The Effects of Subsidence Resulting from Underground Bituminous Coal Mining on Surface Structures and Features and on Water Resources, 2003 to 2008

Bituminous Mine Subsidence and Land Conservation Act

ACT 54 Amendments
Five-Year Report
August 2003 to August 2008

Research Conducted by the University of Pittsburgh for the Pennsylvania Department of Environmental Protection

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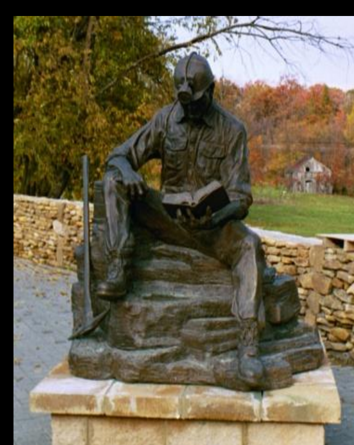

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ACRONYMS and ABBREVIATIONS

%EPT	Percent of all taxa that are Ephemeroptera, Plecoptera and Trichoptera
ACCD	Aquatic Community Classification Database
Act 418	Surface Mining Conservation and Reclamation Act
ACT 54	BMSLCA as amended 1994
ArcGIS	GIS software by ESRI
ARMPS	Analysis of Retreat Mining Pillar Stability
BMR	Bureau of Mining and Reclamation
BMSLCA	Bituminous Mine Subsidence and Land Conservation Act
BUMIS	Bituminous Underground Mining Information System
CAD	Computer Aided Drawing
CDMO	California District Mining Office
Clean Water Act	Federal Water Pollution Control Amendments of 1972 (P.L. 92-500)
Commonwealth	Commonwealth of Pennsylvania
CUP California	University of Pennsylvania
DCNR	Department of Conservation and Natural Resources
DEM	Digital Elevation Model
EIA	Federal Energy Information Administration
EHB	Environmental Hearing Board
ERRI	Environmental Resources Research Institute
ESRI	Environmental Systems Research Institute
FC+PR Richness	Filterer-Collector + Predator Taxa Richness
FGDC Federal	Geographic Data Committee
ft	feet
Geo-TIF	Geo-Tagged Image Format
GIS	Geographic Information System
GPS	Global Positioning System
I79	Interstate 79
JPEG	Joint Photographic Experts Group
m	meter
MOU	Memorandum of Understanding
NAD 1983	
NAD 1927	
NGO	Non-Government Organizations
NHD	National Hydrography Dataset
NIOSH	National Institute for Occupational Safety and Health
NWI	National Wetland Inventory
O&M	Operation and Maintenance
PA	Pennsylvania
PA DCNR PA	Pennsylvania Department of Conservation and Natural Resources
PA DEP	Pennsylvania Department of Environmental Protection
PACC	Pennsylvania Aquatic Community Classification
PaGWIS	Pennsylvania Groundwater Information System
PASDA	Pennsylvania Spatial Data Access
pct	percent
PEM	wetlands showing emergent vegetation

PennDOT	Pennsylvania Department of Transportation
PFO	forested wetlands
PSS	wetlands showing scrub/shrub
PSU	Pennsylvania State University
PUB	wetlands showing less than 30-pct vegetative cover and unconsolidated bottom
R5UBH	riverine with unclassified perennial vegetation, unconsolidated bottom and permanently flooded
RMSE	Root Mean Squared Error
RPZ	Rebuttable Presumption Zone
SA	Subsidence Act
SMCRA	Surface Mining Control and Reclamation Act of 1977
TBS	Total Biological Score
TGD-001	Technical Guidance Document 363-0300-001
TGD-655	Technical Guidance Document 563-2000-655
TIF	Tagged-Image Format
UGISdb	University of Pittsburgh Geographic Information System Database
University	University of Pittsburgh
US	United States
USGS	US Geological Survey
UTM	Universal Transverse Mercator
WL	Water Loss
WPC	Western Pennsylvania Conservancy
WRDS	Water Resources Data System

Reverse Look-up

GIS software by ESRI (ArcGIS)
Analysis of Retreat Mining Pillar Stability (ARMPS)
Aquatic Community Classification Database (ACCD)
Bituminous Mine Subsidence and Land Conservation Act (BMSLCA)
Bituminous Underground Mining Information System (BUMIS)
BMSLCA as amended 1994 (ACT 54)
Bureau of Mining and Reclamation (BMR)
California District Mining Office (CDMO)
California University of Pennsylvania (CUP)
Commonwealth of Pennsylvania (Commonwealth)
Computer Aided Drawing (CAD)
Department of Conservation and Natural Resources (DCNR)
Digital Elevation Model (DEM)
Environmental Hearing Board (EHB)
Environmental Resources Research Institute (ERRI)
Environmental Systems Research Institute (ESRI)
Federal Energy Information Administration (EIA)
Federal Geographic Data Committee (FGDC)
Federal Water Pollution Control Amendments of 1972 (P.L. 92-500) (Clean Water Act)
feet (ft)
Filterer-Collector + Predator Taxa Richness (FC+PR Richness)
forested wetlands (PFO),
Geographic Information System (GIS)
Geo-Tagged Image Format (Geo-TIF)
Global Positioning System (GPS)
Interstate 79 (I79)
Joint Photographic Experts Group (JPEG)
Memorandum of Understanding (MOU)
meter (m)
NAD 1983 or NAD 1927
National Hydrography Dataset (NHD)
National Institute for Occupational Safety and Health (NIOSH)
National Wetland Inventory (NWI)
Non-Government Organizations (NGO)
Operation and Maintenance (O&M)
PA DEP Bureau of Mining and Reclamation Technical Guidance Document (TGD-655)
PA Department of Conservation and Natural Resources (PA DCNR)
PA Department of Transportation (PennDOT)
PA Groundwater Information System (PaGWIS)
Pennsylvania (PA)
Pennsylvania Aquatic Community Classification (PACC)
Pennsylvania Department of Environmental Protection (PA DEP)
Pennsylvania Spatial Data Access (PASDA)
Pennsylvania State University (PSU)
percent (pct)

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University of Pittsburgh (University)
US Geological Survey (USGS)
Water Loss (WL)
Water Resources Data System (WRDS)
Western PA Conservancy (WPC)
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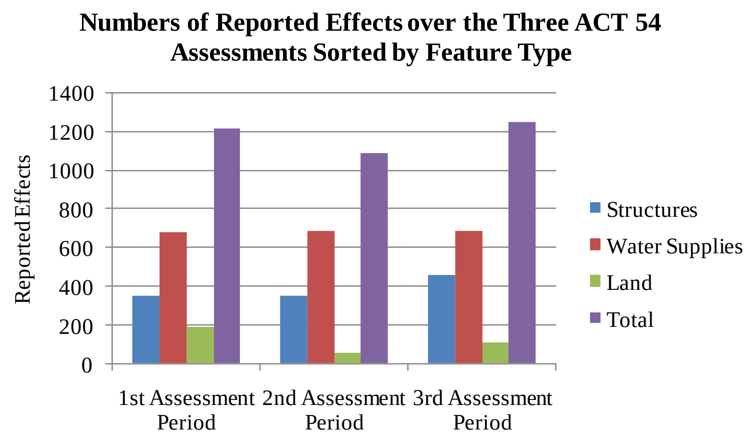
wetlands showing less than 30-pct vegetative cover and unconsolidated bottom (PUB)
wetlands showing scrub/shrub (PSS)

EXECTIVE SUMMARY

Laws, governing how environmental impacts from underground bituminous coal mining are anticipated and mitigated, have been evolving within the Commonwealth of Pennsylvania over the last four decades. Initially, with the passage of the Bituminous Mine Subsidence and Land Conservation Act (BMSLCA) of 1966 and the Surface Mining Control and Reclamation Act (SMCRA) of 1977, structures, land, and highways were the focus of action.

As time passed, mine operators learned how to mitigate damage to key structures, i.e. homes, garages, barns, silos, etc., and developed methods to fairly compensate property owners. During the 3rd assessment period, spanning August 21, 2003 to August 20, 2008, 456 structures and 108 lands with reported effects occurred from a total 3,735 inventoried structures and 3,587 properties. That is just 12-pct of the total structures and 3-pct of the total properties undermined.

A reported effect refers to an incident reported to the Pennsylvania Department of Environmental Protection (PA DEP) by its staff, representatives of the coal companies, or land owners. A total of 1,247 reported effects occurred during the 3rd assessment period. That represents a 14-pct increase over the 2nd ACT 54 assessment period.



The eight longwall mines operating in Greene and Washington Counties account for almost 94-pct of the structure and 89-pct of land reported effects. The average number of days to resolved structure reported effects was 207 days and for land 246. Compared with other feature types, i.e. water supplies, streams, and wetlands, this is a relative low time frame.

In the early 1980s, interstate highways were first subjected to longwall mining subsidence impacts. During the timeframe of this study, nine longwall panels undermined Interstate 79. The commonwealth spent over 19 million dollars monitoring, maintaining, and repairing the highway. It is estimated that this was a fraction of the cost necessary for the state to condemn the coal and compensate the owners of the mineral rights to prevent longwall mining. Most importantly, no accidents were attributed to longwall mining subsidence and restrictions were limited to reduced speeds and single lane traffic during times of active mining or repairs.

In the mid 1980's new environmental concerns were raised about the BMSLCA. In 1994, the state legislator passed the ACT 54 amendments to the BMSLCA. This law gave coal companies the capability to subside the ground using the longwall mining method as long as the potential impacts were identified and planned for during the permitting process and compensation to land owners was provided.

Fifty underground coal mines were active during the 3rd assessment period undermining 38,256 acres of land. Thirty-six of the mines are room-and-pillar, eight are longwall, and six are room-and-pillar mines with pillar recovery. Overburden varies from less than 100-ft at several room-and-pillar mines to over 1,100-ft at the Blacksville No.2 Longwall Mine. Overburdens for room-and-pillar mines averaged 276-ft and for longwall mines 687-ft. The High Quality Mine was classified as the only shallow longwall mine with an average overburden of 338-ft. This mine was involved in a highly publicized case where a permit for mining their 6-East longwall panel was denied in a court decision. In general, impacts from longwall subsidence are more significant at shallow overburdens.

Water supplies became a major focus after the passage of ACT 54. During the 3rd assessment period, 2,789 wells, spring, and ponds were undermined with 683 reported effects accounting for 24.5-pct of the total water supplies undermined. Water supplies have proven a challenge but they are being resolved. At the end of the 3rd assessment period, 234 reported effects or 34-pct of the cases were still awaiting a final resolution. The average number of days to resolve water supplies reported effects was 321, a considerable increase compared to structures and land reported effects. Resolution strategies for recovering water supplies are often multi-step, especially when wells and springs are being replaced. For example, longwall mining subsidence takes approximately 7 months to stabilize before meaningful repair can begin. In addition, operation and maintenance costs must often be calculated and agreed upon.

In late 1990's, the quality and quantity of water flowing in streams undermined by longwall mines became a major focus. The diminution and contamination of streams have been the traditional measures for determining impacts. While the number of stream investigations has varied over the three assessment periods, the amount of technical information collected and kinds of analysis required have changed dramatically. In the early 2000's data became available on the biologic health of streams, largely through the assessment of diversity of the benthic macroinvertebrates (a source of food for fish). In 2005, Technical Guidance Document 563-2000-655 established protocols for assessing biological health and for determining when a stream was impaired and when it attained a resolution of repaired to this reported impact, be it low flow or degraded macroinvertebrate diversity.

Fifty-five stream investigation reports occurred in the 3rd assessment period and 20 have been resolved. The average number of days to resolve stream impacts was 688, nearly double the time required to resolve water supply reported effects. The other 35 cases are in some state of an interim resolution such as:

- *Monitoring flow,*
- *Measuring biological diversity,*
- *Grouting open fractures,*
- *Altering stream gradients,*
- *Re-vegetating stream banks,*
- *Augmenting stream flow,*
- *Promoting aquatic diversity and health, or*
- *Repairing obstacles within the streams that impair flow.*

Because these protocols were first implemented in October of 2005, many of the questions concerning what streams have been impaired by longwall mining and, after mitigation actions, which have attained pre-mining stream flow and biological diversity standards are yet to be answered. There is one statement that can be made - stream remediation activities have increased dramatically through the three assessment periods.

The impact to wetlands by undermining continues to elude measurement. The 1st assessment didn't make an attempt to investigate wetlands. The 2nd assessment, relying on the NWI database and site visits by PA DEP biologist, found 78 acres of wetlands undermined. The 3rd assessment, again relying on the Nation Wetlands Inventory database and company documented wetlands from their permit file and from 6-month mining maps, found 93.9 acres undermined. Similar to streams, a new protocol for measuring and characterizing wetlands was introduced in 2005 (Technical Guidance Document 563-2000-655) and implemented in 2007. Recently submitted permit revisions have shown a more significant effort is currently underway by the companies to report accurate wetlands data.

In summary, the historical focus was on structures, water supplies, and land features undermined by bituminous coal mines. Currently, capabilities and resources are in-place, both at the coal company level, through their in-house staff and consultants, and the PA DEP, through their district mining offices, to monitor these impacts and work towards an amiable solution as outlined in ACT 54.

The more recent focus of standards and protocols for dealing with stream and wetlands impacted by underground longwall mines has been developing over the last decade. Presently the coal companies, under the guidance of the PA DEP, are collecting necessary information on the pre- and post-mining conditions of streams and wetlands. Some period of time will be required to fully understand these impacts and to measure how effectively they return to their previous states. In some cases mitigation actions have been required and in others, natural processes have been successful since no impacts were observed in more than half of the streams undermined by longwall panels.

ACT 54 has set standards for the coal mining industry so that environmental impacts are lessened. These standards and the associated protocols are changing and developing as more information and understanding about the impacts is gained and mitigation efforts become more commonplace at coal operations. The 3rd assessment period saw the collection of much more data to more rigorously analyze these impacts. Structures, water supplies, and land features were the early focus of legislation and enforcement. Streams have become a major focus in the last decade, and will likely continue to be, while authorities and industry complete their understanding of the impacts and resolutions. Wetlands are expected to become a major focus going forward.

SECTION I: Introduction

I.A - Overview

This section focuses on the need for this study, an examination of its aims and objectives and the context in which the report is formulated and written. There are also background explanations of certain topics that are either germane to the subject or as context to statements in multiple 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 (PA DEP) to compile, on an ongoing basis, information from mine permit applications, monitoring reports, and enforcement actions. It also requires the PA DEP to report its findings regarding the effects of underground mining on overlying land, structures, and water resources to the Governor, General Assembly and Citizen Advisory Council at five year intervals.

The act further stipulates that the PA DEP is to engage the services of recognized professionals or institutions for purposes of assessing the effects of underground mining and preparing these reports. The PA DEP initiated a contract with the University of Pittsburgh (the University) on February 2, 2009 to fulfill the assessment and reporting requirements for the period from August 21, 2003 to August 20, 2008.

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

The extraction of bituminous coal from the Commonwealth of Pennsylvania's (the Commonwealth) rock formations plays a significant role in the state's economic development as it has for over 125 years. This role is still prominent today. In 2008, The Federal Energy Information Administration (EIA) reported Pennsylvania's bituminous underground coal mines employed 5,331 miners and produced 53,318 million tons (short tons) of coal (Anon, 2009a).

From a national perspective, Pennsylvania's mines represent:

- 8.7-pct of the total number of underground coal mines,
- 14.9-pct of the total production from underground coal mines,
- 10.8-pct of the total employment for underground coal mines, and
- 33-pct higher average production per employee per hour than the average underground coal mine in the nation.

All of these statistics indicate that Pennsylvania (PA) underground bituminous coal mines are larger and more productive than the national average.

While much coal has been mined, the EIA estimates there are still approximately 10.2 billion tons of recoverable reserves of bituminous coal remaining in Pennsylvania (Anon, 2008a). In addition, The Pennsylvania Coal Association estimates the coal industry directly and indirectly employs approximately 49,100 workers with an annual payroll of in excess of $2.2 billion and tax revenues of approximately $750 million (Anon, 2009b). This data demonstrates the prominent role coal plays in the lives of Commonwealth citizens.

I.A.3 – Environmental Consequence of Mining

As with the development of other natural resources, the extraction of bituminous coal by underground mining methods comes at a price to the environment. Up until the latter half of the last century, there were no widespread attempts to mine coal in a sustainable and environmentally neutral manner. It is not the purpose of this report to judge the ethics of these past practices. One fact appears to be clear -- coal was viewed as an asset to be exploited and this exploitation helped to fuel one of the greatest economic expansions in human history. Today, society places significant demands on the coal mining industry to extract this mineral in an environmentally acceptable manner. The manner in which the industry currently complies is the subject of this report.

I.B – Environmental Laws and Coal Mining

In the 1940's the Commonwealth began to realize the necessity of environmental stewardship to prevent permanent and widespread destruction of its land and water. The Clean Stream Law was amended in 1945 to include acid mine drainage as a pollution source that required regulation. In this 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 coalbeds.

I.B.1 – Bituminous Mine Subsidence and Land Conservation ACT of 1966

The most significant of these was the BMSLCA of 1966. For the first time, 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-pct 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-deg. 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 at 500-ft of overburden, at least 3.4 times that needed at 100-ft. This method, while straight forward, did not accommodate changing geologic and mining conditions and, therefore, has been replaced by more advanced methods.

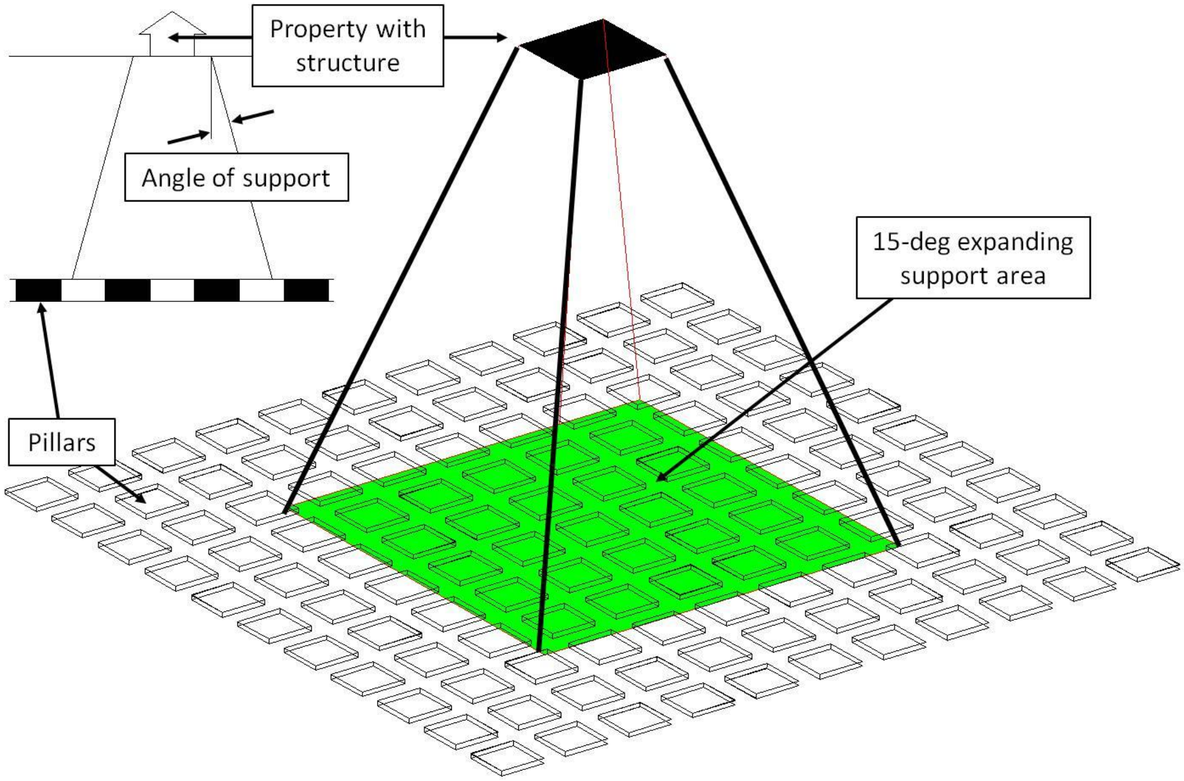


Figure I-1 – An interpretation of pillar support required by the BMSLCA (1966) to protect structures from subsidence damage (adapted from Gray and Meyers, 1970).

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 April 27, 1966. Section 6 required operators of underground mines to 1) repair the damage within 6 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 – Surface Mining Control and Reclamation ACT of 1977

The BMSLCA was first amended in 1980 to help bring it in 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.

I.B.3 – ACT 54

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 (NGOs) for the purpose of attaining a consensus position on the BMSLCA. Three years later, consensus was achieved to address:

- Replacement of impaired water supplies,
- Treatment of mine discharges,
- Incentives for re-mining previously abandoned areas,
- Additional remedies for structural damage, and
- Relaxation of regulatory obstacles to full extraction, i.e. longwall and pillar recovery mining.

The state legislature prepared a number of statutory amendments in 1992 and the governor signed the legislation on June 22, 1994, which became effective on August 21, 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.

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 pertinent structures and improvements, and certain agricultural structures.
- Entitled the structure owner or occupant to payments for temporary relocation and other incidental expenses.
- 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 land owners.
- Underground mining allowed 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 the PA DEP. 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 the PA DEP responsible for ensuring the regulations and official mining permits were followed. PA DEP 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 – Special ACT 54 Requirements

ACT 54 contained a special provision requiring the PA DEP to produce an assessment of the surface impacts of underground bituminous coal mining every five years. To date two reports have been issued. One, by the PA DEP in 1999 and later amended (Anon, 2001), covered the period from August 21, 1993 to August 20, 1998 (*known as the 1st assessment*), and a second by California University of Pennsylvania, (CUP), in 2005 (Conte and Moses, 2005), covered the period from August 21, 1998 to August 20, 2003 (*known as the 2nd assessment*). The University was contracted in 2009 to conduct the 3rd assessment, covering the period from August 21, 2003 to August 20, 2008 (*known as the 3rd assessment*).

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

Mine operators use three general underground methods to extract bituminous coal. The most common method is room-and-pillar mining. During the 3rd assessment period, all of the 50 underground bituminous mines operating in Pennsylvania used some form of the room-and-pillar mining method. Thirty-six of these mines used only the room-and-pillar mining method. Six mines also used the room-and-pillar technique but, in addition, practiced pillar recovery and are herein designated as mines using the pillar recovery mining method. Eight mines employed the longwall mining method in conjunction with room-and-pillar mining.

I.C.1 – Room-and-Pillar Mining Method

Because every mine uses the room-and-pillar mining method, certain characteristics are similar between all mines. For example, rooms or entries are typically driven 18 to 20-ft wide with continuous mining machines. These rooms use outline pillars designed to prevent failure of the overlying strata and to support the overburden weight above the mine. 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 focus on extracting 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. In general, impacts are minimal because subsidence generally does not occur, but a few room-and-pillar mines did have significant numbers of recorded impacts during the 3rd assessment period.

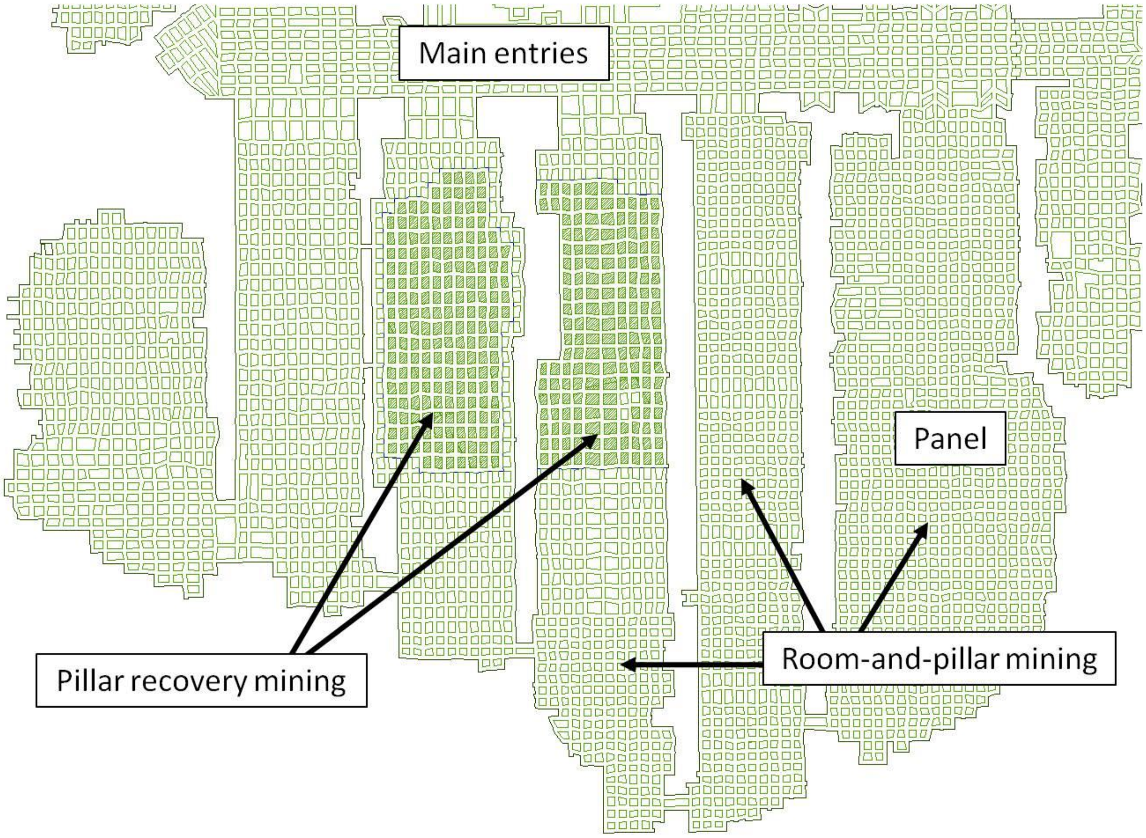


Figure I-2 - Example of a room-and-pillar mine where main entries provide long-term access to production panels. Six mines in Pennsylvania practice pillar recovery.

I.C.2 – Pillar Recovery Mining Method

Room-and-pillar mines use pillar recovery to more fully extract the coal in select production panels (Figure I-2). These 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. This method sees infrequent use and, when employed, 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 the PA DEP's files. Only six of the 50 mines active during the 3rd assessment period practiced pillar recovery.

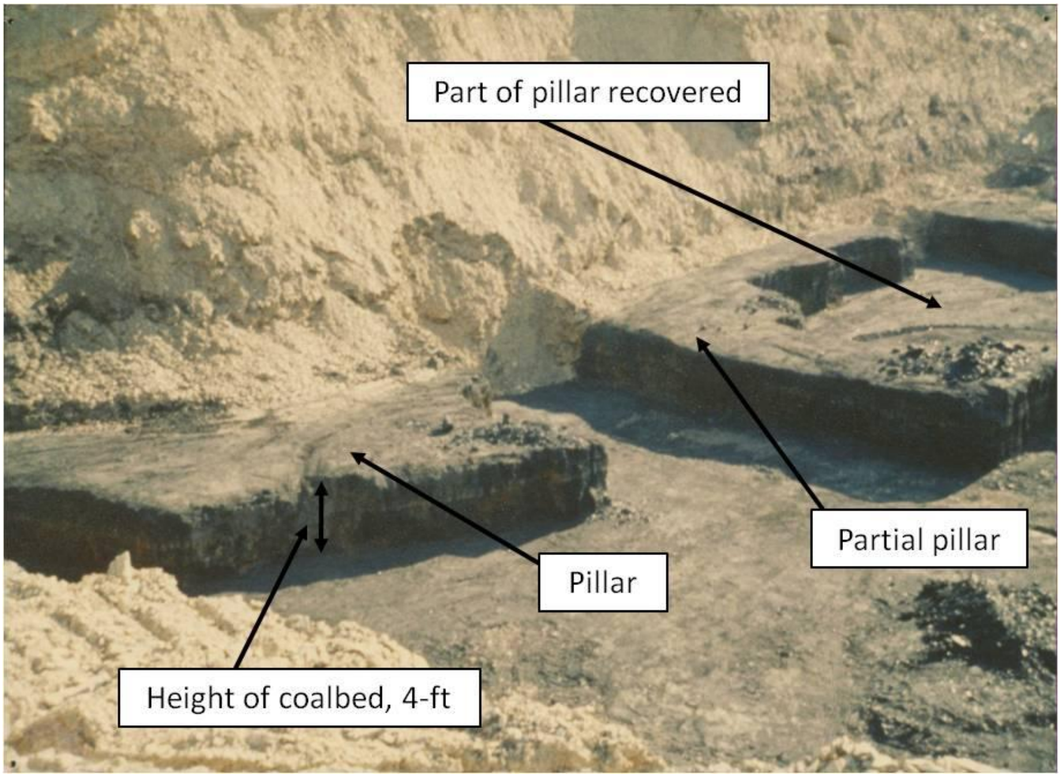


Figure I-3 - In this photograph an abandoned mine was uncovered by surface mining revealing a partially mined pillar (photograph courtesy of K. Brady).

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). The mine operation uses the 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 1,400-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 advance 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. Eight mines employed the longwall method during the 3rd assessment period.

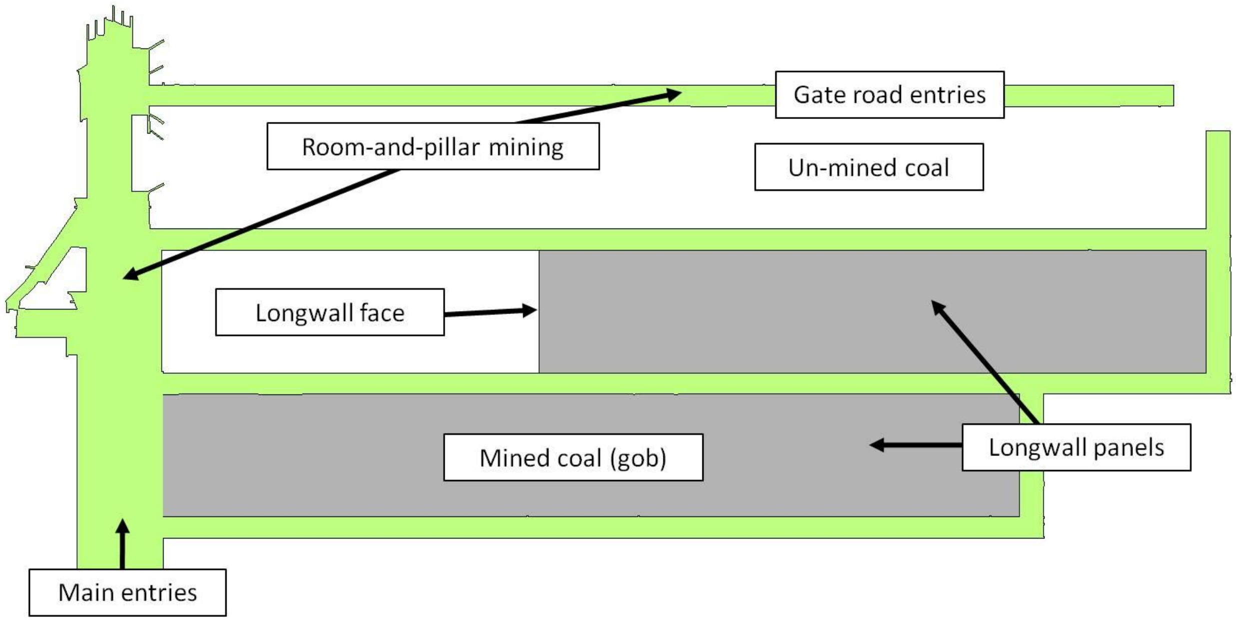


Figure I-4 - Example of longwall mining method where longwall panels are developed off main entries and accessed by gate road entries both developed via room-and-pillar mining methods.

I.D – General Description of Impacts and Resolutions Associated with Underground Bituminous Coal Mining

Historical analysis and documentation of the types of impacts commonly associated with underground bituminous coal mining by various researchers (Conte and Moses, 2005; Miller, 2001; Parizek and Ramani, 1996) provides a rich source of data. These findings provide excellent background on past trends for this report.

I.D.1 – General Description of Coal Mining Impacts

Impacts from underground bituminous coal mining include impacts to:

- Buildings and structures – Impacts to buildings and structures include shifting of foundations, extensional cracks in walls and floors, and buckling of walls and floors.
- Surface land – Impacts to surface land can be in the form of a) extensional cracks or fractures in the surface soil and rock that allow water to drain into them or that represent a public safety hazard, and b) flooding of fields or pasture lands caused by subsidence depressions that pool water.
- Water sources, both wells and springs – Impacts to water sources can diminish water flow or contaminate water composition thereby reducing its' residential, agricultural and commercial value and use.
- Streams, wetlands and water bodies, i.e. ponds – Impacts to streams consist of diminution, i.e. changes to the general seasonal water flow patterns, or contamination. These changes affect storage capacities and are capable of harming or eliminating existing species. Impacts to wetlands are more difficult to recognize in the span of a few seasons but, if left unchecked, can have a dramatic effect of the flora and fauna that

inhabit these environments. Wetlands are known to have special abilities to filter toxins and pollution from natural water systems and the elimination of wetlands can have long term detrimental impacts on water supplies. Impacted ponds typically are recognized by lower water levels and higher concentrations of contaminated water.

- Utilities, i.e. gas pipelines, water and gas service lines to residential and business structures, power lines, etc. - Damage to electrical lines and steel towers and/or ruptures or separations of underground water and gas service lines. All of these impacts result in some form of loss of service to residential and commercial customers.
- Public infrastructure, i.e. roads, highways, bridges, parks, dams, etc. – roads and highways might see transverse and longitudinal cracking and compression bumps, while bridge foundations might experience differential settlement.

I.D.2 – General Description of Coal Mining Resolutions

Pre- and post-mining agreements and settlements are commonly used to compensate land owners for damages. Other examples include:

- Buildings and structures – Mitigation techniques include trenching around structures to dissipate horizontal ground strains and bracing, bridging and banding to strengthen buildings to withstand differential movements caused by subsidence.
- Surface land – Mitigation techniques include filling of open fractures and milling of compression bumps that impact public safety or diminish land use. Also, if land use or access is negatively impacted, i.e. pooling in fields or pastures etc., corrections to surface drainage infrastructure may be required.
- Water sources, both wells and springs – Mitigation techniques include repairing wells and springs to enhance flow or improve water quality, drilling replacement wells or connecting to public water supplies. Temporary water replacement is often used to supplement water usage until a permanent water supply is provided.
- Streams, wetlands and water bodies, i.e. ponds – Mitigation techniques include augmenting stream flow, repairing stream and wetland ecologies, grouting fractures that rob stream of water, and re-grading stream gradients, i.e. gate cutting, to reduce pooling.
- Utilities – Gas transmission lines are often excavated and supported on the surface until subsidence ceases. The financial responsibilities for the cost associated with these resolutions differ. However, if residential gas or water service is interrupted, temporary supplies are provided at the company’s expense until remedied.
- Public infrastructure – Mitigation techniques are varied and depend on local circumstances. For example, the cost of rehabilitating interstate highways is paid for by the government. In other cases, coal companies repair and improve public recreation areas. Figure I-5 shows the East Finley Township Park before and after restorations made by a coal company.

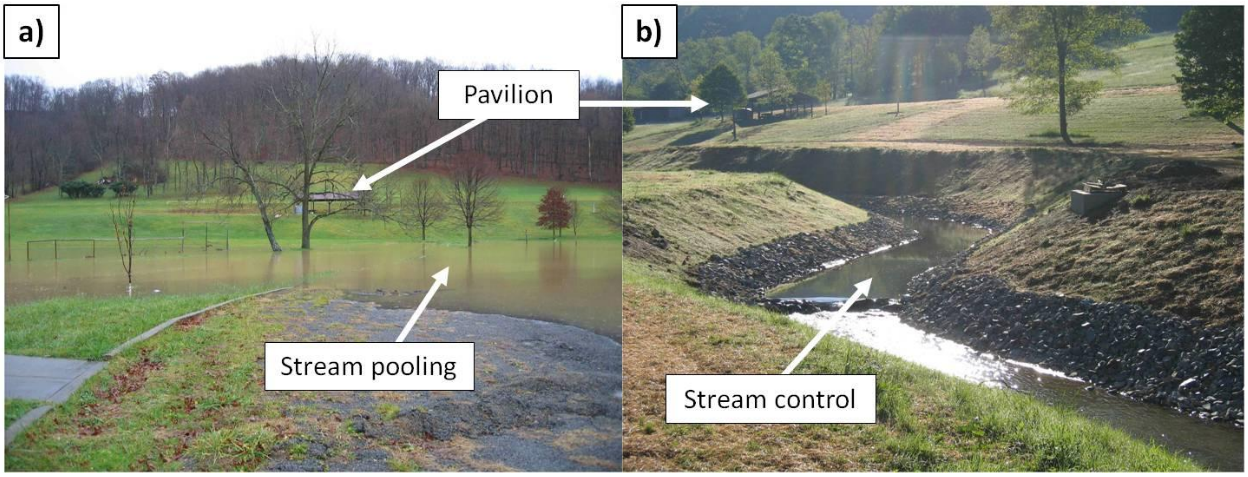


Figure I-5 - Photographs of a) stream pooling impacts to East Finley Township Park and b) coal company stream repairs to eliminate pooling and return the park to a functional state (Photograph from PA DEP files).

I.E – Subsidence Related Impacts

The majority of possible impacts discussed above are related to mining induced surface subsidence. The formation of a subsidence basin is typically associated with full extraction mining. Full extraction mining consists of longwall mining and pillar recovery after room-and-pillar mining has developed the underground areas. Longwall mining is the dominant mining method in Pennsylvania responsible for subsidence and is the focus of this report.

I.E.1 – Potential Impacts Associated with Room-and-Pillar Mining

Whenever coal is mined by the underground room-and-pillar mining method, an opening is created. Groundwater moving through overlying strata can often find its way into these openings. If care is not taken, water passing through the underground openings can become contaminated. The permit process requires designs that minimize this contamination and, if it occurs, requires treatment systems that return the water quality to acceptable levels. This report shows that room-and-pillar mining, with extraction ratios less than 50-pct, have a lower reported incidence of impacts to water supplies or surface features. However, altered groundwater flow paths can occur under specific conditions as discussed in this report (see Section VI) that may impact the quantity and character of water produced by wells and springs. Also, surface structural impacts can damage residential buildings, especially when increased extraction ratios allow under-designed pillars to punch into a softer floor rock (Figure I-6) and potentially produce subsidence on the surface.

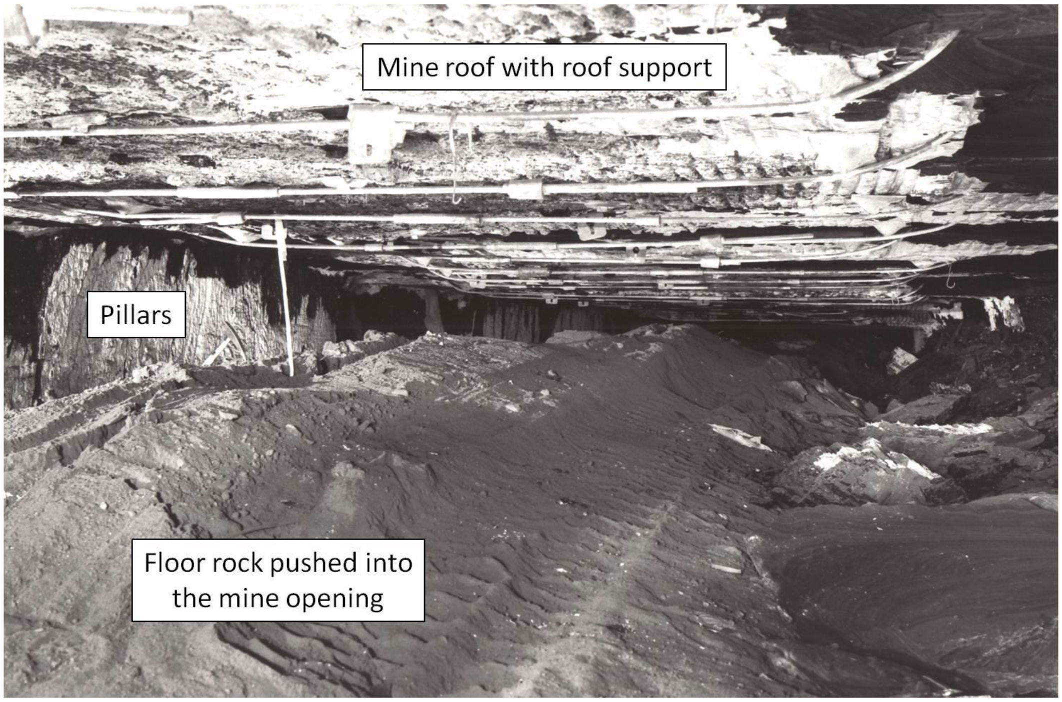


Figure I-6 - Example of floor heave at the Kitt Mine in West Virginia. The pillars in this photograph have punched into the mine's floor rock causing it to rotate upward into the entry (photograph courtesy of A. Iannacchione).

I.E.2 – Potential Impacts Associated with Pillar Recovery and Longwall Mining

More serious impacts can potentially occur when the supporting coal pillars are removed as in the pillar recovery mining method, or when large panels are mined as in the longwall mining method. Both methods allow the overlying strata to collapse into the mine void (Figure I-7). Immediately above the caved, un-stratified rock layers, is a zone of extensive fracturing, as much as 20 times the extraction zone height in thickness. In the Pittsburgh Coalbed, where all of Pennsylvania longwall mining 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 in relatively rare circumstances, can 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.

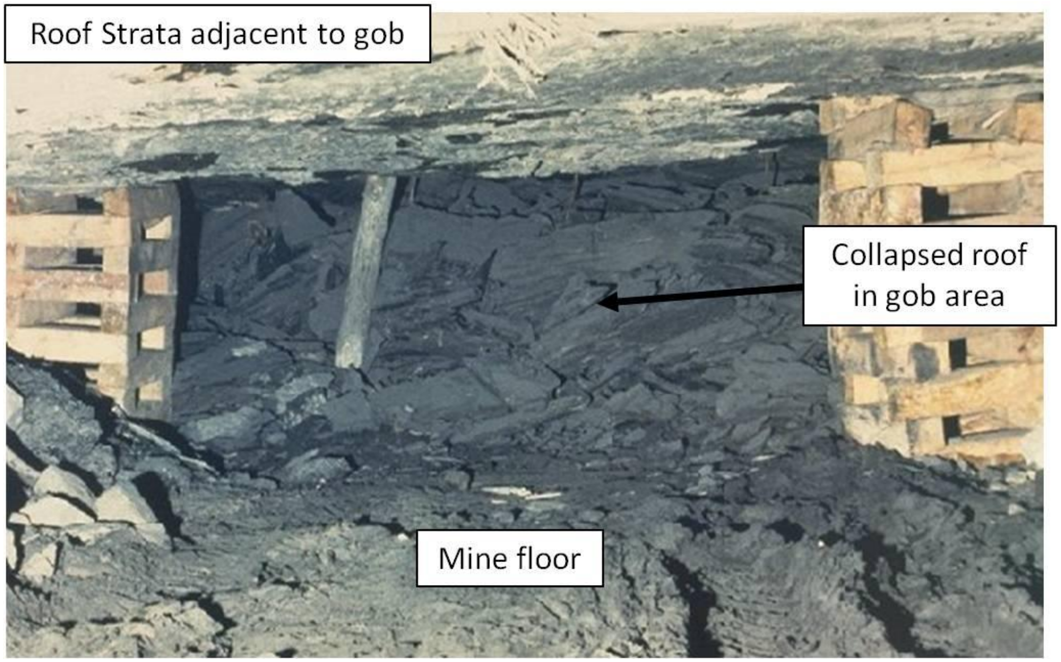


Figure I-7 - Example of full extraction mining at the VP No.3 Mine in Virginia. At this mine the roof rock collapses into the void created by the extraction of the longwall panel (photograph courtesy of A. Iannacchione).

I.E.3 – Formation of Subsidence Basins

A subsidence basin can form when the ratio of the width of the extraction zone to the depth of overburden (h) exceeds 0.25. In longwall mining, the width of the extraction zone is the width of the longwall panel, W. Since most longwall panels are deeper than 500-ft (h), a subsidence basin will form at panel widths (W) greater that 125-ft. As shown later (see Section IV), most Pennsylvania longwall panels are greater than 1000-ft wide, hence subsidence basins can be expected to form in association with every panel mined.

As might be imagined, a subsidence basin forms as the coal is mined and the overlying strata are allowed to fail and collapse into the recently created void (Figure I-8). 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, or δ, (Peng and Geng, 1982) (Figure I-8).

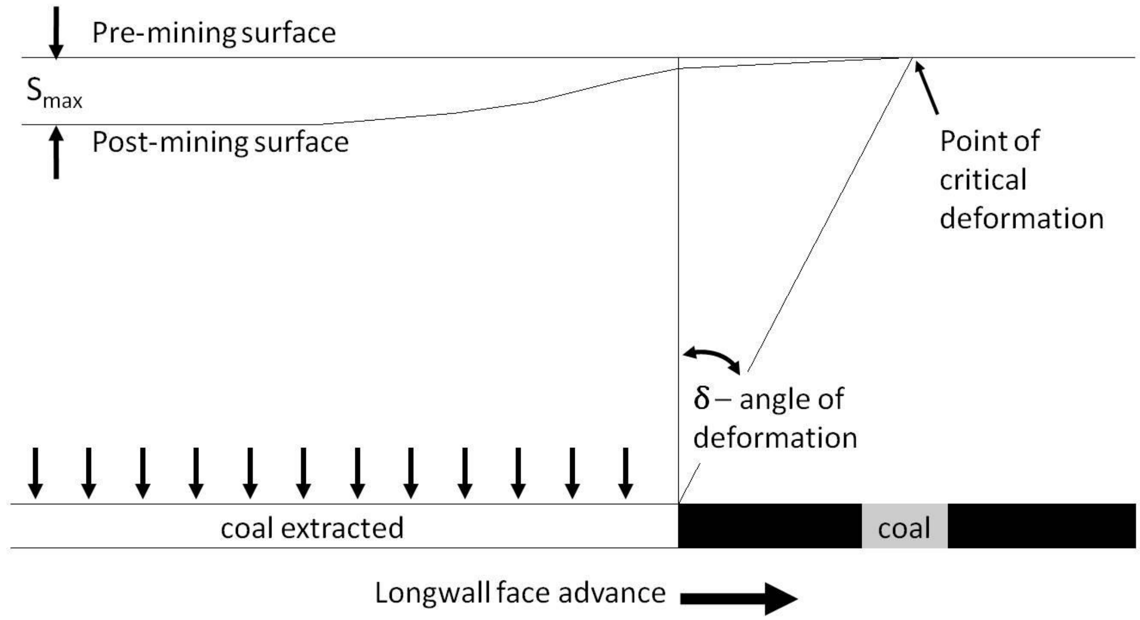


Figure I-8 - Generalized model showing how a subsidence basin forms in association with longwall mining.

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 the longwall face 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 the longwall face 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.E.4 – The Final Shape and Impact of the Subsidence Basins

Longwall mining subsidence basins are elliptically shaped, 3-dimensional surfaces (Figure I-9). 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. 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 water sources have been occasionally known to extend beyond the subsidence basin. All of these factors will be discussed later in the report (see Sections IV, V, VI, VII, and VIII).

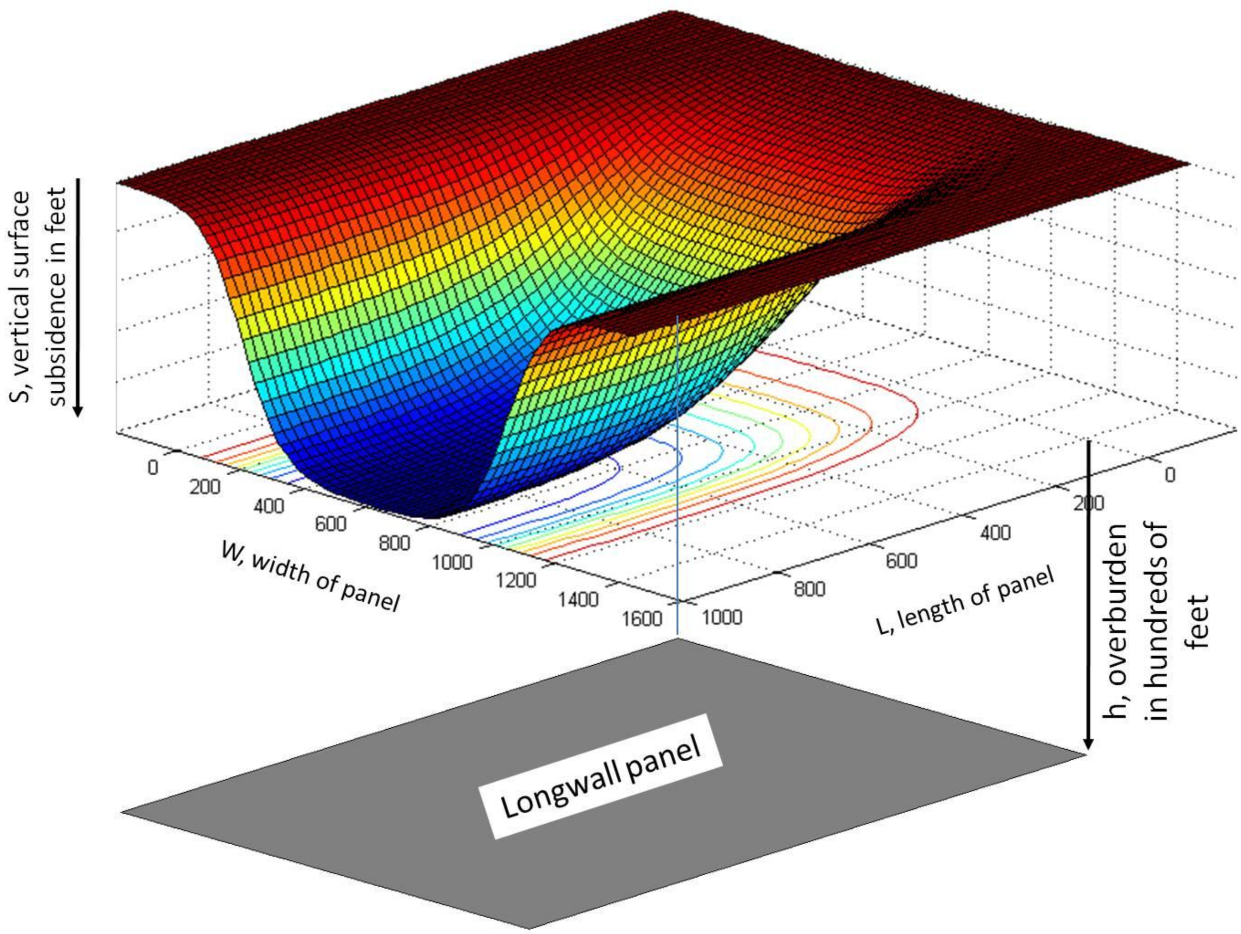


Figure I-9 - 3D view of an idealized subsidence basin overlying a portion of a typical longwall panel in Pennsylvania (adapted from Gutiérrez, et al., 2010).

I.F – Context of this Report

Information about underground bituminous coal mining impacts comes from observations and measurements collected by land owners, company representatives, PA DEP staff, and the University. The majority of the data used in this report is derived from the files, maps, and investigations by the PA DEP. Many of these files are contained within the Bituminous Underground Mining Information System (BUMIS) database or paper files maintained by the California District Mining Office (CDMO). The examination and analysis of these files is a primary work product of this report. Mining company data, mainly in the form of digital maps and files is incorporated into this report as well. There is no legal requirement for the companies to provide the University with this data. They did it willingly, saving the University considerable time and effort and increasing the accuracy of the data. In a few cases, selected interviews with private and public sector entities help supplement existing information. This report includes information from publicly available spatial data sources, such as eMapPA, Pennsylvania Spatial Data Access (PASDA), Western Pennsylvania Conservancy's Aquatic

Community dataset, and U.S. Geological Survey digital elevation models, as necessary to facilitate and supplement analytical work and the map preparation.

This report includes the results of University field investigations as required to gather additional information not contained within PA DEP files or to verify information contained within individual mine permits and on 6-month mining maps. University biologist's results of surveys of streams either undermined during the 3rd assessment period or undermined during previous assessment periods and recommended for analysis by the PA DEP are included in Section VIII. Despite best efforts to gather all pertinent information related to this subject matter, the University recognizes that certain proprietary information is not available to this study.

I.F.1 – 1st Assessment

The 1st assessment was conduct by the PA DEP with an initial report filed in June 1999. As reported by Conte and Moses (2005), a meeting of the Coal Caucus of the General Assembly in February of 2000 at Belle Vernon, PA, encouraged additional analysis and a supplemental report was produced (Miller, 2001).

I.F.2 – 2nd Assessment

In 2004, CUP entered into a contract with the PA DEP to analyze the impacts of bituminous underground coal mining between August 21, 1998 and August 20, 2003. The researchers from CUP completed their analysis in 160-days and set a high standard for this report (Conte and Moses, 2005). During the 2nd assessment period, over 37,000 acres of land in ten counties was undermined. This mining was accomplished by nine longwall and 72 room-and-pillar mines (some of these mines practiced pillar recovery). Mining occurred under 3,033 properties and 3,656 structures of various kinds. The PA DEP received 684 reported effects of wells and springs that potentially impacted water supplies. In addition, almost 116 miles of streams were undermined and habitat assessment procedures were used and the post-mining conditions scored.

I.F.3 – 3rd Assessment

In 2009, the University of Pittsburgh began to assimilate data from the PA DEP files and other sources into a GIS database using ArcEditor software by the Environmental Systems Research Institute (ESRI). All relevant data collected between August 21, 2003 and August 20, 2008 are now part of the University's GIS database. The current assessment does not discuss repair cost since few records on this subject are available.

I.G – Current Contract Tasks and Report Structure

The contract that funded this report identified major areas of investigation including impacts to structures, water sources, land, streams and wetlands.

I.G.1 – Data Collection and Spatial Analysis (Section II)

Early in the project University researchers used BUMIS to determine which structures, water sources, land, streams and wetlands have been undermined during the 3rd assessment period. Data from BUMIS was segmented by mine and impacts and entered into Excel spreadsheets for analysis. A synopsis of the processes used is given in Section II and summaries of the data developed are provided in Appendix A and B. Next, University researchers investigated permit files to locate additional background information. At the same time, the University collected approximately 900 images of the 6-month mining maps from the CDMO, geo-referenced 317 maps, and placed the images within the GIS database (Appendix C). Lastly, information about the streams has been collected by the University and supplemented with information from PA DEP, i.e. BUMIS, stream investigation files, and compliance files (see Appendix D).

I.G.2 – Mining During the 3rd Assessment Period (Section III)

The University constructed a GIS database containing a complete dataset for all the properties, structures, water supplies, land, streams, and wetlands undermined during the 3rd assessment period. Strict buffers around the areas mined were used for the spatial inventory of the previously mentioned features. The 6-month mining maps were used to locate all active underground bituminous coal extracted during the 3rd assessment period and to estimate the total acres of coal mined. Geologic information on the structural elevation of the coalbeds and surface elevations for all 50 mines operating during the 3rd assessment period were created and used to determine the precise overburden above each mine. The value of the University's GIS database and the associated overburden information is demonstrated in Section III and Appendix C.

I.G.3 – Effects of Mining on Interstate 79 (Section IV)

Nine longwall panels were extracted under Interstate 79 (I79) during the 3rd assessment period. The specific or detailed affects were not assessed in this report due to the lack of centrally reported information. However, certain data was derived from summary reports prepared by the CDMO staff assigned to monitor this highway. The University evaluated the extent of impacts and the types of controls used to mitigate these impacts.

I.G.4 – Effects of Mining on Structures (Section V)

The University determined the impacts of underground mining on structures damaged during the 3rd assessment period. This required a detailed analysis of surface properties undermined during the period and a determination of which of those properties experienced mining-related impacts (land damage or structure damage). The University then calculated the number of undamaged and reportedly damaged structures (i.e., dwelling, barn, commercial building, etc.). The resolution status and type of resolution of all reported structure damage cases were summarized. All of these analyses were organized by mining method and type of structure. Also, examples of mitigation techniques were included.

I.G.5 – Effects of Mining on Water Supplies (Section VI)

The University reviewed and analyzed all data related to water loss problems and claims as reported by property owners and mine operators during the 3rd assessment period. Each reported effect and claim was associated with 1) a natural ground-water recharge cycle, 2) a location and type of underground bituminous coal mining, 3) water loss categories i.e., related to subsidence effects of underground mining, flooding of underground mines, and 4) causes other than underground mining, i.e., refuse disposal, surface mining, gas well drilling, etc. In addition, the overburden information and mining outlines contained in the University's GIS database were used to calculate the Rebuttable Presumption Zone (RPZ), i.e. the 35-deg angle projected upward from the outside of underground mining areas. The number of water supplies undermined during the 3rd assessment period were identified, with results organized by mining method and water supply type (well, springs, or public water connection) and water supply use (domestic, agricultural, industrial, etc.). The studied water supplies falling within the RPZ were analyzed, with results organized by mining method and water supply type. A complete analysis of the resolution status of each water supply was determined. The result was a better understanding of how shallow aquifers were impacted by underground mining.

I.G.6 – Effects of Mining on Land (Section VII)

The University reviewed and analyzed all data related to land reported effects. The resolution status of each reported effect was analyzed and the potential cause classified into one of five general categories: 1) tension cracks, 2) mass wasting, 3) settlement, 4) compression ruptures, and 5) unknown. Each of the eight active mines with land reported effects was analyzed separately and several examples of mitigation efforts were documented.

I.G.7 – Effects of Mining on Streams (Section VIII) and Wetlands (Section IX)

The University measured the number and length of streams undermined during the 3rd assessment period and examined the effects of underground mining on the biological integrity and flow status of undermined stream segments (Appendix D). Biological integrity was determined using "total biological score" calculated in accordance with the PA DEP Technical Guidance 563-2000-655 over 320-ft (100-m) stream segments. The requirements for evaluating and reporting the character of wetlands were changed mid-way through the 3rd assessment period. These changes did not afford the University the opportunity to adequately assess impacts to wetlands. However, several pre-mining wetland assessment reports have been submitted to the PA DEP in association with permit modifications. The University examined these recent submissions, compared them with previous submissions, and determined how effective they were in addressing past concerns.

I.G.8 – Effects on Utilities and Transportation (not covered)

Utilities potentially impacted by undermining include pipelines, power distribution lines, and water lines. Transportation units not covered in this report and possibly impacted include: State roads, local community roads, and railroads. CUP, during the 2nd assessment period, found it difficult to obtain information on these impacts. As a result, the PA DEP did not require the

University to include this information in the current report. However, it should be noted that utility and transportation related impacts are sometimes addressed within the report especially when they are related to other issues being discussed. For example, reported effects to structures that carry electrical utilities are covered in Section V. In addition, a few reported effects to water lines are addressed in Section VI. Lastly, it is obvious that considerable work continues to be done to mitigate potential impacts to utilities such as gas pipelines. The PA DEP occasionally notes gas pipeline mitigation activities, similar to the one shown in Figure I-10, when investigating other reported effects. However, these mitigation activities are often covered under legal agreements and are generally not discoverable through public inquiry.

Figure I-10 - Gas pipelines are routinely excavated and temporarily supported to mitigate the impacts from longwall mining (Photograph from PA DEP files).

SECTION II: Data Collection and Methods of Analysis

II. A - Overview

This section provides an overview of the data sources and software used in the creation and maintenance of data for the study, a discussion of existing data collected from various providers, a description of the University's data creation methodology, and a brief outline of the resulting database structure.

The University spent 15 months collecting and analyzing data. The data collection process proved cyclical and continuous, continuing into the spring of 2010. Much effort during the study was spent collecting available data and transforming and combining these items into user friendly products for analysis. Important gaps in the data were supplemented with University field studies.

The study area for this report included ten counties in Pennsylvania where active underground bituminous coal mining occurred during the study period. They were: Armstrong, Beaver, Cambria, Clearfield, Elk, Greene, Indiana, Jefferson, Somerset, and Washington. See Section III for a breakdown of mining in each county.

The University amassed a large spatial and non-spatial database for the study area. The deliverables required the creation of tabular data, spatial data, photographic materials, and the collection of biological specimens. The resulting datasets of tabular and spatial data were approximately 900-MB and 53-GB, respectively. Tabular data, about features on the surface, and spatial data, enabling identification of spatial relationships between features, were combined to generate a powerful tool for analyzing the effects of underground bituminous coal mining on surface features.

II.B - Data Sources and Software

Spatial and non-spatial data were gathered to answer the questions posed in the scope of work. The data gathering effort spanned 15 months and continued until the end of the contract. Spatial data, in this study, refers to records in a spatial format which includes both location (coordinate) and attribute (descriptive) information. Non-spatial data is used to refer to records that do not include location information such as spreadsheets, photographs, paper documents, etc. Sources of spatial data include:

- PASDA geospatial clearinghouse,
- PA DEP CDMO and the Bureau of Mining and Reclamation (BMR) in Harrisburg, PA,
- The U.S. Census Bureau,
- The U.S. Geological Survey (USGS),
- The Western Pennsylvania Conservancy,
- Several mining operators voluntary submissions of digitized maps, and
- University generated data based on field research.

Formats for spatial data include Shapefiles, Geo-database files, Interchange files, Geo-Tagged Image Format (Geo-TIF) files, and Computer Aided Drawing (CAD) files. Shapefiles, and Geo-database files are proprietary formats used by ESRI's ArcEditor application, while Interchange files are designed for compatibility between Geographic Information System (GIS) applications. Geo-TIF files are similar to Tagged-Image Format (TIF) files with the exception that the Geo-TIF includes location information. Finally, CAD drawing files are proprietary formats used by AutoDesk's CAD application.

Sources for spatial data include PA DEP CDMO, PA Department of Conservation and Natural Resources (PA DCNR), and several mining operators. Sources for non-spatial data include Microsoft Excel spreadsheets, Joint Photographic Experts Group (JPEG) images, TIF files, and paper files.

The accumulation of digital data necessitates the use of applications to read and manipulate the information. As a result, various software programs are employed for data collection and analysis. Table II-1 lists the software programs used in this study, their use, and year of publication.

Table II-1 – Software programs used in this study, use, and year of publication.

Programs	Use	Year
Adobe Photoshop *CS4*	Image Processing Software	2008
ArcGIS Desktop Evaluation Edition *v.9.3*	Mapping and spatial analysis	2008
Analysis of Retreat Mining Pillar Stability (ARMPS)	Pillar Stability	2009
AutoCAD	View and export data	2007
Garmin MapSource	GPS Data Importation	2005
Irfanview	Image Processing Software	2008
Microsoft Office Suite	Data Tabulation and Analysis	2003 & 2007
Microsoft Vista or XP	Operating System	2006
Surface Deformation Prediction Software	Subsidence Prediction	2006

II.C – Collection of Existing Data

Building a database with the capability to analyze the surface impacts of underground bituminous coal mining began with the acquisition of various types of existing data. The tasks set forth in the scope of work merited the collection of base data such as roads and streams, 6-month mining maps, and non-spatial information regarding surface features undermined. The University also obtained access to PA aquatic community data, and a collection of AutoCAD maps that included areas and features undermined. This section details the collection and manipulation of existing data collected during the study. The data described below provided the building blocks for the subsequent tasks of data creation and spatial analysis.

