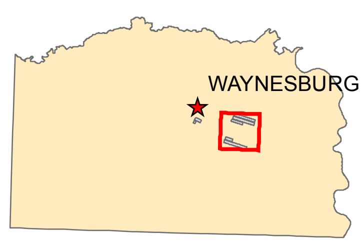
Map Key

Minimum Length (Wet Season)

Maximum Length (Wet Season)

Streams

Longwall Panel (4th)

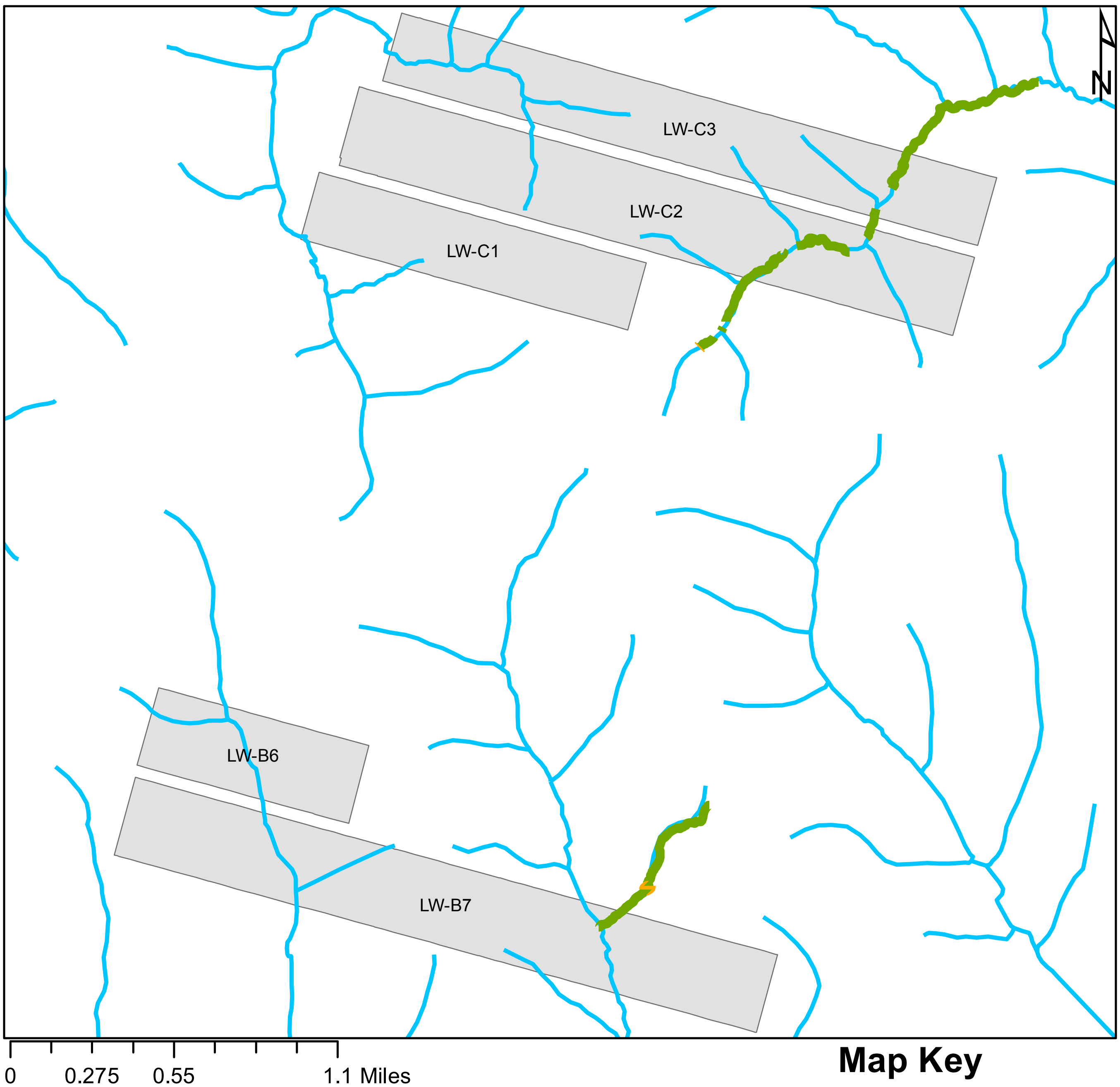


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Emerald Mine, Minimum and Maximum Stream Flow Loss, Dry Season



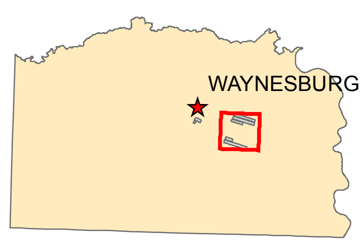
Map Key

Minimum Length (Dry Season)

Maximum Length (Dry Season)

Streams

Longwall Panel (4th)

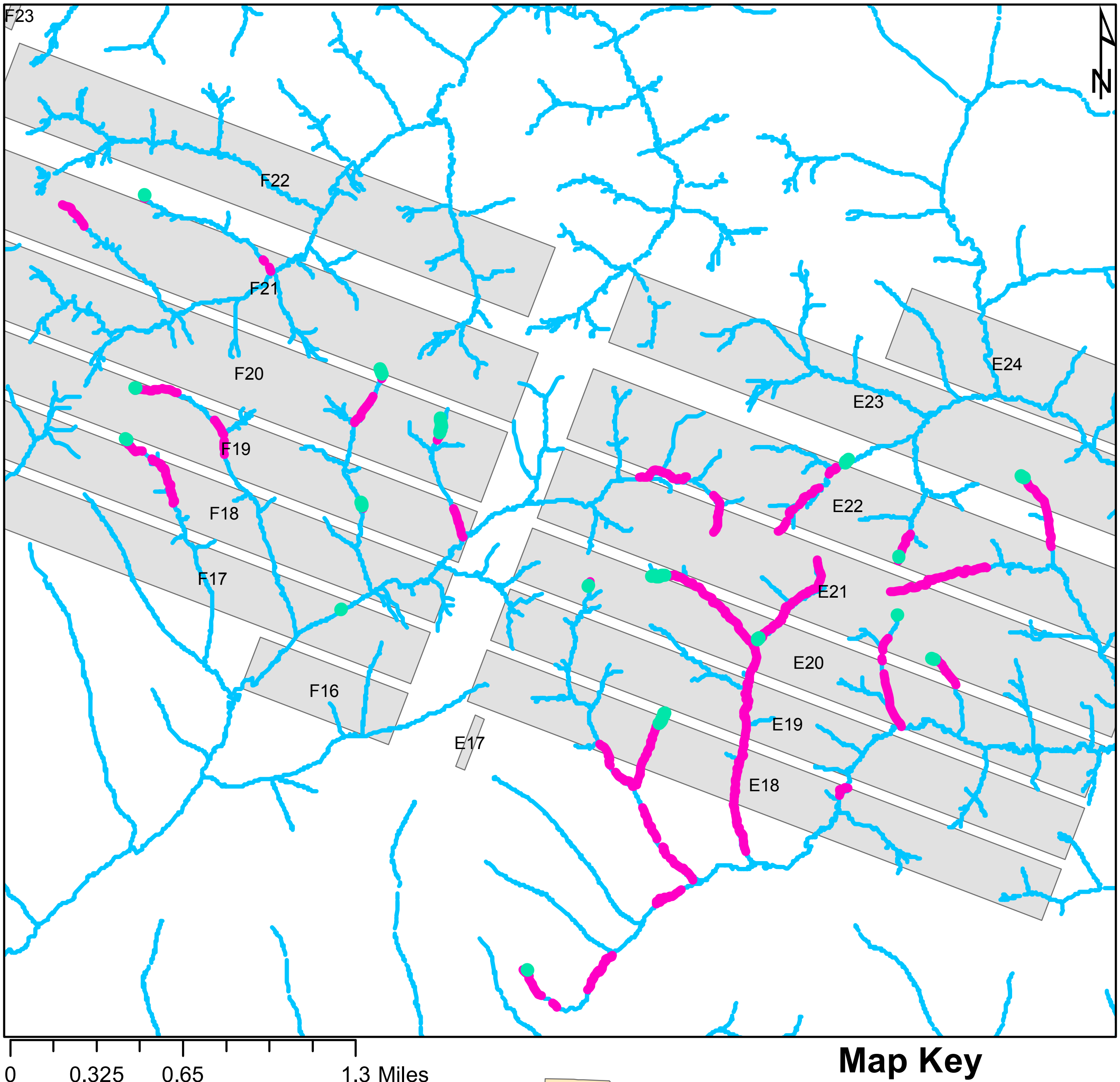


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine, Minimum and Maximum Stream Flow Loss, Wet Season



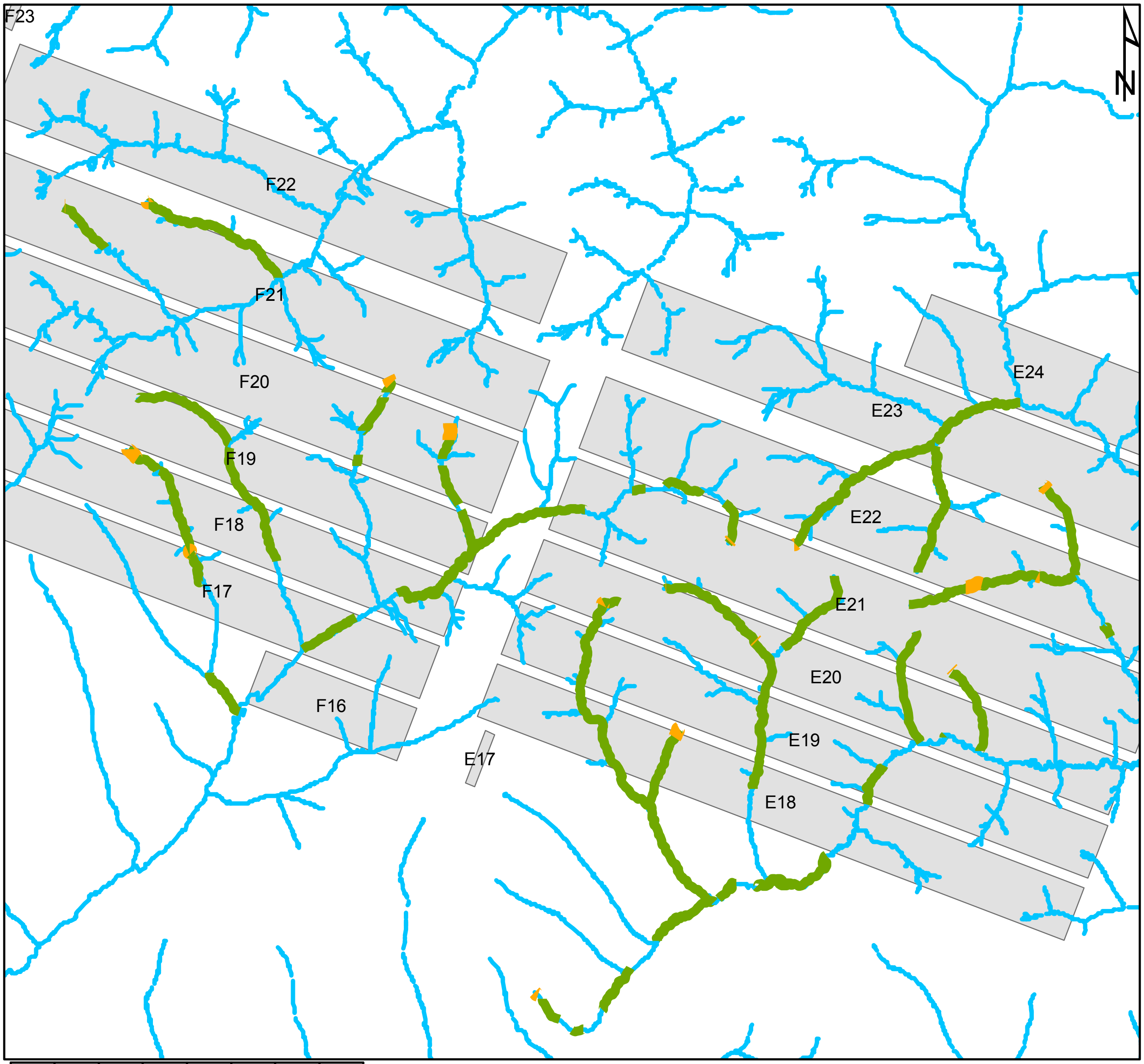
Map Key

- Minimum Length (Wet Season)
- Maximum Length (Wet Season)
- Streams
- Longwall Panel (4th)

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine, Minimum and Maximum Stream Flow Loss, Dry Season



0 0.325 0.65 1.3 Miles

Map Key

Minimum Length (Dry Season)

Maximum Length (Dry Season)

Streams

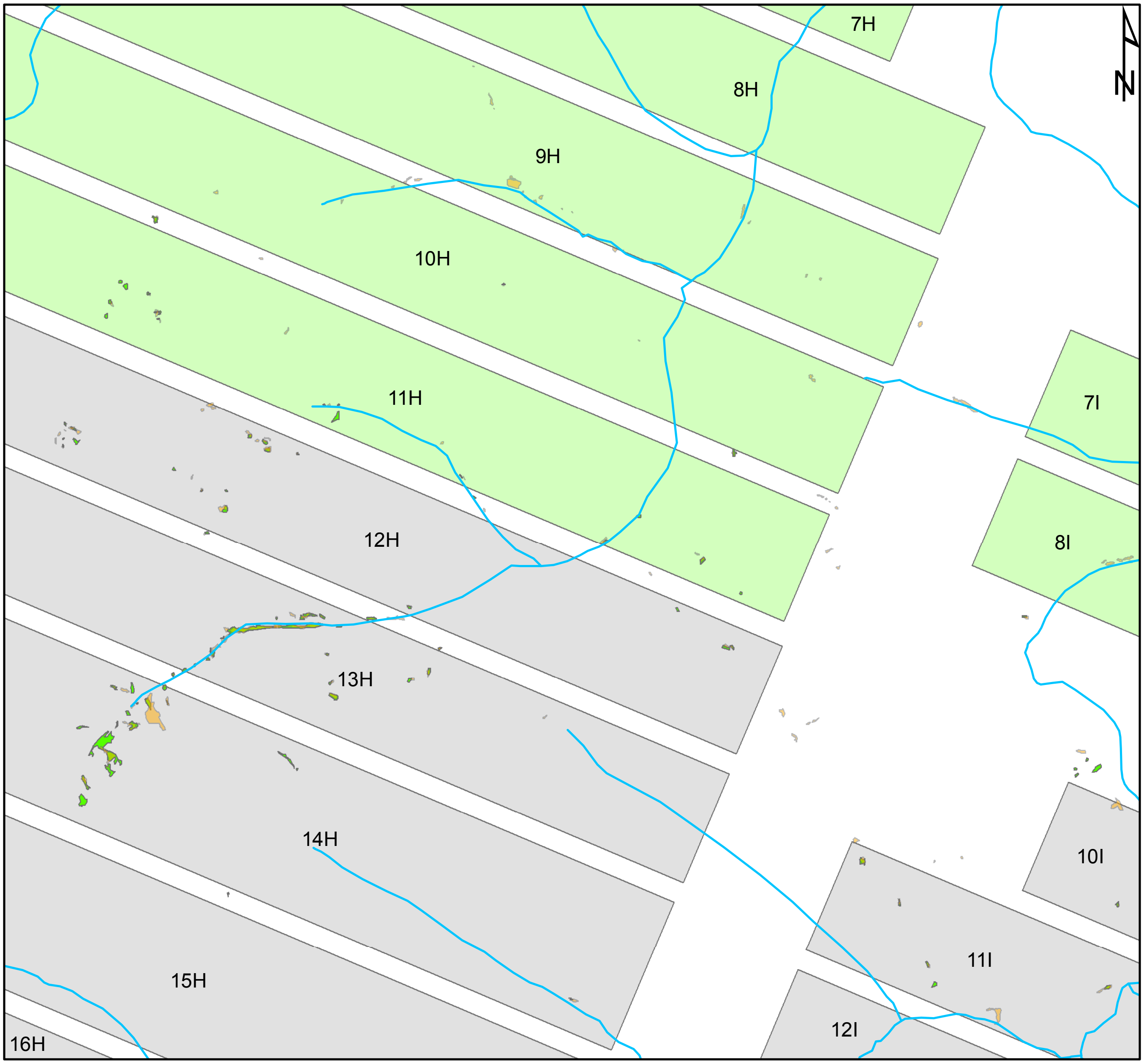
Longwall Panel (4th)

Washington County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Bailey Mine Wetlands



0 0.175 0.35 0.7 Miles

Map Key

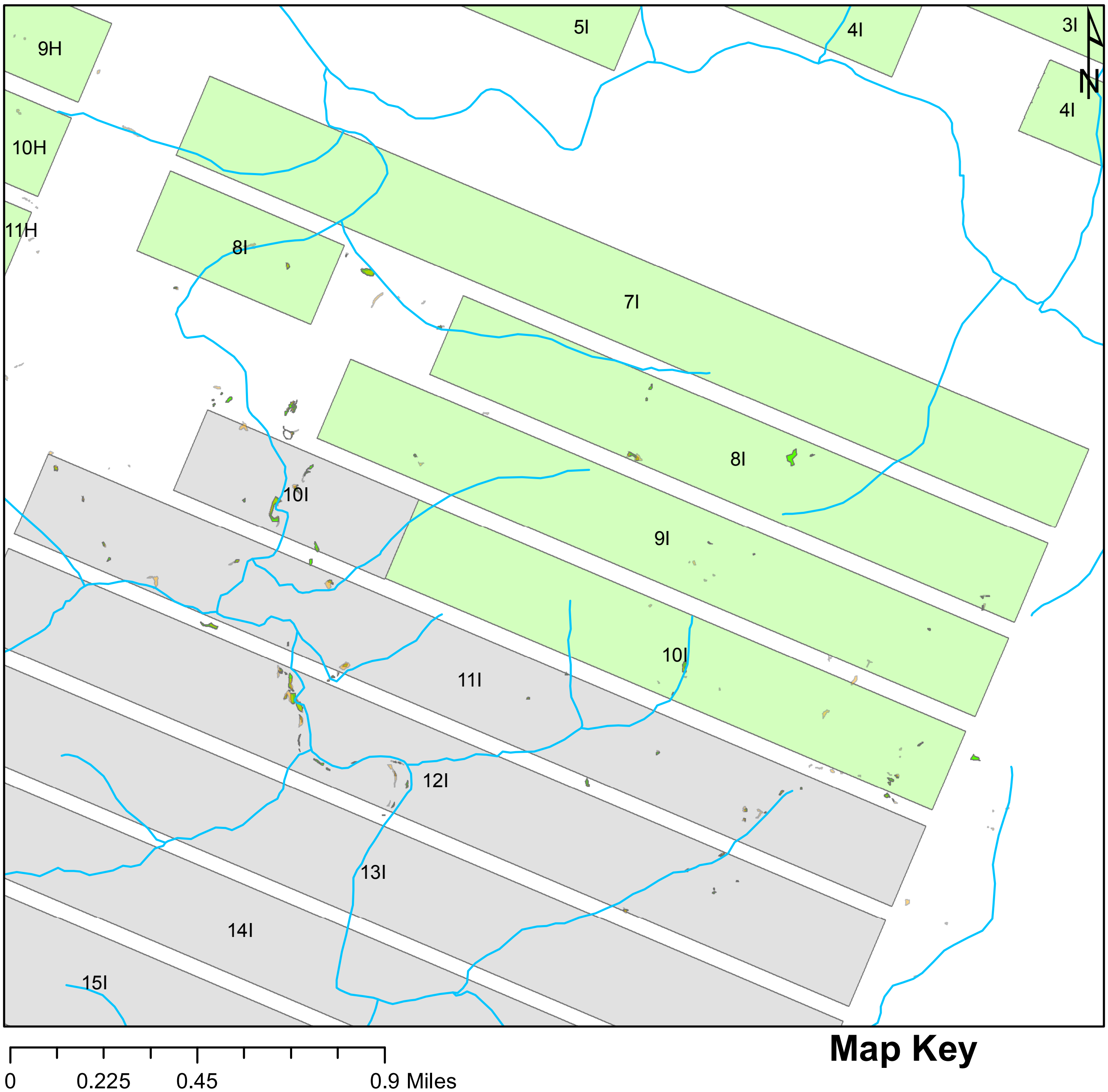
- Streams
- Post-mining wetlands
- Pre-mining wetlands
- Longwall Panel (4th)
- Longwall Panel (3rd)

Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

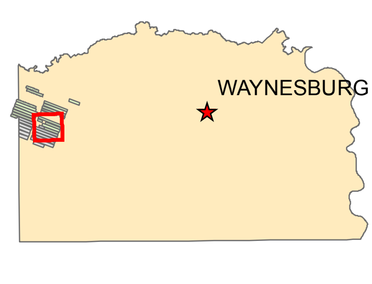
Prepared by:
University of Pittsburgh

Bailey Mine
Wetlands



Map Key

- Streams
- Post-mining wetlands
- Pre-mining wetlands
- Longwall Panel (4th)
- Longwall Panel (3rd)

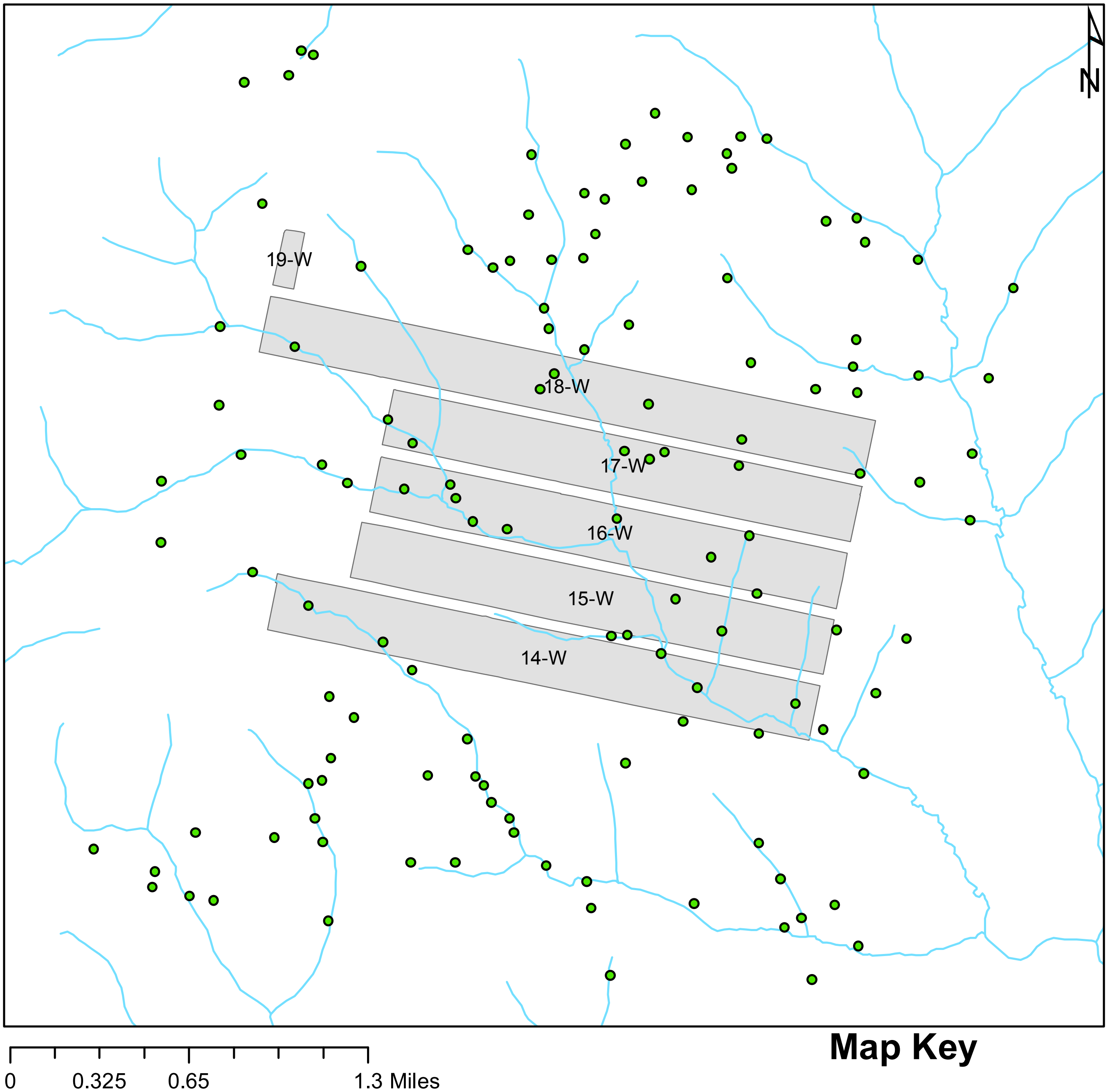


Greene County

Prepared for:
Pennsylvania Department of
Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Blacksville 2 Mine
Wetlands

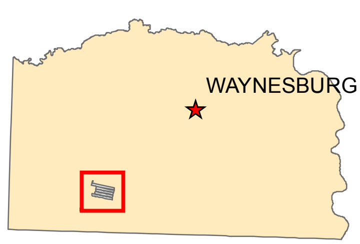


Map Key

Pre-mining wetlands

Streams

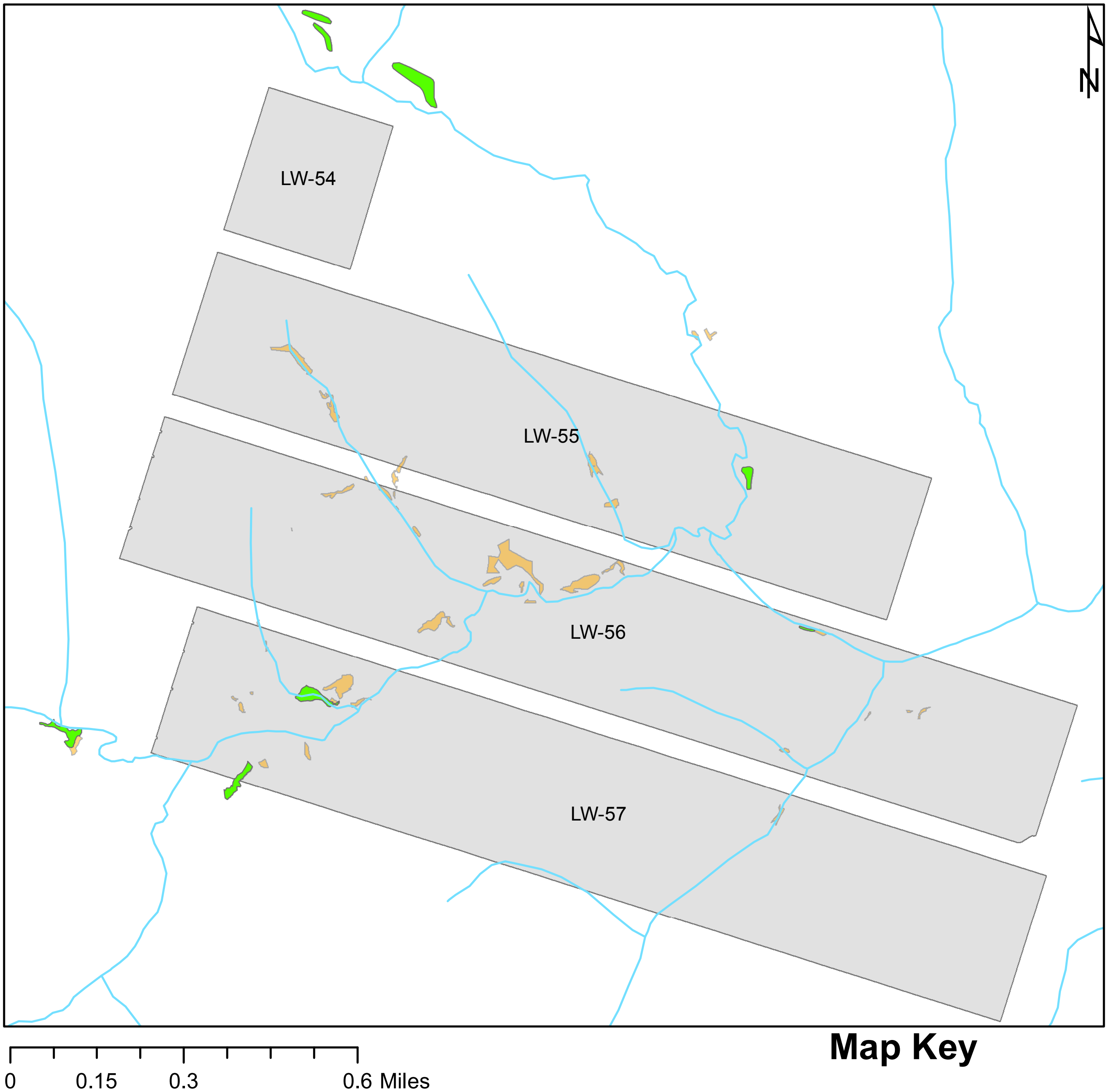
Longwall Panel



Prepared for:
Pennsylvania Department of
Environmental Protection (DEP)

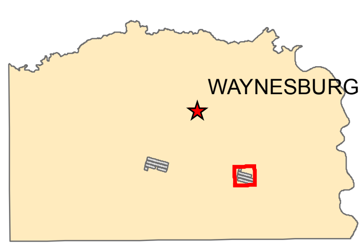
Prepared by:
University of Pittsburgh

Cumberland Mine
Wetlands



Map Key

- Streams
- Pre-mining wetlands
- Post-mining wetlands
- Longwall Panel (4th)