II.C.1 – Base Data

In this study, base data is defined as spatial data with locations of transportation networks, hydrologic features, and political boundaries. These kinds of spatial layers were acquired from the PASDA geospatial clearinghouse maintained by The Pennsylvania State University (PSU) and the Geography Division of the U.S. Census Bureau. They include the following:

- Road datasets:
    - Local and state road datasets created by the PA Department of Transportation (PennDOT), and
    - Topologically Integrated Geographic Encoding and Referencing System of the U.S. Census Bureau.
- Hydrologic datasets:
    - Small watersheds generated from the USGS Water Resources Division's major watersheds dataset by the Environmental Resources Research Institute (ERRI) at PSU,
    - Waterbodies from the National Hydrography Dataset (NHD) created by the USGS,
    - Networked streams of PA created by ERRI,
    - PA Chapter 93 streams with designated use created from the NHD by PSU Institutes of the Environment and Research Triangle Institute, and
    - PA DEP CDMO's GIS/Global Positioning System (GPS) stream observation database.
- Political boundaries datasets:
    - Statewide PA county boundaries created by PennDOT, and
    - Individual county outlines created by CUP during the 2nd assessment.

II.C.2 – Aquatic Community Data

The Aquatic Community Classification Database (ACCD) is both a project and product of the PA Natural Heritage Program of the PA DCNR. The project's goal is to describe communities of fish, mussels, and macroinvertebrates found in streams within PA. The ACCD includes tabular and spatial datasets detailing these aquatic communities, associated geology, stream reaches and watershed boundaries. This database proved useful for analysis related to macroinvertebrate populations and water supply impact classifications. The University obtained access to this database through the Western Pennsylvania Conservancy.

II.C.3 – 6-Month Mining Maps

One core dataset was the collection and consolidation of 6-month mining maps for each mine operating during the study period. These maps were obtained from the PA DEP CDMO. As required by Department regulations, operators submit mine maps at a predetermined scale to the CDMO every six months. This is the PA DEP method for monitoring the progression of mining. The maps are called 6-month mining maps because they depict the location of the last six months of mining prior to the creation date, and a forecast of projected mining during the impending six months. The maps also include information regarding the locations of surface features such as properties, structures, water supplies and utilities. Some maps include coal and surface elevation contours and road and stream networks. An estimated 900 6-month mining maps were received as TIF images by the University and after duplicate and inactive mine maps were eliminated, 317 were used in the assessment.

II.C.4 – Bituminous Underground Mining Information System (BUMIS) Inventory

The PA DEP uses a database called the BUMIS to maintain an inventory of surface features related to underground bituminous mining activities. Surface features are defined as properties, structures, water supplies, utilities, and streams. The University queried the BUMIS database for surface features undermined during the 3rd assessment period, as well as any reported effects. For an explanation of inventory methods for undermined streams refer to Section VIII.

The initial search was conducted by querying each mine name to discover the associated properties undermined between the dates of August 21, 2003 and August 20, 2008, and their corresponding BUMIS System ID number. The second search utilized the BUMIS System ID number for undermined properties to harvest the associated structures, water supplies and utilities undermined for each property. The collected data was organized, sorted, and maintained using Microsoft Excel spreadsheets. Tables were produced for each mine in the study area.

The property numbers in the tables were then compared with property numbers on the 6-month mining maps. Sub-section II.E.3.a has a more detailed discussion of the property rectification procedures. After comparison, any new properties found were queried in BUMIS, and, if found, were added to the University's features undermined inventory. Additionally, several properties were removed from the inventory because they were found to be outside the University's criteria for the active mining region.

After all available information was collected from BUMIS; the University generated final tables for each mine. A Mine Information Spreadsheet and a Final GIS Spreadsheet for each mine were created. These were essentially the summation of the spatial data in tabular form.

The purpose of the Mine Information Spreadsheet is to display the BUMIS inventory and more detailed comment information for features with reported effects. The purpose of the Final GIS Spreadsheet is to enable the collected BUMIS information to join with the spatial attribute table for each feature type in each mine. Sub-section II.E.3 discusses the record matching process for appending the BUMIS information with University generated spatial data.

II.C.5 – Operator Data

University field representatives visited several operators' offices to obtain more accurate digital spatial data regarding mining outlines, surface features undermined, and digital tabular data for Module 8: Hydrologic Information of the permit files. The CDMO has traditionally obtained these materials in paper format, and while this process is migrating toward digital format, during the 3rd assessment period the method of collection was still printed form. Therefore this data had to be manually entered into the electronic repositories.

II.C.6 – Elevation Data

Surface elevation layers were obtained from the National Elevation Dataset available from the USGS. Two digital elevation models (DEM) were acquired for the study area, one covering

Beaver, Washington and Greene counties and a second covering Armstrong, Cambria, Clearfield, Elk, Indiana, Jefferson, and Somerset counties. The spatial resolution upon acquisition was 30-meters (98.4-ft).

Coal contour and some overburden data were collected from Chapter C and Chapter D of "Resource Assessment of Selected Coalbeds and Zones in the Northern and Central Appalachian Basin Coal Regions" (Anon, 2000). These contours proved too coarse to use for overburden generation over each mine, but provided a useful dataset that encompassed the entire study area and allowed comparison between USGS and University generated overburden values.

II.C.7 – Pennsylvania Groundwater Information System

The PA DCNR's Topographic and Geologic Survey compiles and maintains an online database for groundwater information called the PA Groundwater Information System (PaGWIS). Tabular data for groundwater in the study area was obtained from this online resource and imported into a spatial dataset using x, y, coordinate values.

II.C.8 – ACT 54 2nd Assessment Spatial Data

The University acquired spatial data utilized during the 2nd assessment report at the initial stages of this study. That dataset was created by CUP (as a course of completing the 2nd assessment) and included geo-referenced 6-month mining maps, and spatial data for most longwall mines and a small number of room-and-pillar mines. This data was generally used for comparison with several datasets for longwall mines created during this assessment.

II.D – Data Standardization

Each spatial dataset needed a coordinate system to display its location on the Earth's surface. This coordinate system measured the respective locations using geodetic coordinates such as latitude and longitude, Cartesian grid coordinates, or polar coordinates. Once all existing spatial datasets were collected, they were re-projected to the Universal Transverse Mercator (UTM) Coordinate System, using the North American Datum of 1983 and the map projection for UTM Zone 17 North.

The use of a map projection allowed areas and distances to be calculated. A map projection (a mathematical technique) was used to translate the spherical dimensions of the earth (3D) to the planar dimensions of a flat map (2D) (DeMers, 2003). The combination of a coordinate system and a map projection is called a spatial reference.

Several of these datasets required geographic or coordinate transformation because they used a different datum. A datum is a reference surface used to model the shape or size of the Earth (DeMers 2003). Datum are used as the reference surface in most coordinate systems. To transform the spatial reference of a dataset to the reference standard, a coordinate transformation was performed. Coordinate transformation uses one of several mathematical models to adapt the input coordinate system to match the desired format.

II.D.1 – Spatial Reference

The North American Datum of 1983 was chosen as the reference datum because it is based on a newer spheroid, the Geodetic Reference System of 1980. While the North American Datum of 1927, (based on the Clarke spheroid from 1866) was still being used by some entities, and by older datasets, the use of the newer earth shape model for this study was warranted.

The UTM system is used for the entire earth, whereas, the state plane system is exclusive to the US. The UTM system is composed of 60 zones each equaling 6-deg in width. The zones are oriented in a north-south direction; therefore, the state of Pennsylvania is cut through the center leaving an eastern and western half. All mines in the study area are encompassed by zone 17 within the UTM system. This knowledge, coupled with the use of the UTM projection for data in the 2nd assessment led the University to choose the UTM projection as the reference standard for the study.

Acquired base data were produced using various map projections and either NAD 1983 or NAD 1927. These data were re-projected to the reference standard used in the study. All 6-month mining maps, digitized features and PA GWIS point dataset were assigned this reference standard during the creation of the dataset.

II.D.2 – Use of the Geo-Database Format

Base and PA Aquatic Community Data were imported to and stored in the geo-database. ESRI's ArcGIS personal geo-database does not allow simultaneous editing, however, multiple users can view contents and the database can hold up to 2-GB of spatial and tabular data. A geo-database of this kind was populated for each mine in the study. Data within each mine geo-database was trimmed to the extent of the respective county of operation. Geo-databases produced using these methods were incorporated in the final database structure.

II.E –Data Creation

As noted in Section II.C, a considerable amount of data was collected in the initial stages of the study. Most of these items were used to generate necessary data to answer the questions posed in the contract scope of work. While a substantial amount of data was collected, the majority was generated by the University.

Several deliverables required the creation of new data. First, locating each mine required geo-referencing of the 6-month mining maps; as well as digitizing the extent of mining and locations of all features undermined. Second, creating the overburden maps required digitization of mining outlines, surface features and structure contours from the geo-referenced maps.

Overall, the University created data layers in seven categories: "Geo-referenced Maps," "Mining Outlines," "Surface Features," "Contours," "Overburden," "Buffers," and "Stream

Observations." The following sub-sections explain the methodology for the creation of this data as well as how existing data was integrated during the process.

II.E.1 – Geo-referenced Maps

This section explains the process utilized in geocoding the mine maps for this analysis. The first task was to determine the location of mines operating during the study period. As mentioned in Section II. C. over 900 6-month mining maps were acquired in hardcopy (paper) format from the PA DEP CDMO. A subset of these maps were scanned to create usable digital images. The method to geocode these scanned images into their location on the earth is called geo-referencing.

Folders obtained for each mine have sub-folders by year of operation during the assessment period that contain sheet maps and, if present, generally one copy of an index map. For example, 20 maps might be acquired for one mine that include an index and different versions of each sheet map over time. This results in a large number of maps with similar information. Since the University needed to identify the extent of mining and surface features on these maps deciding which version of the sheet maps to use posed a challenge.

The University developed a protocol for the most recent versions of all index and sheet maps to be entered into the geo-referencing stream. The analysis of those 900 maps led to the subsequent geo-referencing of 317 6-month mining maps for the assessment period. The average number of maps geo-referenced per mine for longwall mines was 16 maps while the average number per mine for room-and-pillar and room-and-pillar with pillar recovery mines was five maps. The protocol further stipulated the desired accuracy of the geo-referencing process. During the process the scanned images were loaded into the software application and referenced to base data such as roads and streams using control points. The protocol required a minimum of three control points to reference an image, two to pin the image to a plane, and a third to disable rotation. The application tool, called the Geo-referencing tool, calculated a root mean squared error (RMSE) for all control points in relation to each other. The protocol set the minimum number of control points at four and the largest allowable RMSE at 10-m. Figure II-1 shows the distribution of the RMSE and the mean number of control points used for each mine in the study area. The blue lines represent the mean number of points and red lines represent the average RMSE. As evidenced by the graph, mines with a higher average number of points tended to have a lower average RMSE. One outlier was Dooley Run which had nine control points and a RMSE of 9.6-m (meters). This is typically the result of divergent data points on the input maps. The average RMSE and average number of points for all 6-month mining maps were 3-m and 6.8, respectively. This meant the average horizontal accuracy for any 6-month mining map in the University GIS Database (UGISdb) was 3.0-m.

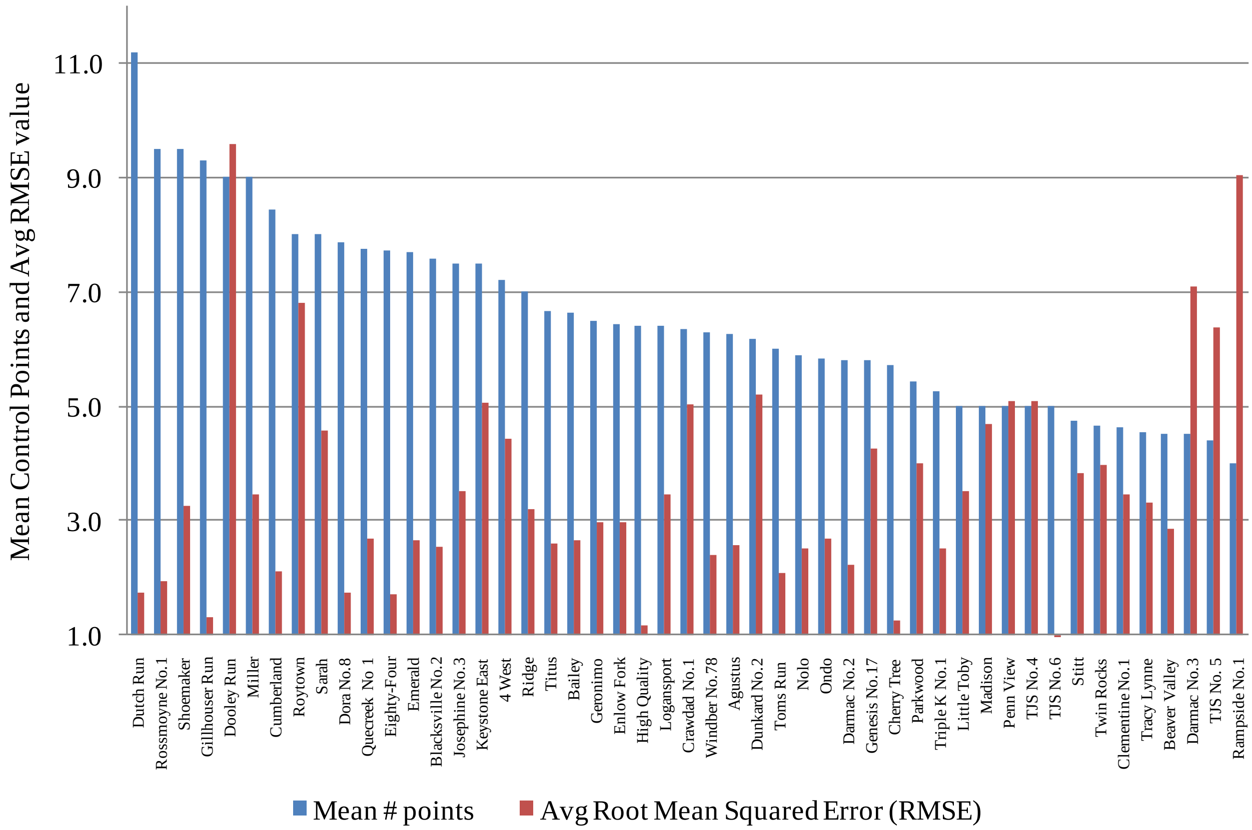


Figure II-1 - The mean number of control points and average root mean square error (in meters) for each mine in the study area. The total number of maps included here is 317.

II.E.2 – Mining Outlines

Once the location of all the mines was determined and a series of 6-month mining maps were geo-referenced, the University began the task of determining the extent or amount of mining that occurred during the assessment period. Refer to Section III for a listing of the acre per mine.

The extent of mining was generated by digitizing the outline of mining from the geo-referenced 6-month maps, and obtaining the outlines in AutoCAD or preferably, a shapefile format was received from a mine operator. All operator data was verified using the 6-month maps. In total, 24 mining extents were obtained from the respective operator, and the remaining 26 mines were digitized from 6-month mining maps.

II.E.3 – Surface Features

The most difficult task proved to be rectifying the BUMIS inventory with that of the GIS feature inventory. Features are defined within this study as properties, structures, and water supplies. In brief, this process included joining the BUMIS inventory to the spatial datasets that were generated from, or verified using, the 6-month mining maps.

A 200-ft buffer was created around all areas mined during the 3rd assessment period. The designation of 200-ft was a product of both the use of a 200-ft buffer by the CDMO for inventory purposes and the variance in other inventorying zones such as the 100-ft buffer for structures and the variable RPZ buffer for water supplies. The 200-ft buffer standardized the management of several feature types and other data layers to a uniform boundary limit.

The 200-ft buffer used in this process served as the perimeter of the GIS inventory with the exception of features with reported effects. A reported effect was any feature with a corresponding problem file indicating a possible mining related impact during the assessment period. The final totals for GIS features within 200-ft of mining or having a reported effect were: 3,587 properties, 3,735 structures, and 2,789 water supplies.

The remainder of this section details the process for digitizing and joining BUMIS feature spreadsheets with their respective spatial counterparts. There were many surface features on the 6-month mining maps that were within 200-ft of mining, yet not included in the inventory extracted from BUMIS; at the same time, there were many surface features in the BUMIS inventory that were outside 200-ft buffer. These discrepancies were rectified within UGISdb.

II. E.3.a - Properties

The University, using the property lists generated from BUMIS and the 6-month mining maps, identified properties within 200-ft of the extent of mining for each mine in the study. As mentioned above, properties listed in the BUMIS inventory that are located outside 200-ft from active mining were not included in the joining process unless the property listed a reported effect. All properties within or intersecting the 200-ft buffer were inventoried. The identification process found approximately 370 new properties not listed in the original BUMIS inventory. After a second round of queries, 175 of the new 370 properties were found in BUMIS and more detailed information was present in the UGISdb. The remaining 195 properties were added to the UGISdb, but lacked information commonly found in BUMIS such as property owner, feature use, etc. Reasons for the lack of information in BUMIS regarding the remaining 195 properties found within 200-ft of active mining remains unknown.

Once the two sources were evaluated, a further step was required to merge the two datasets into one. This process began with the feature shapefile and the BUMIS inventory spreadsheet for each mine. A unique identifier was added to each input and used as a common field to append the non-spatial tabular data into the spatial attribute table. Next, a record matching algorithm was applied to the spatial dataset and the non-spatial data is appended. This result was then exported to a new dataset and given a name to show it was successfully merged. This process appended the basic information derived from BUMIS, i.e. Owner, County, Feature Type, etc. Spacial data (maps) can now be queried by this non-spatial set of criteria.

In many cases, a second merge was required to append information related to reported effects for each feature, i.e. claim ID, occurrence date, resolution, etc. A unique identifier was placed in the new spatial dataset. Additionally, a second spreadsheet containing information regarding reported effects included this same identifier, the BUMIS Problem ID. Finally, a record matching algorithm was applied to the dataset, the new tabular information was appended, and an updated dataset was exported which had both the mine information and information regarding reported effects.

Limitations of the property dataset included the accuracy of property boundaries and inclusion of all properties present in the mined area. First, since the extent of input information for 50-pct of the mines was limited to the 6-month mining maps, the property boundaries only extended to the borders of these maps which in many cases do not represent the real boundary of the property. Second, if a property was subdivided toward the end of the assessment period, it could have been missed in the spatial inventory due to temporal conflicts between the dates of the BUMIS inventory, dates of the 6-month maps being used, etc.

II. E.3.b - Structures and Water Supplies

Once the property inventory was complete, the task of locating the remaining features, structures and water supplies, within each property boundary was the next step in the progression. The 200-ft buffer was also added, and any structure or water supply, without a reported effect, located outside the buffer was eliminated. A similar process, as described for the property identification, was used for these features. Lists generated from the BUMIS inventory were compared to lists generated from a spatial inventory using 6-month mining maps and operator provided data. Discrepancies found during this cross-referencing were resolved.

As time elapsed between the BUMIS inventory, in the fall of 2008, and the completion of the study, a discovery query tool was used to find all reported effects that occurred during the 3rd assessment that had not been entered into BUMIS by the end of 2008. These reported effects were referred to colloquially, by the University, as Blue Features.

In some cases, the blue features were located far from mining or out of the extent of the 6-month mining maps, and in others, the features were in the original spatial inventory without appended BUMIS information or were in the original BUMIS inventory but without a reported effect. A total of 365 blue features, or new reported effects, were found using the query tool. Of these 365 blue features 332 were assigned spatial locations and 33 were added as attributes in tabular form to the University GIS Database. The methods for locating the blue features with reported effects were as follows:

- Features that were found within the original inventory(s) were updated with new claim/problem information;
- Features not found in the original inventory were first located based on a property number, if present; or
- Using Topologically Integrated Geographic Encoding and Referencing system (TIGER) line files created by the U.S. Census Bureau, or
- Searching Google Maps web-based mapping application for the address listed in the dataset, and
- Once found, the information was updated in the UGISdb.

II.E.4 – Contours

Structure contours in this study included overburden, coal, and surface contour layers. These datasets were digitized from 6-month mining maps, obtained in AutoCAD, raster format from an operator, or taken from the PA portion of a regional coalbed assessment (Anon, 2009). There were a total of 14 overburden contour datasets, 36 coal contour datasets, and 2 surface contour datasets. Table II-2 shows the data sources for each category. Surface datasets were not included in the UGISdb. However, University generated overburden contour layers were included in the UGISdb. See sub-section II.E.5 for a description of the overburden creation process.

Table II-2 –Three categories of contour and their respective data sources.

Category	Digitized from Geo-referenced Map	Obtained from Operator	Used Chapter D Coal Contour (USGS)
Overburden	1	13	0
Coal	24	11	1
Surface	1	1	0

II.E.5 – Overburden

The creation of an overburden map for each mine was an important task. The resulting overburden dataset was used as an input for the generation of the RPZ buffer and was referenced as a key source of all analysis in the report. Two main processes were used to generate the resulting overburden maps. Each process is defined in the following paragraphs.

The processes were divided by the contour input. Since the database included both coal contours and overburden contours, there were parallel processes used to reach the desired result, a final overburden contour dataset accurate to 500-ft beyond the edge of mining.

The process used for an overburden contour input was interpolated using spline interpolation method. This method, developed by Hutchinson (1989), is still the only contour-based interpolation method in use. The tool, found in the Spatial Analyst module of ArcEditor, was used to interpolate the overburden contours in line form to a continuous raster surface with 10-m pixels (cells). Each contour was measured using units of feet resulting in the surface cells storing measurements in feet. A buffer of 500-ft was used in the interpolation process; therefore, the accuracy of the interpolation is bound by this distance.

In a parallel process, if coal contour dataset was used as input, there was an additional step to create the overburden map. The coal contour was interpolated to a continuous surface as described above. Meanwhile, the two National Elevation Dataset DEMs of the surface were re-sampled from 30 to 10-m pixels. The final step was to subtract the interpolated coal elevation raster surface from the modified DEM raster surface with the difference image representing the overburden surface. Once a raster surface was derived for each mine, each surface was used to generate new overburden contours extending 500-ft beyond mining.

One significant limitation for this dataset was the provenance of coal contours in both the 6-month mining maps and AutoCAD files. Knowledge of the National Elevation Dataset origin could be combined with knowledge of contour datasets to develop an estimation of temporal resolution. Due to the absence of this key piece of information an accurate temporal resolution for the generated overburden datasets could not be identified.

An estimation of horizontal accuracy for the resulting overburden contour datasets were made for coal contours digitized by the University (approximately 24 mines). An estimation of this error can be found by adding the pixel size of University generated overburden surfaces (10-m) and the average geo-referencing error (3-m) resulting in a maximum of a 13-m horizontal error. A more detailed estimate of error can be calculated for each mine using the average geo-referencing error for each specific mine. Other datasets were estimated to have at least 10-m error, yet the real error could be larger. One mine had no available contour information so data from Chapters C and D of Resource Assessment of Selected Coal Beds and Zones in the Northern and Central Appalachian Basin Coal Regions (Anon, 2000) was used. These data were generated using 100-m pixels and the horizontal error was estimated as high as ¼ mile (approximately 400-m). A statement of vertical accuracy cannot be made due to the lack of provenance for all contour data with the exception of Chapter C and D data which estimate a 30-m vertical accuracy.

II.E.6 – Buffers

Several buffers were used in the study to determine relationships based on proximity, create a boundary for analysis, or model an existing regulatory boundary. These buffers included both uniform and variable distances, and extended both outside or around a feature and inside or within a feature (Figure II-2).

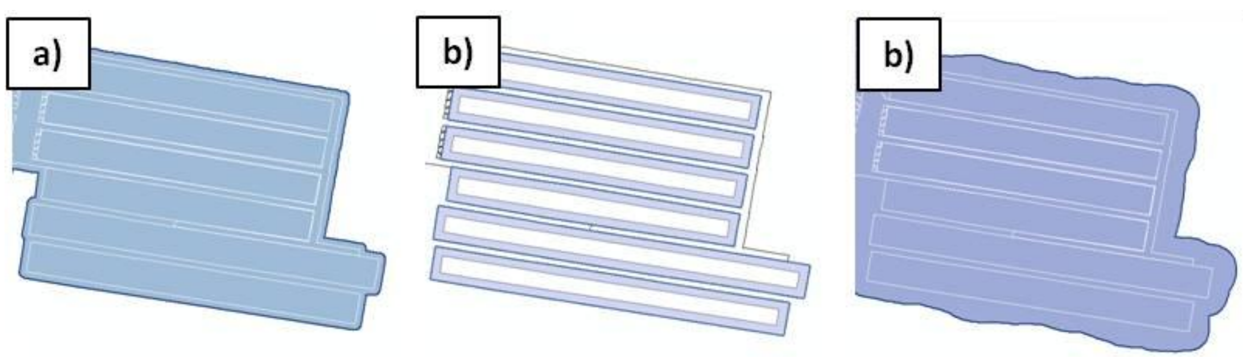


Figure II-2 – The uniform, variable, inner and outer buffers used in the study; a) Uniform outer 200-ft buffer, b) Variable inner – Quarter width, and c) Variable outer – RPZ.

II. E.6.a - Uniform Distance Buffer

Two uniform distance outer buffers were used for all mines in the study. A 200-ft (Figure II-10a) and 500-ft buffer were generated from the mining outline and used as a boundary for feature inventory and analysis, and overburden generation, respectively.

II. E.6.b - Quarter-Width Panel Buffer

A variable, inner buffer was generated for each longwall panel based on the following equation (Panel Width x 0.25). The resulting buffer was generated inside the polygon panel feature (Figure II-10b). This buffer was used to determine each water supply and structure's position along the longwall panel and inference about proximal relationships between the surface feature and its position over mining.

II. E.6.c - RPZ Buffer

A variable, outer buffer was generated based on the depth of mining (Figure II-10c). Two equations were used to create the buffer: (Overburden value x Tan (35-deg x (π/180)) and (Calculated RPZ Distance / 3.281). For a full discussion of the purpose and use of the RPZ boundary by the PA DEP, refer to Section VI.C.

The creation of this variable, outer buffer was an effort to model the complex boundary used by the PA DEP. The input dataset was the overburden map discussed in Section II.E.5. The raster surface was then converted to a polygon shapefile where each polygon stored an overburden value. This new polygon shapefile was clipped to the edge of mining.

The equations listed above were applied to the overburden values at the edge of mining and stored as an attribute. The variable buffer was created based on this calculated attribute. The resulting dataset included many small buffers around each polygon and a dissolve procedure was used to generate visual clarity. Note that equation two was necessary because the spatial reference used by the dataset was measured in meters and the input overburden dataset is measured in feet; therefore, the calculated RPZ distance used in the buffer generation must match the units of spatial reference.

II.E.7 – Stream Observations

The University was tasked with surveying streams with reported effects or for control conditions. The goal was to obtain data for tabulating a Total Biological Score for impacted streams. For more information about stream assessments and calculated Total Biological Scores see Section VII.

II. E.7.a - GPS Data Collection

During each surveying trip the University Team used a Garmin ETrex GPS device to accurately capture each sampling location. The status of sections of each stream walked was caterogrized as flowing, dry, or intermittent. This data was imported into Garmin MapSource software and exported to an AutoCAD Drawing Exchange Format File which was converted to an ESRI shapefile for use in the University GIS database. The GPS data points were collected in the World Geodetic System of 1984 geographic coordinate system which is the default coordinate system used in most GPS data collection. After extraction from the device, the GPS data points were transformed to the North American Datum of 1983 and projected to the UTM Zone 17 North projection in accordance with study standards.

II. E.7.b - Stream Segments

After the GPS data was extracted and placed in the UGISdb, the University digitized segments between the captured points following the streams on an existing stream dataset called Net Streams 1998. The resulting dataset included all sections of surveyed stream and their status on the date of observation. Maps showing these observations are included in Appendix D.

II.E.8 – Land Use

The digitized stream segments discussed in the preceding section were used to create a layer of data showing the associated land use within 100-ft of the stream. Each surveyed segment was given a 100-ft buffer and this buffered area was used to select only overlapping land use information for that area. For a full discussion of the results of this analysis refer to Section VII.

II.E.9 – Wetland Maps

Wetland maps for several mines were obtained from one longwall operator. Of these, 21 were geo-referenced with an average of 3.27 control points and 1.69-m RMSE. A more accurate estimate of the area of wetlands in these mines were not possible as several maps marked a wetland as a point, rather than defining the encompassed area; and maps with more accurate delineations included few features for geo-referencing. A second limitation was the age of the only national wetland dataset. The National Wetland Inventory, created in 1992, was no longer representative of the number of wetlands currently present in the study area. Refer to Section IX for more discussion on wetlands.

II.F – University GIS Database Structure

The UGISdb was structured as a functional collection of discrete datasets organized by mine. The contents included AutoCAD data, the geo-referenced 6-month mining maps, University generated spatial data, University generated BUMIS spreadsheets, and the geo-database of existing data clipped to the extent of the county where the mine operated. The benefit of maintaining the dataset in this structure is its portability. With this strategy, each mine's dataset is manageable, but if it had been organized by feature type, any assessment of a particular mine would have required copying data from many different folders and sharing data that would have been time consuming. The following section defines the file structure of the database, and associated attributes assigned to specific layers.

II.F.1 – File Structure

In the mine information portion of the database, a folder for each mining type (i.e. Longwall, Room-and-pillar, and Room-and-pillar with Recovery) assessed in the study provides the highest level of the database. Each mining type folder includes folders for each mine classified as that type in this study period. Each mine folder included all data collected or created by the University.

Other categories of data in the database include Streams and Wetlands. These data extend beyond the boundaries of a single mine so the data is managed at the feature level. Folders for these features are the highest level of the database along with the mine information data. Each folder is then organized by data type similar to the mine information dataset. Figure II-3 compares the size of all datasets, mine information, streams, and wetlands.

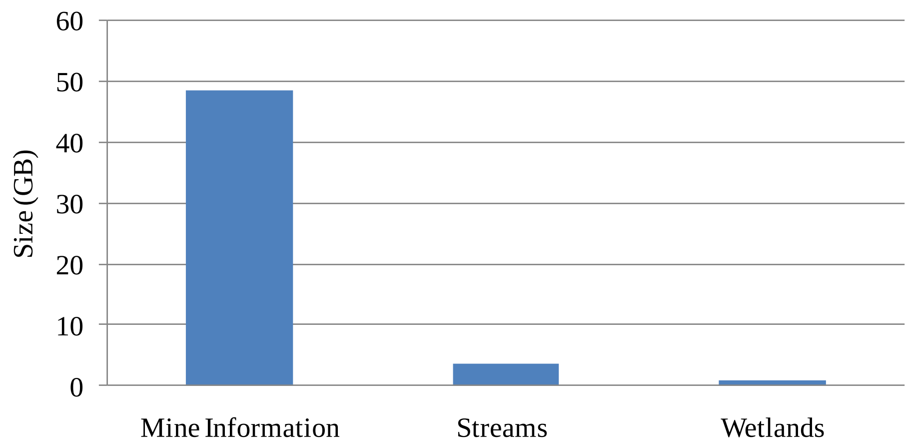


Figure II-3 – Comparison of the size of the three highest level datasets, Mine Information, Streams, and Wetlands. Mine information is the largest dataset with 48.5-GB, the Streams dataset contains 3.5-GB, and the Wetland dataset is much smaller at 0.8-GB.

II.F.2 – Attributes

Every dataset has a set of attributes. Attributes are non-spatial information that describe a spatial feature. There are approximately 22 feature files in each mine dataset. Each dataset includes specific attributes for analysis. A general list of primary attributes for Features, Mining Outlines, Contours, Overburdens, and Buffers follows.

II. F.2.a - Features

The surface features are a core product of the study. These features are used to assess the overall impact of underground bituminous coal mining within the study area. General attributes for the three generated feature layers, properties, structures and water supplies are as follows: Property Number, Property System ID, Unique Identifier, Property Owner, County, Feature ID, Feature Number, Feature Type, Feature Use, Problem ID, Claim Number, Cause, Occur Date, Interim Resolution Date, Final Resolution Date, Resolution Status, Mine Name, Operator, Topographic Location, Overburden, Surface Elevation, Panel Location, Coal bed, and Area in Square Feet.

II. F.2.b. - Mining Outlines

The mining outlines are used to calculate the acres of mined coal, serve as the boundary to base the 200-ft buffer inventory extent, and provide positional information for reported effects to water supplies and structures. General attributes for these datasets include: Mine Name, Operator Name, Coal bed, Status, Mining Type, Acres, and Area in Square Feet. Longwall Panel datasets included extra attributes such as: Panel Number, Panel Length, Panel Width, Year Complete, Start Date and End Date.

II. F.2.c - Contours

The contour layers are used to generate elevation surfaces for both coal and overburden elevations. General attributes in these datasets include: Mine Name, Operator Name, Coal bed and Elevation Value.

II. F.2.d - Overburden

Overburden datasets are used for analysis of water supplies and structures and provide an analysis of the average depth of mining for mines operating during the assessment period. The raster overburden datasets do not have multiple attributes. The raster data structure stores a single attribute, in this case an elevation value in each cell composing the grid. The raster overburden datasets were converted to shapefile format and more attributes were added to this dataset. General attributes for the overburden shapefile include: elevation value, and calculated RPZ distance.

II. F.2.e - Buffers

Several buffers were employed in the study. A uniform buffer of 200-ft was used to inventory all surface features, a quarter-width buffer to determine panel position for water supplies and structures, and a custom buffer for the RPZ distance from mining. General attributes for the 200-ft buffer include: Mine Name, Operator Name, and Buffer Size. General attributes for the quarter-width buffer include: Mine Name, Operator Name, Panel Number, and Buffer Size. General attributes for the RPZ buffer include: Mine Name, Operator Name, Buffer Distance, and Dissolve.

II.G – Metadata Creation

Due to the immense effort put forth to create these datasets, the University places a high priority on enabling the efficient use of the data in the future. Metadata was added to all datasets to ensure the proper information about purpose, geo-processing, and other data manipulation is transferred to future users. A formal definition lists the main components of metadata as properties and descriptions. The properties are pieces of information populated automatically by the GIS software such as the spatial reference and geo-processing history while descriptions are human entered information explaining access, use, purpose, current location, and publication date of a dataset. For any data to be truly useful, it is important to have information about the data including what the data is used for, how it can be used and accessed, and especially, how it was created.

The metadata standard chosen for this study is the Content Standard for Geographic Metadata developed by the Federal Geographic Data Committee (FGDC). This standard was developed for and is used predominately in the U.S., but several data providers in Canada have also employed it for metadata design.

This metadata standard is supported by the ArcCatalog module of ArcEditor. To access the metadata for these datasets, select the FGDC Classic as the metadata viewing format within the module and then select the dataset for which the information is needed. The FGDC metadata standard includes the following categories:

- Citation Information,
- Publication Date,
- Title,
- Abstract,
- Purpose,
- Time Period of Content,
- Spatial Coordinates,
- Keywords,
- User Constraints,
- Attribute Information, and
- Contact Information.

II.H – Summary Observations

Data collection proved to be an on-going process. The amount of data collected resulted in databases of 900-MB and 53-GB. Existing data was obtained from many providers including local, state, and federal government entities, non-profit organizations, and mine operators. Efforts to gather existing data, geo-referencing and feature rectification proved the most time consuming tasks. There were several new data products created during the 3rd assessment period, such as the generation of overburden maps, RPZ maps, and quarter-width panel buffers.

All data in the UGISdb is transformed into the reference standard for the study. Based on its accuracy for the entire region under study the reference standard is viewed as the best choice; however, as models of the earth and new projections see continued development, this could most certainly change in the future.

The utility of the database structure proved itself time and again as a flexible and portable collection which enabled many to utilize each dataset and understand its simple structure. While the database structure proved efficient, the task of data management included many hurdles.

The creation of metadata in the UGISdb ensures the data created during this assessment has the potential to be used for many years to come. The methodology and database presented in this report will both inform researchers of potential obstacles, as well as aid them in amassing large datasets in future assessment periods.

SECTION III: Underground Bituminous Coal Mining During the 3rd Assessment Period

III.A - Overview

The determination of impacts began by ascertaining what lands were undermined by bituminous coal mines between August 21, 2003 and August 20, 2008. The University accomplished this by collecting and analyzing the 6-month mining maps that are part of every mine's permit files and by company supplied digital maps. Fifty mines were identified as active during this period and their mining extents were determined and sorted by the type of mine, mining method, coalbed, overburden, size, and location. It should be noted that throughout this report, maps show only those areas undermined during the 3rd assessment period and not the total subsidence boundary.

III.B – Mines in Operation during the 3rd Assessment Period

The identity of the mines that operated during the 3rd assessment period were determined with PA DEP assistance, using coal production records, 6-month mine maps, and BUMIS records. Areas within individual mines where active mining operations took place were determined from 6-month mining maps and through digital maps obtained from the mine operators. In many cases, the digital maps included additional details which made it easier to determine the extent of mining that occurred during the period. 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. A list of all active mines is provided in Appendix A and their locations are displayed on Plate 1.

III.B.1 – Room-and-Pillar Mines

Ten companies operated 36 underground room-and-pillar mines during the 3rd assessment period (Table III-1). The percentage of mines operated by the ten companies is shown in Figure III-1. The largest company was Rosebud Mining, followed by AmFire, TJS, and Roxcoal. These four companies accounted for 81-pct of the room-and-pillar mines. Six other companies operated the remaining 19-pct of the mines. Many of the room-and-pillar operations were locally owned.

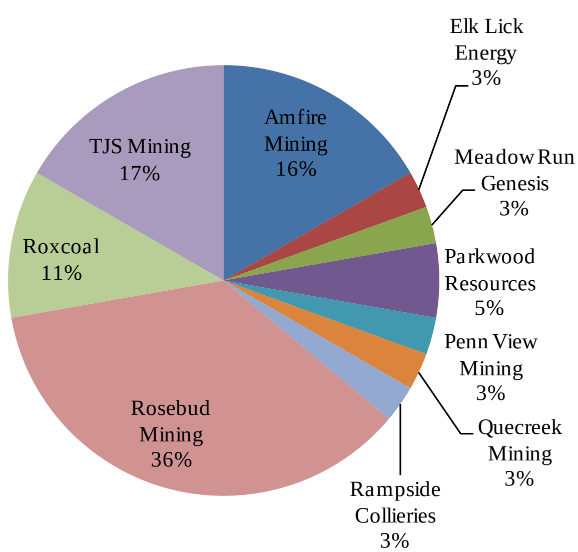


Figure III-1 - Percentage of room-and-pillar mines operated by ten different companies.

Table III-1 - Active room-and-pillar mines sorted by mining company.

Company	#	Mine Name
AmFire Mining Co.	6	Dora No.8, Gillhouser Run, Madison, Ondo, Ridge, Triple K No.1[1]
Elk Lick Energy Inc.	1	Roytown
Meadow Run Genesis Inc	1	Genesis No.17
Parkwood Resources Inc.	2	Cherry Tree, Parkwood
Penn View Mining Inc.	1	Penn View
Quecreek Mining Inc.	1	Quecreek No.1
Rampside Collieries Inc.	1	Rampside No.1
Rosebud Mining Co.	13	Beaver Valley, Clementine No.1[2], Josephine No.3, Little Toby, Penfield, Toms Run[3], Tracy Lynne, Twin Rocks, Windber No.78, Dutch Run, Keystone East, Logansport, Stitt
Roxcoal Inc.	4	Agustus, Geronimo, Miller, Sarah
TJS Mining Inc.	6	Darmac No.2, Darmac No.3, Rossmoyne No.1, TJS No.4, TJS No.5, TJS No.6

[1] - Formerly Mears Enterprises Inc.; [2] - Formerly McVille Mining Co.; [3] - Formerly Burrell Mine owned by Pennamerican Coal LP

III.B.2 – Room-and-Pillar Mines with Pillar Recovery

Six additional room-and-pillar mines employing the pillar recovery mining methods were active during the 3rd assessment period (Table III-2). These mines were operated by three companies: AmFire, Cobra Mining, and Dana Mining. In all six operations, pillar recovery occurred in relatively small mining blocks, typically less than 1000-ft in length. These areas were mostly within production panels but occasionally occurred along main entries as the mines retreated from their reserves.

Table III-2 – Active room-and-pillar mines with pillar recovery sorted by mining company.

Company	Number	Mine Name
AmFire Mining Co.	1	Nolo
Dana Mining Co. of Pennsylvania Inc.	4	Crawdad No.1, Dooley Run, Titus, 4 West
Cobra Mining LLC	1	Dunkard No.2

III.B.3 – Longwall Mines

Eight longwall mines were active during the 3rd assessment period (Table III-3). The Shoemaker mine operated largely in the state of West Virginia but a small portion of its reserve crossed over into Washington County. These eight mines were owned by three large companies: Consol Energy, Alpha Resources (formerly Foundation Coal), and UMCO Energy (a part of Murray Energy Corp.). Many of these longwall operations were among the most productive underground coal mines in the nation.

Table III-3 – Active longwall mines sorted by mining company.

Company	Number	Mine Name
Consol Energy	5	Bailey, Blacksville No.2, Enlow Fork, Mine Eighty-Four, Shoemaker
Foundation (now Alpha Resources)	2	Cumberland, Emerald
UMCO Energy	1	High Quality

III.C – Mining in Different Coalbeds (Stratigraphic Influences)

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 3rd assessment period. Rocks within the Pennsylvanian System range from 299 to 318-million years old (Anon, 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 named:

- Uniontown Formation – late Pennsylvanian shales, sandstones, and thin coalbeds
- **Pittsburgh Formation** – **minable coalbeds,** shales, sandstones, and limestones
- Casselman Formation - claystones, shales, sandstones, and thin limestones
- Glenshaw Formation – claystones, shales, sandstones, and thin limestones
- **Allegheny Formation** – **minable coalbed,** shales, claystones, sandstones, and limestones
- Pottsville Formation – 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-2).

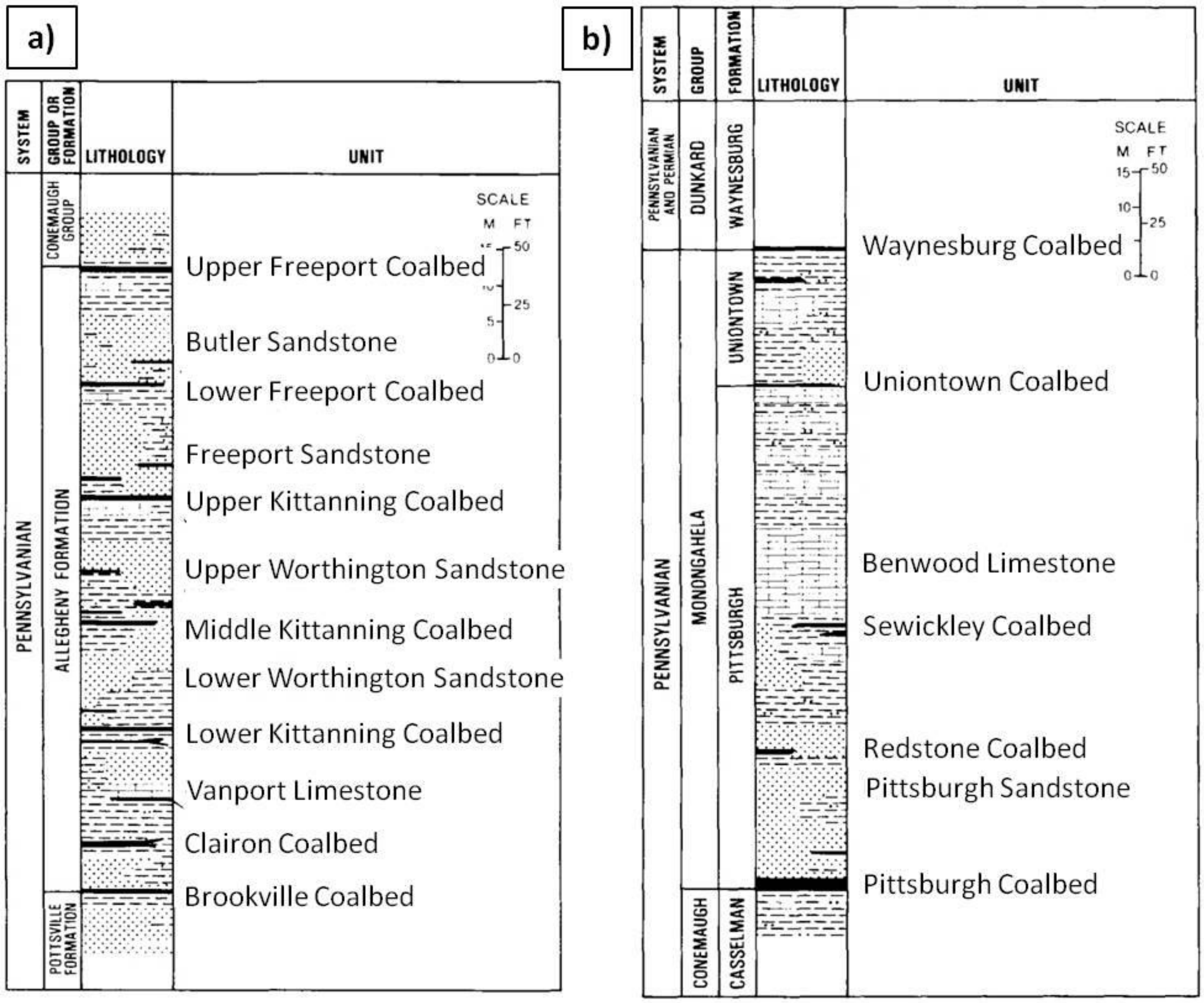


Figure III-2 - Generalized stratigraphic sections of the a) Allegheny and b) Pittsburgh Formations of western Pennsylvania (Edmunds, et. al, 1999).

III.C.1 – Coalbeds Mined

Six coalbeds were mined during the 3rd assessment period. Four of the coalbeds are contained within the Allegheny Formation and two within the Pittsburgh Formation (Table III-4). The Allegheny Formation contains 36 mines while the Pittsburgh Formation has 14 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, 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 that ranges in thickness from 520-ft in western Washington County to 890-ft in Somerset County (Edmunds, 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-4 - Coalbeds with active mines, listed by number and Formation.

Formation	Coalbed	Number of Mines
Pittsburgh	Sewickley	5
	Pittsburgh	9
Allegheny	Upper Freeport	14
	Lower Freeport	2
	Upper Kittanning	8
	Lower Kittanning	12

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-3 shows the relationship between the areas mined by a particular coalbed versus the number of mines operated in this coalbed. The nine mines in the Pittsburgh Coalbed were, with the exception of the Ridge Mine, all large longwall operations and their corresponding footprint on the surface was equally large. On the other end of the spectrum were the 14 mines in the Upper Freeport Coalbed. These mines were generally very small room-and-pillar mines that were limited by the number and extent of mineable blocks of coal.

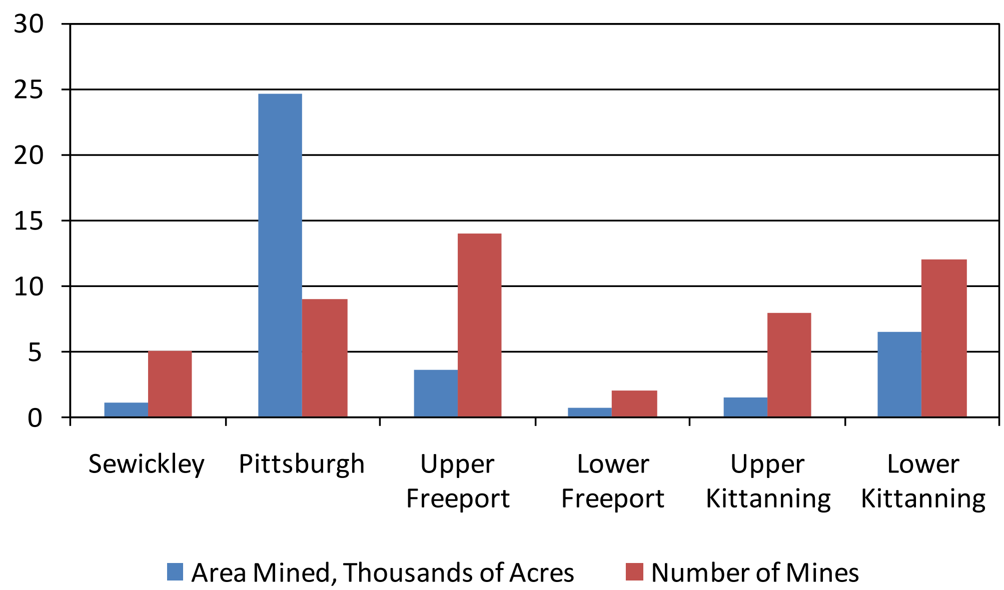


Figure III-3 - Distribution of areas mined by coalbed.

III.C.2 – Allegheny Formation Coalbeds (Freeport and Kittanning Coalbeds)

Because the Allegheny Formation Coalbeds are lower in the stratigraphic section than Pittsburgh Formation Coalbeds, they occur under larger areas of surface land. The broad lateral expression of the Allegheny Formation Coalbeds is due to a combination of factors, including erosional history, structural setting, depositional environment and stratigraphic position. Figure III-4 is a map of the extensive surface area underlain by the Upper Freeport Coalbed in western Pennsylvania. The Lower Freeport and Kittanning Coalbeds, to the extent they are present, are found beneath the same general areas.

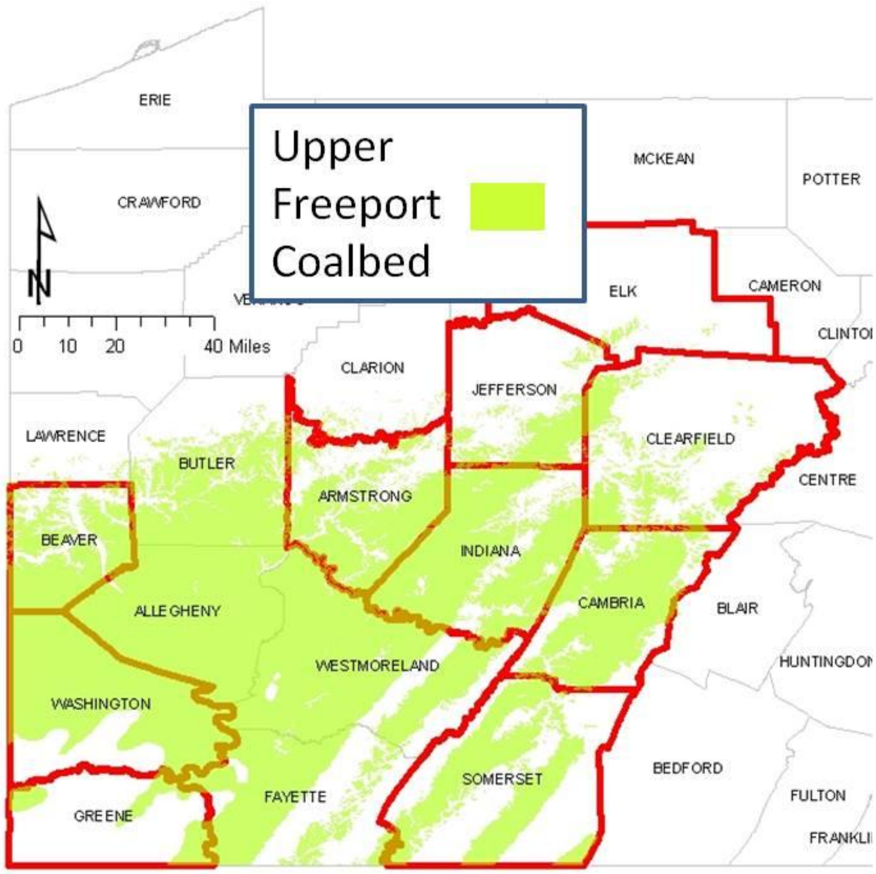


Figure III-4 - Areas underlain by the Upper Freeport Coalbed. Note - The footprint of the Freeport approximates the areas underlain by other Allegheny Formation Coalbeds.

Since the coal basin dips gently to the southwest, the Allegheny Formation Coalbeds mainly crop out along a belt from Beaver County through Butler, Armstrong, Indiana and Cambria Counties and finally bends southward through Somerset and Fayette Counties (Figure III-5). Mines in these areas tend to be less than 500-ft below the surface. Mineable blocks of coal are segmented by outcropping of the coalbed or by areas of un-mineable coal thickness, i.e. less than 3-ft. In addition, these same areas have witnessed significant mining in the past. Further to the southwest into western Washington and Greene Counties, the Allegheny Coalbeds are under significant overburden (approaching 2,000-ft in some areas). These areas represent future mining prospects.

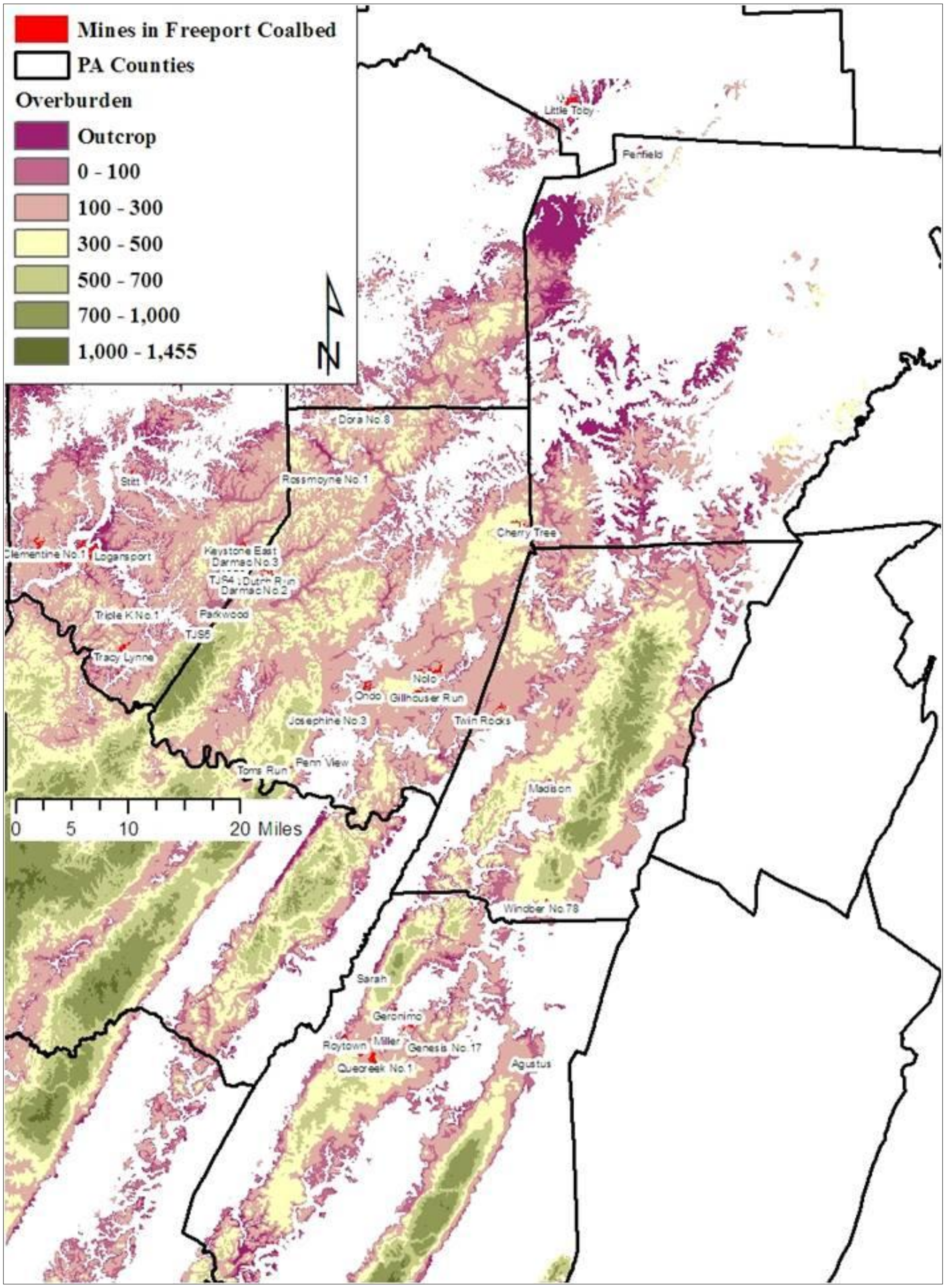


Figure III-5 –The overburden of the Upper Freeport Coalbed and the locations of the 36 mine operated in Allegheny Formation Coalbeds.

III.C.3 – Pittsburgh Formation Coalbeds (Pittsburgh and Sewickley)

Pittsburgh Formation Coalbeds are found in eight counties (Figure III-6). The vast majority of the current, and future, mining in the Pittsburgh Formation Coalbeds is located in Greene and

Washington Counties where the coal is relatively continuous and, for the most part, relatively deep (400 to 2,000-ft). Allegheny, Fayette, and Westmoreland Counties also have continuous deposits of the Pittsburgh Coalbed, however, the shallow depth (< 400-ft) of the coal made it easily accessible for underground mining and it is now largely mined out.

In Armstrong, Indiana and Somerset Counties, the Pittsburgh Coalbed occurs in a few relatively small basins remote from the main group of Pittsburgh Coalbed mines that operated during the reporting period. Only one operation, the Ridge Mine in Armstrong County, mined in an isolated small pocket of yet un-mined Pittsburgh Coalbed with an overburden less than 200-ft.

Figure III-6 - Areas underlain by the Pittsburgh Coalbed. Note - While current mining in the Pittsburgh Coalbed is largely limited to Greene and Washington Counties, drift and shaft mining have occurred in Allegheny, Armstrong, Fayette, Indiana, Somerset and Westmoreland Counties over the last 100 years.

The current mining in Pittsburgh Formation Coalbeds primarily occurred as:

- Large longwall mine in the Pittsburgh Coalbed within Greene and Washington Counties, and
- Small room-and-pillar mining with some pillar recovery in the Sewickley Coalbed within Greene County.

The overburden above the Pittsburgh Formation increases steadily to the southwest (Figure III-7). Current longwall mining occurred at depths ranging from greater than 400-ft to approximately 1,000-ft. The one exception to this is the High Quality Mine where the depth of cover ranged from 195 to 560-ft. Most of the un-mined coal reserves lie within the central portion of the basin where the overburden is between 700 and 1,400-ft (Figure III-7). Conversely, the Sewickley Coalbed was mined towards the eastern margin of the Pittsburgh Formation extent where overburdens ranged between 300 and 500-ft. These operations typically mined isolated, relatively small, blocks of coal.

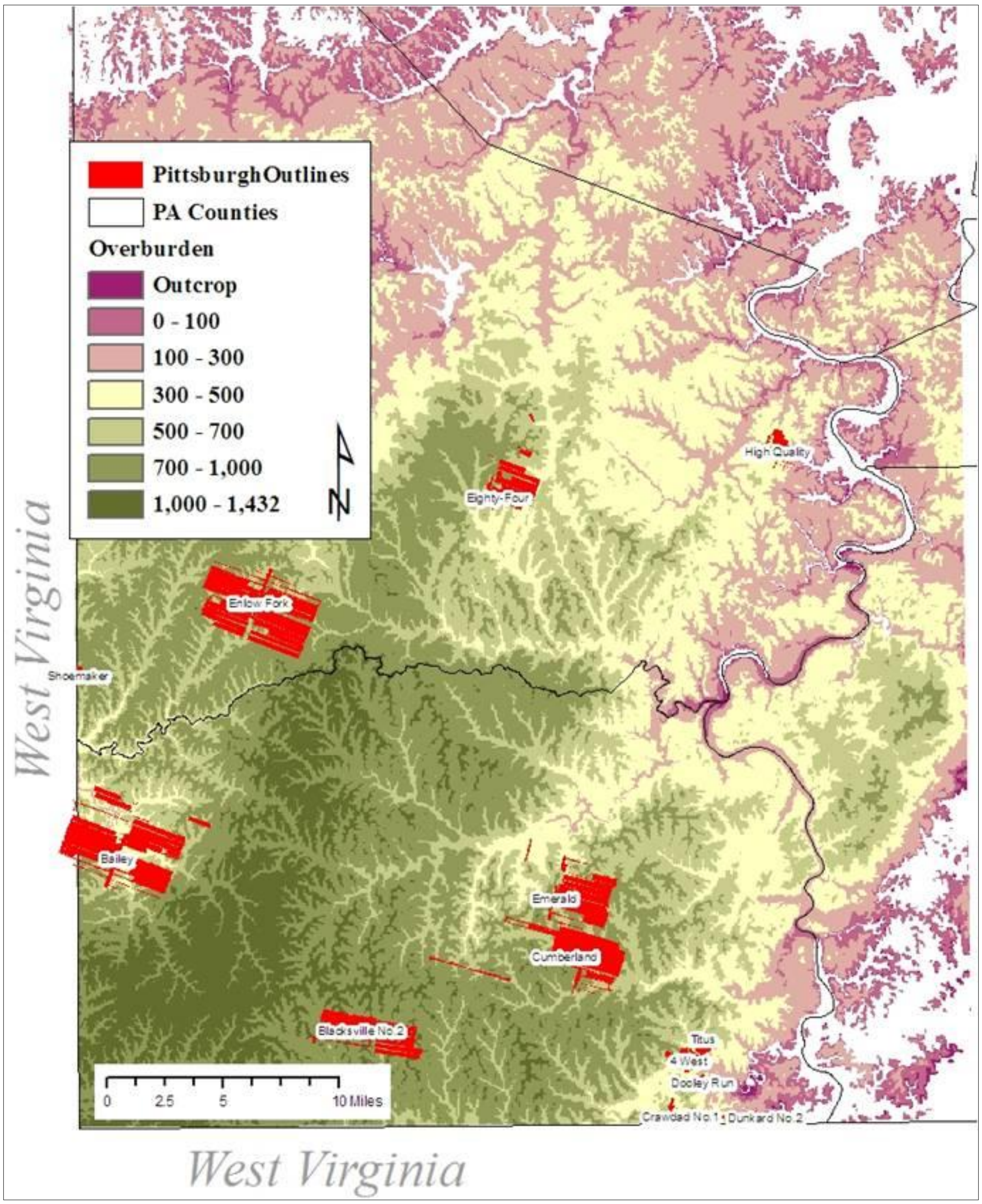


Figure III-7 - The overburden of the Pittsburgh Coalbed and the location of 13 mines that operated in Pittsburgh Formation Coalbeds. The 14th Pittsburgh Formation Coalbed mine is located to the north of this map view in Armstrong County.

III.D – Area and Surface Properties Undermined Organized by the Type and Method of Mining

As the data in Section III.C.1 indicate, the operations with the largest areas mined during the study period are longwall mines in the Pittsburgh Coalbed. Conversely, operations with the smallest areas mined were room-and-pillar operations in the Freeport and Kittanning Coalbeds. This section makes a more detailed comparison between the areas mined, surface properties undermined, type of mines, and mining methods.

Of the three types of mines, longwall mines comprised 64.3-pct of the total area, followed by room-and-pillar mines with 30.2-pct, and room-and-pillars mines with pillar recovery with 5.5-pct (Table III-5). A total of 3,587 properties were undermined during the 3rd assessment period. Room-and-pillar mines undermined 1,738 (48.5-pct) of the total surface properties and longwall and pillar recovery mines 1,572 (43.8-pct) and 277 (7.7-pct) respectively. The average size of properties above room-and-pillar mines was 6.7 acres while properties over longwall mines averaged 15.7 acres.

*Table III-5 - Acres of the three **mine types** during the 3rd assessment period.*

Type of Mine	Area Mined, Acres	Percentage	Properties Undermined	Percentage
Room-and-pillar	11,552	30.2	1,738	48.5
Room-and-pillar with pillar recovery	2,097	5.5	277	7.7
Longwall	24,607	64.3	1,572	43.8

When areas mined were compared by the *mining method*, a different trend was observed. For an explanation of the different mining methods used during this reporting period, refer to Section I-C. Room-and-pillar mining (including the longwall gate road developments) accounted for 53.3-pct with longwall mining (panels only) at 46-pct (Table III-6). This was not surprising since every longwall panel was surrounded by a section of the main entry and gate road developments. These areas were designed to maintain stability by supporting a portion of the overlying strata.