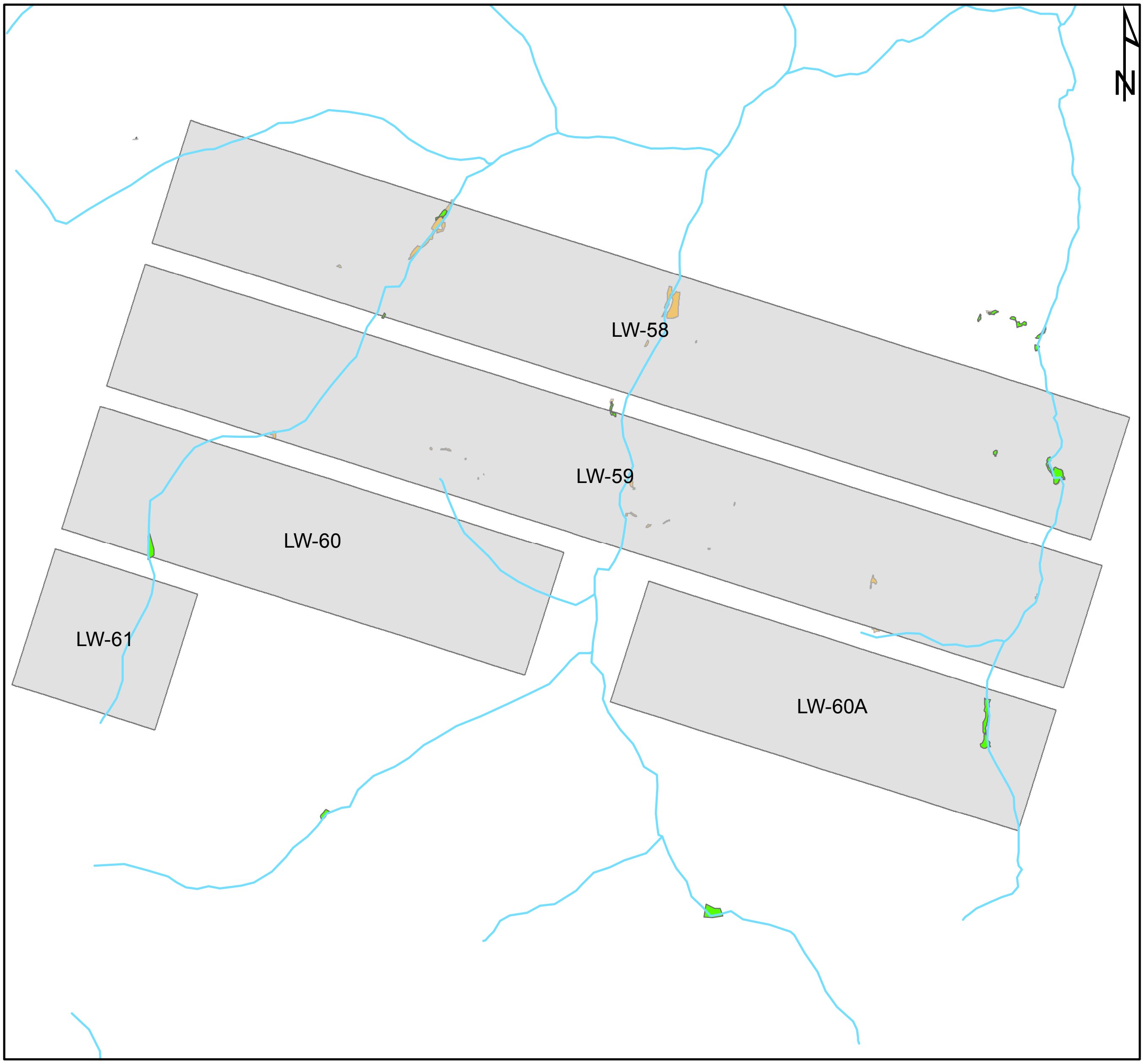


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

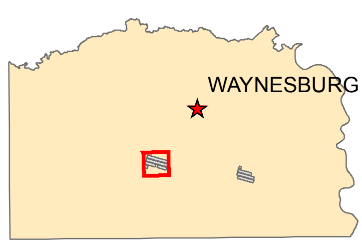
Cumberland Mine
Wetlands



0 0.175 0.35 0.7 Miles

Map Key

- Streams
- Pre-mining wetlands
- Post-mining wetlands
- Longwall Panel (4th)

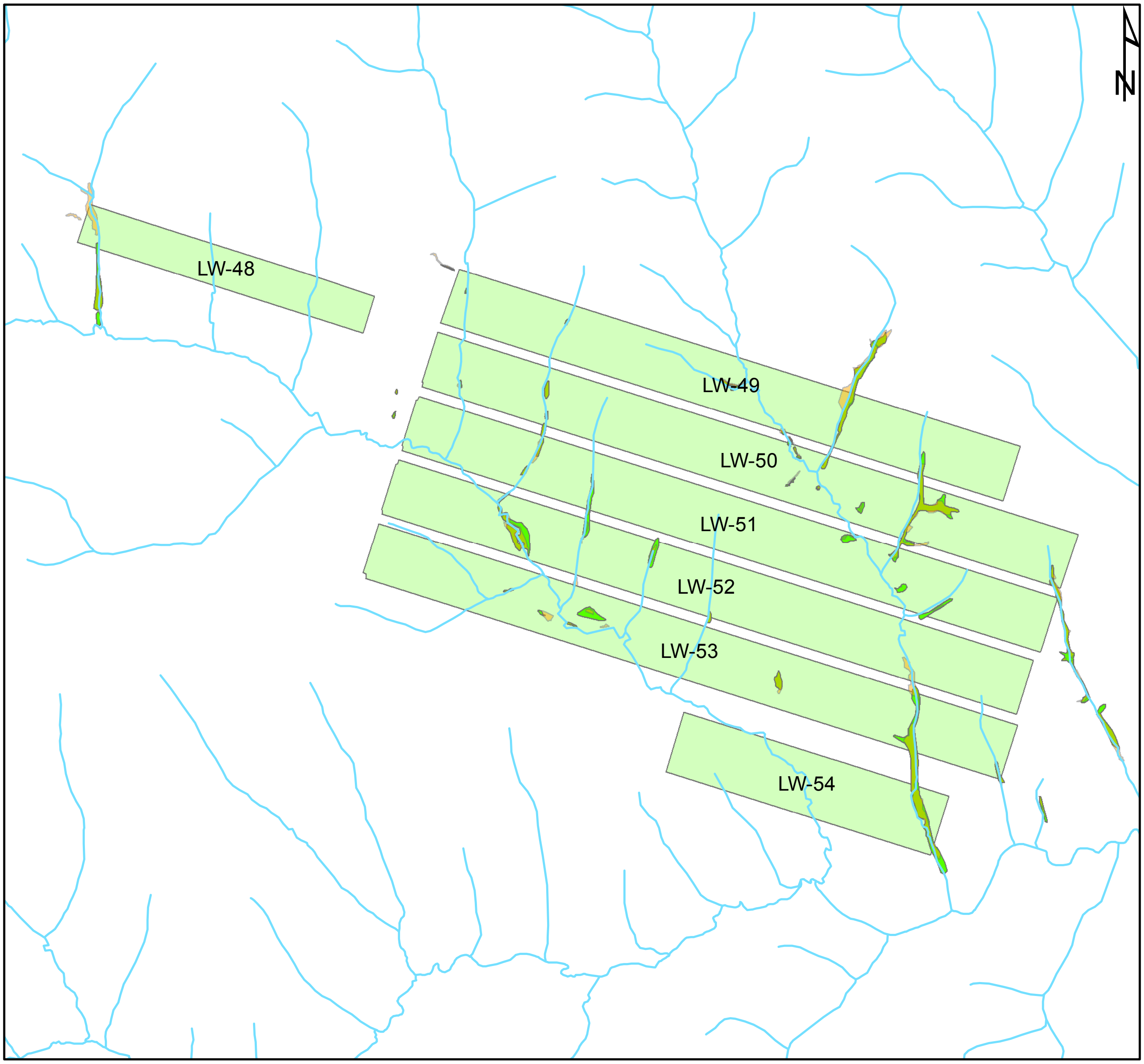


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

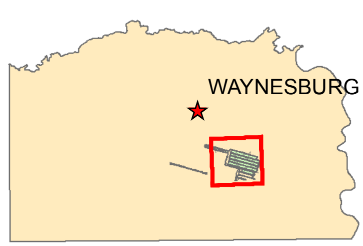
Cumberland Mine
Wetlands



0 0.375 0.75 1.5 Miles

Map Key

- Streams
- Post-mining wetlands
- Pre-mining wetlands
- Longwall Panels (3rd)

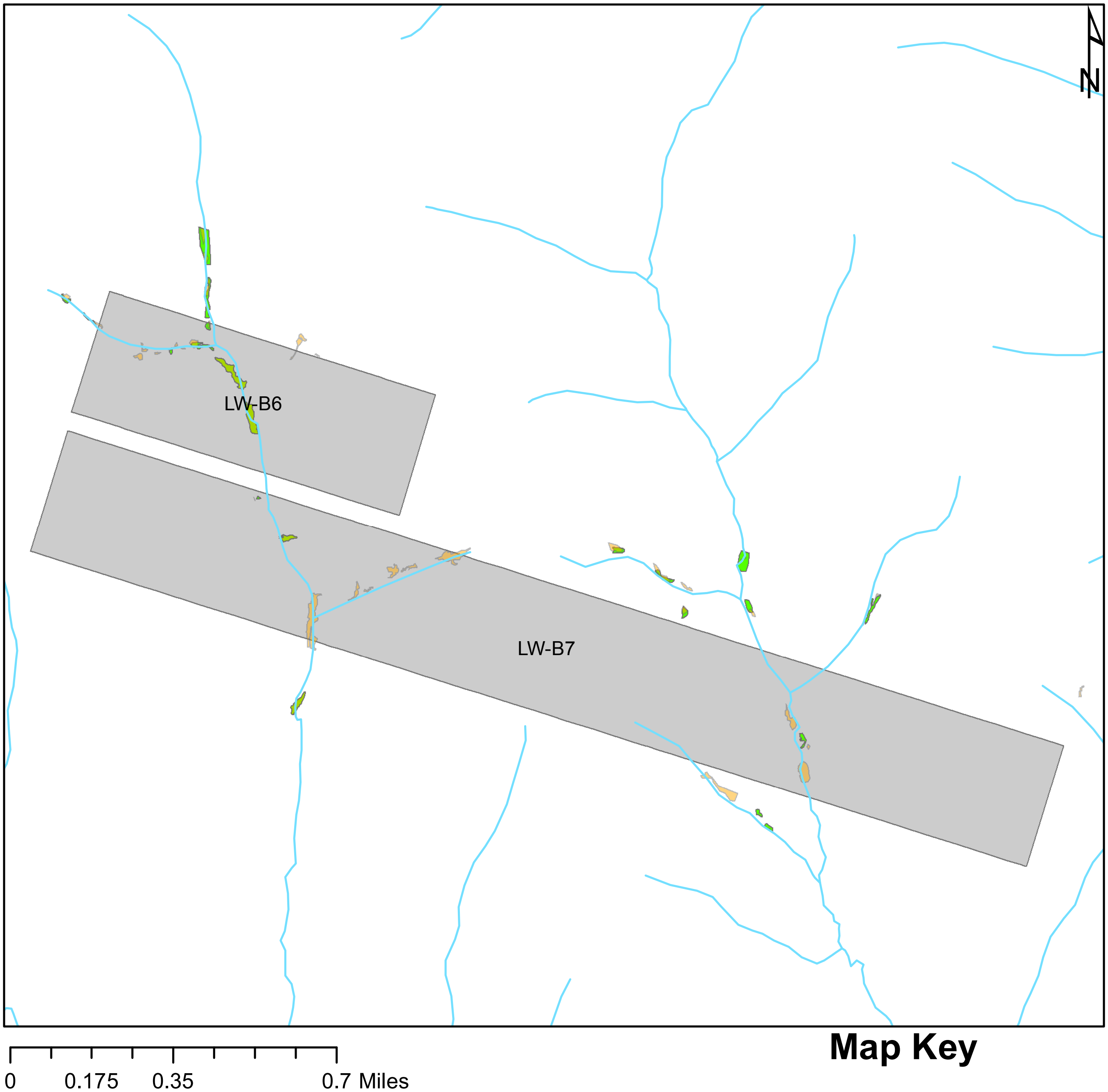


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Emerald Mine Wetlands



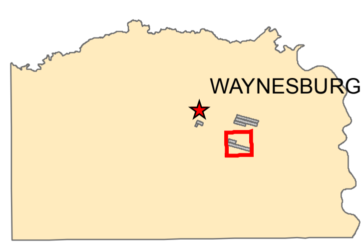
Map Key

Streams

Post-mining wetlands

Pre-mining wetlands

Longwall Panel (4th)

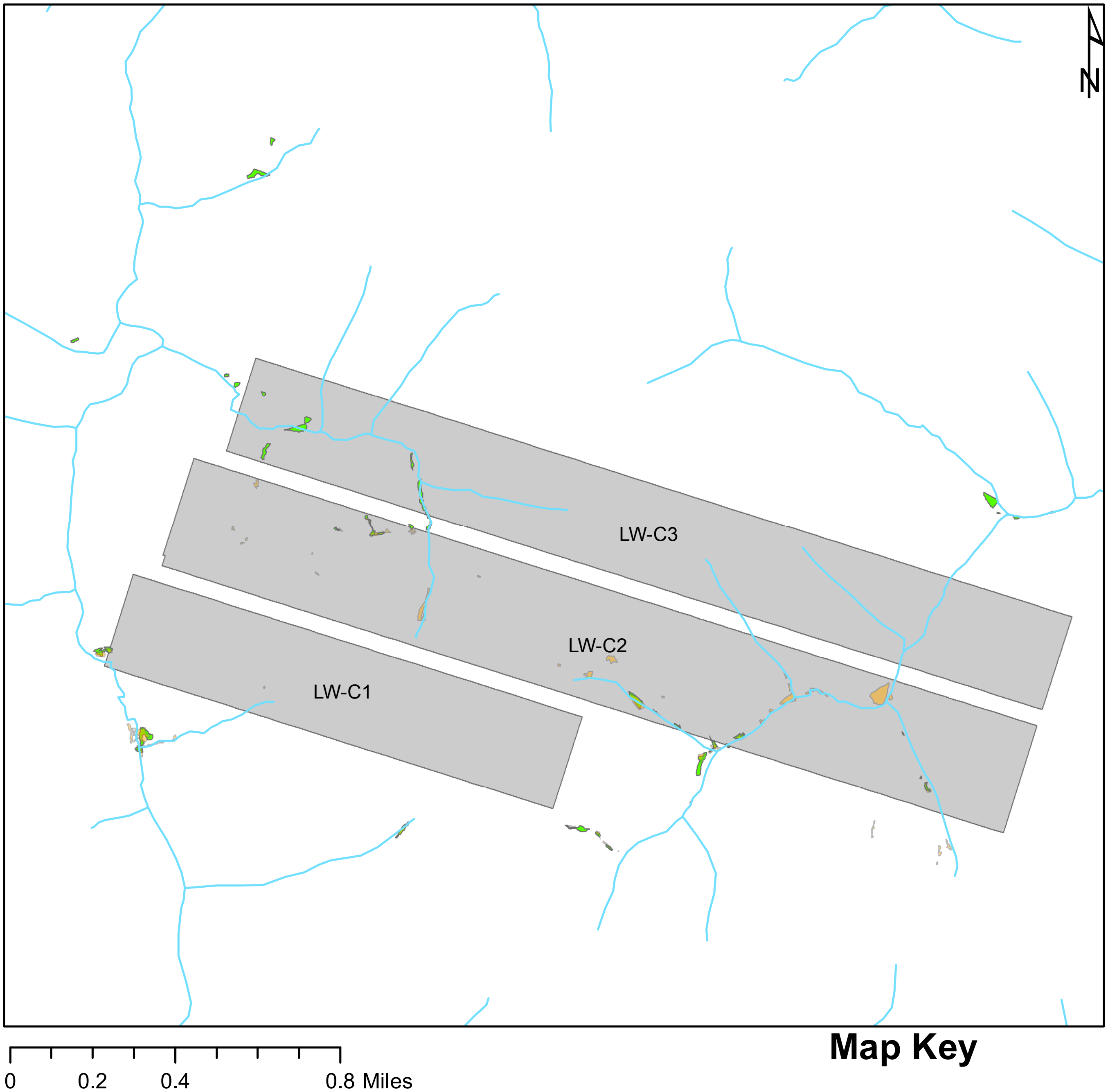


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

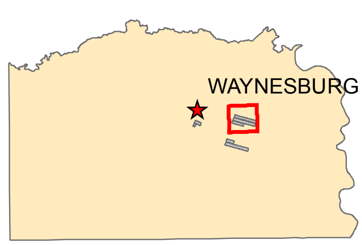
Prepared by:
University of Pittsburgh

Emerald Mine
Wetlands



Map Key

Streams
Post-mining wetlands
Pre-mining wetlands
Longwall Panel (4th)

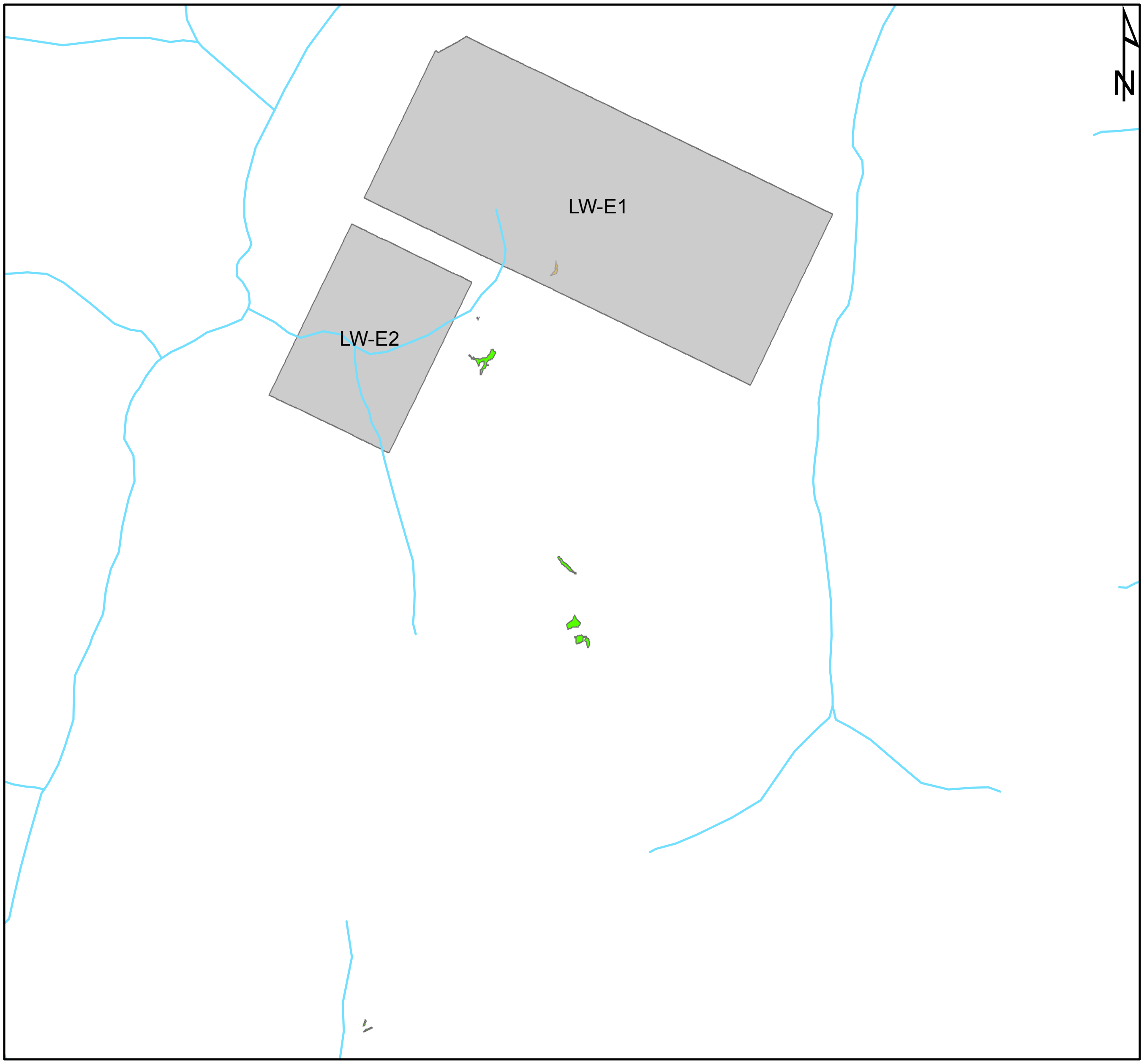


Greene County

Prepared for:
Pennsylvania Department of
Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Emerald Mine
Wetlands



0 0.125 0.25 0.5 Miles

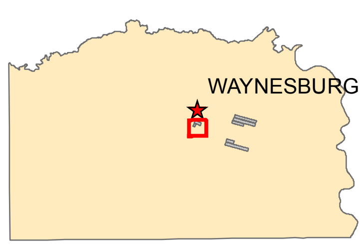
Map Key

Streams

Post-mining wetlands

Pre-mining wetlands

Longwall Panel (4th)

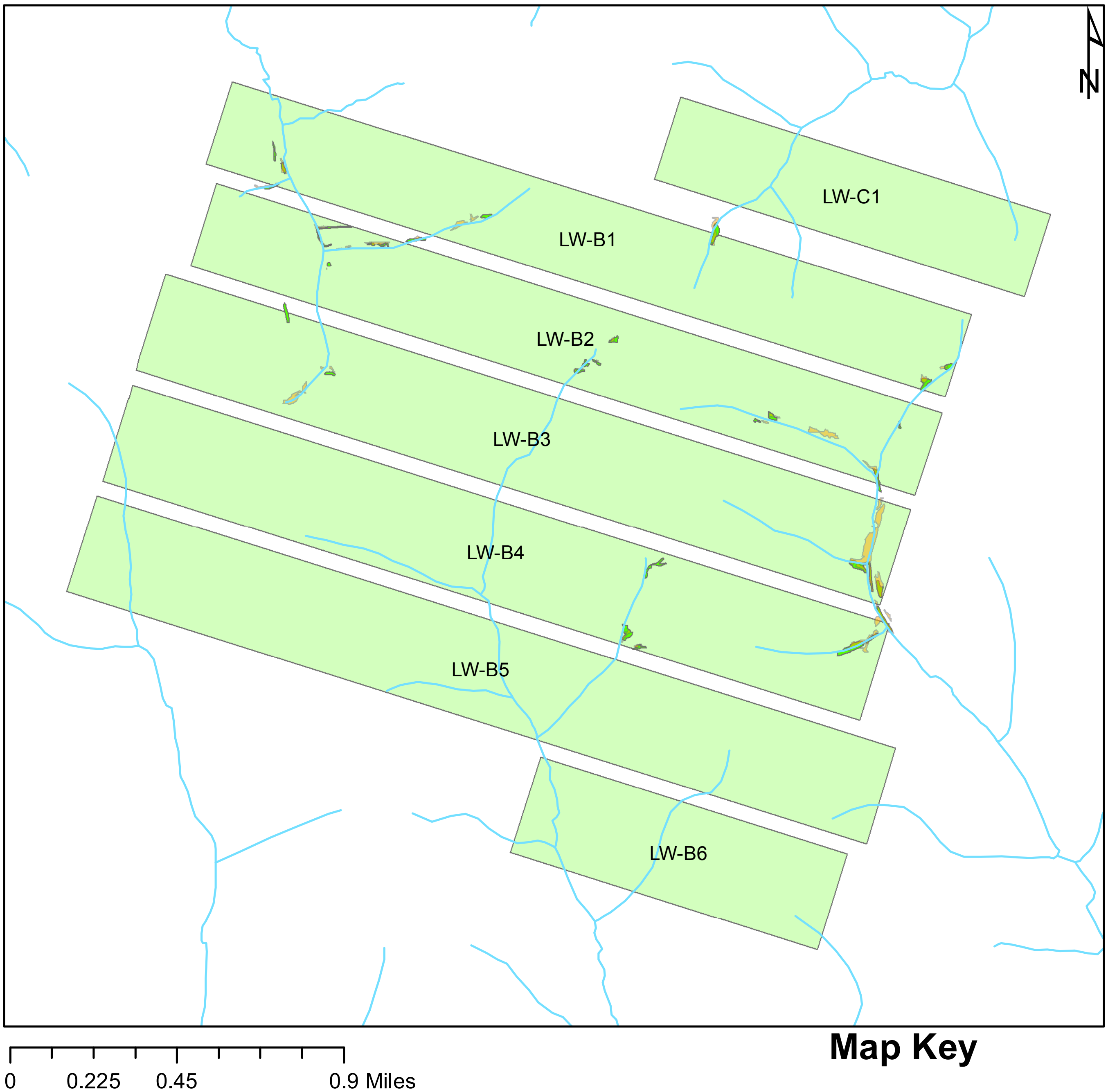


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

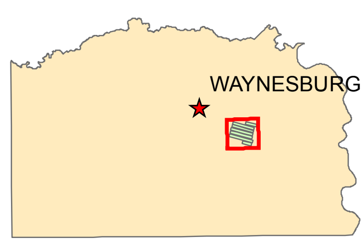
Prepared by:
University of Pittsburgh

Emerald Mine Wetlands



Map Key

- Streams
- Post-mining wetlands
- Pre-mining wetlands
- Longwall Panel (3rd)

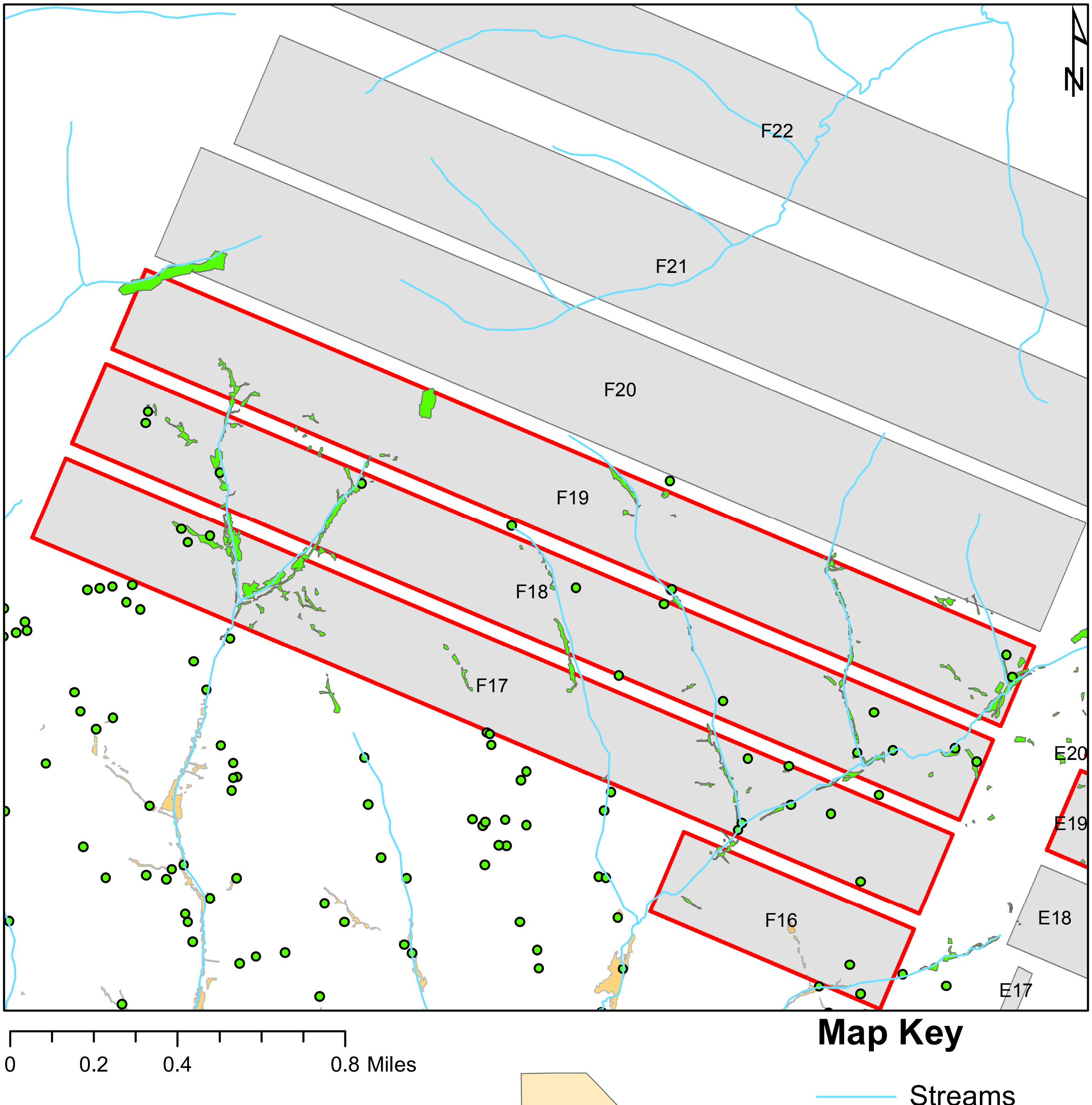


Greene County

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine
Wetlands



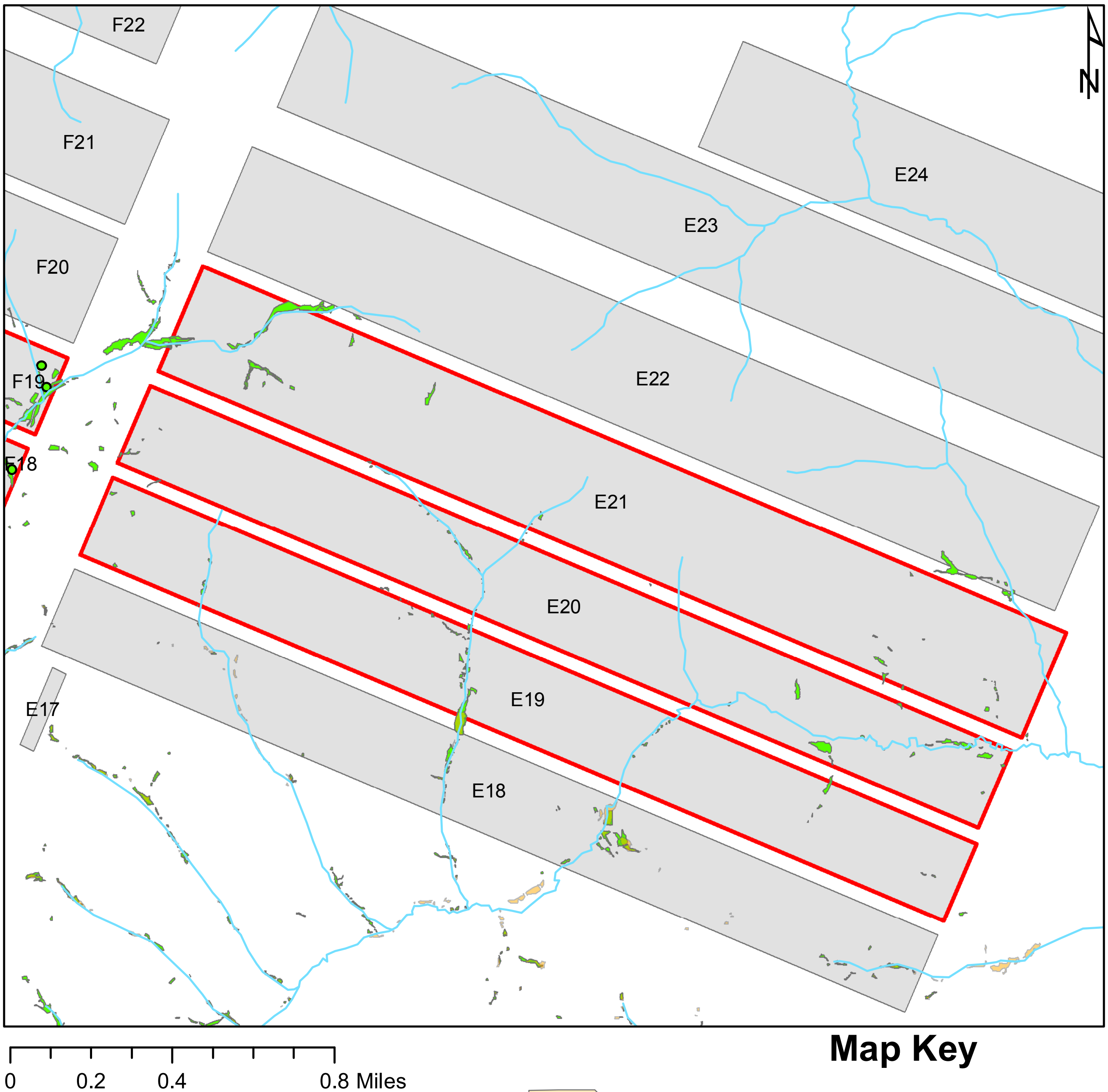
Map Key

Streams
Pre-mining wetlands
Post-mining wetlands
Post-mining wetlands
Pre-mining wetlands
No post-mining survey
Longwall Panel (4th)

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine
Wetlands



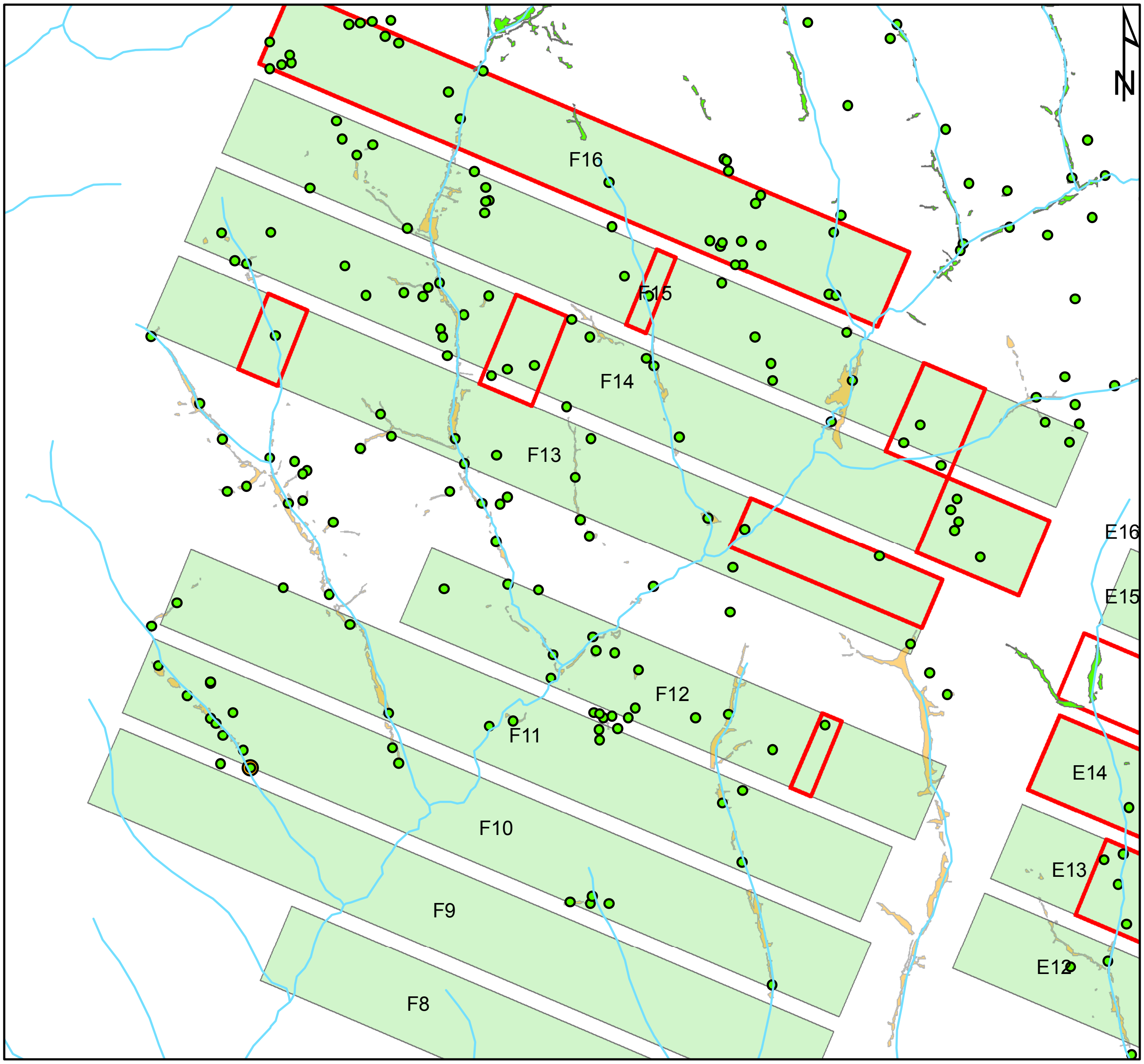
Map Key

- Streams
- Pre-mining wetlands
- Post-mining wetlands
- Post-mining wetlands
- Pre-mining wetlands
- No post-mining survey
- Longwall Panel (4th)

Prepared for:
Pennsylvania Department of
Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine
Wetlands



0 0.25 0.5 1 Miles

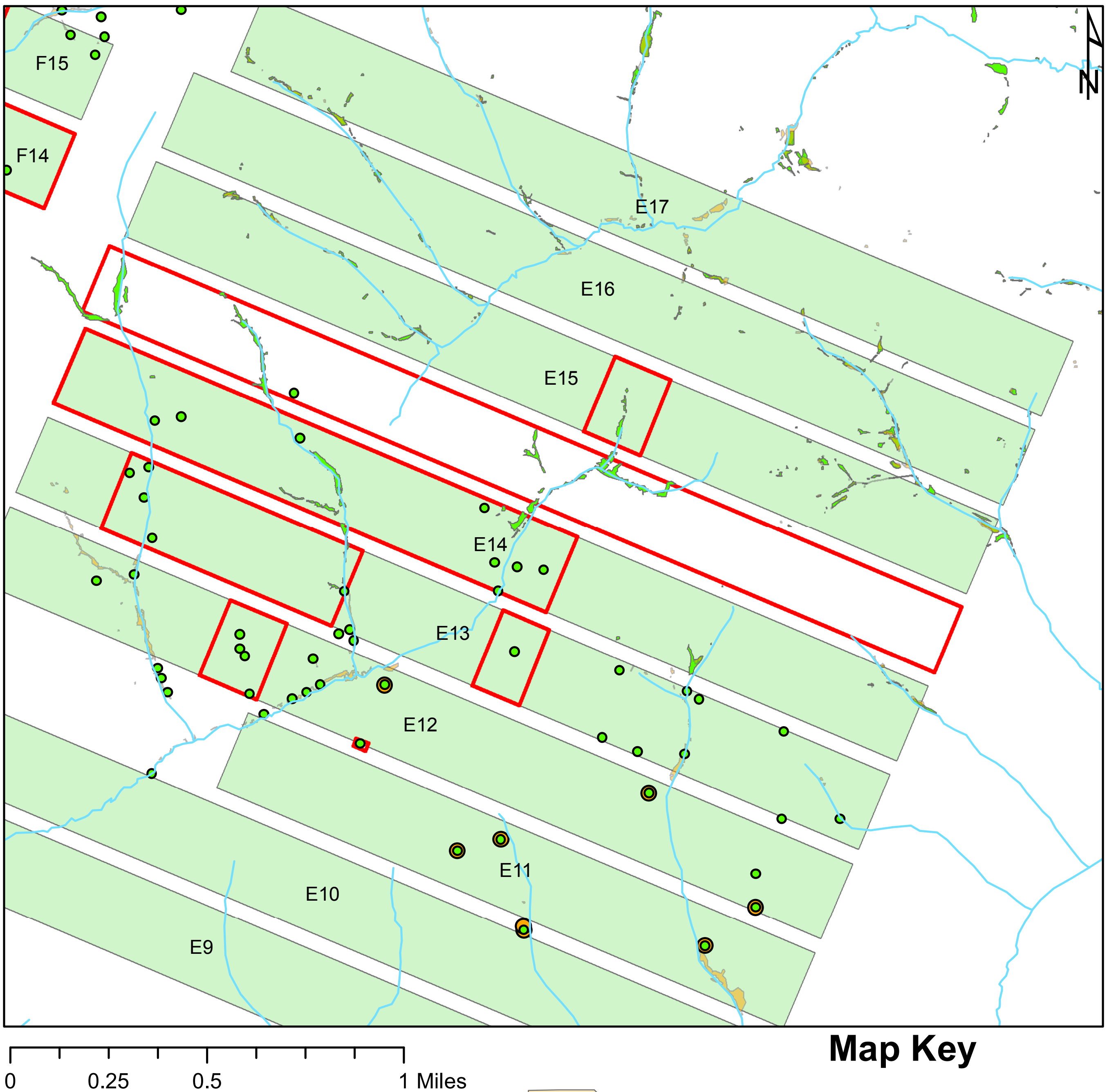
Map Key

- Streams
- Pre-mining wetlands
- Post-mining wetlands
- Post-mining wetlands
- Pre-mining wetlands
- No post-mining survey
- Longwall Panel (3rd)

Prepared for:
Pennsylvania Department of
Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Enlow Fork Mine Wetlands



Washington County

Map Key

- Streams
- Pre-mining wetlands
- Post-mining wetlands
- Post-mining wetlands
- Pre-mining wetlands
- No post-mining survey
- Longwall Panel (3rd)

Prepared for:
Pennsylvania Department of Environmental Protection (DEP)

Prepared by:
University of Pittsburgh

Appendix D1: Quantitative macroinvertebrate data for streams undermined and sampled during the 3rd assessment period and re-sampled by the University

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Bailey Mine
Stream Name: UNT to Wharton Run, 32507
Stream NHD#:
Sample Date: 4/16/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: 1 or X2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): G. Noble, A. Hale, K. Garmire
Comments:

Starting Lat/Long: 39.90799°/ -80.51289°
Ending Lat/Long: 39.90848°/ -80.51389°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. _____ F	Sub. _____ G	Sub. _____ F	Sub. _____ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		35						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7		15						
Plecoptera		Nemouridae		Podmosta		SH	2		1						
Plecoptera		Nemouridae		Amphinemura		SH	3		8						
Plecoptera		Perlodidae		Isoperla		PR	2		38						
Plecoptera		Capniidae		Allocapnia		SH	3		1						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		3						
Trichoptera		Uenoidae		Neophylax		SC	3		18						
Trichoptera		Limnephilidae		Ironoquia		SH	3		13						
Trichoptera		Lepidostomatidae		Lepidostoma		SH	1		1						
Coleoptera		Psephenidae		Ectopria		SC	5		2						
Diptera		Tabanidae		Tabanus		PR	5		1						
Diptera		Tipulidae		Pilaria		PR	7		7						
Diptera		Chironomidae				CG	6	22							
Diptera		Ceratpogonidae				PR	6	2							
Bivalvia		Sphaeriidae				FC	8	3							
Odonata		Cordulegastridae		Cordulegaster		PR	3		1						
Megaloptera		Corydalidae		Nigronia		PR	1		1						
Oligochaeta		Oligochaeta				CG	10	1							
Decapoda		Cambaridae				CR	6	3							
Gastropoda		Physidae				SC	8	1							
				Total Number of Individuals:				32	145						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Bailey Mine Stream Name: UNT to Wharton Run

Stream ID#: 32507 Segment ID: ____

Sampler(s): A. Hale, J. Phillips, C. Fisher (sample 1); G. Noble, A. Hale, K. Garmire (sample 2) Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/26/2009

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	15	49.2	49.2
Trichoptera Richness	4	38.1	38.1
Percent EPT Richness	66.7	108.3	100.0
Intolerant Taxa Richness	9	56.3	56.3
FC + PR Taxa Richness	5	37.0	37.0
Total Biological Score 1 (Mean of adjusted values):			56.1

Score 2 - Sample Date: 4/16/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	21	68.9	68.9
Trichoptera Richness	4	38.1	38.1
Percent EPT Richness	47.6	77.3	77.2
Intolerant Taxa Richness	11	68.8	68.8
FC + PR Taxa Richness	8	59.3	59.3
Total Biological Score 2 (Mean of adjusted values):			62.4

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *10.7 %

2.) Mean Total Biological Score (Average of Score 1 and Score 2): 59.3

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Bailey Mine
Stream Name: UNT to Dunkard Fork, 32532
Stream NHD#:
Sample Date: 4/23/13
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: 1 or X2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): T. Hann, A. Hale
Comments:

Starting Lat/Long: 39.899957°/ -80.492992°
Ending Lat/Long: 39.899157°/ -80.493253°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ephemerellidae		Ephemerella		CG	1		2						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4		8						
Ephemeroptera		Ameletidae		Ameletus		CG	0		32						
Plecoptera		Perlodidae		Cultus		PR	2		1						
Plecoptera		Nemouridae		Amphinemura		SH	3		98						
Plecoptera		Perlodidae		Isoperla		PR	2		3						
Plecoptera		Perlodidae		Clioperla		PR	2		1						
Plecoptera		Perlidae		Unidentified		PR	3		1						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		6						
Coleoptera		Elmidae		Optioservus		FC	4		1						
Coleoptera		Elmidae		Stenelmis		SC	5		2						
Diptera		Empididae		Clinocera		PR	6		9						
Diptera		Chironomidae				CG	6	13							
Diptera		Simuliidae		Prosimulium		FC	5		6						
Diptera		Simuliidae		Simulium		FC	6		4						
Bivalvia		Sphaeriidae				FC	8	1							
Gastropoda		Physidae				SC	8	2							
Oligochaeta		Oligochaeta				CG	10	2							
					Total Number of Individuals:			18	174						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Bailey Mine Stream Name: UNT to Dunkard Fork

Stream ID#: 32532 Segment ID: ____________

Sampler(s): A. Hale, J. Phillips, C. Fisher, A. Glassmire (sample 1); T. Hann, A. Hale (sample 2) Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/5/2009

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	24	78.7	78.7
Trichoptera Richness	5	47.6	47.6
Percent EPT Richness	66.7	108.3	100.0
Intolerant Taxa Richness	14	87.5	87.5
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			73.1

Score 2 - Sample Date: 4/16/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	18	59.0	59.0
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	50	81.17	81.2
Intolerant Taxa Richness	10	62.5	62.5
FC + PR Taxa Richness	10	74.1	74.1
Total Biological Score 2 (Mean of adjusted values):			57.3

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *24.4 %

2.) Mean Total Biological Score (Average of Score 1 and Score 2): 65.2

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine
Stream Name: UNT to Templeton Fork, 32740
Stream NHD#:
Sample Date: 5/9/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: 1 or X2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, G. Noble, K. Piper, L. Kiefer
Comments:

Starting Lat/Long: 40.05283°/ -80.389657°
Ending Lat/Long: 40.053718°/ -80.389913°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	3
Snag	1
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		10						
Ephemeroptera		Baetidae		Baetis		CG	6		18						
Ephemeroptera		Baetidae		Centroptilium		CG	2		1						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7		1						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4		1						
Plecoptera		Chloroperlidae		Haploperla		PR	0		1						
Plecoptera		Nemouridae		Amphinemura		SH	3		28						
Plecoptera		Perlodidae		Isoperla		PR	2		36						
Plecoptera		Perlidae		Perlesta		PR	4		3						
Plecoptera		Leuctridae		Leuctra		SH	0		2						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		3						
Trichoptera		Hydropsychidae		Diplectrona		FC	0		4						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4		2						
Trichoptera		Glossomatidae		Agapetus		SC	0		2						
Trichoptera		Uenoidae		Neophylax		SC	3		1						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Coleoptera		Elmidae		Stenelmis		SC	5		1						
Coleoptera		Psephenidae		Psephenus		SC	4		1						
Diptera		Tipulidae		Tipula		SH	4		1						
Diptera		Tipulidae		Hexatoma		PR	2		2						
Diptera		Tipulidae		Pseudolimnophila		PR	2		3						
Diptera		Ephydridae				PI	6		2						
Diptera		Ceratopogonidae				PR	6	8							
Diptera		Chironomidae				CG	6	53							
Decapoda		Cambaridae				CG	6	3							
Oligochaeta						CG	10	6							
				Total Number of Individuals:				70	122						

Lab sub-sample 1-4 (200 +/- 20%) (Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Enlow Fork Mine Stream Name: UNT to Templeton Fork

Stream ID#: 32740 Segment ID: ______

Sampler(s): A. Hale, S. Tonsor, J. Phillips (sample 1); A. Hale, G. Noble, K. Piper, L. Kiefer (sample 2) Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/29/2009

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	16	52.5	52.5
Trichoptera Richness	4	38.1	38.1
Percent EPT Richness	68.8	111.7	100.0
Intolerant Taxa Richness	12	75.0	75.0
FC + PR Taxa Richness	4	29.6	29.6
Total Biological Score 1 (Mean of adjusted values):			59.0

Score 2 - Sample Date: 5/9/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	26	85.2	85.2
Trichoptera Richness	5	47.6	47.6
Percent EPT Richness	57.7	93.7	93.7
Intolerant Taxa Richness	18	112.5	100.0
FC + PR Taxa Richness	8	59.3	59.3
Total Biological Score 2 (Mean of adjusted values):			77.2

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *26.6 %

2.) Mean Total Biological Score (Average of Score 1 and Score 2): 68.1

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine

Stream Name: Dyers Fork, 41261, DF STA 2

Stream NHD#:

Sample Date: 5/7/2013

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: 1 or X2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): A. Hale, G. Noble, K. Piper, L. Kiefer

Comments:

Starting Lat/Long: 39.829797, -80.122747

Ending Lat/Long: 39.830363, -80.123902

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	4
Snag	0
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	4
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Caenidae		Caenis		CG	7		1						
Ephemeroptera		Baetidae		Baetis		CG	6		1						
Plecoptera		Perlodidae		Isoperla		PR	2		2						
Plecoptera		Perlidae		Perlesta		PR	4		6						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4		43						
Coleoptera		Elmidae		Dubiraphia		SC	6		3						
Coleoptera		Elmidae		Stenelmis		SC	5		23						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Diptera		Ceratopogonidae				PR	6	1							
Diptera		Chironomidae				CG	6	139							
Bivalvia		Sphaeriidae				FC	6	1							
Oligochaeta		Oligochaeta				CG	10	4							
Total Number of Individuals:								145	80						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine
Stream Name: Dyers Fork

Stream ID#: 41261
Segment ID: DF STA 2

Sampler(s): A. Hale, S. Tonsor, J. Phillips (sample 1); A. Hale, G. Noble, K. Piper, L. Kiefer (sample 2)
Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/12/2009

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	21	68.9	68.9
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	28.6	46.4	46.4
Intolerant Taxa Richness	9	56.3	56.3
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			48.5

Score 2 - Sample Date: 5/7/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	12	39.3	39.3
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	41.7	67.6	67.6
Intolerant Taxa Richness	4	25.0	25.0
FC + PR Taxa Richness	3	22.2	22.2
Total Biological Score 2 (Mean of adjusted values):			32.7

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *38.7 %

2.) Mean Total Biological Score (Average of Score 1 and Score 2): 40.6

*If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine
Stream Name: Dutch Run, 41246, DR STA 5
Stream NHD#:
Sample Date: 5/1/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: 1 or X2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A.Hale, K.Piper, G.Noble, S. Iannacchione
Comments:

Starting Lat/Long: 39.817813°/ -80.089375°
Ending Lat/Long: 39.818703°/ -80.089533°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	3
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Leptophlebidae				CG	4	1							
Plecoptera		Nemouridae		Amphinemura		SH	3		4						
Plecoptera		Perlidae		Perlesta		PR	4		16						
Plecoptera		Perlodidae		Isoperla		PR	2		17						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4		22						
Coleoptera		Elmidae		Stenelmis		SC	5		3						
Diptera		Ephydridae				PI	6		2						
Diptera		Tipulidae		Molophilus		SH	4		1						
Diptera		Ceratopogonidae				PR	6	3							
Diptera		Chironomidae				CG	6	104							
Oligochaeta		Oligochaeta				CG	10	4							
Total Number of Individuals:								112	65						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: Dutch Run

Stream ID#: 41246 Segment ID: DR STA 5

Sampler(s): S. Tonsor, J. Phillips (sample 1); A. Hale, G. Noble, K. Piper, S. Iannacchione (sample 2) Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/15/2009

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	20	65.6	65.6
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	30	48.7	48.7
Intolerant Taxa Richness	7	43.8	43.8
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			43.9

Score 2 - Sample Date: 5/1/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	11	36.1	36.1
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	45.5	73.9	73.9
Intolerant Taxa Richness	6	37.5	37.5
FC + PR Taxa Richness	3	22.2	22.2
Total Biological Score 2 (Mean of adjusted values):			35.8

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *20.2 %

2.) Mean Total Biological Score (Average of Score 1 and Score 2): 39.9

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

Appendix D2: Quantitative macroinvertebrate data for streams undermined during the 4th assessment period and sampled by the University

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Bailey Mine
Stream Name: Strawn Hollow, 32547- BSW39
Stream NHD#:
Sample Date: 4/18/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, K. Garmire
Comments:

Starting Lat/Long: 39.8653°/ -80.48559°
Ending Lat/Long: 39.86501°/ -80.48651°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		51						
Ephemeroptera		Baetidae		Baetis		CG	6		1						
Plecoptera		Nemouridae		Amphinemura		SH	3		25						
Plecoptera		Perlodidae		Isoperla		PR	2		23						
Plecoptera		Perlodidae		Diploperla		PR	2		3						
Plecoptera		Perlodidae		Clioperla		PR	2		6						
Plecoptera		Perlidae		Attaneuria		PR	3		1						
Trichoptera		Limnephilidae		Ironoquia		SH	3		2						
Trichoptera		Uenoidae		Neophylax		SC	3		6						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		1						
Coleoptera		Psephenidae		Ectopria		SC	5		1						
Coleoptera		Elmidae		Dubiraphia		SC	6		1						
Diptera		Tipulidae		Hexatoma		PR	2		2						
Diptera		Tipulidae		Molophilus		SH	4		1						
Diptera		Tipulidae		Limonia		SH	6		1						
Diptera		Simulidae		Prosimulium		FC	5		4						
Diptera		Tabanidae		Chrysops		PI	7		2						
Diptera		Chironomidae				CG	6	35							
Oligochaeta		Oligochaeta				CG	10	1							
				Total Number of Individuals:				36	131						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Bailey Mine Stream Name: Strawn Hollow

Stream ID#: 32547 Segment ID: BSW39

Sampler(s): A. Hale, K. Garmire Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/18/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	19	62.3	62.3
Trichoptera Richness	3	28.6	28.6
Percent EPT Richness	52.6	85.4	85.4
Intolerant Taxa Richness	11	68.8	68.8
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			59.4

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *__________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ______________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Blacksville #2

Stream Name: Blockhouse Run, 41812, BSW23

Stream NHD#:

Sample Date: 4/25/13

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: X1 or 2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): A. Hale, K. Garmire

Comments:

Starting Lat/Long: 39.77347°/ -80.34307°

Ending Lat/Long: 39.77438°/ -80.34301°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 6 F	Sub. 1 - 6 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Caenidae		Caenis		CG	7		4						
Ephemeroptera		Baetidae		Acentrella		SC	4		1						
Plecoptera		Perlidae				PR	3		1						
Plecoptera		Perlodidae		Isoperla		PR	2		10						
Plecoptera		Nemouridae		Amphinemura		SH	3		1						
Trichoptera		Uenoidae		Neophylax		SC	3		1						
Trichoptera		Limnephilidae		Anabolia		SH	5		1						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4		1						
Amphipoda		Hyalellidae		Hyallela		CG	8		1						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Coleoptera		Elmidae		Dubiraphia		SC	6		3						
Coleoptera		Elmidae		Stenelmis		SC	5		2						
Odonata		Calopterygidae		Calopteryx		PR	6		1						
Diptera		Chironomidae				CG	6	183							
Bivalvia		Sphaeriidae				FC	8	2							
Oligochaeta		Oligocheata				CG	10	4							
					Total Number of Individuals:			189	28						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Blacksville #2 Stream Name: Blockhouse Run

Stream ID#: 41812 Segment ID: BSW23

Sampler(s): A. Hale, K. Garmire Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	16	52.5	52.5
Trichoptera Richness	3	28.6	28.6
Percent EPT Richness	50	81.2	81.2
Intolerant Taxa Richness	7	43.8	43.8
FC + PR Taxa Richness	4	29.6	29.6
Total Biological Score 1 (Mean of adjusted values):			47.1

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Blacksville #2
Stream Name: Roberts Run, 41813, BSW22
Stream NHD#:
Sample Date: 4/25/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, K. Garmire
Comments:

Starting Lat/Long: 39.77194°/ -80.36198°
Ending Lat/Long: 39.77248°/ -80.36292°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	0
Sand / Fine Sediment	3

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		2						
Ephemeroptera		Baetidae		Baetis		CG	6		3						
Ephemeroptera		Baetidae		Diphetor		CG	6		2						
Ephemeroptera		Baetidae		Acentrella		SC	4		2						
Ephemeroptera		Ephemerellidae		Ephemerella		CG	1		5						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4		3						
Plecoptera		Chloroperlidae		Sweltsa		PR	0		1						
Plecoptera		Perlodidae		Diploperla		PR	2		3						
Plecoptera		Perlodidae		Isoperla		PR	2		49						
Plecoptera		Leuctridae		Leuctra		SH	0		3						
Plecoptera		Nemouridae		Amphinemura		SH	3		31						
Trichoptera		Hydropsychidae		Diplectrona		FC	0		2						
Trichoptera		Lepidostomatidae		Lepidostoma		SH	1		1						
Trichoptera		Limnephilidae		Pychnopsyche		SH	4		3						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		1						
Trichoptera		Uenoidae		Neophylax		SC	3		2						
Megaloptera		Sialidae		Sialis		PR	6		2						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Coleoptera		Psephenidae		Ectopria		SC	5		1						
Diptera		Stratiomyidae		Caloparyphus		CG	8		1						
Diptera		Tabanidae		Chrysops		PI	7		2						
Diptera		Tipulidae		Pseudolimnophila		PR	2		2						
Diptera		Tipulidae		Pilaria		PR	7		1						
Diptera		Tipulidae		Tipula		SH	4		4						
Diptera		Chironomidae				CG	6	57							
Decapoda		Cambaridae				CG	6	1							
				Total Number of Individuals:				58	127						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Blacksville #2 Stream Name: Roberts Run

Stream ID#: 41813 Segment ID: BSW22

Sampler(s): A.Hale, K. Garmire Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/25/13

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	26	85.2	85.2
Trichoptera Richness	5	47.6	47.6
Percent EPT Richness	61.5	99.8	99.8
Intolerant Taxa Richness	17	106.3	100.0
FC + PR Taxa Richness	8	59.3	59.3
Total Biological Score 1 (Mean of adjusted values):			78.4

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine
Stream Name: Dyers Fork, 41261, DF STA 1
Stream NHD#:
Sample Date:5/3/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, S. Iannacchione, G. Noble, K. Piper
Comments: Pasture surrounds stream

Starting Lat/Long: 39.82233°/ -80.11618°
Ending Lat/Long: 39.82252°/ -80.11699°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	3
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Caenidae		Caenis		CG	7		1						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7		1						
Ephemeroptera		Heptageniidae		Stenonema		SC	3		1						
Plecoptera		Perlidae		Perlesta		PR	4		5						
Plecoptera		Perlodidae		Isoperla		PR	2		17						
Coleoptera		Elmidae		Stenelmis		SC	5		2						
Coleoptera		Elmidae		Dubiraphia		SC	6		3						
Diptera		Culcidae		Anopheles		FC	8		1						
Diptera		Chironimidae				CG	6	118							
Diptera		Ceratopogoniidae				PR	6	1							
Bivalvia		Sphaeriidae				FC	8	1							
Oligochaeta		Oligochaeta				CG	10	26							
Total Number of Individuals:								146	31						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: Dyers Fork

Stream ID#: 41261 Segment ID: DF STA 1

Sampler(s): A. Hale, G. Noble, K. Piper, S. Iannacchione Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/3/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	12	39.3	39.3
Trichoptera Richness	0	0	0
Percent EPT Richness	41.7	67.7	67.7
Intolerant Taxa Richness	3	18.8	18.8
FC + PR Taxa Richness	5	37.0	37.0
Total Biological Score 1 (Mean of adjusted values):			32.6

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine
Stream Name: Dyers Fork, 41261, DF STA 21
Stream NHD#:
Sample Date: 5/3/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, S. Iannacchione, G. Noble, K. Piper
Comments:

Starting Lat/Long: 39.81441°/ -80.0991°
Ending Lat/Long: 39.814903°/ -80.100013°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	1
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 8 F	Sub. 1 - 8 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Baetidae		Acentrella		SC	4		1						
Plecoptera		Capniidae		Allocapnia		SH	3		2						
Plecoptera		Nemouridae		Amphinemura		SH	3		2						
Plecoptera		Perlidae		Perlesta		PR	4		20						
Plecoptera		Perlodidae		Isoperla		PR	2		6						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4		1						
Coleoptera		Elmidae		Dubiraphia		SC	6		4						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Coleoptera		Elmidae		Stenelmis		SC	5		43						
Diptera		Ceratopogonidae				PR	6	8							
Diptera		Chironomidae				CG	6	56							
Gastropoda		Physidae				SC	8	1							
Oligochaeta		Oligochaeta				CG	10	10							
Total Number of Individuals:								75	80						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: Dyers Fork

Stream ID#: 41261 Segment ID: DF STA 21

Sampler(s): A. Hale, S. Iannacchione, G. Noble, K. Piper Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	13	42.6	42.6
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	46.1	74.8	74.8
Intolerant Taxa Richness	7	43.8	43.8
FC + PR Taxa Richness	3	22.2	22.2
Total Biological Score 1 (Mean of adjusted values):			38.6

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine

Stream Name: Maple Run, 40607, MR4

Stream NHD#:

Sample Date: 4/30/2013

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: X1 or 2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): A. Hale, G. Noble, K. Piper

Comments:

Starting Lat/Long: 39.82333°/ -80.23994°

Ending Lat/Long: 39.82257°/ -80.2405°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	2
Coarse Particulate Organic Matter	1
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		22						
Ephemeroptera		Baetidae		Acentrella		SC	4		1						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7		3						
Ephemeroptera		Leptophlebiidae		Paraleptophlebia		CG	1		1						
Plecoptera		Perlodidae		Isoperla		PR	2		137						
Plecoptera		Leuctridae		Leuctra		SH	0		1						
Plecoptera		Nemouridae		Amphinemura		SH	3		6						
Plecoptera		Perlidae		Perlesta		PR	4		1						
Trichoptera		Limnephilidae		Anabolia		SH	5		1						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		3						
Coleoptera		Elmidae		Stenelmis		SC	5		1						
Diptera		Tabanidae		Chrysops		PI	7		1						
Diptera		Ceratopogonidae				PR	6	1							
Diptera		Chironomidae				CG	6	37							
Oligochaeta						CG	10	11							
			Total Number of Individuals:					49	178						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: Maple Run

Stream ID#: 40607 Segment ID: MR 4

Sampler(s): A. Hale, G. Noble, K. Piper Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/30/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	15	49.2	49.2
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	66.7	108.3	100.0
Intolerant Taxa Richness	8	50.0	50.0
FC + PR Taxa Richness	4	29.6	29.6
		Total Biological Score 1 (Mean of adjusted values):	49.6