*Table III-6 – Acres of the three **mining methods**.*

Mining Method	Area Mined, Acres	Percentage
Room-and-pillar	20,375	53.3
Pillar recovery	276	0.7
Longwall	17,605	46

The entire area where pillar recovery mining occurred accounted for only 0.7-pct of the total area undermined (Table III-6). Perhaps the mining companies purposely avoided using pillar recovery beneath properties with structures and water supplies.

III.D.1 – Area and Surface Properties Undermined by Room-and-Pillar Mines

Thirty-six room-and-pillar mines operated during the 3rd assessment period. These mines extended under 11,552 acres of land and 1,743 surface properties. Room-and-pillar mines had mining developments in all six coalbeds listed (Table III-7).

Table III-7 - Areas undermined by room-and-pillar mines.

Coalbed	Areas Mined, Acres	Properties Undermined
Pittsburgh	85	36
Upper Freeport	3,642	520
Lower Freeport	714	160
Upper Kittanning	1,556	235
Lower Kittanning	5,555	787
Total	11,552	1,738

The thirty-six room-and-pillar mines ranged in area mined from a maximum of 1,149 acres at the Clementine No.1 Mine to a minimum of 3 acres at the Rampside No.1 Mine (Figure III-8). The average room-and-pillar mine undermined 321 acres during the 3rd assessment period with an average mining rate slightly over 5 acres/month.

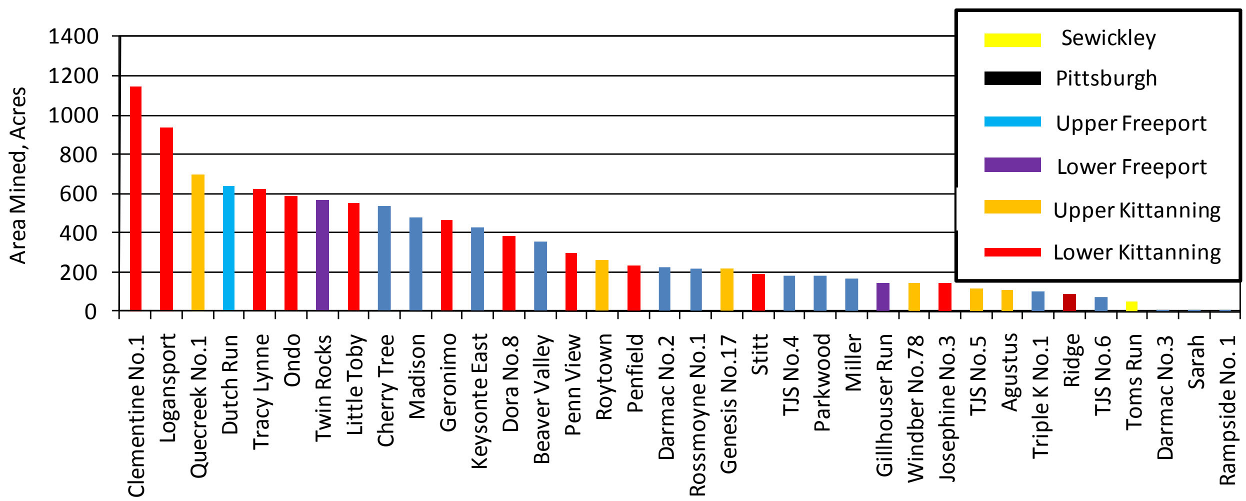


Figure III-8 - Areas mined and coalbeds for thirty-six room-and-pillar mines.

III.D.2 – Area and Surface Properties Undermined by Room-and-Pillar Mines with Pillar Recovery

Six room-and-pillar mines with pillar recovery undermined 2,097 acres and 277 surface properties (Table III-8). The average size of the pillar recovery areas was 46 acres representing about 15-pct of the total area mined.

Table III-8 - Areas undermined by room-and-pillar mines with pillar recovery.

Mine Name	Coalbed	Room and Pillar, Acres	Pillar Recovery, Acres	Total, Acres	Properties Undermined
Nolo	Lower Kittanning	880	50	930	177
Crawdad No.1	Sewickley	326	86	412	18
4 West	Sewickley	407	9	416	45
Titus	Sewickley	187	73	260	18
Dooley Run	Sewickley	21	9	30	7
Dunkard No.2	Sewickley	0	49	49	12
Total		1,821	276	2,097	277

III.D.3 – Area and Surface Properties Undermined by Longwall Mines

Eight longwall operations mined below 24,607 acres of land and 1,572 surface properties (Table III-9). These operations had a combination of room-and-pillar and longwall mining methods. The average percentage of room-and-pillar mining was 28.5-pct. The eight longwall mines ranged in area mined from maximum of 6,339 acres at the Enlow Fork Mine to a minimum of 72 acres at the Shoemaker Mine. The average longwall mine, excluding the Shoemaker Mine where operations mainly occurred in West Virginia, undermined 3,505 acres with an average mining rate of a little more than 58 acres/month. This represented a ten-fold increase in area mined over the room-and-pillar mines. On any given day during the 3rd assessment period, longwall mining undermined an average of 13.5 acres of PA land.

Table III-9 – Amount of land and surface properties undermined by the eight longwall mines.

Mine Name	Longwall, Acres	Room-and-Pillar, Acres	Total, Acres	Percentage Longwall Acres	Properties Undermined
Enlow Fork	4,890	1,449	6,339	77.1	249
Bailey	4,529	1,782	6,311	71.8	238
Cumberland	2,322	1,343	3,665	63.4	212
Blacksville No.2	2,107	773	2,880	73.2	144
Emerald	1,973	882	2,855	69.1	244
Eighty-Four	1,562	422	1,984	78.7	209
High Quality	181	320	501	36.1	273
Shoemaker	41	31	72	56.9	3
Totals	17,605	7,002	24,607		1,572

III.E – Mining in Different Counties

As has been noted in the above subsections, 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 counties (Figure III-9). Greene County had nearly double the area mined as Washington County and Washington County was nearly double that of Armstrong County. Longwall mines operated in Greene and Washington counties. The other eight counties accounted for only 33-pct of total areas undermined. In these counties room-and-pillar mines dominated.

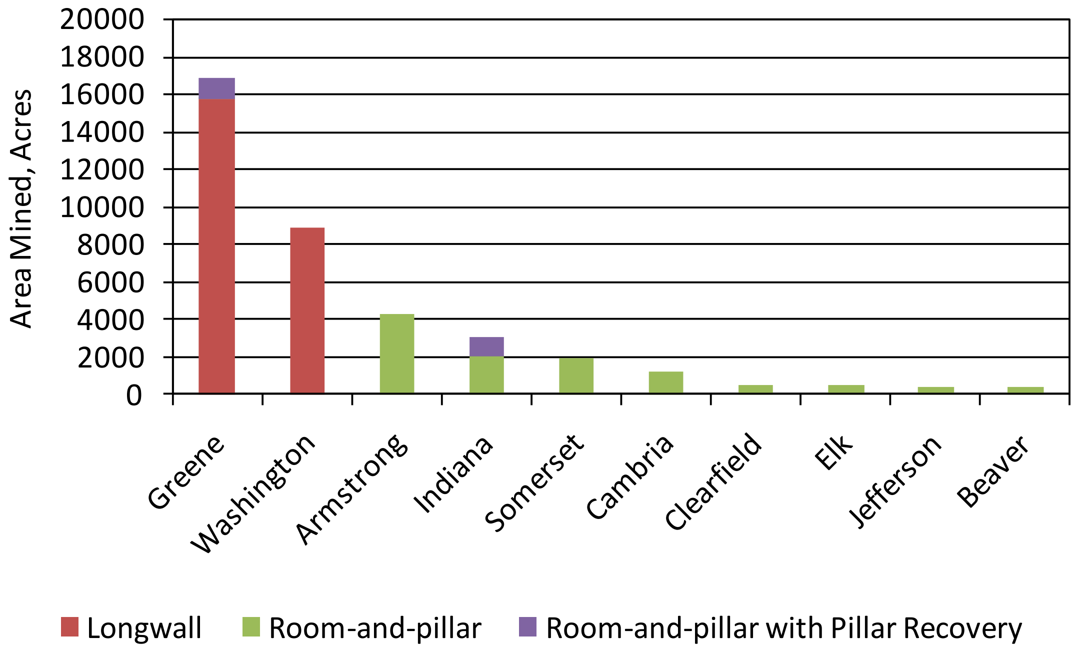


Figure III-9 - Areas undermined by County.

III.E.1 – Armstrong County

Nine mines were located in the southern half of Armstrong County (Figure III-10). All of these mines were room-and-pillar mines. During the 3rd assessment period, these nine operations mined under 4,292 acres of surface land with 833 surface properties.

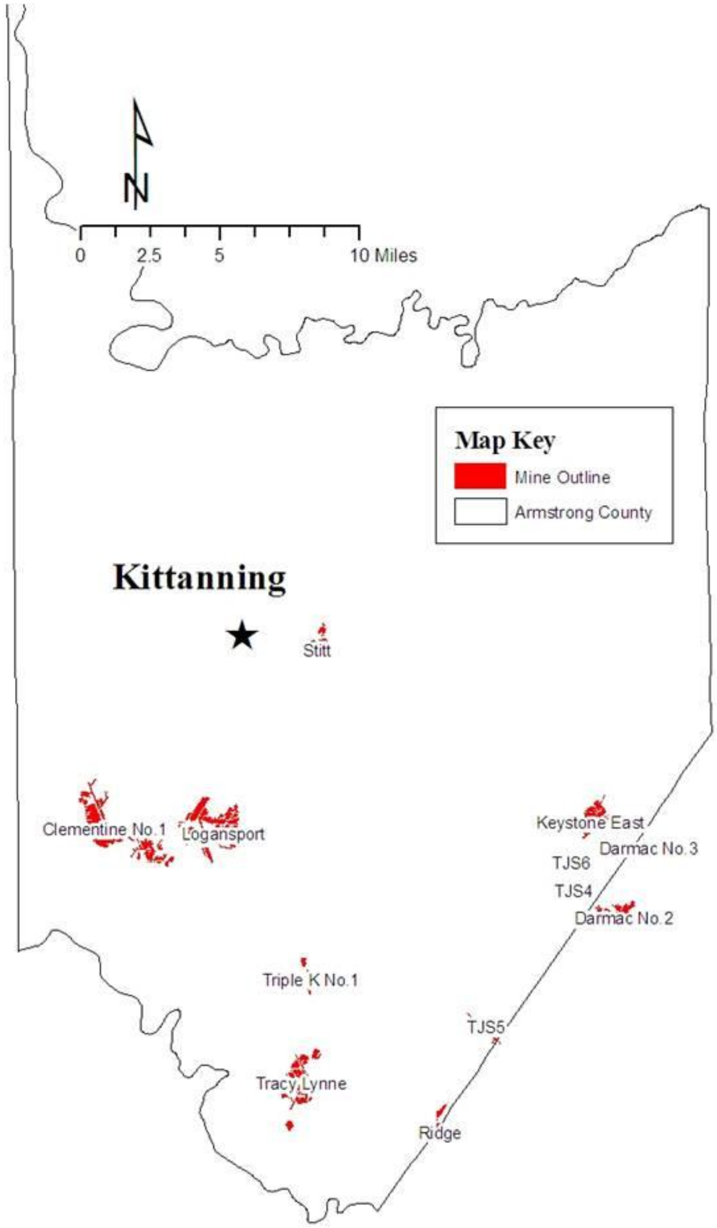


Figure III-10 - Nine mines operating in Armstrong County.

Most of the mining occurred in the Lower Kittanning Coalbed with 2,892 acres or 67-pct of the Armstrong County total (Table III-10). This was followed by the Upper Freeport with 1,199 acres or 28-pct of the total. Very small areas were mined from the Pittsburgh, 85 acres, and the Upper Kittanning, 116 acres.

Table III-10 - Area mined in Armstrong County by coalbed.

Coalbed	Area Mined, Acres	Percentage
Pittsburgh	85	2
Upper Freeport	1,199	28
Upper Kittanning	116	3
Lower Kittanning	2,892	67
Total	4,292	100

III.E.2 – Cambria County

Four mines were located in the southern half of Cambria County (Figure III-11). All of these mines were room-and-pillar mines. These four operations mined under 1,196 acres of surface land with 231 surface properties.

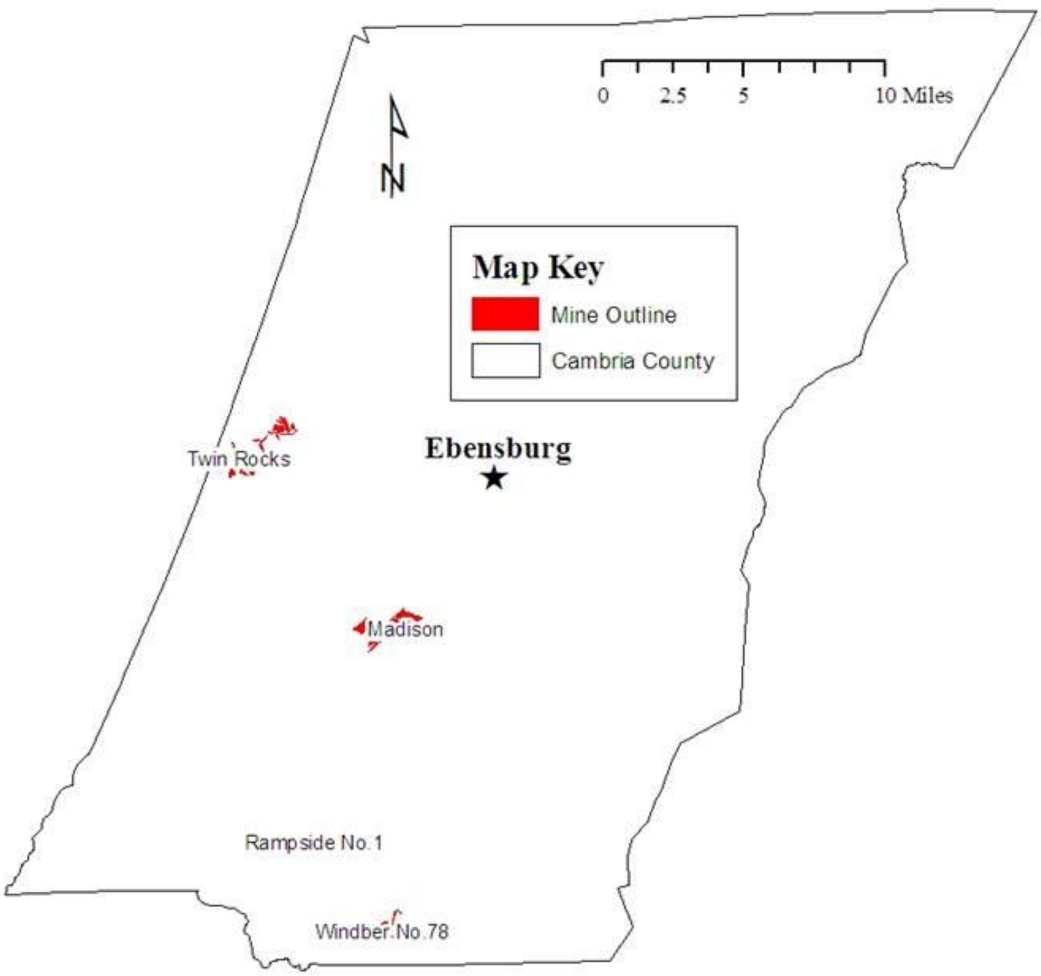


Figure III-11 - Four mines operating in Cambria County.

Most of the mining occurred in the Upper and Lower Freeport Coalbeds with 1,047 acres or 87-pct of the Cambria County total (Table III-11). A very small area was mined from the Upper Kittanning Coalbed, 146 acres.

Table III-11 - Area mined in Cambria County by coalbed.

Coalbed	Area Mined, Acres	Percentage
Upper Freeport	479	40
Lower Freeport	568	47
Upper Kittanning	146	12
Total	1,193	100

III.E.3 – Greene County

Nine mines were located in Greene County (Figure III-12). These mines were a combination of room-and-pillar with pillar recovery and longwall mines, undermining 16,878 acres of surface land with 915 surface properties.

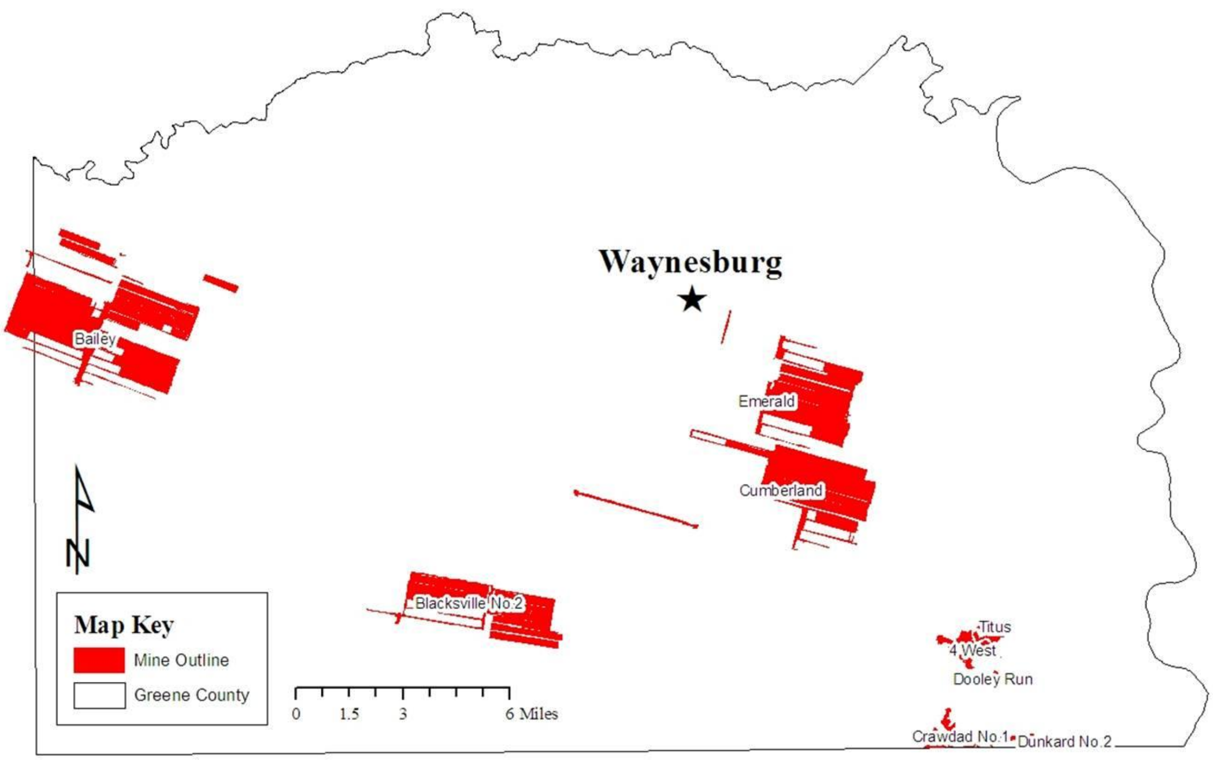


Figure III-12 - Nine mines operated in Greene County.

Most of the mining occurred in the Pittsburgh Coalbed with 15,711 acres or 93.1-pct of the Greene County total (Table III-12). In comparison, the Sewickley Coalbed accounted for 1,167 acres or just 6.9-pct of the total.

Table III-12 - Area mined in Greene County by coalbed and type of mine.

Coalbed	Type of Mine	Area Mined, Acres		Percentage	
		Coalbed	Type of Mine	Coalbed	Type of Mine
Sewickley		1,167		6.9	
Pittsburgh		15,711		93.1	
	R&P with Pillar Recover		1,167		6.9
	Longwall		15,711		93.1
Total		16,878	16,878	100	100

III.E.4 – Indiana County

Eight mines were located in Indiana County (Figure III-13). Seven of these mines were room-and-pillar and one was room-and-pillar mine with pillar recovery. During the 3rd assessment period, these eight operations mined under 3,020 acres of surface land with 429 surface properties. This total does not include acres and properties associated with the Cherry Tree Mine which was partially in Indiana and Clearfield Counties and the Darmac No.2 Mine which was partially in Indiana and Armstrong Counties.

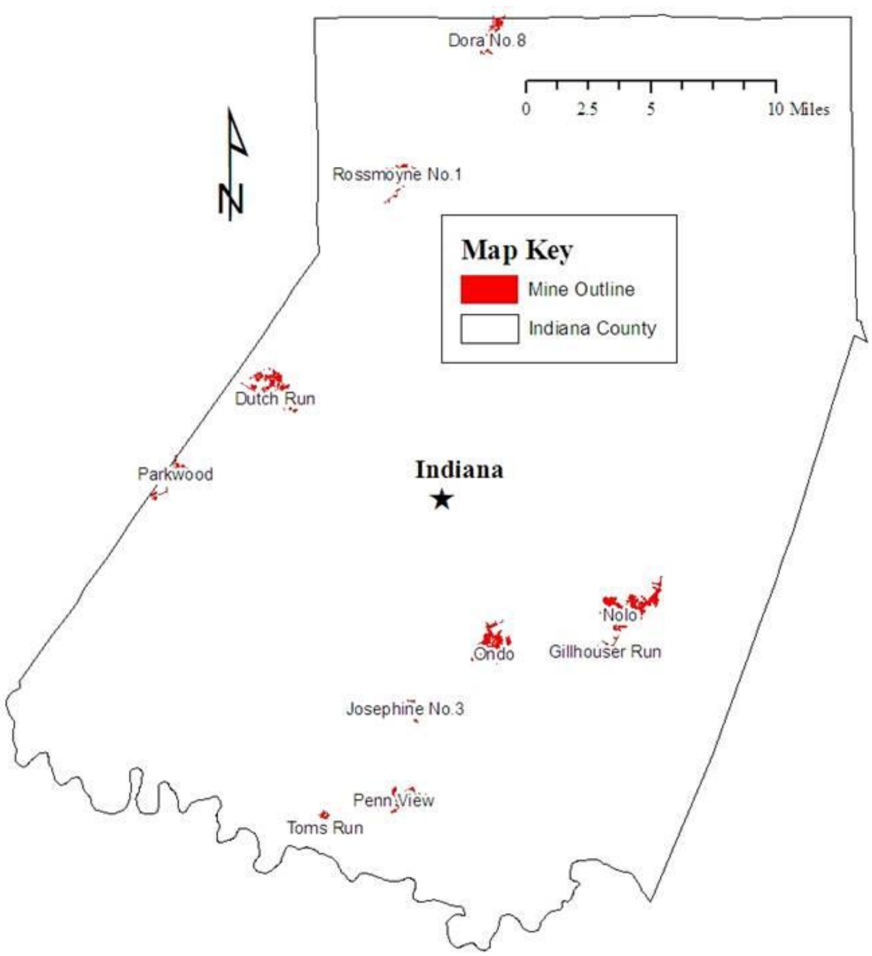


Figure III-13 - Twelve mines operating in Indiana County.

Most of the mining occurred in the Lower Kittanning Coalbed with 1,964 acres or 65-pct of the Indiana County total (Table III-13). Next was the Upper Freeport Coalbed accounting for 910 acres or 30-pct of the total followed by the Lower Freeport Coalbed with 146 acres. The one room-and-pillar mine with pillar recovery, the Nolo Mine, accounted for 930 acres, however, only a small percentage of this total was mined with the pillar recovery techniques.

Table III-13 - Area mined in Indiana County by coalbed and type of mine.

Coalbed	Type of Mine	Area Mined, Acres		Percentage	
		Coalbed	Type of Mine	Coalbed	Type of Mine
Upper Freeport		910		30	
Lower Freeport		146		5	
Lower Kittanning		1,964		65	
	Room-and-Pillar		2,090		69
	R&P with Pillar Recover		930		31
Total		3,020	3,020	100	100

III.E.5 – Somerset County

Seven mines were located in the central portion of Somerset County (Figure III-14). All of these mines were room-and-pillar mines. These seven operations mined under 1,916 acres of surface land with 254 surface properties.

Most of the mining occurred in the Upper Kittanning Coalbed with 1,291 acres or 67-pct of the Somerset County total (Table III-14). Next was the Lower Kittanning Coalbed with 461 acres, or 24-pct. A very small area was mined from the Upper Freeport Coalbed, 164 acres.

Table III-14 - Area mined in Somerset County by coalbed.

Coalbed	Area Mined, Acres	Percentage
Upper Freeport	164	9
Upper Kittanning	1,291	67
Lower Kittanning	461	24
Total	1,916	100

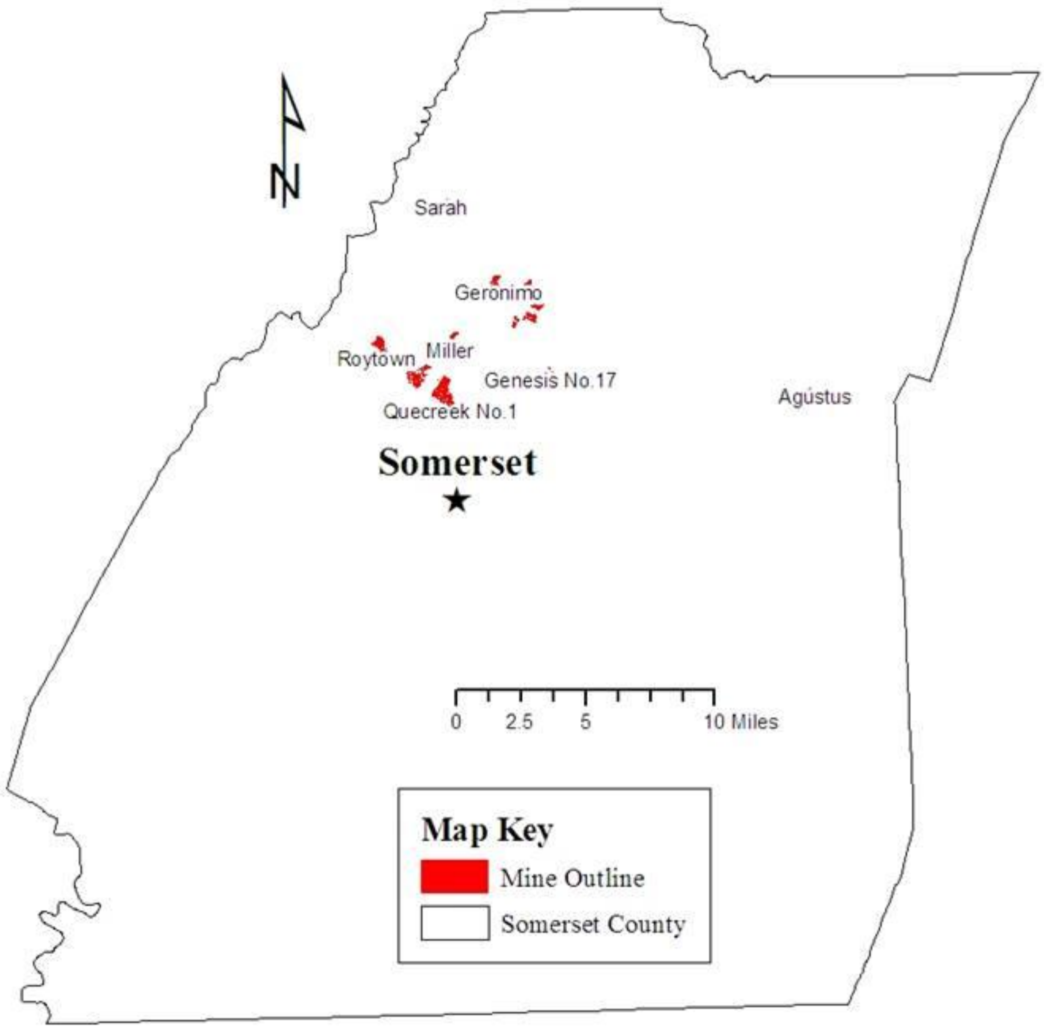


Figure III-14 - Seven mines operated in Somerset County.

III.E.6 – Washington County

Three mines were located in the southern portion of Washington County (Figure III-15). All of these operations were longwall mines within the Pittsburgh Coalbed. These three operations mined under 8,896 acres of surface land with 738 surface properties.

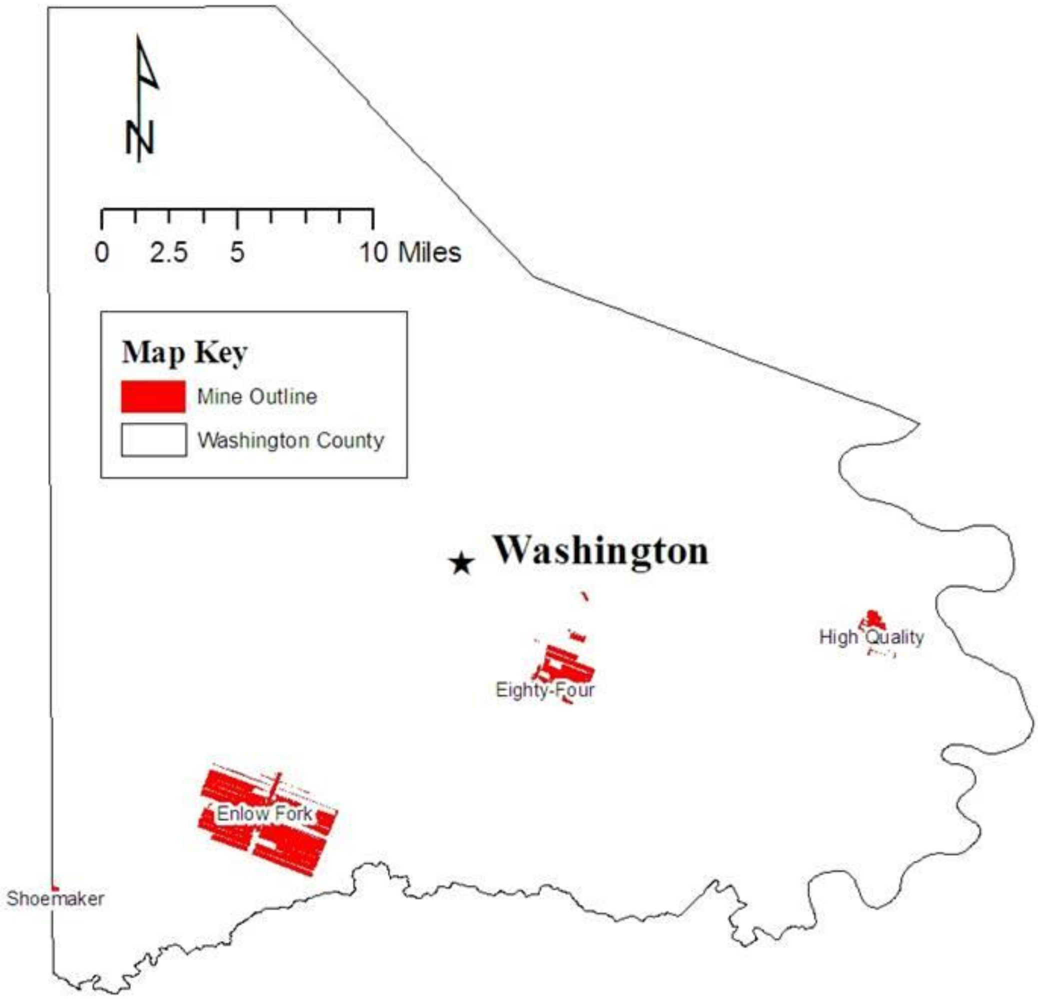


Figure III-15 - Four mines operated in Washington County.

III.E.7 – Beaver, Clearfield, Elk and Jefferson Counties

The remaining four counties, Beaver, Clearfield, Elk and Jefferson, had a combined area mined of 2,058 acres, representing just 5.4-pct of the total area mined (Table III-15). In addition, the five mines operating in these four counties undermined 155 surface properties.

Table III-15 - Area mined and properties undermined in Beaver, Clearfield, Elk and Jefferson Counties by coalbed.

County	Coalbed	Area Mined, Acres	Properties Undermine
Beaver	Upper Freeport	354	30
Clearfield	Upper Freeport	536	21
	Lower Kittanning	235	54
Elk	Lower Kittanning	552	29
Jefferson	Lower Kittanning	381	21
Total		2,058	155

III.F – Variations in Overburden

The variability in the overburden characteristics of the fifty mines studied is significant and important. The shallowest overburden at eighteen different mines was projected at less than 100-ft while four mines had maximum overburdens over 1,000-ft. These significant variations in overburden can affect land, structures, highways, water sources, streams, and wetlands in different ways.

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 measured the variable overburden and calculated the average, standard deviation, minimum, and maximum conditions for each mine. These conditions were grouped by mining type, producing three distinct overburden categories; shallow, average, and deep. The average overburden category comprised all mines whose values fell between one standard deviation of the mean. This accounted for approximately 2/3 of the mines. The other 1/3 were split between shallow or 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-16).

Table III-16 – 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**
Room-and-Pillar (R&P)	Less than 185	185 to 397	More than 397
R&P with Pillar Recovery	Less than 283	283 to 473	More than 473
Longwall	Less than 525	525 to 850	More than 850

III.F.2 – Longwall Mine Overburden

The eight longwall mines varied in overburden from a minimum of 83-ft at the High Quality Mine to a maximum of 1,189-ft at the Blacksville No.2 Mine (Table III-17). The average longwall overburden was 687-ft with a standard deviation of 162-ft. Using the overburden categories discussed in Section III.F.1, six mines were average with one shallow and one deep (Table III-17).

Table III-17 – Overburden characteristics for longwall mines.

Mine	Avg.	SD*	Min.	Max.	Category
Bailey	648	130	311	1061	Average
Blacksville No.2	887	106	649	1189	Deep
Cumberland	739	88	559	1029	Average
Eighty-Four	627	109	362	885	Average
Emerald	725	109	356	999	Average
Enlow Fork	750	102	505	1036	Average
High Quality	338	71	83	544	Shallow
Shoemaker	784	61	661	936	Average
Total	687	162	83	1189	

* SD – Standard Deviation

The spread in the overburden distribution for each of the eight longwall mines is shown in Figure III-16. In this figure, the deep overburden conditions found within the Blacksville No.2 Mine were evident, as were the shallow conditions found at the High Quality Mine.

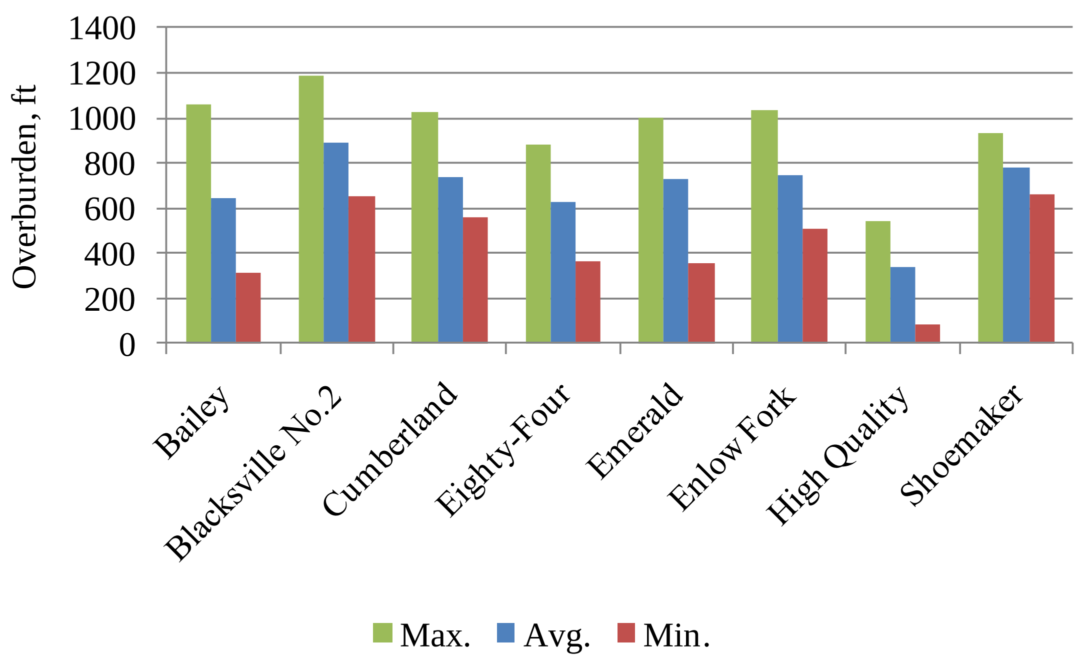


Figure III-16 –The distribution in overburden within each of the eight longwall mines.

III.F.3 – Room-and-Pillar Overburden

When compared to the eight longwall mines above, the 36 room-and-pillar mines had less overburden with an average of 291-ft and a standard deviation of 106-ft. The lowest overburden occurred at the Geronimo Mine 38-ft, and the highest at the Logansport Mine with 663-ft (Table III-18). Twenty-six mines were average with five shallow and five deep (Table III-18). The shallow mines were Rampside, Ridge, Sarah, TJS No.4, and TJS No.6, while the deep mines are Clementine, Darmac No.2, TJS No.5, Toms Run, and Windber No.78.

The spread in the overburden distribution for each of the 36 room-and-pillar mines is shown in Figure III-17. In this figure, the two deepest mines, Toms Run and Windber No.78, were noticeably higher than some of the other deep mines. The opposite is true for the Rampside and TJS No.6 Mines. They were noticeably lower than some of the other shallow overburden mines (Figure III-17).

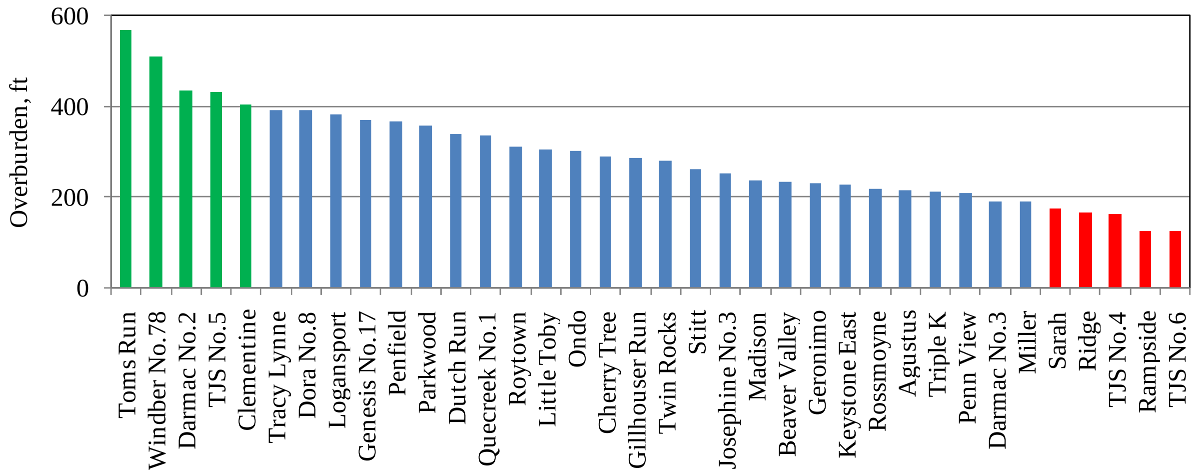


Figure III-17 –Distribution of average overburdens for the 36 room-and-pillar mines. Note green mines are classified as deep, blue mines are average, and red mines are shallow in overburden.

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

When compared to the 36 mines above, the 6 room-and-pillar mines with pillar recovery were higher in overburden with an average of 378-ft and a standard deviation of 95-ft. The lowest overburdens occurred at the Dooley Run and 4 West Mines with approximately 90-ft (Table III-19). The average overburden at Dooley Run was 221-ft, putting it well within the shallow category. The other four mines were average (Table III-19).

Table III-18 - Overburden characteristics for room-and-pillar mines.

Mine name	Avg.	SD	Min.	Max.	Category
Agustus	214	18	169	264	Average
Beaver Valley	232	55	100	420	Average
Cherry Tree	290	55	108	400	Average
Clementine	405	90	171	609	Deep
Darmac No.2	435	82	241	571	Deep
Darmac No.3	191	74	81	314	Average
Dora No.8	390	90	159	551	Average
Dutch Run	340	74	114	525	Average
Genesis No.17	370	65	201	515	Average
Geronimo	231	59	38	372	Average
Gillhouser Run	285	61	95	397	Average
Josephine No.3	251	24	182	307	Average
Keystone East	226	51	58	375	Average
Little Toby	304	47	118	433	Average
Logansport	383	103	160	633	Average
Madison	235	53	47	354	Average
Miller	191	36	69	262	Average
Ondo	300	76	124	461	Average
Parkwood	356	78	103	617	Average
Penfield	366	80	103	523	Average
Penn View	207	37	94	291	Average
Quecreek No.1	335	65	195	566	Average
Rampside	125	28	58	176	Shallow
Ridge	164	30	98	229	Shallow
Rossmoyne	216	70	99	382	Average
Roytown	310	69	100	552	Average
Sarah	174	32	94	245	Shallow
Stitt	261	72	94	423	Average
TJS No.4	161	36	93	237	Shallow
TJS No.5	431	153	78	734	Deep
TJS No.6	125	49	69	219	Shallow
Toms Run	570	18	518	601	Deep
Tracy Lynne	391	72	107	512	Average
Triple K	211	67	32	414	Average
Twin Rocks	280	50	163	363	Average
Windber No.78	509	31	433	565	Deep
Total	291	106	38	633	

* SD – Standard Deviation

Table III-19 – Overburden characteristics for room-and-pillar mines with pillar recovery.

Mine	Avg.	SD*	Min.	Max.	Category
Crawdad	445	91	225	655	Average
Dooley Run	221	48	96	304	Shallow
Nolo	458	52	250	576	Average
Titus	392	83	168	592	Average
4-West	444	136	89	728	Average
Dunkard No.2	306	70	187	474	Average
Average	378	95	89	728	

* SD – Standard Deviation

The overburden distribution for the six room-and-pillar mines with pillar recovery is shown in Figure III-18. The significant spread between minimum and maximum overburdens was evident, but it was most noticeable in the 4 West Mines. Large variations in overburden can produce deviations in mining conditions during pillar recovery.

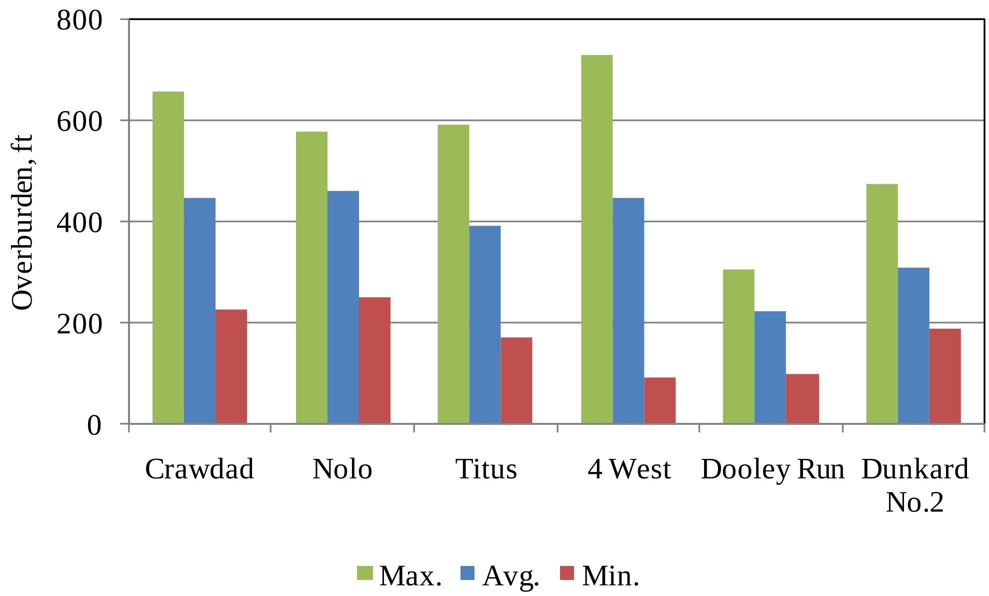


Figure III-18 - The distribution in overburden within each of the six room-and-pillar mines with pillar recovery mines.

III.G – Summary Points

Fifty mines operated during the 3rd assessment period and were classified as room-and-pillar, room-and-pillar with pillar recovery, or longwall. Thirty-six room-and-pillar mines, operated by ten companies, comprised 30.2-pct of the total area mined and 48.5-pct of the total surface properties undermined. They extended under 11,552 acres of land and 1,738 surface properties. The average room-and-pillar mine undermined 321 acres of surface land and mined at a rate of a little more than 5 acres/month. The average overburden for these mines was 291-ft. Based on their overall overburden character, 26 mines were classified as average, five as shallow, and five as deep.

The six mines classified as room-and-pillar mines with pillar recovery comprised 5.5-pct of the total area mined and 7.7-pct of the total surface properties. They extended under 2,097 acres of land and 277 surface properties. The average size of the pillar recovery areas was 46 acres, representing about 15-pct of the total area mined for these six mines. The individual pillar recovery sections were general relatively small, typically less than 1000-ft in length. These areas were mainly contained within production panels with overburden averaging 378-ft.

Eight longwall mines were active and comprised 64.3-pct of the total area mined and 43.8-pct of the total surface properties. They extended under 24,607 acres of land and 1,572 surface properties. An average of 13.5 acres of land was undermined by a longwall mine every day. The average longwall mine undermined 3,505 acres of surface land and mined at a rate of a little more than 58 acres/month. This represented a ten-fold increase in area mined over the average room-and-pillar mine. Three large companies operated these mines: Consol Energy, Alpha Resources, and UMCO Energy. Several of these longwall operations were among the most productive underground coal mines in the U.S. The average longwall overburden was 687-ft. Six of these mines were classified as average overburden, with one shallow, and one deep.

When the actual mining method is examined, room-and-pillar mining (includes the longwall gate road developments) accounted for 53.3-pct of the total area mined. The actual longwall panels accounted for 46-pct and pillar recover only 0.7-pct of the total area mined. This data implied that a high percentage of impacts should be associated with the extensive areas mined by longwall panels. Conversely, few impacts should be expected with the very small areas mined with the pillar recovery method.

All of this mining occurred in six coalbeds contained within two formations. The Allegheny Formation contained 36 mines within the Upper and Lower Freeport and Upper and Lower Kittanning Coalbeds. The Pittsburgh Formation contained14 mines within the Pittsburgh and Sewickley Coalbeds. The Pittsburgh Coalbed is well known for its consistency in thickness and quality, making it well suited for the eight longwall mines. Conversely, The Freeport and Kittanning Coalbeds are generally less continuous, making them better suited for room-and-pillar mining.

The highest concentration of underground mining occurred in Greene County where 16,878 acres of land and 915 surface properties were undermined. The second highest concentration occurs in Washington County where 8,896 acres and 738 surface properties were undermined. Greene and Washington Counties were dominated by longwall mining. Eight other counties had lesser amounts of mining, exclusively using the room-and-pillar and pillar recovery mining methods. Armstrong County led these counties where 14 operations mined 4,292 acres of land and 833 surface properties. Indiana, Somerset, and Cambria Counties were next in mining activity with 3,020, 1,916, and 1,196 acres of land undermined. Beaver, Clearfield, Elk and Jefferson Counties had a combined area mined of 2,058 acres.

SECTION IV: A Summary of the PA DEP Observations on the Effects of Undermining Interstate 79 during the 3rd Assessment Period

IV.A - Overview

The PA DEP requested an in-depth assessment of the effects of undermining Interstate 79 (I79) because of the high profile nature of the mining plan and an interest in gathering information that could be used to improve impact predictions. The PA DEP maintained a web page to keep the public informed about the status of mining beneath I79 and to the subsidence effects. Information collected by the PA DEP afforded an assessment of the duration and extent of land response to planned subsidence.

During the 3rd assessment period, I79 was undermined by portions of nine longwall panels. Three of the panels were extracted by the Emerald Mine and six by the Cumberland Mine, both in Greene County and both owned by Alpha Resources. Previous assessments of longwall mining under Pennsylvania's interstates had identified impacts to the highways but no danger to public safety was detected. In general, the magnitude and extent of impacts during the 3rd assessment period appeared to be similar as those identified in previous studies.

The most significant change in the character of the longwall panels, over previous assessment periods, was their greater size. In 2009, the average panel in the US had a width of 1,075-ft and a length of 10,995-ft (Fiscor, 2010). The nine longwall panels mined in the 3rd assessment period all exceeded previous averages and were among the widest in the US. They were supercritical in character with overburdens ranging between greater than 500-ft to less than 1,000-ft while undermining 3.4 miles of interstate highways.

IV.B - Data Sources

The PA DEP requested the University to summarize observations collected during the 3rd assessment period to evaluate and document the effects of undermining I79. Observations and photographs of impacts to the highway were made by PA DEP staff and entered into reports prepared by CDMO staff and statements written into the BUMIS database. In addition, PennDOT conducted a series of detailed land surveys along the portions of the highway undermined between 2003 and 2008 to characterize the subsidence basins formed by longwall mining. PennDOT information has also been analyzed by another research group within the University (Gutiérrez, J.J., et al. 2010).

IV.C – Previous Experience with Undermining Pennsylvania's Interstate Highways

Prior to the 3rd assessment period, longwall mining under interstate highways within Greene and Washington Counties occurred in three separate episodes. Two of the three episodes occurred under Interstate 70 (I70) at Mine Eight-Four and one under Interstate 79 (I79) at the Gateway Mine (Figure IV-1).

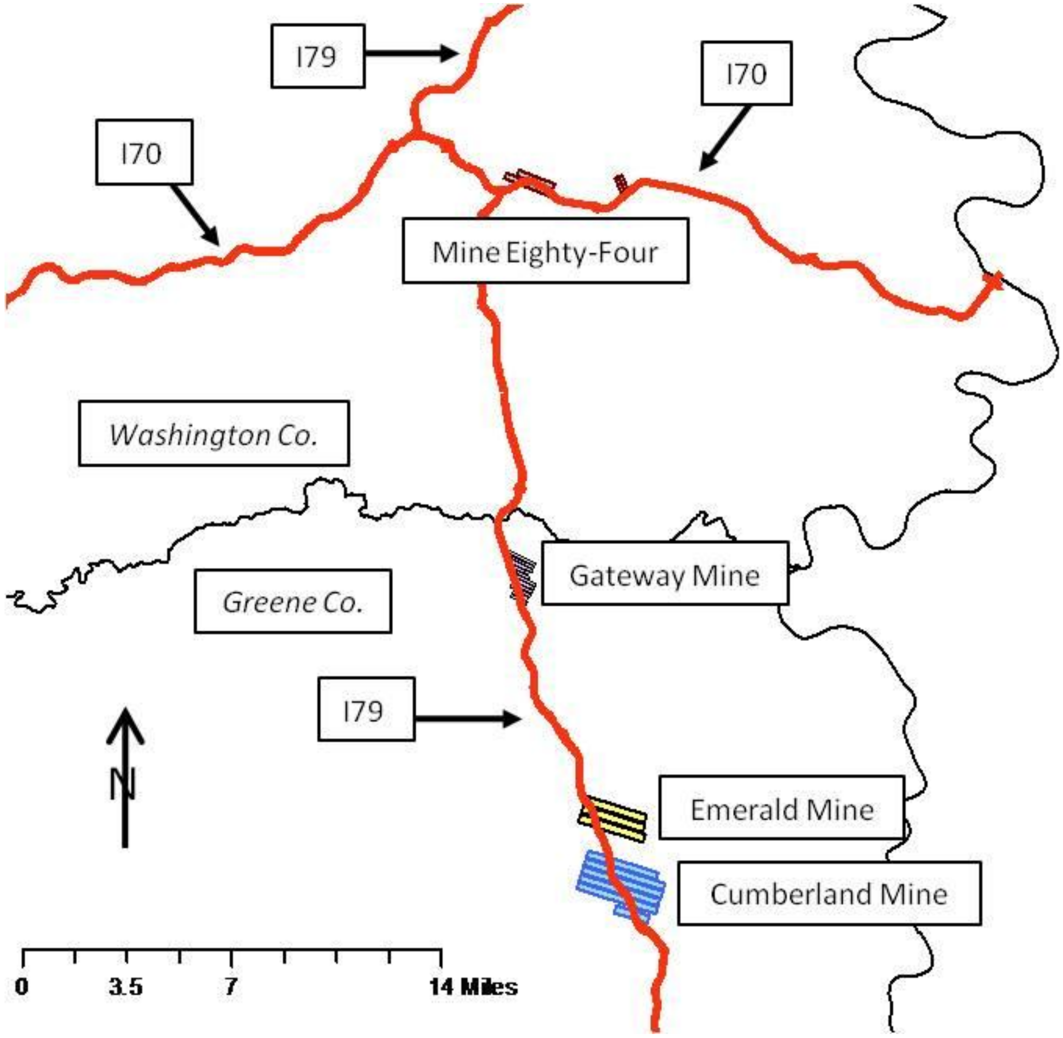


Figure IV-1 - Longwall panels that have undermined Pennsylvania Interstates.

IV.C.1 - I79, Gateway Mine

From June 1982 to September 1989, the Gateway Mine extracted coal from eight panels starting just north of the Ruff Creek Interchange, Exit 19 on I79, Greene County, PA (Figure IV-2). Panels were extracted in sequence progressing from south to north beneath the interstate. The panels were orientated with their long axis at an oblique angle to the interstate and averaged 511-ft wide and 4,100-ft long (Table IV-1). Longwall panels in the 1980's were much smaller than those observed in the 3rd assessment period. An average of 47 acres of surface land overlaid each of these panels with production rates of 5.1 days to mine one acre of longwall coal.

Table IV-1 - Gateway Mine longwall panel characteristics pertinent to the undermining of I79, 1982 to 1989 (Yancich, 1986).

Panel ID	Days to Mine	Acres	Dates Mined		Overburden, ft		Panel Dimensions		Avg. Over-burden, ft	Days to Mine 1 Acre	Width-to-Height
			Start	Finish	Min.	Max.	Width, ft	Length, ft			
0-Butt	336	38	6/16/82	5/18/83	675	850	522	3,218	763	8.8	0.68
1-Butt	235	37	6/18/83	2/8/84	675	950	567	2,842	813	6.4	0.7
2-Butt	258	45	9/15/84	5/31/85	660	910	504	3,957	785	5.7	0.64
3-Butt	344	45	9/13/85	8/23/86	655	905	534	3,969	780	7.6	0.68
4-Butt	179	46	9/15/86	3/13/87	665	930	503	3,967	798	3.9	0.63
7-Butt	158	51	2/15/88	7/22/88	690	890	499	4,468	790	3.1	0.63
8-Butt	170	56	8/15/88	2/1/89	740	915	489	4,995	828	3.0	0.59
9-Butt	227	58	2/15/89	9/30/89	765	890	470	5,386	828	4.0	0.57
Avg.	238	47					511	4,100	795	5.1	0.64

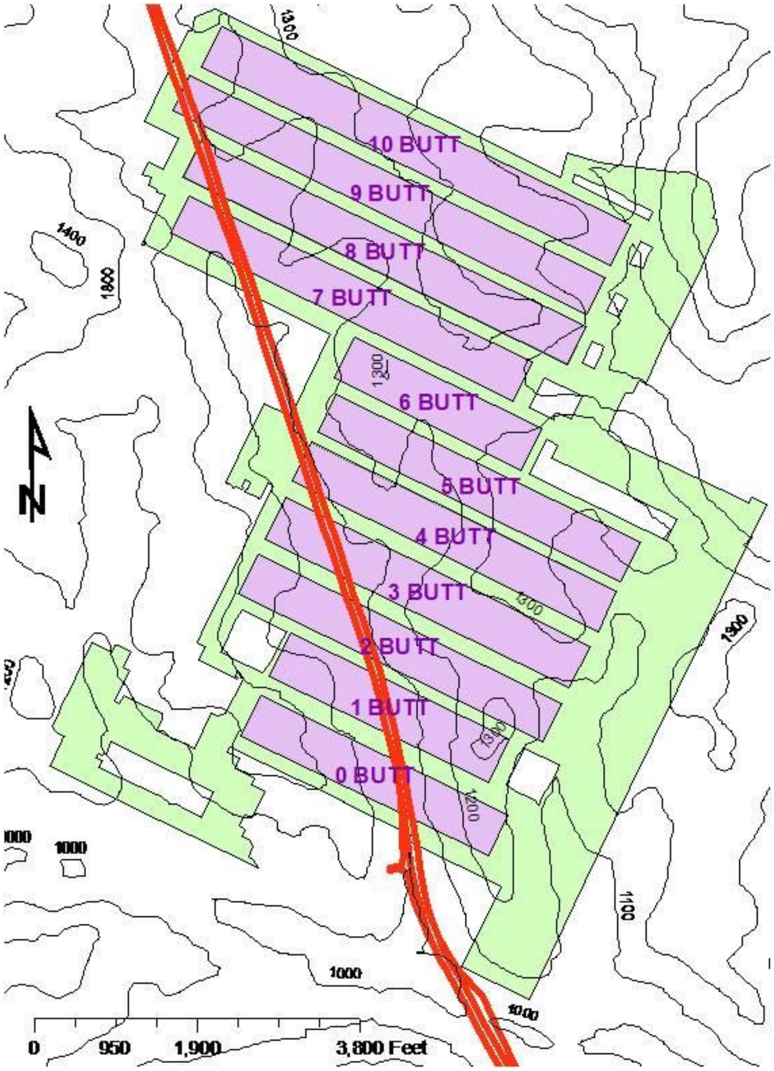


Figure IV-2 - Portions of I79 undermined by Gateway Mine longwall panels with topographic surface contours.

A Master's Thesis by Yancich at West Virginia University (1986) provides an excellent assessment of subsidence characteristics over three Gateway panels. This study included periodic surveys of fixed monuments along I79 and several houses during panel extraction. Transverse survey distances over the 511-ft wide Gateway panels were approximately 650-ft due to the oblique angle at which the panel intersected the highway. Monuments were placed along both the northbound and southbound lanes starting from the southern end of the Ruff Creek Interchange and extended 4,000-ft at 50-ft intervals. The lanes were separated by a grassy median strip approximately 60-ft wide. The final subsidence profiles, taken after the extraction of Panels 0-Butt, 1-Butt, and 2-Butt, are shown in Figure IV-3. The direction of mining relative to I79 is at angles of approximately 54-deg (0-Butt), 49-deg (1-Butt) and 47-deg (2-Butt).

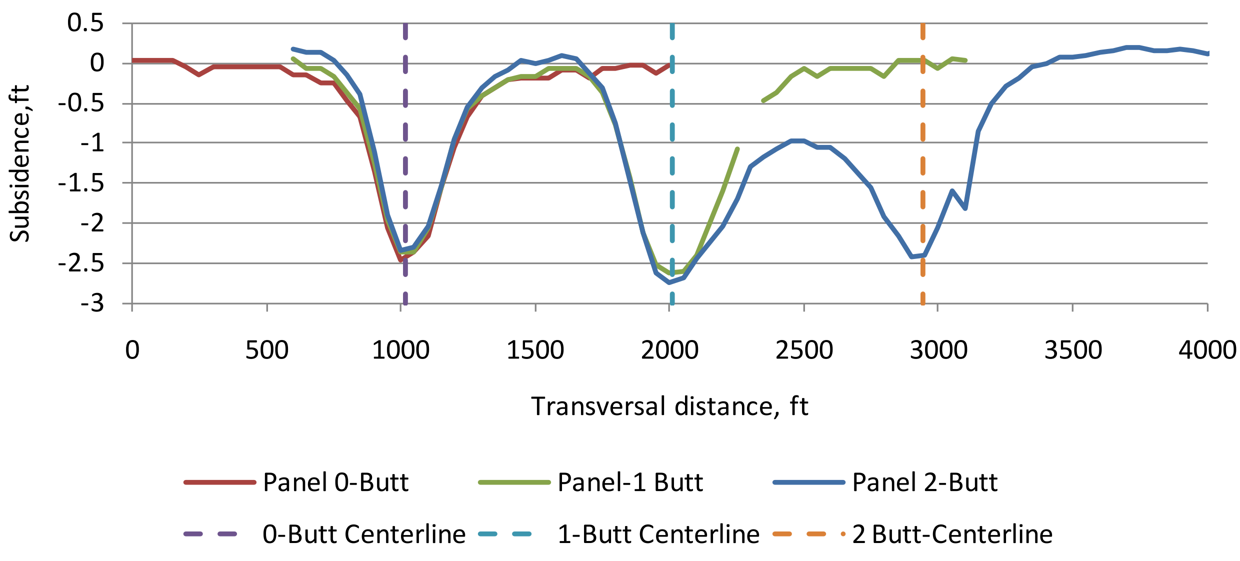


Figure IV-3 - Final subsidence profiles for three Gateway panels extracted under the northbound lanes of I79 (adapted from Yancich, 1986).

The surveys clearly showed the location of the three subsidence basins. The lack of a flat central subsidence profile confirmed that these panels were subcritical in character. The maximum subsidence values in the center of the subsidence basin were a fraction of the maximum possible subsidence for an extraction height of 6.5-ft. The ratio of the maximum subsidence to the mining height yielded subsidence factors (a) of 0.38 for 0-Butt, 0.42 for 1-Butt, and 0.37 for 2-Butt panels.

The surface slope and curvature were other means used to evaluate the impact of subsidence (Figure IV-4). The surface slope and curvature for the Gateway panels were derived from the previously discussed final subsidence profile (Figure IV-3). The maximum slope ranged between +1.9-pct to -1.56-pct, and the points of zero slopes were located at the centerlines of the longwall panels and gateroad entries (Figure IV-4a). The maximum curvature ranged between $+2 \times 10^{-4}$/ft to -2×10^{-4}/ft and the areas of highest curvature occurred between the edges and centerlines of the panels (Figure IV-4b). Impacts to I79 were expected in areas of highest surface slope and curvature.

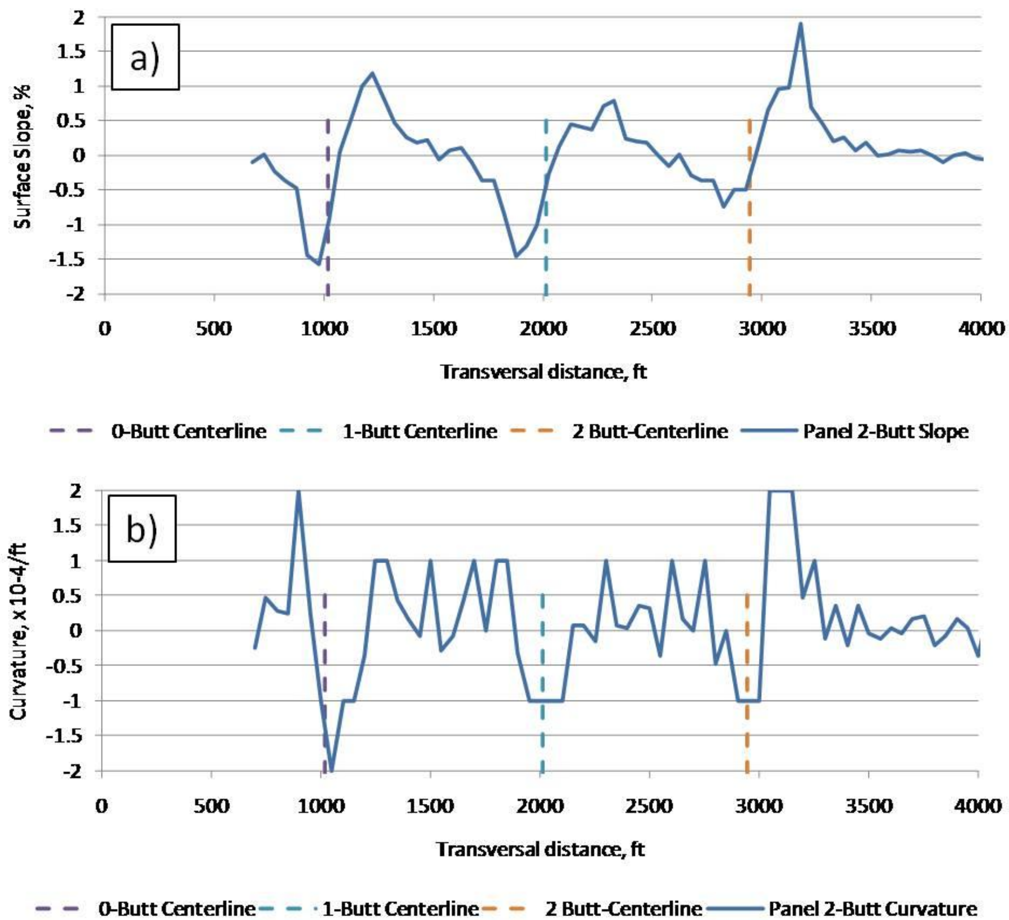


Figure IV-4 – Profiles of a) surface slope and b) curvature from three Gateway panels extracted under the northbound lanes of I79 (adapted from Yancich, 1986).