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
		Total Biological Score 2 (Mean of adjusted values):	

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine
Stream Name: Maple Run, 40607, MR5
Stream NHD#:
Sample Date: 4/30/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): G. Noble, K. Piper, A. Hale
Comments:

Starting Lat/Long: 39.81926°/ -80.24236°
Ending Lat/Long: 39.81831°/ -80.2427°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	4
Snag	1
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	3
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		131						
Ephemeroptera		Ephemerellidae		Ephemerella		CG	1		3						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7		15						
Plecoptera		Nemouridae		Amphinemura		SH	3		2						
Plecoptera		Perlodidae		Isoperla		PR	2		45						
Trichoptera		Limnephilidae		Anabolia		SH	5		1						
Trichoptera		Uenoidae		Neophylax		SC	3		1						
Diptera		Tipulidae		Tipula		SH	4		2						
Diptera		Chironomidae				CG	6	2							
Oligochaeta		Oligochaeta				CG	10	1							
						Total Number of Individuals:		3	200						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: Maple Run

Stream ID#: 40607 Segment ID: MR5

Sampler(s): G. Noble, K. Piper, A. Hale Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4-30-2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	10	32.8	32.8
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	70	113.6	100.0
Intolerant Taxa Richness	6	37.5	37.5
FC + PR Taxa Richness	1	7.4	7.4
Total Biological Score 1 (Mean of adjusted values):			39.3

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Cumberland Mine
Stream Name: UNT to Maple Run, 40608, MR T12
Stream NHD#:
Sample Date: 3/8/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): G. Noble, L. Powell, T. Hann, K. Garmire, A. Hale
Comments:

Starting Lat/Long: 39.8199°/ -80.24544°
Ending Lat/Long: 39.81978°/ -80.2466°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	3
Snag	3
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	0
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		40						
Ephemeroptera		Heptageniidae		Stenonema		SC	3		1						
Ephemeroptera		Ephemerellidae		Ephemerella		CG	1		1						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4		1						
Plecoptera		Perlodidae		Isoperla		PR	2		22						
Plecoptera		Nemouridae		Amphinemura		SH	3		4						
Plecoptera		Nemouridae		Podmosta		SH	2		21						
Plecoptera		Capniidae		Allocapnia		SH	3		7						
Trichoptera		Rhyacophilidae		Ryacophila		PR	1		2						
Trichoptera		Uenoidae		Neophylax		SC	3		12						
Diptera		Dixidae		Dixa		CG	1		1						
Diptera		Simuliidae		Prosimulium		FC	5		2						
Diptera		Tipulidae		Tipula		SH	4		3						
Diptera		Tipulidae		Hexatoma		PR	2		1						
Diptera		Tipulidae		Molophilus		SH	4		2						
Diptera		Simulidae		Stegopterna		FC	6		16						
Diptera		Chironomidae				CG	6	32							
Diptera		Ceratopogonidae				PR	6	4							
Oligochaeta		Oligochaeta				CG	10	3							
				Total Number of Individuals:				39	136						

Lab sub-sample 1-4 (200 +/- 20%) (Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Cumberland Mine Stream Name: UNT to Maple Run

Stream ID#: 40608 Segment ID: MR T12

Sampler(s): G. Noble, L. Powell, T. Hann, K. Garmire, A. Hale Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 3/8/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	19	62.3	62.3
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	52.6	85.4	85.4
Intolerant Taxa Richness	14	87.5	87.5
FC + PR Taxa Richness	6	44.4	44.4
Total Biological Score 1 (Mean of adjusted values):			59.7

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine

Stream Name: Templeton Fork, 32708, BSW19

Stream NHD#:

Sample Date: 5/9/2013

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: X1 or 2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): A. Hale, G. Noble, K. Piper, L. Kiefer

Comments:

Starting Lat/Long: 40.06039°/ -80.37785°

Ending Lat/Long: 40.06106°/ -80.37704°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	4
Snag	0
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	4
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Baetidae		Baetis		CG	6		2						
Ephemeroptera		Caenidae		Caenis		CG	7		6						
Plecoptera		Nemouridae		Amphinemura		SH	3		2						
Plecoptera		Perlidae		Perlesta		PR	4		16						
Plecoptera		Perlodidae		Isoperla		PR	2		2						
Trichoptera		Hydropsychidae		Hydropsyche		FC	5		3						
Odonata		Calopterygidae		Calopteryx		PR	6		1						
Coleoptera		Elmidae		Dubiraphia		SC	6		1						
Coleoptera		Elmidae		Stenelmis		SC	5		4						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Diptera		Empididae		Hemerodromia		PR	6		1						
Diptera		Tipulidae		Hexatoma		PR	2		1						
Diptera		Ceratopogonidae				PR	6	2							
Diptera		Chironomidae				CG	6	183							
Gastropoda		Physidae				SC	8	1							
Total Number of Individuals:								186	40						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Enlow Fork Mine Stream Name: Templeton Fork

Stream ID#: 32708 Segment ID: BSW19

Sampler(s): A. Hale, G. Noble, K. Piper, L. Kiefer Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 5/9/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	15	49.2	49.2
Trichoptera Richness	1	9.5	9.5
Percent EPT Richness	40.0	64.9	64.9
Intolerant Taxa Richness	5	31.3	31.3
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			41.3

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine

Stream Name: Crafts Creek, 40938, BSW20

Stream NHD#:

Sample Date: 4/5/2013

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: X1 or 2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): G. Noble, A. Hale, T. Hann, L. Powell

Comments:

Starting Lat/Long: 40.05588°/ -80.33527°

Ending Lat/Long: 40.05523°/ -80.33606°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Plecoptera		Nemouridae		Amphinemura		SH	3		1						
Plecoptera		Perlodidae		Isoperla		PR	2		7						
Trichoptera		Uenoidae		Neophylax		SC	3		2						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		1						
Isopoda		Asellidae		Caecidotea		CG	6		2						
Coleoptera		Elmidae		Stenelmis		SC	5		3						
Diptera		Tabanidae		Chrysops		PI	7		2						
Diptera		Tipulidae		Pilaria		PR	7		1						
Diptera		Ceratopogonidae				PR	6	15							
Diptera		Chronomidae				CG	6	102							
Bivalvia		Sphaeriidae				FC	8	20							
Gastropoda		Physidae				SC	8	2							
Gastropoda		Planorbidae				SC	6	1							
Oligochaeta		Oligochaeta				CG	10	1							
								Total Number of Individuals: 141	19						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Enlow Fork Mine Stream Name: Crafts Creek

Stream ID#: 40938 Segment ID: BSW20

Sampler(s): G. Noble, A. Hale, T. Hann, L. Powell Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/5/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	14	45.9	45.9
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	28.6	46.4	46.4
Intolerant Taxa Richness	4	25.0	25.0
FC + PR Taxa Richness	5	37.0	37.0
Total Biological Score 1 (Mean of adjusted values):			34.7

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine
Stream Name: UNT to Crafts Creek, 40941, BSW24
Stream NHD#:
Sample Date: 4/5/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, G. Noble, T. Hann, L. Powell
Comments:

Starting Lat/Long: 40.058445°/ -80.334175°
Ending Lat/Long: 40.059292°/ -80.334442°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	2
Snag	3
Coarse Particulate Organic Matter	0
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	3

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4		Sub. ___		Sub. _____		Sub. _____	
								F	G	F	G	F	G	F	G
Plecoptera		Nemouridae		Amphinemura		SH	3		3						
Trichoptera		Uenoidae		Neophylax		SC	3		2						
Trichoptera		Limnephilidae		Limnephilus		SH	3		1						
Trichoptera		Lepidostomatidae		Lepidostoma		SH	1		1						
Trichoptera		Rhyacophilidae		Rhyacophilia		PR	1		4						
Amphipoda		Crangonyctidae		Crangonyx		CG	4		112						
Diptera		Tipulidae		Molophilus		SH	4		2						
Diptera		Tipulidae		Pseudolimnophila		PR	2		1						
Diptera		Simulidae		Stegopterna		FC	6		8						
Diptera		Tabanidae		Tabanus		PR	5		1						
Diptera		Tabanidae		Chrysops		PI	7		1						
Diptera		Ceratopogonidae				PR	6	5							
Diptera		Chironomidae				CG	6	9							
Bivalvia		Sphaeriidae				FC	8	12							
Insecta		Collembola				CG	9	2							
Decapoda		Cambaridae				CG	6	1							
Oligochaeta		Oligochaeta				CG	10	5							
				Total Number of Individuals:				34	136						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Enlow Fork Mine Stream Name: UNT to Crafts Creek

Stream ID#: 40941 Segment ID: BSW24

Sampler(s): A. Hale, G. Noble, T. Hann, L. Powell Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 4/5/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	17	55.7	55.7
Trichoptera Richness	4	38.1	38.1
Percent EPT Richness	29.4	47.7	47.7
Intolerant Taxa Richness	8	50.0	50.0
FC + PR Taxa Richness	6	44.4	44.0
Total Biological Score 1 (Mean of adjusted values):			47.2

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine
Stream Name: UNT to Crafts Creek, 40944, BSW13
Stream NHD#:
Sample Date: 3/29/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): T. Hann, G. Noble, A. Hale, K. Garmire
Comments:

Starting Lat/Long: 40.056469°/ -80.355087°
Ending Lat/Long: 40.05727°/ -80.355423°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	2
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 – 7 F	Sub. 1 – 7 G	Sub. ___ F	Sub. ___ G	Sub. _____ F	Sub. _____ G	Sub. _____ F	Sub. _____ G
Ephemeroptera		Ameletidae		Ameletus		CG	0		14						
Plecoptera		Capniidae		Allocapnia		SH	3		2						
Plecoptera		Nemouridae		Amphinemura		SH	3		30						
Plecoptera		Nemouridae		Nemoura		SH	1		1						
Plecoptera		Perlodidae		Isoperla		PR	2		31						
Trichoptera		Limnephilidae		Ironoquia		SH	3		3						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1		1						
Trichoptera		Uenoidae		Neophylax		SC	3		2						
Amphipoda		Crangonyctidae		Crangonyx		CG	4		12						
Diptera		Simulidae		Prosimulium		FC	5		15						
Diptera		Simulidae		Stegopterna		FC	6		5						
Diptera		Tabanidae		Tabanus		PR	5		1						
Diptera		Tabanidae		Chrysops		PI	7		7						
Diptera		Tipulidae		Molophilus		SH	4		2						
Diptera		Tipulidae		Tipula		SH	4		2						
Diptera		Ceratopogonidae				PR	6	2							
Diptera		Chironomidae				CG	6	46							
Bivalvia		Sphaeriidae				FC	8	2							
Decapoda		Cambaridae				CG	6	1							
Oligochaeta		Oligochaeta				CG	10	10							
				Total Number of Individuals:				61	128						

Lab sub-sample 1-4 (200 +/- 20%) (Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Enlow Fork Mine Stream Name: UNT to Crafts Creek

Stream ID#: 40944 Segment ID: BSW13

Sampler(s): T. Hann, G. Noble, A. Hale, K. Garmire Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 3/29/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	20	65.6	65.6
Trichoptera Richness	3	28.6	28.6
Percent EPT Richness	40	64.9	64.9
Intolerant Taxa Richness	11	68.8	68.8
FC + PR Taxa Richness	7	51.9	51.9
Total Biological Score 1 (Mean of adjusted values):			55.9

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness			
Trichoptera Richness			
Percent EPT Richness			
Intolerant Taxa Richness			
FC + PR Taxa Richness			
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Emerald Mine

Stream Name: Mount Phoebe Run, 41268, MP STA 1

Stream NHD#:

Sample Date: 11/8/2013

Pre-Mining Sampling Survey: 1 or 2 (check one)

Post-Mining Sampling Survey: X1 or 2 (check one)

Length of Sampled Reach: 100 meters

Sampler(s): A. Hale, L. Kiefer

Comments:

Starting Lat/Long: 39.84277°/ -80.12548°

Ending Lat/Long: 39.84368°/ -80.12538°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	1
Snag	3
Coarse Particulate Organic Matter	1
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	3

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Baetidae		Baetis		CG	6		3						
Plecoptera		Capniidae		Allocapnia		SH	3		1						
Trichoptera		Hydropsychidae		Cheumatopsyche		FC	6		12						
Trichoptera		Hydropsychidae		Hydropsyche		FC	5		4						
Coleoptera		Elmidae		Dubiraphia		SC	6		2						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Coleoptera		Elmidae		Stenelmis		SC	5		8						
Odonata		Calopterygidae		Calopteryx		PR	6		1						
Diptera		Tipulidae		Tipula		SH	4		3						
Diptera		Tabanidae		Chrysops		PI	7		1						
Diptera		Chironomidae				CG	6	179							
Diptera		Ceratopogonidae				PR	6	6							
Gastropoda		Physidae				SC	8	1							
Oligochaeta		Oligochaeta				CG	10	3							
					Total Number of Individuals:			189	36						

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Lab sub-sample 1-4 (200 +/- 20%) (Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Emerald Mine Stream Name: Mount Phoebe Run

Stream ID#: 41268 Segment ID: MP STA 1

Sampler(s): A. Hale, L. Kiefer Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 11/8/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	14	45.9	45.9
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	28.6	46.4	46.4
Intolerant Taxa Richness	3	18.8	18.8
FC + PR Taxa Richness	4	29.6	29.6
Total Biological Score 1 (Mean of adjusted values):			32.0

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *_________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): _____________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Emerald Mine
Stream Name: Muddy Creek, 41014, MC B2
Stream NHD#:
Sample Date: 11/15/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): L. Kiefer, S. Tonsor, A. Hale
Comments:

Starting Lat/Long: 39.87832°/ -80.09304°
Ending Lat/Long: 39.877965°/ -80.09382°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	0
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	3
Sand / Fine Sediment	3

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 – 4 F	Sub. 1 – 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Baetidae		Callibaetis		CG	9		5						
Trichoptera		Phryganeidae		Ptilostomis		SH	5		4						
Trichoptera		Limnephilidae		Limnephilus		SH	3		1						
Coleoptera		Elmidae		Dubiraphia		SC	6		1						
Coleoptera		Elmidae		Optioservus		SC	4		1						
Odonata		Coenagrionidae		Argia		PR	6		1						
Megaloptera		Sialidae		Sialis		PR	6		1						
Diptera		Tipulidae		Hexatoma		PR	2		1						
Diptera		Tabanidae		Chrysops		PI	7		1						
Diptera		Ceratopogonidae				PR	6	1							
Diptera		Chironomidae				CG	6	124							
Bivalvia		Sphaeriidae				FC	8	6							
Gastropoda		Lymnaidae				SC	7	5							
Oligochaeta		Oligochaeta				CG	10	59							
				Total Number of Individuals:				195	16						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

FORM 8.8D: BIOMETRIC AND TOTAL BIOLOGICAL SCORE SUMMARY

Mine Name: Emerald Mine Stream Name: Muddy Creek

Stream ID#: 41014 Segment ID: MC B2

Sampler(s): L. Kiefer, S. Tonsor, A. Hale Length of Sampled Reach: 100 meters

☐ Pre-Mining ☒ Post-Mining

Score 1 - Sample Date: 11/15/2013

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness	14	45.9	45.9
Trichoptera Richness	2	19.0	19.0
Percent EPT Richness	21.4	34.7	34.7
Intolerant Taxa Richness	3	18.8	18.8
FC + PR Taxa Richness	5	37.0	37.0
Total Biological Score 1 (Mean of adjusted values):			31.1

Score 2 - Sample Date:

Biological Metric	Observed Value	Normalized Score (observed value / 95th percentile value) * 100	Adjusted Value
Taxa Richness		**30.5**	
Trichoptera Richness		**10.5**	
Percent EPT Richness		**61.6**	
Intolerant Taxa Richness		**16.0**	
FC + PR Taxa Richness		**13.5**	
Total Biological Score 2 (Mean of adjusted values):			

1.) Quality Assurance Check (% difference between Score 1 and Score 2): *__________________%

2.) Mean Total Biological Score (Average of Score 1 and Score 2): ______________________

* If percentage difference is greater than 16%, reach should be re-sampled to obtain additional set of metrics.

Appendix E: Spearman correlation matrix for reach and catchment-scale variables that can influence stream biology. Correlations significant at the P < 0.0001 level (line 1) and with $r_s > 0.5$ (line 2) are highlighted in dark orange (sample size for correlation analysis on line 3). LPI = Largest Patch Index. DO = dissolved oxygen. Habitat Score = U.S. EPA low gradient habitat assessment score.

	% Pasture	% Forest	% Dev Open Space	% Crops	% Developed	LPI	Edge Density	Shape	Contiguity	Patch Richness	Simpson's Diversity	Simpson's Evenness	Watershed Area	Conductivity	pH	DO	Habitat Score
% Pasture		-0.91 <.0001 151	0.21 0.0104 151	0.30 0.0002 151	0.13 0.1015 151	-0.78 <.0001 151	0.69 <.0001 151	0.28 0.0005 151	-0.65 <.0001 151	0.16 0.0478 151	0.83 <.0001 151	0.86 <.0001 151	0.08 0.3136 151	0.14 0.0861 148	0.07 0.4071 150	-0.23 0.0052 151	-0.16 0.0506 146
% Forest			-0.42 <.0001 151	-0.40 <.0001 151	-0.24 0.0027 151	0.89 <.0001 151	-0.86 <.0001 151	-0.34 <.0001 151	0.79 <.0001 151	-0.27 0.0009 151	-0.95 <.0001 151	-0.94 <.0001 151	-0.10 0.2029 151	-0.25 0.002 148	-0.15 0.0629 150	0.23 0.0038 151	0.12 0.1395 146
% Dev Open Space				0.10 0.2391 151	0.37 <.0001 151	-0.46 <.0001 151	0.62 <.0001 151	0.32 <.0001 151	-0.48 <.0001 151	0.29 0.0003 151	0.49 <.0001 151	0.41 <.0001 151	0.16 0.056 151	0.37 <.0001 148	0.19 0.0216 150	0.01 0.9432 151	0.04 0.6194 146
% Crops					0.24 0.0029 151	-0.49 <.0001 151	0.49 <.0001 151	0.54 <.0001 151	-0.23 0.0046 151	0.61 <.0001 151	0.48 <.0001 151	0.33 <.0001 151	0.48 <.0001 151	0.11 0.1678 148	0.16 0.0498 150	-0.11 0.171 151	-0.05 0.5192 146
% Developed						-0.36 <.0001 151	0.24 0.0025 151	0.39 <.0001 151	-0.005 0.9537 151	0.59 <.0001 151	0.30 0.0002 151	0.16 0.0466 151	0.44 <.0001 151	0.15 0.0746 148	0.15 0.0752 150	0.12 0.1409 151	0.30 0.0003 146
LPI							-0.85 <.0001 151	-0.48 <.0001 151	0.67 <.0001 151	-0.45 <.0001 151	-0.93 <.0001 151	-0.86 <.0001 151	-0.32 <.0001 151	-0.31 0.0001 148	-0.24 0.003 150	0.14 0.0889 151	0.03 0.7489 146
Edge Density								0.46 <.0001 151	-0.84 <.0001 151	0.36 <.0001 151	0.91 <.0001 151	0.84 <.0001 151	0.17 0.0397 151	0.28 0.0007 148	0.16 0.0455 150	-0.19 0.0175 151	-0.12 0.1462 146
Shape									-0.03 0.7361 151	0.79 <.0001 151	0.41 <.0001 151	0.21 0.0097 151	0.89 <.0001 151	0.21 0.0101 148	0.23 0.0038 150	0.13 0.1153 151	-0.05 0.5597 146
Contiguity										0.06 0.4619 151	-0.77 <.0001 151	-0.85 <.0001 151	0.30 0.0002 151	-0.17 0.042 148	-0.03 0.7215 150	0.33 <.0001 151	0.15 0.0653 146
Patch Richness											0.37 <.0001 151	0.12 0.1376 151	0.82 <.0001 151	0.21 0.0093 148	0.26 0.0012 150	0.19 0.0179 151	0.08 0.333 146
Simpson's Diversity												0.95 <.0001 151	0.20 0.0147 151	0.27 0.0011 148	0.17 0.0419 150	-0.17 0.0348 151	-0.06 0.446 146
Simpson's Evenness													-0.03 0.7526 151	0.22 0.0079 148	0.11 0.1638 150	-0.24 0.0032 151	-0.10 0.2193 146

	% Pasture	% Forest	% Dev Open Space	% Crops	% Developed	LPI	Edge Density	Shape	Contiguity	Patch Richness	Simpson's Diversity	Simpson's Evenness	Watershed Area	Conductivity	pH	DO	Habitat Score
Watershed Area														0.16 0.055 148	0.26 0.0016 150	0.25 0.0024 151	0.08 0.3454 146
Conductivity															0.76 <.0001 148	0.11 0.1814 148	-0.10 0.231 144
pH																0.32 <.0001 150	-0.05 0.5723 145
DO																	-0.02 0.769 146
Habitat Score																	

Appendix F: Maximum and minimum lengths of post-mining flow loss for streams receiving augmentation during the 4th assessment period. "Flowing" indicates that the stream did not exhibit flow loss during either the wet or dry season (or both).

				DRY SEASON				WET SEASON			
Mine	**PA WRDS Stream Code[1]**	**Stream Name**	**Company Code**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**
Bailey	32540	Barneys Run	BarR	21-Oct-12	8,216	2-Jun-13	46	2-Dec-12	2,133	18-Mar-12	35
Bailey	NA	UNT to Barneys Run	BarR-2R	8-Jul-12	2,791	30-Nov-08	30	2-Dec-12	1,365	28-Mar-10	20
Bailey	NA	UNT to UNT of Barneys Run	BarR-2R-1L	No data	.	No data	.	No data	.	No data	.
Bailey	32541	UNT to Barneys Run	BarR-3R	2-Aug-09	3,194	23-Nov-08	187	10-Jan-10	1,960	3-May-09	22
Bailey	32542	UNT to Barneys Run	BarR-5R	9-Sep-12	5,276	7-Nov-10	98	23-Jan-11	3,460	7-Mar-10	52
Bailey	NA	UNT to UNT of Barneys Run	BarR-5R-4R	No data	.	No data	.	No data	.	No data	.
Bailey	NA	UNT to UNT of Barneys Run	BarR-8R-1R	30-Sep-12	2,589	11-Sep-11	36	29-Apr-12	2,026	4-Dec-11	77
Bailey	32543	UNT to UNT of Barneys Run	BarR-8R-2R	22-Jul-12	5,961	11-Aug-13	40	29-Apr-12	3,804	25-Dec-11	30
Bailey	32532	UNT to Dunkard Fork	DF-19R	31-Oct-10	10,883	7-Aug-11	13	7-Dec-08	4,183	17-Apr-11	8
Bailey	32533	UNT to UNT of Dunkard Fork	DF-19R-1R	12-Sep-10	2,099	7-Jun-09	499	7-Dec-08	2,076	1-Feb-09	25
Bailey	32534	UNT to UNT of Dunkard Fork	DF-19R-2R	14-Oct-12	4,257	20-Nov-11	128	7-Dec-08	3,186	22-Jan-12	107
Bailey	NA	UNT to UNT of Dunkard Fork	DF-19R-2R-1R	31-Aug-08	1,651	7-Jun-09	697	7-Dec-08	1,651	11-Jan-09	598
Bailey	NA	UNT to UNT of Dunkard Fork	DF-19R-7R	14-Jun-09	1,745	9-Oct-11	128	24-May-09	1,406	2-May-10	19
Bailey	32511	UNT to Dunkard Fork	DF-9L	9-Sep-12	6,076	13-Nov-11	198	2-Dec-12	3,791	18-Dec-11	45
Bailey	32551	Mudlick Fork	MdlkF	9-Sep-12	3,222	24-Jun-12	124	Flowing	.	Flowing	.
Bailey	NA	Crow's Nest	NoF-1L	19-Oct-08	2,003	30-Oct-11	150	7-Dec-08	1,679	22-Jan-12	138
Bailey	32595	UNT to North Fork of Dunkard Fork	NoF-3L	19-Aug-12	4,539	7-Jul-13	151	7-Dec-08	4,300	17-Jan-10	40
Bailey	32597	UNT to North Fork of Dunkard Fork	NoF-3R	19-Oct-08	1,962	20-Jun-10	653	15-Mar-09	789	15-Feb-09	45
Bailey	32596	UNT to North Fork of Dunkard Fork	NoF-5L	16-Sep-12	6,083	18-Sep-11	20	7-Dec-08	4,652	27-Dec-09	30
Bailey	32698	Polly Hollow	PlyH	17-Oct-10	3,654	21-Jun-09	30	13-Feb-11	2,638	13-Dec-09	50
Bailey	32536	South Fork of Dunkard Fork	SoF	19-Sep-10	5,273	30-Aug-09	25	7-Dec-08	1,276	7-Dec-08	1,276
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-11L	21-Oct-12	2,009	25-Nov-12	35	29-May-11	1,086	18-Apr-10	13
Bailey	32566	UNT to South Fork of Dunkard Fork	SoF-12L	29-Aug-10	5,229	20-Sep-09	40	15-Mar-09	837	6-Dec-09	36
Bailey	32537	UNT to South Fork of Dunkard Fork	SoF-1R	12-Sep-10	2,295	26-Aug-07	138	3-Dec-06	1,183	25-Feb-07	30
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-2R	12-Sep-10	2,017	6-Jul-08	63	15-Mar-09	1,076	11-Jan-09	37
Bailey	NA	UNT to South Fork of Dunkard Fork	SoF-4R	12-Jul-09	2,850	28-Jun-09	178	20-Dec-09	1,593	27-Dec-09	182
Bailey	32539	UNT to South Fork of Dunkard Fork	SoF-5L	5-Aug-12	5,909	25-Jul-10	32	22-Apr-12	4,664	22-Jan-12	19
Bailey	32546	UNT to South Fork of Dunkard Fork	SoF-6L	11-Oct-09	3,213	2-Oct-11	187	23-Jan-11	2,528	17-Jan-10	124
Bailey	32549	UNT to South Fork of Dunkard Fork	SoF-8L	9-Sep-12	4,465	8-Nov-09	27	26-Dec-10	1,564	4-Jan-09	5
Bailey	32550	UNT to UNT of South Fork of Dunkard Fork	SoF-8L-2L	3-Oct-10	2,117	20-Nov-11	54	5-May-13	1,949	25-Dec-11	20
Bailey	32565	UNT to South Fork of Dunkard Fork	SoF-9L	10-Oct-10	7,143	31-Jul-11	20	26-Dec-10	3,313	19-Dec-10	81

				DRY SEASON				WET SEASON			
Mine	**PA WRDS Stream Code[1]**	**Stream Name**	**Company Code**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**
Bailey	32547	Strawn Hollow	StrnH	14-Oct-12	5,676	5-Jun-11	30	29-Apr-12	1,919	13-Jan-13	8
Bailey	32548	UNT to Strawn Hollow	StrnH-2R	5-Sep-10	2,233	28-Nov-10	153	6-Feb-11	1,811	25-Apr-10	20
Bailey	32504	Wharton Run	WhrtnR	5-Oct-08	3,823	5-Jul-09	50	7-Dec-08	1,714	7-Dec-08	1,714
Bailey	NA	UNT to Wharton Run	WhrtnR-7L	28-Sep-08	1,661	21-Jun-09	707	7-Dec-08	1,124	15-Feb-09	84
Bailey	32508	UNT to Wharton Run	WhrtnR-8R	8-Aug-10	936	14-Jun-09	149	23-May-10	1,384	15-Mar-09	189
Blacksville 2	41812	Blockhouse Run	BlkhR	9-Sep-12	5,486	23-Jun-13	15	Flowing	.	Flowing	.
Blacksville 2	41826	UNT to Blockhouse Run	BlkhR-15R	19-Aug-12	3,488	28-Oct-12	21	Flowing	.	Flowing	.
Blacksville 2	41820	UNT to Blockhouse Run	BlkhR-1L	7-Oct-12	3,044	18-Sep-11	12	2-Dec-12	779	27-Jan-13	18
Blacksville 2	41824	UNT to Blockhouse Run	BlkhR-2L	12-Aug-12	1,835	31-Jul-11	20	Flowing	.	Flowing	.
Blacksville 2	41818	UNT to Blockhouse Run	BlkhR-2R	26-Aug-12	3,218	9-Oct-11	33	22-Jan-12	96	13-Jan-13	4
Blacksville 2	41819	UNT to Blockhouse Run	BlkhR-3R	5-Aug-12	4,540	7-Jul-13	20	26-May-13	414	20-May-12	60
Blacksville 2	41813	Roberts Run	RbtsR	26-Aug-12	8,104	2-Jun-13	483	Flowing	.	Flowing	.
Blacksville 2	41833	UNT to Tom's Run	TmsR-8R	8-Jul-12	6,847	25-Nov-12	106	26-May-13	843	26-May-13	843
Cumberland	41282	UNT to Whiteley Creek	WC_41282	4-Sep-12	3,637	3-Oct-11	189	3-Dec-12	2,736	24-Jan-12	124
Cumberland	40614	UNT to Pursley Creek	PC_40614	31-Aug-11	2,660	10-Jul-11	20	30-Apr-12	1,502	6-Feb-13	20
Cumberland	NA	UNT to Pursley Creek	PC_40592-L7	17-Sep-12	1,341	5-Nov-12	71	6-May-13	1,219	3-Jan-13	40
Cumberland	41264	UNT to Dyers Fork	DF_41264	22-Sep-10	5,686	21-Sep-11	58	29-Dec-10	3,255	11-May-11	13
Cumberland	41267	UNT to Dyers Fork	DF_41267	18-Sep-09	5331	9-Nov-11	80	29-May-13	3,219	28-Jan-13	101
Emerald	41014	Muddy Creek	MC_41014	13-Jul-12	10,233	8-Sep-09	20	20-Dec-10	1,474	28-Apr-10	16
Emerald	41252	UNT to Dutch Run	DR_41252	16-Nov-09	3,465	27-Sep-11	98	2-May-13	3,020	29-Jan-13	20
Enlow	32999	UNT to Buffalo Creek	BufC-12R	5-Aug-12	2,308	16-Sep-12	22	28-Apr-13	192	27-Jan-13	18
Enlow	33000	UNT to Buffalo Creek	BufC-13R	10-Jun-12	1,255	28-Oct-12	5	27-May-12	632	4-Dec-11	13
Enlow	40938	Crafts Creek	CrC	12-Sep-10	6,066	6-Jun-10	50	6-Dec-09	2,544	7-Apr-13	8
Enlow	NA	UNT to Crafts Creek	CrC-1.7R	12-Aug-12	1,843	31-Jul-11	17	9-Dec-12	702	6-Jan-13	62
Enlow	40939	UNT to Crafts Creek	CrC-1R	16-Sep-12	8,319	18-Nov-12	395	26-Dec-10	2,057	5-May-13	24
Enlow	40940	UNT to UNT of Crafts Creek	CrC-1R,2R	30-Sep-12	2,023	28-Oct-12	125	20-May-12	1,180	9-Dec-12	64
Enlow	40941	UNT to Crafts Creek	CrC-2R	19-Sep-10	2,403	28-Jul-13	1	10-Jan-10	1,380	7-Apr-13	1
Enlow	40942	UNT to Crafts Creek	CrC-3R	19-Sep-10	8,494	29-Nov-09	30	2-Dec-12	8,106	15-Jan-12	93
Enlow	40943	UNT to UNT of Crafts Creek	CrC-3R,1R	22-Aug-10	2,547	20-Nov-11	70	2-Dec-12	2,531	21-Mar-10	25
Enlow	40944	UNT to Crafts Creek	CrC-4R	10-Oct-10	7,899	7-Aug-11	57	19-May-13	2,747	28-Mar-10	20
Enlow	NA	UNT to UNT of Crafts Creek	CrC-4R,2R	6-Nov-11	1,611	20-Nov-11	196	20-May-12	1,605	25-Dec-11	219
Enlow	32708	Templeton Fork	TemF	12-Sep-10	5,390	20-Nov-11	42	6-May-12	2,024	24-May-09	20
Enlow	32742	UNT to Templeton Fork	TemF-25L	21-Oct-12	4,892	19-Jul-09	107	2-Dec-12	1,664	14-Mar-10	25