Yancich (1986) reported that only minor damage occurred to the northbound lanes of I79 that were undermined by longwall mining. Figure IV-5 shows repaired damage to I79 at: a) 900-ft along the survey profile, between the centerline and southern edge of the 0-Butt panel; b) 1,800-ft along the survey profile, near the southern edge of 1-Butt panel; and c) 3,300-ft along the survey profile, near the northern edge of 2-Butt panel. The Yancich study described a subset of impacts, making it difficult to determine the overall magnitude of damage and repairs associated with the development of multiple Gateway Mine subsidence basins under I79.

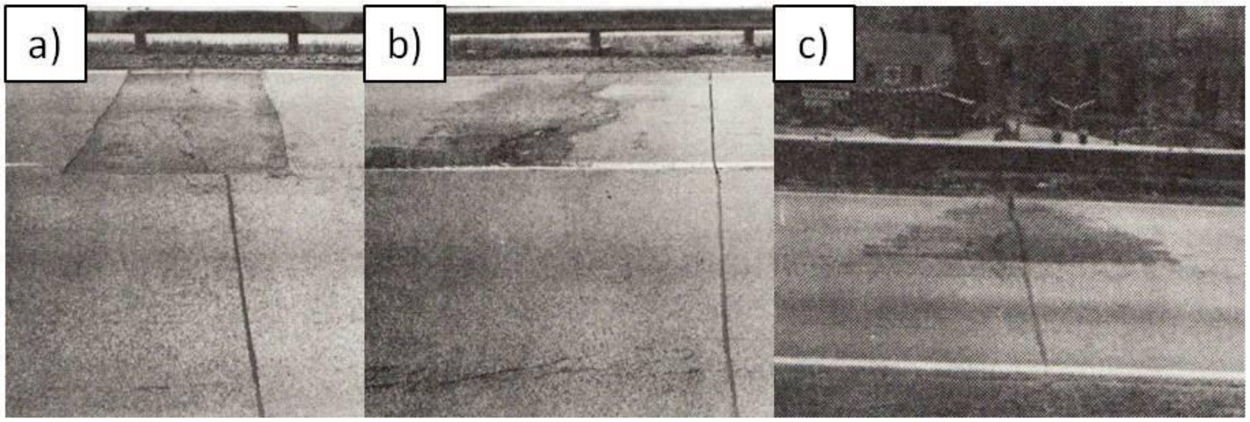


Figure IV-5 - Photographs of impacts to the northbound lanes of I79 over the 0-Butt (a), 1-Butt (b), and 2-Butt (c) panels of the Gateway Mine (Photographs from Yancich, 1986).

IV.C.2 - I70, Mine Eighty-Four

I70 is a major east-west highway that crosses the Pittsburgh Coalbed Basin in Washington County, PA. This interstate was first undermined by longwall panels from Mine Eighty-Four in 1987 and 1988. The southern extreme ends of two longwall panels (4B and 4C) intersected I70 (Figure IV-6). The authors were not able to find information on impacts of this initial episode of mining under I70.

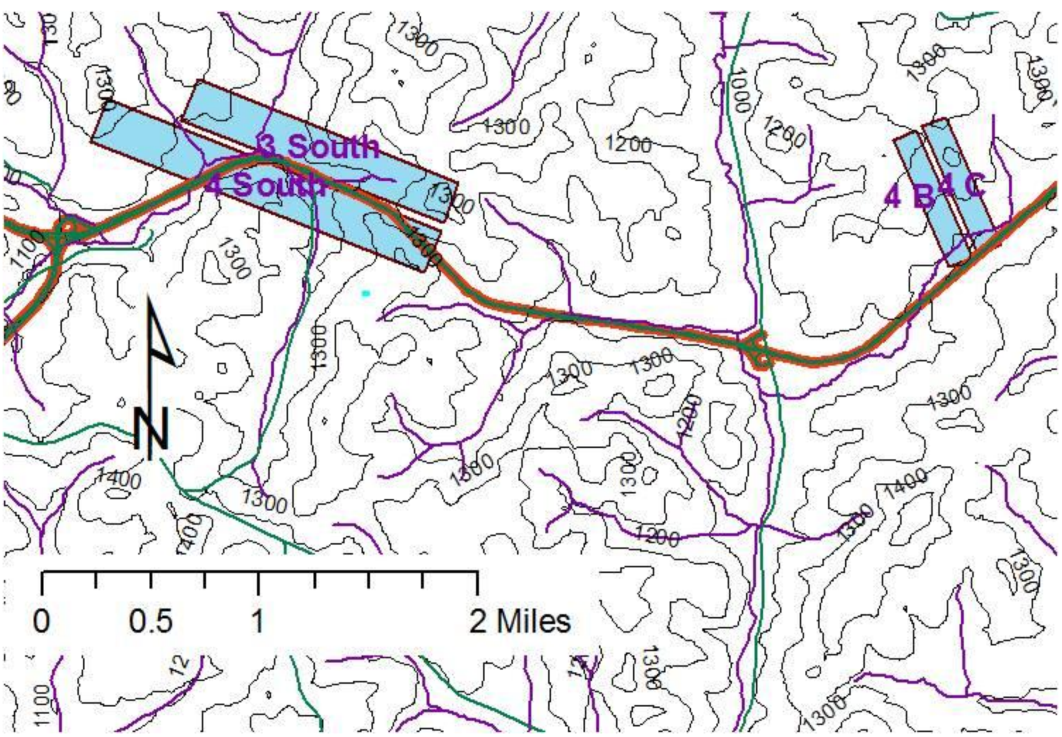


Figure IV-6 - Mine Eighty-Four longwall panels under I70.

A second undermining of I70 occurred from Nov. 22, 1999 to Oct., 16, 2000, when two longwall panels in South Strabane Township, Washington County, between the I79 interchange and State

Route 519, were mined (Figure IV-6). The surface topography over Mine Eighty-Four is gently rolling. Each panel averaged 1,059-ft wide, 6,810 to 8,685-ft long, and approximately 7-ft high. The layout of these panels was designed in an attempt to minimize impacts to the overlying interstate highway. As was noted from the survey information over the Gateway Mine, critical subsidence properties, such as surface slope and curvature, are less over the gateroad entries adjacent to longwall panels. The gateroad entries between 3- and 4-South Panels were designed to follow a ¾-mile section of I70, with the intent of minimizing damage to the highway. In theory the impacts along this section would be similar in nature since the vertical subsidence, slope, curvature and horizontal strains would not significantly change. Conversely the nature of impacts along highway sections that transect the 4-South Panel in its central and eastern ends should experience considerable variation.

Information on the undermining of this section of I70 was reported by O'Connor in 2001. An array of tiltmeters was installed adjacent to the highway to detect hazardous deformations to the highway during undermining. The 32 tiltmeters were outfitted with real-time data acquisition systems, capable of sounding an alarm if levels of tilt exceeded 0.002-ft/ft. During undermining PennDOT implemented a plan that: 1) temporarily supported the Zediker Station Road overpass (Figure IV-7), 2) dismantled some of some overhead signs, 3) imposed a speed-limit of 40-mph, 4) provided for lane closures and detours, and 5) visually monitored highway conditions (O'Connor, 2001). As a result, there were no accidents attributed to undermining this section of I70.

Figure IV-7 – Mitigation techniques used at the Zediker Station Road Overpass (Photograph from PA DEP files).

Table IV-2 - Mine Eighty-Four longwall panel characteristics pertinent to the undermining of I70, 1999 to 2000.

Panel ID	Days to Mine	Acres	Dates Mined		Overburden, ft		Panel Dimensions, ft		Avg. Over-burden ft	Days to Mine 1 Acre	Width-to-Height
			Start	Com-pleted	Min.	Max.	Width	Length			
3-South	101	165.8	11/22/99	3/2/00	520	765	1,057	6,810	643	0.61	1.65
4-South	221	215.2	3/9/00	10/16/00	550	760	1,061	8,685	655	1.03	1.62
Avg.	161	190.5					1,059	7,748	649	0.82	1.63

According to O'Connor (2001) vertical subsidence was measured and differed from prediction –

> "…..The ground surface ultimately deformed into a trough with maximum subsidence of three to five feet with surface tilting occurring around the margins of the trough. Precursor movement occurred ahead of the mine face, and outside the edges of the panel being mined. Predicted subsidence profiles, however, differed from the actual measured subsidence. As a consequence of differential tilt, (the) ground surface, pavement and structures were subjected to greater curvature and larger curvature strain than anticipated. Buried culverts and an overpass along the undermined section of I70 were not damaged, but longitudinal cracks developed between lanes, as did transverse bumps. This led to temporary lane closures as cracks were filled and bumps milled down. Along secondary roads, some transverse cracking occurred and the wall blocks in a railroad bridge abutment cracked and shifted…."

IV. D – Characteristics of Longwall Panels Undermining Portions of I79 during the 3rd Assessment Period

The location of the nine longwall panels, operated by Alpha Resources' Emerald and Cumberland Mines, and their associated overburdens are shown in Figure IV-8. As with the Gateway Mine panels, the Alpha longwall panels cut across I79 at oblique angles ranging between 45 to 80-deg. The overburden from the Pittsburgh Coalbed to the overlying I79 ranged between greater than 500-ft to less than 1,000-ft.

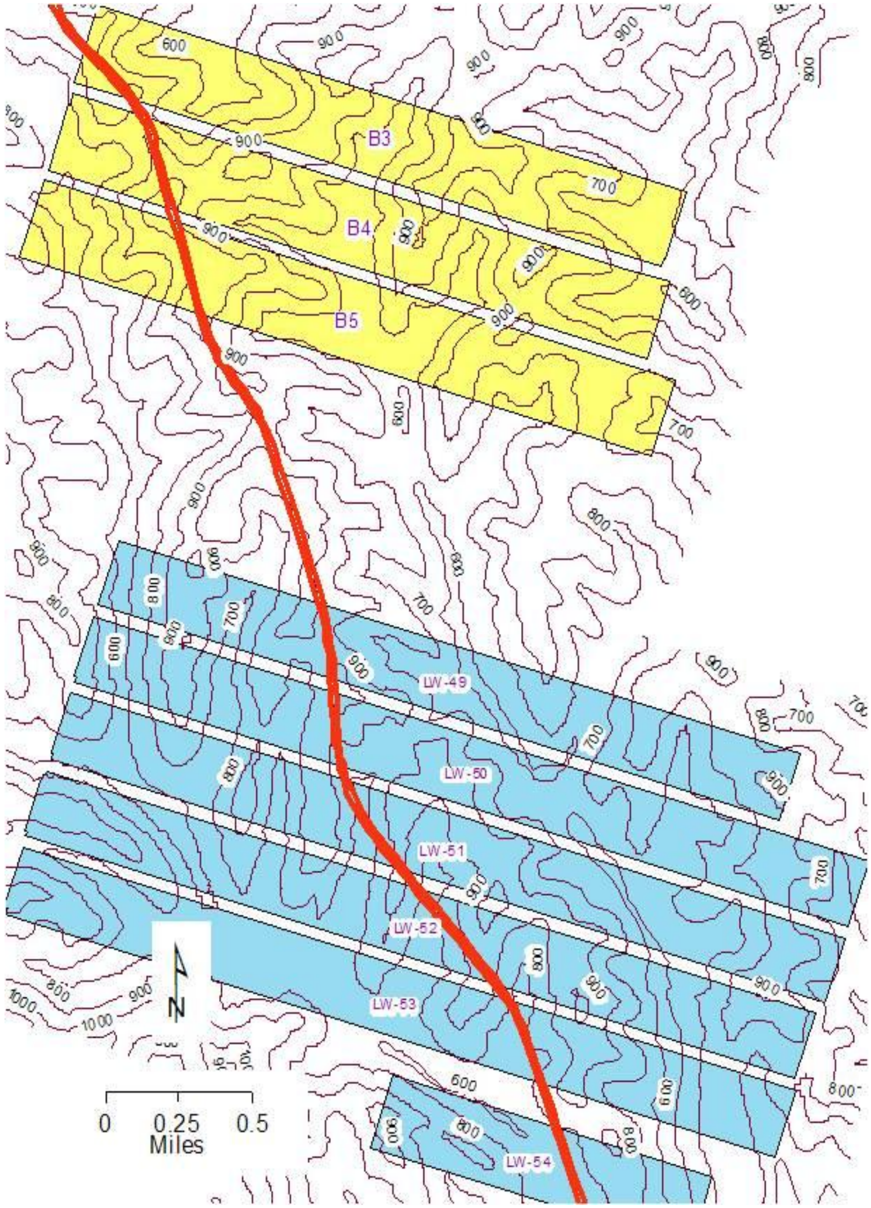


Figure IV-8 - Portions of I79 undermined by Emerald and Cumberland longwall panels including the overburden above the Pittsburgh Coalbed.

IV.D.1 - Panel Characteristics

The difference between the size and mining rate for the panels mined at the Gateway Mine in the 1980's and Emerald and Cumberland Mines during the 3rd assessment period was significant. The Emerald and Cumberland panels had an average width of 1,295-ft, an average length of 13,208-ft, and an average area of 372 acres (Table IV-3). This made these panels nearly 8 times larger in area than the Gateway panels. Another dramatic different was the rate of mining. The average Emerald and Cumberland panel was mined in 275 days, meaning that it took just 0.7 days to mine one acre (Table IV-3). This indicates that during an average day, the Emerald and Cumberland Mines mined approximately 7.6 times more coal than comparable longwall mines in the early 1980's. This is an important trend to note for this study since it indicated that the rate of mining has increased with time, which has, in turn, decreased the total length of time needed for the longwall subsidence basin to form and reach equilibrium.

Table IV-3 - Emerald and Cumberland longwall panel characteristics undermining I79 during the 3rd assessment period.

Panel ID	Days to Mine	Acres	Dates Mined		Panel Overburden, ft		Panel Dimensions, ft		Days to Mine an Acre
			Start	Completed	Min.	Max.	Width	Length	
B3	252	365	6/30/05	3/9/06	528	960	1,432	11,114	0.7
B4	274	370	3/20/06	12/19/06	601	955	1,430	11,289	0.7
B5	328	392	12/31/06	11/24/07	570	1,000	1,432	11,924	0.8
49	354	366	12/29/03	12/17/04	585	925	1,234	12,855	1.0
50	290	418	1/6/05	10/23/05	578	916	1,243	14,664	0.7
51	284	418	11/5/05	8/16/06	569	916	1,153	14,641	0.7
52	281	415	8/31/06	6/8/07	587	918	1,242	14,538	0.7
53	271	416	6/30/07	3/27/08	578	960	1,137	14,635	0.7
54*	144	189	4/9/08	As of 8/31/08	581	932	1,354	6,077	0.8
Avg	275	372					1,295	13,208**	0.76

* - for Panel 54, mining continued after 8/31/08
** - excluding Panel 54

IV.D.2 - Subsidence Properties

An evaluation of the subsidence properties of longwall panels operating under I79 demonstrate how this highway was impacted by the formation of the subsidence basin. Figure IV-9 illustrates some of the properties involved in defining a subsidence basin.

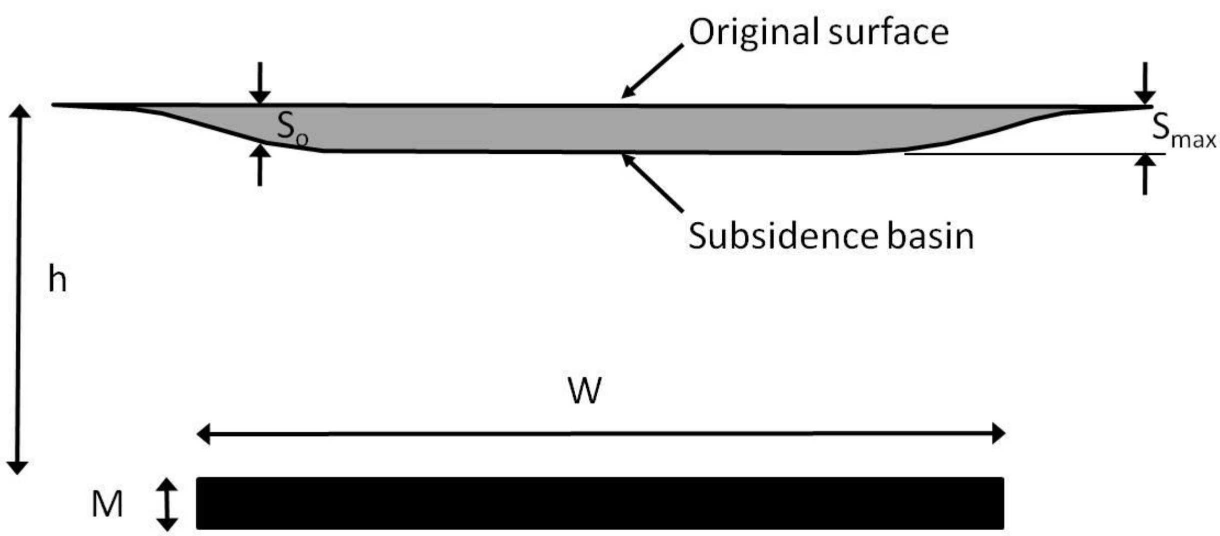


Figure IV-9 – Subsidence properties: M = coalbed thickness, W = longwall panel width, H = depth of cover, S = incremental value of vertical surface subsidence across the basin, and S_{max} = maximum vertical surface subsidence per panel.

As a general rule, the critical width (Lc) of a longwall panel is defined by:

Lc = W/H

When a critical width (Lc) is achieved, the maximum subsidence (S_{max}) potential is realized. If the critical width (Lc>1) is exceeded, the panel is said to have supercritical characteristics. In these cases, vertical subsidence reaches a maximum value, where S/S_{max} equals 1, and maintains that value over the center portion of the panel. For most US coalfields, the Lc is between 1.2 and 1.4 (Peng, 1992). In the case of the Emerald and Cumberland panels undermining I79, the W/H ratio averaged 1.7 (Table IV-4), producing a large, flat bottom subsidence basin. In contrast, the Gateway panels are subcritical in width with a W/H ratio that averaged 0.64. These subcritical panels never achieved their maximum subsidence potential and did not develop a flat bottom subsidence basin. The Mine Eight-Four panels were much like the Emerald and Cumberland panels. They were supercritical in width with a W/H ratio that averaged 1.63.

Table IV-4 - Subsidence properties of longwall panels that undermined I79 during the 3rd assessment period.

Mine	Panel ID	Mining height (M), ft	Max. subsidence (S_{max}), ft	Subsidence factor, (a)	Avg. 0verburden, ft (H)	Width-to-Height (W/H)
Emerald	B3	6.6	4.7	0.71	744	1.9
Emerald	B4	6.3	3.9	0.62	778	1.8
Emerald	B5	NA*	NA	NA	785	1.8
Cumberland	LW-49	7.4	4.6	0.62	755	1.6
Cumberland	LW-50	7.4	4.6	0.62	747	1.7
Cumberland	LW-51	7.4	4.7	0.64	743	1.6
Cumberland	LW-52	7.4	4.9	0.66	753	1.7
Cumberland	LW-53	7.7	5.3	0.69	769	1.5
Cumberland	LW-54	7.7	5.5	0.71	757	1.8
Avg.		7.2	4.8	0.66	759	1.7

* - NA = Not available

The vertical subsidence along I79 was monitored by the Emerald and Cumberland Mines and reported to PennDOT. Subsidence measurements were provided to the University as part of a PennDOT contract and were reported by Gutiérrez, J.J. et al. (2010). A profile of the vertical transversal subsidence for Cumberland Panel LW-49 is shown in Figure IV-10. The profile of a subsidence basin with a supercritical character was clearly developed. Zero and 1,234-ft transversal distances represented the boundaries between the gate road entries and the panel. Very small amounts of vertical subsidence occurred over the gate roads (S_o < 0.5-ft). At both margins of the panel, the vertical subsidence rapidly dropped off into a flat central basin. The maximum vertical subsidence (S_{max}) in the center of panel LW-49 reached 4.8-ft.

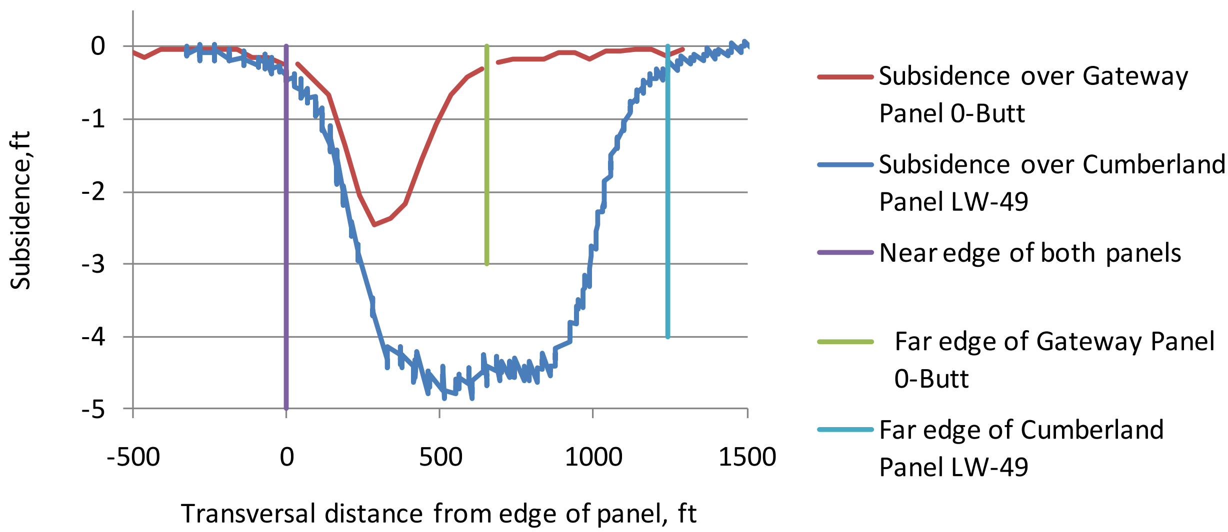


Figure IV-10 – Vertical transversal subsidence across Cumberland Panel LW-49 and comparison with vertical subsidence across Gateway Panel 0-Butt. Note the maintenance of a flat maximum vertical subsidence profile along the center of the subsidence basin indicative of supercritical subsidence basin. Also note the comparison with the vertical transversal subsidence across Gateway Panel 0-Butt which exemplifies a subcritical subsidence basin.

Figure IV-10 also provides a comparison between the supercritical Cumberland Panel 49 and the subcritical Gateway Panel 0-Butt. The Gateway subsidence basin also showed small amounts of vertical movement over the gate roads (S_o < 0.3-ft). The vertical subsidence rapidly dropped to a point and rose up to the other panel edge. The maximum vertical subsidence (S_{max}) in the center of this basin reached 2.5-ft.

Another important property is the subsidence factor (a). This property is calculated using the following relationship:

$a = S_{max} / M$

The average Emerald and Cumberland Mine subsidence factor for the panels undermining I79 was 0.66 (Table IV-4). The maximum subsidence factor was influenced by the geometry of the panel and geology of the overburden.

Zacharias and Karmis (2008) provide a means to estimate the percent of hard rock contained within an overburden when the maximum subsidence factor (a) and the W/h are known. As the percent of hard rock in the overburden increases, the maximum vertical subsidence decreases. The converse is also true. Hard rocks are typically sandstone and limestone, while soft rocks are shale, siltstone, clay stone, and coal. Using the procedure defined in Zacharias and Karmis (2008), the percent of hard rock at the Emerald and Cumberland panels was calculated to be 24-pct. All of the above properties are important in modeling the subsidence basin and account for the diverse range of subsidence conditions found in Pennsylvania’s longwall mines.

IV.D.3 – Nature of Impacts

As the surface is undermined by a longwall panel, two distinct regions of deformation occur. First, as the longwall approaches, vertical subsidence begins slowly, speeds up until the inflection point in the subsidence event is encountered, and then begins to slow down until equilibrium is achieved (Figure IV-11). The inflection point moves forward with the advancing longwall face and generally represents the point where the vertical subsidence (S) is ½ S_{max}. The onset of vertical subsidence is defined by the angle of dynamic subsidence (δ_d) and the depth of cover (H). As the δ_d and H increase, the on-set of vertical subsidence increases. The inflection point defines the point of zero curvature. Ground surfaces in front of the inflection point are subjected to tension while surfaces behind the inflection point experience compression.

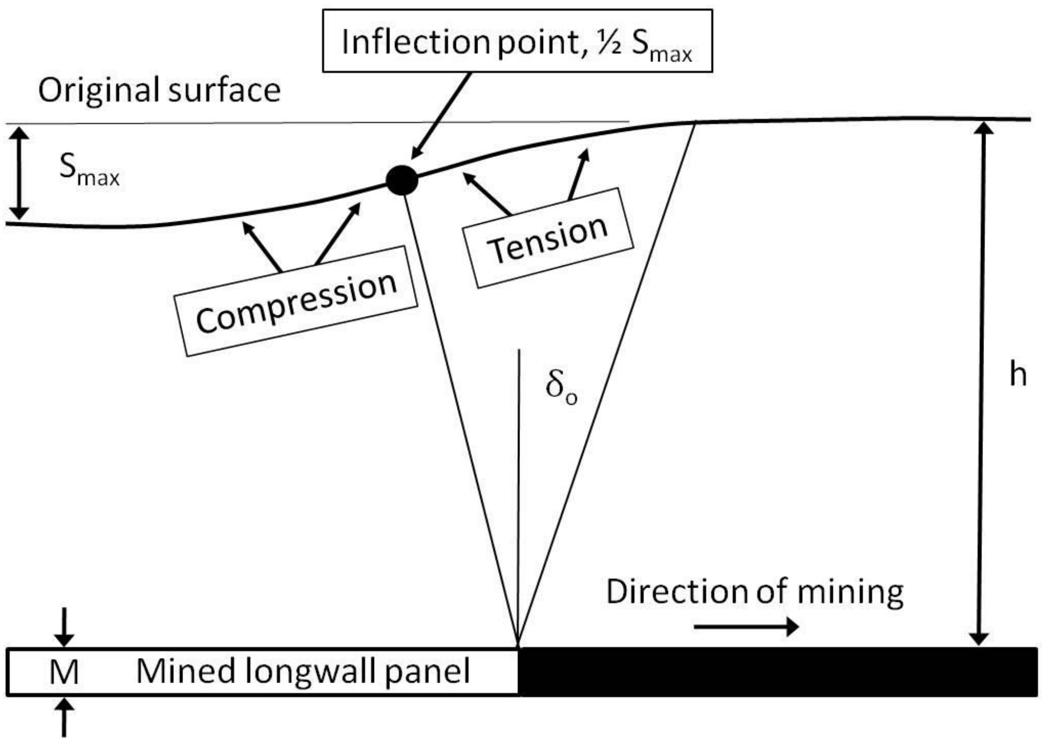


Figure IV-11 – Generalized relationship between vertical subsidence (S), h, δ_d, M and the occurrence of deformations caused by compression and tension.

These two general regions impacted the surface of I79 as the longwall panel moved under the highway. The methods developed by the Federal Highway Administration (Miller and Bellinger, 2003) helped to categorize the distress condition of jointed cement concrete-surface pavements. Four general categories with 16 subcategories of distress were defined (Table IV-5). These methods were applied to I79 in Greene County where the concrete sections were 62.5-ft long and were covered by several inches of asphalt (Painter, 2010).

TableIV-5 - Jointed concrete surface pavement distress types (Miller and Bellinger, 2003).

Category	**#**	**Distress Type**
Cracking	1	Corner Breaks – A portion of the slab separated by a crack, which intersects the adjacent transverse and longitudinal joints, describing approximately a 45-deg angle with the direction of traffic. The length of the sides is from 1-ft to one-half the width of the slab on each side of the corner.
	2	Durability Cracking – Closely spaced, crescent-shaped hairline cracking pattern, occurring adjacent to joints, cracks, or free edges. Initiates in slab corners with dark coloring of the cracking pattern and surrounding area.
	3	Longitudinal Cracking – Cracks that are predominantly parallel to the pavement centerline.
	4	Transverse Cracking – Cracks that are predominantly perpendicular to the pavement centerline.
Joint Deficiencies	5	Joint Seal Damage – Conditions which enable incompressible materials or water to infiltrate the joint from the surface. Typical types of joint seal damage are: extrusion, hardening, adhesive failure (bonding), cohesive failure (splitting), or complete loss of sealant; intrusion of foreign material in the joint; and weed growth in the joint.
	6	Spalling of Longitudinal Joint – Cracking, breaking, chipping, or fraying of slab edges within 0.3 m from the face of the longitudinal joint.
	7	Spalling of Transverse Joint – Cracking, breaking, chipping, or fraying of slab edges within 0.3 m from the face of the transverse joint.
Surface Defects	8	Map Cracking and Scaling – Map cracking is a series of cracks that extend only into the upper surface of the slab. Larger cracks frequently are oriented in the longitudinal direction of the pavement and are interconnected by finer transverse or random cracks. Scaling is the deterioration of the upper concrete slab surface, normally 3 mm to 13 mm, and may occur anywhere over the pavement.
	9	Polished Aggregate - Surface mortar and texturing worn away to expose coarse aggregate.
	10	Popouts - Small pieces of pavement broken loose from the surface, normally ranging in diameter from 25 mm to 100 mm, and depth from 13 mm to 50 mm.
Miscellaneous Distress	11	Blowups - Localized upward movement of the pavement surface at transverse joints or cracks, often accompanied by shattering of the concrete in that area.
	12	Faulting of Transverse Joints and Cracks - Difference in elevation across a joint or crack.
	13	Lane-to-Shoulder Dropoff - Differences in elevation between the edge of slab and outside shoulder; typically occurs when the outside shoulder settles.
	14	Lane-to-Shoulder Separation - Widening of the joint between the edge of the slab and the shoulder.
	15	Patch/Patch Deterioration - A portion, greater than 0.1 m^2, or all of the original concrete slab that has been removed and replaced, or additional material applied to the pavement after original construction.
	16	Water Bleeding and Pumping - Seeping or ejection of water from beneath the pavement through cracks. In some cases, detectable by deposits of fine material left on the pavement surface, which were eroded (pumped) from the support layers and have stained the surface.

Several of the distress types described in Table IV-5 can be associated with surface deformations induced by longwall mining. For example, "blowups" (No. 11, Table IV-5), can be associated with compressive surface deformations. Accordingly, blowups would not be expected until after the longwall face and the inflection point have moved under a point on the surface. Therefore they should occur later in the formation of the subsidence basin. Some other concrete distress types, i.e. transverse cracking (No. 4, Table IV-5), spalling of transverse joint (No. 7, Table IV-5), faulting of transverse joints and cracks (No. 12, Table IV-5), are often associated with tensile surface deformations. These concrete distress types should be more frequent earlier in the subsidence basin formation, often in association with the longwall face moving under a point on the surface.

IV.E – Observations During Undermining of I79

PA DEP staff routinely visited I79 while the longwall face was mined under the highway. During these visits they often took pictures of highway conditions and, on occasion, made written observations. The visual clues and written descriptions were usually sufficient to establish the general location and perspective of the photographs. Documentation of the impacts to I79 in response to longwall mining during the 3rd assessment period follows.

IV.E.1 – Emerald Panels

Three Emerald panels impacted the overlying sections of I79 (Figure IV-12). The overburden at the area where I79 crossed these three panels ranged from approximately 700 to over 900-ft (Figure IV-12). I79 crossed all the Emerald panels at oblique angles ranging between 35 to 70-deg.

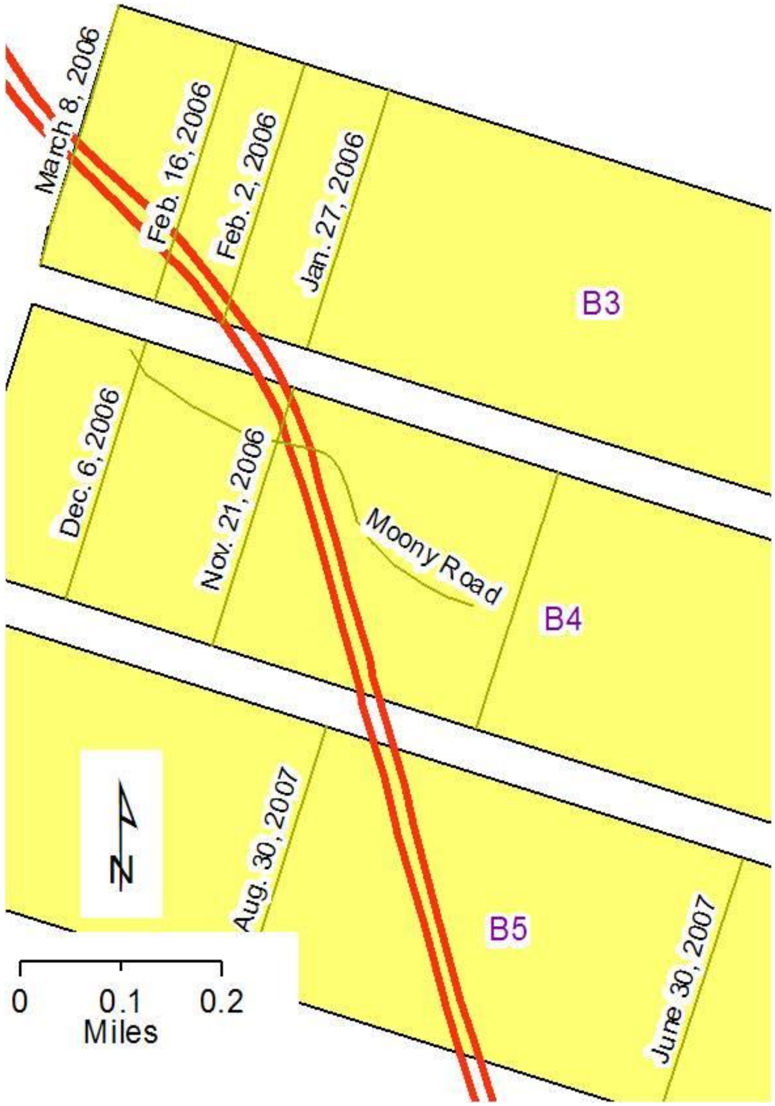


Figure IV-12- Locations of Emerald Panels B3, B4, and B5 with dated face positions during undermining of I79. Also shown is the section of Moony Road where it intersects I79.

IV.E.1.a - Panel B3

The Emerald Panel B-3 impacted the overlying sections of I79 from January 27, 2006 to February 28, 2006 (Figure IV-12). By January 27, 2006 the initial tensile subsidence wave from Panel B-3 began to impact I79. The impact at this point was predicted to be marginal. PennDOT workers removed signs and marked the road for monitoring purposes. The overburden at the I79 crossing of panel B-3 ranged from 750 to 850-ft (Figure IV-12). Results from undermining Panel B-3 were expected to be different from other panels mined during the 3rd assessment period because the highway bisected only the corner-end of the panel.

Cracks along the I79 were first observed on February 14, 2006, in the northbound lanes. One section of pavement contained longitudinal cracking (No. 3, Table IV-5) with a separation of about 1-in. Other longitudinal cracking was observed closer to the edges of the road with separations between 1/4 and 1/2-in. At this point most of I79 had experienced less than half of the total expected subsidence. The surface curvature produced at this time would have exerted almost exclusively tensile forces on the highway foundation. No compression or buckling road surfaces were observed at this time.

On February 21, 2006, the southbound lanes were still relatively free of impacts. A small transverse compression heave or blowup (No. 11, Table IV-5 developed in the northbound passing lane (Figure IV-13a) and required milling and patching (Figure IV-13c). In addition, a large lane-to-shoulder separation (No. 14, Table IV-5) formed along the boundary between the pavement and the shoulder (Figure IV-13b). Between February 22, 2006 and March 8, 2006, PennDOT restricted traffic to one-lane and did extensive patching to the shoulders of both the north and southbound sides (Figure IV-13d). While this area had not required extensive milling, some heaving was noted near the end of the panel. The surface curvature produced at this time would have exerted a dominant compressive force on the highway foundation. The lane-to-shoulder separation might have been caused by the heaving of large concrete slabs in response to this compressive loading.

Figure IV-13 – Panel B3 photographs showing (a) a transverse compression heave, (b) lane-to-shoulder separation ,(c) blowup compression bump being milled, (d) single lane restrictions with longitudinal patching, February 21, 2006 (Photographs from PA DEP files).

IV.E.1.b - Panel B4

Panel B4 was undermined between October 22, 2006 and December 6, 2006 (Figure IV-12). The overburden at the I79 crossing of Panel B-4 ranged from approximately 820 to 920-ft (Figure IV-12). On October 30, 2006, the longwall face was located directly underneath the southbound lane at the southern edge of panel B-4 and no new subsidence damage was observed to I79.

PennDOT personnel installed cameras to take photos of the roadway every 5-min. (Figure IV-14a). Some minor longitudinal and transverse cracking (No. 3 & 4, Table IV-5) were observed (Figure IV-14b and c). Many of these cracks existed prior to undermining and were observed to extend and widen during the observation period.

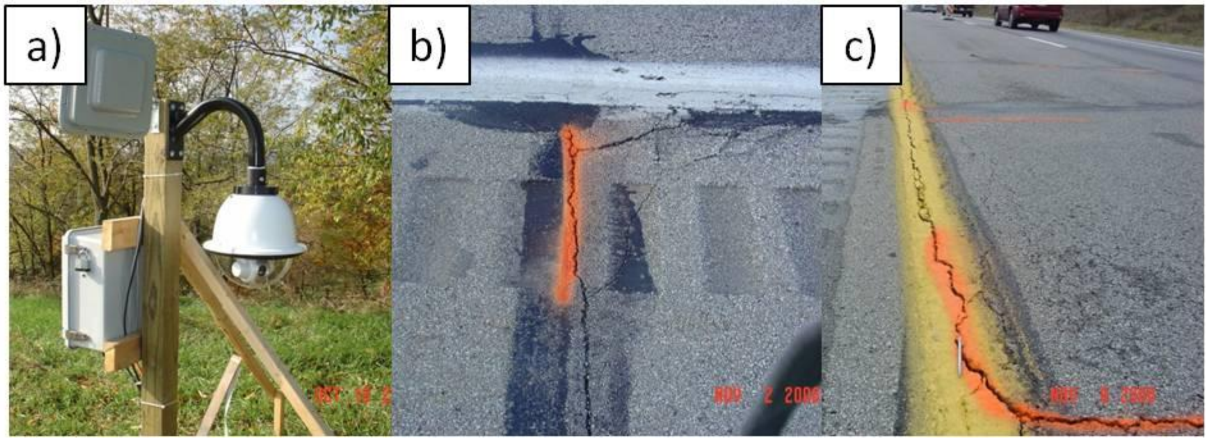


Figure IV-14 – Panel B4 Photograph showing a (a) remote camera system, (b) transverse crack, and (c) longitudinal crack (Photographs from PA DEP files).

On November 6, 2006, some hairline cracks were visible in the northbound lanes. Minor lane-to-shoulder separations (No. 14, Table IV-5) occurred in both northbound and southbound lanes by November 16, 2006 (Figure IV-15a). These separations were typically 1/8 to 3/4-in wide. Some minor lane-to-shoulder drop-off (No. 13, Table IV-5) was also observed in these same areas. On November 22, 2006, a large blowup (No. 11 Table IV-5 and Figure IV-15b) and deformed guard rails were observed (Figure IV-15c).

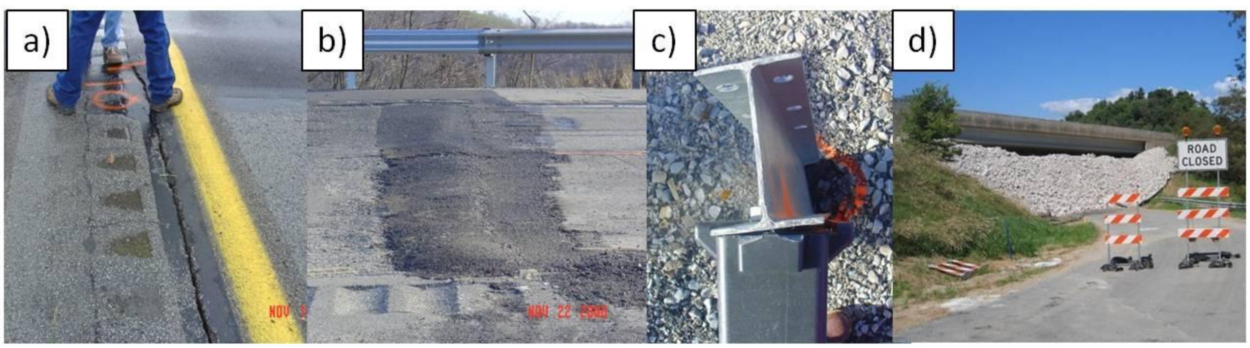


Figure IV-15 - Panel B4 photograph showing a (a) lane-to-shoulder separation, (b) blowup, (c) distressed guard rails, and (d) mitigation method to protect I79 Bridge at Moony Road (Photographs from PA DEP files).

Moony Road (also known as Tower Road) crosses under I79 in this area (Figure IV-12). PennDOT placed aggregate underneath both the north- and southbound overpass structures as well as in the median area (Figure 15d). Once the aggregate was at sub-grade, a temporary section of road was built in the median area. The southbound traffic was relocated to the median area and the southbound structure (bridge deck, beams, and parapets) were then removed. The structure was replaced with a two lane asphalt roadway. When the work was completed on the southbound side, the same measures were completed on the northbound overpass structures.

IV.E.1.c - Panel B5

Panel B5 was undermined from June 30, 2007 to September 30, 2007 (Figure IV-12). The overburden at the I79 crossing of panel B5 ranged between approximately 880 and 940-ft. No roads cross over or under this portion of I79, however, a communications tower was located near the highway and the impact to this structure is explained later in the report.

PennDOT utilized remote data acquisition systems and transferred information collected while I79 was undermined to their offices for review and analysis (Figure IV-16a). Monitoring occurred 24-hours a day and traffic was limited to one lane in each direction at a rate of 45-mph. Tensile forces caused the first recognized impacts. For example, on June 21, 2007, a corner break (No. 1, Table IV-5) was observed (Figure IV-16b). Later, in late July and early August (Figure IV-16c and d) spalling of transverse joints (No. 6, Table IV-5) and transverse cracking (No. 4, Table IV-5) occurred. Many of the joints and cracks ranged in size between 1/8 and 2-in.

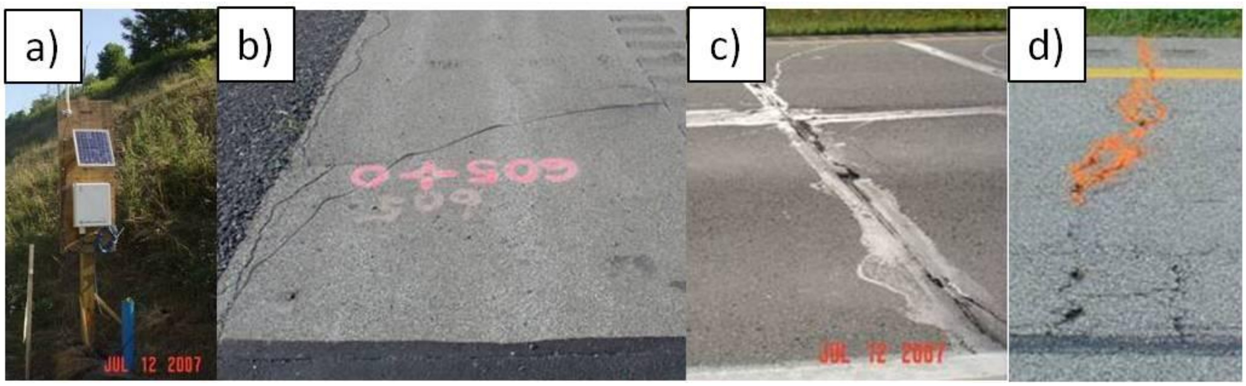


Figure IV-16 – Panel B5 photographs showing (a) data acquisition equipment, (b) corner breaks, (c) transverse joints, and (d) transverse cracks (Photographs from PA DEP files).

In August, the compressive failures became more dominant. Lane-to-shoulder dropoff (No. 13, Table IV-5) and separation (No. 14, Table IV-5 and Figure IV-17a) and blowup (No. 11, Table IV-5 and Figure IV-17b) were observed. In addition, transverse cracks (No. 4, Table IV-5) continued to occur (Figure IV-17c). Open joints were either filled or patched. The blowups were repaired by milling and patching. Figure IV-17d provides a view of the subsidence basin as of September 11, 2007.

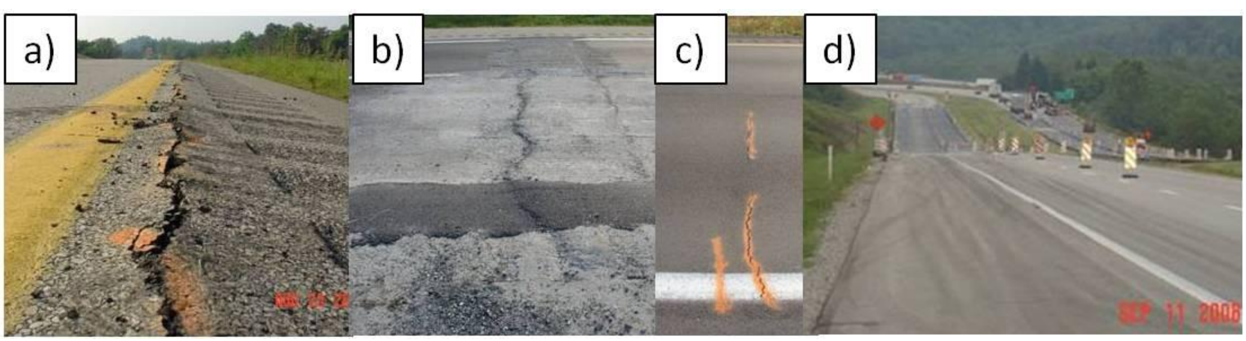


Figure IV-17 – Panel B5 photographs showing (a) lane-to-shoulder separation, (b) blowups, (c) transverse cracks, and (d) view of the final subsidence basin (Photograph from PA DEP files).

IV.E.2 – Cumberland, Panels

Six Cumberland panels impacted the overlying sections of I79 (Figure IV-18). No photographs were available for Panel LW-49 (September and October, 2004). The distance between Panels LW-53 and LW-54 was much larger than any other panel. The larger distance was related to the inclusion of a main entry system running between both longwall panels. The overburden at the area of I79 crossing these six panels ranged between approximately 760 to almost 1,000-ft (Figure IV-18). In all of these panels, I79 crossed the Cumberland panels at oblique angles ranging between 35 to 70-deg.

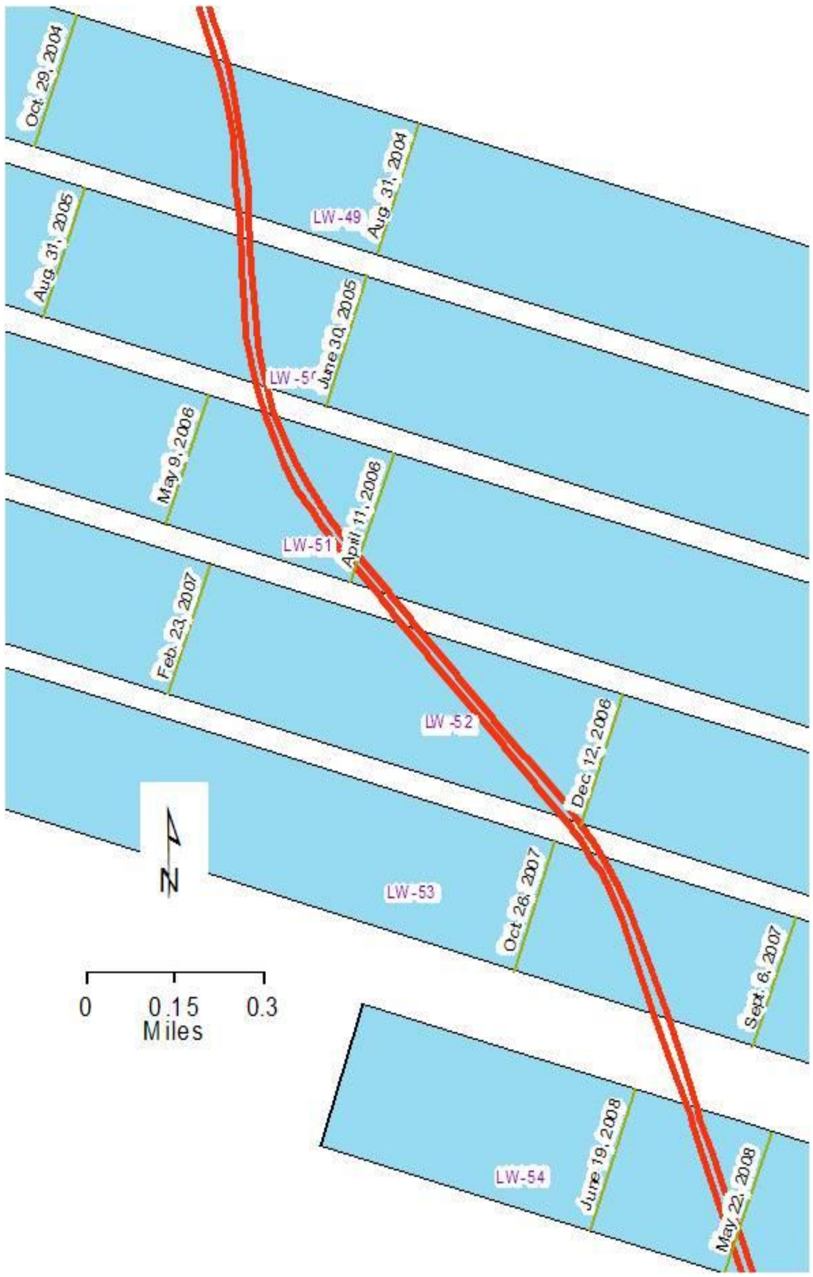


Figure IV-18 – Location of Cumberland Panels LW-49, LW-50, LW-51, LW-52, LW-53, and LW-54 with associated face positions while the undermining of I79 occurred.

IV.E.2.a - Panel LW-49

Panel LW-49 was mined from December 29, 2003 to December 17, 2004. The I79 portion of the panel was undermined during end of September and beginning of October 2004. The overburden at the I79 crossing of Panel LW-49 ranged between approximately 810 and 900-ft (Figure IV-18). No impacts or photographs relating to the undermining of this section were found.

IV.E.2.b - Panel LW-50

Panel LW-50 was mined from January 6, 2005 to October 23, 2005. The I79 portion of the panel was undermined during mid-July and early August 2005. The overburden at the I79 crossing of Panel LW-50 ranged between approximately 780 and 910-ft (Figure IV-18).

By August 3, 2005 the longwall panel had mined past I79 and PennDOT began patching damaged sections (Figure IV-19a). On that same day, a corner break (No. 1, Table IV-5) was observed (Figure IV-19b). Two days later, faulting occurred along a joint (No. 12, Figure IV-19c). Figure IV-19d shows the subsidence basin on August 11, 2005.

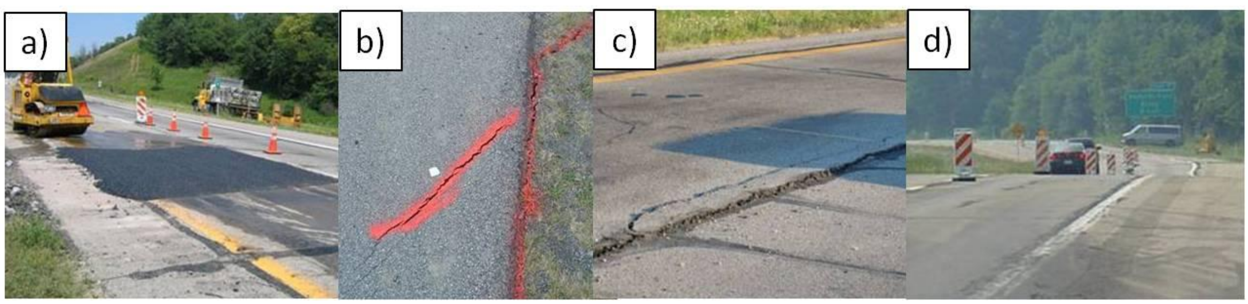


Figure IV-19 - Panel LW-50 photographs showing (a) patching activity, (b) a corner break, (c) faulting of joints, and (d) subsidence basin (Photographs from PA DEP files).

IV.E.2.c - Panel LW-51

Panel LW-51 was mined from November 5, 2005 to August 16, 2006 (Figure IV-18). The I79 portion of the panel was undermined during April and early May 2006. The overburden at the I79 crossing of Panel LW-51 ranged between approximately 650 and 820-ft (Figure IV-18).

Transverse joint spalling (No. 7, Table IV-5) was observed on April 21st (Figure IV-20a). On April 27, 2005 PennDOT patched separations (No. 14, Table IV-5) along the lane-to-shoulder area (Figure IV-20b). Figure IV-20c shows compression along highway guard rail and a photograph on May 11, 2005 (Figure IV-20d) shows a recently repaired blowup (No. 11, Table IV-5).

Figure IV-20 – Panel LW-51 photographs showing (a) spalling of transverse joint, (b) lane-to-shoulder separation, (c) compression of guard rail, and (d) blowup (Photographs from PA DEP files).

IV.E.2.d - Panel LW-52

Panel LW-52 was mined from August 31, 2006 to June 8, 2007 (Figure IV-18). The I79 portion was undermined during December 2006 and January 2007. The overburden at the I79 crossing of Panel LW-52 ranged between approximately 680 and 840-ft (Figure IV-18).

On December 21, 2006 the longwall panel began to advance underneath I79 at a 30-deg angle, and a large transverse crack (No. 7, Table IV-5) was observed (Figure IV-21a). Corner breaks (No. 1, Table IV-5) were observed on January 4, 2007 as the longwall face advanced to half the transversal distance (Figure IV-21b). PennDOT used saw cuts to de-stress the highway on January 11, 2007 (Figure IV-21c). Figure IV-21d shows the resurfaced highway on July 12, 2007 approximately 6-months after longwall mining.

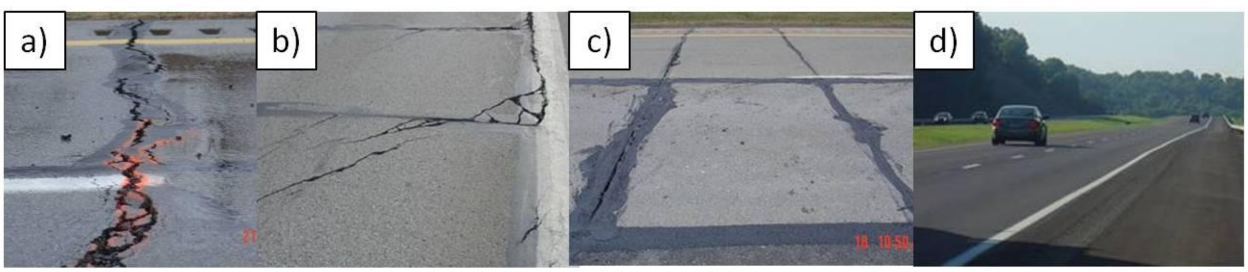


Figure IV-21 – Panel LW-52 photographs showing (a) transverse cracking, (b) corner breaks, (c) highway deformation between saw cuts in the slabs, and (d) rehabilitated highway surface (Photographs from PA DEP files).

IV.E.2.e - Panel LW-53

Panel LW-53 was mined from June 30, 2007 to March 27, 2008 (Figure IV-18). The I79 portion was mined during mid September and late October 2007. The overburden at the I79 crossing of Panel LW-53 ranged between approximately 670 and 730-ft (Figure IV-18).

Several months prior to the undermining of I79, PennDOT used saw cuts on sections of highway slabs to help mitigate future deformations (June 26, 2007, Figure IV-22a). Temporary patching occurred during various stages of I79 undermining (Sept. 27, 2007, Figure IV-22b). On Oct. 4, 2007, I79 was directly over the center portion of the advancing longwall face. Faulting of transverse joints (No. 12, Table IV-5) and lane-to-shoulder drop-off (No. 13, Table IV-5) were observed by PA DEP personnel.

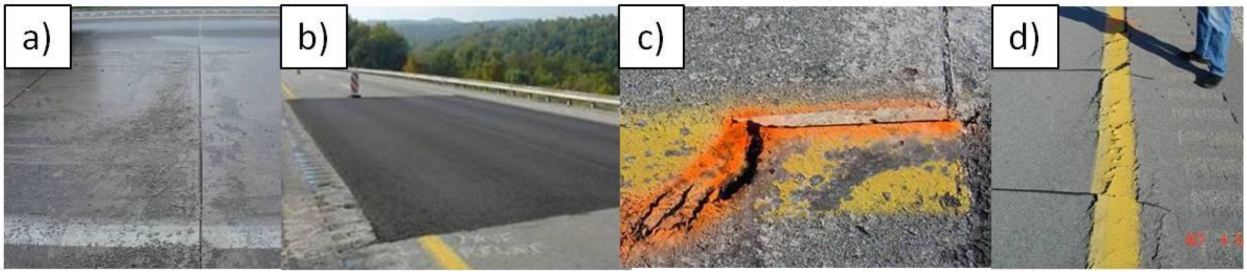


Figure IV-22 – Panel LW-53 photographs showing (a) pre-mining saw cuts, (b) temporary patching, (c) faulting of transverse joints, and (d) lane-to-shoulder drop-off (Photographs from PA DEP files).

IV.E.2.f - Panel LW-54

Panel LW-54 was mined from April 9, 2008 to August 31, 2008 (Figure IV-18). The I79 portion of the panel was undermined during mid May and mid June 2008. The overburden at the I79 crossing of Panel LW-54 ranged between approximately 640 and 700-ft (Figure IV-18).

During the mining of Panel LW-54, lane-to-shoulder drop-off (No. 13, Table IV-5) and transverse (No. 4, Table IV-5) and longitudinal cracking (No. 3, Table IV-5) occurred (Figures IV-23a and b). Figure IV-23c shows the final subsidence basin as of June 12, 2008.

Figure IV-23 – Panel LW-54 photographs showing a (a) lane-to-shoulder drop-off, (b) transverse and longitudinal cracking between saw cuts, and (c) final subsidence basin (Photographs from PA DEP files).

<u>IV.F – Summary Points</u>

Two Interstate highways in southwestern Pennsylvania have been undermined by 21 longwall panels since the early 1980s. Longwall panels in the 1980s were significantly narrower than contemporary longwall panels, and often produced subcritical subsidence characteristics. The nine recent longwall panels located under I79 (2003 to 2008) were among some of the widest in the US, producing supercritical subsidence characteristics. In addition, the rate of mining has steadily increased with time, which has in turn decreased the total length of time needed for the longwall subsidence basin to form and reach equilibrium.

In general, tension type distress features, i.e. longitudinal and transverse cracking, began to impact the highway prior to and during the undermining of the highway by the longwall face. Conversely, compression type distress features, i.e. blowups or heaving, were more common after the longwall face had passed underneath the highway.

In the cases studied, longwall mining resulted in numerous localized effects. Some of the effects were transitory in nature as the subsidence wave passed through the area. These effects were successfully managed through traffic controls and temporary support measures. In general, damage effects were addressed through routine road maintenance such as milling, patching, repaving, and straightening guardrails. An exception was the preemptive approach taken by PennDOT to prevent a potential catastrophic differential subsidence event of the bridges carrying I79 over Mooney (Tower) Road. The Commonwealth of Pennsylvania spent over 19 million dollars (Painter, 2010) monitoring and rehabilitating sections of I79 impacted by longwall mining (Table IV-6).

Table IV-6 – Cost to maintain, monitor, and repair I79 during undermining (Painter, 2010).

Year	Detour Preparation Cost, $	Monitor and Equipment, $	Construction, $	Total, $
2002-2003	6,263,597			6,263,597
2004		244,048	467,608	711,656
2005		65,309	1,644,856	1,710,165
2006		239,176	3,192,371	3,431,548
2007		152,871	3,090231	3,243,102
2008		230,131	4,016737	4,246,868
Total 2003 to 2008				19,606936

* - Estimated

Impacts to I79 could be considered significant in three ways. First, traffic through the monitoring areas was adversely affected for a span of over 5-years. During active mining or repair period, the speed-limit was reduced to 45-mph and the lanes were reduced from two to one in both directions. Second, longwall mining impacted the vertical curvature and sight distances of the highway. Third, the Commonwealth of Pennsylvania was required to spend approximately 20 million dollars monitoring and rehabilitating sections of I79 impacted by longwall mining.

However, traffic flow was safely maintained at all times. State Police reported no driving related injuries as a result of longwall mining. The majority of the damages noted consisted of longitudinal cracking, mainly along the edges of the highway, and heaving, mainly along transverse joints. These kinds of damages are within the range of commonly observed distress concrete documented by the Federal Highway Administration (FHA) (Table IV-5). The vast majority of highway deformations were transient; therefore the highway monitoring and rehabilitation efforts were concentrated over a span of several months for each panel mined.

One fact is certain, in the cases that have transpired to date, it has been more cost effective to allow longwall mining to proceed than to condemn the coal needed to provide support for the highway. The cost to condemn the coal was estimated by O'Connor (2001) at approximately one order of magnitude higher than the current repair cost sighted earlier.

SECTION V: Effects of Mining on Structures

V.A - Overview

The University collected information on the structures in the proximity of active underground coal mines between August 21, 2003 and August 20, 2008. The structures that met the PA DEP criteria for tracking were entered into the UGISdb and are explained within this section.

A total of 3,735 structures were tracked. Four-hundred-fifty-six reported effects were found, each required additional information and analysis (Appendix B1). Another 26 were analyzed from the 2nd assessment period for a total of 482 reported effects analyzed (Appendix B2). The majority of the reported effects were associated with the eight longwall mines. Characteristics of the structures were analyzed and discussed, with special attention to those with reported effects. The number of undamaged and reportedly damaged structures (i.e., dwelling, barn, commercial building, etc.) undermined during the assessment period were listed. Lastly, the resolution status and type of resolution were analyzed for all structure reported effects.

V.B - Data Sources

The impacts of undermining during the assessment period were determined by examining the following sources: 1) BUMIS reports, 2) 6-month mining maps submitted to the CDMO by mine operators, 3) paper files at the CDMO, 4) damage reports faxed to the CDMO by mine operators, 5) interviews with technical staff at the CDMO, 6) Subsidence Act (SA) reports, and 7) company supplied AutoCAD mine maps. All of the University's analysis was organized by mining type and category of structure.

The University determined the precise distance from mining to each structure as well as the overburden and topographic conditions. Agent Observations and Problem Tables in BUMIS supplemented observed conditions in the field. Structures with reported effects were compared to mining maps within the University GIS database. From these data several related conditions were assessed and summarized within this section.

V.B.1 - Structures Tracked

Pennsylvania law requires that approved subsidence control plans contain information about structures that will be undermined. In some cases, the size of the structure must be considered for tracking to occur. Performance standards for subsidence control are set forth in Pennsylvania Code, Title 25, Chapter 89.142a. The parts of the code of particular relevance to this report are summarized in Sections V.B.1.a to V.B.1.d.

V.B.1.a – Overburden Less Than 100-ft

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

V. B. 1. b. – Pre-mining Surveys

§ 89.142b, requires the mine operator to 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-deg 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.

V.B.1.c – Mining Beneath Structures and Features

§ 89.142c, the default standard for mining beneath structures and features is 50-pct coal support, although the PA DEP may require a greater percentage. Subsection (c) also clarifies alternatives to the coal support standard including surface measures which may be undertaken in conjunction with planned and controlled subsidence.

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

§ 89.142d, 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.

V.B.2 – The 200-ft Buffer

The University used a 200-ft buffer zone around all areas mined during the 3rd assessment period as a basic criterion for inventorying structures. The buffer starts at the edge of the mined area and extends outward 200-ft. The buffer, constructed in ArcGIS, was used to determine if an individual structure fell within 200-ft of mining. Appendix C contains figures with the 200-ft buffer for each of the 50 operating mines discussed in this report.

V.B.3 – 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. This process contained seven steps:

> <u>Step 1</u> - BUMIS data from the 50 mining operations active during the 3rd assessment period were extracted by the University using available query techniques.
>
> <u>Step 2</u> – Other map sources, i.e. 6-month mining maps, subsidence control maps, mining company supplied AutoCAD files, etc., were searched. When data initially not found

during Step 1 was discovered, the locations of these structures were added to the UGISdb.

Step 3 – Information about each structure was collected and entered into the UGISdb. This information consisted of the following:

- Property Owner (name),
- Property ID (number),
- Property Number (typically the tax ID),
- County,
- Feature ID,
- Feature Number (number),
- Feature Type (dwelling, trailer, garage, cemetery, building, barn, silo, shed or outbuilding, bridge, driveway, grain bin, milk house, storage truck, tower, pool, septic tank, chicken coop, reservoir, dam, springhouse, and Rail Road sub-station),
- Feature Use (Residential, Recreational, Agricultural, Community/Institution, Public, Commercial, Industrial, and Unknown), and
- Problem (Yes or No).

Step 4 – Additional attributes for each structure contained within the UGISdb were analyzed. Characteristics identified and measured included the following:

- Topographic Location (valley bottom, hillside, hilltop),
- Mining Method (room-and-pillar, longwall panel or pillar recovery),
- Distance from Mining (feet),
- Overburden (feet), and
- Area (square feet).

Step 5 – Structures with reported effects occurring within the 3rd assessment period or before the 3rd assessment period but resolved during the period were identified. Special characteristics about these structures were entered into the UGISdb. These characteristics included:

- 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, and
- Resolution Status.

Step 6 – The extent of mining information discussed in Section III were utilized to establish a 200-ft buffer around the areas mined during the 3rd assessment period. All structures that fell outside the 200-ft buffer zone were eliminated with one exception.

That exception is as follows -- if a structure was associated with a reported effect within or prior to the 3rd assessment period, it was retained within the UGISdb.

Step 7 – The size of each structure was calculated and those that didn't meet the minimal square footage requirements ($\geq$ 500-ft^2) as outlined in § 89.142a (f)(1)(v) were eliminated with several exceptions. These exceptions to this size restriction were dwelling, garages, barns, silos, public and commercial buildings and towers, churches, and cemeteries.

The following analysis presents information from structures that passed these seven steps.

V.C – Summary Information about Structures Undermined During the 3rd Assessment Period

Impacts to structures from undermining are influenced by many factors. For example, the most effective means to minimize impacts is to leave protective or safety pillars. Section IV discusses the regulation and standards that define the characteristics of these safety pillars. In other cases, full extraction mining occurs and the pillars are removed to increase extraction rates. When this happens, planned subsidence is expected to follow. In Pennsylvania, two mining methods typically produce planned subsidence; longwall and pillar recovery. No structures were located over the six room-and-pillar mines with pillar recovery during the 3rd assessment period.

The fifty longwall and room-and-pillar mines undermined 3,735 structures with 456 structures reporting effects during the 3rd assessment period (Table V-1). Longwall mines have a higher percent of reported effects, 23.0-pct, than room-and-pillar mines, 1.5-pct.

Table V-1 - Summary of the number of structures, reported effects, and percentage of reported effects sorted by mining type occurring during the 3rd assessment period.

Mining Type	Undermined Structures	Reported Effects*	Percent with Reported Effects
Longwall	1,856	427	23.0
Room-and-Pillar	1,879	29	1.5
Total	3,735	456	12.2

* - Some structures had more than one reported effect.

Of the 456 reported effects, 301 were Company Liable representing 66.0-pct of the total. In addition, 59 were Company Not Liable accounting for 12.9-pct and 96 Unresolved for 21.1-pct of the total (Table V-2). Unresolved reported effects often had interim resolutions. The most striking trends from this table are the high percentage of Company Liable reported effects for longwall mines (70.2-pct), and the high percentage of Unresolved reported effects for room-and-pillar mines (72.4-pct). The higher percentage Company Liable reported effects are most likely related to the formation of subsidence basins associated with longwall panel extraction, while the higher percentage of Unresolved room-and-pillar cases occurred late in the 3rd assessment period.

Table V-2 - Summary of the resolution status sorted by mining type.

Mining Type	Company Liable	Percent Company Liable*	Company Not Liable	Percent Company Not Liable*	Unresolved	Percent Unresolved
Longwall	300	70.2	52	12.2	75	17.6
Room-and-Pillar	1	3.5	7	24.1	21	72.4
Total	301	66.0	59	12.9	96	21.1

* - based on all reported effects

V.C.1 – Features Undermined

Within BUMIS, the PA DEP categorizes structures by feature type. Thirty-one feature types are associated with the 3,735 undermined structures. The ten most common feature types are shown in Table V-3. All dwellings, garages, barns, trailers, buildings, silos, cemeteries, churches, and schools within the 200-ft buffer zone around mining or having a reported effect are tracked within the University's database. All other feature types must have the minimum area requirements of 500-ft^2 or are associated with a reported affect. Three-hundred-and-sixty-six structures, or 9.8-pct of the total, are classified as unknown.

Table V-3 – The ten most common structural features undermined.

Feature Type	Number	Percent Total
Dwelling	1,502	40.2
Garage	593	15.9
Barn	357	9.6
Shed	264	7.1
Trailer	230	6.2
Outbuilding	169	4.5
Building	95	2.3
Silo	35	0.9
Pool	32	0.9
Septic Tank	21	0.6
Total	3,298	88.1

V.C.2 – Notable Structural Features Undermined

Notable structural features undermined (< 0.5-pct of total) are cemeteries, towers, churches, schools, bridges, and dams.

V.C.2.a – Cemeteries

Eleven cemeteries were inventoried at four longwall mines. In general, these cemeteries were very small with an average of 2,771-ft^2. Five of the cemeteries were directly over longwall panels, four were over gate road entries, and two were outside of mining but within the 200-ft buffer zone. Only one cemetery reported an effect and it had a private waiver for damages.

V.C.2.b – Towers

Eleven towers were inventoried. Towers can range in function from supports for high-voltage transmission lines to transmission towers. For example, a high-voltage transmission lines cross the Beaver Valley Mine partially within the 200-ft mining barrier. At this site, the mine did not directly undermine these structures (Figure V-1a). Other mines with towers included Cumberland, Emerald, Enlow Fork, High Quality, and Eighty-Four. One tower over the Emerald Mine was reported to have been impacted by longwall mining causing it to be out of level (Figure V-1b). Subsidence impacts were mitigated with banding techniques (Figure V-1c, also see Section V.F.1).

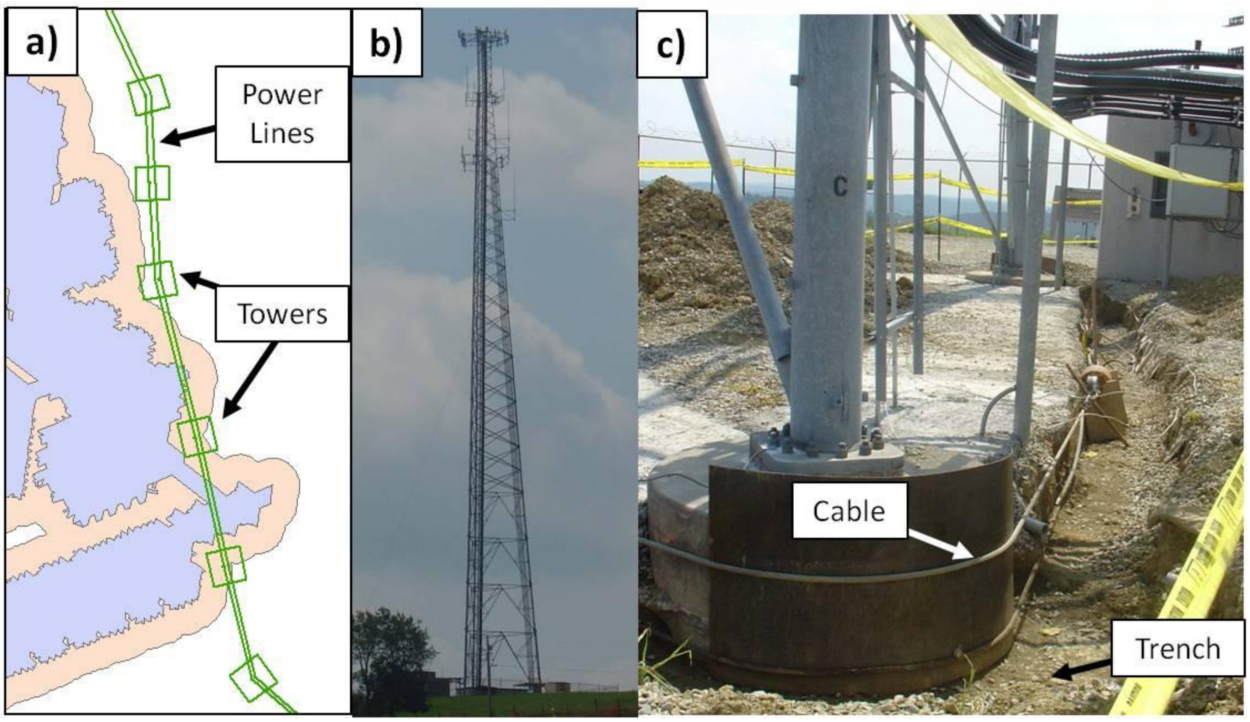


Figure V-1 – Map and photographs of a) the power lines crossing the Beaver Valley Mine, b) the transmission tower over the Emerald Mine, and c) banding to mitigate subsidence impacts (Photographs from PA DEP files).

V.C.2.c – Churches

Two churches were inventoried. One church, located in the 200-ft buffer zone, was not directly undermined by Mine Eighty-Four. A second church was undermined by a Bailey Mine longwall panel and had a reported effect. Foundation cracks were observed and an unspecified agreement was reached between the company and the land owner.

V.C.2.d – Schools

Six schools were inventoried. Five of the schools were undermined by room-and-pillar mines and one school was located in the 200-ft buffer zone. Two of the schools were community based and were relatively small in scale averaging 1,000-ft^2. The other four schools were public and were much larger averaging over 53,000-ft^2. No reported effects occurred to these six schools.

V.C.2.e – Bridges

Four bridges were inventoried. Two of the bridges were residential, one was community, and one was public. Three of the bridges were located directly over longwall panels. The fourth was above the longwall gateroad entry system. No reported effects occurred to these four bridges.

V.C.2.f – Dams

Two dams were inventoried. The larger and more significant of the two was the Ryerson Station Dam, constructed by the PA Department of Conservation and Natural Resources (DCNR) in 1960, creating a 62-acre recreational lake. The DCNR claimed that the mining operations to the northeast impacted the dam. The nature of damages were documented in the PA DEP Interim Report entitled “Ryerson Station Dam Damage Claim Number SA 1736,” published on February 16, 2010. The report stated that during late spring and early summer of 2005, significant movements and structural damages occurred as longwall mining operations occurred in the vicinity of the dam (Figure V-2a). The PA DEP’s Division of Dam Safety ordered DCNR to drain the Duke Lake and breach the dam to prevent further impounding of water in the reservoir (Figure V-2b). The PA DEP Interim report concluded that longwall mining operations did result in ground movements which damaged the Ryerson Station Dam. The mine operator claimed their longwall mining activity occurred at sufficient distances to not impact the dam. A final resolution is pending.

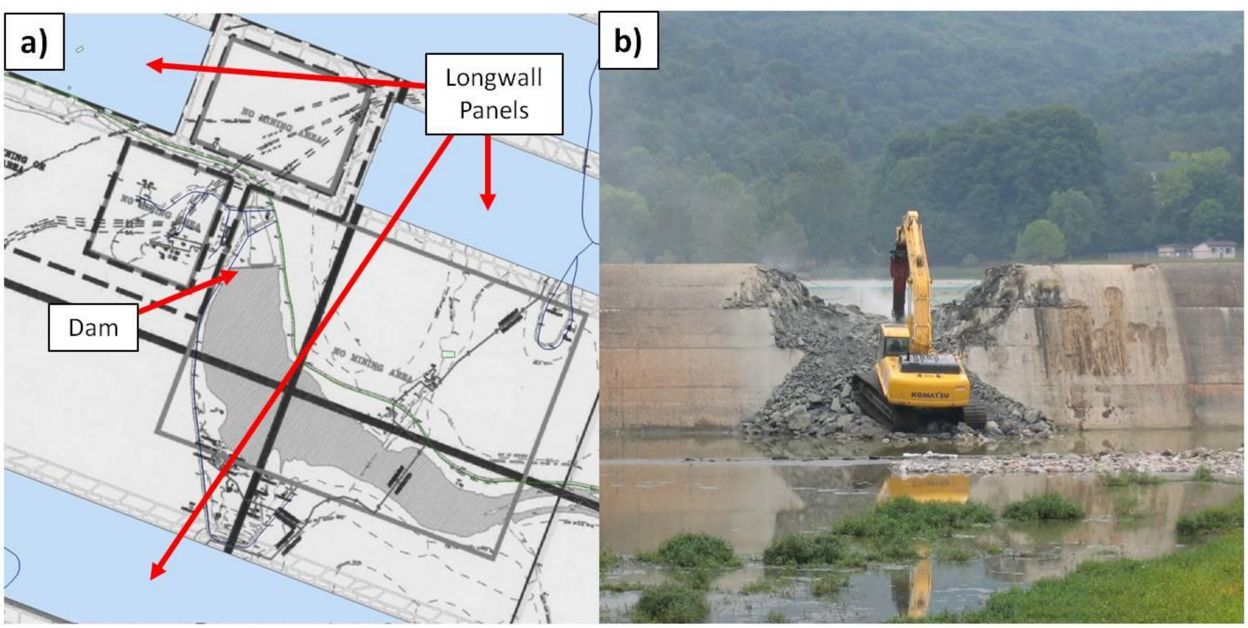


Figure V-2 – a) Map of the longwall panels in the vicinity of the dam and b) photograph of the dam in the act of being breached (Photograph from PA DEP files).

V.D – Structures and Longwall Mining

Longwall mining is an important underground bituminous coal extraction method in PA, accounting for 64-pct of all the acres mined (Table III-5). It also accounts for 50–pct of the structures undermined and 93.6–pct of the structures with reported effects (Table V-1).

V.D.1 – Structures Undermined

During the 3rd assessment period, 1,856 structures were undermined by longwall mines (Table V-4). Enlow Fork had the most structures undermined with 507 and Shoemaker the least with six. The number of structures was influenced by the proximity of the mine to populated areas. For example, the Bailey Mine had 216 structures spread over 6,311 acres (Table III-9) in rural Greene County. The average acres-per-structures ratio for Bailey Mine was 29.2. In contrast, the High Quality Mine had 218 structures over 501 acres (Table III-9) and Mine Eighty-Four had 321 structures over 1,984 acres (Table III-9) both in northern Washington County. The acres-per-structure ratios for these mines were 2.3 and 6.2 respectively. The average acres-per-structure for all longwall mines was 14.2.

Table V-4 - Number of structures undermined and acres-per-structure, sorted by longwall mine (see Table III-9 for acreage data).

Mine Name	Total Structures Undermined	Acres-per-Mine	Acres-per-Structure
Bailey	216	6,311	29.2
Blacksville No.2	125	2,880	23.0
Cumberland	224	3,665	16.4
Eighty-Four	321	1,984	6.2
Emerald	239	2,855	11.9
Enlow Fork	507	6,339	12.5
High Quality	218	501	2.3
Shoemaker	6	72	12.0

V.D.2 – Structures with Reported Effects during the 3rd Assessment Period

Of 1,856 structures undermined by longwall mines, 427 had reported effects in BUMIS (Table V-5). Mine Eighty-Four had the highest number with 126 and Shoemaker had the lowest with zero. One way to evaluate the relative degree of structures with reported effects is to evaluate the acres-per-reported effects ratio for each mine. The High Quality Mine and Mine Eighty-Four had a much higher rate of reported effects, with 14.7 and 15.7 respectively, than the other six longwall mines (Table V-5). These two mines were the closest to the Pittsburgh metropolitan area (~ 25 miles south of downtown Pittsburgh) where there was less farm land and more residential development.

Table V-5 - Structures with reported effects sorted by mine.

Mine Name	Reported Effect*	Acres-per-Mine	Acres-per-Reported Effect
Bailey	53	6,311	119.1
Blacksville No.2	16	2,880	180.0
Cumberland	41	3,665	89.4
Eighty-Four	126	1,984	15.7
Emerald	42	2,855	68.0
Enlow Fork	115	6,339	55.1
High Quality	34	501	14.7
Shoemaker	0	72	
Total	427		

* - Twenty structures had two reported effects

Another way to evaluate the relationship between structures and reported effects is to compare the relative percentages of each mine (Figure V-3). The mines with the highest percentage of reported effects are Mine Eighty-Four with 39-pct, the Bailey Mine with 25-pct, and the Enlow Fork Mine with 23-pct. The mines with the lowest percentages are the Cumberland Mine with 18-pct, the Emerald and High Quality Mines with 16-pct, the Blacksville No.2 Mine with 13-pct, and the Shoemaker Mine with zero.

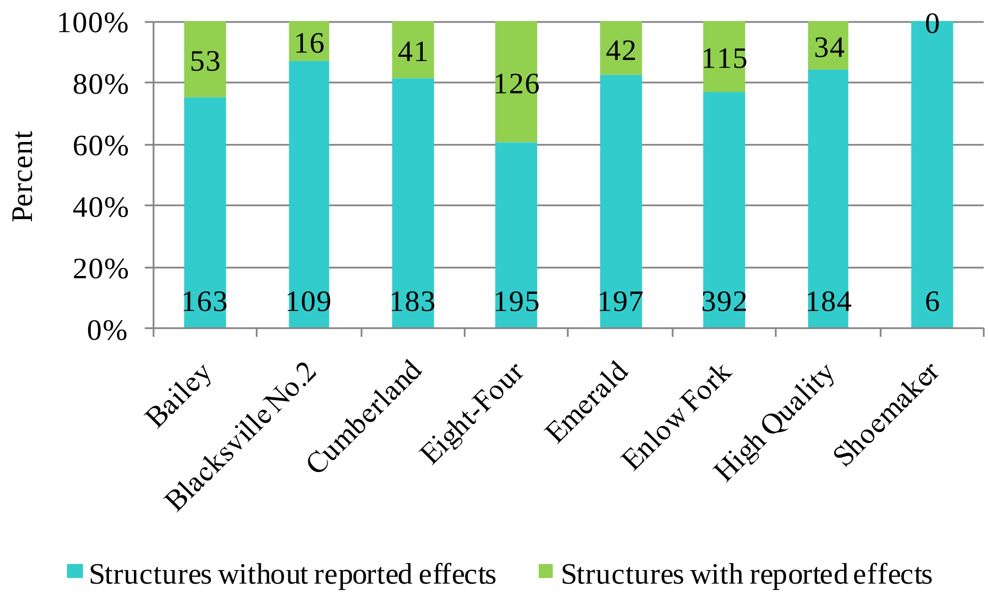


Figure V-3 - Relationship between structures with and without reported effects, sorted by mine.

V.D.3 – Relationship between the Position of Structures with and without Reported Effects and Position with Respect to the Longwall Panel

This report describes the various characteristics of Pennsylvania's supercritical longwall subsidence basins (Sections I and IV). Surface strains and corresponding stresses are related to the position occupied in the subsidence basin (Agioutantis, et al., 1988 and Karmis, et al., 1992). To help illustrate this, a typical supercritical longwall panel is sectioned into components (Figure

V-4). A longwall panel is a large block of coal where mining is focused along one end. This is called the longwall face. Surrounding the longwall panel are room-and-pillar mining sections. These sections are functionally distinct and referred to as the main entries, bleeders and gate road entries. The longwall mining panel can be thought of containing two geometric parts: mid- and quarter-panels (Figure V-4). For supercritical panels, the most horizontal strain and greatest permanent alteration of the surface curvature should occur within the quarter-panel areas. Structures in the mid-panel areas typically experience 1) significant short-term dynamic subsidence as the longwall face passes underneath, 2) small long-term excessive horizontal strains, 3) non-permanent alteration of surface curvature and, 4) a permanent drop in elevation as the subsidence basin stabilizes. Much less strain and surface curvature changes, like those experienced over the quarter-panel section, are expected over the adjacent room-and-pillar mining areas, i.e. mains, bleeders, and gate road entries.

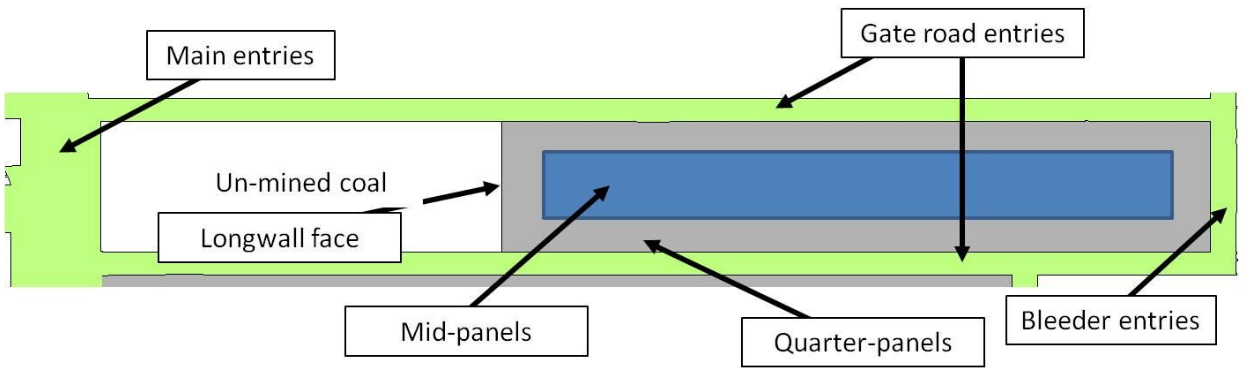


Figure V-4 – Conceptual drawing shows the two geometric components of a longwall panel (mid- and quarter-panels) and the three functional components of the room-and-pillar (main, bleeder, and gate road entries) mining methods.

The University identified the location of each structure with respect to the underlying mining method (Table V-6). The two longwall panel parts, i.e. quarter-panel and mid-panel, were listed separately, while all structures overlying main, bleeder, and gate road entries and within 200-ft of these areas were listed under the room-and-pillar category (Table V-6). Any structure beyond the 200-ft mining buffer was listed as outside current mining. Note the relatively high number of structures with reported effects in both categories of the longwall panels and that both categories have similar percentages. It is also worth noting that the category of Outside Current Mining produced a high percentage of reported effects for Room-and-Pillar Mining.

Table V-6 – Occurrence of reported effects based on the position with respect to mining method.

	Longwall		Room-and-Pillar	Outside Current Mining	Total
	Quarter-Panel	Mid-Panel			
Structures without Reported Effects*	347	297	351	419	1,414
Structures with Reported Effects**	147	122	36	103	408
Percent Reported Effects	29.8-pct	29.1-pct	9.3-pct	19.7-pct	
Total	494	419	387	521	1,822**

* - A total of eight structures could not be located
** - Structures with two reported effects were counted only once
*** - Structure undermined during the 2nd assessment period with unresolved reported effects were not counted

If the mid- and quarter panel categories are combined into one panel category and compared to the structures in the room-and-pillar category, a significant difference is observed (Figure V-5). Thirty percent of structures over longwall panel areas had reported effects, whereas nine-pct of structures over room-and-pillar mining areas had reported effects. These trends demonstrate the influence of the subsidence basin over the panel on structures with reported effects compared to conditions over the adjacent room-and-pillar areas.

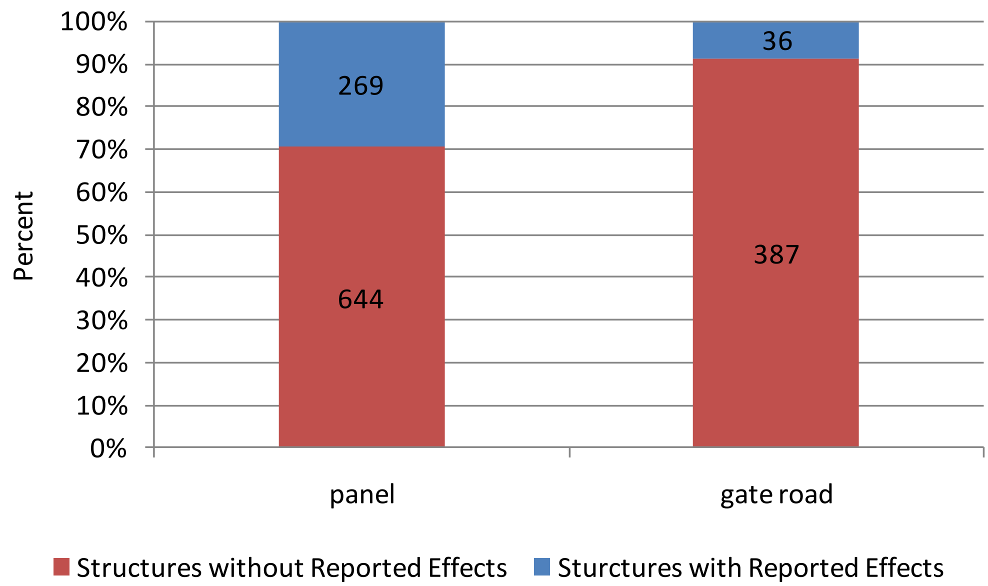


Figure V-5- Relationship between structures with and without reported effects as per mining method.

V.D.4 – Relationship between the Position of Structures with and without Reported Effects and Topography Conditions

The University identified the location of all structures with respect to its topographic condition. Each structure was placed in one of three topographic categories; hillside, valley bottom, and hilltop (Table V-7). The majority of the structures were located on hillsides, followed by valley bottom and hilltop.

Table V-7 – Occurrence of reported effects based on the topographic position.

	Hillside	Valley Bottom	Hilltop	Could Not Determine	Total
Structures without Reported Effects	629	513	270	7	1,419
Structures with Reported Effects	189	130	82	1	433
Percent Reported Effects	23.1-pct	20.2-pct	23.3-pct		
Total	818	643	352	9	1,856

The analysis of the topographic conditions of structures undermined did not show any significance. The percentage of structures with and without reported effects over hillsides, valley bottoms, and hilltops lay within a tight range of 20.2 to 23.3-pct (Figure V-6).

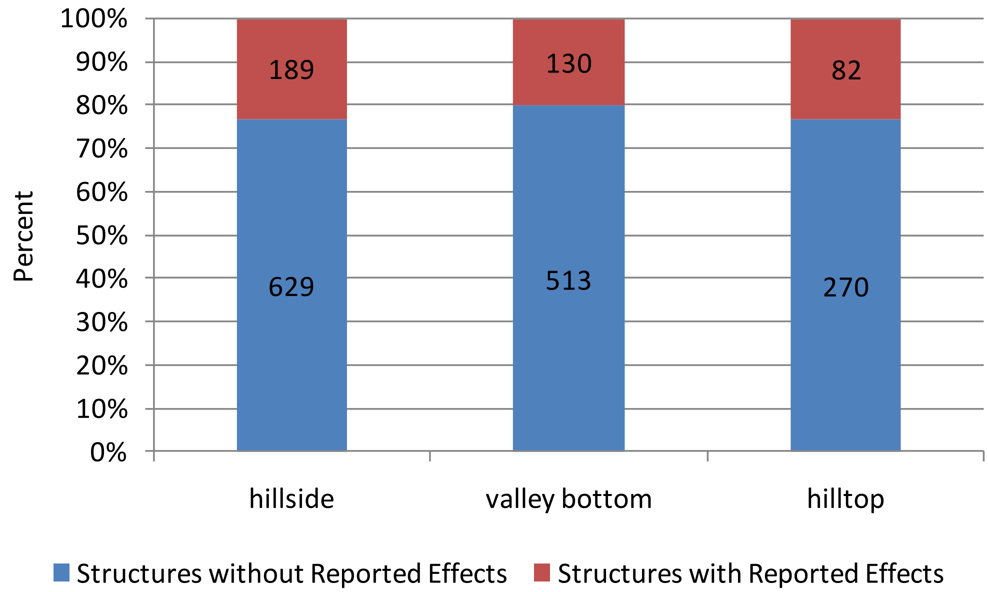


Figure V-6 - Relationship between structures with and without reported effects and topography.

V.D.5 – Days to Resolve Reported Effects

When an effect was reported, it was logged into the BUMIS database and an occurrence date was assigned. The discovery of a potential subsidence-related structure impact was not necessarily at the same time as the date of occurrence listed in BUMIS. This date was established when a reported effects case was logged into BUMIS. Regulations allowed the operator up to 10 days to file a report.

The University collected information related to the date of occurrence, interim resolution, and final resolution for every reported effect. There were 427 reported effects during the 3rd assessment period with 352 final resolutions. It took an average of 238 days to reach a final resolution on these cases (Table V-8). Seventy-five of these reported effects did not have a final resolution as of August 20, 2008. The 289 interim resolutions took an average of 107 days.

Table V-8 – Days to resolve reported effects for longwall mines.

	Interim Resolution	**Final Resolution**
Mean	107	238
Standard Deviation	219	281
Median	22	132
Minimum	0	0
Maximum	1,470	1,496
Number Resolved	289	352
Number Unresolved		75

V.D.6 – Resolution Status of Reported Effects

The resolution status at the end of the 3rd assessment period is presented in Table V-9. Of the 352 final resolutions, 85-pct, or 300, were assigned as Company Liable. The other 15-pct, or 52, were assigned as Company Not Liable. Of the remaining 75 reported effects, 63 had an interim resolution but no final resolution and 12 had an outstanding reported effect with no interim resolution (Table V-9).

Table V-9 - Resolution status at the end of the 3rd assessment period for all reported effects sorted by longwall mine.

Mine Name	Resolved		Unresolved		Total
	Company Liable	Company Not Liable	Interim Resolution	Outstanding Reported Effect (No Interim Resolution)	
Bailey	33	6	11	3	53
Blacksville No.2	11	2	2	1	16
Cumberland	26	7	5	3	41
Eighty-Four	91	12	19	4	126
Emerald	27	9	6	0	42
Enlow Fork	92	4	19	0	115
High Quality	20	12	1	1	34
Shoemaker					
Total	300	52	63	12	427

V.D.6.a – Final Resolution Status

For the 300 structures with reported effects where the company was found liable (Table V-10), the most common final resolution at 31-pct was for the company to purchase the property. Next was the unspecified resolution at 27-pct, where a private agreement was reached with the landowner and the details of the agreement were not made public. In 23-pct of the cases, the company compensated the land owner in some fashion. Pre-mining agreements were used in 12-pct of the company liable cases. The company performed repairs to a structure in only 6-pct of the liable agreements.

Table V-10 - Status of longwall mining final resolution where the company was liable.

Mine Name	Pre-mining	Unspecified	Appended to Another Case	Company Purchased Property	Compensated or Resolved	Repaired	Total
Bailey	5	6	2	7	13		33
Blacksville No.2		7		2	1	1	11
Cumberland	2	13		8	1	2	26
Eighty-Four	10	14		41	20	6	91
Emerald		17		5	1	4	27
Enlow Fork	14	23		30	24	1	92
High Quality	5	2			8	5	20
Shoemaker							
Total	36	82	2	93	68	19	300

For 52 structures with reported effects, the company was found not liable (Table V-11). The most cited reason for no liability was Not Due to Underground Mining with 77-pct of the total. Other less used reasons were Withdrawn (11.5-pct), No Actual Reported Effect (7.7-pct), and no Liability (3.8-pct).

Table V-11 - Status of longwall mining final resolution where the company was not liable.

Mine Name	With-drawn	No Actual Reported Effect	No Liability	Not Due to Underground Mining	Total
Bailey		1		5	6
Blacksville No.2			1	1	2
Cumberland	3			4	7
Eighty-Four	1			11	12
Emerald	2			7	9
Enlow Fork			1	3	4
High Quality		3		9	12
Shoemaker					
Total	6	4	2	40	52

V.D.6.b – Interim Resolution Status

Interim resolutions were an important tool for tracking the progress of a reported effect. Sixty-three interim resolutions were distributed in seven categories (Table V-12). The most popular interim resolution was currently monitoring with 51-pct of the totals. In many of these cases, visual observations or output from instrumentation was used to monitor important characteristics of the structure that were needed to arrive at a final resolution. Currently monitoring can also imply that mitigation measures were being applied (see Section V.F). The other six interim resolutions were used less frequently. For example, additional time may be needed to make sure the full impact of undermining can be assessed. In these cases, the interim resolution was listed as Awaiting Additional Effects. In Negotiation and Pending Owners Approval implied that a resolution is imminent. An interim resolution of Temporary Repairs implied that some work is being done in preparation of a permanent fix. Lastly, Unresolved implied a resolution was not imminent.

Table V-12 - Status of interim resolution where the company was liable.

Mine Name	P[1]	AAE[2]	CM[3]	IN[4]	POA[5]	TR[6]	U[7]	Total
Bailey	4		6			1		11
Blacksville No.2							2	2
Cumberland				1	1	3		5
Eighty-Four	1	3	6	1	1	3	4	19
Emerald			4		2			6
Enlow Fork		3	16					19
High Quality							1	1
Shoemaker								
Total	5	6	32	2	4	7	7	63

P[1] = Pending; AAE[2] = Awaiting Additional Effects; CM[3] = Currently Monitoring; IN[4] = In Negotiation; POA[5] = Pending Owner Approval; TR[6] = Temporary Repairs; and U[7] = Unresolved

V.D.6.c – Outstanding Reported Effects at the End of the 3rd Assessment Period and Reported Effects Occurring in the 2nd Assessment Period

There were 12 reported effects with no interim or final resolution at the end of the 3rd assessment period (Table V-13). Their date of occurrence ranged from July 20, 2004 until April 15, 2008, with an average length of time to the end of the assessment period of 689 days. This indicated that these reported effects had been particularly difficult to solve. The Emerald and Enlow Fork Mines did not have any outstanding reported effects.

Table V-13 – Summary of cases for longwall mines where there is no interim or final resolution at the end of the 3rd assessment period.

Mine Name	Outstanding Reported Effects
Bailey	3
Blacksville No.2	1
Cumberland	3
Eighty-Four	4
Emerald	0
Enlow Fork	0
High Quality	1
Shoemaker	0
Total	12

V.D.6.d – Relationship between a Structure's Distance from a Longwall Panel and Reported Effects Resolution Category

The University determined the distance of each structure from the edge of the closest longwall panel. With this information and the overburden data, the projection angle every structure makes with the edge of the closest longwall panel can be determined. When the angle is zero degrees, the structure is located directly above a longwall panel. As the structure becomes more distant from the panel, the angle increases. Increases in overburden have an opposite effect. As the overburden increases with respect to a fixed distance from the edge of the panel, the projection angle decreases. Deformations associated with the longwall subsidence basin generally diminish rapidly as the distance from the panel increases. It is therefore reasonable to expect less impact to structures as the distance from a longwall panel increases; however, many factors can create exceptions to this rule. Some of these factors are the stiffness or strength of the overburden, the slope of the surface, the thickness of the colluviums (or soil) layers, and the magnitude and direction of the in-situ horizontal stress field.

The relationship between the structure's distance from a longwall panel and the reported effects resolution category can be determined using the projection angle discussed above. This relationship provides insight as to what resolution outcome can be expected as the projection angle increases. Figure V-7 shows that a significant percentage of structures from every resolution category were located directly over the longwall panel, i.e. zero-deg projection angles. When the entire spectrum of resolutions were examined, it was clear that Repaired and Pre-Mining final agreements occur most often when structures were located very near to a longwall panel (< 35-deg). Conversely, when the projection angle is large (> 35-deg), companies more often resorted to Compensation and Company Purchased Property as a final resolution.

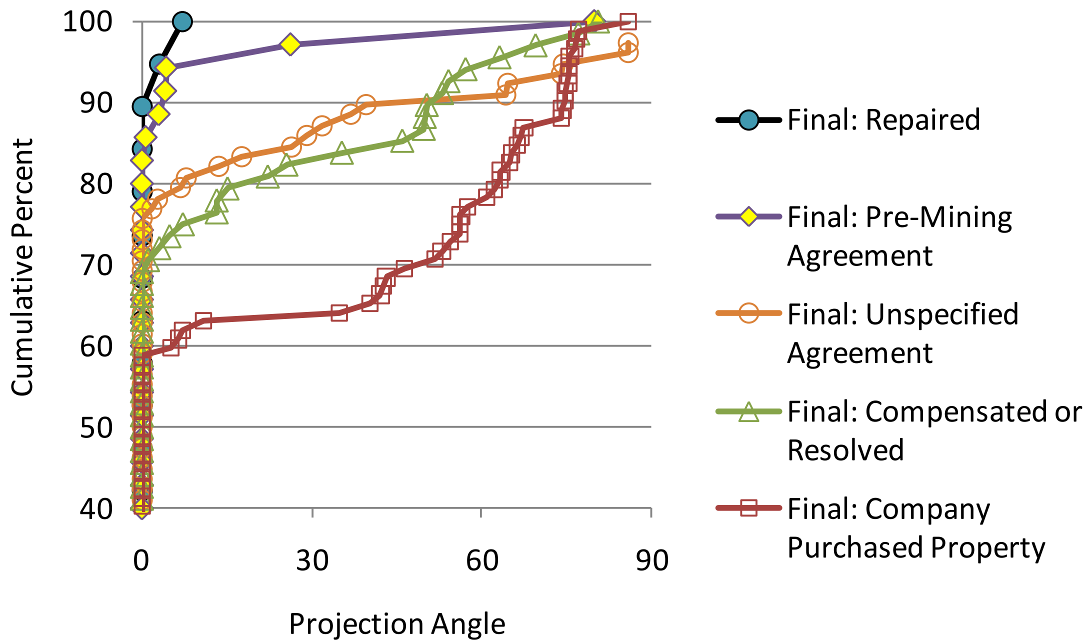


Figure V-7 – Relationship between projection angles and resolution category. Each data point represents the angle between the structure and the edge of mining.

V.D.7 – Resolved Reported Effects from the 2nd Assessment Period

Twenty-six structures from the 2nd assessment period were resolved during the 3rd assessment period. All of these reported effects were from longwall mines. The Bailey Mine had the most cases with 12 followed by Enlow Fork with seven, Cumberland with three, Eighty-Four with two, and Blacksville No.2 and High Quality with one each. It took an average of 643 days to resolve these cases with a minimum of 199 and a maximum of 1,175 days (Table V-14). All of these reported effects were found to be Company Liable.

Table V-14 – Days to resolve reported effects from the 2nd assessment period.

	Final Resolution
Mean	643
Standard Deviation	324
Median	509
Minimum	199
Maximum	1,175
Number Resolved	26
Number Unresolved	0

V.E – Structures and Room-and-Pillar Mining

Room-and-pillar mining is an important mining method in Pennsylvania, accounting for 36-pct of all the acres mined (Table III-5, Section III). It also accounts for 50–pct of the structures undermined but only 6.4–pct of the structures with reported effects. This is largely due to the pervasive use of "safe" pillar designs that minimize unplanned mine subsidence.

V.E.1 – Structures Undermined

During the 3rd assessment period, 1,879 structures were undermined by 42 room-and-pillar mines (Table V-15). The structures were not uniformly distributed over these mines. For example, the Clementine Mine had the most with 307 and Dunkard No.2 and TJS No.4 had the least with zero structures undermined. Table V-13 also shows the average acres-per-structure for all room-and-pillar mines. Mines with the densest concentration of structures (less than five acres-per-structure) were Agustus, Clementine No.1, Darmac No.3, Miller, Parkwood, Rampside, Ridge, Sarah, Toms Run, Twin Rocks, and Windber No.78. Mines with the lowest concentration of structures (greater than 20 acres-per-structure) were Crawdad No.2, Dooley Run, Josephine No. 3, Little Toby, Madison, Penfield, and Triple K No.1. Two mines, Dunkard No.2 and TJS No. 4 did not undermine structures during the 3rd assessment period. The average acres-per-structure for all room-and-pillar mines was 14.5, very similar to the 14.1 average for all longwall mines.

Table V-15 - Number of structures undermined and acres-per-structure, sorted by room-and-pillar mine (see Table III-8 and Figure III-8 for acreage data).

Mine Name	Total Structures Undermined	Acres-per-Structure	Mine Name (continued)	Total Structures Undermined	Acres-per-Structure
4 West (PR)	56	7.4	Nolo (PR)	124	7.5
Agustus	36	3.1	Ondo	96	6.1
Beaver Valley	47	7.5	Parkwood	48	3.7
Cherry Creek	54	9.9	Penfield	8	29.4
Clementine No.1	307	3.7	Penn View	17	17.7
Crawdad No.2 (PR)	4	103	Quecreek	83	8.3
Darmac No.2	44	5.1	Rampside	3	1
Darmac No.3	8	1.3	Ridge	28	3
Dooley Run (PR)	1	30	Rossmoyne	23	9.6
Dora No.8	26	14.7	Roytown	34	7.6
Dunkard No.2 (PR)	0	ND	Sarah	4	2
Dutch Run	54	11.9	Stitt	26	7.2
Genesis No.17	11	19.9	Titus (PR)	14	18.6
Geronimo	24	19.2	TJS No.4	0	ND
Gillhouser Run	8	18.3	TJS No.5	13	8.9
Josephine No.3	2	71.5	TJS No.6	7	9.9
Keystone East	81	5.3	Toms Run	16	3.1
Little Toby	22	25.1	Tracy Lynne	124	5
Logansport	71	13.2	Triple K No.1	4	25.8
Madison	16	29.9	Twin Rocks	172	3.3
Miller	100	1.6	Windber No.78	62	2.4

ND – Not determined because no structures are present

PR – Room-and-pillar mines with pillar recovery (all structures are over room-and-pillar mining areas, none are over pillar extraction areas)

V.E.2 – Structures with Reported Effects

Of 1,879 structures undermined by room-and-pillar mines, 29 had reported effects (Table V-16). Seven mines had structures with reported effects. Clementine No.1 had the highest number with 15. Thirty-six room-and-pillar mines had no structures with reported effects during the 3rd assessment period.

Table V-16 - Structures with reported effects sorted by mine.

Mine Name	Total Structures	Structure with Reported Effects
Clementine No.1	307	15
Ondo	96	5
Tracy Lynne	124	3
Ridge	28	2
Stitt	26	2
Josephine No.3	2	1
Triple K No.1	103	1
Total	686	29

V.E.2.a – Resolution Status of Reported Effects

Of the 29 reported effects, eight had a final resolution with one Company Liable and seven had Company Not Liable (Table V-16). The average days to resolution for these seven reported effects was 107. There were a large percentage of reported effects listed as interim resolutions and outstanding. Three mines contained all 18 of these reported effects, Clementine No.1, Ondo, and Tracy Lynne. All of the 18 interim resolutions and three outstanding reported effects occurred after April 4, 2007. The average days to the interim resolution was 47.

Table V-17 - Resolution status of all reported effects sorted by room-and-pillar mine.

Mine Name	Final Resolution			Interim Resolution	Outstanding Reported Effect (No Interim Resolution)	Total
	Company Liable	Company Not Liable	Day to Resolution			
Clementine No.1		2	41 & 134	13		15
Ondo				4	1	5
Tracy Lynne				1	2	3
Ridge	1	1	7 & 283			2
Stitt		2	20 & 135			2
Josephine No.3		1	131			1
Triple K No.1		1	90			1
Total	1	7		18	3	29

V.E.2.b – Cause of Reported Effects

Pillar failure was the overwhelming cause of the reported effects listed in BUMIS for room-and-pillar mines with a total of 21 cases (Table V-18). Almost every BUMIS description listed cracks as the damage to the overlying structure. These cracks occurred in foundations, basement walls, brick exteriors, and chimneys, and ranged in size from open separations to hairline cracks in walls.

Table V-18 – Cause of reported effects sorted by room-and-pillar mine.

Cause	Final Resolution		Interim Resolution Pending	Outstanding (No Interim Resolution)	Total
	Company Liable	Company Not Liable			
Pillar Failure		2	16	3	21
Other		4			4
Unknown	1		2		3
Underground Mining		1			1
Total	1	6	18	3	29

V.E.3 – Potential Cause of Pillar Failures

Marino (1986) discussed three mine instability mechanisms capable of causing the overburden to fail and increasing the potential for surface subsidence. These three mechanisms are immediate roof rock collapse, pillar crushing, and pillars punching into the roof or floor. With any of these mechanisms, excessive roof-to-floor entry convergence can occur at the mine level. This convergence can be transmitted through the overburden and can result in the formation of a subsidence basin on the surface. These subsidence basins would be, in principle, similar in character to those developed during longwall mining. However, their character would be highly dependent on the shape of the deformations underground. Also, the magnitude of vertical subsidence would be generally much less then for longwall mining. Deformations within a subsidence basin can result in damage to any structure that may be present on the surface.

Since pillar failures dominate the list of reported effects, it is relevant to understand the probable cause and potential effects. In some ways, the term “pillar failure” is restrictive and may be a misnomer. Mark and Iannacchione (1992) examined the behavior of coal pillars with different characteristics and found: 1) pillars with width-to-height ratios less than 4 are prone to failure under elevated overburden loads, and 2) pillars with width-to-height ratios greater than 4 are, in general, much less likely to fail. Failure refers to the pillar’s inability to hold the load applied from the overburden. Once a pillar fails, its’ load transfers to adjacent pillar structures and thus begins a phase of significant deformation.

Mine layouts using pillars with width-to-height ratios less than 4 are more likely to have failures that result in rapid deformations as the pillars soften. The University did not observe pillars with a width-to-height ratio less than 4, so this kind of failure is not anticipated. Many pillars with width-to-height ratios greater than 4 were observed. When these pillars are stronger than the underlying floor rock and have sufficient overburden loads, they have the potential to punch into the floor strata. Over time, interaction with water may weaken the floor. When the foundation under a pillar ruptures and fails, the floor material either squeezes or heaves into the adjacent mine opening (See Figure I-5). This squeezing or heaving can cause significant roof-to-floor entry convergence.

To help design pillar layouts capable of resisting squeezes and heaves, the National Institute for Occupational Safety and Health (NIOSH) developed software called “The Analysis of Retreat Mining Pillar Stability (ARMPS). This model helps define pillars capable of carrying both development and abutment loads (Mark and Chase, 1997). The ARMPS program provides a means to test the stability characteristics of pillars systems associated with many of the 18 pillar failures listed in Table V-16.

V.E.3.a - Clementine No.1 Pillar Failures

At the Clementine No.1 Mine, from May 11, 2006 to June 16, 2008, 15 structures with reported effects occurred over a fairly large portion of the mine. In one section of the mine, five reported effects occurred within a relatively confined area (Figure V-8). As noted from the mine map, the Clementine No.1 Mine developed main entries with a continuous haulage mining unit.

Continuous haulage mining systems use a conveyor belt, located in the center entry, to remove the coal from the working faces. Crosscuts are typically driven at 70-deg angles from the belt entry to optimize the continuous haulage equipment. This gives the sections a V-shaped appearance. The main entries are protected with regularly spaced barrier pillars. Production panels are driven off the main entries, again at a 60 to 70-deg angles. Production panels utilize a similar pillar layout as the adjacent main entries.

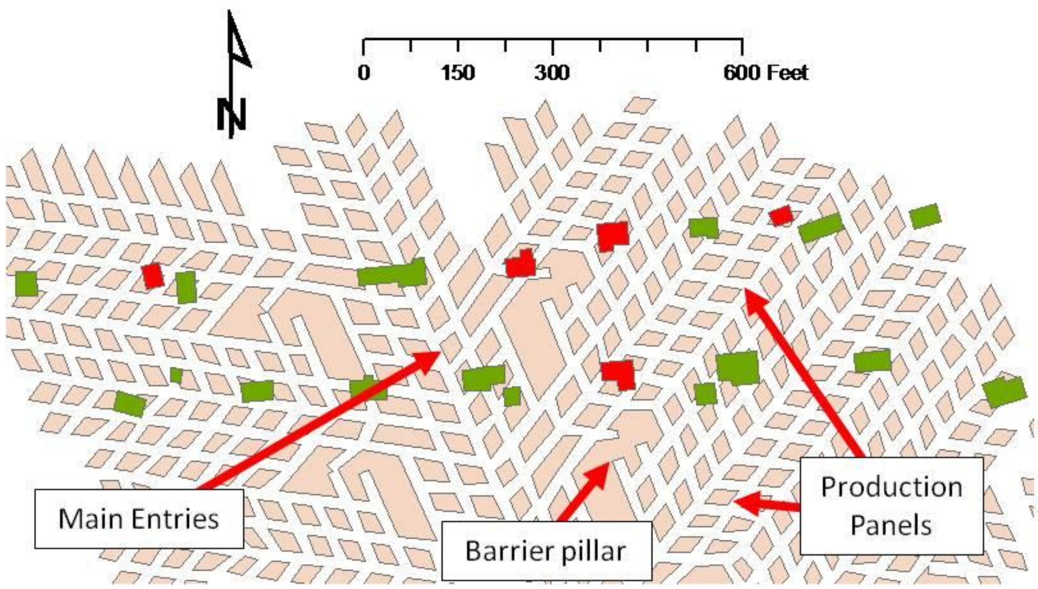


Figure V-8 – Area of the Clementine No.1 Mine where five structures with reported effects occur. This area contains main entries, production panels, and barrier pillars. Barrier pillars provide protection for the main entries. Note – Red = structures with reported effects, and Green = structures without reported effects.

An ARMPS investigation was conducted using general pillar layout configurations measured from the 6-month mining maps (Figure V-9). The average size of pillars located in the production panels were 28-ft wide by 33-ft long. The average width of the entries was 20-ft and the mining height was assumed to be 4-ft, yielding an extraction ratio of 65-pct. The overburden for the five structures with reported effects in this area ranged from 391 to 460-ft. The output from the ARMPS program indicated this pillar layout had a development stability factor of 2.11, well within the pillar safety factor of 2.0 required by the PA DEP (Anon, 1997). The ARMPS program manual indicates that the risk of pillar failures increases significantly when the stability factor is less than 1.5. However, changes in the local mining conditions, i.e. increase extraction thickness, pillars with dimensions less than those sited above, wider entry dimensions, etc., can act to locally reduce this stability factor. For example, if the mining height is increase from 4-ft to 5-ft, the stability factor decreases to 1.77.

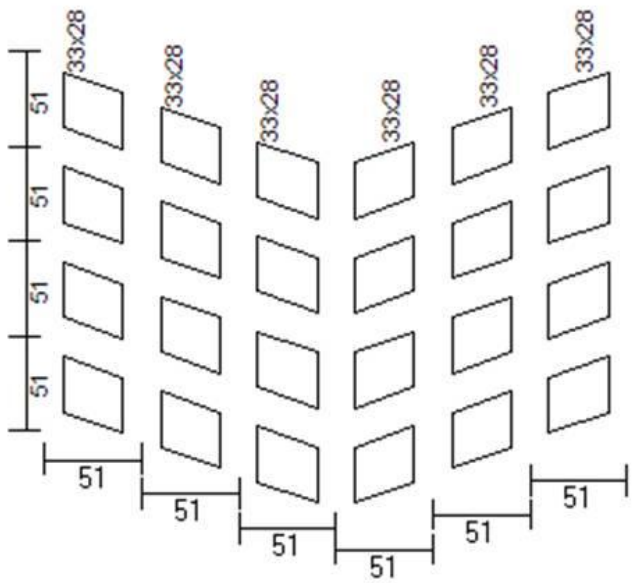


Figure V-9 – Mine layout used for Clementine No.1 ARMPS investigation.

In this example, the stability of the pillar layout was acceptable. However, if any of the local conditions listed above change, this layout might not prevent pillar squeezes and could be responsible for the formation of a surface subsidence basin. Unfortunately, the University was not able to find any information concerning the local conditions encountered underground.

V.E.3.b - Ondo Pillar Failures

In one small area of the Ondo Mine, a series of pillar failures may have occurred over a relatively short period of time. From November 11, 2007 to April 24, 2008, five structures with reported effects (Figure V-10) occurred over a production panel. Typically production panels are developed and abandoned in a relatively short period of time, often measured in months. The pillar sizes in the production panels are slightly smaller than those in the adjacent main entries. The main entries generally function for longer periods of time, typically measured in years. Overburdens for these five structures ranged from 378 to 402-ft. Note that three of the structures were outside the production panel with one over a solid barrier and two over the adjacent main entries. One of the key “signs of trouble” for this area was the phrase “Area Heaved” written on the 6-month mining map (Figure V-10).

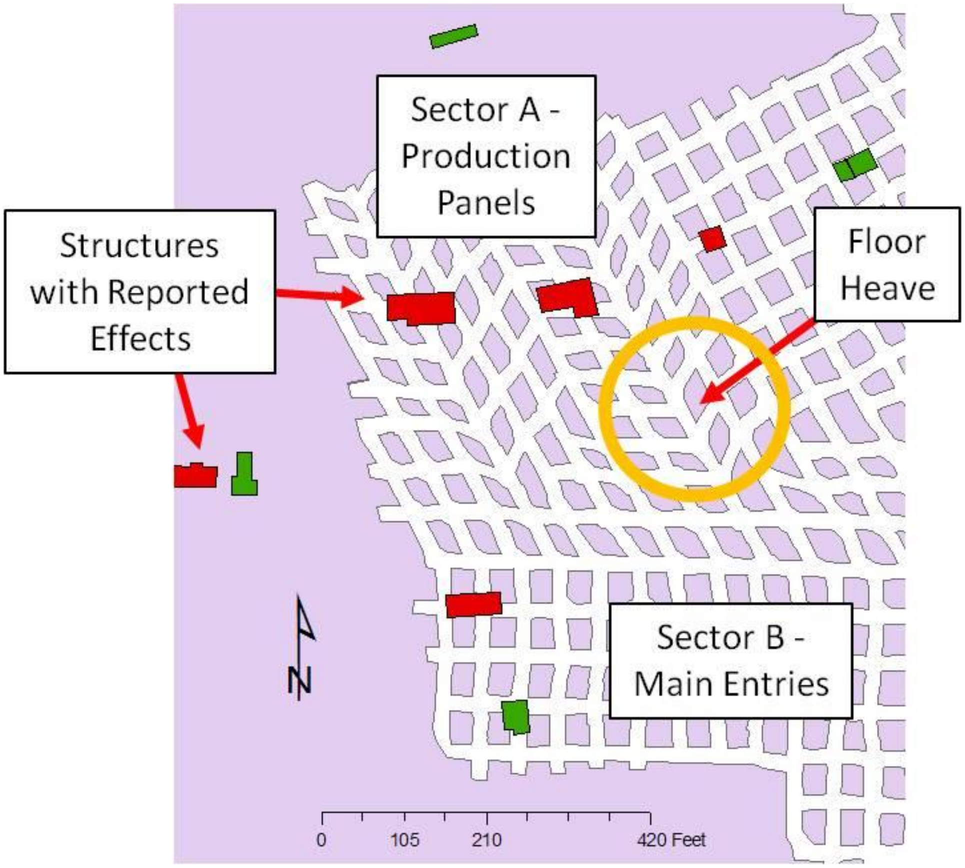


Figure V-10 – Area within the Ondo Mine where five structures with reported effects occurred within two distinct pillar layouts, A & B. Note – Red = structures with reported effects, and Green = structures without reported effects.

The <u>Sector A</u> mine layout consisted of pillars, averaging 27-ft wide by 37-ft long with entries 21-ft wide. The extraction ratio within Sector A was approximately 65-pct and the coal thickness was assumed to be 4-ft. Crosscuts were driven on 70-deg angles left and right from the central belt entry (Figure V-11a). <u>Sector B</u> had slightly larger pillars, averaging 30-ft wide and 40-ft long with 20-ft wide entries. The extraction ratio was approximately 60-pct. This area had crosscuts driven at 90-deg angles producing rectangular pillars (Figure V-11b).

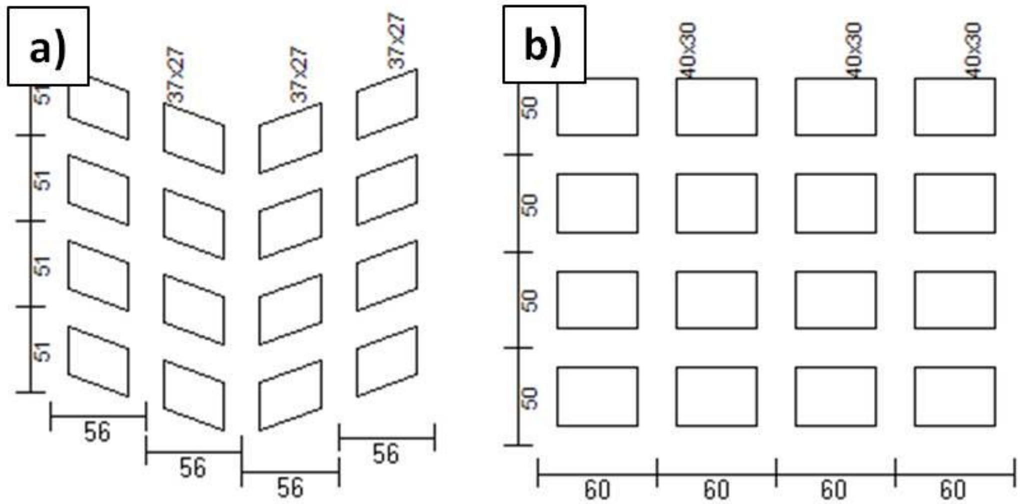


Figure V-11 – Two distinct mine layouts used in area where five structures reported effects at the Ondo Mine. Map a) Sector A with an extraction ratio of 65-pct, and b) Sector B with an extraction ratio of 60-pct.

The ARMPS program was used to investigate the two pillar layouts show in Figure V-11. The layout conditions were measured from the 6-month mining maps. The output from the ARMPS program indicated that Sector A production panels had a development stability factor of 2.45 while the Sector B main entry developments have a stability factor of 3.02. While both Sector A and B layouts have stability factors in excess of 1.5, a localized thickening of the coalbed, decrease in floor rock strength, or an increase in overburden could shift the stability factor into the unstable zone. The 6-month mining map identified an area of floor heave (Figure V-10); indicating unstable conditions existed within Sector A.

V.E.3.c – Tracy Lynne Pillar Failures

From April 3, 2008 to July 18, 2008, three structures with reported effects occurred over a relatively concentrated portion of the Tracy Lynne mine (Figure V-12). In this portion of the mine, large areas of the Lower Kittanning Coalbed remain unmined. Overburden for these structures range from 436 to 498-ft. The extraction ratio is 62-pct and the average pillar sizes in the production panels were 30-ft wide by 42-ft long with entries 21-ft wide. For this section, a stability factor of 2.25 was calculated for a 4-ft extraction height.

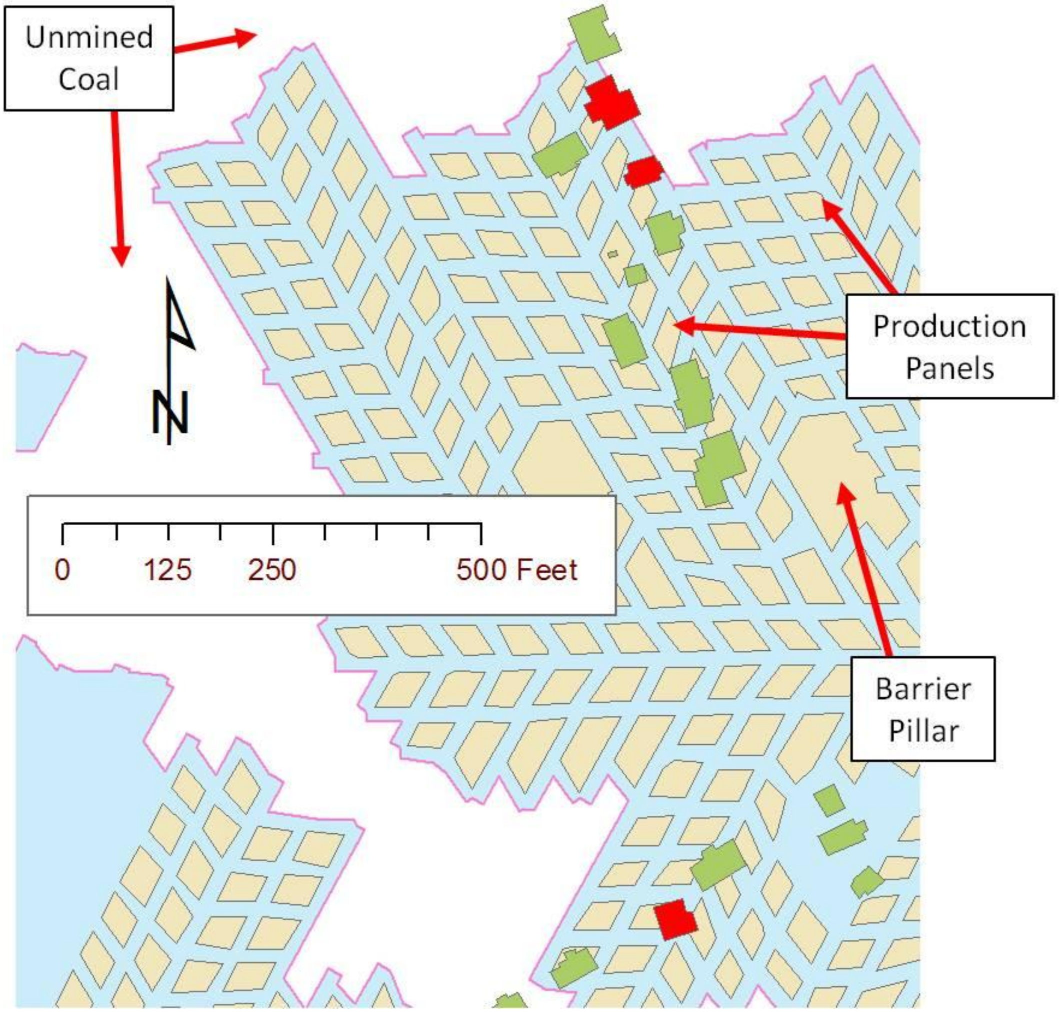


Figure V-12 - Section of the Tracy Lynne Mine where three structures with reported effects occurred. Note – Red = structures with reported effects, and Green = structures without reported effects.