				DRY SEASON				WET SEASON			
Mine	**PA WRDS Stream Code[1]**	**Stream Name**	**Company Code**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**	**Date of max flow loss**	**Length dry (ft)**	**Date of min flow loss**	**Length dry (ft)**
Enlow	32743	UNT to Templeton Fork	TemF-26L	31-Oct-10	4,660	18-Sep-11	30	30-May-10	1,313	5-Feb-12	18
Enlow	32744	UNT to Templeton Fork	TemF-27L	16-Sep-12	2,871	7-Aug-11	98	20-May-12	1,045	26-Dec-10	50
Enlow	32745	UNT to Templeton Fork	TemF-28L	29-Aug-10	2,179	28-Nov-10	99	19-Dec-10	763	10-Apr-11	78
Enlow	40285	Ten Mile Creek	TenC	Flowing	.	Flowing	.	Flowing	.	Flowing	.
Enlow	40949	UNT to Ten Mile Creek	TenC-8L	2-Sep-12	6,542	14-Aug-11	35	12-May-13	1,244	19-May-13	30
Enlow	40951	UNT to UNT of Ten Mile Creek	TenC-8L,1L	12-Aug-12	2,602	9-Sep-12	3	11-Dec-11	673	30-Dec-12	25
				TOTALS (ft):	**275,869**		**7,744**		**125,079**		**7,231**
				TOTALS (mi):	**52.2**		**1.5**		**23.7**		**1.4**

[1] NA = Zero order tributary

Appendix G1: Stream investigations for the 4th assessment period

Panels	PA WRDS Stream Code[1]	Stream Name	Nature of Damage	Claim #	Days to Resolution	Final Resolution Status	Stream Designated Use
Bailey Mine							
1-4I	32596	UNT to North Fork of Dunkard Fork	Flow loss	ST1203	2623	Compensatory Mitigation Required	Trout-stocked fishery
Cumberland Mine							
56, 57	41258	UNT to Whiteley Creek	Flow loss	ST0902	225	Not Due to Underground Mining	Trout-stocked fishery
49	41250	UNT to Dutch Run	Flow loss	ST1201	132	Stream Recovered	Trout-stocked fishery
Emerald Mine							
B6	41252	UNT to Dutch Run	Flow loss	ST0901	NR	Unresolved	Trout-stocked fishery
Enlow Fork Mine							
E18	40937	UNT to Ten Mile Creek	Flow loss	ST1001	NR	Unresolved	Trout-stocked fishery
F15	NA	UNT to UNT 32738 of Templeton Fork	Flow loss	ST1101	NR	Unresolved	No Data
F13, F14	32736	UNT to Templeton Fork	Flow loss	ST1102	260	No Actual Problem	Trout-stocked fishery
F6-F8	32719	UNT to Rocky Run	Flow loss	ST1202	NR	Unresolved	Trout-stocked fishery
TJS No. 6 Mine							
NA	46501	Cessna Run	Flow loss	ST0903	638	Not Due to Underground Mining	Cold water fishes

[1]NA = Zero order tributary

Appendix G2: Stream recovery reports from the 4th assessment period

Panels	PA WRDS Stream Code[1]	Stream Name	Nature of Damage	Claim #	Days to Resolution	Time in Review at DEP	Final Resolution Status	Stream Designated Use
Bailey Mine								
9H	32508	UNT to Wharton Run	Flow Loss	SR0902	1358	353	Released	Warm water fishes
8H	32533	UNT to UNT 32532 of Dunkard Fork	Flow Loss	SR0903	1785	561	Released	Warm water fishes
7I, 8I	32538	UNT to South Fork of Dunkard Fork	Flow Loss	SR0904	1014	117	Released	Trout-stocked fishery
8H, 9H, 10H	32504	Wharton Run	Flow Loss	SR0905	No Data	83	Released	Warm water fishes
7I	32537	UNT to South Fork of Dunkard Fork	Flow Loss	SR0906	1058	268	Released	Trout-stocked fishery
7I, 8I	32597	UNT to North Fork of Dunkard Fork	Flow Loss	SR1001	1569	248	Released	Trout-stocked fishery
8I	NA	UNT to South Fork Dunkard Fork (SoF-2R)	Flow Loss	SR1002	.	.	In review	No Data
4I, 5I	NA	Crow's Nest	Flow Loss	SR1003	2626	659	Compensatory Mitigation Required	No Data
16C	32511	UNT to Dunkard Fork	Flow Loss	SR1004	2674	659	Compensatory Mitigation Required	Warm water fishes
8H	32533	UNT to UNT 32532 of Dunkard Fork	Flow Loss	SR1005	1785	43	Released	Warm water fishes
Cumberland Mine								
49	41250	UNT to Dutch Run	Flow Loss	SR1101	132	21	Released	Trout-stocked fishery
Emerald Mine								
	41256	UNT to Dutch Run	Flow Loss	NA	.	.	In review	Trout-stocked fishery
C-1	41014	Muddy Creek	Flow Loss	SR1102	.	.	In review	Warm water fishes
Enlow Fork Mine								
F13, F14, F15, F16	32740	UNT to Templeton Fork	Flow Loss	SR0901	1253	147	Released	Trout-stocked fishery

[1]NA = Zero order tributary

Appendix H1: Relative frequency (%) of Ephemeroptera, Plecoptera and Trichoptera occurrences in pre- (N = 28) and post-mining (N =34) samples from sites experiencing mining-induced flow loss. While the bulk of the samples were identified to the genus level, consultants were at times only able to identify to the family level.

Order	Family	Genus	Pre-mining	Post-mining
Ephemeroptera	Ameletidae	*Ameletus*	71.43	55.88
Ephemeroptera	Baetidae	*Acentrella*	3.58	5.89
Ephemeroptera	Baetidae	*Baetis*	35.71	26.47
Ephemeroptera	Baetidae	*Centroptilum*	32.14	2.94
Ephemeroptera	Baetidae	*Diphetor*	7.14	17.65
Ephemeroptera	Caenidae	*Caenis*	14.28	0.00
Ephemeroptera	Ephemerellidae	*Ephemerella*	53.57	26.47
Ephemeroptera	Ephemerellidae	*Eurylophella*	57.14	20.59
Ephemeroptera	Ephemerellidae	*Serratella*	3.57	0.00
Ephemeroptera	Ephemerellidae	Ephemerellidae	10.71	2.94
Ephemeroptera	Ephemeridae	*Ephemera*	17.86	5.89
Ephemeroptera	Heptageniidae	*Epeorus*	50.00	23.53
Ephemeroptera	Heptageniidae	*Stenacron*	14.28	2.94
Ephemeroptera	Heptageniidae	*Stenonema/ Maccaffertium*	14.28	2.94
Ephemeroptera	Heptageniidae	*Nixe*	14.28	26.47
Ephemeroptera	Heptageniidae	Heptageniidae	7.14	0.00
Ephemeroptera	Leptophlebiidae	*Leptophlebia*	14.28	0.00
Ephemeroptera	Leptophlebiidae	*Paraleptophlebia*	39.29	23.53
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	25.00	23.53
Ephemeroptera	Siphlonuridae	*Siphlonurus*	10.71	11.76
Plecoptera	Capniidae	*Allocapnia*	46.4	41.2
Plecoptera	Capniidae	*Paracapnia*	14.3	8.8
Plecoptera	Capniidae	Capniidae	7.1	0.0
Plecoptera	Chloroperlidae	*Alloperla*	14.3	11.8
Plecoptera	Chloroperlidae	*Haploperla*	3.6	20.6
Plecoptera	Chloroperlidae	*Sweltsa*	50.0	61.8
Plecoptera	Chloroperlidae	Chloroperlidae	14.3	8.8
Plecoptera	Leuctridae	*Leuctra*	60.7	64.7
Plecoptera	Leuctridae	Leuctridae	10.7	11.8
Plecoptera	Nemouridae	*Amphinemura*	60.7	73.5
Plecoptera	Nemouridae	*Prostoia*	3.6	17.6
Plecoptera	Nemouridae	*Soyedina*	10.7	8.8
Plecoptera	Nemouridae	Nemouridae	7.1	8.8
Plecoptera	Peltoperlidae	*Peltoperla*	21.4	11.8
Plecoptera	Peltoperlidae	Peltoperlidae	3.6	0.0

Order	**Family**	**Genus**	**Pre-mining**	**Post-mining**
Plecoptera	Perlidae	*Acroneuria*	14.3	5.9
Plecoptera	Perlidae	*Perlesta*	7.1	8.8
Plecoptera	Perlidae	Perlidae	7.1	14.7
Plecoptera	Perlodidae	*Clioperla*	21.4	14.7
Plecoptera	Perlodidae	*Cultus*	32.1	23.5
Plecoptera	Perlodidae	*Diploperla*	7.1	14.7
Plecoptera	Perlodidae	*Isoperla*	53.6	97.1
Plecoptera	Perlodidae	*Malirekus*	10.7	2.9
Plecoptera	Perlodidae	*Yugus*	0.0	5.9
Trichoptera	Glossomatidae	*Agapetus*	17.9	2.9
Trichoptera	Hydropsychidae	*Cheumatopsyche*	0.0	5.9
Trichoptera	Hydropsychidae	*Diplectrona*	39.3	55.9
Trichoptera	Hydropsychidae	Hydropsychidae	3.6	0.0
Trichoptera	Hydroptilidae	*Hydroptilia*	3.6	0.0
Trichoptera	Lepidostomatidae	*Lepidostoma*	21.4	26.5
Trichoptera	Lepidostomatidae	Lepidostomatidae	0.0	2.9
Trichoptera	Limnephilidae	*Anabolia*	0.0	2.9
Trichoptera	Limnephilidae	*Hydatophylax*	7.1	0.0
Trichoptera	Limnephilidae	*Ironoquia*	3.6	50.0
Trichoptera	Limnephilidae	*Pycnopsyche*	60.7	47.1
Trichoptera	Limnephilidae	Limnephilidae	17.9	5.9
Trichoptera	Molannidae	*Molanna*	3.6	5.9
Trichoptera	Phryganeidae	*Ptilostomis*	3.6	0.0
Trichoptera	Philopotamidae	*Wormaldia*	7.1	2.9
Trichoptera	Polycentropodidae	*Polycentropus*	10.7	8.8
Trichoptera	Polycentropodidae	Polycentropodidae	0.0	2.9
Trichoptera	Rhyacophilidae	*Rhyacophila*	42.9	67.6
Trichoptera	Uenoidae	*Neophylax*	42.9	55.9

Appendix H2: Relative frequency (%) of Ephemeroptera, Plecoptera, and Trichoptera occurrences in pre- (N = 14) and post-restoration (N =21) samples for sites with gate cut mitigation. While the bulk of the samples were identified to the genus level, consultants were at times only able to identify to the family level.

Order	Family	Genus	Pre-mining	Post-restoration
Ephemeroptera	Ameletidae	*Ameletus*	35.0	19.0
Ephemeroptera	Baetidae	*Acentrella*	21.4	19.0
Ephemeroptera	Baetidae	*Baetis*	14.0	28.6
Ephemeroptera	Baetidae	*Centroptilum*	0.0	19.0
Ephemeroptera	Baetidae	*Diphetor*	21.0	23.8
Ephemeroptera	Caenidae	*Caenis*	100.0	95.2
Ephemeroptera	Ephemerellidae	*Ephemerella*	57.1	28.6
Ephemeroptera	Ephemerellidae	*Eurylophella*	78.6	81.0
Ephemeroptera	Ephemerellidae	*Serratella*	7.1	4.8
Ephemeroptera	Ephemerellidae	Ephemerellidae	7.1	4.8
Ephemeroptera	Ephemeridae	*Ephemera*	57.1	28.6
Ephemeroptera	Heptageniidae	*Epeorus*	36.0	19.0
Ephemeroptera	Heptageniidae	*Stenacron*	28.6	33.3
Ephemeroptera	Heptageniidae	*Stenonema/ Maccaffertium*	71.0	57.1
Ephemeroptera	Heptageniidae	*Nixe*	7.1	23.8
Ephemeroptera	Heptageniidae	Heptageniidae	7.1	0.0
Ephemeroptera	Leptophlebiidae	*Leptophlebia*	14.3	4.8
Ephemeroptera	Leptophlebiidae	*Paraleptophlebia*	14.3	14.3
Ephemeroptera	Leptophlebiidae	Leptophlebiidae	21.4	4.8
Plecoptera	Capniidae	*Allocapnia*	57.1	23.8
Plecoptera	Capniidae	*Paracapnia*	0.0	4.8
Plecoptera	Chloroperlidae	*Alloperla*	14.3	4.8
Plecoptera	Chloroperlidae	*Haploperla*	14.3	4.8
Plecoptera	Chloroperlidae	*Sweltsa*	28.6	9.5
Plecoptera	Leuctridae	*Leuctra*	21.4	28.6
Plecoptera	Nemouridae	*Amphinemura*	57.1	52.4
Plecoptera	Nemouridae	*Prostoia*	14.3	14.3
Plecoptera	Nemouridae	Nemouridae	7.1	0.0
Plecoptera	Perlidae	*Acroneuria*	21.4	23.8
Plecoptera	Perlidae	*Perlesta*	21.4	38.1
Plecoptera	Perlidae	Perlidae	7.1	0.0
Plecoptera	Perlodidae	*Clioperla*	7.1	4.8
Plecoptera	Perlodidae	*Cultus*	7.1	4.8
Plecoptera	Perlodidae	*Diploperla*	0.0	4.8
Plecoptera	Perlodidae	*Isoperla*	28.8	52.4

Order	**Family**	**Genus**	**Pre-mining**	**Post-restoration**
Trichoptera	Hydropsychidae	*Ceratopsyche*	0.0	28.6
Trichoptera	Hydropsychidae	*Cheumatopsyche*	57.1	66.7
Trichoptera	Hydropsychidae	*Diplectrona*	0.0	4.8
Trichoptera	Hydropsychidae	*Hydropsyche*	7.1	33.3
Trichoptera	Hydropsychidae	*Hydroptilia*	7.1	4.8
Trichoptera	Hydropsychidae	*Ochrotrichia*	7.1	14.3
Trichoptera	Limnephilidae	*Pycnopsyche*	28.6	14.3
Trichoptera	Philopotamidae	*Chimarra*	14.3	19.0
Trichoptera	Philopotamidae	*Wormaldia*	0.0	4.8
Trichoptera	Rhyacophilidae	*Rhyacophila*	35.7	52.4
Trichoptera	Uenoidae	*Neophylax*	7.1	0.0

Appendix I1: QA by PADEP on University's TGD-563-2000-655 Sampling Protocol

Pennsylvania Department of Environmental Protection

Division of Water Quality Standards

Benthic Macroinvertebrate Field sampling QA audit form:

~~**Name:** Keith Garmire~~

Date: April 25, 2013

Location: Blockhouse Run

Station ID: BSW23 (Lat. 39.773555 Long. -80.34321)

Type of Stream Sampled: **Freestone** **Low-gradient** **Limestone**

Is stream reach appropriate for sampling? **Yes** **No**

The sampling reach collected was a monitoring station used by CONSOL Coal Co. to determine if mining affected the use of Blockhouse Run within this mining panel. As part of the Act 54 five year studies this monitoring sampling point was being sampled to determine if the sampling protocol were being met.

Is sample reach representative of the stream segment? **Yes** **No**

The stream sampling segment (100 meters) was mapped prior to sampling. The reach had the five habitats needed to meet the requirements of the Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol).

Were field parameters (water temperature, specific conductance, pH, dissolved oxygen, alkalinity, turbidity, etc.) collected and recorded appropriately. **Yes** **No**

Were water chemistry samples collected? If yes, PA DEP BOL# = ______; SAC = ______

Not Collected **Yes** **No**

Were manual flows measurements taken? If yes, meter manufacturer/model = __________

Not Taken **Yes** **No**

Is there a variety of flow/depth regimes being sampled? **Yes** **No**

The stream segments lower portion had a small mining induced pool with the middle and upper portions of the sampling segment was a normal riffle, run, pool configuration. Samples collected: (2) CPOM, (2) Vegetation, (2) Snags, (2) Cobble / Gravel, and (2) Silt / Sands; equaling 10 total samples required by Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol).

Is the kick duration between 45 and 60 seconds? **Yes** **No**

Kick duration was between 45 and 60 seconds with substrate thoroughly disturbed.

Is an appropriate area (100 cm x 100 cm) being disturbed for each kick? **Yes** **No**

Is net being emptied after each kick in order to minimize clogging / back wash?

<u>Yes</u> **No**

~~The D-frame net was emptied after each kick cycle. No clogging or backwash was observed.~~

Are samples being composited carefully to avoid loss of material? **<u>Yes</u>** **No**

The D-frame net was being cleaned and the debris was being transferred to a sample container with a bucket and sieve.

Are sample bottles being labeled clearly and properly? **<u>Yes</u>** **No**

Sample bottles were labeled properly.

Are nets and sieves checked carefully for bugs prior to cleaning? **<u>Yes</u>** **No**

The D-frame and Sieves were examined very carefully after each kick.

Is habitat assessment conducted after careful observation and walking of sample reach?

<u>Yes</u> **No**

A habitat assessment was conducted after careful observation, mapping and walking the sampling reach.

Is investigator meeting QA requirements? **Yes** **No**

Comments/Recommendations:

Sampling procedure was performed according to the Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol), completed all necessary tasks to meet QA requirements: I recommend that Keith Garmire consider collecting water chemistry samples when collecting macroinvertebrate samples if the Act 54 contract permits. I also recommend checking D.O. calibrations against the D.O. chart available @ http://water.usgs.gov/owq/FieldManual/.

Reviewer: Joel C. Folman **Employee:** Keith Garmire

Signature: Joel C Folman **Signature:** Keith M Garmire

5/2/2013

Pennsylvania Department of Environmental Protection

Division of Water Quality Standards

Benthic Macroinvertebrate Field sampling QA audit form:

~~**Name:** Alison Hale PhD~~

Date: April 30, 2013

Location: Maple Run

Station ID: MR-4 (Lat. 39.82312 Long. -80.24027)

Type of Stream Sampled: **Freestone** <u>**Low-gradient**</u> **Limestone**

Is stream reach appropriate for sampling? <u>**Yes**</u> **No**

The sampling reach collected was a monitoring station used by Alpha / Cumberland Mine to determine if mining affected the use of Maple Run within this mining panel. As part of the Act 54 five year studies this monitoring sampling point was being sampled to determine if the sampling protocol were being met.

Is sample reach representative of the stream segment? <u>**Yes**</u> **No**

The stream sampling segment (100 meters) was mapped prior to sampling. The reach had the five habitats needed to meet the requirements of the Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol).

Were field parameters (water temperature, specific conductance, pH, dissolved oxygen, alkalinity, turbidity, etc.) collected and recorded appropriately. **Yes** <u>**No**</u>

Were water chemistry samples collected? If yes, PA DEP BOL# = ______; SAC = ______

Not Collected Yes No

Were manual flows measurements taken? If yes, meter manufacturer/model = __________

Not Taken Yes No

Is there a variety of flow/depth regimes being sampled? **Yes** No

The stream segment is located in a small 2 order stream channel, the sampling segment was a normal riffle, run, pool configuration. Samples collected: (1) CPOM, (2) Vegetation, (2) Snags, (3) Cobble / Gravel, and (2) Silt / Sands; equaling 10 total samples required by Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol).

Is the kick duration between 45 and 60 seconds? **Yes** No

Kick duration was between 45 and 60 seconds with substrate thoroughly disturbed.

Is an appropriate area (100 cm x 100 cm) being disturbed for each kick? **Yes** No

Yes, 100 cm X 100 cm area was properly disturbed.

Is net being emptied after each kick in order to minimize clogging / back wash?

Yes No

The D-frame net was emptied after each kick cycle. No clogging or backwash was observed.

Are samples being composited carefully to avoid loss of material? **Yes** No

The D-frame net was being cleaned and the debris was being transferred to a sample container with a bucket and sieve.

Are sample bottles being labeled clearly and properly? **Yes** No

Sample bottles were labeled properly.

Are nets and sieves checked carefully for bugs prior to cleaning? **Yes** No

The D-frame and Sieves were examined very carefully after each kick.

Is habitat assessment conducted after careful observation and walking of sample reach?

Yes No

A habitat assessment was conducted after careful observation, mapping and walking the sampling reach.

Is investigator meeting QA requirements? **Yes** **No**

Comments/Recommendations:

Sampling procedure was performed according to the Surface Water Protection (563-2000-655) - Underground Bituminous Coal Mining Operations (Protocol), completed all necessary tasks to meet QA requirements: I recommend that Alison Hale PhD consider collecting water chemistry samples when collecting macroinvertebrate samples if the Act 54 contract permits. I also recommend checking D.O. calibrations against the D.O. chart available @ http://water.usgs.gov/owq/FieldManual/.

Reviewer: Joel C. Folman **Employee:** Alison Hale PhD

Signature: Joel C Folman 5/2/2013 **Signature:** Alison Hale, PhD

Pennsylvania Department of Environmental Protection

Division of Water Quality Standards

Benthic Macroinvertebrate Field sampling QA audit form

Name: Tom Hann

Date: 3/29/2013

Location: UNT 40944 to Crafts Creek

Station ID: BSW13 (Lat. 40.05639 Long. -80.355253)

Type of Stream Sampled: Freestone Low-gradient Limestone

Is stream reach appropriate for sampling? Yes No

The sampling reach collected was a monitoring station used by CONSOL Coal Co. to determine if mining affected the use of this tributary 40944 to Crafts Creek. As part of the Act 54 five year studies this monitoring sampling point was being sampled to determine if the sampling protocol was being met.

Is sample reach representative of the stream segment? Yes No

The sampling stream segment (100 meter) was mapped prior to sampling. The reach had the five habitats needed to meet the requirements of the Surface Water Protection (563-2000-655)- Underground Bituminous Coal Mining Operations (protocol).

Were field parameters (water temperature, specific conductance, pH, dissolved oxygen, alkalinity, turbidity, etc.) collected and recorded appropriately. Yes No

Were water chemistry samples collected? If yes, PA DEP BOL# = ______; SAC = ______

Not Collected Yes No

Were manual flows measurements taken? If yes, meter manufacturer/model = ________

Not Taken Yes No

Is there a variety of flow/depth regimes being sampled? Other Yes No

Samples collected: (2) Cobble /Gravel, (2) Silt/Sand, (2) Vegetation, (2) Snags and (2) CPOM; equaling 10 total samples required by Surface Water Protection (563-2000-655)-Underground Bituminous Coal Mining Operations (protocol).

Is the kick duration between 45 and 60 seconds? Yes No

Kick duration was between 45 and 60 seconds with substrate thoroughly disturbed.

Is an appropriate area (100 cm x 100 cm) being disturbed for each kick? Yes No

Yes, 100 cm X 100 cm area was properly disturbed.

Is net being emptied after each kick in order to minimize clogging / back wash?

Yes **No**

The D-frame net was emptied after each kick cycle. No clogging or back wash was observed.

Are samples being composited carefully to avoid loss of material? **Yes** **No**

The D-Frame net was being cleaned and the debris was being transferred to a sample container with a bucket and sieve.

Are sample bottles being labeled clearly and properly? **Yes** **No**

Sample bottles were labeled properly.

Are nets and sieves checked carefully for bugs prior to cleaning? **Yes** **No**

The D-Frame was examined very carefully after each kick.

Is habitat assessment conducted after careful observation and walking of sample reach?

Yes **No**

A habitat assessment was conducted after careful observation, mapping and walking the sample reach.

Is investigator meeting QA requirements? Yes No

Comments/Recommendations:

Sampling procedure was performed according to the Surface Water Protection protocol (563-2000-655). Tom Hann completed all necessary tasks to meet QA requirements; I recommend that Tom Hann consider collecting water chemistry samples when collecting macroinvertebrate samples if the Act 54 contract permits.

Reviewer: Joel C. Folman **Employee:** Tom Hann

Signature: Joel C. Folman 4/1/2013 **Signature:** Tom Hann

Pennsylvania Department of Environmental Protection

Division of Water Quality Standards

Benthic Macroinvertebrate Field sampling QA audit form

Name: Grace Noble

Date: 4/5/2013

Location: Crafts Creek

Station ID: BSW20 (Lat. 40° 3.3569' Long. -80° 20.1215)

Type of Stream Sampled: **Freestone** **Low-gradient** **Limestone**

Is stream reach appropriate for sampling? **Yes** **No**

The sampling reach collected was a monitoring station used by CONSOL Coal Co. to determine if mining affected the use of Crafts Creek. As part of the Act 54 five year studies this monitoring sampling point was being sampled to determine if the sampling protocol were being met.

Is sample reach representative of the stream segment? **Yes** **No**

The sampling stream segment (100 meter) was mapped prior to sampling. The reach had the five habitats needed to meet the requirements of the Surface Water Protection (563-2000-655)-Underground Bituminous Coal Mining Operations (protocol).

Were field parameters (water temperature, specific conductance, pH, dissolved oxygen, alkalinity, turbidity, etc.) collected and recorded appropriately. Yes **No**

Were water chemistry samples collected? If yes, PA DEP BOL# = ______; SAC = ______

Not Collected **Yes** **No**

Were manual flows measurements taken? If yes, meter manufacturer/model = __________

Not Taken **Yes** **No**

Is there a variety of flow/depth regimes being sampled? **Other** **Yes** **No**

Samples collected: (2) Cobble /Gravel, (2) Silt/Sand, (2) Vegetation, (2) Snags and (2) CPOM; equaling 10 total samples required by Surface Water Protection (563-2000-655)-Underground Bituminous Coal Mining Operations (protocol).

Is the kick duration between 45 and 60 seconds? **Yes** **No**

Kick duration was between 45 and 60 seconds with substrate thoroughly disturbed.

Is an appropriate area (100 cm x 100 cm) being disturbed for each kick? **Yes** **No**

Yes, 100 cm X 100 cm area was properly disturbed.

Is net being emptied after each kick in order to minimize clogging / back wash?

Yes No

The D-frame net was emptied after each kick cycle. No clogging or back wash was observed.

Are samples being composited carefully to avoid loss of material? Yes No

The D-Frame net was being cleaned and the debris was being transferred to a sample container with a bucket and sieve.

Are sample bottles being labeled clearly and properly? Yes No

Sample bottles were labeled properly.

Are nets and sieves checked carefully for bugs prior to cleaning? Yes No

The D-Frame and Sieves were examined very carefully after each kick.

Is habitat assessment conducted after careful observation and walking of sample reach?

Yes No

A habitat assessment was conducted after careful observation, mapping and walking the sample reach.

Is Investigator meeting QA requirements? **Yes** No

Comments/Recommendations:

Sampling procedure was performed according to the Surface Water Protection protocol (563-2000-655). **Grace Noble** completed all necessary tasks to meet QA requirements; I recommend that **Grace Noble** consider collecting water chemistry samples and flow measurements when collecting macroinvertebrate samples if the Act 54 contract permits.

Grace Noble was reminded that in cobble /gravel habitats that using her toe and heal to dig and agitate the substrate is very important when collecting this habitat.

Reviewer: Joel C. Folman Employee: Grace Noble

Signature: [signature] 4/8/2013 Signature: [signature]

Appendix I2:
QA by PADEP on University’s Macroinvertebrate Identification

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Blacksville #2
Stream Name: Roberts Run, 41813, BSW22
Stream NHD#:
Sample Date: 4/25/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: X1 or 2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, K. Garmire
Comments:

Starting Lat/Long: 39.77194°/ -80.36198°
Ending Lat/Long: 39.77248°/ -80.36292°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats

	Number of jabs
Cobble / Gravel Substrate	3
Snag	2
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	0
Sand / Fine Sediment	3

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0	OK	2						
Ephemeroptera		Baetidae		Baetis		CG	6	3	~~5~~	Diphetor				2	
Ephemeroptera		Baetidae		Acentrella		SC	4	OK	2						
Ephemeroptera		Ephemerellidae		Ephemerella		CG	1	OK	5						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4	OK	3						
Plecoptera		Chloroperlidae		Sweltsa		PR	0	OK	1						
Plecoptera		Perlodidae		Diploperla		PR	2	OK	3						
Plecoptera		Perlodidae		Isoperla		PR	2	OK	49						
Plecoptera		Nemouridae		Amphinemura		SH	3	31	~~30~~						
Trichoptera		Hydropsychidae		Diplectrona		FC	0	OK	2						
Trichoptera		Lepidostomatidae		Lepidostoma		SH	1	OK	1						
Trichoptera		Limnephilidae		Pychnopsyche		SH	4	OK	3						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1	OK	1						
Trichoptera		Uenoidae		Neophylax		SC	3	OK	2						
Megaloptera		Sialidae		Sialis		PR	6	OK	2						
Coleoptera		Elmidae		Optioservus		SC	4	OK	1						
Coleoptera		Psephenidae		Ectopria		SC	5	OK	1						
Diptera		Stratiomyidae		Caloparyphus		CG	8	OK	1						
Diptera		Tabanidae		Chrysops		PI	7	OK	2						
Diptera		Tipulidae		Pilaria		PR	7	1	~~3~~	Pseudolimnophila 2					
Diptera		Tipulidae		Tipula		SH	4	OK	4						
Diptera		Chironomidae				CG	6	57	OK						
Decapoda		Cambaridae		Cambarus		CG	6	1							
				Total Number of Individuals:				58	123						

Lab sub-sample 1-4 (200 +/- 20%)
(Continue to sub-sample if numbers are <160 or >240.)