The overlying Upper Freeport Coalbed was mined in mid 1990's by the Roaring Run Mine. The Upper Freeport was approximately 300-ft above the Lower Kittanning Coalbed at the Tracy Lynne Mine. The Roaring Run Mine layout was similar to that used by the Tracy Lynne Mine. The University believes the influence of multiple-seam mining for development room-and-pillar mining should be minimal, especially in this case where the interburden is approximately 300-ft.

V.F – Room-and-Pillar Mines with Pillar Recovery

Room-and-pillar mines with pillar recovery are not covered in this section because the full extraction mining associated with this method did not undermine a single structure during the 3rd assessment period.

V.G – Mitigation Measures for All Methods of Mining

Mitigation measures, as defined in Section V.D.6.b. under interim resolutions, are sometimes used by companies to reduce the impact of subsidence to structures. Typically, companies prepare a report prior to undermining that 1) predicts the potential subsidence characteristics associated with the structure under review and 2) outlines site-specific mitigation measures.

Subsidence prediction consists of final surface movements and deformations estimates, as well as dynamic surface deformations associated with the passage of the underlying longwall face. These data are used to develop the appropriate mitigation measure and determine when these measures should be initiated and how long they should be left in-place. There are five general categories of mitigation measures. They are banding, bracing, bridging, trenching, and cribbing. Each technique is described below.

V.G.1 – Banding

One of the most common mitigation methods is banding (Figure V-13a). Typically, polypropylene or nylon rope or steel cables are wrapped around the structures and tensioned (Figure V-13b). Most of these bands are located at the foundation level but some can be used higher on the structure as needed. The forces are distributed through wood boards placed between the rope or cables and the corners of the structure. The ropes and cables are tensioned with a turn-buckle that consistently applies the force. A spring is used to relieve sudden changes in the lateral force, and this force is monitored with a gage (Figure V-13c).

Figure V-13 - Photographs of a) residential structure with polypropylene rope around the foundation, b) steel cable spring and tension assembly, and c) spring and gage assembly (photographs courtesy of N. Iannacchione).

V.G.2 – Bracing

Bracing is typically applied to stiffen a structure. It does this through a supporting beam or a connecting wire or rope that steadies and holds the structure in the correct position against vertical and horizontal rotations. Bracing can be made of wood or metal. This measure is generally applied diagonally between intersecting components on the structure (Figure V-14)

Figure V-14 - Photograph of bracing (photograph courtesy of N. Iannacchione).

V.G.3 – Bridging

Bridging is used to strengthen and stiffen a structure against differential movement. It is generally applied within the attic of the structure (Figure V-15). Bridging reinforces levels within a structure, decreasing the impact of differential settlement. This can be an effective means of withstanding the passage of a subsidence wave propagating through a large structure.

Figure V-15 - Bridging applied to a structures attic to stabilize the roof (Photograph from PA DEP files).

V.G.4 – Trenching

One of the most effective measures to reduce high surface horizontal strains is trenching (Figure V-16). In general, a trench is excavated near the structure to absorb horizontal strain. The trench should extend to a depth approximately 2-ft below the lowest point in the structure's foundation. Typically, the trench is covered over with planks to satisfy safety concerns.

Figure V-16 - Photograph of a trench excavated adjacent to a structure to mitigate high horizontal strains (Photograph from PA DEP files).

V.G.5 – Cribbing

Cribbing is one of the most cost effective mitigation measures. In general, cribbing is used to arrest vertical movement within a structure (Figure V-17). Most cribs are constructed of wood and can withstand considerable vertical movement without losing their load bearing capacity. Wood cribs are not effective when significant horizontal movement occurs.

Figure V-17 – Photograph of cribbing (photograph courtesy of N. Iannacchione).

V.G.6 – Mitigation Measure Effectiveness

Some companies rely on these measures, while others prefer compensation to the property owner. Regardless, there is little doubt that these measures can be effective. For example, Figure V-18a (before) and Figure V-18b (after) photographs show the application of mitigation measures applied to this historic structure. It should be noted that this structure did sustain some minor damage that was later repaired.

Figure V-18 – Photographs of a) historic farm house in 2001 treated with several mitigation techniques, i.e. banding, cribbing, and trenching and b) farm house on May 21, 2003 (Photograph from PA DEP files).

V.H – Summary Points

The University collected information concerning 3,735 structures. The precise distance to mining of each structure as well as the overburden and topographic conditions were measured. Each structure was compared to mining maps within the UGISdb and categorized according to requirements of PA law.

The University found 456 reported effects listed within the PA DEP files. Three broad categories of liability were analyzed:

- Company Liable = 301 (66.0-pct),
- Company Not Liable = 59 (12.9-pct), and
- Unresolved = 96 (21.1-pct).

Longwall mines had a higher percent of reported effects per structure, 23-pct, than room-and-pillar mines, 1.5-pct. In addition, the percentage of company liable effects was much higher for longwall mines with 70.2-pct compared to 3.5-pct for room-and-pillar mines.

Thirty-one feature types were identified. The most common features were dwellings (1,502), followed by garages (593), barns (357), sheds (264), trailers (230), outbuildings (169), buildings (95), silos (35), pools (32), and septic systems (21). There were several notable structural features of importance including cemeteries, towers, churches, schools, bridges, and dams.

Mitigation measures were sometimes used by companies to reduce the impact of subsidence to structures. In many cases the company prepared a report prior to undermining that 1) predicted the potential subsidence characteristics associated with the structure under review and 2) outlined site-specific mitigation measures.

There are five general categories of mitigation measures:

- Banding - Polypropylene / nylon rope or steel cables are wrapped around the structures and tensioned,
- Bracing - Typically applied to stiffen a structure,
- Bridging - Used to strengthen and stiffen a structure against differential movement,
- Trenching - An effective measures to reduce high surface horizontal strains, and
- Cribbing - Used to arrest vertical movement within a structure.

V.H.1 – Longwall Mining

Longwall mines undermined 1,856 structures. Enlow Fork had the most with 507 and Shoemaker the least with 6. The average acres-per-structure for all longwall mines was 14.2. The total number of reported effects from longwall mines during the 3rd assessment period was 427. A final resolution occurred in 352 of the 427 cases, taking an average of 238 days. Seventy-five of these reported effects did not have a final resolution as of August 20, 2008.

At the end of the 3rd assessment period the following conditions existed:

- 300 structures with company liable for the reported effects
  - Company Purchased the Property, 31-pct,
  - Unspecified Resolution, 27-pct,
  - Company Compensated the land owner, 23-pct,
  - Pre-Mining Agreements, 12-pct, and
  - Structures Repaired, 6-pct.
- 52 structures with company not liable for reported effects
  - Not Due to Underground Mining, 77-pct,
  - Withdrawn, 11.5-pct,
  - No Actual Reported Effect, 7.7-pct, and
  - No Liability, 3.8-pct.
- 63 structures with interim resolutions
  - Currently Monitoring, 50.8-pct,
  - Temporary Repaired, 11.1-pct,
  - Unresolved, 11.1-pct,
  - Awaiting Additional Effects, 9.5-pct
  - Pending, 7.9-pct,
  - Pending Owner Approval, 6.3-pct, and
  - In Negotiation, 3.2-pct.

- 12 reported effects have no interim or final resolution with an average length of time of 689 days

Twenty-six reported effects from the 2nd assessment period were resolved during the 3rd assessment period. A final resolution occurred in all 26 cases, taking an average of 643 days.

Twenty-three percent of the structures located over longwall panels had reported effects. The average acres-per-structure for all longwall mines was 14.2. The analysis of the topographic conditions of structures undermined did not show any significance.

The relationship between the structures distance from a longwall panel and the reported effects provided insight as to what resolution outcome can be expected as the distance from mining increases. The final resolution of Repaired and Pre-Mining agreements occurred most often when structures were located very near to a longwall panel (< 35-deg). Conversely, when the projection angle was large (> 35-deg), companies more often resorted to purchasing properties as a final resolution.

V.H.2 – Room-and-Pillar Mining

Room-and-pillar mines had 50-pct of the structures undermined but only 1.5-pct of the structures with reported effects. This was largely due to the pervasive use of "safe" pillar designs that minimizes unplanned mine subsidence. During the 3rd assessment period, 1,879 structures were undermined by 42 room-and-pillar mines. The average acres-per-structure for all room-and-pillar mines was 14.5.

Of 1,879 structures undermined by room-and-pillar mines, 29 had reported effects. Seven mines reported effects with Clementine No.1 showing the highest number with 15. Thirty-six room-and-pillar mines did not have any structures with reported effects during the 3rd assessment period. Of the 29 reported effects, eight had a final resolution; one Company Liable and seven Company Not Liable. The average days to resolution for these seven reported effects was 107. There were 18 interim resolution and three outstanding reported effects, all of which occurred after April 4, 2007. The average days to the interim resolution was 47.

Pillar failure was the overwhelming cause of the reported effects listed in BUMIS for room-and-pillar mines with a total of 21 cases. The ARMPS program was used to test the stability characteristics of pillars systems associated with many of the 18 pillar failures. In all cases the ARMPS stability factor was calculated to be greater than 2.0 and met the PA DEP requirement of a pillar safety factor greater than or equal to 2.0. However, minor changes in the assumed conditions can significantly increase the risk for unstable conditions in the pillars and adjacent roof and floor strata.

SECTION VI: Effects of Mining on Water Supplies

VI.A - Overview

The PA DEP tasked the University to assess the impacts of underground bituminous coal mining on the water supplies undermined during the 3rd assessment period. This section provides details of the determination of liability, actions by the mine operators and PA DEP, development of permanent replacement water supplies, and length of time required to resolve these reported effects. This section also includes an inventory of water supplies undermined by the 50 mines active during this assessment. A conceptual model is provided to aid in assessing the vulnerability of water supplies based on their proximity to mining and their hydro geologic settings. A brief summary is also provided regarding the status of effected water supplies that were undermined during the 2nd assessment.

VI.B – Data Collection

An inventory of the undermined water supplies was accomplished by cross referencing the PA DEP's BUMIS database with the company submitted 6-month mining maps. A 200-ft buffer was extended from the edge of the mining that occurred during the 3rd assessment period to determine which properties and corresponding water supplies were considered undermined. Water supplies must have a use, as stated by the property owner in the pre-mining survey, to be considered in the inventory provided by BUMIS and the 6-month mining maps. The University compiled the inventoried water supplies, by mine, into an Excel spreadsheet, annotating the water supply type (well, spring, or pond) and the water supply use (residential, agricultural, commercial, etc.).

A water supply impact record was established in BUMIS when either the property owner or mining company contacted the CDMO and reported a problem. Using a BUMIS query tool, the University determined the total number of reported effects that occurred during the assessment time period. A second Excel database was created to track these reported effects by mine type, date of occurrence/resolution, type of effect, type of resolution, and actions taken by the DEP and mine operators.

The two Excel spreadsheets were joined to the spatial UGISdb, and the University researchers added additional details related to distances to active mining, topographic characteristics, and other relevant information. The University gathered these additional details via the archival permit and water loss files from the CDMO, the PaGWIS database, and both existing and University generated topographical maps.

VI.C – PA DEP 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 PA DEP of any claim made by a landowner or water user. The PA DEP tracks the claims from origin to settlement. A mining company and a property owner may settle a claim without further PA DEP involvement as long as the owner is satisfied with the company's actions. If the property owner is not satisfied with the mining company's actions, a claim is filed with the PA DEP for further investigation of liability.

The PA DEP is responsible for determining the liability of reported effects when it is unresolved if mining is responsible for the water supply impairment. A liability buffer, or RPZ, is created by projecting a 35-deg line from vertical, from the edge of mining to the surface (PA DEP, 2008). If the water supply falls within this 35-deg angle, the mining company is assumed liable for the impact, and it is the company's responsibility to dispute this assumption. If the water supply is located outside of this buffer region, the PA DEP is responsible for proving that mining was 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 PA DEP determines that the mining company is responsible for the water supply impact, the company must provide the property owner with a temporary water supply, if the property owner is without water, until a permanent replacement of pre-mining quality and quantity or an agreement is established. During the 3rd assessment period, temporary water was provided to property owners in 277 cases for longwall mines, 69 cases for room-and-pillar mines, and 12 cases for room-and-pillar with pillar recovery mines. Permanent water supply replacements include repaired wells or springs, new wells or springs, or connection to public water.

Reported effects include *contamination, diminution, contamination and diminution, or damage to physical components*. A reported effect can also have the classification of *not an actual problem*, which describes a reported effect that upon investigation by the mining company or PA DEP was not impacted. *Not an actual problem* can also be assigned to a reported effect if a mining company provides a temporary water supply as a precaution.

Diminution can signify either a reduction of water quantity or a complete loss of the supply. During this assessment period, there were 683 reported effects to undermined wells, springs, and ponds; the effects were tabulated in Table VI-1 and sorted 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 August 21, 2003 assessment start date.

Table VI-1- Number of reported effects tabulated based on mining type.

Mining Type	Reported Effects
Room-and-Pillar	238
Room-and-Pillar with Pillar Recovery	20
Longwall	397
Mines not in operation during 3rd assessment (Closed)	28
Total	683

A final resolution status indicates that there is no longer an impact to the water supply, or simply that the water supply case is closed. Final resolutions are divided into three categories: 1) Company Not Liable, 2) Company Liable, and 3) Unresolved or Resolution Pending. A reported effect classified as Company Not Liable indicates the case was withdrawn or there was not an actual water supply problem upon investigation by the mining company or PA DEP. The

Company Liable classification indicates that the water supply has recovered, been repaired or replaced, or that an agreement between the property owner and mine operator has been reached. The Company Not Liable classification is given to situations where 1) mining is not responsible for the reported effect, 2) the associated problem existed prior to mining, or 3) a claim was not filed within two years of mining. The determination of liability requires action on the part of the PA DEP at the CDMO. Table VI-2 lists the twenty categories used by the PA DEP when recording the final resolutions for water supplies with reported effects.

Table VI-2- Categorized effects based on final resolution status as of August 20, 2008.

Final Resolution		**Number**
Class	**Category**	
Company Not Liable (Unaffected / No Liability)	No Actual Problem	5
	Withdrawn	7
	No Liability	4
	Not Due to Underground Mining	159
	Water Supply Not Covered by BMSLCA	5
Company Liable (Assigned / Assumed Liable)	Agreement (Pre-mining)	1
	Agreement (Unspecified)	96
	Company Purchased Property	34
	Compensated	8
	Permanent Supply (Public) & O&M* Bond	2
	Permanent Supply (Public)	9
	Permanent Supply (Public) & Agreement	7
	Permanent Supply (Unspecified)	1
	Permanent Supply (Unspecified) & Agreement	1
	Permanent Supply (Well/Spring)	59
	Permanent Supply (Well/Spring) & Agreement	3
	Permanent Supply (Well/Spring) & O&M* Bond	3
	Recovered	19
	Repaired	6
	Resolved	20
Total		449

*Operation and Maintenance (O&M)

The Unresolved (Resolution Pending) classification indicates that the water supply case is not resolved or is still open at the end of the 3rd assessment period (Table VI-3). The interim status classification is divided into two categories: 1) Operator Assigned / Assumed Liability-Resolution Pending and 2) Under Investigation. Operator Assigned / Assumed Liability with Resolution Pending are cases where the mine operator is liable and is evaluating possible supply replacements or working to develop an adequate water supply. In some instances the permanent water supply has been developed but operation and maintenance (O&M) costs for yearly usage were being negotiated. The cost of operating and maintaining the new replacement supply cannot exceed the pre-mining O&M cost or the company must provide payment for the additional costs. The Under Investigation category simply means that liability has not yet been determined or monitoring of the water supply is still taking place.

Table VI-3- Categorized Unresolved (Resolution Pending) status reported effects as of August 20, 2008.

Unresolved (Resolution Pending)		Number
Class	**Category**	
Assigned / Assumed Liable	Agreement Pending	4
	Evaluate Permanent Supply	18
	Implementing WS Replacement Plan	27
	O&M Review	2
	Pending Owner Approval	2
	Public Water / O&M Pending	6
	Temp Water / Awaiting Public Water	5
	Temp Water / Will Be Undermined	21
	Temporary Water	3
	Well, Spring / O&M Pending	32
	WS Replacement Plan Under Development	13
	WS Replacement Plan Under Review	3
Under Investigation	Currently Monitoring	17
	In Litigation	2
	Unresolved	2
	Unresolved / Pending Investigation	17
	Outstanding Problem	60
Total		234

Figure VI-1 provides a visual summary of Tables VI-2 and VI-3. The Operator Assigned / Assumed Liability category has been divided into four subsections of Agreement / Compensation, Permanent Supply, Recovered / Repaired, and Resolved. The 234 reported effects categorized in Table VI-3 are all considered as resolution pending cases in Figure VI-1.

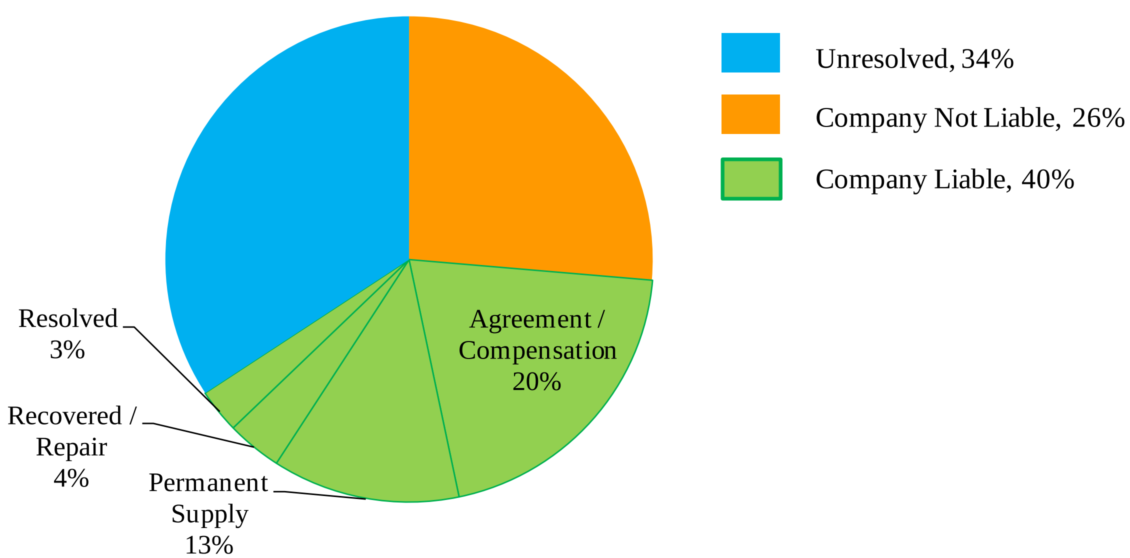


Figure VI-1 – Reported Effects (n=683) classification as of August 20, 2008. The Company Liable Classification has been separated into four categories: Agreement / Compensation, Permanent Supply, Recovered / Repaired, and Resolved.

As shown in Table VI-2, 449 reported effects were resolved during the 3rd assessment period; Table VI-4 provides the breakdown of the resolution types by mining type for each of these 449 reported effects. Figure VI-2, below, summarizes the number of days required for a reported effect to be resolved based on the resolution type and by mining type. The final resolution date and the date of occurrence were subtracted and then averaged to determine the number of elapsed days for each resolution type. The pending resolution effects were not analyzed because there was no final resolution date or the resolution date provided by BUMIS was after the 3rd assessment period. However, there were 12 cases exceeding three years without a final resolution; eight attributed to longwall mines and four to room-and-pillar mines. The No Liability category, represented in Figure VI-3, has the lowest average number of days that were required; the category of no liability is a based solely on the PA DEP ruling, not actions taken by a mine operator.

Table VI-4- Final Resolutions tabulated based on resolution type and mine type.

Mine Type	Company Not Liable		Company Liable			
	Unaffected	No Liability	Agreement / Compensation	Permanent Supply	Recovered / Repaired	Resolved
Room-and-Pillar	8	95	22	47	7	7
Pillar Recovery	0	4	0	4	6	0
Longwall	4	59	110	30	11	12
Closed Mines	0	10	7	4	1	1
Totals	12	168	139	85	25	20

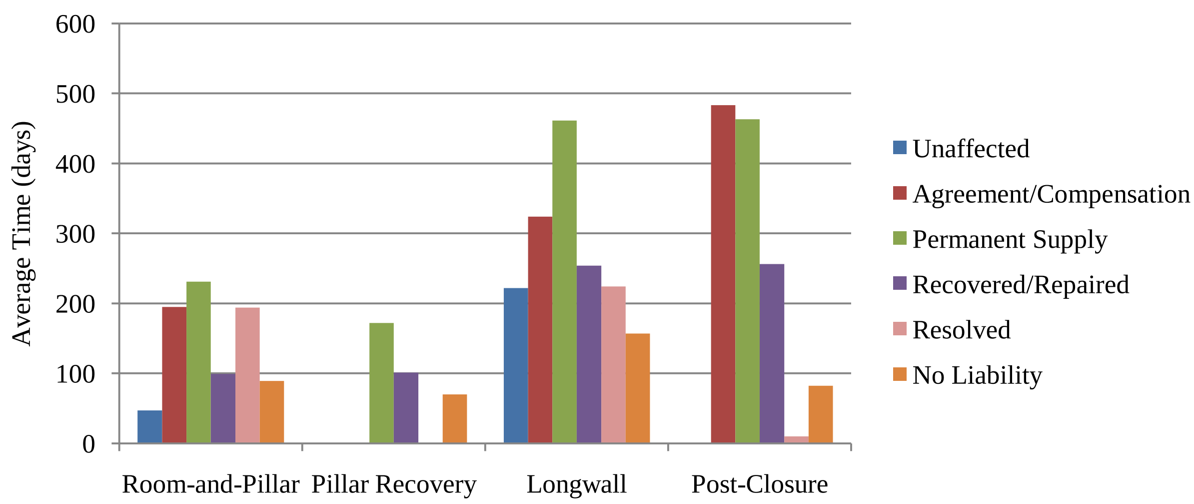


Figure VI-2 – The average number of days required to resolve the reported effects (n=449) classified by mining type and categorized based on the resolution status as of August 20, 2008.

Of the 683 reported effects, 248 claims were filed and required a resolution via a CDMO ruling during this assessment period. The 248 claims were divided by mining type (Table VI-5) and resolution status (Figure VI-3). There were a larger number of reported effects due to longwall mining as compared to room-and-pillar mining (Table VI-1), but there were a larger number of claims requiring PA DEP intervention associated with room-and-pillar mining. This may be the result of longwall mining companies tending to assume liability, and room-and-pillar mining companies tending to allow the PA DEP to make the final ruling; it could also be related to presumptions that room-and-pillar mining has less potential to affect water supplies because it causes less disturbance of overlying strata. Further discussion pertaining to the trends in determination of liability is presented Section VI.E.

Table VI-5 - Number of Water Loss (WL) Claims filed by mining type.

Mining Type	Number
Room-and-Pillar	141
Room-and-Pillar with Pillar Recovery	3
Longwall	86
Closed Mines	18
Total	248

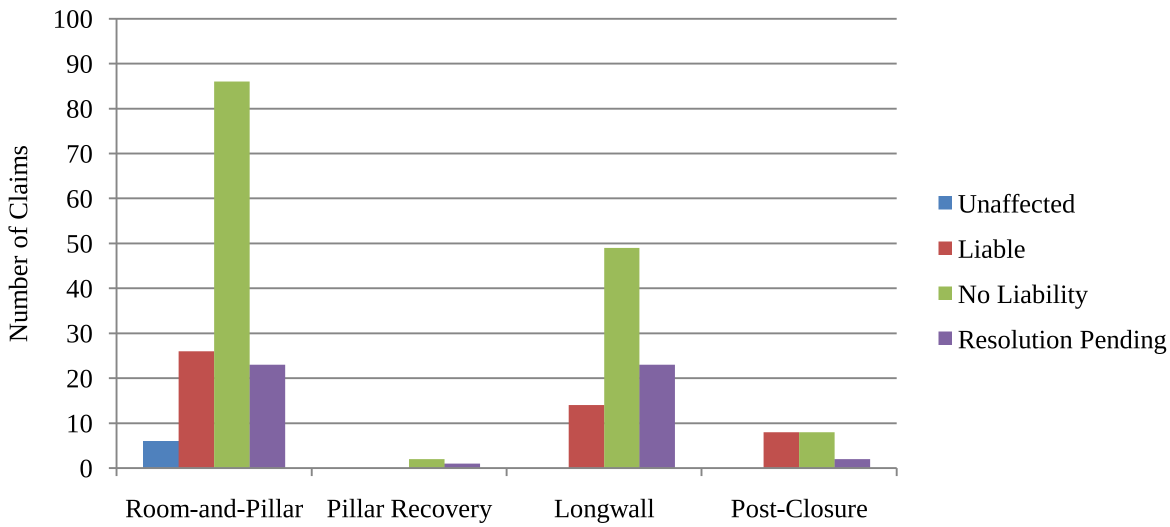


Figure VI-3 – Total number of claims (n=248) classified by mining type and categorized based on the resolution status as of August 20, 2008.

VI.D –Water Supply Analysis by Mining Type

This section provides an analysis of the influence of mining on water supplies by mining type. The section is divided into four parts to discuss: Room-and-Pillar Mines, Room-and-Pillar with Pillar Recovery Mines, Longwall Mines, and Closed Mines. Closed mines include room-and-pillar and longwall mines. Each subsection provides an inventory of the water supplies undermined and an analysis of the reported effects. Refer to Section I for details regarding the expected subsidence characteristics of mining type.

VI.D.1 – Room-and-Pillar Mines

Thirty-six underground room-and-pillar mines were in operation during the 3rd assessment period, with a total of 11,552 acres (see Section III). The room-and-pillar operations undermined 1,212 water supplies. Sixty-seven percent of undermined supplies were of residential use, 25-pct other/unknown, and the remaining 8-pct distributed among agricultural, commercial, recreational, and community/institution uses.

Although subsidence is generally not an issue with room-and-pillar mining, by creating a void in the earth within or below an aquifer there is a chance that the groundwater flow path can become altered, impacting overlying water supplies. The movement of water through the stratigraphic layers of the ground is influenced by permeability. Permeability may be classified as primary or secondary permeability. According to Wyrick & Borchers (1981), primary permeability refers to the movement of water through the intergranular pore spaces of the strata layers; whereas secondary permeability refers to groundwater movement through geologic features such as fractures, bedding plane separations, joints, and cleats associated with the strata. Western Pennsylvania hydrogeology is largely influenced by secondary permeability. Enlargement of fractures and bedding planes by subsidence will increase the secondary permeability of the strata. The total number of water supplies undermined and reported effects by each mine are shown in the Figure VI-4.

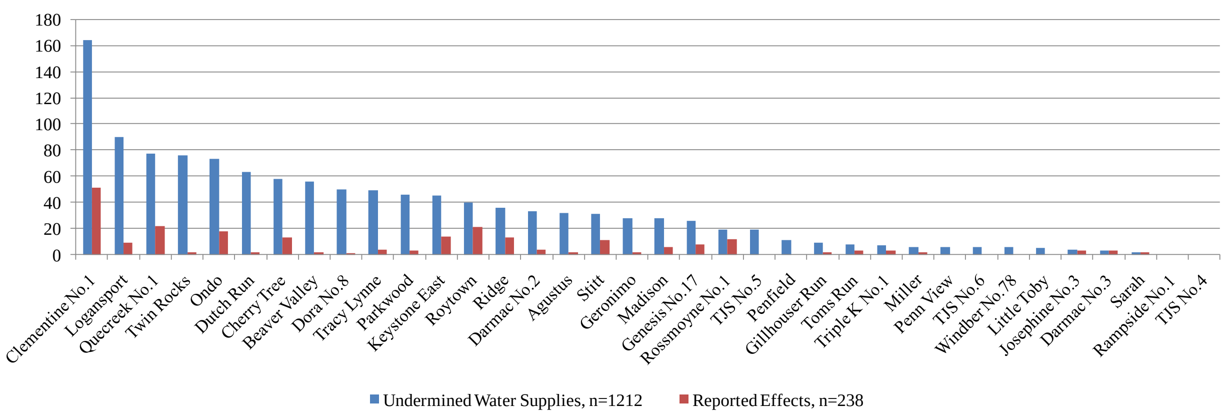


Figure VI-4 – Total number of undermined water supplies (n=1,212) and number of reported effects (n=238) associated with room-and-pillar mines.

Alteration of the groundwater flow path can cause diminution in the form of an insufficient quantity or total loss because of a drop in the groundwater levels. Contamination can also be an issue with altered flow paths as groundwater from contaminated sources such as mine pools or surface water is drawn into the recharge area or as fluctuating water levels cause oxidation of acid producing minerals in the overburden. As shown in Figure VI-5, diminution was reported most frequently as the cause of the water supply impacts, with a quarter of the impacts being the result of contamination. Of the 238 reported effects, 226 were wells and the remaining 12 were springs or ponds.

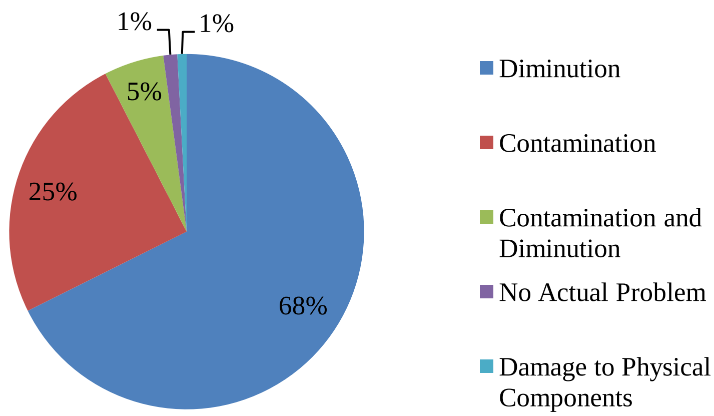


Figure VI-5 – Impact types for the reported effects due to room-and-pillar mining

Figure VI-6 tabulates the number of cases for room-and-pillar mining and their resolution status as of the end of the 3rd assessment. It was determined in 40-pct of cases, or 95 of the 238, that mining was not the cause of the water supply impact. Thirty-five percent of the reported effects were considered as liable impacts, and three percent of cases were unaffected after investigation. The remaining 22-pct of cases were unresolved at the end of the assessment period.

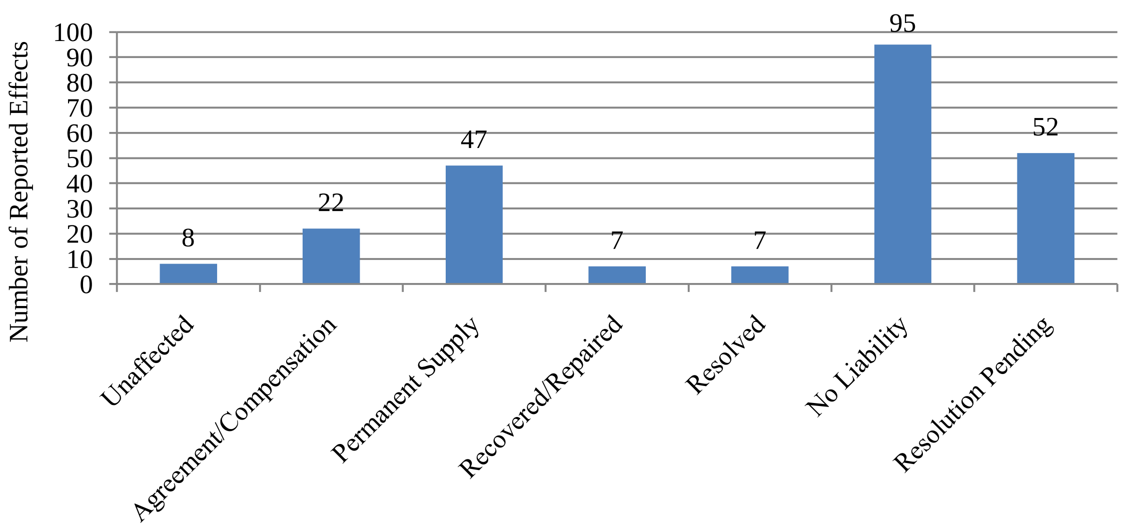


Figure VI-6 – Tabulation showing the status of the 238 reported effects for room-and-pillar mines.

VI.D.2 – Room-and-Pillar Mines with Pillar Recovery

Six underground room-and-pillar with pillar recovery mines operated during the 3rd assessment period, accounting for 2,097 acres undermined. The majority of contributing acres came from the conventional room-and-pillar method; only 13-pct (276 acres) were actually associated with the pillar recovery mining method (see Section III). Although the pillar recovery area is very small, the concepts discussed in the room-and-pillar subsection still apply. In areas where pillar recovery took place, additional impacts can be seen. As discussed in Section I, pillar recovery involves removing roof support pillars which will, in turn, allow the roof to collapse into the mined cavity. The overburden strata experiences additional fracture development, causing the secondary permeability to increase. These fractures are passageways through which groundwater may drain by gravity into the mine workings. As shown in Figure VI-7, there were 75 undermined water supplies, 20 of which had reported effects. Sixty-four of the 75 water supplies undermined were wells and the remaining 10 were springs. Uses of the 75 water supplies included 57 residential, 16 other/unknown, one recreational, and one of commercial use.

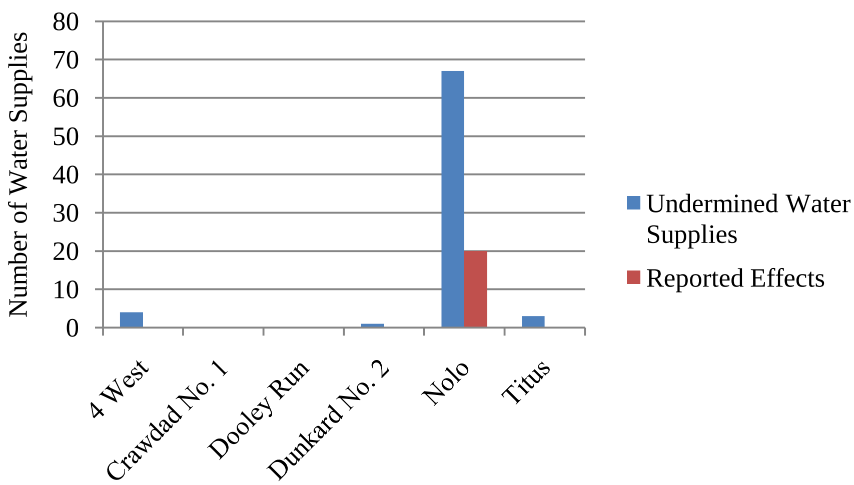


Figure VI-7 – Total number of undermined water supplies (n=75) and number of reported effects (n=20) associated with Room-and-Pillar with Pillar Recovery mines.

The 20 reported effects have been categorized based on impact and resolution type in Figure VI-8. Diminution was reported as being the cause of impact 90-pct of the time. As shown in Figure VI-9, mining company liability was assigned for ten of the 20 reported effects. Four cases were classified as no liability, and the remaining six cases did not have a final resolution status.

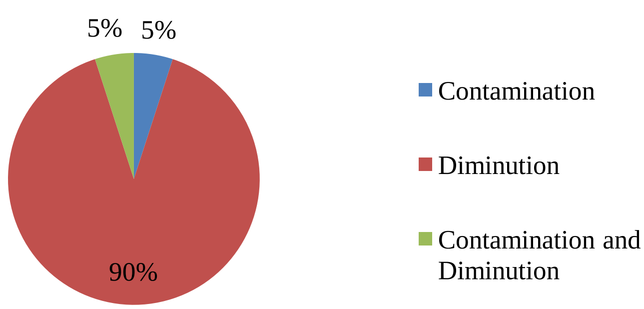


Figure VI-8 – Impact types for the reported effects due to room-and-pillar with pillar recovery mining.

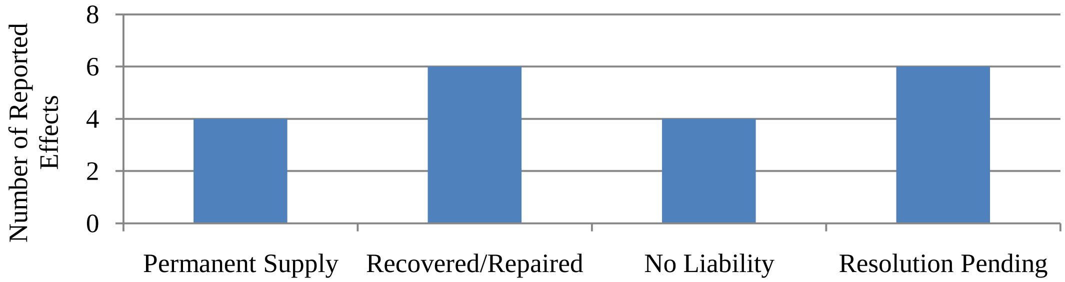


Figure VI-9 – Tabulation showing the status of the 20 reported effects for room-and-pillar with pillar recovery mines.

As shown in Figure VI-7, the Nolo Mine was the only mine with reported effects. Upon further investigation, the University determined that, on average, the distance of all water supplies to the pillar recovery portion of the mine were almost a mile (> 5,000-ft). Only one water supply was located directly above a pillar recovery section, and this water supply showed no reported effects.

VI.D.3 – Longwall Mines

Eight longwall mines operated during the 3rd assessment period. These eight longwall mines undermined 24,607 acres, approximately 64-pct, of the total 38,256 acres mined during the five year study period. Based on the data collection strategy, the University determined that 1,502 water supplies were undermined by longwall mines. Table VI-6 lists the total number of undermined water supplies for each of the eight longwall mines with a comparison to the total acres to determine the water supply density per acre undermined. The water supplies undermined included a combination of wells, springs, and ponds which are shown tabulated for each mine (Figure VI-10). Unlike the room-and-pillar mines, there are considerably more inventoried springs. Forty-nine percent of inventoried water supplies were of residential use, followed by 39-pct other/unknown, 11-pct agricultural, and 1-pct for both commercial and recreational.

Table VI-6- The inventory of undermined water supplies with water supply density calculation.

Mine Name	Undermined Water Supplies	Acres	Water Supply Density per Acre
Bailey	337	6311	0.05
Blacksville No.2	114	2880	0.04
Cumberland	159	3665	0.04
Emerald	199	2855	0.07
Enlow Fork	400	6339	0.06
High Quality	10	501	0.02
Eighty-Four	274	1984	0.14
Shoemaker	9	72	0.13

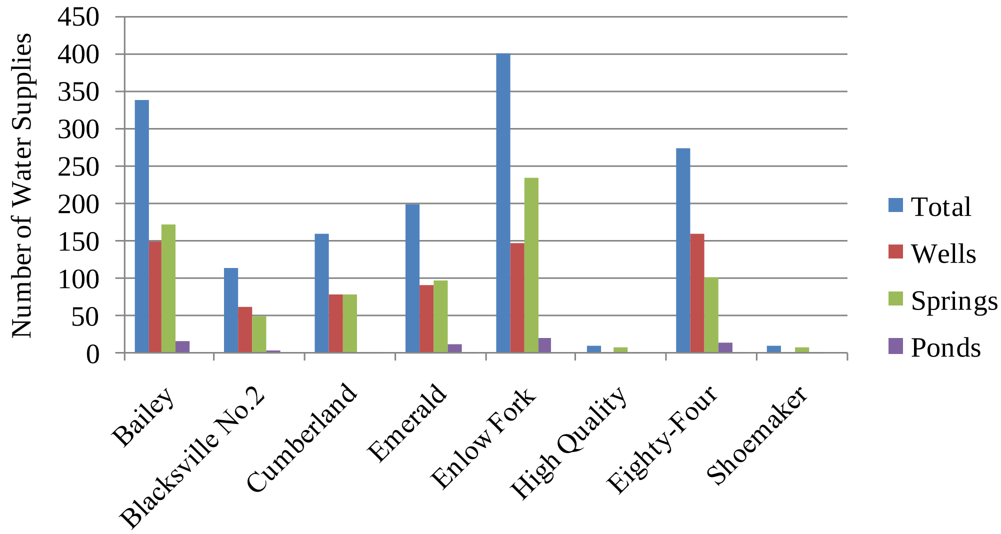


Figure VI-10 – Number of undermined water supplies (n=1,502) and the water supply type by each longwall mine

As discussed in Section I, longwall mining is a full extraction technique in which large panels of coal are removed and immediate subsidence occurs when the overlying roof strata collapses into the mine void causing a subsidence basin to form. According to Peng (1992) and shown in Figure VI-11, the subsided overburden strata are divided into four zones with differing degrees of fracturing. The variances noted in the height of the zones are primarily due to the types of material comprising the strata. The zone closest to the mine void, called the caved zone, is where the roof rock caves, irregularly, into the mined out void. The height of this zone can be two to ten times the thickness of the mining height. The mining height for the longwall mines averaged around 6-ft in thickness. Above the caved zone is the fractured zone. The strata within the fractured zone are highly fractured, but remain stratified. This zone thickness can range between 28 to 52 times the mining heights. The next zone is called the continuous deformation zone, where the strata bends and separates but does not fracture. The uppermost zone is known as the soil zone, and this is where the basin intercepts the ground surface. It is possible for tension cracks to develop in this zone and propagate downward from the surface. Based on the subsidence zones of movement descriptions, it is apparent that the fracturing the overburden strata can cause impacts to the natural hydrology of the overburden by increasing the permeability and groundwater flow pathways.

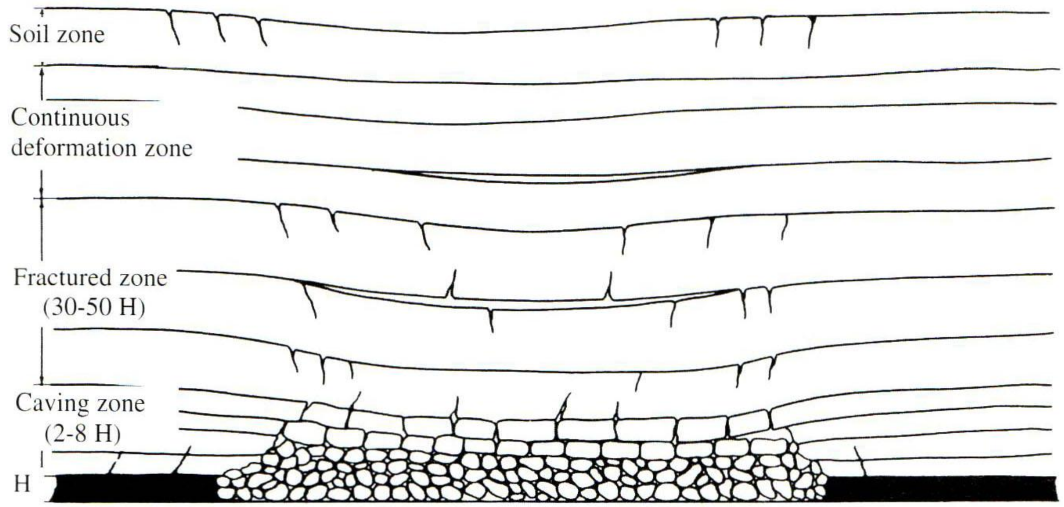


Figure VI-11 – Depiction of the four subsidence zones according to Peng (1992).

Of the 1,502 water supplies undermined by longwall mines, there were 397 with reported effects. The number of undermined water supplies and reported effects, by mine are shown in Figure VI-11. Figure VI-12 categorizes the reported effects by impact type. Diminution was reported as the leading cause of impact at 78-pct, with contamination reported in approximately 12-pct of cases. Eight percent of the reported effects were defined as No Impact / Not Affected, and generally these cases were entered in the records because temporary water was provided to the property owner in advance of mining as a precaution. Of the number of reported effects, 60-pct involved wells, 37-pct involved springs, and 3-pct involved ponds.

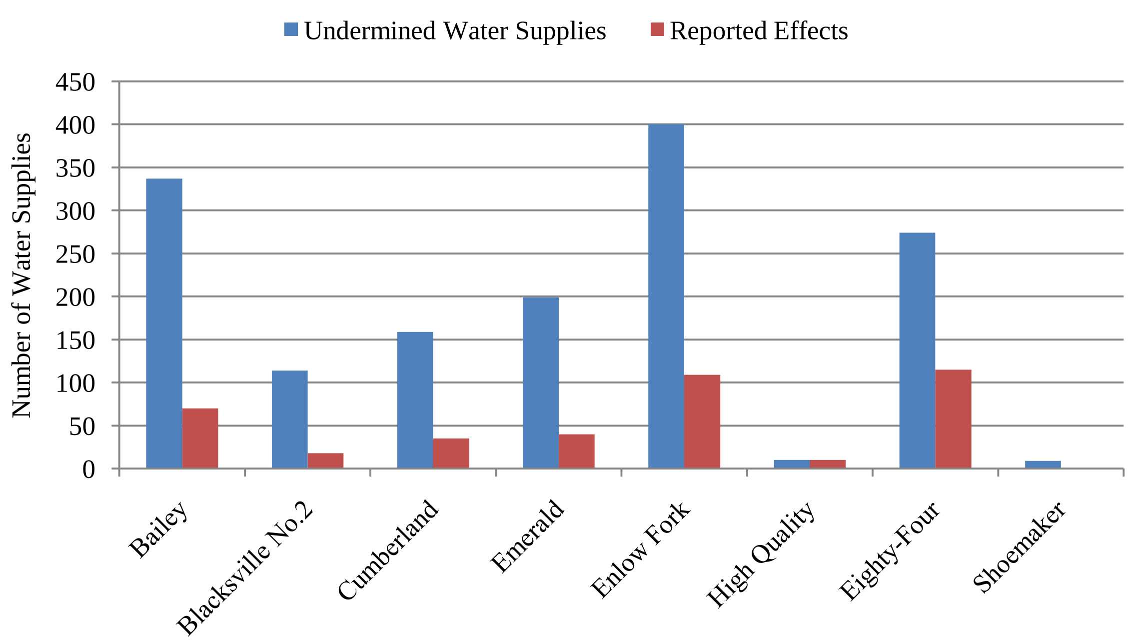


Figure VI-12 – Number of undermined water supplies (n=1,502) and the reported effects (n=397) by longwall mine.

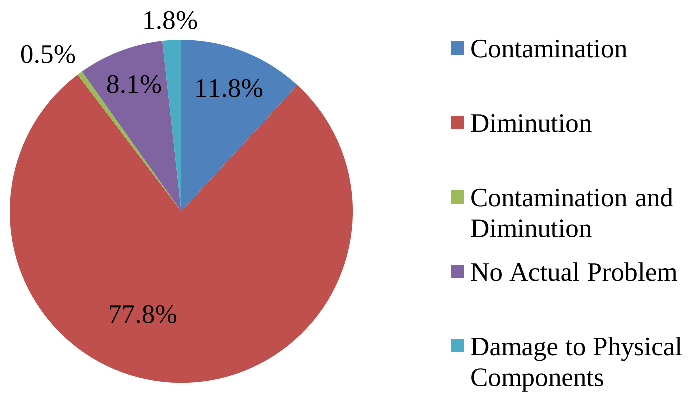


Figure VI-13 – Number reported effects (n=397) classified by type of impact.

Seven out of the eight longwall mines had reported effects associated with their longwall operations. The resolution statuses for each of the mines are presented in Figure VI-14.

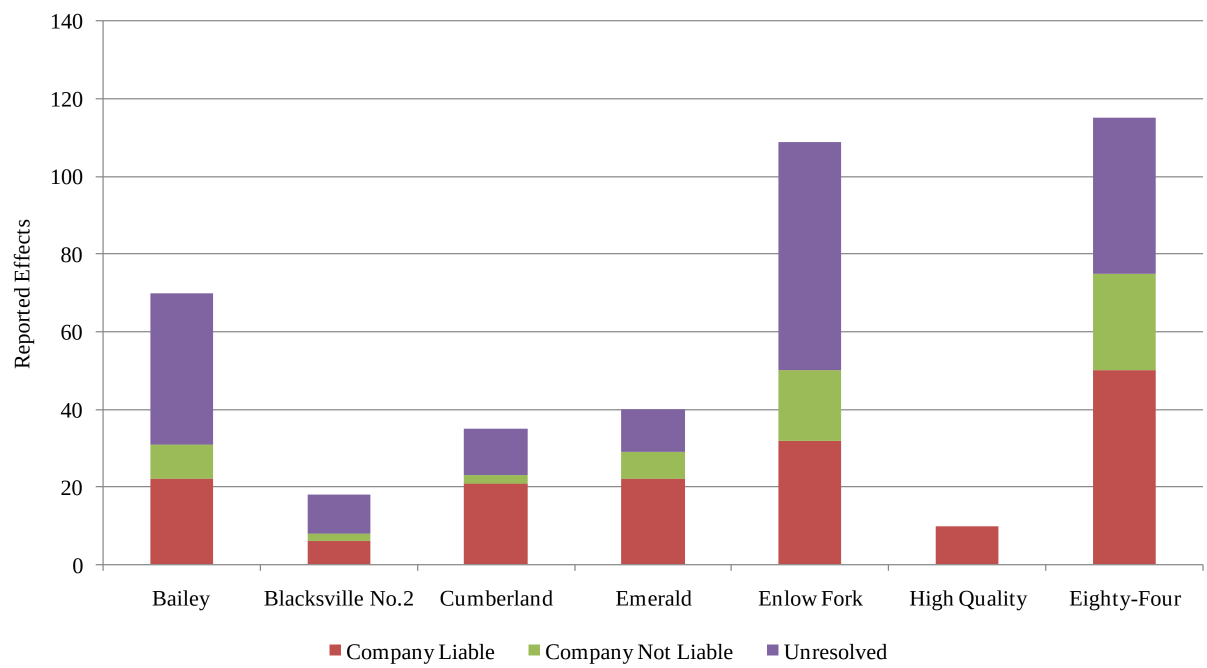


Figure VI-14 – Number reported effects (n=397) classified by resolution status and operation for longwall mines.

Figure VI-15 presents the percentage of liable effects out of all undermined water supplies associated with each longwall mine based solely on the resolved cases. The University expects these percentages to rise appreciably as the unresolved cases become categorized.

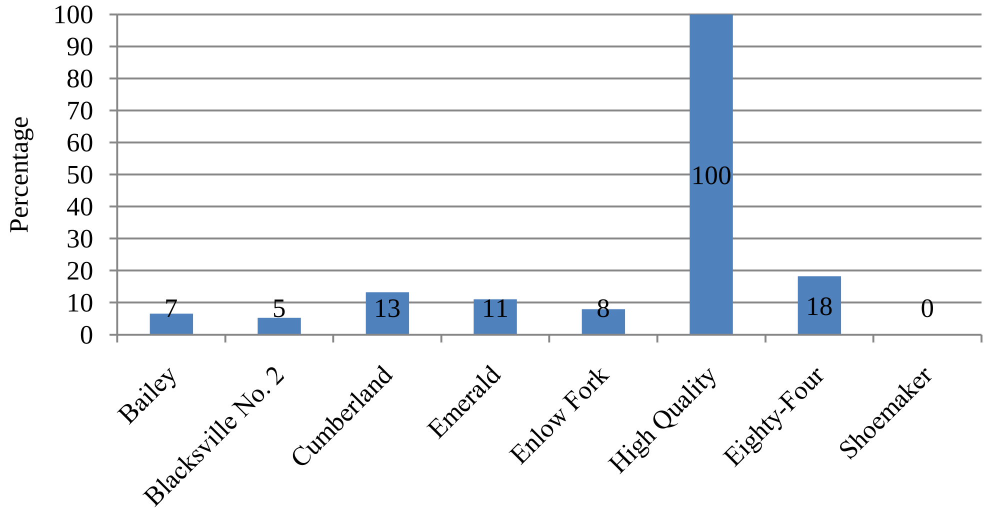


Figure VI-15 – Percentage of Liable effects versus total number of undermined water supplies by mine. The University expects these percentages to rise appreciably as the unresolved cases become categorized.

Longwall mine subsidence tends to alter the hydrogeology of the overburden. But to assess the overall impact of mining on the post-mining aquifer system, the University further analyzed the resolution statuses for the liable impacts to see how the impacted water supplies were being replaced. A permanent supply must be adequate to serve the pre-mining and reasonably foreseeable needs of the property owner. In some cases the pre-mining water supply needed repaired, replaced, or public water was provided to the property owner. For some of the more rural mines, public water lines were not available as a replacement water source. In other more populated areas, connection to public water is the most cost effective and efficient means of replacing a water supply. Figure VI-16 summarizes the permanent water supply types provided as a means of impact resolution for the longwall mining liable cases. The resolutions pertaining to agreements, compensation, and company purchasing properties are included in this figure under the agreement category. The impacts associated with these resolutions may be more complicated than just a water supply issue. Other issues pertaining to the property's land or structural damages may also play a role in the type of resolution that was established between the land owner and mine operator. While 83-pct of the finalized cases were resolved using some kind of agreement or compensation, 17-pct of the cases used a preexisting or new well or spring to establish a permanent water supply. Only in 7-pct of cases was public water used as the water supply replacement.

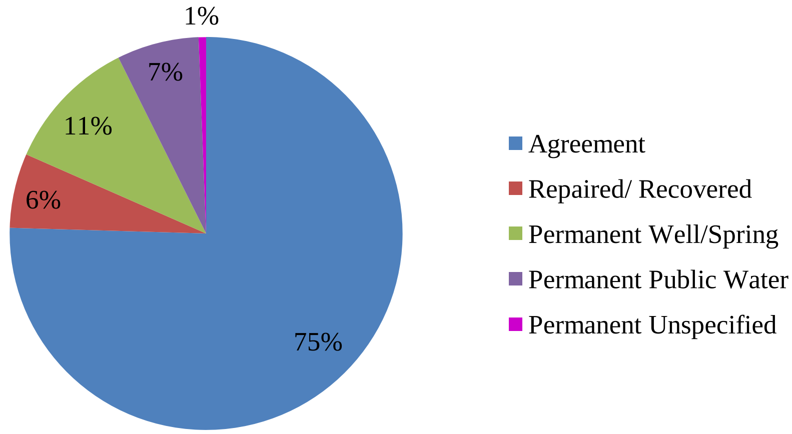


Figure VI-16 – Company Liable effects of longwall mining (n=163) tabulated by type of resolution detailing type of water supply replacement

VI.D.4 – Mines closed prior to the 3rd Assessment

A number of mines, which ceased operation prior to the 3rd assessment period, were reported as having post-closure effects on water supplies. The mines and number of reported effects are shown in Figure VI-17. The mines listed as having post-closure impacts include both room-and-pillar mines and longwall mines.

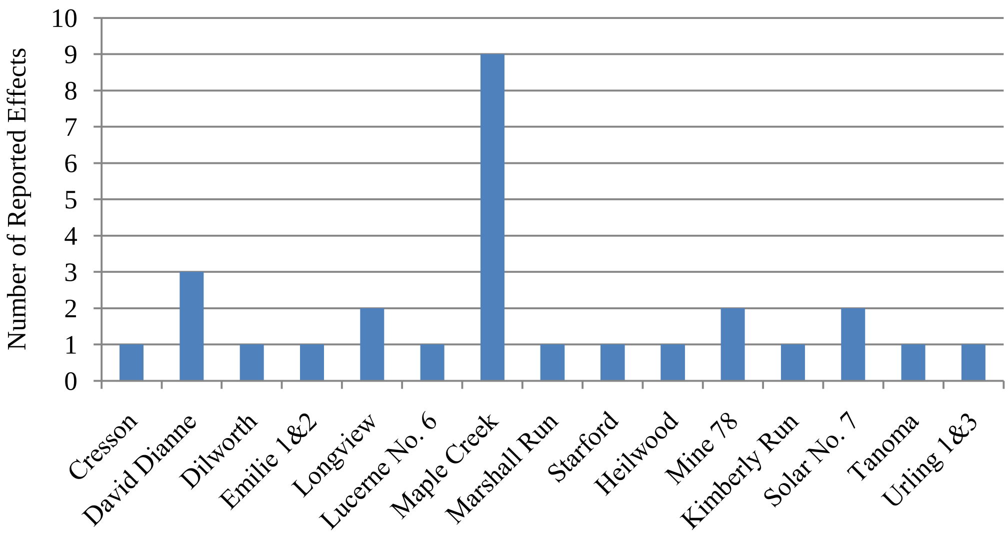


Figure VI-17 – Reported Effects (n=28) on water supplies of closed mines prior to August 21, 2003.

Of the 28 reported effects, 17 were diminution related, seven involved contamination, and four had an unspecified impact listed in the BUMIS description. In 13 cases the company was deemed liable, and in ten cases the company was deemed not liable. Five of the cases were pending resolution.

VI.E – Conceptual Model: Water Supply Vulnerability to Mining/Supporting Literature

Using the water supply assessment data, information from the permit files, and supporting literature, a conceptual model was created to aid in assessing the vulnerability of water supplies. This model was based on factors pertaining to the hydro-geologic setting, proximal location to mining, and the timing related to undermining. The focus of this section is to assess the hydrologic impacts due to longwall mining on the shallow aquifer system of Greene and Washington Counties. Additional descriptions of the hydro-geologic character of this region are contained in the Module 8 permit file information and the supporting literature. The Module 8 section of the permit files describes the topic of hydrology for each mine's location. The mine operator is required to provide information regarding natural hydrology, water supply and stream inventories, background sampling, prediction of hydrologic consequences/protection of hydrologic balance, and a hydrologic monitoring plan.

VI.E.1 – Hydro-geologic Characteristics of Greene and Washington Counties

In order to assess possible hydrologic impairment of the shallow aquifer system in Greene and Washington Counties, it is necessary to understand the natural hydro-geologic settings as they were prior to mining. The primary geologic units for Greene and Washington Counties are the recent alluvial deposits associated with the Pleistocene/Holocene and the Dunkard and Monongahela Group, which includes the current minable coalbeds.

The water bearing characteristics of interest to this study are found in many different hydro-geologic units above the Pittsburgh Coalbed and have been identified in geologic reports (Newport, 1973; Stoner, et al., 1987). These hydro-geologic units include:

- Pleistocene/Holocene Group:
    - The Pleistocene/Holocene Group contains the alluvium formation, resulting from material being deposited by the movement of water along large stream valleys. It is an adequate to excellent water bearing layer depending on the grain size distribution of the clay, sand, silt, gravel, etc. found in the local formation. According to Newport (1973), sand, gravel, or loosely cemented sandstone allow water to flow vertically and horizontally through the pore spaces.

- Dunkard Group:
    - The Greene Formation consists of shale, sandstone, and thin limestone; the sandstone units are generally the most important layers for water production in the region. Sandstones and coals are the most hydrologically productive stratigraphic units because of the large number of fractures and planes of weakness. Units such as shale, siltstone, or limestone have low hydraulic conductivities and are poor water producing layers. The Greene Formation has generally low yielding wells because of the scarcity of fractures within the stratigraphic units, and the large number of impermeable shale units within the formation. On average, most wells will yield approximately 2-gpm (gallons per minute) and the majority of wells are less than 120-ft deep (Newport, 1973).

  - The Washington Formation consists of shale, sandstone, limestone, and several coalbeds in Washington County. In both counties, wells penetrating the Washington Formation have an average yield between 2 and 3-gpm, and are approximately 30 to 300-ft deep. On average, the area springs discharge 0.50 gpm. According to Stoner, et al. (1987), discharge in the form of springs is common in the Washington and Greene Formations of the Dunkard Group.
  - The Waynesburg Formation is the lowest unit of the Dunkard group. This formation is reported to have an average well yield of 3.8-gpm, most likely from the sandstone and coal water bearing units.

- Monongahela Group:
  - The Uniontown and Pittsburgh Formations consist of limestone, shale, sandstone, and coal. The water bearing capabilities of the formation vary widely across both counties. The fine grained shale, found in Washington County, is largely impermeable; however there is water stored in the fracture and joint system. The median yield of wells in Washington County is around 1-gpm, and most wells exceed 100-ft deep. In Greene County, wells in the Uniontown Formation have a median yield of 8-gpm.
  - Generally the Pittsburgh Formation wells yield a sufficient quantity for domestic supplies in the eastern portion of Greene County, but the formation is too deep in the central and western portion of the county for domestic supplies. The basal unit is the Pittsburgh coal seam, which is where all longwall mining takes place in both counties.

The production of potable water from the geologic formations described above, not including the alluvium formation, is largely dependent on the secondary permeability of the strata, and not as much on the primary permeability. These natural groundwater conduits make it possible for water to move through the shallow aquifer system in the region. The secondary permeability decreases by an order of magnitude as the overburden increases every 100-ft (Stoner, et al., 1987). This is why the majority of the groundwater resources circulate within the first 200-ft of the ground surface. According to Wyrick and Borchers (1981), the natural stress relief fractures located in valley walls and valley bottoms will lead to increased secondary permeability, which also means that the fracture density will be higher in the valley bottoms as compared to the hilltop locations. Because of this principle, the hilltop will tend to produce less water as compared to the valley bottom.

Aside from permeability, the hilltop water supplies are located in the recharge areas. These areas are dependent on the amount of water infiltrating into the ground after a precipitation event. Valley bottoms are almost always areas of water discharge. Water enters into the groundwater system through infiltration, and flows from areas of high hydraulic head to low hydraulic head, or by gravity, to eventually discharge into the valley bottom. As water travels downward, it often encounters a stratigraphic layer of very low permeability, also known as perched or semi-perched aquifers. This impermeable layer will impede the water from percolating vertically, forcing the water to move laterally along the horizontal bedding plane to eventually discharge as a hillside spring or seep. These springs will exit the hillside where a fractured and permeable layer outcrops above an unfractured and impermeable layer.

Seasonal fluctuations in the amount of precipitation and the rate of infiltration can alter the amount of water circulating through the shallow aquifer system. Areas of recharge, or hilltop supplies, will see the greatest fluctuation of water levels during periods of low precipitation. In addition, recharge water takes more time to reach deeper supply levels because hilltop supplies tend to be deeper than valley bottom supplies. According to Stoner, et al. (1987), discharges from hillside springs and water levels in wells less than 100-ft deep can see large production decreases during times of low precipitation. However, springs lower on the hillside may prove more viable during times of low precipitation. Recharge rates are the highest between late fall and early spring. During the growing season (May to August) much of the recharge potential is lost to evapotranspiration (evaporation and vegetation usage). Therefore, the groundwater levels are generally highest in late winter, and lowest in late summer. According to Newport (1973), 40-pct of the average annual precipitation is lost to evapotranspiration throughout the year.

Generally the natural quality of the groundwater found in Greene and Washington County wells and springs is adequate for domestic supply. There are areas, however, that tend to have high levels of iron, manganese, sulfate, aluminum, or hardness, which may require treatment before human consumption.

VI.E.2 – Effects of Longwall Mining

The longwall mining technique, as described above, creates a subsidence basin and causes differing degrees of fracturing within the overburden. The subsidence basins also produce different regions of compressive and tensile stresses. Compressive stresses cause the strata to shift laterally along the bedding planes or rupture in shear; this process can open horizontal bedding planes and increase the lateral water movement, or create additional fracture planes when ruptured. The tensile stresses cause natural fractures to open up or new fractures to form, which can create new vertical pathways for water movement or additional space for water storage.

In addition to the subsidence zones provided by Peng (1992) and described above, Kendorski (1993) presents details on the hydrologic responses of five zones located above high-extraction mining. These zones include (from mine to surface) a caved zone, fractured zone, dilated zone, constrained strata zone, and surface fracture zone. Figure VI-18 shows a depiction of the five zones with their relative thicknesses and their hydrologic response descriptions.

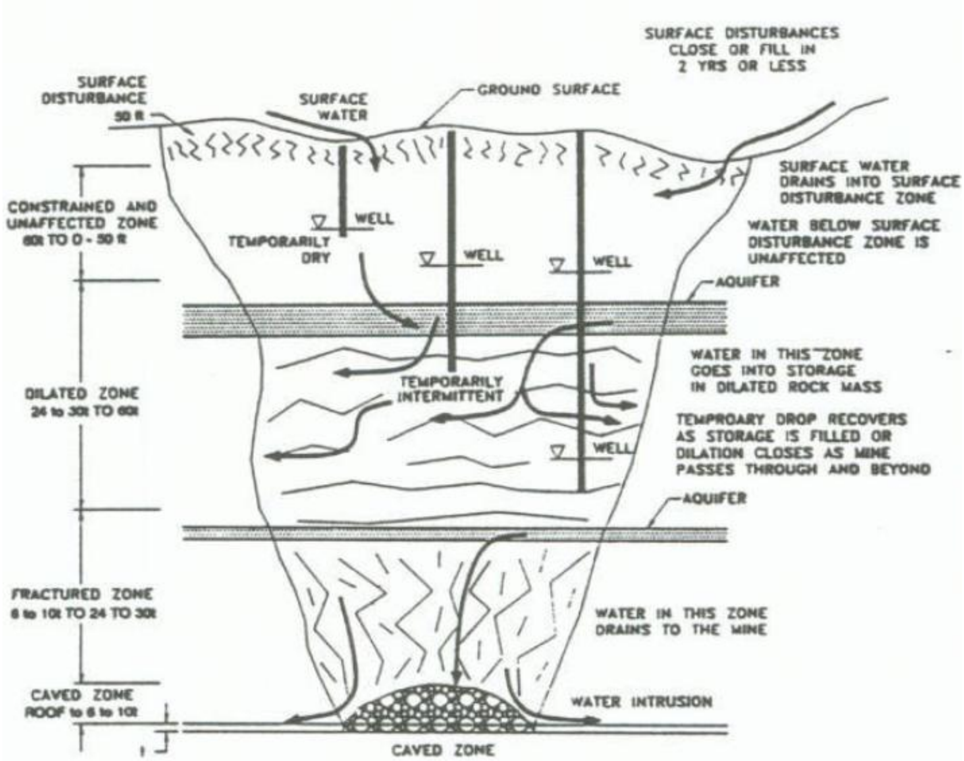


Figure VI-18 – Hydrologic response zone described by Kendorski (1993).

VI.E.3 – Vulnerability Influences

Certain factors will make a water supply more or less susceptible to the effects of longwall mining. These factors include:

- topography or overburden composition,
- lateral proximity to mining,
- location in relation to the longwall panel and the corresponding subsidence basin,
- climatic characteristics, and
- mine inflow.

The following subsections provide supporting data to substantiate or refute the influence of these water supply settings on the likelihood of an impact. The important matter of headwater springs is also addressed. The three categories used in this analysis are: 1) Unaffected, 2) Operator Liable, and 3) No Liability (Table VI-7). Reported effects that did not have a resolution status with an indication of liability are not included in the analysis; water supplies with pending resolutions that assigned liability were included in the liable impact count. The water supplies undermined that had no reported effects have been added to the unaffected category, along with the water supplies with reported effects that were later investigated and classified as having no impact.

Table VI-7 - The number of Unaffected, Company Liable, and Company Not Liable cases for each longwall mine are tabulated using the categorization listed above.

Mine Name	Unaffected	Company Liable	Company Not Liable
Bailey	268	46	9
Blacksville No.2	96	10	2
Cumberland	123	30	2
Emerald	162	28	6
Enlow Fork	293	85	17
High Quality	0	10	0
Eighty-Four	165	74	23
Shoemaker	9	0	0
Totals	1116	283	59

VI.E.3.a – Topography and Overburden Thickness

The water supplies were classified as being topographically located on a hilltop, hillside, or valley bottom using University generated surface and slope contours. Hilltops and valley bottoms were low slope areas classified by their relative high and low topographic elevations, respectively. Hillsides were areas of midrange elevations with high slope values. Using the overburden raster files generated by the University, the researchers were able to determine the overburden to the Pittsburgh coal seam for each water source undermined. The University determined that the average overburden for all eight longwall mines was approximately 687-ft with a standard deviation of 97-ft (Section III). For normally distributed data like longwall overburden, one standard deviation above and below 687-ft accounted for 2/3 of the data. Data in this range was considered average for this study. Overburden values less than 590-ft were considered shallow and, conversely, greater than 784-ft were classified as deep. The water supplies were classified based on their surface relief characteristic and overburden and sorted into one of the three categories of unaffected, operator liable, and no liability (Table VI-8).

Table VI-8 - The number of Unaffected, Company Liable, and Company Not Liable water supplies based on topographic and overburden characteristics

Depth	Topographic Location	Impact Category		
		Unaffected	Company Liable	Company Not Liable
Shallow	Hilltop	2	6	0
	Hillside	90	13	4
	Valley Bottom	150	47	12
Average	Hilltop	98	25	3
	Hillside	328	74	15
	Valley Bottom	223	55	6
Deep	Hilltop	102	24	6
	Hillside	111	31	4
	Valley Bottom	9	0	2
Unknown		3	8	7

The liable impact percentage to a water source was calculated based on the topographic position relative to the depth to mining. As shown in Figure VI-19, 75-pct of shallow hilltop water supplies were impacted by mining, as compared to a zero percent impact for deep valley bottom supplies. These findings coincide with the idea that hilltop supplies may be more vulnerable to small water level changes whereas valley bottom, or discharge areas, are more likely to recover. Because there were only eight shallow hilltops and 11 deep valley bottoms, out of nearly 1,450 water supplies, the University cannot state with certainty that this trend would apply using a larger data set. The other topographic and overburden scenarios resulted in approximately 80-pct retained viability, with only 20-pct of the water supplies impacted by mining.

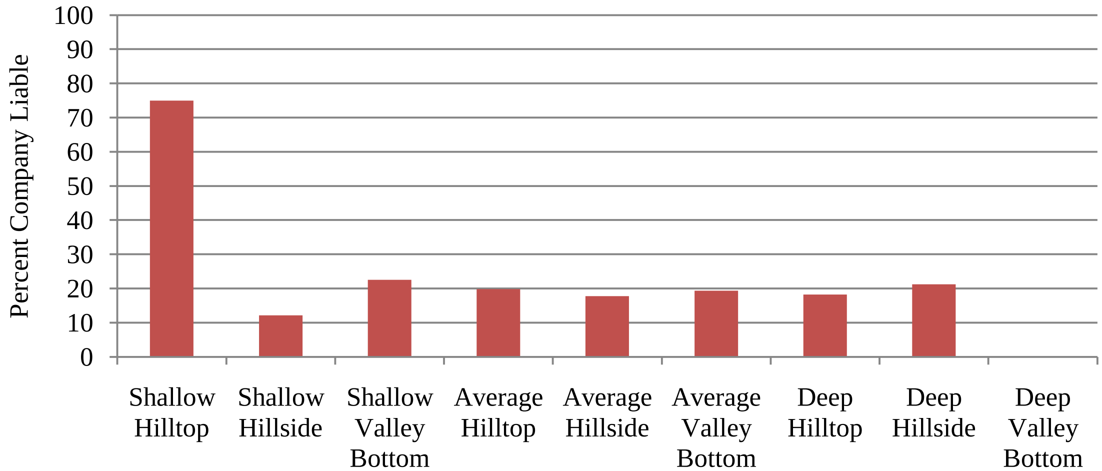


Figure VI-19 – Percent Company Liable calculated for each topographic overburden scenario.

VI.E.3.b – Lateral Proximity to Mining/ RPZ Discussion

The University measured the distance between each water source to the nearest longwall panel, and entered these distances into the GIS attribute tables. Using the lateral distance and the calculated overburden values, the University calculated the projection angles from the edge of the nearest longwall panel to each water supply (Figure VI-20).

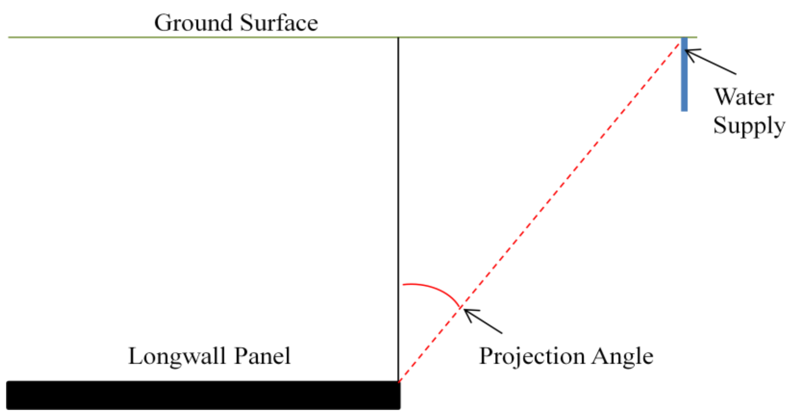


Figure VI-20 – Diagram showing the projection angle calculation from the edge of the longwall panel to the surface water supply.

The University recognizes that using a standardized range of lateral distances may not sufficiently depict the differentiation of hydrologic responses to longwall mining at varying overburden depths. The water supplies were categorized as being Company Liable or Company Not Liable and distribution curves were created. As discussed in the determination of liability section, the projection angle of 35-deg is used to presume liability of an impact. The results are shown in Figure VI-21. It is important to note that the CDMO determines liability in relation to all mining that has occurred in the vicinity of a water supply, and the University's distances were measured based on active mining during this assessment period only. Distances to mining were only provided in the BUMIS database when there was a record of a reported effect. Therefore it was necessary to calculate distance values based on the University generated mining outlines for all water supplies, impacted or not.

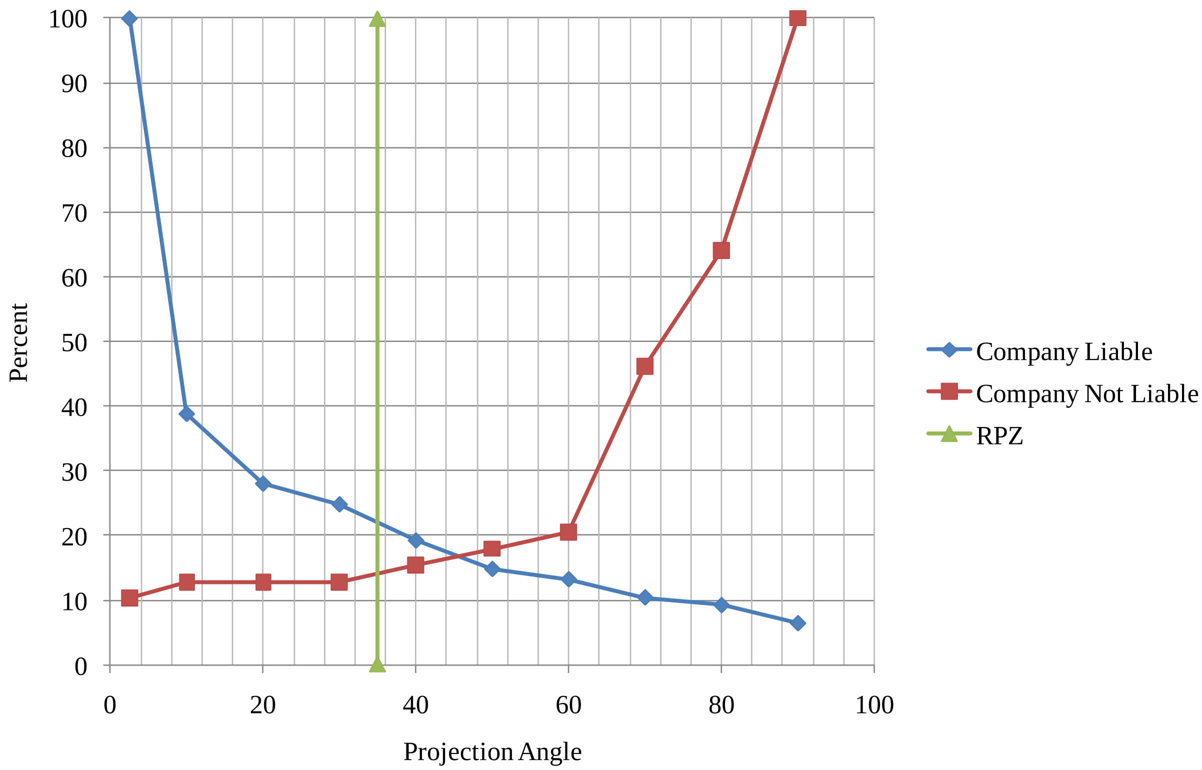


Figure VI-21 – Distribution curves representing the percentage of projection angle values within or outside of the RPZ.

Approximately 77-pct of water supply impacts were deemed Company Liable if within the RPZ. Conversely, 14-pct of Company Not Liable cases were within the 35-deg RPZ. The two distribution curves intersect at approximately 46-deg. Of the 22-pct of liable cases outside of the RPZ, factors pertaining to pre-mining agreements or non-water supply related impacts (i.e. structural or land impacts) could have occurred resulting in a liable resolution status. Regarding the 14-pct of water supplies within the RPZ that were resolved as no liability, the mine operator either successfully refuted the claim, the problem was pre-existing, or not caused by mining, i.e. drought conditions, poor water supply construction / maintenance.

VI.E.3.c – Panel Location/Subsidence

The research team created a model with quarter-width buffer for each side of the panel mined during the 3rd assessment. This buffer separated the panel into mid-panel (50-pct of the panel width) and quarter-panel (two outer 25-pct panel regions) sections. These regions depict the potential types of fracturing of the strata near the ground surface. As provided by Booth (1986), Figure VI-22 depicts the zones of compression and tensile fracturing within the subsidence basin.

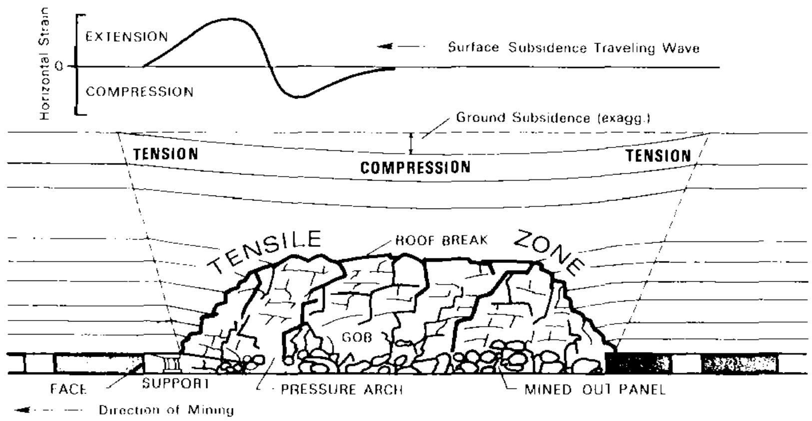


Figure VI-22 – Zones of compression and tensile strata fracturing from Booth (1986).

The water supplies were provided with an attribute in the UGISdb noting the panel location, as quarter or mid-panel. If the water supply was located outside of the panel, it was classified as being located over the gate roads or outside of active mining. The water supplies were categorized as being Company Not Liable or Company Liable and tabulated based on their panel location, as shown in the Table VI-9.

Table VI-9 - The number of Company Not Liable and Company Liable water supplies based on their panel locations.

Mine Name	Company Not Liable				Company Liable				N/A
	Mid	Quarter	Gate	Outside	Mid	Quarter	Gate	Outside	
Bailey	66	50	54	107	8	3	5	30	0
Blacksville No.2	13	24	12	48	2	2	2	4	1
Cumberland	40	32	30	23	8	7	12	3	0
Emerald	30	34	35	69	10	9	4	5	0
Enlow Fork	79	101	49	79	20	26	13	20	8
High Quality	0	0	0	0	5	2	2	1	0
Eighty-Four	30	38	27	89	18	25	8	21	6
Shoemaker	0	0	3	6	0	0	0	0	0
Total:	258	279	210	421	71	74	46	84	15

Figure VI-23 shows the liability percentages for each panel location scenario. Due to the formation of a subsidence basin directly over the mined panel, the expectation of an impact is greater over the panel, and less likely as the distance between the water supply and the longwall panel increases. This principle is affirmed in Figure VI-23. Water supplies located directly over mined longwall panels showed a 22-pct and 21-pct chance of being impacted by mining, based on their location whether over the mid-panel or quarter-panel regions, respectively. According to a study conducted by Walker et al. (1986), wells that were located in the mid-panel region of the longwall panel had greater water level fluctuations and head loss, as compared to wells located outside of this region. This can most likely be attributed to the change from dynamic extensional strains and fracturing to static compressive strains or recompression of fractures in the mid-panel region of the subsidence basin. The quarter-panel region, however, will be subject to extensional strains throughout the mining process. A report by Trevits & Matetic (1991) observed water level fluctuations that began approximately when the ground surface was subjected to tensile strains, and maximum rate of water loss and lowest water levels corresponded to the point of maximum tensile ground strains. That study also showed that water levels began to recover once the point of maximum compressional strain was achieved, most likely attributed to the closure or reduction of extensional fractures.

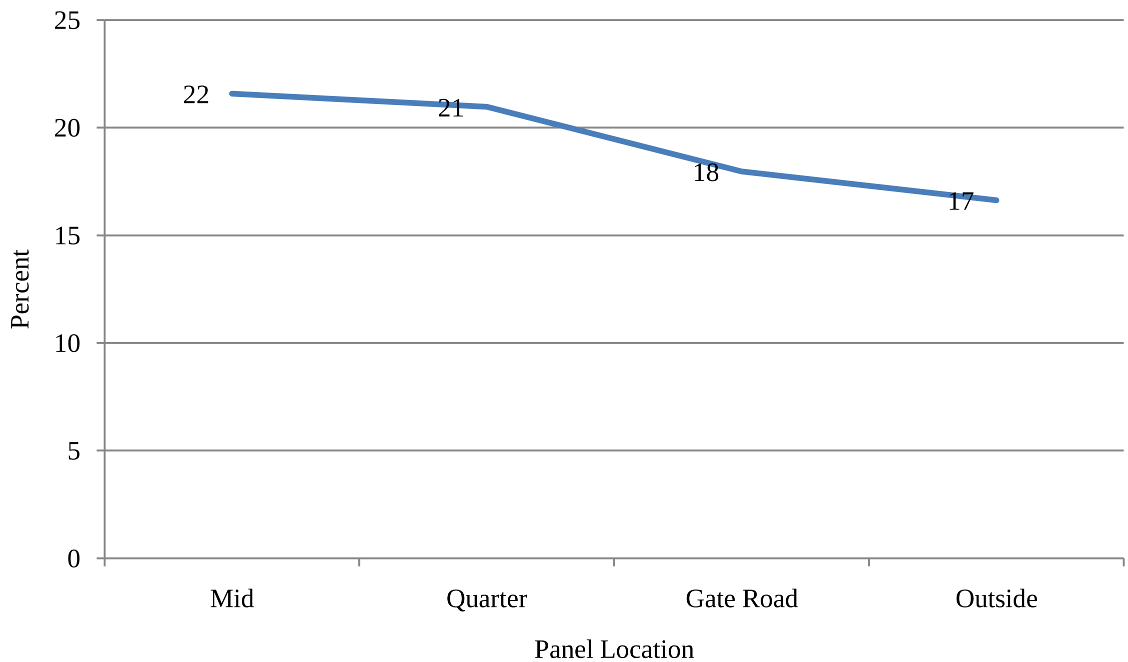


Figure VI-23 –The post-mining percentage of liable water supply shown for each panel location.

VI.E.3.d – Other Influences

The University team collected the daily precipitation totals for the duration of the assessment period. The precipitation totals were measured at the Waynesburg Wastewater Treatment Facility. These values are identical to the ones used by the CDMO. The daily totals were summed to calculate monthly totals during the assessment period. The monthly totals for the years 2003 to 2008 were compared to the long term average precipitation rates for each month for Waynesburg, PA (Figure VI-24). The long-term average values were collected from Canty & Associate’s *Weatherbase* website (http://www.weatherbase.com).

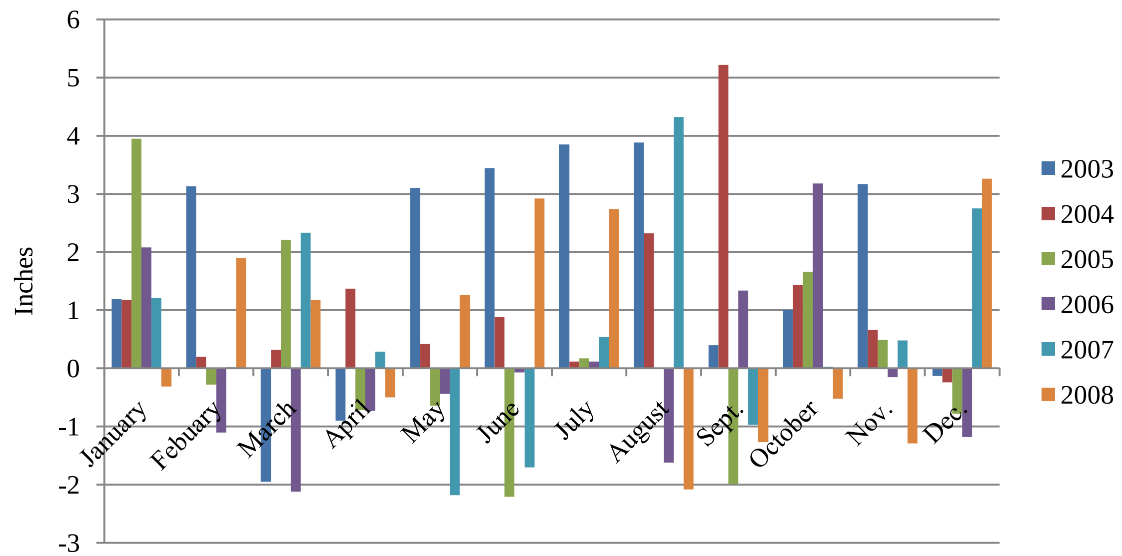


Figure VI-24 – Precipitation totals compared to the long-term precipitation averages determined from Canty & Associates' website for Waynesburg, PA.

The below average precipitation months include: December 2003 and 2004; February, April, May, June, September, and December of 2005; February through June, August, November, and December of 2006; May, June, and September of 2007; and January, April, and August of 2008. The months of the assessment period have been compared to the distribution of all reported water supply effects for longwall mines (Table VI-10). For this analysis the date of occurrence for the reported effects was considered.

Table VI-10 – The total number of reported effects (n=397) for all longwall mines is shown divided into month of occurrence is shown. Below average precipitation rates are shown in italic.

Date	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
2003								**0**	**0**	**11**	**2**	*1*
2004	**0**	**3**	**1**	**3**	**2**	**11**	**12**	**3**	**3**	**1**	**3**	*1*
2005	**2**	*3*	**3**	*1*	*1*	*6*	**3**	**7**	*7*	**9**	**9**	*5*
2006	**5**	*2*	*8*	*56*	*10*	*13*	**6**	*3*	**7**	**3**	*6*	*4*
2007	**5**	**1**	**5**	**5**	*6*	*5*	**9**	**11**	*4*	**21**	**23**	**24**
2008	*2*	**8**	**5**	*5*	**6**	**7**	**4**	*5*				

Italic & Underline = below average precipitation
Bold = above average precipitation

As shown in Table VI-10, there were a total of 397 reported effects attributed to longwall mining during the 3rd assessment; with 154 occurring in below average precipitation months and 243 occurring in at or above normal precipitation months. There were 22 months of below average and 39 of normal or above precipitation. By dividing the number of reported effects by number of months, the University determined that there was an average of seven effects reported per below average month, and 6.2 effects reported for above average months. This ratio shows that there may be a slight relationship between months of below average precipitation resulting in more reported water supply effects.

Additionally, the University was able to extract the mine inflow records for the majority of the longwall mines by referencing the Module 8 permit files for each mine. The mine inflow rates were converted into gallons per minute per acre, and shown in the Table VI-11. The value for Blacksville No.2 was not determined because discharges from the mine occurred in West Virginia.

Table VI-11 – The mine inflow rates (rates of pumping required) for each longwall mine.

Mine Name	Inflow (gpm/acre)
Bailey	0.032
Blacksville No.2	n/a
Cumberland	0.250
Emerald	0.130
Enlow Fork	0.005
High Quality	0.480
Eighty-Four	0.036
Shoemaker	0.009

These inflow rates were estimated by the rate at which water was pumped out of the mine. The water infiltrating into the mine can be moving in from the groundwater system above the mine or from nearby abandoned and flooded mines. As previously discussed, water will move by gravity or from pressure areas of high hydraulic head to areas of low hydraulic head. Some of the higher inflow rates, shown in Table VI-11, were the result of infiltration of water from adjacent mines.

According to Booth (1986), groundwater will only drain to the underground mine from the shallow aquifer system if they are hydraulically connected via the fractured strata. As shown in Figure VI-18, Kendorski (1993) describes a dilated zone of increased storativity with little or no vertical transmissivity. This zone is defined as the layer that prevents large amounts of surface and groundwater intrusion into the mine from above. The two layers below this layer are the fractured and caved zones, which account for approximately 30 times the thickness of mining. In order for the shallow aquifer system to infiltrate into the mine, with a mining height of 6-ft, the shallow aquifer system would predictably need to be within 180-ft of the fractured zone to hydraulically connect the shallow aquifer system directly with the mine. The overburden of the longwall mining that occurred during the assessment period was greater than 180 feet deep; therefore little infiltration of the shallow aquifer system was expected.

VI.E.3.e – Headwater Springs Discussion

Headwater springs are vital in contributing to the local stream flow in the region. Impairment of these springs can change the hydrology, biology, and overall health of headwater streams in the region. For the purposes of this analysis, the WPC's Pennsylvania Aquatic Community Classification (PACC) methodology (Walsh et al., 2007) was used to determine which Greene and Washington County watersheds were classified as headwater watersheds. According to the PACC methodology, headwater watersheds range from 0-2 square miles in area; these areas are the location of stream reaches that mainly support the headwater macro invertebrate communities. Using the PASDA GIS online database, the University downloaded the small watershed GIS layer, and calculated the areas of each watershed in square miles. The springs located in these watersheds were exported to the UGISdb for further analysis of the impacts associated with these springs. Table VI-13 provides an inventory of the number of headwater springs undermined by each longwall mine, and the number of associated reported effects.

Table VI-13- Inventory of headwater springs and whether there was an associated impact and the corresponding likelihood of impact.

Mine Name	Total Number	Company Not Liable	Company Liable	Unresolved
Bailey	30	26	0	4
Blacksville No.2	4	4	0	0
Cumberland	8	7	1	0
Emerald	19	17	1	1
Enlow Fork	0	0	0	0
High Quality	0	0	0	0
Eighty-Four	21	15	3	3
Shoemaker	7	7	0	0

As shown in the table above, the percentages of liable impacts on headwater springs are no greater than the overall percentages of likelihood of impacts for all water supplies undermined by longwall mines as shown in Figure VI-15.

VI.F – Status of Water Supplies Impacted during the 2nd Assessment

According to 2nd assessment period report published by Conte and Moses (2005), there were 684 reported effects attributed to the undermining of water supplies during the assessment period. Of the 684, 21.7-pct of reported effects were pending a final resolution (Unresolved) as of August 20, 2003. The current research team was not able to verify these exact case numbers as reported in the previous assessment. The University utilized a Discovery query associated with the BUMIS database in December of 2009, but since BUMIS is an ever-evolving database, the elapsed time may be the reason for the discrepancies in the number of reported effects that were extracted years later.

For this analysis the University used the number of reported effects and the resolution status of these reported effects as provided by the Discovery query from 2009. Table VI-14 summarizes the status of the reported effects occurring in the previous assessment.

Table VI-14- Inventory of reported effects of the 2nd assessment as of the end of the 3rd assessment.

Status	Reported Effects
Total Number that Occurred 1998-2003	603
Number Resolved as of 8/2003	359
Number Resolved as of 8/2008	212
Unresolved as of 8/2008	32

Figure VI-25 shows the breakdown of resolution statuses of the 244 reported effects at the end of the 3rd assessment period. The reported effects have been categorized based on their resolution status as being Company Liable, Company Not Liable, or Unresolved. Company Liable accounts for 81.6-pct of the total and has been shown divided into the classifications of Agreement / Compensation, Permanent Supply, Recovered/Repaired, and Resolved.

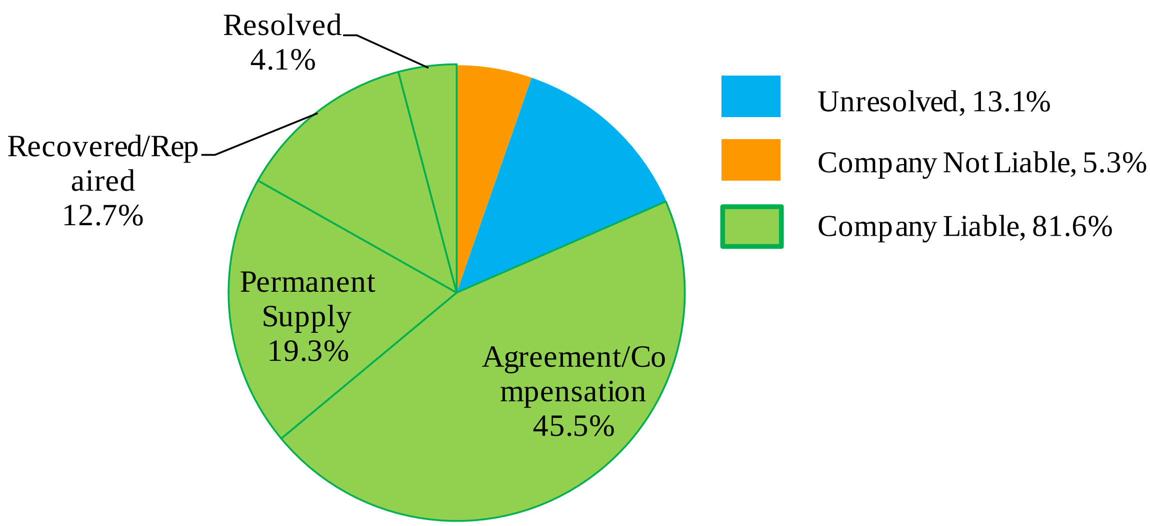


Figure VI-25– Resolution statuses of outstanding 2nd assessment effects resolved during the 3rd assessment period.

Based on categories used in the preceding figure, Figure VI-26 presents the average elapsed time required for a resolution to be finalized. As shown in the figure, the majority of the effects required over three years to resolve; with the Resolved category cases requiring the longest amount of time to resolve at 5.7 years. A few of these Resolved cases described the involvement of an insurance company, and the other provided no extra details to determine what actions were taken within those nearly six years. The Recovered / Repaired category may not reflect the actual average time to resolution because only one out of 31 cases was tracked for time. The remaining 30 cases were attributed to a mine pool contamination of the Dora No.6 Mine.

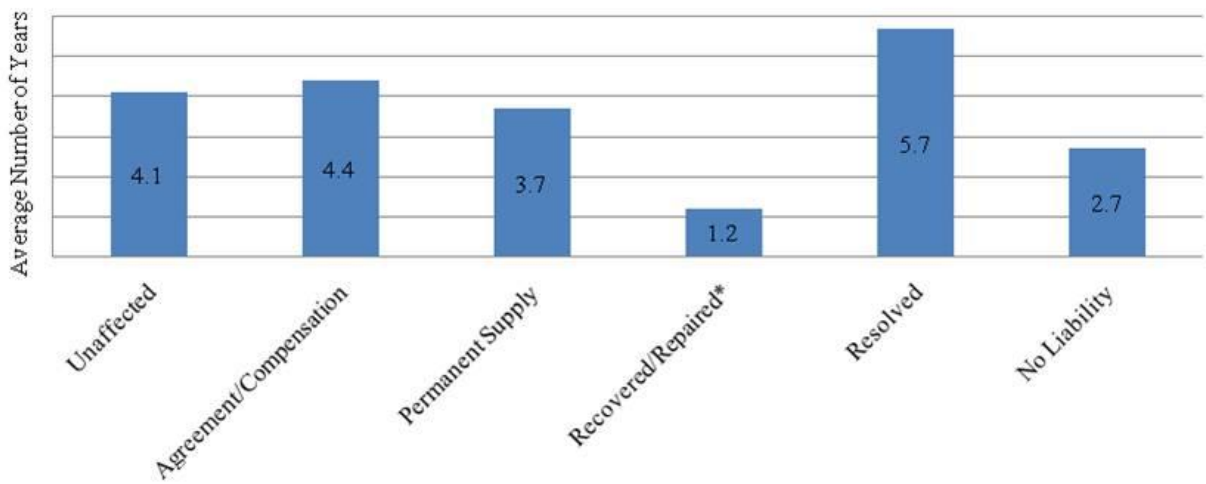


*Figure VI-26– Average number of years required for resolution of each type of resolution status. *Only one out of 31 cases was tracked to resolution time.*

There are 32, or five-pct, of 2nd assessment reported effects that are still not resolved as of August 20, 2008. These pending resolution cases are averaging approximately 6.8 years since the initial effect was reported. Table VI-15 categorizes each of the 32 reported effects based on their interim resolution statuses. The table identifies that the majority of cases are working toward a final resolution in some capacity.

Table VI-15- Interim Resolution status breakdown of the remaining 32 unresolved reported effects from the 2nd assessment period

Interim Status	Reported Effects
Agreement Pending	1
Implementing WS Replacement Plan	2
In Litigation	2
In Negotiation	1
O & M Review	5
O&M Bond Requested	3
Pending Owner Approval	5
Public Water/O&M Pending	3
Temp Water/Awaiting Public Water	3
Temporary Water	1
Well, Spring/O&M Pending	5
WS Replacement Plan Under Development	1

VI.G – Summary Points

The University determined that the total number of water supplies undermined during the 3rd assessment was 2,789 wells, springs, and ponds. The room-and-pillar mines accounted for 1,212 undermined water supplies, room-and-pillar with pillar recovery mines accounted for 75, and longwall mines accounted for 1,502 of the total undermined. There were 683 reported effects associated with the undermined water supplies; 238 from room-and-pillar mines, 20 from room-and-pillar with pillar recovery mines, 397 from longwall mines, and 28 from post-closure mines.

Seventy-four percent of reported effects were associated with water supply diminution. The date of final resolution was tracked and the University determined that 449 of the 683, or 66-pct, of the reported effects were resolved as of the end of the assessment period, leaving 234, or 34-pct of cases, still awaiting a final resolution. Of the resolved cases, it was determined that 256 out of the 449, or 57-pct, of resolved cases were deemed Company Liable. The average number of days required for a final resolution to be achieved was 143 days for room-and-pillar mines, 115 days for room-and-pillar with pillar recovery mines, 274 days for longwall mines, and 259 days for post-closure mines. There were also 12 cases exceeding three years without a final resolution. 212 of the 244 unresolved 2nd assessment reported effects were resolved during the 3rd assessment period. The remaining 32 reported effects were still unresolved as of August 20, 2008

Based on the extensive data collected, the University analyzed potential trends to help create a conceptual water supply vulnerability model. The potential vulnerability influences analyzed included topographic/overburden, lateral proximity/RPZ, longwall panel location, climatic, mine inflow, and headwater location. The following trends were observed:

- *Topographic/Overburden Influence:* Approximately 80-pct of water supplies remained viable after being undermined for all settings except for shallow hilltops where the impact rate was 75-pct and deep valley bottoms with 100-pct viability.
- *Lateral Proximity/RPZ Influence:* Approximately 77-pct of Company Liable impacts occurred within the 35-deg projection angle (RPZ). Nearly 86-pct of cases outside of the RPZ were determined as Company Not Liable.
- *Longwall Panel Location Influence:* Water supplies located over the mid or quarter-panel regions of the longwall panel were 22 and 21-pct likely to be impacted, respectively. When located over the gate roads or outside of mining the likelihood of impact decreased to 18 and 17-pct, respectively.
- *Climatic Influence:* The number of reported effects during the below average precipitation months was an average of 7 per month, and the above average months was calculated to be 6.2 effects per month; which may indicate a slight relationship between precipitation values and water supply reported effects.
- *Mine Inflow Influence:* There did not seem to be any data that would suggest that the shallow aquifer system is being lost to mine inflow. Generally, overburden values for the longwall mines of this study were not shallow enough to hydraulically connect the shallow aquifer system directly with the mine.
- Headwater springs were no more likely to be impaired by subsidence than any of the other water supplies undermined by longwall mining, but the impairment of these supplies can be detrimental to the biological health of the stream systems to which they contributed water flow.

During this study period, 256 water supplies were deemed impacted by mining out of a total of 2,789 undermined; therefore, on average, 9-pct of water supplies within 200-ft of active mining were affected. This shows that the process of underground bituminous coal mining affects the natural hydrogeologic characteristics of overburden strata.

SECTION VII: Effects of Mining on Land

VII.A - Overview

Through an examination of the BUMIS files, the University found 108 land reported effects that occurred during the 3rd assessment period. Ninety-seven of these cases were from active mines and 11 were from inactive mines. Another five cases, not included in the total of 108, occurred during a previous assessment period.

All longwall mines, with the exception of Shoemaker where minimal mining occurred within PA, have land reported effects. Conversely, five land reported effects occurred over room-and-pillar mines but only in two of these was the company (Ridge Mine) held liable.

VII.B – Land Reported Effects by Mining Type

The distribution of the 108 land reported effects during the 3rd assessment period and overlying 13 active and closed mines is shown in (Figure VIII-1). Nine longwall mines accounted for 95.4-pct of the total while four room-and-pillar mines provided the remaining 4.6-pct. Eleven of the reported effects came from four mines that did not operate during the 3rd assessment period. These were Maple Creek (8), Dilworth (1), Humphrey No.7 (1), and Tanoma (1). Of the four room-and-pillar mines (Figure VII-1), only the Tanoma Mine practiced pillar recovery.

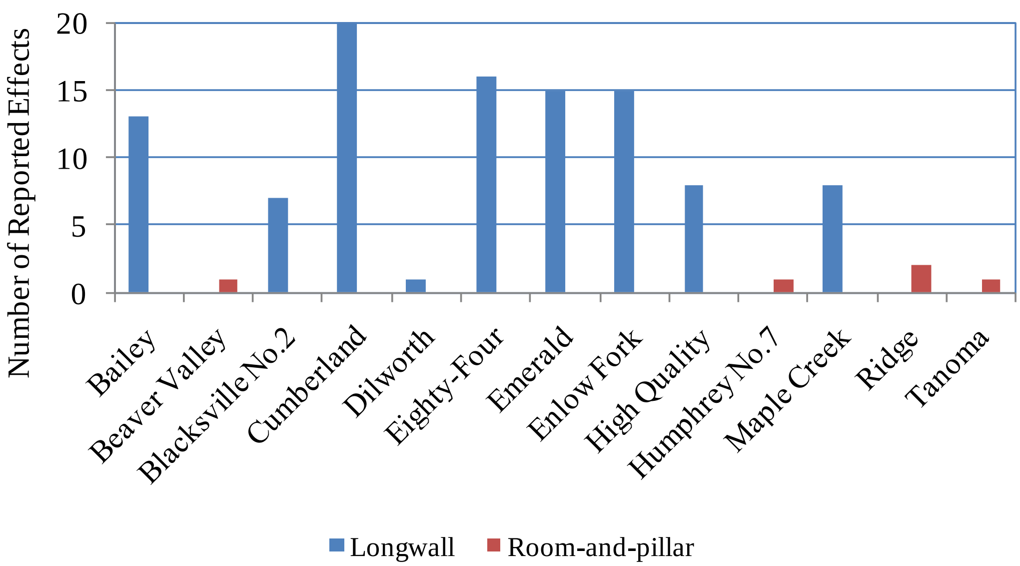


Figure VII-1 – The distribution of 108 land reported effects over 13 mines

One way to evaluate the rate at which land reported effects took place was to analyze the frequency of occurrence by mining type (Table VIII-1). This analysis covered only mines that operated during the 3rd assessment period. The percent of properties with reported effects (Table VII-1) provided some insight as to the significance of land impacts. In this study, the vast majority of room-and-pillar mines, with and without pillar recovery, had near zero land reported effects while longwall mines had an average of 6.0-pct.

Table VII-1 – Percent of properties with land reported effects organized by mining type.

Mining Type	Land Reported Effects	Properties Undermined	Percent Properties with Reported Effects
Longwall (active mines)	94	1,571	6.0
Longwall (in-active mines)	9	NA	NA
Room-and-pillar (active mines)	3	1,738	0.2
Room-and-pillar (in-active mines)	2	NA	NA
Room-and-pillar with pillar recovery	0	277	0
Total	108		

NA – Not Available (mines were not part of 3rd assessment period)

VII.B.1 – Days to Resolve Land Reported Effects

The University collected information related to the date of occurrence, interim resolution, and final resolution for every land reported effect. Of the 108 reported effects that occurred during the 3rd assessment period, 87 had final resolutions. It took an average of 206 days for these cases to reach a final resolution (Table VII-2). The average days to an interim resolution was 109 days.

Table VII-2 – The number of days to resolve land reported effects and number of resolved / unresolved cases for all mines in the 3rd assessment period.

	Interim	Final
Mean, days	109	206
Standard Deviation, days	207	256
Median, days	13	105
Minimum, days	0	0
Maximum, days	1,164	1,253
Number of Resolved Cases	85	87
Number of Unresolved Cases	23	21

VII.B.2 – Resolution Status of Land Reported Effects

The land resolution status at the end of the 3rd assessment period was presented in Table VII-3. Of the 87 final resolutions, 57-pct, or 50, were assigned as Company Liable. The other 43-pct, or 37, were assigned as Company Not Liable. Of the remaining 21 land reported effects, 18 had an Interim Resolution but no final resolution and three had an outstanding reported effect with No Interim Resolution (Table VIII-3).

Table VII-3 - Resolution status at the end of the 3rd assessment period for all reported effects sorted by active and in-active mines.

Mine Name	Final Resolution		Interim Resolution	Outstanding Reported Effect (No Interim Resolution)	Mine Total	Total
	Company Liable	Company Not Liable				
Active Mines						
Bailey	3	7	3		13	
Beaver Valley		1			1	
Blacksville No.2	3	2	2		7	
Cumberland	11	6	3		20	
Eighty-Four	7	3	3	3	16	
Emerald	5	6	4		15	
Enlow Fork	12	1	2		15	
High Quality	5	3			8	
Ridge	2				2	
Sub-total	48	28	18	3		97
In-active Mines						
Dilworth		1			1	
Humphrey No.7		1			1	
Maple Creek	2	6			8	
Tanoma		1			1	
Sub-total	2	9				11
Total	50	37	18	3		108

For the 50 Company Liable reported effects, the most common resolution, with 52-pct (26 cases), was to Repair the property (Table VII-4). This was followed by private agreements, both pre- and post-mining, with 24-pct (12 cases) and some form of compensation to the land owner with 14-pct (7 cases). In five cases, the company purchased the property.

Table VII-4 - Results of land reported effects where the final resolution was Company Liable.

Mine Name	Company Purchased Property	Compensated / Resolved / Settled	Repaired	Agreement	Total
Bailey		2	1		3
Beaver Valley					
Blacksville No.2			3		3
Cumberland			8	3	11
Dilworth					
Eighty-Four	1		4	2	7
Emerald	1	1	2	1	5
Enlow Fork	3	4		5	12
High Quality			4	1	5
Humphrey No.7					
Maple Creek			2		2
Ridge			2		2
Tanoma					
Total	5	7	26	12	50

For 37 land reported effects, Company Not Liable was found (Table VII-5). The most frequent reason for no liability was Not Due to Underground Mining with 83.8-pct of the total. The other reasons accounted for only 16.2-pct of the total and include Withdrawn (2.7-pct), No Actual Reported Effect (2.7-pct), No Liability (5.4-pct), and Not Covered by BMSLSA (5.4-pct).

Table VII-5 - Results of land reported effects where the final resolution was Company Not Liable.

Mine Name	With-drawn	No Actual Reported Effect	No Liability	Not Due to Underground Mining	Not Covered by BMSLCA*	Total
Bailey			1	6		7
Beaver Valley				1		1
Blacksville No.2				1		1
Cumberland				6		6
Dilworth				1		1
Eighty-Four				3		3
Emerald	1			5		6
Enlow Fork			1			1
High Quality		1		2		3
Humphrey No.7					1	1
Maple Creek				6		6
Tanoma					1	1
Total	1	1	2	31	2	37

*BMSLCA = *Bituminous Mine Subsidence and Land Conservation Act*

VII.B.3 – Resolution Status from Land Reported Effects from the 2nd Assessment Period

Five reported effects were carried over from the 2nd assessment period. Four were resolved during the 3rd assessment period, taking an average of 583 days to reach a final resolution (Table VII-6). Of the four resolved cases, three were found to be Company Liable and one Company Not Liable. The one unresolved reported effect had an interim resolution on August 21, 2007, but was still being litigated as of August 20, 2008. All of these reported effects were from longwall mines.

Table VII-6 – Days to resolve reported effects from the 2nd assessment period.

	2nd Interim Resolution	2nd Final Resolution
Mean		583
Standard Deviation		455
Median		576
Minimum		63
Maximum	1999*	1115
Number Resolved		4
Number Unresolved	1**	0

* - Interim resolution on August 21, 2007
** - Case being litigated as of August 20, 2008

VII.C – Land Reported Effects by Cause

The University categorized the cause of the land reported effects from Agent Observations found in BUMIS. This was necessary because BUMIS descriptions were written by multiple authors using a wide variety of terms, definitions, and descriptive language. Five categories were established: *mass wasting, tension cracks, settlements, compression ruptures, and unknown*. The University used the term compression ruptures to represent the following BUMIS terms: compression fractures, heaves, or heaving. Seventy-six cases are identified where land reported effects had resolutions with a Company Liable or an Interim / Outstanding condition at the end of the 3rd assessment period (Table VII-7). Tension cracks accounted for 48.7-pct of the total causes followed by mass wasting with 26.3-pct and settlement with 15.8-pct. No compression ruptures were found among these cases; however, ruptures caused some stream damage (Section VII.C.4).

Table VII-7 – Cause of land reported effects where Company Liable or Interim Resolution / Outstanding Claim existed at the end of the assessment period.

Mine Name	Mass Wasting	Tension Cracks	Settlement	Unknown	Total
Bailey	3	1		2	6
Blacksville No.2	3		3		6
Cumberland	2	9	3	1	15
Eighty-Four	3	6	3	1	13
Emerald	4	4		2	10
Enlow Fork	5	10	2		17
High Quality		3	1	1	5
Maple Creek		2			2
Ridge		2			2
Total	20	37	12	7	76

VII. C. 1 – Causes Related to Tension Cracks

Tension cracks were a dominate cause of land reported effects. There were 37 claims with tension cracks identified as the primary cause (Table VII-6). These features were associated with the formation of the subsidence basin (Section IV, V, and VI). Typically, the largest tension cracks were curvilinear and extended for hundreds of feet along the surface with an open fracture several feet in depth (Figure VII-2). In one case, the property owner reported hearing a loud boom and, upon inspection the next day, found a large crack in their front yard. When the tension cracks were smaller in scale, i.e. tens of feet, they might be associated with other causes such as mass wasting or settlement.

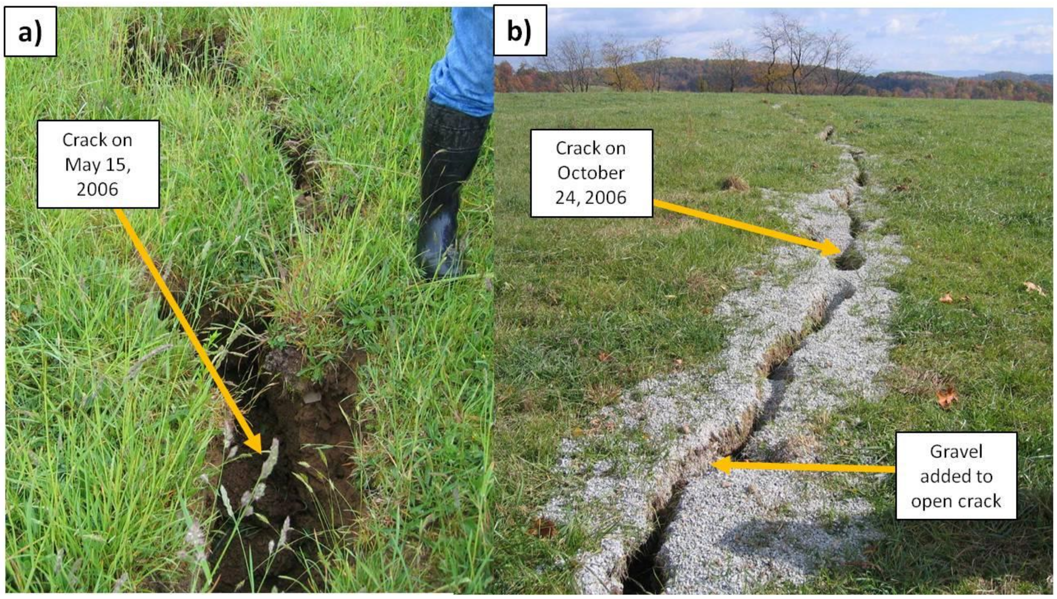


Figure VIII-2 – Photograph of large tension crack a) open shortly after the underlying longwall panel was mined, and b) partially repaired by filling with gravel and other aggregate products until the ground surface becomes level (Photographs from PA DEP files).

VII.C.2 – Causes Related to Mass Wasting

Mass wasting (20 reported cases) is the process whereby soil and rock move down slope under the force of gravity. There are many forms of mass wasting including: creep, landslides, flows, topples, and slumps. These forms produce slips, humps, and scarps in the ground surface. The speed at which the material moves ranges from a fraction of inches per day to feet per second. Seventeen of the 20 claims are deemed to be related to mass wasting.

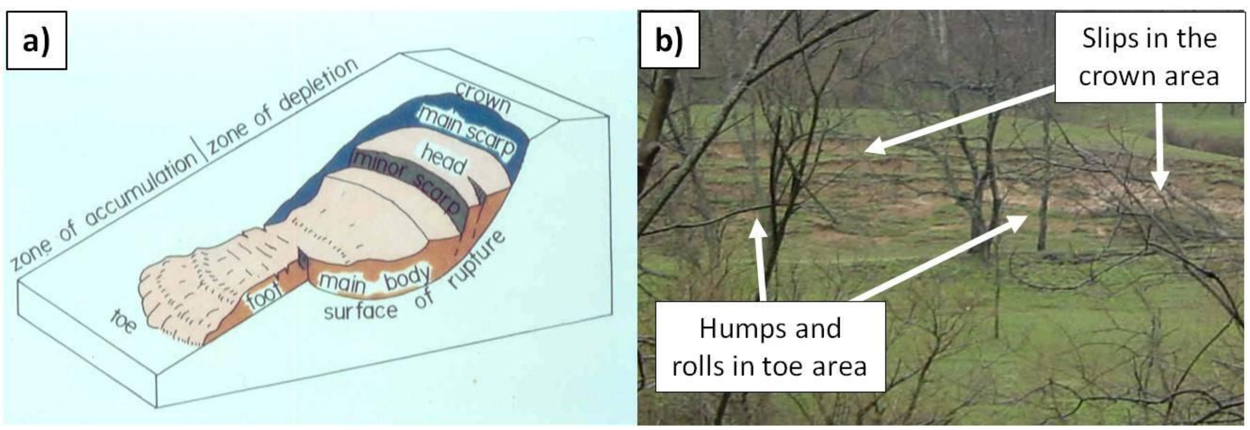


Figure VII-3 – a) General characteristics of mass wasting episodes taken from Varnes (1978) and b) large mass wasting event in Greene Co., PA (photograph from PA DEP files).

Western Pennsylvania is known to have significant problems with mass wasting (Davies, et al. 1978; and Hackman, et al, 1978). These problems are particularly acute in Greene and Washington Counties where steep slopes contain thick masses of slumped hummocky soil and rock from ancient remnants of mass wasting events. When a subsidence basin is formed above a longwall panel, these thick colluvial slopes can become unstable. Iannacchione and Ackman (1984) mapped several such features similar to the one shown in Figure VII-3b over the Gateway Mine. In that study, the two largest reactivated landslides occurred above a thin sandstone strata with several associated springs, and ranged from 100 to 300-ft in length and from 100 to 200-ft in width. The maximum scarp-slope displacements were approximately 7-ft. The University found a few examples of similar large mass wasting cases in the PA DEP files. The sizes of these mass wasting events could only be estimated from photographs.

Less dramatic mass wasting occurs when the colluvial soil layer is thinner. This type of mass wasting is associated with creep or flowing colluviums that produce rolling features with occasional slip surfaces (Figure VII-4). The Agent Observations found within BUMIS of mass wasting were mainly of this nature.

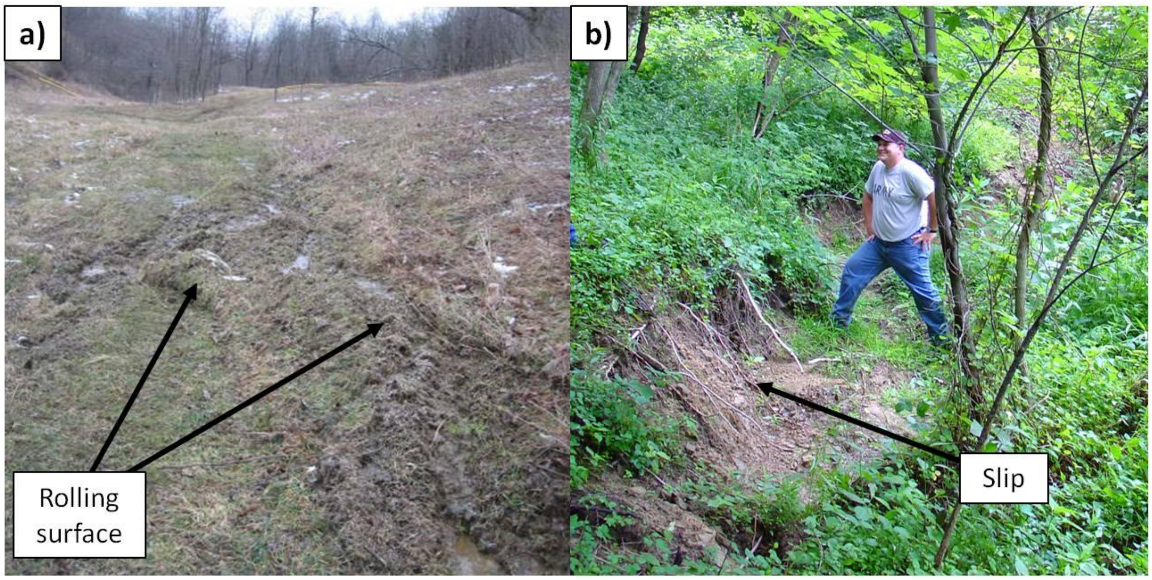


Figure VII-4 - Photographs of a) rolling surface and b) slip (Photographs from PA DEP files).

Determining the triggering mechanism for mass wasting is not always straight forward. Mass wasting can also be triggered by dynamic ground vibrations, increased water content, or undercutting of the slope by excavation or erosion.

VII.C.3 – Causes Related to Settlement

Twelve cases were classified as caused by settlement. When a subsidence basin is formed in relatively flat topography, settlement of the ground produced depressions that impact the normal use of the land. The maximum vertical subsidence over a Pittsburgh Coalbed longwall panel reached over 4-ft (see Section IV). This amount of surface elevation change can disrupt drainage patterns which can in-turn allow water to pond (Figure VII-5). Ponding of water in fields, pastures, and residential lawns impacts the intended use of this land.

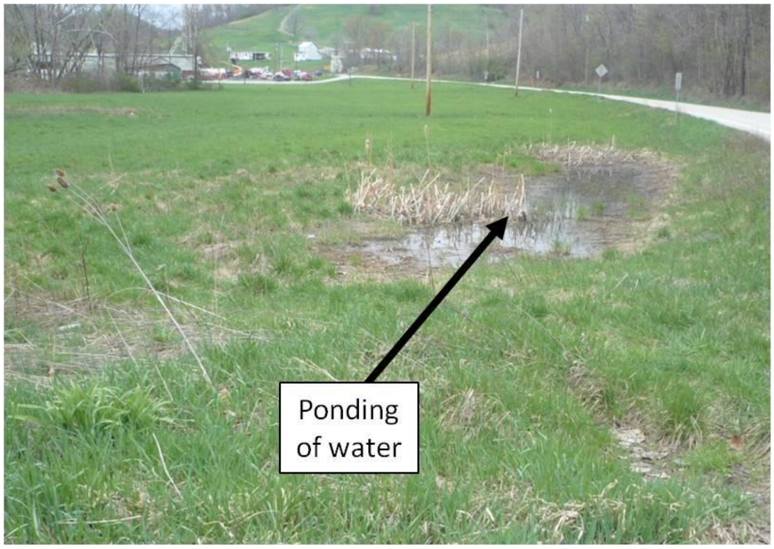


Figure VII-5 - Ground settlement over a longwall panel allowed water to pond in depression (Photograph courtesy of N. Iannacchione).

VII.C.4 – Causes related to Compression Rupture

Subsidence basins associated with longwall mining and room-and-pillar mining with pillar recovery produce significant horizontal compressive forces in ground surface (see Section IV). The subsidence event causes the surface to curve in a manner that compresses the strata, producing a buckling failure. These buckling failures often compress the ground surface into features described as bumps or humps. The impact of these compression features on highways and structures was discussed in Section IV and V. When these events occur in an open field or within a forested area, their impact often goes unnoticed for they might not affect property owners' land use requirements. However, in some circumstances the creation of a linear elevation increase of a few feet can disrupt drainage patterns or impair road surfaces. The University found that most significant impact of surface compression ruptures was the damage caused to a small percentage of the streams in Greene County.

VII.C.2.a – Source of Excessive Compression Forces

The Northern Appalachian Coal Basin has long been known to contain excessive amounts of horizontal stresses within both coal measure and limestone rock formations (Mark and Gadde, 2008). Detailed horizontal stress measurements have shown a regional stress field with an orientation of approximately N 70° to 80° E that is many times higher than the overburden stress (Table VII-8).

Table VII-8 – Stress and strain measurements within Pennsylvania coal and limestone mines (Iannacchione, et al, 2002).

Strata	**Max. Stress, psi**	**Max. Stress Orientation**	**Max. Horizontal Strain**	**Depth, ft**	**Estimated Vertical Stress, psi**	**Ratio Horizontal-to-Vertical Stress**
Kittanning Coalbed Site No.1	3,340	N 87° E	575	719	790	4.2
Kittanning Coalbed Site No.2	3,020	N 75° E	721	551	606	5.0
Pittsburgh Coalbed Site No.1	1,320	N 32° E	736	400	440	3.0
Pittsburgh Coalbed Site No.2	2,360	N 78° E	557	699	769	3.1
Pittsburgh Coalbed Site No.3	3,080	N 70° E	461	801	881	3.5
Loyalhanna Limestone	6,920	N 71° E	607	400	440	15.7

VII.C.2.b – Horizontal Stresses Concentrated in Stream Valleys

Molinda, et al. (1992) reported a close relationship between the valley bottom and unstable roof conditions at Mine 60. This mine is located adjacent to Mine Eighty-Four. The unstable conditions are often associated to compression ruptures occurring in the mine's roof rock. Mining professionals refer to this condition as cutter-roof failures (Figure VII-6). These compression ruptures buckle the strata, producing a very distinctive inverted "tee pee" shaped structure. Local mine operators reported that the most severe roof rock conditions occurred in north-south oriented entries (Molinda, et al., 1992), especially at low overburden (< 300-ft). Numerical modeling exercises indicated that steep-walled valleys concentrate more horizontal stress than broad-bottom valleys (Molinda, et al., 1992).

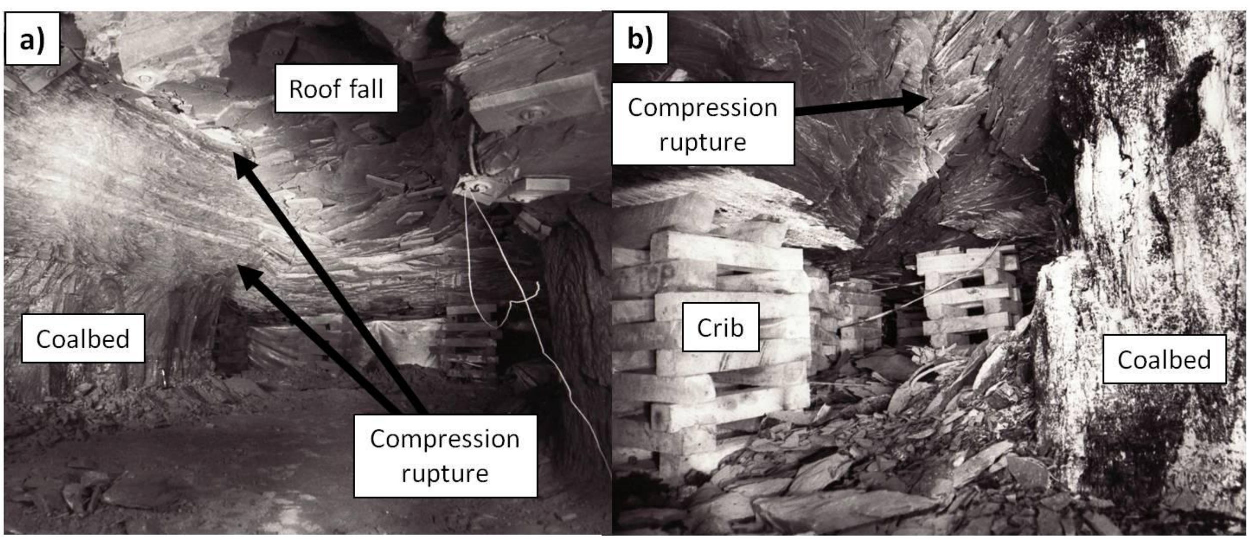


Figure VIII-6 - Photographs of compression ruptures a) along the side of a roof fall and b) close up within the roof-rib intersection area, Kitt Mine, northern West Virginia (photograph courtesy of A. Iannacchione).

VII.C.2.c – Expressions of Stream Bed Compression Ruptures

Compression ruptures, similar to those found in unstable roof rock conditions below north-south trending steep-sided stream valleys, can be found in several stream beds undermined by longwall mining. These compression ruptures buckle the strata, producing a distinctive "tee pee" shaped structure (Figure VII-7). These features are immediately subjected to the pull of gravity and to weathering, making them somewhat short-lived. When observed in the field, it is a relatively recent occurrence. Also, when stiff rocks like sandstone and siltstones rupture in response to compressive forces, the rupture surface propagates rapidly. Some residences have reported loud rumblings during the times when compression ruptures presumably occurred.