2nd bottle
Isoperla 3
Leuctra 3

2 pupae
1 exuvia
1 adult stonefly
} Do NOT Count

FORM 8.8C: QUANTITATIVE MULTI-HABITAT BIOASSESSMENT OF DIVERSE COMMUNITY

Mine Name: Enlow Fork Mine
Stream Name: UNT to Templeton Fork, 32740
Stream NHD#:
Sample Date: 5/9/2013
Pre-Mining Sampling Survey: 1 or 2 (check one)
Post-Mining Sampling Survey: 1 or X2 (check one)
Length of Sampled Reach: 100 meters
Sampler(s): A. Hale, G. Noble, K. Piper, L. Kiefer
Comments:

Starting Lat/Long: 40.05283°/ -80.389657°
Ending Lat/Long: 40.053718°/ -80.389913°

Composite of 10 jabs from 10 sampling locations that effectively represents the observed habitats	Number of jabs
Cobble / Gravel Substrate	3
Snag	1
Coarse Particulate Organic Matter	2
Submerged Aquatic Vegetation	2
Sand / Fine Sediment	2

Enter the number of individuals for each Genus identified in lab. (F = Family / G = Genus)

Class or Order: Voltine Status (M) Multi, (U) uni, (S) semi		Family: Voltine Status (M) Multi, (U) uni, (S) semi		Genus:		Functional Feeding Group	Pollution Tolerance Value	Sub. 1 - 4 F	Sub. 1 - 4 G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G	Sub. ___ F	Sub. ___ G
Ephemeroptera		Ameletidae		Ameletus		CG	0	OK	10						
Ephemeroptera		Baetidae		Baetis		CG	6	OK	18						
Ephemeroptera		Baetidae		Centroptilium		CG	2	OK	1						
Ephemeroptera		Siphlonuridae		Siphlonurus		CG	7	OK	1						
Ephemeroptera		Ephemerellidae		Eurylophella		SC	4	OK	1						
Plecoptera		Chloroperlidae		Haploperla		PR	0	OK	1						
Plecoptera		Nemouridae		Amphinemura		SH	3	OK	28						
Plecoptera		Perlodidae		Isoperla		PR	2	OK	36						
Plecoptera		Perlidae		Perlesta		PR	4	OK	3						
Plecoptera		Leuctridae		Leuctra		SH	0	OK	2						
Trichoptera		Rhyacophilidae		Rhyacophila		PR	1	OK	3						
Trichoptera		Hydropsychidae		Diplectrona		FC	0	OK	4						
Trichoptera		Hydroptilidae		Ochrotrichia		SC	4	OK	2						
Trichoptera		Glossomatidae		Agapetus		SC	0	OK	2						
Trichoptera		Uenoidae		Neophylax		SC	3	OK	1						
Coleoptera		Elmidae		Optioservus		SC	4	OK	1						
Coleoptera		Elmidae		Stenelmis		SC	5	OK	1						
Coleoptera		Psephenidae		Psephenus		SC	4	OK	1						
Diptera		Tipulidae		Tipula		SH	4	OK	1						
Diptera		Tipulidae		Hexatoma		PR	2	OK	2						
Diptera		Tipulidae		~~Pilaria~~		PR	7		3	Pseudolimnophila					
Diptera		Ephydridae		~~Scatella~~		CG	6		2	Only key to Family					
Diptera		Ceratopogonidae				PR	6	8	OK						
Diptera		Chironomidae				CG	6	53	OK						
Decapoda		Cambaridae		Cambarus		CG	6	3							
Oligochaeta						CG	10	6	OK						
				Total Number of Individuals:				70	122						

Lab sub-sample 1-4 (200 +/- 20%) (Continue to sub-sample if numbers are <160 or >240.)

Appendix J1: Data on wetland type and acreage in Bailey Mine submitted to PADEP during the 4th assessment period. All data are from the permit renewal 161. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014).

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Data from Permit Renewal					
9H Panel					
Bailey-9H_Panel-2A	0.083	PEM	0.051	PEM	-0.032
Bailey-9H_Panel-3A	0.031	PEM	0.029	PEM	-0.002
Bailey-9H_Panel-4A	0.265	PEM	0.032	PEM	-0.233
Bailey-9H_Panel-5A	0.225	PEM	0.207	PEM	-0.018
Bailey-9H_Panel-6A	0.151	PEM	0.034	PEM	-0.117
Bailey-9H_Panel-7A	0.028	PEM	0.027	PEM	-0.001
Bailey-9H_Panel-8A	0.029	PEM/PSS	0.013	PEM/PSS	-0.016
PM-Bailey-22B	0.000	.	0.006	PEM	0.006
PM-Bailey-23B	0.000	.	0.051	PEM	0.051
PM-Bailey-3D	0.000	.	0.136	PEM1B/PUBHh	0.136
10H Panel					
Bailey-1B	0.044	PEM	0.030	PEM	-0.014
Bailey-6B	0.028	PEM	0.018	PEM	-0.010
Bailey-29B	0.005	PEM	0.003	PEM	-0.002
PM-Bailey-8B	0.000	.	0.030	PEM	0.030
PM-Bailey-18B	0.000	.	0.017	PEM	0.017
PM-Bailey-19B	0.000	.	0.007	PEM	0.007
PM-Bailey-20B	0.000	.	0.008	PEM	0.008
PM-Bailey-21B	0.000	.	0.003	PEM	0.003
PM-Bailey-2D	0.000	.	0.030	PEM1B/PUBHh	0.030
11H Panel					
Bailey-2B	0.012	PEM	0.007	PEM	-0.005
Bailey-3B	0.025	PEM	0.028	PEM	0.003
Bailey-4B	0.100	PEM	0.021	PEM	-0.079
Bailey-7B	0.018	PEM	0.003	PEM	-0.015
Bailey-8B	0.031	PEM	0.055	PEM	0.024
Bailey-9B	0.037	PEM	0.024	PEM	-0.013
Bailey-10B	0.010	PEM	0.000	.	-0.010
Bailey-26B	0.012	PEM	0.007	PEM	-0.005
Bailey-27B	0.068	PEM	0.000	.	-0.068
Bailey-28B	0.014	PEM	0.017	PEM	0.003
PM-Bailey-6D	0.000	.	0.017	PEM	0.017
PM-Bailey-7D	0.000	.	0.011	PEM	0.011

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
PM-Bailey-11D	0.000	.	0.008	PEM	0.008
PM-Bailey-12D	0.000	.	0.011	PEM	0.011
PM-Bailey-2E	0.000	.	0.019	PEM	0.019
12H Panel					
Bailey-32A	0.060	PEM	0.089	PEM	0.029
Bailey-33A	0.060	PEM	0.110	PEM	0.050
Bailey-34A	0.020	PEM	0.029	PEM	0.009
Bailey-35A	0.070	PEM	0.086	PEM	0.016
Bailey-36A	0.050	PEM	0.043	PEM	-0.007
Bailey-37A	0.020	PEM	0.011	PEM	-0.009
Bailey-38A	0.010	PEM	0.012	PEM	0.002
Bailey-39A	0.050	PEM	0.081	PEM	0.031
Bailey-40A	0.010	PEM	0.014	PEM	0.004
Bailey-11B	0.013	PEM	0.000	.	-0.013
PM-Bailey-8D	0.000	.	0.047	PEM	0.047
PM-Bailey-9D	0.000	.	0.018	PEM	0.018
PM-Bailey-10D	0.000	.	0.031	PEM	0.031
PM-Bailey-1E	0.000	.	0.066	PEM	0.066
13H Panel					
Bailey-1E	0.014	PEM	0.007	PEM	-0.007
Bailey-2E	0.542	PEM	0.631	PEM	0.089
Bailey-3E	0.032	PEM	0.013	PEM	-0.019
Bailey-4E	0.057	PEM	0.089	PEM	0.032
Bailey-5E	0.124	PEM	0.124	PEM	0.000
Bailey-6E	0.064	PSS	0.056	PSS	-0.008
Bailey-7E	0.081	PEM	0.068	PEM	-0.013
PM-Bailey-5E	0.000	.	0.011	PEM	0.011
14H Panel					
Bailey-41D	0.007	PEM	0.003	PEM	-0.004
Bailey-42D	0.068	PEM	0.002	PEM	-0.066
Bailey-23E	0.006	PEM	0.032	PEM	0.026
Bailey-24E	0.071	PEM	0.010	PEM	-0.061
Bailey-25E	0.065	PEM	0.573	PEM	0.508
Bailey-26E	0.643	PEM	0.188	PEM	-0.455
Bailey-27E	0.057	PEM	0.057	PEM	0.000
Bailey-28E	0.078	PEM	0.090	PEM	0.012
Bailey-29E	0.126	PEM	0.000	.	-0.126
Bailey-30E	0.031	PEM	0.000	.	-0.031
Bailey-31E	0.065	PEM	0.053	PEM	-0.012
Bailey-39E	0.003	PEM	0.025	PEM	0.022

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
8I Panel					
Bailey-4A	0.042	PEM/PSS	0.062	PEM/PSS	0.020
Bailey-6A	0.015	PEM/PFO	0.005	PEM/PFO	-0.010
Bailey-9A	0.049	PEM	0.000	.	-0.049
Bailey-13A	0.198	PEM	0.185	PEM	-0.013
Bailey-14A	0.027	PEM	0.024	PEM	-0.003
Bailey-19B	0.007	PEM/PFO	0.004	PEM/PFO	-0.003
Bailey-22B	0.051	PEM	0.052	PEM	0.001
Bailey-23B	0.114	PEM	0.171	PEM	0.057
Bailey-25B	0.300	PEM	0.000	.	-0.300
Bailey-1D	0.015	PFO/PSS	0.017	PFO/PSS	0.002
PM-Bailey-9B	0.000	.	0.109	PEM	0.109
PM-Bailey-11B	0.000	.	0.104	PEM	0.104
PM-Bailey-12B	0.000	.	0.005	PEM	0.005
PM-Bailey-13B	0.000	.	0.013	PEM	0.013
PM-Bailey-17B	0.000	.	0.018	PEM	0.018
9I Panel					
Bailey-3A	0.016	PEM	0.004	PEM	-0.012
Bailey-7A	0.005	PEM/PSS	0.002	PEM/PSS	-0.003
Bailey-10A	0.012	PEM	0.003	PEM	-0.009
Bailey-16B	0.049	PEM	0.045	PEM	-0.004
Bailey-18B	0.199	PEM/PFO	0.087	PEM/PFO	-0.112
Bailey-24B	0.018	PEM	0.015	PEM	-0.003
Bailey-2D	0.108	PEM	0.045	PEM	-0.063
PM-Bailey-4B	0.000	.	0.020	PEM	0.020
PM-Bailey-5B	0.000	.	0.029	PEM	0.029
PM-Bailey-6B	0.000	.	0.028	PEM	0.028
PM-Bailey-7B	0.000	.	0.025	PEM	0.025
PM-Bailey-15B	0.000	.	0.127	PEM	0.127
PM-Bailey-16B	0.000	.	0.025	PEM	0.025
10I Panel					
Bailey-1A	0.020	PEM	0.000	.	-0.020
Bailey-2A	0.101	PEM/PFO	0.000	.	-0.101
Bailey-11A	0.130	PEM	0.078	PEM	-0.052
Bailey-12A	0.021	PEM	0.039	PEM	0.018
Bailey-15A	0.122	PEM	0.074	PEM	-0.048
Bailey-16A	0.009	PEM	0.010	PEM	0.001
Bailey-26A	0.014	PEM	0.007	PEM	-0.007
Bailey-12B	0.368	PEM	0.321	PEM	-0.047
Bailey-13B	0.020	PEM	0.013	PEM	-0.007

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Bailey-14B	0.048	PEM	0.088	PEM	0.040
Bailey-15B	0.130	PEM	0.019	PEM	-0.111
Bailey-17B	0.071	PEM	0.026	PEM	-0.045
PM-Bailey-4D	0.000	.	0.005	PEM	0.005
PM-Bailey-5D	0.000	.	0.006	PEM	0.006
PM-Bailey-13D	0.000	.	0.007	PEM	0.007
PM-Bailey-14D	0.000	.	0.003	PEM	0.003
PM-Bailey-15D	0.000	.	0.037	PEM	0.037
PM-Bailey-16D	0.000	.	0.016	PEM	0.016
PM-Bailey-17D	0.000	.	0.082	PEM	0.082
PM-Bailey-18D	0.000	.	0.015	PEM	0.015
PM-Bailey-19D	0.000	.	0.004	PEM	0.004
PM-Bailey-20D	0.000	.	0.017	PEM	0.017
PM-Bailey-21D	0.000	.	0.013	PEM	0.013
PM-Bailey-22D	0.000	.	0.081	PEM	0.081
PM-Bailey-23D	0.000	.	0.085	PEM	0.085
11I Panel					
Bailey-17A	0.030	PEM	0.000	.	-0.030
Bailey-18A	0.020	PEM	0.027	PEM	0.007
Bailey-19A	0.020	PEM	0.022	PEM	0.002
Bailey-20A	0.050	PEM/PSS	0.051	PEM/PSS	0.001
Bailey-21A	0.030	PEM	0.064	PEM	0.034
Bailey-22A	0.160	PEM	0.068	PEM	-0.092
Bailey-23A	0.050	PEM	0.206	PEM	0.156
Bailey-24A	0.040	PEM	0.141	PEM	0.101
Bailey-25A	0.010	PEM	0.013	PEM	0.003
Bailey-27A	0.020	PEM	0.009	PEM	-0.011
Bailey-28A	0.060	PEM	0.031	PEM	-0.029
Bailey-29A	0.030	PEM	0.077	PEM	0.047
Bailey-30A	0.010	PEM	0.005	PEM	-0.005
Bailey-31A	0.050	PEM	0.027	PEM	-0.023
PM-Bailey-3E	0.000	.	0.141	PEM	0.141
PM-Bailey-4E	0.000	.	0.065	PEM	0.065
PM-Bailey-7E	0.000	.	0.079	PEM	0.079
12I Panel					
Bailey-3D	0.010	PEM	0.130	PEM	0.120
Bailey-4D	0.030	PEM	0.096	PEM	0.066
Bailey-5D	0.030	PEM	0.025	PEM	-0.005
Bailey-6D	0.020	PEM	0.040	PEM	0.020
Bailey-7D	0.020	PEM	0.003	PEM	-0.017

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Bailey-8D	0.010	PEM	0.006	PEM	-0.004
Bailey-14D	0.530	PEM	0.682	PEM	0.152
Bailey-15D	0.180	PEM	0.057	PEM	-0.123
PM-Bailey-6E	0.000	.	0.009	PEM	0.009

Appendix J2: Data on wetland type and acreage in Blacksville 2 Mine submitted to PADEP during the 4th assessment period. All data are from permit revision 67. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014). Post-mining surveys have not yet been conducted.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
BLM-W-1A	0.04	PEM	.	.	.
BLM-W-2A	0.12	PEM	.	.	.
BLM-W-3A	0.16	PEM/PSS	.	.	.
BLM-W-4A	1.36	PEM/PSS	.	.	.
BLM-W-5A	0.04	PEM/PSS	.	.	.
BLM-W-6A	0.06	PEM	.	.	.
BLM-W-7A	0.69	PEM/PSS	.	.	.
BLM-W-8A	0.39	PSS/PEM	.	.	.
BLM-W-9A	0.95	PEM/PSS	.	.	.
BLM-W-10A	0.24	PEM	.	.	.
BLM-W-11A	0.36	PEM	.	.	.
BLM-W-12A	0.28	PEM	.	.	.
BLM-W-13A	0.03	PEM	.	.	.
BLM-W-14A	2.37	PEM	.	.	.
BLM-W-15A	0.67	PEM/PFO	.	.	.
BLM-W-16A	0.05	PEM	.	.	.
BLM-W-17A	0.01	PEM	.	.	.
BLM-W-18A	0.03	PEM/PFO	.	.	.
BLM-W-19A	0.05	PEM	.	.	.
BLM-W-20A	0.41	PEM	.	.	.
BLM-W-21A	0.07	PEM	.	.	.
BLM-W-22A	2.24	PEM	.	.	.
BLM-W-23A	0.01	PEM/PFO	.	.	.
BLM-W-24A	0.17	PEM/PSS	.	.	.
BLM-W-25A	0.05	PEM/PSS	.	.	.
BLM-W-26A	0.06	PEM	.	.	.
BLM-W-27A	0.17	PEM	.	.	.
BLM-W-28A	0.06	PEM/PSS	.	.	.
BLM-W-29A	0.01	PEM/PSS	.	.	.
BLM-W-30A	0.06	PEM	.	.	.
BLM-W-31A	0.05	PEM	.	.	.
BLM-W-32A	0.05	PEM	.	.	.
BLM-W-33A	0.87	PEM	.	.	.
BLM-W-34A	0.09	PEM	.	.	.
BLM-W-35A	0.23	PEM/PFO	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
BLM-W-36A	0.05	PEM/PFO	.	.	.
BLM-W-37A	0.03	PEM	.	.	.
BLM-W-38A	0.04	PEM	.	.	.
BLM-W-39A	0.05	PEM	.	.	.
BLM-W-40A	0.10	PEM/PFO	.	.	.
BLM-W-41A	0.07	PEM	.	.	.
BLM-W-42A	0.05	PEM	.	.	.
BLM-W-43A	0.51	PEM	.	.	.
BLM-W-44A	0.07	PEM	.	.	.
BLM-W-45A	0.07	PEM	.	.	.
BLM-W-46A	0.08	PEM	.	.	.
BLM-W-47A	0.03	PEM/PFO	.	.	.
BLM-W-48A	0.04	PEM	.	.	.
BLM-W-49A	0.15	PEM	.	.	.
BLM-W-50A	0.42	PEM	.	.	.
BLM-W-51A	0.09	PEM/PSS	.	.	.
BLM-W-52A	0.10	PEM/PSS	.	.	.
BLM-W-53A	0.02	PEM/PSS	.	.	.
BLM-W-54A	0.06	PEM	.	.	.
BLM-W-55A	0.02	PEM	.	.	.
BLM-W-56A	0.88	PEM	.	.	.
BLM-W-57A	0.06	PEM	.	.	.
BLM-W-58A	0.18	PEM	.	.	.
BLM-W-59A	0.79	PEM	.	.	.
BLM-W-60A	0.02	PEM	.	.	.
BLM-W-61A	0.50	PEM	.	.	.
BLM-W-62A	0.05	PEM/PFO	.	.	.
BLM-W-63A	0.01	PEM/PFO	.	.	.
BLM-W-64A	0.70	PEM	.	.	.
BLM-W-65A	0.02	PEM	.	.	.
BLM-W-66A	0.04	PEM/PFO	.	.	.
BLM-W-67A	0.24	PEM	.	.	.
BLM-W-68A	0.59	PEM	.	.	.
BLM-W-69A	2.11	PEM	.	.	.
BLM-W-70A	0.07	PEM/PSS	.	.	.
BLM-W-71A	0.67	PEM	.	.	.
BLM-W-72A	0.03	PEM	.	.	.
BLM-W-73A	0.09	PEM	.	.	.
BLM-W-74A	0.04	PEM	.	.	.
BLM-W-75A	0.71	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
BLM-W-76A	0.14	PEM	.	.	.
BLM-W-77A	0.08	PEM	.	.	.
BLM-W-78A	0.02	PEM	.	.	.
BLM-W-79A	0.71	PEM	.	.	.
BLM-W-80A	0.36	PEM	.	.	.
BLM-W-81A	0.07	PEM/PSS	.	.	.
BLM-W-82A	0.20	PEM	.	.	.
BLM-W-83A	0.11	PEM/PFO	.	.	.
BLM-W-84A	0.07	PEM	.	.	.
BLM-W-85A	0.18	PEM/PSS	.	.	.
BLM-W-86A	0.05	PEM/PSS	.	.	.
BLM-W-87A	0.18	PEM	.	.	.
BLM-W-88A	0.92	PEM	.	.	.
BLM-W-89A	0.24	PEM	.	.	.
BLM-W-90A	0.01	PEM	.	.	.
BLM-W-91A	0.65	PEM	.	.	.
BLM-W-92A	0.04	PEM	.	.	.
BLM-W-93A	0.05	PEM	.	.	.
BLM-W-94A	0.01	PEM	.	.	.
BLM-W-95A	0.09	PEM	.	.	.
BLM-W-96A	0.17	PEM/PSS	.	.	.
BLM-W-97A	0.08	PEM	.	.	.
BLM-W-98A	0.22	PEM	.	.	.
BLM-W-99A	0.03	PEM	.	.	.
BLM-W-100A	0.11	PEM/PSS	.	.	.
BLM-W-101A	0.06	PEM	.	.	.
BLM-W-102A	0.37	PEM	.	.	.
BLM-W-103A	1.7	PEM	.	.	.
BLM-W-104A	0.02	PEM	.	.	.
BLM-W-105A	0.61	PEM	.	.	.
BLM-W-106A	0.67	PEM	.	.	.
BLM-W-107A	0.73	PEM	.	.	.
BLM-W-108A	0.78	PEM	.	.	.
BLM-W-109A	0.84	PEM	.	.	.
BLM-W-110A	0.9	PEM	.	.	.
BLM-W-111A	0.95	PEM	.	.	.
BLM-W-112A	1.01	PEM/PSS	.	.	.
BLM-W-113A	1.07	PEM/PSS	.	.	.
BLM-W-114A	1.13	PEM	.	.	.
BLM-W-115A	1.18	PEM/PSS	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
BLM-W-1B	0.1	PEM	.	.	.
BLM-W-2B	0.14	PEM/PSS	.	.	.
BLM-W-3B	0.01	PEM	.	.	.
BLM-W-4B	0.08	PEM	.	.	.
BLM-W-5B	0.51	PEM/PSS	.	.	.
BLM-W-6B	0.14	PEM/PSS	.	.	.
BLM-W-7B	0.15	PEM	.	.	.
BLM-W-8B	0.44	PEM	.	.	.
BLM-W-9B	0.07	PEM	.	.	.
BLM-W-10B	0.09	PEM	.	.	.
BLM-W-11B	0.18	PEM/PSS	.	.	.
BLM-W-12B	0.09	PEM/PSS	.	.	.
BLM-W-13B	0.06	PEM	.	.	.

Appendix J3: Data on wetland type and acreage in Cumberland Mine submitted to PADEP and the University during the 4th assessment period. Data are from permit renewal 115 and Alpha Natural Resources, Inc. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014).

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Data from Permit Renewal					
DR 37	0.09	PEM	0.00	.	-0.09
LW48-1	0.00	.	0.02	PEM	0.02
LW48-2	0.00	.	0.49	PEM	0.49
LW48-3	0.00	.	0.34	PEM	0.34
LW48-4	0.00	.	3.14	PEM	3.14
NDF-1	0.00	.	0.11	PEM	0.11
NDF-2	0.00	.	0.28	PEM	0.28
DF 16	0.47	PEM	0.47	PEM	0.00
DF 19	0.15	PEM	0.15	PEM	0.00
DF 20	0.16	PEM	0.11	PEM	-0.05
DF 21	0.08	PEM	0.08	PEM	0.00
DF 29	3.52	PEM	2.07	PEM	-1.46
DR 2	0.66	PEM	0.52	PEM	-0.14
DR 28	1.20	PEM	0.06	PEM	-1.13
DR 29	0.65	PEM	0.03	PEM	-0.62
DR 31	0.92	PEM	0.22	PEM	-0.69
DR 34	0.13	PEM	0.13	PEM	0.00
DR 36	0.11	PEM	0.11	PEM	0.00
DR 38	0.17	PEM	0.16	PEM	0.00
MP 2	0.08	PEM	0.08	PEM	0.00
MP 3	0.15	PEM	0.33	PEM	0.18
MP 4	0.31	PEM	0.31	PEM	0.00
WC 5	4.99	PEM	4.58	PEM	-0.41
DF 11	0.17	PEM	0.61	PEM	0.44
DF 12	0.16	PEM	0.16	PEM	0.00
DF 13	5.23	PEM	4.25	PEM	-0.99
DR 1	6.32	PEM/PSS	8.74	PEM	2.42
DF 4	1.24	PEM	1.24	PEM	0.00
DF 5	0.36	PEM	0.36	PEM	0.00
DF 6	0.59	PEM	0.59	PEM	0.00
DF 7	2.08	PEM	0.28	PEM	-1.8
DF 8	0.19	PEM	0.19	PEM	0.00
DR 33	0.07	PEM	0.12	PEM/PFO	0.04
WC 2	0.78	PEM/PSS	0.78	PEM/PFO	0.00

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
DR 27	13.66	PEM	11.92	PEM/PSS	-1.74
DR 30	8.06	PEM	7.42	PEM/PSS	-0.64
DR 35	0.10	PEM	0.08	PEM/PSS	-0.02
DR 39	0.13	PEM	0.27	PEM/PSS	0.14
MP 1	0.16	PEM	0.18	PEM/PSS	0.02
DF 10	2.58	PEM	0.65	PEM/PSS	-1.93
DF 14	0.34	PEM	0.34	PEM/PSS	0.00
DF 2	0.97	PEM/PFO	1.09	PEM/PSS	0.12
DF 15	0.36	PEM/PSS	0.90	PEM/PSS	0.54
WC 3	0.59	PEM/PSS	0.35	PEM/PSS	-0.24
DF 9	1.54	PEM	0.65	PEM/PSS	-0.89
DF 17	0.25	PEM	0.25	PEM/PSS/PFO	0.00
DF 18	0.66	PEM	0.66	PEM/PSS/PFO	0.00
DR 32	0.52	PEM	0.11	PEM/PSS/PFO	-0.41
WC 4	2.28	PEM	2.40	PEM/PSS/PFO	0.12
Data from Alpha Natural Resources, Inc. ArcGIS files					
WC_04Y	0.00	.	0.29	.	0.29
WC_11102	0.00	.	0.60	.	0.60
WC_11104	0.00	.	0.48	.	0.48
DF_01X	0.00	.	0.10	.	0.10
DF_02X	0.00	.	0.06	.	0.06
WC_019Y	0.00	.	0.05	.	0.05
WC_01X	0.00	.	0.51	.	0.51
WC_01Y	0.00	.	0.28	.	0.28
WC_020Y	0.00	.	0.12	.	0.12
WC_02Y	0.00	.	0.15	.	0.15
WC_03Y	0.00	.	0.19	.	0.19
WC_04X	0.00	.	0.09	.	0.09
WC_05X	0.00	.	0.18	.	0.18
WC_05Y	0.00	.	0.07	.	0.07
WC_06X	0.00	.	0.02	.	0.02
WC_06Y	0.00	.	0.02	.	0.02
WC_07X	0.00	.	0.01	.	0.01
WC_07Y	0.00	.	0.01	.	0.01
WC_08X	0.00	.	1.42	.	1.42
WC_08Y	0.00	.	0.00	.	0.00
WC_10Y	0.00	.	0.03	.	0.03
WC_11101	0.00	.	0.09	.	0.09
WC_11Y	0.00	.	0.05	.	0.05
WC_12Y	0.00	.	0.02	.	0.02

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
WC_13Y	0.00	.	0.08	.	0.08
WC_14Y	0.00	.	0.11	.	0.11
DF_1	0.28	.	0.28	.	0.00
WC_015Y	0.00	.	0.13	.	0.13
WC_016Y	0.00	.	0.05	.	0.05
WC_017Y	0.00	.	0.65	.	0.65
WC_018Y	0.00	.	0.15	.	0.15
WC_09Y	0.00	.	0.01	.	0.01
WC_10	0.00	.	0.10	.	0.10
WC_11	0.00	.	0.01	.	0.01
WC_12	0.00	.	0.07	.	0.07
WC_6	0.53	.	0.68	.	0.15
WC_7	0.47	.	0.47	.	0.00
WC_8	0.64	.	0.69	.	0.05
WC_9	0.06	.	0.13	.	0.07
SR_1	0.03	.	.	.	.
MR_01Y	0.00	.	0.02	.	0.02
MR_02Y	0.00	.	0.04	.	0.04
MR_03Y	0.00	.	0.08	.	0.08
MR_22312	0.54	.	.	.	.
PC_010Y	0.00	.	0.04	.	0.04
PC_011Y	0.00	.	0.01	.	0.01
PC_01X	0.00	.	0.01	.	0.01
PC_01Y	0.00	.	0.04	.	0.04
PC_02X	0.00	.	0.58	.	0.58
PC_02Y	0.00	.	0.03	.	0.03
PC_03X	0.00	.	0.02	.	0.02
PC_03Y	0.00	.	0.02	.	0.02
PC_04X	0.00	.	0.22	.	0.22
PC_04Y	0.00	.	0.01	.	0.01
PC_05X	0.00	.	0.03	.	0.03
PC_05Y	0.00	.	0.00	.	0.00
PC_06X	0.00	.	0.07	.	0.07
PC_06Y	0.00	.	0.05	.	0.05
PC_07Y	0.00	.	0.00	.	0.00
PC_08Y	0.00	.	0.00	.	0.00
PC_09Y	0.00	.	0.00	.	0.00
TH_01X	0.00	.	0.09	.	0.09
MR_2	0.04	.	0.04	.	0.00
MR_3	0.07	.	0.07	.	0.00

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
MR_4	0.12	.	0.12	.	0.00
MR_5	0.06	.	0.09	.	0.03
MR_6	0.02	.	0.02	.	0.00
MR_1	0.44	.	0.44	.	0.00
MR_7	0.04	.	0.04	.	0.00
PC_1	0.08	.	0.11	.	0.03
PC_2	0.11	.	.	.	.
PC_3	0.47	.	.	.	.
TH_1	0.10	.	0.70	.	0.60
TH_2	0.02	.	0.02	.	0.00
TH_3	0.30	.	.	.	.
Wetland_	0.00	.	0.01	.	0.01

Appendix J4: Data on wetland type and acreage in Emerald Mine submitted to PADEP and the University during the 4th assessment period. Data are from permit renewal 115 and Alpha Natural Resources, Inc. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014).

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Data from Permit Renewal					
CL-1	0.55	PEM	0.20	PEM	-0.34
CL-10	0.14	PEM	0.09	PEM	-0.04
CL-11	0.15	PEM	0.15	PEM/PFO	0.00
CL-12	0.05	PEM	0.00	PEM	-0.05
CL-13	0.19	PEM	0.00	.	-0.19
CL-14	0.13	PEM	0.04	PEM	-0.08
CL-14A	0.00	.	0.02	PEM	0.02
CL-14B	0.00	.	0.57	PEM	0.57
CL-1A	0.00	.	0.23	PEM	0.23
CL-1B	0.00	.	0.44	PEM	0.44
CL-1C	0.00	.	0.05	PEM	0.05
CL-2	0.10	PEM	0.00	.	-0.10
CL-3	0.08	PEM/PSS	0.19	PEM	0.11
CL-4	0.10	PEM	0.10	PEM	0.00
CL-5	0.30	PEM	0.16	PEM	-0.14
CL-6	0.01	PEM	0.05	PEM	0.04
CL-7	0.05	PEM	*	.	*
CL-8	0.09	PEM	0.18	PEM	0.09
CL-9	0.20	PEM	0.06	PEM/PSS	-0.14
CL-9A	0.00	.	0.22	PEM	0.22
DR-17	0.13	PEM/PSS	0.06	PEM	-0.08
DR-18	0.38	PEM	0.14	PEM	-0.24
DR-19	0.29	PEM	0.00	.	-0.29
DR-22	0.13	PEM	0.07	PEM	-0.06
DR-23	0.11	PEM	0.00	.	-0.11
DR-24	0.06	PEM	0.01	PEM	-0.05
DR-25	0.15	PEM	0.06	PEM	-0.09
FR-10	0.16	PEM	0.10	PEM	-0.06
FR-10A	0.00	.	0.55	PEM	0.55
FR-11	0.05	PEM	0.04	PEM	-0.01
FR-2	0.84	PEM	0.60	PEM	-0.24
FR-3	0.27	PEM	0.10	PEM	-0.17
FR-4	0.31	PEM	0.53	PEM	0.23
FR-4A	0.00	.	0.09	PEM	0.09

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
FR-5	0.63	PEM	2.51	PEM	1.88
FR-5A	0.00		0.35	PEM	0.35
FR-6	0.25	PEM	0.25	PEM	-0.01
FR-6A	0.00	.	0.14	PEM	0.14
FR-7	0.04	PEM	0.00	.	-0.04
FR-8	0.32	PEM	0.18	PEM	-0.14
FR-9	0.17	PEM	0.08	PEM	-0.09
MC-1	0.43	PEM	0.37	PEM/PSS	-0.06
Data from Alpha Natural Resources, Inc. ArcGIS files					
CBCL_1	.	.	0.07	.	0.07
CBCL_2	0.27	.	0.15	.	-0.12
CBMC_1	0.35	.	0.12	.	-0.23
CBMC_2	0.06	.	0.01	.	-0.05
CBMC_3	0.02	.	0.03	.	0.01
CBMC_4	0.32	.	0.40	.	0.08
CBMC_5	0.09	.	0.10	.	0.01
CBMC_6	0.10	.	0.10	.	0.00
CBMC_7	0.01	.	0.00	.	-0.01
CBMC_8	0.01	.	0.00	.	-0.01
CBMC_9	0.08	.	0.05	.	-0.03
DR_10	0.17	.	0.06	.	-0.11
DR_11	0.12	.	0.08	.	-0.04
DR_12	0.18	.	0.08	.	-0.10
DR_13	0.16	.	0.22	.	0.06
DR_14	1.74	.	.	.	.
DR_5	0.13	.	0.00	.	-0.13
DR_6	0.23	.	0.05	.	-0.18
MC_2	0.04	.	0.05	.	0.01
MC_3	0.05	.	0.04	.	-0.01
MC_4	0.21	.	0.02	.	-0.19
MP_10	0.04	.	0.03	.	-0.01
MP_11	0.04	.	0.05	.	0.01
MP_12	0.10	.	0.11	.	0.01
MP_13	0.08	.	0.03	.	-0.05
MP_14	0.32	.	0.15	.	-0.17
MP_15	2.88	.	.	.	.
MP_6	0.02	.	0.00	.	-0.02
MP_9	0.21	.	0.15	.	-0.06
DR_01Y	0.00	.	0.27	.	0.27
DR_02X	0.00	.	0.03	.	0.03

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
DR_04X	0.00	.	0.51	.	0.51
DR_05X	0.00	.	0.02	.	0.02
DR_06X	0.00	.	0.05	.	0.05
DR_07X	0.00	.	0.55	.	0.55
DR_12A	0.00	.	0.17	.	0.17
DR_3	0.08	.	.	.	.
DR_4	0.07	.	.	.	.
DR_6A	0.00	.	0.01	.	0.01
MP_01Y	.	.	.	.	.
MP_02Y	0.00	.	0.10	.	0.10
MP_03Y	0.00	.	0.01	.	0.01
MP_04Y	.	.	.	.	.
MP_05Y	0.00	.	0.01	.	0.01
MP_06Y	0.00	.	0.07	.	0.07
MP_07Y	0.00	.	0.11	.	0.11
MP_08Y	0.00	.	0.60	.	0.60
MP_09Y	0.00	.	0.09	.	0.09
MP_10Y	0.00	.	0.21	.	0.21
MP_11A	0.00	.	0.06	.	0.06
MP_11B	0.00	.	0.02	.	0.02
MP_11Y	0.00	.	0.00	.	0.00
MP_12Y	0.00	.	0.03	.	0.03
MP_13Y	0.00	.	0.13	.	0.13
MP_14Y	0.00	.	1.08	.	1.08
MP_15A	0.00	.	0.28	.	0.28
MP_15A1	.	.	.	.	.
MP_15B	0.00	.	0.11	.	0.11
MP_5	0.20	.	0.20	.	0.00
MP_7	0.57	.	0.57	.	0.00
MP_8	0.63	.	0.63	.	0.00
CBCL_02X	0.00	.	0.01	.	0.01
CBCL_3	0.07	.	.	.	.
CBCL_4	0.32	.	.	.	.
CBCL_5	0.27	.	.	.	.
CBCL_6	0.03	.	.	.	.
CBCL_7	0.07	.	.	.	.
CBCL_8	0.46	.	.	.	.
CBCL_9	0.03	.	.	.	.
CBMC_10	0.01	.	.	.	.
CBMC_11	0.05	.	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
CBMC_12	0.08	.	.	.	.
CBMC_15	0.38	.	.	.	.
CBMC_5A	0.02	.	0.00	.	-0.02
CBRM_1	0.19	.	0.03	.	-0.16
CBRM_1A	0.00	.	0.11	.	0.11
CBRM_1A1	0.00	.	0.04	.	0.04
CBRM_2	0.03	.	0.02	.	-0.01
CBRM_3	0.05	.	0.07	.	0.02
CBRM_4	0.08	.	.	.	.
CBRM_5	0.18	.	.	.	.
CBRM_6	0.21	.	.	.	.
CBRM_7	0.09	.	.	.	.
CBRM_8	0.17	.	.	.	.
HH_1	0.00	.	0.86	.	0.86
MC_001Y1	0.00	.	0.06	.	0.06
MC_002Y	0.00	.	0.03	.	0.03
MC_009Y	0.00	.	0.10	.	0.10
MC_009Y1	0.00	.	0.02	.	0.02
MC_010Y	0.00	.	0.30	.	0.30
MC_010Y1	0.00	.	0.05	.	0.05
MC_010Y2	0.00	.	0.02	.	0.02
MC_011Y	0.00	.	0.01	.	0.01
MC_012Y	0.00	.	0.03	.	0.03
MC_013Y	0.00	.	0.04	.	0.04
MC_014Y	0.00	.	0.02	.	0.02
MC_015Y	0.00	.	0.13	.	0.13
MC_016Y	0.00	.	0.18	.	0.18
MC_01Y	0.00	.	0.08	.	0.08
MC_02Y	0.00	.	0.06	.	0.06
MC_03Y	0.00	.	0.01	.	0.01
MC_05Y	0.00	.	0.06	.	0.06
MC_06Y	0.00	.	0.01	.	0.01
RM_006X	0.00	.	0.01	.	0.01
RM_01X	0.00	.	0.03	.	0.03
RM_02X	0.00	.	0.09	.	0.09
RM_03X	0.00	.	0.01	.	0.01
RM_03X1	0.00	.	0.02	.	0.02
RM_04X	0.00	.	0.01	.	0.01
RM_05X	0.00	.	0.00	.	0.00
RM_07X	0.00	.	0.31	.	0.31

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
RM_07X1	0.00	.	0.05	.	0.05
GR_1	0.18	.	.	.	.
SFTC_1	0.21	.	.	.	.
SC_01Y	0.00	.	0.04	.	0.04
SC_17	0.07	.	.	.	.
SC_18	0.13	.	.	.	.
SC_19	0.11	.	.	.	.
SC_20	0.01	.	.	.	.
SC_21	0.01	.	.	.	.
SC_22	0.18	.	.	.	.
SC_23	0.00	.	.	.	.

* = Wetland merged with CL-8 in 2009

Appendix J5: Data on wetland type and acreage in Enlow Fork Mine submitted to PADEP during the 4th assessment period. All data are from permit renewal 105. Wetland types follow the classification system of Cowardin et al. 1979 and are described using the classification codes of the U.S. Fish and Wildlife Service (2014).

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
E11 Panel					
Enlow Fork Mine-Gate E10/E11-26C	ND	PEM	0	.	ND
Enlow Fork-E11 Panel-18A[1]	0.390	PEM	0.260	PEM	-0.130
Enlow Fork-E11 Panel-1A[1]	1.431	PEM	1.750	PEM	0.319
Enlow Fork-E11 Panel-3A[1]	0.009	PEM	0.010	PEM	0.001
Enlow Fork-E11/E12 Gate-19A[1]	0.016	PEM	0.010	PEM	-0.006
New Enlow Fork-5A	.	.	0.010	PEM/PSS	0.010
Enlow Fork MineE10/E11 Gate-17A[1]	0.060	PEM/PSS	0.030	PEM/PSS	-0.030
Enlow Fork Mine-Panel E11-13C[2]	0.017	PEM	0.028	PEM	0.011
Enlow Fork Mine-Panel E11-14C[2]	0.003	PEM	0.018	PEM	0.015
Enlow Fork Mine-Main-58C [5]	Unknown	.	0.828	PEM	.
PM-Enlow-7A	0.000	.	0.020	PSS	0.020
PM-Enlow-8A	0.000	.	1.760	PEM	1.760
PM-Enlow Fork Mine-1C	0.000	.	0.012	PEM	0.012
PM-Enlow Fork Mine-2C	0.000	.	0.168	PEM	0.168
PM-Enlow Fork Mine-5C	0.000	.	0.007	PEM	0.007
PM-Enlow Fork Mine-9C	0.000	.	0.014	PEM	0.014
PM-Enlow Fork Mine-10C	0.000	.	0.008	PEM	0.008
PM-Enlow Fork Mine-11C	0.000	.	0.012	PEM	0.012
PM-Enlow Fork Mine-12C	0.000	.	0.016	PEM	0.016
PM-Enlow Fork Mine-13C	0.000	.	0.022	PEM	0.022
PM-Enlow Fork Mine-14C	0.000	.	0.025	PEM	0.025
PM-Enlow Fork Mine-15C	0.000	.	0.020	PEM	0.020
PM-Enlow Fork Mine-16C	0.000	.	0.007	PEM	0.007
PM-Enlow Fork Mine-17C	0.000	.	0.029	PEM	0.029
PM-Enlow Fork Mine-18C	0.000	.	0.006	PEM	0.006
PM-Enlow Fork Mine-19C	0.000	.	0.017	PEM	0.017
E12 Panel					
Enlow Fork-E12 Panel-20A [1]	0.023	PEM	0.000	.	-0.023
Enlow Fork-E12 Panel-2A [1]	0.380	PEM	0.260	PEM	-0.120
Enlow Fork Mine-Panel E12-2C [2,4]	0.040	PEM	.	.	.
Enlow Fork Mine-Panel E12-96C [1]	1.056	PEM	1.379	PEM	0.323
Enlow Fork Mine-Panel E12-6C [2]	0.060	PEM	0.027	PEM	-0.033
Enlow Fork Mine-Panel E12-7C [2]	0.117	PEM	0.783	PEM	0.666

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork MIne-Panel E12-8C [2]	0.034	PEM	0.041	PEM	0.007
Enlow Fork Mine-Panel E12-9C [2]	0.003	PEM	0.120	PEM	0.117
Enlow Fork Mine-Gate E11/E12-10C [2]	0.003	PEM	0.003	PEM	0.000
Enlow Fork Mine-Panel E12-11C [2]	2.951	PEM	1.577	PEM	-1.374
Enlow Fork Mine-Panel E12-12C [2]	0.053	PEM	0.013	PEM	-0.040
Enlow Fork Mine-Panel E12-15C [2]	0.287	PEM	0.142	PEM	-0.145
Enlow Fork Mine-Panel E12-16C [2,4]	0.016	PEM	.	.	.
Enlow Fork Mine-Panel E12-17C [2,4]	0.026	PEM	.	.	.
Enlow Fork Mine-Panel E12-18C [2,4]	0.009	PEM	.	.	.
Enlow Fork Mine-Panel E12-19C [2,4]	0.006	PEM	.	.	.
Enlow Fork Mine-Main-59C [5]	Unknown	.	0.694	PEM	
Enlow Fork Mine-Main-60C [5]	Unknown	.	1.695	PEM	
Enlow Fork Mine-Main-61C [5]	Unknown	.	0.751	PEM	
PM-Enlow Fork-3C	0.000	.	0.007	PEM	0.007
PM-Enlow Fork-4C	0.000	.	0.003	PEM	0.003
PM-Enlow Fork-20C	0.000	.	0.009	PEM	0.009
PM-Enlow Fork-21C	0.000	.	0.023	PEM	0.023
PM-Enlow Fork-22C	0.000	.	0.003	PEM	0.003
PM-Enlow Fork-23C	0.000	.	0.006	PEM	0.006
E13 Panel					
Enlow Fork-E13 Panel-4A [2]	1.795	PEM	0.789	PEM	-1.006
Enlow Fork-E13 Panel-5A [2]	0.212	PEM	0.040	PEM	-0.172
Enlow Fork-E13 Panel-6A [2]	0.026	PEM/PFO	0.000	.	-0.026
Enlow Fork-E13 Panel-7A [2]	0.029	PEM	0.014	PEM	-0.015
Enlow Fork-E13 Panel-10A [2]	0.052	PEM	0.000	.	-0.052
Enlow Fork-E13 Panel-11A [2]	0.233	PEM	0.095	PEM	-0.138
Enlow Fork-E13 Panel-12A [2]	0.011	PEM/PSS	0.000	.	-0.011
Enlow Fork-E13 Panel-13A [2]	0.048	PEM	0.000	.	-0.048
Enlow Fork-E13 Panel-14A [2]	0.005	PEM	0.000	.	-0.005
Enlow Fork-E13/E14 Gate-9A [2]	0.024	PEM	0.000	.	-0.024
PM-Enlow-16A	.	.	0.032	PEM	0.032
Enlow Fork Mine-Panel E12-1C [2]	0.080	PEM	0.228	PEM	0.148
Enlow Fork Mine-Panel E13-36C [4]	0.072	PEM	.	.	.
Enlow Fork Mine-Panel E13-37C [4]	1.309	PEM	.	.	.
Enlow Fork Mine-Panel E13-70C [2,4]	0.034	PEM	.	.	.
Enlow Fork Mine-Panel E13-71C [2]	0.077	PEM	0.000	.	-0.077
Enlow Fork Mine-Panel E13-72C [2]	0.043	PEM	0.233	PEM	0.190
Enlow Fork Mine Panel E13-73C [2,4]	0.172	PEM	.	.	.
Enlow Fork Mine-Panel E13-74C [2]	0.069	PEM	0.000	.	-0.069

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Panel E13-75C [2,4]	1.210	PEM	.	.	.
Enlow Fork Mine-Panel E13-76C [2,4]	0.052	PEM	.	.	.
Enlow Fork Mine-Panel E13-77C [2,4]	0.229	PEM	.	.	.
Enlow Fork Mine-Panel E13-78C [2,4]	0.010	PEM	.	.	.
PM-Enlow Fork-6C	.	.	0.051	PEM	0.051
PM-Enlow Fork-7C	.	.	0.019	PEM	0.019
PM-Enlow Fork-8C	.	.	0.029	PEM	0.029
E14 Panel					
Enlow-1E	0.025	PEM	0.000	.	-0.025
Enlow-2E	0.005	PEM	0.005	PEM	0.000
Enlow-3E	0.565	PEM	0.118	PEM	-0.447
Enlow-4E	0.383	PSS/PFO	0.285	PSS/PFO	-0.098
Enlow Fork Mine-Panel E14-1A	0.193	PEM	.	.	.
PM-Enlow-10A	.	.	0.039	PEM	0.039
PM-Enlow-11A	.	.	0.034	PEM	0.034
Enlow Fork Mine-Panel E14-20C [4]	0.057	PEM	.	.	.
Enlow Fork Mine-Panel E14-21C [4]	0.488	PEM	.	.	.
Enlow Fork Mine-Panel E14-22C [4]	0.049	PEM	.	.	.
Enlow Fork Mine-Panel E14-23C [4]	0.022	PEM	.	.	.
Enlow Fork Mine-Panel E14-35C [4]	0.032	PEM	.	.	.
Enlow Fork Mine-Panel E14-37C [4]	1.309	PEM	.	.	.
Enlow Fork Mine-Panel E14-38C [4]	0.420	PEM	.	.	.
Enlow Fork Mine-Panel E14-72C [2,4]	0.767	PEM	.	.	.
Enlow Fork Mine-Panel E14-77C [2,4]	3.191	PEM	.	.	.
Enlow Fork Mine-Panel E14-78C [2,4]	0.131	PEM	.	.	.
Enlow Fork Mine-Panel E14-79C [2,4]	0.016	PEM	.	.	.
Enlow Fork Mine-Panel E14-80C [2,4]	0.124	PEM	.	.	.
Enlow Fork Mine-Panel E14-81C [2,4]	0.310	PEM	.	.	.
Enlow Fork Mine-Panel E14-82C [2,4]	0.367	PEM	.	.	.
Enlow Fork Mine-Panel E14-83C [2,4]	0.146	PEM	.	.	.
E Tailgate [4]					
Enlow Fork Mine-Panel E15-30C	0.010	PEM	.	.	.
Enlow Fork Mine-Panel E15-31C	0.184	PEM	.	.	.
Enlow Fork Mine-Panel E15-32C	1.194	PEM	.	.	.
Enlow Fork Mine-Panel E15-33C	1.185	PEM	.	.	.
Enlow Fork Mine-Panel E15-29C	1.484	PEM	.	.	.
Enlow Fork Mine-Panel E15-28C	0.078	PEM	.	.	.
Enlow Fork Mine-Gate E14/E15-73C 2	0.018	PEM	.	.	.
Enlow Fork Mine-Gate E14/E15-24C	0.281	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Gate E14/E15-25C	0.009	PEM	.	.	.
Enlow Fork Mine-Panel E15-26C	0.033	PEM	.	.	.
Enlow Fork Mine-Panel E15-27C	0.056	PEM	.	.	.
Enlow Fork Mine-Panel E15-17C	1.772	PEM	.	.	.
Enlow Fork Mine-Panel E15-19C	0.468	PEM	.	.	.
E15 Panel					
Enlow-11B	0.148	PEM	0.141	PEM	-0.007
Enlow-17B	0.126	PEM	0.099	PEM	-0.027
Enlow-18B	0.293	PEM	0.123	PEM	-0.170
Enlow-19B	0.033	PEM	0.000	.	-0.033
Enlow-20B	0.186	PEM	0.058	PEM	-0.128
Enlow-21B	0.010	PEM	0.000	.	-0.010
Enlow-22B	0.220	PEM	0.057	PEM	-0.163
Enlow-23B	0.197	PEM	0.069	PEM	-0.128
Enlow-24B	0.007	PEM	0.014	PEM	0.007
Enlow-25B	0.018	PEM	0.005	PEM	-0.013
Enlow-29B	0.024	PEM	0.016	PEM	-0.008
Enlow-30B	0.004	PEM	0.010	PEM	0.006
Enlow-31B	0.032	PEM	0.026	PEM	-0.006
Enlow-32B	0.076	PEM	0.077	PEM	0.001
Enlow-33B	0.557	PEM/PSS	0.076	PEM/PSS	-0.481
Enlow-34B	0.045	PEM	0.000	.	-0.045
Enlow-10E	0.261	PEM	0.175	PEM	-0.086
Enlow-67E	0.253	PEM/PSS	0.345	PEM/PSS	0.092
Enlow-71E	0.772	PFO1/PEM1	0.490	PFO1/PEM1	-0.282
PM-Enlow-12A [2]	0.350	PEM	0.020	PEM	-0.330
PM-Enlow-13A	.	.	0.009	PEM	0.009
PM-Enlow-14A [2]	1.390	PEM	0.522	PEM	-0.868
PM-Enlow-15A	.	.	0.009	PEM	0.009
PM-Enlow-113	.	.	0.052	PEM	0.052
PM-Enlow-213	.	.	0.105	PEM	0.105
Enlow Fork Mine-Panel E16-18C [4]	0.469	PEM	.	.	.
E16 Panel					
Enlow-1B	0.014	PEM	0.016	PEM	0.002
Enlow-2B	0.009	PEM	0.004	PEM	-0.005
Enlow-3B	0.240	PEM	0.249	PEM	0.009
Enlow-4B	0.010	PEM	0.011	PEM	0.001
Enlow-5B	0.030	PEM	0.049	PEM	0.019
Enlow-6B	0.005	PEM	0.000	.	-0.005

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow-7B	0.065	PEM	0.038	PEM	-0.027
Enlow-9B	0.055	PEM	0.083	PEM	0.028
Enlow-10B	0.032	PEM	0.000	.	-0.032
Enlow-12B	0.342	PEM	0.465	PEM	0.123
Enlow-13B	0.013	PEM	0.000	.	-0.013
Enlow-14B	0.674	PEM	0.456	PEM	-0.218
Enlow-15B	0.283	PEM	0.318	PEM	0.035
Enlow-16B	0.191	PEM	0.139	PEM	-0.052
Enlow-5E	0.036	PEM	0.028	PEM	-0.008
Enlow-6E	0.063	PEM/PSS	0.022	PEM/PSS	-0.041
Enlow-8E	0.048	PEM	0.019	PEM	-0.029
Enlow-9E	0.031	PEM	0.011	PEM	-0.020
Enlow-68E	0.011	PEM	0.007	PEM	-0.004
Enlow-74E	0.020	PEM1	0.000	.	-0.020
Enlow-76E	0.110	PEM1	0.117	PEM1	0.007
Enlow-86E	0.050	PEM	0.065	PEM	0.015
E17 Panel					
Enlow-7E	0.100	PSS	0.036	PSS	-0.064
Enlow-69E	0.035	PEM	0.025	PEM	-0.010
Enlow-73E	0.002	PEM	0.000	.	-0.002
Enlow-75E	0.211	PEM	0.025	PEM	-0.186
Enlow-77E	0.180	PEM	0.151	PEM	-0.029
Enlow-78E	0.400	PEM	0.393	PEM	-0.007
Enlow-79E	0.021	PEM	0.027	PEM	0.006
Enlow-80E	0.004	PEM	0.000	.	-0.004
Enlow-81E	0.120	PEM	0.043	PEM	-0.077
Enlow-82E	0.065	PEM	0.330	PEM	0.265
Enlow-83E	0.060	PEM	0.038	PEM	-0.022
Enlow-84E	0.010	PEM	0.009	PEM	-0.001
Enlow-85E	0.050	PEM	0.048	PEM	-0.002
Enlow-1F	0.149	PEM	0.054	PEM	-0.095
Enlow-11F	0.192	PEM	0.162	PEM	-0.030
Enlow-54F	0.034	PEM	0.030	PEM	-0.004
Enlow-60F	0.024	PEM	0.000	.	-0.024
Enlow-97G	0.124	PEM/PSS	0.017	PEM/PSS	-0.107
PM-Enlow-313	.	.	0.091	PEM	0.091
PM-Enlow-413	.	.	0.011	PEM	0.011
PM-Enlow-513	.	.	0.595	PEM	0.595
PM-Enlow-713	.	.	0.026	PEM	0.026
PM-Enlow-813	.	.	0.007	PEM	0.007

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
E18 Panel					
Enlow-2F	0.377	PEM/PSS	0.085	PEM/PSS	-0.292
Enlow-3F	0.038	PEM	0.043	PEM	0.005
Enlow-4F	1.17	PEM	1.410	PEM	0.240
Enlow-44F	0.531	PEM	0.792	PEM	0.261
Enlow-45F	0.035	PEM	0.008	PEM	-0.027
Enlow-46F	0.079	PEM	0.019	PEM	-0.060
Enlow-47F	0.562	PEM	0.446	PEM	-0.116
Enlow-50F	0.021	PEM	0.008	PEM	-0.013
Enlow-55F	0.072	PEM	0.031	PEM	-0.041
Enlow-56F	0.376	PEM	0.177	PEM	-0.199
Enlow-61F	0.012	PEM	0.000	.	-0.012
Enlow-93D	0.056	PEM	0.007	PEM	-0.049
Enlow-94D	0.069	PEM	0.012	PEM	-0.057
Enlow-87E	0.031	PEM	0.051	PEM	0.020
Enlow-88E	0.027	PEM	0.088	PEM	0.061
Enlow-89E	0.024	PEM	0.036	PEM	0.012
Enlow Fork Mine-Main-25C [4]	0.070	PEM	.	.	.
Enlow Fork Mine-Main-26C [4]	0.335	PEM	.	.	.
PM-Enlow-6B	.	.	0.032	PEM	0.032
PM-Enlow-9B	.	.	0.993	PEM	0.993
PM-Enlow-10B	.	.	0.025	PEM	0.025
PM-Enlow-11B	.	.	0.008	PEM	0.008
PM-Enlow-1H	.	.	0.073	PEM	0.073
E19 Panel [4]					
Enlow-5F	0.340	PEM/PFO	0.733	PEM/PFO	0.393
Enlow-10F	0.156	PEM/PFO	0.171	PEM/PFO	0.015
Enlow-13F	0.107	PEM/PFO	0.319	PEM/PFO	0.212
Enlow-43F	0.236	PEM	0.052	PEM	-0.184
Enlow-57F	0.049	PEM	0.000	.	-0.049
Enlow-58F	0.048	PEM	0.000	.	-0.048
Enlow-89E	0.166	PEM	0.400	PEM	0.234
PM-Enlow-16B	.	.	0.121	PEM	0.121
PM-Enlow-19B	.	.	0.211	PEM	0.211
Enlow Fork Mine-Panel E19-22C	0.057	PEM	.	.	.
Enlow Fork Mine-Panel E19-23C	0.028	PEM	.	.	.
Enlow Fork Mine-Panel E19-24C	0.049	PEM	.	.	.
E20 Panel [4]					
Enlow-6F	0.341	PEM/PFO	0.535	PEM/PFO	0.194
Enlow-8F	0.017	PEM/PFO	0.014	PEM/PFO	-0.003

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow-14F	0.580	PEM	0.801	PEM	0.221
Enlow-16F	0.013	PEM	0.023	PEM	0.010
Enlow-17F	0.665	PEM	2.805	PEM	2.140
Enlow-19F	0.021	PEM	0.041	PEM	0.020
Enlow-20F	0.026	PEM	0.023	PEM	-0.003
Enlow-21F	0.118	PEM	0.165	PEM	0.047
Enlow-22F	0.083	PEM	0.129	PEM	0.046
Enlow-35F	0.006	PEM	0.000	.	-0.006
Enlow-42F	0.242	PEM	0.248	PEM	0.006
Enlow-95D	0.013	PEM	0.021	PEM	0.008
Enlow Fork Mine-E/F Main-17C	0.074	PEM	.	.	.
Enlow Fork Mine-Panel E20-18C	0.003	PEM	.	.	.
Enlow Fork Mine-E/F Main-19C	0.024	PEM	.	.	.
Enlow Fork Mine-Panel E19/E20-20C	0.040	PEM	.	.	.
Enlow Fork Mine-Panel E20-21C	0.007	PEM	.	.	.
PM-Enlow-12B	.	.	0.230	PEM	0.230
PM-Enlow-13B	.	.	0.044	PEM	0.044
PM-Enlow-15B	.	.	0.368	PEM	0.368
PM-Enlow-18B	.	.	0.095	PEM	0.095
E21 Panel [4]					
Enlow Fork Mine-1C	1.257	PEM	.	.	.
Enlow Fork Mine-Panel E21-49C	0.214	PEM	.	.	.
Enlow Fork Mine-Gate E21/E22-53C	0.065	PEM	.	.	.
Enlow Fork Mine-Panel E21-54C	0.077	PEM	.	.	.
Enlow Fork Mine-Gate E21/E22-55C	0.659	PEM/PSS	.	.	.
Enlow Fork Mine-Mains F20/E21-74C	1.267	PEM	.	.	.
Enlow Fork Mine-Panel E21-75C	0.181	PEM	.	.	.
Enlow Fork Mine-Panel E21-76C	0.609	PEM	.	.	.
Enlow Fork Mine-Panel E21-80C	0.034	PEM	.	.	.
Enlow Fork Mine-Panel E21-81C	0.033	PEM	.	.	.
Enlow-98D	0.064	PEM	.	.	.
Enlow-9F	0.058	PEM/PFO	.	.	.
Enlow-22F	0.110	PEM	.	.	.
Enlow-23F	0.561	PEM	.	.	.
Enlow-24F	0.382	PEM	.	.	.
Enlow-25F	0.106	PEM	.	.	.
Enlow-26F	0.137	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow-40F	0.018	PEM	.	.	.
Enlow-52F	0.001	PEM	.	.	.
Enlow-53F	0.083	PEM	.	.	.
Enlow-41G	1.460	PEM/PSS	.	.	.
Enlow-43G	0.619	PEM	.	.	.
F10 Panel					
Enlow Fork Mine-Panel F10-41C [2]	0.014	PEM	0.000	.	-0.014
Enlow Fork Mine-Panel F10-44C [2]	0.184	PEM	0.000	.	-0.184
Enlow Fork Mine-Panel F10-51C [2]	0.034	PEM	0.000	.	-0.034
Enlow Fork Mine-Panel F10-58C [2]	0.838	PEM	1.550	PEM	0.712
Enlow Fork Mine-Panel F10-59C [2]	0.012	PEM	0.141	PEM	0.129
Enlow Fork Mine-Panel F10-61C [2]	0.057	PEM	0.027	PEM	-0.030
Enlow Fork Mine-Panel F10-62C [2]	0.534	PEM	0.330	PEM	-0.204
Enlow Fork Mine-Panel F10-64C [2]	0.459	PEM	0.240	PEM	-0.219
Enlow Fork Mine-Panel F10-66C [2]	0.032	PEM	0.392	PEM	0.360
Enlow Fork Mine-Panel F10-67C [1]	0.010	PEM	0.000	.	-0.010
(Pre) Enlow Fork Mine-Panel F10-68C [1]	0.037	PEM	0.000	.	-0.037
Enlow Fork Mine-Panel F10-68C [2]	0.189	PSS	0.325	PSS	0.136
(Pre) Enlow Fork Mine-Panel F10-69C [1]	0.023	PEM	0.000	.	-0.023
Enlow Fork Mine-Panel F10-69C [2]	0.145	PSS	0.106	PSS	-0.039
Enlow Fork Mine-Panel F9-71C [1]	0.669	PEM	0.234	PEM	-0.435
Enlow Fork Mine-Panel F10-71C [2]	0.021	PEM	0.033	PEM	0.012
Enlow Fork Mine-Panel F10-74C [2]	0.179	PEM	0.000	.	-0.179
Enlow Fork Mine-Panel F10-75C [2]	0.028	PEM	0.000	.	-0.028
PM-Enlow-Panel F10-70C	.	.	0.133	PEM	0.133
F11 Panel					
Enlow Fork Mine-Panel F11-43C [2]	0.027	PEM	0.151	PEM	0.124
Enlow Fork Mine-Panel F11-57C [2]	0.028	PEM	0.000	.	-0.028
Enlow Fork Mine-Panel F11-62C [2]	0.110	PEM	0.094	PEM	-0.016
Enlow Fork Mine-Panel F11-65C [2]	0.918	PEM	0.504	PEM	-0.414
Enlow Fork Mine-Panel F11-66C [2]	0.009	PEM	0.037	PEM	0.028
Enlow Fork Mine-Panel F11-75C [2]	0.073	PEM	1.369	PEM	1.296
Enlow Fork Mine-Panel F11-77C [2]	0.045	PEM	0.405	PEM	0.360
Enlow Fork Mine-Panel F11-95C [2]	0.046	PEM	0.034	PEM	-0.012
Enlow Fork Mine-Gate F10/F11-97C [2]	0.115	PEM	0.265	PEM	0.150
Enlow Fork Mine-Panel F11-98C [2]	0.010	PEM	0.010	PEM	0.000
Enlow Fork Mine-Panel F11-110C [2]	0.005	PEM	0.015	PEM	0.010
Enlow Fork Mine-Panel F11-111C [2]	0.011	PEM	0.023	PEM	0.012

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
PM-Enlow-Panel F11-63C	.	.	0.197	PEM	0.197
PM-Enlow-Panel F11-64C	.	.	0.024	PEM	0.024
PM-Enlow-Panel F11-76C	.	.	0.188	PEM	0.188
PM-Enlow-Panel F11-96C	.	.	0.044	PEM	0.044
PM-Enlow-Panel F11-99C	.	.	0.031	PEM	0.031
F12 Panel					
Enlow Fork Mine-Panel F12-9B [2]	0.040	PEM	0.000	.	-0.040
Enlow Fork Mine-Panel F12-36C [2]	0.021	PSS	0.185	PSS	0.164
Enlow Fork Mine-Panel F12-51C [2]	0.077	PEM	0.000	.	-0.077
Enlow Fork Mine-Panel F12-53C [2]	0.100	PEM	0.000	.	-0.100
Enlow Fork Mine-Panel F12-55C (combined with F12-50C) [2]	0.014	PEM	0.000	.	-0.014
Enlow Fork Mine-Gate F11/F12-56C [2]	0.098	PEM	0.000	.	-0.098
Enlow Fork Mine-Gate F11/F12-57C [2]	0.037	PEM	0.000	.	-0.037
Enlow Fork Mine-Panel F12-58C [2]	0.184	PEM	0.000	.	-0.184
Enlow Fork Mine-Panel F12-63C [2,4]	0.055	PEM		PEM	
Enlow Fork Mine-Panel F12-69C (includes wetlands F12-52C& F12-67C- 72C) [2]	2.809	PEM	2.465	PEM	-0.344
Enlow Fork Mine-Panel F12-72C (combined with F12-30C) [2]	1.607	PEM	1.096	PEM	-0.511
Enlow Fork Mine-Panel F12-73C [2]	0.069	PEM	0.031	PEM	-0.038
Enlow Fork Mine-Gate F11/F12-78C [2]	0.243	PEM	0.321	PEM	0.078
Enlow Fork Mine-Panel F12-82C [2]	0.513	PEM	1.517	PEM	1.004
Enlow Fork Mine-Panel F12-85C [2]	0.052	PEM	0.164	PEM	0.112
Enlow Fork Mine-Panel F12-87C [2]	0.115	PEM	0.133	PEM	0.018
Enlow Fork Mine-Panel Bleeder-91C [2]	0.316	PEM	0.465	PEM	0.149
Enlow Fork Mine-Panel Bleeder-92C [2]	0.096	PEM	0.093	PEM	-0.003
Enlow Fork Mine-Panel F12-101C [2]	0.069	PEM	0.062	PEM	-0.007
Enlow Fork Mine-Panel F12-104C [2]	0.092	PEM	0.056	PEM	-0.036
Enlow Fork Mine-Panel F12-105C [2]	0.186	PEM	0.106	PEM	-0.080
Enlow Fork Mine-Gate F11/F12-106C [2]	0.007	PEM	0.011	PEM	0.004
Enlow Fork Mine-Gate F11/F12-107C [2]	0.114	PEM	0.097	PEM	-0.017
Enlow Fork Mine-Gate F11/F12-108C [2]	0.011	PEM	0.028	PEM	0.017
Enlow Fork Mine-Gate F11/F12-	0.015	PEM	0.027	PEM	0.012

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
109C [2]					
Enlow Fork Mine-148C [2]	0.082	PEM	0.025	PEM	-0.057
PM-Enlow-Panel F12-35C	.	.	0.107	PSS	0.107
PM-Enlow-Panel F12-37C	.	.	0.084	PSS	0.084
PM-Enlow-Panel F12-38C	.	.	0.005	PSS	0.005
PM-Enlow-Panel F12-39C	.	.	0.110	PEM	0.110
PM-Enlow-Panel F12-41C	.	.	0.022	PEM	0.022
PM-Enlow-Panel F12-42C	.	.	0.016	PEM	0.016
PM-Enlow-Panel F12-79C	.	.	0.068	PEM	0.068
PM-Enlow-Panel F12-80C	.	.	0.004	PEM	0.004
PM-Enlow-Panel F12-81C	.	.	0.002	PEM	0.002
PM-Enlow-Panel F12-83C	.	.	0.049	PSS	0.049
PM-Enlow-Panel F12-84C	.	.	0.058	PEM	0.058
PM-Enlow-Panel F12-86C	.	.	0.005	PEM	0.005
PM-Enlow-Panel F12-90C	.	.	0.026	PEM	0.026
PM-Enlow-Panel F12-94C	.	.	0.013	PEM	0.013
PM-Enlow-Panel F12-102C	.	.	0.030	PEM	0.030
PM-Enlow-Panel F12-103C	.	.	0.110	PEM	0.110
PM-Enlow-Panel F12-112C	.	.	0.008	PEM	0.008
PM-Enlow Fork Mine-Panel F12-113C	.	.	0.164	PEM	0.164
F Tailgate[6]					
Enlow Fork Mine-Panel F14-10C [2]	0.631	PEM	0.508	PEM	-0.123
Enlow Fork Mine-149C [2]	0.115	PEM	0.046	PEM	-0.069
Enlow Fork Mine-Panel F13-24C [2]	0.075	PEM	0.000	.	-0.075
Enlow Fork Mine-131C [2]	1.208	PEM	1.439	PEM	0.231
Enlow Fork Mine-128C [2]	0.174	PEM	0.477	PEM	0.303
Enlow Fork Mine-Panel F13-17C [2]	0.006	PEM	0.000	.	-0.006
Enlow Fork Mine-Panel F13-18C [2]	0.014	PEM	0.000	.	-0.014
Enlow Fork Mine-Panel F13-19C [2]	0.025	PEM	0.000	.	-0.025
Enlow Fork Mine-179C [2]	0.021	PEM	0.047	PEM	0.026
Enlow Fork Mine-178C [2]	0.116	PEM	0.116	PEM	0.000
Enlow Fork Mine-124C [2]	0.069	PEM	0.056	PEM	-0.013
Enlow Fork Mine-Panel F13-37C [2]	0.034	PEM	0.015	PEM	-0.019
Enlow Fork Mine-Panel F13-60C [2]	8.421	PEM / PSS	6.571	PEM / PSS	-1.850
Enlow Fork Mine-Panel F13-61C [2]	0.077	PEM	0.000	.	-0.077
Enlow Fork Mine-173C [2]	0.026	PEM	0.080	PEM	0.054
Enlow Fork Mine-175C [2]	0.284	PEM	0.068	PSS	-0.216
Enlow Fork Mine-147C [2]	0.059	PEM	0.017	PEM	-0.042
	0.554	PEM / PSS	0.420	PEM / PSS	-0.134

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-126C [2]	0.015	PEM	0.018	PEM	-0.016
	0.019	PFO / PEM			
Enlow Fork Mine-142C [2]	0.076	PEM/PSS	0.303	PEM/PSS	0.227
PM-Enlow Fork Mine-Gate F12/FTG-88C	.	.	0.085	PEM	0.085
PM-Enlow-122C	.	.	0.011	PEM	0.011
PM-Enlow-123C	.	.	0.011	PEM	0.011
PM-Enlow-125C	.	.	0.012	PEM	0.012
PM-Enlow-127C	.	.	0.105	PEM	0.105
PM-Enlow-129C	.	.	0.008	PEM	0.008
PM-Enlow-130C	.	.	0.020	PEM	0.020
PM-Enlow-133C	.	.	0.005	PEM	0.005
PM-Enlow-134C	.	.	0.069	PEM	0.069
PM-Enlow-135C	.	.	0.022	PEM	0.022
PM-Enlow-136C	.	.	0.018	PEM	0.018
PM-Enlow-137C	.	.	0.030	PEM	0.030
PM-Enlow-143C	.	.	0.039	PEM	0.039
PM-Enlow-144C	.	.	0.014	PEM	0.014
PM-Enlow-145C	.	.	0.007	PEM	0.007
PM-Enlow-150C	.	.	0.019	PEM	0.019
PM-Enlow-174C	.	.	0.033	PEM	0.033
PM-Enlow-176C	.	.	0.046	PEM	0.046
PM-Enlow-177C	.	.	0.104	PEM	0.104
F13 Panel					
Enlow Fork Mine-Panel F14-7B [2]	0.976	PEM	1.739	PEM	0.763
Enlow Fork Mine-132C [2]	0.651	PEM	0.159	PEM	-0.492
Enlow Fork Mine-Panel F14-34C [2,4]	3.291	PEM	.	.	.
Enlow Fork Mine-Panel F14-11C [2]	0.742	PEM	0.676	PEM	-0.066
Enlow Fork Mine-Panel F14-12C [2]	0.110	PEM	0.020	PEM	-0.090
Enlow Fork Mine-Panel F14-16C [2]	0.054	PEM	0.000	.	-0.054
Enlow Fork Mine-Gate F13/F14-41C [2]	0.284	PEM	0.213	PEM	-0.071
Enlow Fork Mine-Panel F14-42C [2]	0.099	PEM	0.274	PEM	0.175
Enlow Fork Mine-Panel F14-44C [2]	0.017	PEM	0.005	PEM	-0.012
Enlow Fork Mine-Panel F14-45C [2]	0.396	PEM	0.519	PEM	0.123
Enlow Fork Mine-Gate F13/F14-36C [2]	0.014	PEM	0.014	PEM	0.000
Enlow Fork Mine-139C [2]	0.091	PEM	0.156	PEM	0.065
Enlow Fork Mine-Panel F14-12A [2,4]	0.110	PEM	.	.	.
PM-Enlow-138C	.	.	0.007	PEM	0.007
F14 Panel					

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Panel F15-1C [2]	0.753	PEM	0.242	PEM	-0.511
Enlow Fork Mine-Panel F15-2C [2]	0.012	PEM	0.000	.	-0.012
Enlow Fork Mine-Panel F15-3C [2]	0.004	PEM	0.000	.	-0.004
Enlow Fork Mine-Panel F15-4C [2]	0.023	PEM	0.000	.	-0.023
Enlow Fork Mine-Panel F15-5C [2]	0.024	PEM	0.013	PEM	-0.011
Enlow Fork Mine-Panel F15-6C [2]	0.172	PEM	0.115	PEM	-0.057
Enlow Fork Mine-Panel F15-7C [2]	0.068	PEM	0.015	PEM	-0.053
Enlow Fork Mine-Panel F15-8B [2]	1.171	PEM	0.610	PEM	-0.561
Enlow Fork Mine-Panel F15-8C [2]	0.077	PEM	0.000	.	-0.077
Enlow Fork Mine-Panel F15-9C [2]	0.009	PEM	0.000	.	-0.009
Enlow Fork Mine-Panel F15-13C [2,7]	0.100	PEM	.	.	.
Enlow Fork Mine-Panel F15-14C [2,7]	0.029	PEM	.	.	.
Enlow Fork Mine-Panel F14-15C [2,7]	0.230	PEM	.	.	.
Enlow Fork Mine-Panel F15-30C [2]	0.698	PEM	0.192	PEM	-0.506
Enlow Fork Mine-Panel F15-31C [2]	0.034	PEM	0.008	PEM	-0.026
Enlow Fork Mine-Gate F14/F15-32C [2]	0.666	PEM/PSS	0.247	PEM/PSS	-0.419
Enlow Fork Mine-Panel F15-33C [2]	0.028	PSS	0.012	PSS	-0.016
Enlow Fork Mine-Gate F14/F15-43C [2]	0.028	PEM	0.011	PEM	-0.017
Enlow Fork Mine-Panel F15-46C [2]	0.069	PEM	0.000	.	-0.069
Enlow Fork Mine-Panel F15-47C [2]	0.147	PEM	0.000	.	-0.147
Enlow Fork Mine-Panel F15-48C [2]	1.788	PEM	0.716	PEM	-1.072
Enlow Fork Mine-Panel F15-49C [2]	0.479	PEM	0.485	PEM	0.006
Enlow Fork Mine-Panel F15-50C [2]	0.138	PEM	0.039	PEM	-0.099
Enlow Fork Mine-Panel F15-64C [2,7]	0.021	PEM	.	.	.
Enlow Fork Mine-Panel F15-65C [2,7]	0.052	PEM	.	.	.
Enlow Fork Mine-Panel F15-66C [2,7]	0.403	PEM	.	.	.
Enlow Fork Mine-Panel F15-67C [2,7]	0.026	PEM	.	.	.
Enlow Fork Mine-Panel F15-68C [2,7]	0.098	PEM	.	.	.
Enlow Fork Mine-Panel F15-69C [2,7]	0.193	PEM	.	.	.
PM-Enlow-29C	.	.	0.008	PEM	0.008
PM-Enlow-35C	.	.	0.031	PEM	0.031
PM-Enlow-37C	.	.	0.047	PEM	0.047
PM-Enlow-43C	.	.	0.030	PEM	0.030
F15 Panel					
Enlow Fork Mine-Panel F16-90C [2]	0.907	PEM	0.428	PEM	-0.479
Enlow Fork Mine-Panel F16-91C [2]	0.207	PEM	0.045	PEM	-0.161
Enlow Fork Mine-Panel F16-92C [2]	0.275	PEM	0.199	PEM	-0.077
		PFO	0.055	PFO	0.055
Enlow Fork Mine-Panel F16-93C [2]	0.037	PEM	0.012	PEM	-0.025

Wetland Name	**Pre-mining acreage**	**Pre-mining type**	**Post-mining acreage**	**Post-mining type**	**Net change in acreage**
Enlow Fork Mine-Panel F16-94C [2]	0.115	PEM	0.000	.	-0.115
Enlow Fork Mine-Panel F16-95C [2]	0.021	PEM	0.012	PEM	-0.009
Enlow Fork Mine-Panel F16-22C [2]	0.023	PEM	0.025	PEM	0.002
Enlow Fork Mine-Panel F16-23C [2]	0.028	PEM	0.035	PEM	0.007
Enlow Fork Mine-Panel F16-24C [2]	0.006	PEM	0.000	.	-0.006
Enlow Fork Mine-Panel F16-25C [2]	0.018	PEM	0.008	PEM	-0.010
Enlow Fork Mine-Panel F16-28C [2,4]	2.863	PEM	.	.	.
Enlow Fork Mine-Panel F16-29C [2]	0.048	PEM	0.000	.	-0.048
Enlow Fork Mine-Panel F15/F16-31C [2]	0.057	PEM	0.000	.	-0.057
Enlow Fork Mine-Panel F16-32C [2]	0.017	PEM	0.000	.	-0.017
Enlow Fork Mine-Panel F16-33C [2]	0.017	PEM	0.042	PEM	0.025
Enlow Fork Mine-Gate F15/F16-52C [2,4]	0.032	PEM	.	.	.
Enlow Fork Mine-Panel F16-53C [2,4]	0.017	PEM	.	.	.
Enlow Fork Mine-Panel F16-54C [2,4]	0.798	PEM	.	.	.
Enlow Fork Mine-Panel F16-57C [2]	0.073	PEM	0.018	PEM	-0.055
Enlow Fork Mine-Panel F16-59C [2]	0.100	PEM	0.051	PEM	-0.049
Enlow Fork Mine-Panel F15/F16-10A [2]	0.141	PEM	0.196	PEM	0.055
Enlow Fork Mine-Panel F16-9A (includes F16-8A & 9A) [2]	0.502	PEM	3.732	PEM	3.230
Enlow Fork Mine-Panel F15-16B (includes 17B, 18B, 19B, 20B, 21B, & 22B) [2]	3.456	PEM	2.806	PEM	-0.650
PM-Enlow Fork-27C	.	.	0.051	PEM	0.051
PM-Enlow Fork-30C	.	.	0.021	PEM	0.021
PM-Enlow-42C	.	.	0.004	PEM	0.004
F16 Panel [4]					
Enlow-67G [2]	0.224	PEM	.	.	.
Enlow-68G [2]	0.017	PEM	.	.	.
Enlow-67H [2]	5.370	PEM	.	.	.
Enlow Fork Mine-Panel F17-1C	0.010	PEM	.	.	.
Enlow Fork Mine-Panel F17-2C	1.039	PEM	.	.	.
Enlow Fork Mine-Panel F17-10C [2]	0.765	PEM / PFO	.	.	.
Enlow Fork Mine-Gate F17/F18-11C	0.395	PEM / PFO	.	.	.
Enlow Fork Mine-Panel F17-11C [2]	0.121	PFO	.	.	.
Enlow Fork Mine-Panel F17-12C [2]	0.047	PEM	.	.	.
Enlow Fork Mine-Panel F17-14C [2]	0.073	PEM	.	.	.
Enlow Fork Mine-Panel F17-15C [2]	0.007	PEM	.	.	.
Enlow Fork Mine-Panel F17-17C [2]	0.021	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Panel F17-18C [2]	0.021	PEM	.	.	.
Enlow Fork Mine-Panel F17-19C [2]	0.068	PEM	.	.	.
Enlow Fork Mine-Panel F16-20C [2]	0.110	PEM	.	.	.
Enlow Fork Mine-Panel F17-21C [2]	0.118	PEM	.	.	.
Enlow Fork Mine-Panel F17-23B [2]	0.028	PEM	.	.	.
Enlow Fork Mine-Main-25C	0.070	PEM	.	.	.
Enlow Fork Mine-Panel F16/F17-27C [2]	0.009	PEM	.	.	.
Enlow Fork Mine-Main-27C	0.296	PSS	.	.	.
Enlow Fork Mine-Main-28C	0.058	PEM	.	.	.
Enlow Fork Mine-Main-29C	0.204	PEM	.	.	.
Enlow Fork Mine-Panel F16-30C [2]	0.052	PEM	.	.	.
Enlow Fork Mine-Gate F16/F17-34C [2]	0.456	PEM	.	.	.
Enlow Fork Mine-Panel F17-35C [2]	1.011	PEM	.	.	.
Enlow Fork Mine-Panel F17-36C [2]	0.005	PEM	.	.	.
Enlow Fork Mine-Panel F17-37C [2]	0.023	PEM	.	.	.
Enlow Fork Mine-Panel F17-38C [2]	0.032	PEM	.	.	.
Enlow Fork Mine-Panel F16-39C	0.118	PEM	.	.	.
Enlow Fork Mine-Panel F17-39C [2]	0.100	PSS	.	.	.
Enlow Fork Mine-Panel F16-40C	0.222	PEM	.	.	.
Enlow Fork Mine-Panel F17-40C [2]	0.010	PEM	.	.	.
Enlow Fork Mine-Panel F16-41C	0.098	PEM	.	.	.
Enlow Fork Mine-Panel F17-41C [2]	0.014	PEM	.	.	.
Enlow Fork Mine-Panel F17-42C [2]	0.032	PEM	.	.	.
Enlow Fork Mine-Panel F17-43C [2]	0.060	PEM	.	.	.
Enlow Fork Mine-Panel F17-44C [2]	0.121	PEM	.	.	.
Enlow Fork Mine-Panel F17-45C [2]	0.103	PEM	.	.	.
Enlow Fork Mine-Panel F17-47C [2]	0.011	PEM	.	.	.
Enlow Fork Mine-Panel F17-48C [2]	0.074	PEM	.	.	.
Enlow Fork Mine-Panel F17-50C [2]	0.943	PEM	.	.	.
Enlow Fork Mine-Panel F17-51C [2]	1.096	PEM	.	.	.
Enlow Fork Mine-Panel F16-55C [2]	0.649	PEM	.	.	.
Enlow Fork Mine-Panel F17-56C [2]	0.179	PEM	.	.	.
Enlow Fork Mine-Gate F16/F17-58C [2]	0.008	PEM	.	.	.
Enlow Fork Mine-Panel F17-60C [2]	0.338	PEM	.	.	.
F17 Panel [4]					
Enlow-1G	0.517	PEM	.	.	.
Enlow-2G	0.117	PEM	.	.	.
Enlow-3G	1.154	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow-4G	0.138	PEM	.	.	.
Enlow-5G	0.174	PEM	.	.	.
Enlow-7G	0.009	PEM	.	.	.
Enlow-9G	0.076	PEM	.	.	.
Enlow-10G	0.450	PEM	.	.	.
Enlow-99G	0.021	PEM	.	.	.
Enlow-100G	0.025	PEM	.	.	.
Enlow-101G	0.226	PEM	.	.	.
Enlow Fork Mine-Panel F17-13C [2]	0.006	PEM	.	.	.
Enlow Fork Mine-Panel F17-16C [2]	0.021	PEM	.	.	.
Enlow Fork Mine-Panel F18-3C	0.433	PEM	.	.	.
Enlow Fork Mine-Panel F18-4C	1.143	PEM	.	.	.
Enlow Fork Mine-Panel F18-5C	0.136	PEM	.	.	.
Enlow Fork Mine-Panel F18-6C	1.326	PEM	.	.	.
Enlow Fork Mine-Panel F18-13C	0.774	PSS	.	.	.
Enlow Fork Mine-Panel F18-9C	0.083	PEM	.	.	.
Enlow Fork Mine-Panel F18-7C	0.377	PEM	.	.	.
Enlow Fork Mine-Panel F18-8C	0.051	PEM	.	.	.
Enlow Fork Mine-Panel F18-10C	0.059	PEM	.	.	.
Enlow Fork Mine-Panel F18-12C	0.130	PFO	.	.	.
Enlow Fork Mine-Panel F18-14C	0.650	PEM	.	.	.
Enlow Fork Mine-Panel F18-15C	0.047	PEM	.	.	.
Enlow Fork Mine-Gate F17/F18-42C	0.025	PEM	.	.	.
Enlow Fork Mine-Gate F17/F18-43C	0.091	PEM	.	.	.
Enlow Fork Mine-Panel F17-44C	0.095	PEM	.	.	.
Enlow Fork Mine-Panel F18-44C	0.015	PEM	.	.	.
Enlow Fork Mine-Panel F18-65C	0.094	PEM	.	.	.
Enlow Fork Mine-Panel F18-46C	0.233	PEM	.	.	.
Enlow Fork Mine-Gate F17/F18-46C [2]	0.207	PEM	.	.	.
Enlow Fork Mine-Panel F18-47C	0.427	PEM	.	.	.
Enlow Fork Mine-Panel F18-48C	0.032	PEM	.	.	.
Enlow Fork Mine-Gate F17/F18-49C [2]	0.021	PEM	.	.	.
Enlow Fork Mine-Panel F18-49C	0.031	PEM	.	.	.
Enlow Fork Mine-Panel F18-50C	0.093	PEM	.	.	.
Enlow Fork Mine-Panel F18-51C	0.203	PEM	.	.	.
Enlow Fork Mine-Panel F18-52C	0.104	PEM	.	.	.
Enlow Fork Mine-Panel F18-53C	0.060	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
F18 Panel [4]					
Enlow-6G	0.728	PEM	.	.	.
Enlow-8G	0.035	PEM	.	.	.
Enlow-11G	0.025	PEM/PSS	.	.	.
Enlow-12G	0.346	PEM/PSS	.	.	.
Enlow-13G	0.832	PEM	.	.	.
Enlow-14G	0.125	PEM	.	.	.
Enlow-16G	0.038	PEM	.	.	.
Enlow-39G	0.282	PEM	.	.	.
Enlow-40G	0.154	PEM	.	.	.
Enlow-44G	0.051	PEM	.	.	.
Enlow-45G	0.152	PFO	.	.	.
Enlow-46G	0.062	PEM	.	.	.
Enlow-48G	1.696	PEM	.	.	.
Enlow-92G	0.065	PEM	.	.	.
Enlow-102G	0.189	PEM	.	.	.
Enlow Fork Mine-Panel F18-1C	0.049	PEM	.	.	.
Enlow Fork Mine-Panel F18-2C	0.020	PEM	.	.	.
Enlow Fork Mine-Panel F18-3C	0.622	PEM	.	.	.
Enlow Fork Mine-Panel F18-4C	0.122	PEM	.	.	.
Enlow Fork Mine-Gate F18/F19-5C	0.209	PEM	.	.	.
Enlow Fork Mine-Gate F18/F19-6C	0.044	PEM	.	.	.
Enlow Fork Mine-Panel F17/F18-7C	0.790	PEM	.	.	.
Enlow Fork Mine-Panel F18-8C	0.062	PEM	.	.	.
Enlow Fork Mine-Panel F18-9C	0.017	PEM	.	.	.
Enlow Fork Mine-Panel F18-10C	0.024	PEM	.	.	.
Enlow Fork Mine-Panel F18-11C	0.125	PEM	.	.	.
Enlow Fork Mine-Panel F19-16C	0.082	PEM	.	.	.
Enlow Fork Mine-Panel F18-30C	0.794	PEM	.	.	.
Enlow Fork Mine-Panel F18-31C	0.271	PEM	.	.	.
Enlow Fork Mine-Panel F18-32C	0.541	PSS / PEM	.	.	.
Enlow Fork Mine-Panel F18-33C	0.098	PSS	.	.	.
Enlow Fork Mine-Panel F18-34C	0.012	PEM	.	.	.
Enlow Fork Mine-Panel F18-44C	1.270	PEM	.	.	.
Enlow Fork Mine-Panel F18-45C	0.461	PFO / PEM	.	.	.
Enlow Fork Mine-Panel F18-46C	0.050	PEM	.	.	.
Enlow Fork Mine-Gate F18/F19-47C	0.076	PEM	.	.	.
Enlow Fork Mine-Panel F19-48C	0.065	PEM / PSS	.	.	.
Enlow Fork Mine-Panel F18-49C	0.078	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Gate F18/F19-50C	0.794	PEM	.	.	.
Enlow Fork Mine-Gate F18/F19-51C	0.027	PEM	.	.	.
Enlow Fork Mine-Panel F19-53C	0.541	PEM	.	.	.
Enlow Fork Mine-Panel F18-54C	0.012	PEM	.	.	.
Enlow Fork Mine-Panel F18-56C	0.047	PEM	.	.	.
Enlow Fork Mine-Panel F18-57C	0.033	PEM	.	.	.
Enlow Fork Mine-Panel F18-120C	0.069	PEM	.	.	.
Enlow Fork Mine-Panel F18-121C	0.019	PEM	.	.	.
Enlow Fork Mine-Panel F18-122C	0.258	PEM	.	.	.
Enlow Fork Mine-Panel F18-123C	0.356	PEM	.	.	.
Enlow Fork Mine-Panel F18-128C	0.050	PEM	.	.	.
Enlow Fork Mine-Panel F18-129C	0.258	PEM	.	.	.
Enlow Fork Mine-Main-124C	0.024	PEM	.	.	.
Enlow Fork Mine-Main-125C	0.064	PEM	.	.	.
Enlow Fork Mine-Main-126C	0.011	PEM	.	.	.
Enlow Fork Mine-Main-127C	0.011	PEM	.	.	.
F19 Panel [4]					
Enlow Fork Mine-Panel F19-1C	0.879	PEM	.	.	.
Enlow Fork Mine-Panel F19-10C	0.224	PEM	.	.	.
Enlow Fork Mine-Main-12C	0.167	PEM	.	.	.
Enlow Fork Mine-Main-13C	0.051	PEM	.	.	.
Enlow Fork Mine-Main-14C	0.041	PEM	.	.	.
Enlow Fork Mine-Main-15C	0.052	PEM	.	.	.
Enlow Fork Mine-Main-16C	0.203	PSS	.	.	.
Enlow Fork Mine-Panel F19-16C	0.660	PEM	.	.	.
Enlow Fork Mine-Panel F19-17C	1.008	PEM	.	.	.
Enlow Fork Mine-Panel F19-21C	0.144	PEM	.	.	.
Enlow Fork Mine-Panel F19-29C	0.025	PEM	.	.	.
Enlow Fork Mine-Panel F19-30C	0.118	PEM	.	.	.
Enlow Fork Mine-Panel F19-31C	0.192	PEM	.	.	.
Enlow Fork Mine-Panel F19-33C	0.021	PEM	.	.	.
Enlow Fork Mine-Panel F19-35C	0.125	PEM	.	.	.
Enlow Fork Mine-Panel F19-36C	0.098	PEM	.	.	.
Enlow Fork Mine-Panel F19-37C	0.514	PEM	.	.	.
Enlow Fork Mine-Panel F19-43C	0.039	PEM	.	.	.
Enlow Fork Mine-Panel F19-52C	0.107	PEM	.	.	.
Enlow Fork Mine-Panel F19-55C	0.034	PEM	.	.	.
Enlow Fork Mine-Main-F19/E20-77C	0.018	PEM	.	.	.

Wetland Name	Pre-mining acreage	Pre-mining type	Post-mining acreage	Post-mining type	Net change in acreage
Enlow Fork Mine-Main-F19/E20-78C	0.056	PEM	.	.	.
Enlow Fork Mine-Main-F19/E20-79C	0.030	PEM	.	.	.
Enlow Fork Mine-Panel F19-101C	0.049	PEM	.	.	.
Enlow Fork Mine-Panel F19-102(a)C	0.615	PEM	.	.	.
	3.798	PSS	.	.	.
Enlow Fork Mine-Panel F19-115C	0.240	PEM	.	.	.
Enlow Fork Mine-Panel F19-116C	0.009	PEM	.	.	.
Enlow Fork Mine-Panel F19-119C	0.131	PEM	.	.	.
Enlow Fork Mine-181C	0.014	PEM	.	.	.
Enlow Fork Mine-182C	0.014	PEM	.	.	.
Enlow Fork Mine-183C	0.090	PEM	.	.	.
Enlow Fork Mine-184C	0.044	PEM	.	.	.
Enlow Fork Mine-185C	0.182	PEM	.	.	.
Enlow Fork Mine-186C	0.091	PEM	.	.	.
Enlow-17G	0.969	PEM	.	.	.
Enlow-18G	0.148	PEM	.	.	.
Enlow-19G	0.482	PEM	.	.	.
Enlow-70G	0.037	PEM	.	.	.

ND = Not determined. Wetland identified but sketch map and dimensions not recorded. Loss and/or gain cannot be determined.
[1] = Pre-mining and post-mining wetland acreage estimated from field sketch map and dimensions.
[2] = Pre-mining wetland acreage estimated from field sketch map and dimensions.
[4] = Wetland(s) will be revisited in 2011 or 2012 to complete post-mining monitoring.
[5] = Pre-mining monitoring not conducted; post-mining acreage not included in net change in acreage.
[6] = F-Tailgate not directly mined, but post-mining inventory completed to assess possible effects from mining adjacent longwall panels.
[7] = Post-mining monitoring not performed due to property access issues.

References

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. (1979) “Classification of wetlands and deepwater habitats of the United States”. U.S. Fish and Wildlife Service Report FWS/OBS-79/31, 131 p.

U.S. Fish and Wildlife Service. (2014) “National Wetlands Inventory: Wetland Classification Codes”. http://www.fws.gov/wetlands/Data/Wetland-Codes.html.