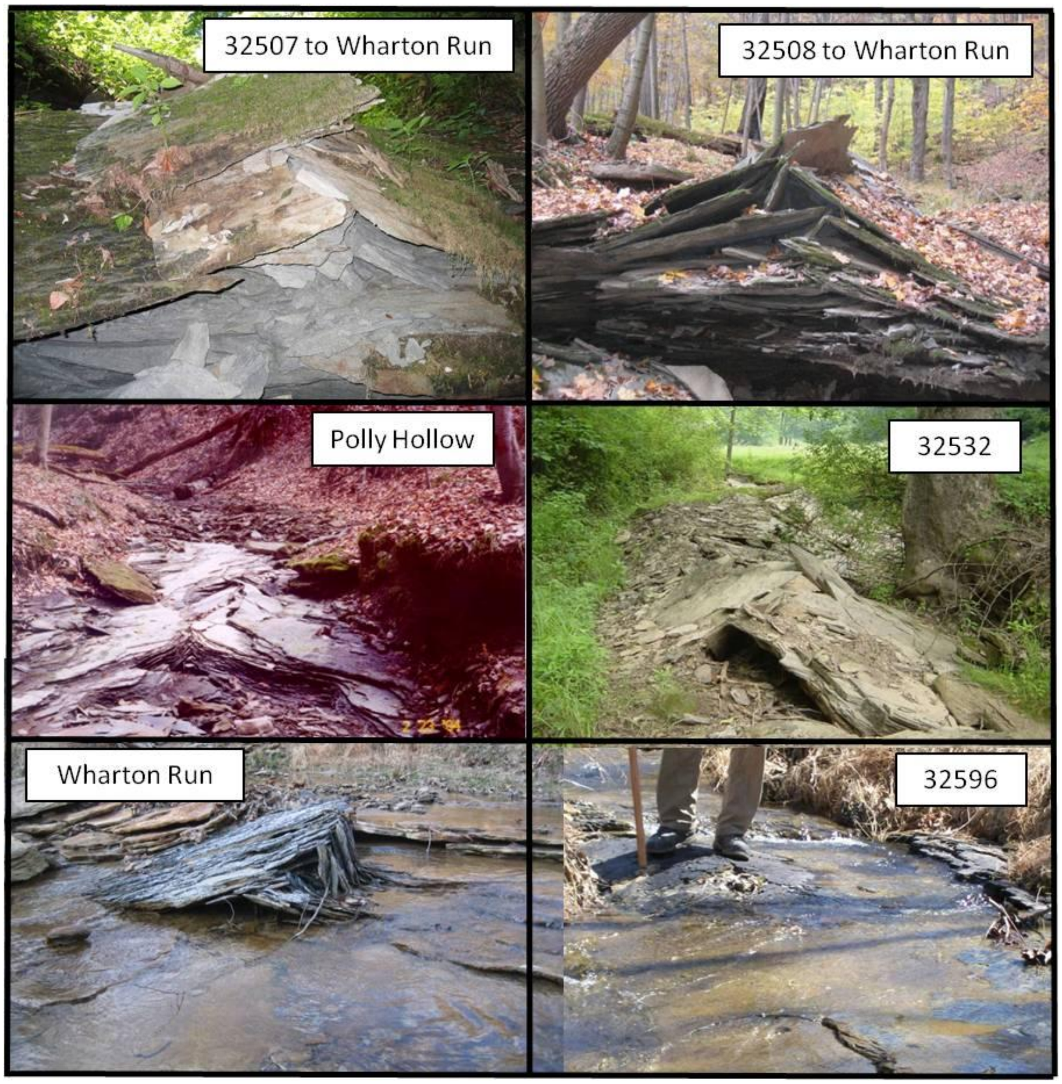


Figure VII-7 –Photographs of compression ruptures found in stream beds over the Bailey Mine (Photographs from PA DEP files).

When a compression rupture occurs, the stream flow can be diverted beneath the surface. For this to occur, the rupture must extend many feet into the stream bed and propagate the entire length of dry sections. The force needed to generate ruptures of the magnitude shown in Figure

VII-7 must be large. The University observed grout pumped into the rupture along stream No. 32596 (Figure VII-7). This grouting effectively filled the voids associated with the rupture surface and kept the water flowing across the top of the stream bed.

VII.C.2.d – Location of Stream Beds Impacted by Compression Ruptures

The compression ruptures shown in Figure VII-7 were located over the Bailey Mine (Figure VII-8). The majority of the segments were oriented in the Northeast direction. Molinda, et al. (1992) reported similar stream orientation for areas of increased roof instabilities in coal mines. The University believes that streams oriented in this direction have a higher likelihood for compression ruptures. Also note that most of the streams with compression ruptures were located within the Washington and Waynesburg Formations (Figure VII-8).

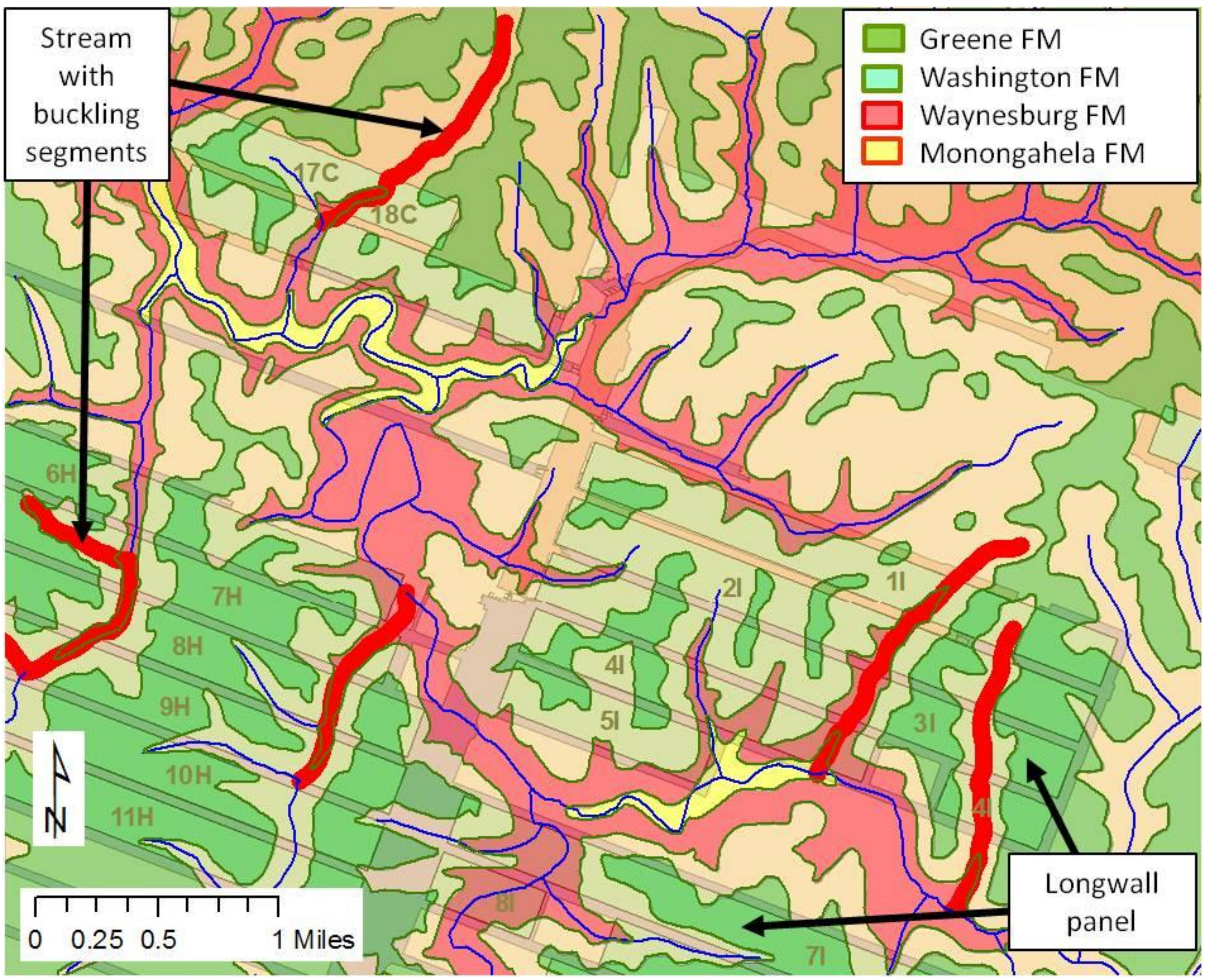


Figure VII-8 – Location of stream segments with compression rupture (thick red lines) above the Bailey Mine. Rock formations outcrop areas are also shown: Greene FM, Washington FM, Waynesburg FM, and Monongahela FM.

It should be noted that the Bailey Mine is not the only mine with reports of compression ridges. These features were also recognized by PA DEP agents along Bulldog Run over the Blacksville No.2 Mine, Dutch Run and Dyers Fork over the Cumberland Mine, and tributaries to Rocky Run and Templeton Fork over the Enlow Fork Mine (Appendix D). The orientation of these streams is predominately North-northwest:

- Bulldog Run is oriented North-northeast,
- Tributary 32721 to Rock Run is oriented North-northwest,
- Tributary 32740 to Templeton Fork is oriented North-northwest,
- Dutch Run over Panels 52 and 53 is oriented North-northwest, and
- Dyers Fork over Panels 52 and 53 is oriented Northwest.

The University believes that some stream valleys in PA's coal fields contain elevated levels of horizontal stresses and have the potential to cause compression ruptures within stream beds if undermined by a longwall panel. This potential is influenced by the magnitude and orientation of the stress field, the shape and orientation of the valley, and the physical properties of the strata.

VII.D – Examples from Mines

The University located examples of land reported effects where the outcome had been Company Liable or Interim Resolution. These examples provided an opportunity to examine the nature of the impacts in more detail and to assess the remediation efforts used to mitigate their impact.

VII.D.1 - Bailey Mine

The Bailey Mine had 13 land reported effects. The location of the six assigned as Company Liable or Interim Resolution are shown in Figure VII-9. The three properties having impacts caused by mass wasting were adjacent to one another. The two unknown causes were related to driveway impacts. The one property with tension cracks was located over a gate road.

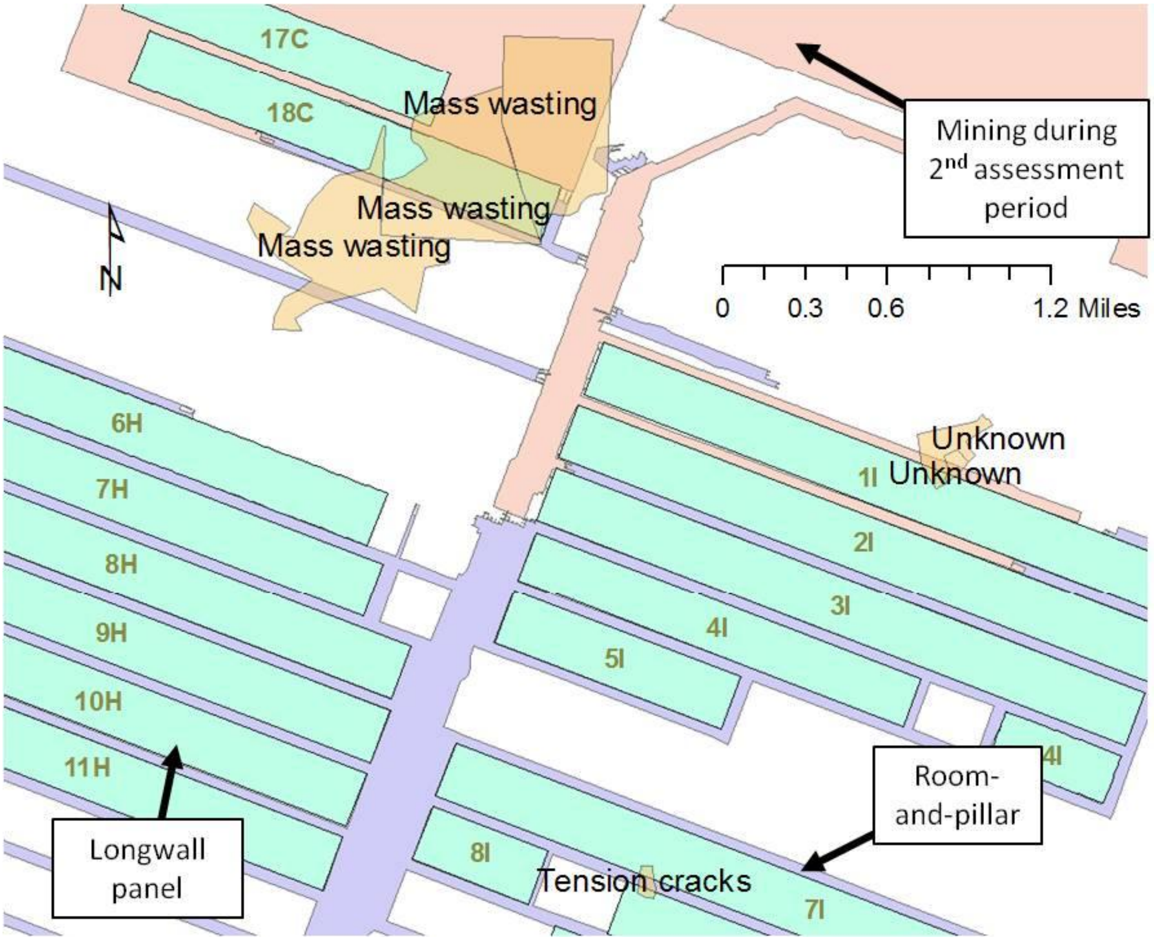


Figure VII-9 - Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the Bailey Mine. Note – property boundaries are in tan and the principle causes are highlighted.

VII.D.2 - Blacksville No.2 Mine

The Blacksville No.2 Mine had seven land reported effects. The location of the six assigned as Company Liable or Interim Resolution are shown in Figure VII-10. Three were caused by settlement and three from mass wasting. All three of the properties with settlement impacts were located over areas mined during the 2nd assessment period. Two of the three properties with mass wasting impacts were located, at least in part, over longwall panels mined during the 3rd assessment period.

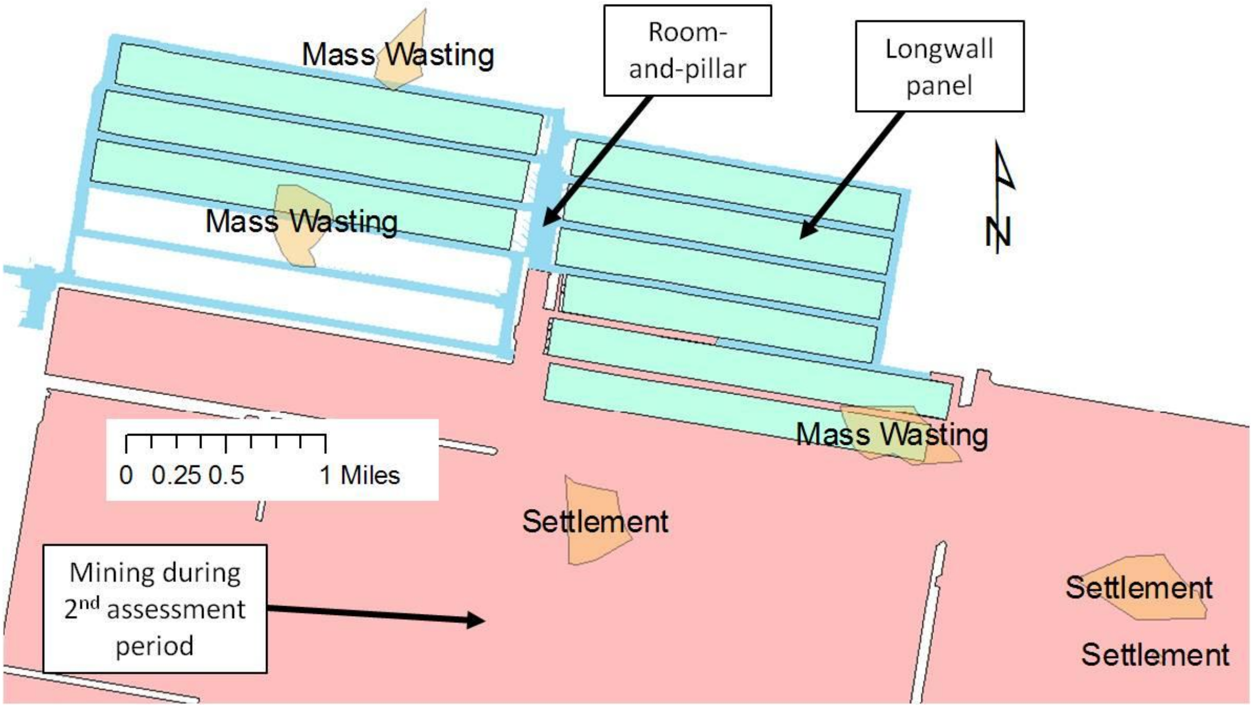


Figure VII-10 – Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the Blacksville No. 2 Mine. Note – property boundaries are in tan and the principle causes are highlighted.

When the settlement impact resulted in ponding within a field or pasture, the repairs often occurred in the following manner:

- The extent of abnormal standing water was established (Figure VII-11a),
- A ditch was established to improve drainage (Figure VII-11b),
- The settled area was re-graded (Figure VII-11c), and
- The site was re-vegetated (Figure VII-11d).

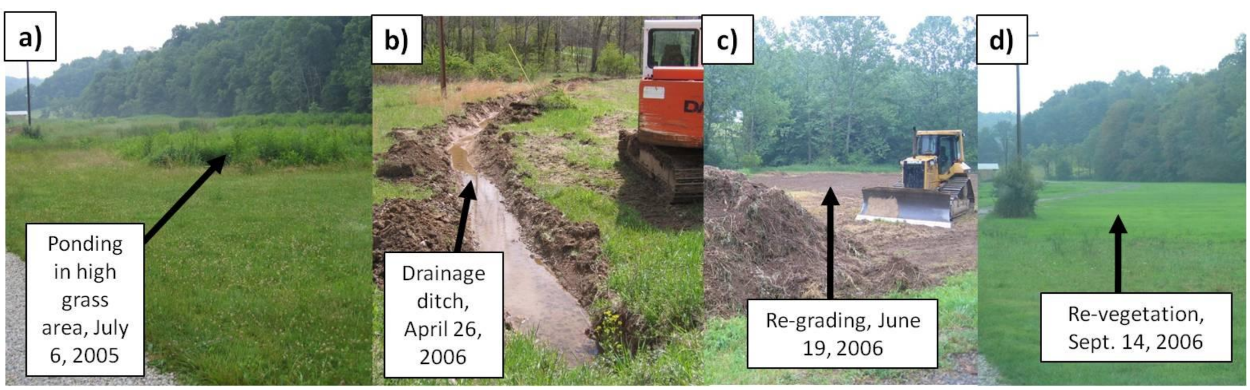


Figure VII-11 – Photographs of a commonly used method to repair settlement impacts after ponding resulted within a field or pasture (Photographs from PA DEP files).

If the settlement impact was adjacent to a stream, the repairs follow a slightly different sequence:

- The extent of abnormal standing water was established,
- The bank of stream was built-up to prevent the stream from flooding the adjacent field or pasture (Figure VII-12a),
- The settled area was re-graded (Figure VII-12b), and
- The site was re-vegetated (Figure VII-12c).

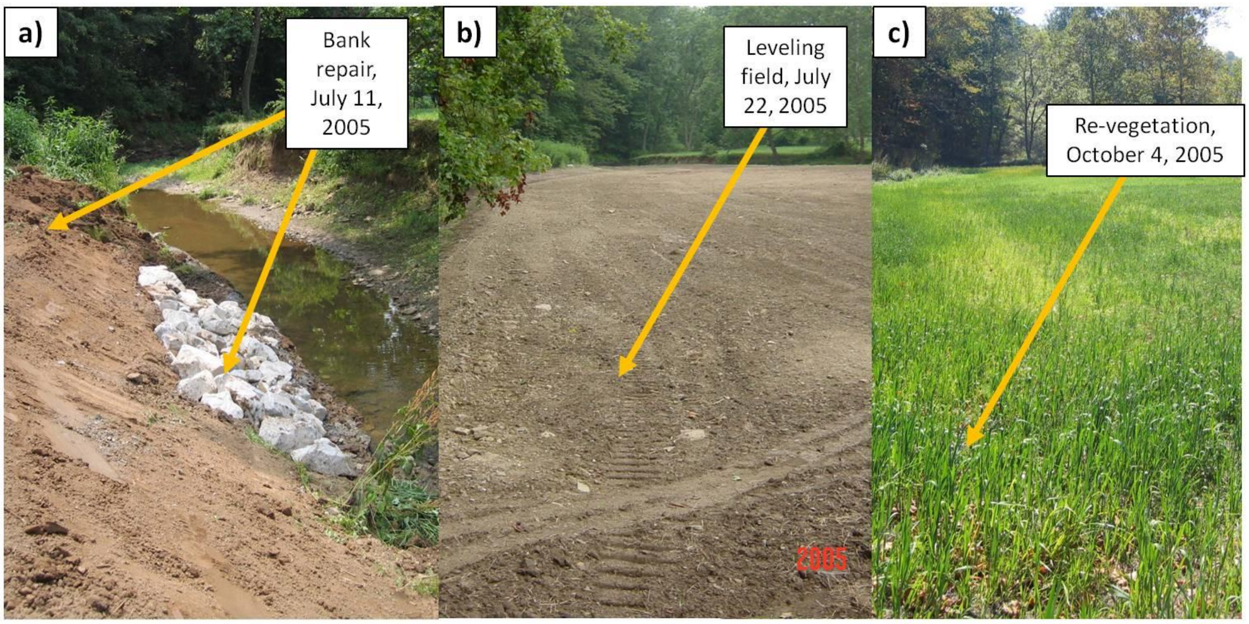


Figure VII-12 – Photographs of a common repair technique for settlement impacts adjacent to streams that caused ponding within a field or pasture (Photographs from PA DEP files).

VII.D.3 - Cumberland Mine

The Cumberland Mine had 21 land reported effects. The location of the 15 assigned as Company Liable or Interim Resolution are shown in Figure VII-13. The 14 properties, having impacts caused by tension cracks, settlement or mass wasting, were all over longwall panels or gate road entries. The one unknown reported effect occurred late in the 3rd assessment period and a cause has not been established.

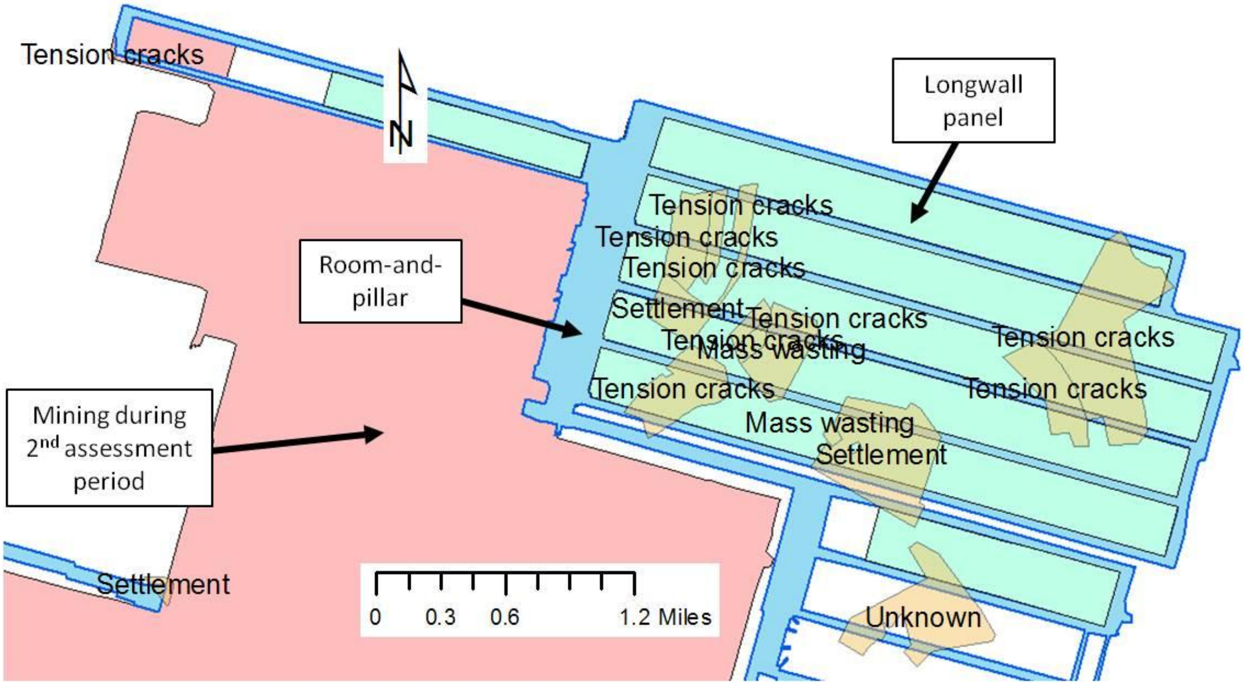


Figure VII-13 – Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the Cumberland Mine. Note – property boundaries are in tan and the principle causes are highlighted.

Examples of a tension crack and a mass wasting impacts are shown in Figure VII-14. Tension cracks like the one shown in Figure VII-14a can present a hazard for people and animals traveling over them. Determining the cause of mass wasting impacts requires professional judgment. Figure VII-14b shows a mass wasting impact over the Cumberland Mine that was not classified as a reported effect.

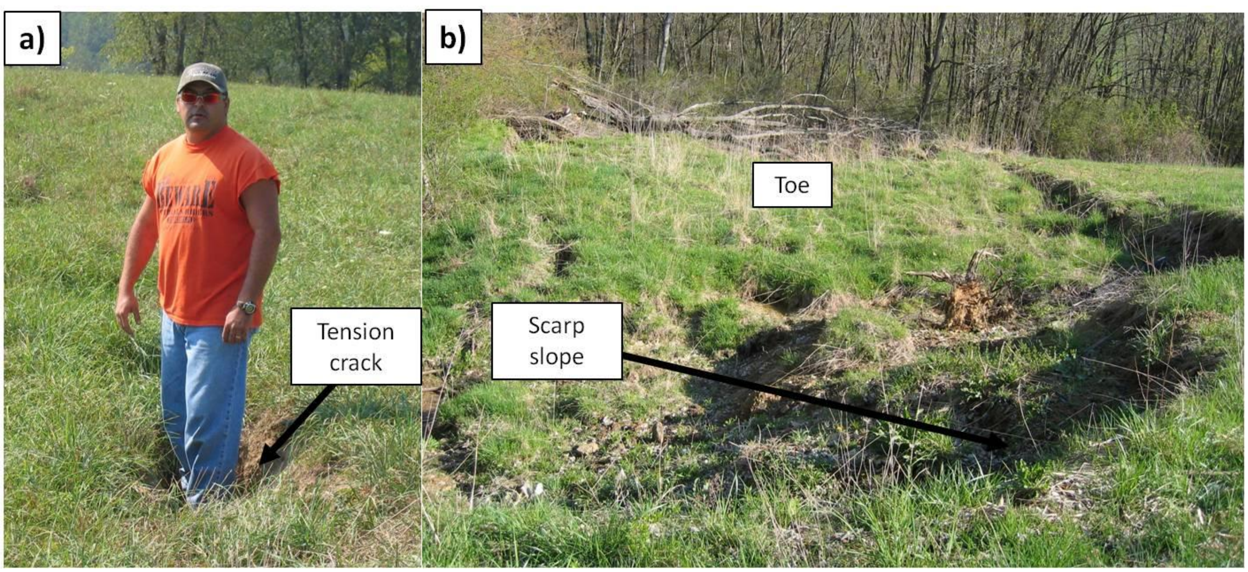


Figure VII-14 - Photographs of a) tension crack and b) mass wasting impacts to the surface. The first is a reported effect and the second is not (Photograph from PA DEP files).

VII.D.4 – Mine Eighty-Four

The Mine Eighty-Four had 16 land reported effects. The location of 12 of the 13 assigned as Company Liable, Interim Resolution or, No Resolution are shown in Figure VII-15. One of these properties is far to the north, located over areas mined during the 2nd assessment period. Twelve of the properties were located over longwall panels and gate road entries mined during the 3rd assessment period.

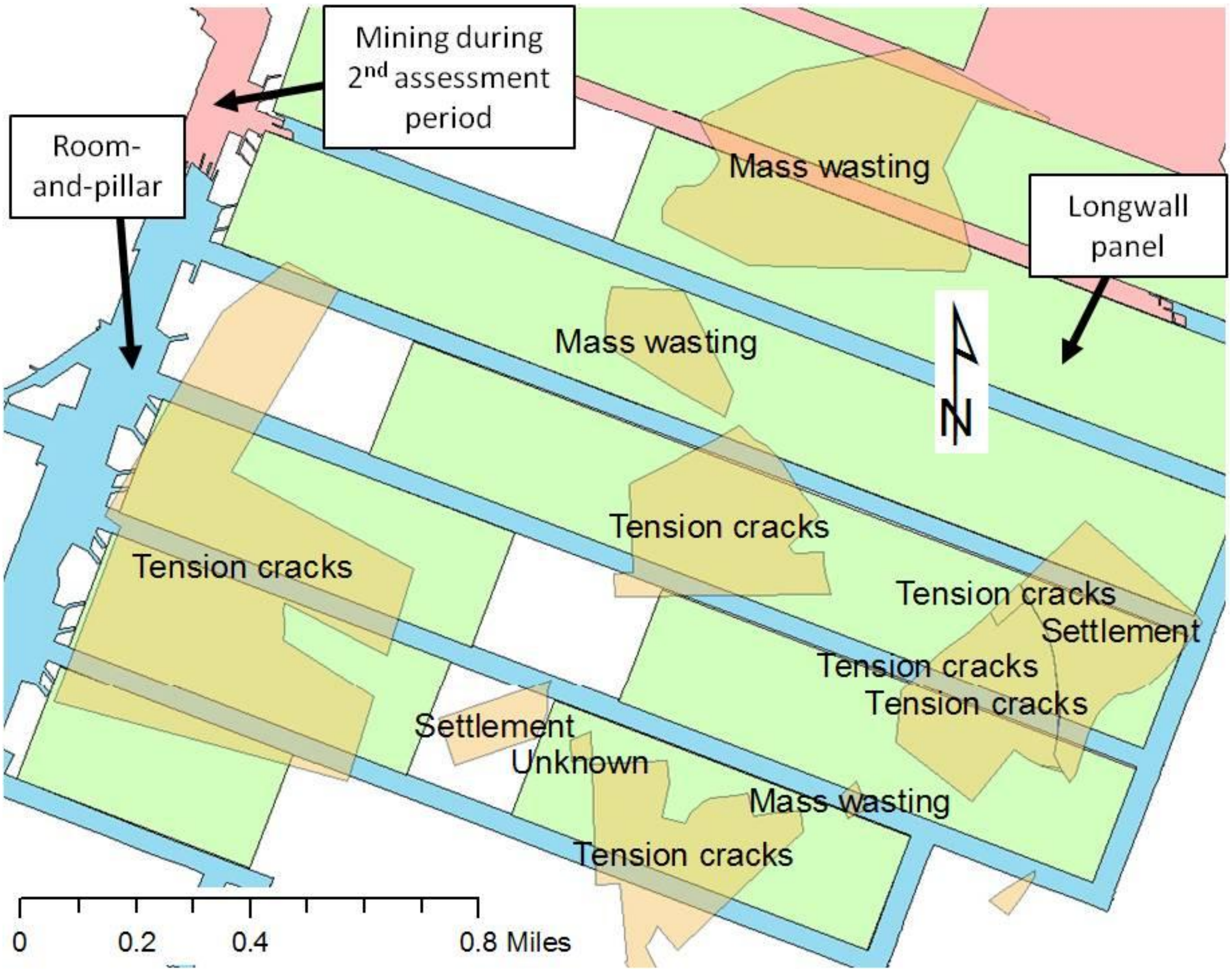


Figure VII-15 - Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at Mine Eighty-Four. Note – property boundaries are in tan and the principle causes are highlighted.

VII.D.5 – Emerald Mine

The Emerald Mine had 15 land reported effects. The location of seven of the properties assigned as Company Liable or Interim Resolution at the end of the 3rd assessment period are shown in Figure VII-16. Two other properties could not be located. It is possible that they were located over areas mined during the 2nd assessment period.

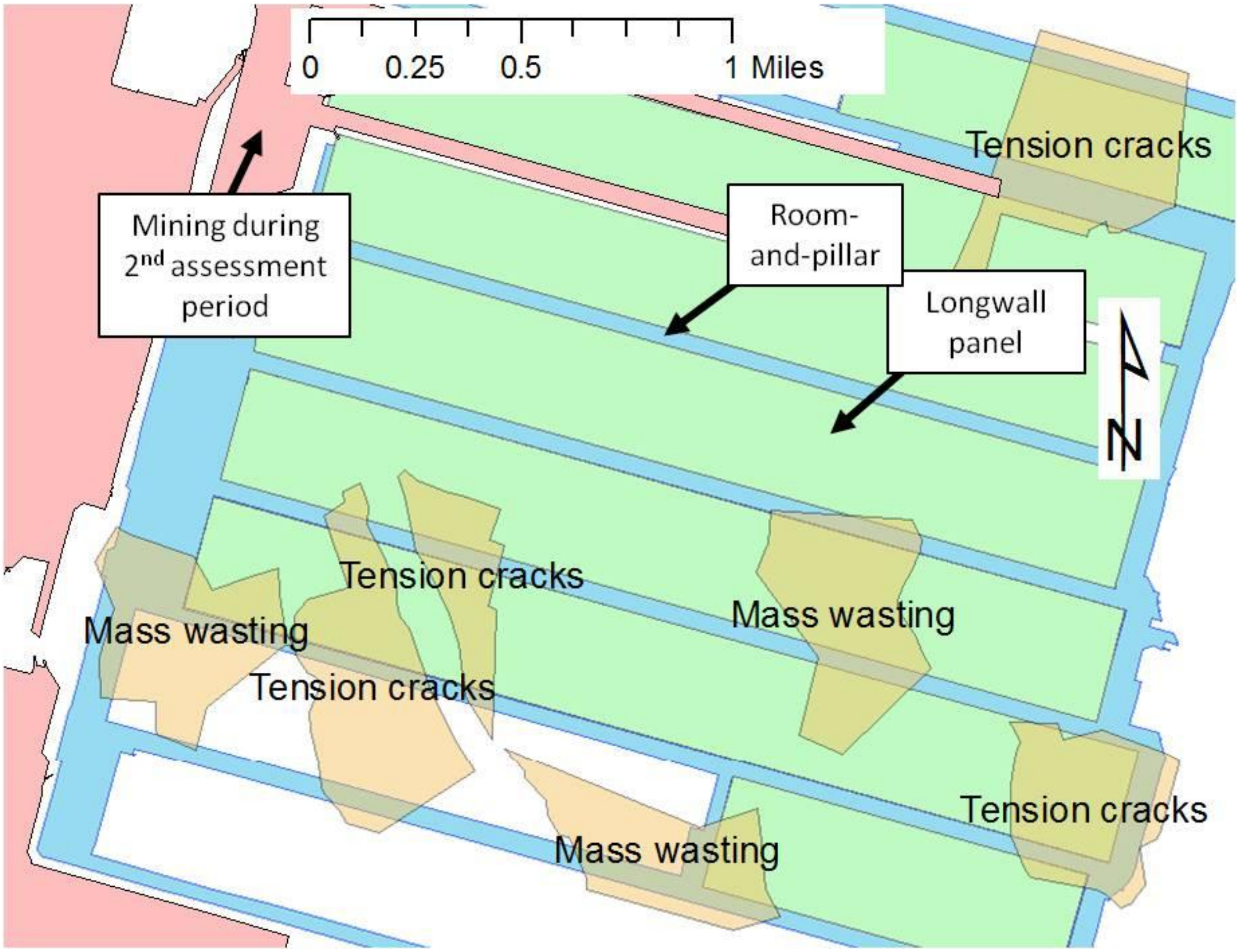


Figure VII-16 - Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the Emerald Mine. Note – property boundaries are in tan and the principle causes are highlighted.

VII.D.6 - Enlow Fork Mine

The Enlow Fork Mine had 18 total reported effect, three occurring during the 2nd assessment period. The location of the 17 assigned as Company Liable or Interim Resolution are shown in Figure VII-17. There were ten properties with tension cracks as the main cause, five with mass wasting, and two with settlement. Only one of the properties was not over an area mined during the 3rd assessment period.

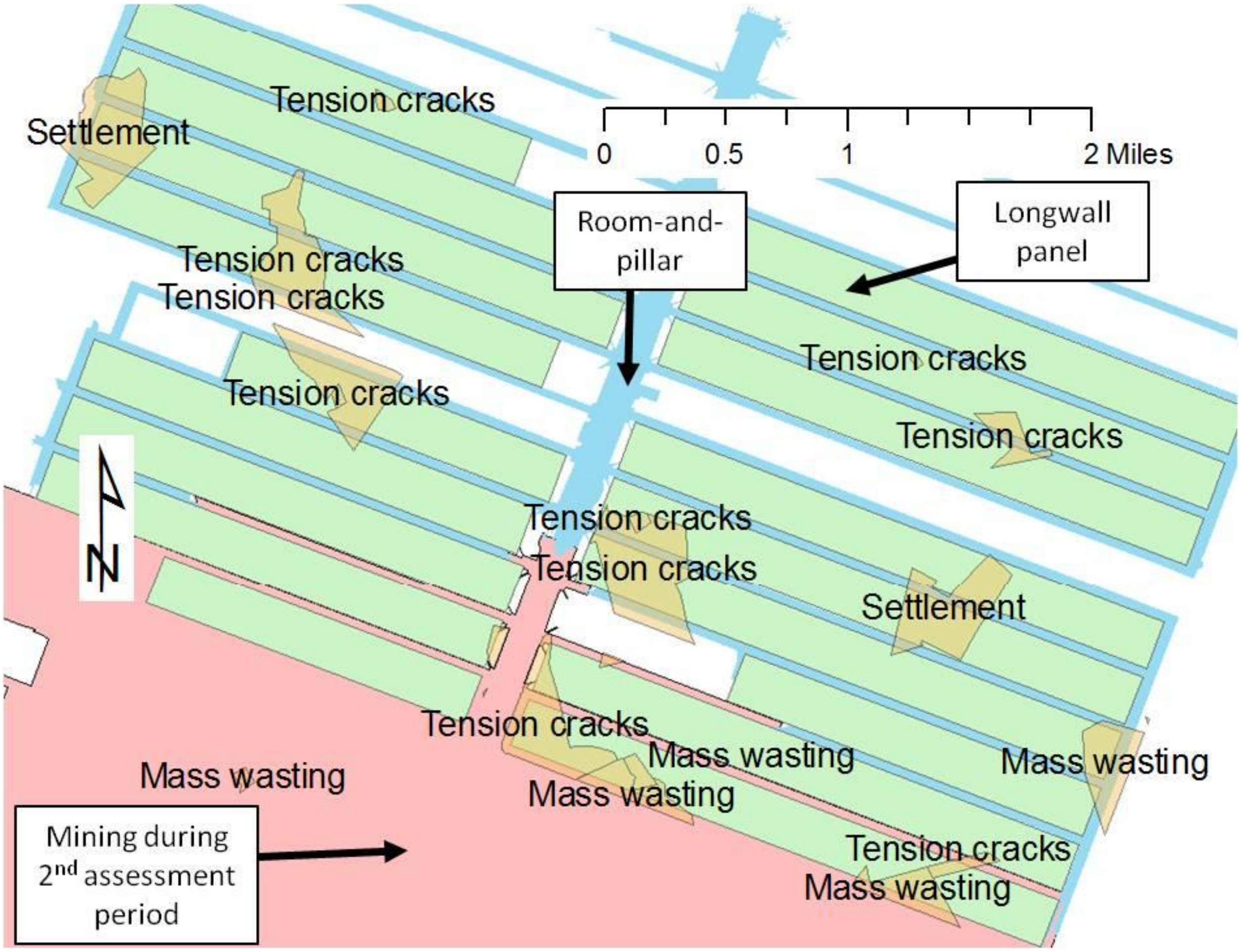


Figure VII-17 - Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the Enlow Fork Mine. Note – property boundaries are in tan and the principle causes are highlighted.

VII.D.7 - High Quality Mine

The High Quality Mine had eight land reported effects. The location of the five assigned as Company Liable or Interim Resolution are shown in Figure VII-18. There were three properties with tension cracks as the main cause, one with settlement, and one unknown.

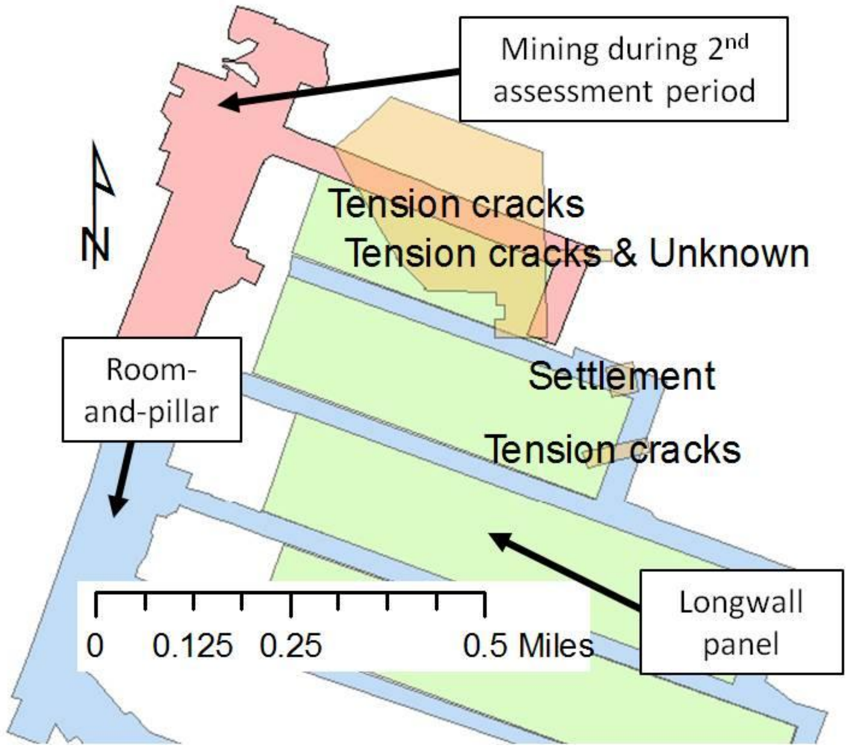


Figure VII-18 - Location of properties with land reported effects where Company Liable or Interim Resolution was the outcome at the High Quality Mine. Note – property boundaries are in tan and the principle causes are highlighted.

VII.D.8 – Ridge Mine

The Ridge Mine had two land reported effects and both were Company Liable (Figure VII-19a). Both property descriptions involved cracks in the ground surface. BUMIS listed pillar failure as the source of the impact, but the pillar layout does not change over the mine (Figure VII-19b) and the overburden above the room-and-pillar areas of the two properties was shallow (< 185-ft, Table II-16). The ARMPS program was used to examine the stability factor for this design. Using the 6-ft extraction height that is common for the Pittsburgh coalbed, 32 by 32-ft pillars, 16-ft entry widths, and an overburden of 150-ft, a stability factor of approximately <u>six</u> was calculated (Figure VII-19c). With a stability factor this large, it is highly unlikely that pillar failure was the cause of these reported effects. An alternative cause might be associated with roof falls that occurred in different parts of the mine where the overburden ranges from 100 to 200-ft. These roof falls were found on 6-month mining maps. It is possible that the surface could develop tension cracks above large roof fall areas underground, when overburden is low.

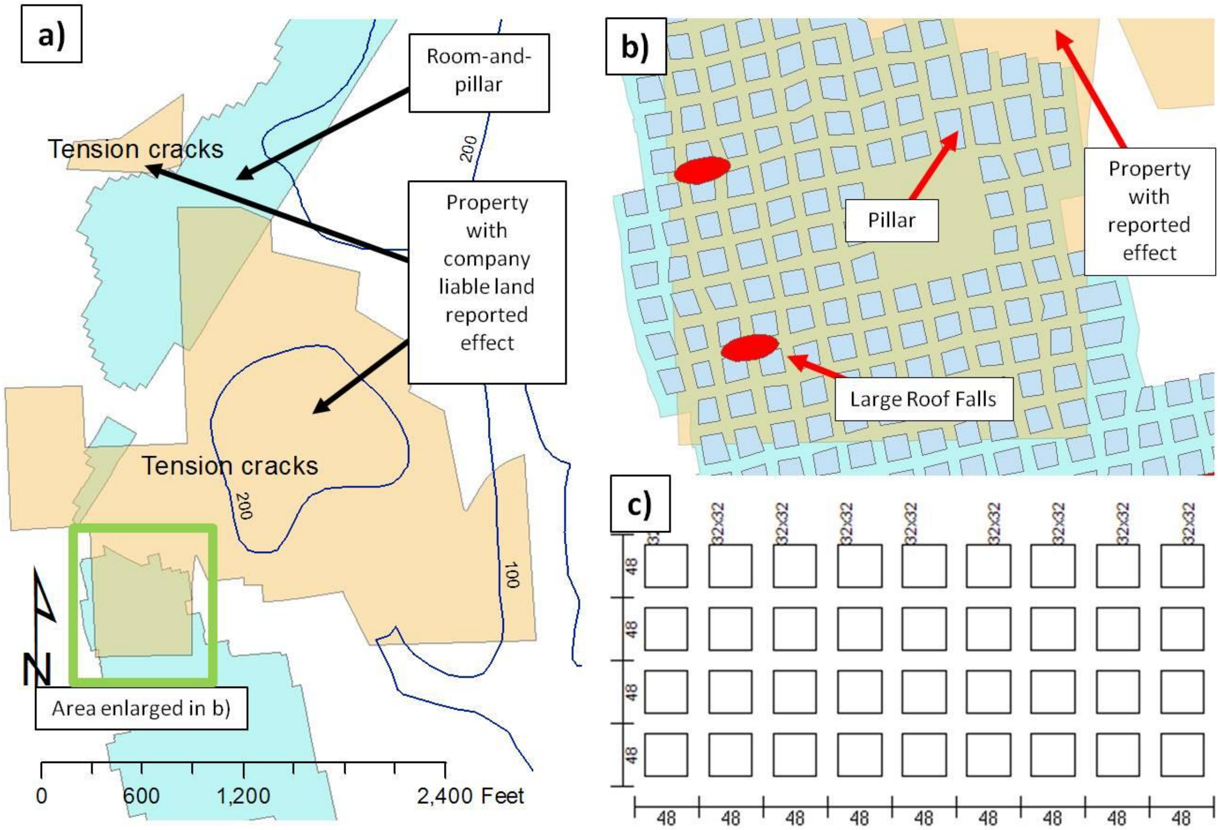


Figure VII-19 - Location of a) properties with land reported effects where the Ridge Mine is liable, b) pillar layout beneath the property where tension cracks were observed and roof falls noted on the 6-month mining maps, and c) ARMPS pillar layout characteristics.

The tension cracks associated with these land reported effects were smaller in length and narrower in width then some of the tension cracks discussed for longwall mines (Figure VII-20a). For both reported effects, the tensions cracks were filled to produce a level surface (Figure VII-20b).

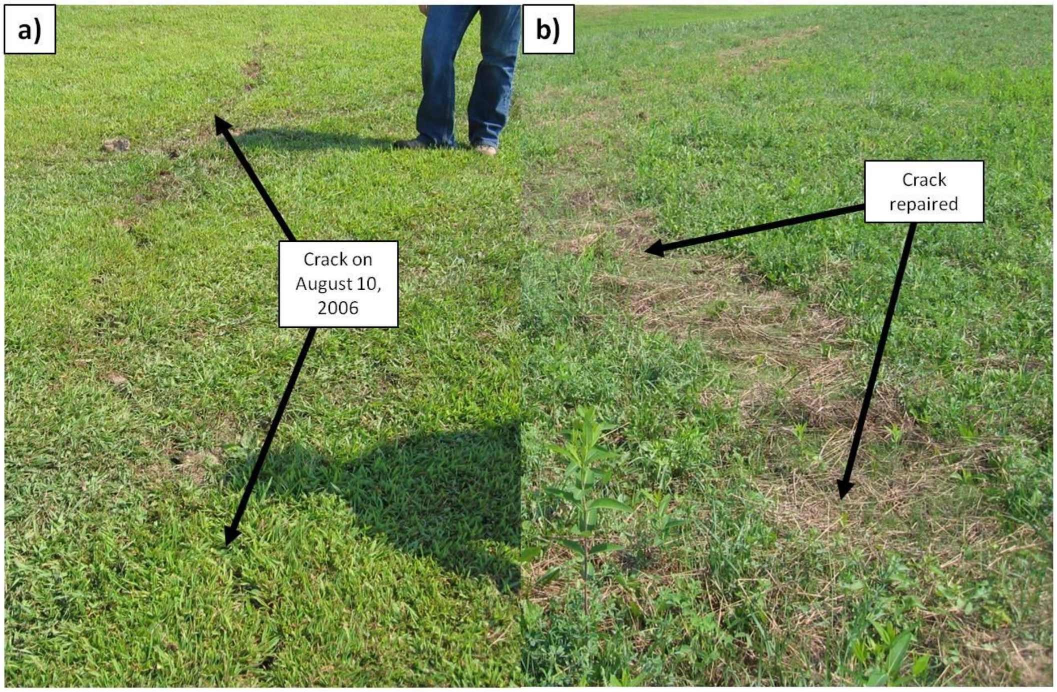


Figure VII-20 - Photographs of a) crack on August 10, 2006 and b) repair of a previous crack at the Ridge Mine (Photographs from PA DEP files).

VII.E – Summary Points

The University found 108 land reported effects during the 3rd assessment period and five from the 2nd assessment period.

VII.E.1 - Mine Type

The 108 land reported effects were distributed over 13 active and closed mines during the 3rd assessment period. Nine longwall mines accounted for 95.3-pct of the total while four room-and-pillar mines provided the remaining 4.7-pct. Properties over longwall mines had land reported effects at a rate of 6.3-pct. Room-and-pillar mines, with and without pillar recovery, had close to zero (0.02) land reported effects. Eleven of the reported effects came from mines that did not operate during the 3rd assessment period. They were Maple Creek (8), Dilworth (1), Humphrey No.7 (1), and Tanoma (1). Five additional reported effects occurred at active mines that were not resolved at the end of the 2nd assessment period.

The University collected information related to the date of occurrence, interim resolution, and final resolution for every land reported effect. Of the 113 land reported effects:

- 87 had final resolutions, taking an average of 206 days to reach a final resolution,
  - 57-pct, or 50, were assigned as Company Liable,
  - 43-pct, or 37, were assigned as Company Not Liable,
- 21 did not have a final resolution as of August 20, 2008,
  - 18 had an interim resolution,
  - 3 had an outstanding reported effect with no interim resolution, and

- 1 is from the 2nd assessment period with an interim resolution at 1,999 days and no final resolution at the end of the 3rd assessment period.

For the 50 Company Liable land reported effects, resolutions consisted of:
- 26, or 52-pct, property repaired,
- 12, or 24-pct, pre- and post-mining agreements,
- 7, or 14-pct, property owner compensated,
- 5, or 10-pct, property purchased by the company.

For 37 Company Not Liable land reported effects, resolutions consisted of:
- 31, or 83.8-pct, Not Due to Underground Mining,
- 2, or 5.4-pct, Not Covered by BMSLSA,
- 2, or 5.4-pct, No Liability,
- 1, or 2.7-pct, Withdrawn, and
- 1, or 2.7-pct, No Actual Reported Effect.

VII.E.2 - Causes

The University identified 76 land reported effects that were classified into five categories: *mass wasting, tension cracks, settlements, compression ruptures, and unknown*. These 76 cases were identified where land reported effects had resolutions with the Company Liable or with an Interim / Outstanding condition at the end of the 3rd assessment period.
- 37, or 48.7-pct, cases with tension cracks varying in scale and impact,
- 20, or 26.3-pct, cases with mass wasting ranging from large landslides hundreds of feet across (estimated from PA DEP photographs) to small mass soil movements that produced hump, rolls, and slips in the surface,
- 12, or 1.58–pct, settlement cases often disrupting drainage patterns resulting in ponding of water in fields, pastures, and residential lawns.
- 7, or 9.2–pct, cases of unknown cause.

Compression ruptures were found in steep-sided valley stream bottoms over the Bailey, Blacksville No.2, Cumberland, and Enlow Fork Mines that trend in a Northwest to Northeast direction. These compression rupture features were caused by significant levels of horizontal stresses found in Pennsylvania's near-surface strata that can be locally influenced by the shape and orientation of the stream valley and the physical properties of the bed rock strata. When compression ruptures occur, they can have an adverse impact on land in general and streams in particular.

VII.E.3 - Examples from Mines

The University presents specific examples of land reported effects and summarized some repair methods to mitigate their impact. Seven longwall mines and one room-and-pillar mine were examined. The examples from the longwall mines focused on the location and remediation of tension cracks, mass wasting, and settlement impacts. The example from the room-and-pillar mine focused on the potential cause for this un-planned event.

SECTION VIII: Effects of Mining on Streams

VIII.A – Overview

The PA DEP tasked the University with assessing the impacts of underground bituminous coal mining on the flow and biological health of streams that overlay the active mines during the 3rd assessment period. The impacts of underground bituminous coal mining on streams can arise either from contamination or from subsidence. During the 3rd assessment period they occurred almost exclusively from subsidence. Subsidence can occur with any kind of underground bituminous coal mining, but is an expected outcome with longwall mining. The few examples of subsidence associated with room-and-pillar mining were documented in Sections V.E and VII.D.8 and were found to rarely lead to stream flow problems.

The predominance of longwall mining and the low prevalence of subsidence-associated flow problems with room-and-pillar mining together resulted in nearly all stream flow reports being associated with longwall mining during the 3rd reporting period. The typical subsidence basin has its greatest depth toward the center of the mined panel, rising to the historical surface height at the edges of the panel. For streams, this can create five kinds of problems:

- First, stream water pools in the lowest part of the subsidence basin, flooding previously dry land.
- Second, the unmined areas between panels are now higher than grade and act as dams, preventing stream flow across them. As the subsidence basin is formed, considerable deformation stress is placed on the underlying rock layers as they bend to conform to the shape of the subsidence basin. Some rock layers lack sufficient plasticity and fracture at points of greatest stress.
- The third kind of stream problem results from the compression ruptures discussed in Section VII.C.4. Stresses are concentrated in the valley bottoms causing the rock layers forming the base of the streams to rupture. These compression ruptures can block water flow and, in some cases, the flow can propagate to the base of the fracture zone many feet below the surface.
- The fourth kind of problem results from tension cracks (similar to those shown in Section IV.E and VII.C.1), either through the direct loss of surface flow into deeper layers of rock through the fissures, or through loss of the groundwater that feeds the surface flow.
- The fifth has to do with variation of flow altering the biological properties of the streams, changing sediment load, oxygen content and habitat availability and quality. This can result in non-attainment of the designated use, either through direct stresses on the fish species, or by altering food and habitat availability.

In general, these five causes of stream impacts are referred to in the PA DEP reports as incidents of pooling or flow loss, regardless of the precise cause.

If the PA DEP determines that stream flow has been diminished as a result of undermining, the mining company is required to restore flow to its pre-mining condition. Initially, mining companies may augment flow with water pumped from wells or trucked in from remote sources (Figure VIII-1). This is a temporary solution.

Figure VIII-1 - An augmentation line supplying temporary flow to stream 32508 over Bailey Mine (Photograph from PA DEP files).

For more permanent and long-term solutions, the PA DEP requires that the mining company submit a mitigation plan for approval. At the end of this assessment period, it was noted that mining companies were now required to submit these mitigation plans along with their mining permit applications so that work can proceed as quickly as possible in cases where impacts occur. Using simulations and modeling, mining companies predict which streams have a chance to be impacted by underground mining and can thus design detailed mitigation plans prior to subsidence. This may facilitate a faster resolution time for stream impacts. Appendix E2 provides examples of stream mitigation efforts and associated flow observations made by the University on these same streams.

The change in vertical subsidence as discussed in Section IV.D.2 often causes both pooling in the low areas over the longwall panel and loss of flow in the high areas over the gate roads. In such cases, mitigation involves cutting a new channel in the high areas between subsided panels (often referred to a gate cutting), along with stream bank restoration in the channeled areas. This often restores normal flow. Cutting new channels is also often effective when compression ruptures block normal stream flow.

Tension fractures or cracks can result in loss of flow because the surface water retreated to subsurface aquifers through the newly created fractures. When sufficient clay overlays the fractured bedrock, the clay often works down into the fracture and the water loss self-seals. When the fractures do not self-seal, the mining company must resort to grouting. Grouting involves drilling boreholes in the fractured rock layer and injecting one of a number of substances, typically clay, cement-based mixtures, epoxies or urethanes (Figure VIII-2) into the holes. In rare instances, when repeated grouting does not seal the fractures, the substrate may be temporarily removed and an impermeable membrane, referred to as a liner, is constructed over the stream channel. The substrate material is then re-deposited into the stream bed and the stream bank vegetation is restored.

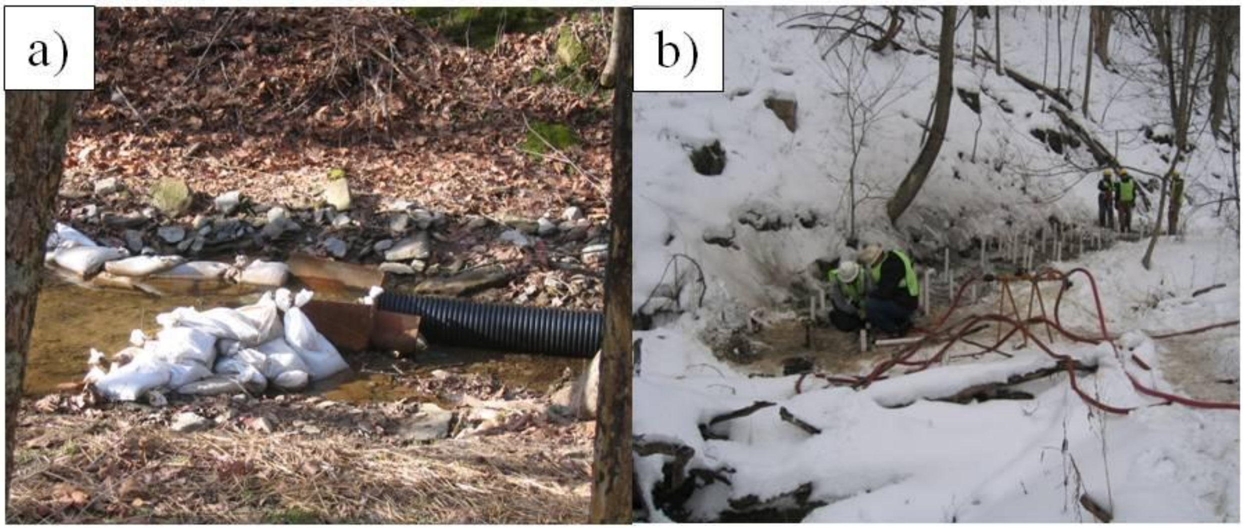


Figure VIII-2 - *Grouting operation procedures. First, a) stream flow must be collected and diverted around the area where grouting will occur - shown at stream 32532 in Bailey Mine and then b) boreholes are drilled and clay pumped into fractures - shown at stream 32740 in Enlow Fork Mine (Photographs from PA DEP files).*

While restoring flow to pre-mining conditions is often sufficient to regain the biological health of a stream, additional measures may be taken to ensure sufficient re-colonization of the stream by aquatic taxa. Mining companies may create various habitats within the stream channel by using log vanes, j-hooks, root wads, and other methods to promote the re-establishment of macroinvertebrate and fish populations. These artificial habitats provide the aquatic taxa with breeding grounds and places to hide from predators, which are necessary for sufficient recovery of the aquatic community as a whole. When mitigation techniques are successful, a period of monitoring follows. If the monitoring indicates the stream is within the 88-percentile of the pre-mining or control stream TBS, the PA DEP designates the problem as resolved.

The goals of the University were to:

1. Determine the total length of undermined streams, categorized by mining method and mine.
2. Report on the resolution status at the end of the 3rd assessment period for all PA DEP stream investigations associated with underground bituminous coal mining.
3. Report the number of stream investigations per mile of undermined stream, by mining method and mine, and categorized by their resolution status (Withdrawn, Resolved, or Unresolved) at the end of the 3rd assessment period.
4. Conduct independent stream surveys of flow and biological health for a subsample of the undermined streams, to determine the extent to which reported flow problems had

resulted in decreased biological health and the extent to which stream biological health had recovered following mitigation.

VIII.B – Data Collection

VIII.B.1 – Definition of 'Stream' and Identification of Individual Streams

Under PA Code, Title 25, Environmental Protection, Chapter 93, Water Quality Standards, a lotic ecosystem (i.e. flowing body of water) must meet specific criteria to be designated a stream. A stream must support at least two recognizable taxonomic groups in the macroinvertebrate community. These taxa must be sufficiently large to be seen without the aid of a microscope and they must spend a "living part of their life cycle" in an aquatic habitat. Other lotic bodies that do not meet these requirements are not streams and therefore do not fall under the scope of this report.

Furthermore, the PA DEP, working with the U.S. Geological Survey (USGS), created a Water Resources Data System (WRDS) for PA streams. Each named stream has a 5-digit numeric identification code referred to as a WRDS number. The PA Gazetteer of Streams (PADER, 1989) provides a complete list of these numbers. They are also available in USGS digital watershed coverage (Hoffman & Kernan, 1996). All streams with WRDS numbers that overlay the regions undermined (see below) were included in the inventory.

VIII.B.2 – Definition of Designated Stream Use

The PA DEP has assigned designated uses to streams, based on use designations defined in the PA Code section 93.3 (http://www.pacode.com/secure/data/025/chapter93/s93.3.html), indicating the type of fishery supported by the stream: Trout Stocked, Warm Water, High Quality (HQ) Trout Stocked, HQ Warm Water, and HQ Cold Water, and Exceptional Value. The designated uses of all undermined streams were recorded in UGISdb.

VIII.B.3 – Compilation of Undermined Stream Inventory

An inventory of the undermined streams was requested by the PA DEP, classified by mining method and mine name (Table VIII-1). This was accomplished by cross-referencing data in BUMIS with the 6-month mining maps. The 200-ft buffer was extended from the edge of the areas mined and all streams within these mined areas and buffers were inventoried. This information was joined to UGISdb (Section II) and details related to topographic characteristics and other relevant information were added. The identities of undermined streams were compiled, their undermined lengths were determined, and an inventory was created using Excel spreadsheets, by mine, mining method, and designated use.

Table VIII-1 – Lengths of Undermined Streams by Mine and Mining Method.

Mine Name	Mining Method						Total
	Room-and-Pillar		Longwall		Pillar Recovery		
	Length, mi	# of Segments*	Length, mi	# of Segments	Length, mi	# of Segments	
4 West	1.8	5					1.8
Agustus	0.5	1					0.5
Bailey	5.8	38	11.4	28			17.2
Blacksville No.2	2.7	20	7.5	18			10.2
Cherry Tree	0.2	3					0.2
Clementine No.1	3.8	13					3.8
Crawdad No.1	0.5	2					0.5
Cumberland	4.9	38	11	24			15.9
Darmac No.2	0.4	5					0.4
Dora No.8	0.9	5					0.9
Dutch Run	1.3	12					1.3
Eighty-Four	1.5	10	5.2	16			6.7
Emerald	3.3	27	8.4	23			11.7
Enlow Fork	5.5	39	19.9	43			25.4
Genesis No.17	0.4	2					0.4
Gillhouser Run	0.2	2					0.2
High Quality	0.2	3	0.4	2			0.6
Keystone East	1.3	4					1.3
Little Toby	0.6	3					0.6
Logansport	1.8	8					1.8
Madison	0.6	2					0.6
Miller	0.1	2					0.1
Nolo	1.9	5					1.9
Ondo	1.6	5					1.6
Parkwood	0.4	3					0.4
Penfield	0.2	3					0.2
Penn View	0.2	3					0.2
Quecreek No.1	2.2	6					2.2
Rossmoyne No.1	0.3	2					0.3
Roytown	0.3	3					0.3
Shoemaker	0.1	3	0.01	1			0.1
Stitt	0.8	2					0.8
Titus	0.2	2			0.01	1	0.2
TJS No.5	0.1	2					0.1
Toms Run	0.2	1					0.2
Tracy Lynne	1.7	7					1.7
Twin Rocks	0.9	4					0.9
Windber No.78	0.3	4					0.3
Total							113.7

* Segments - The part of a stream extending between designated tributary junctions

Nearly two-thirds of all undermined streams were associated with longwall mining and the remainders were undermined by room and pillar in the 3rd assessment period (Table VIII-2).

Table VIII-2 - Lengths of undermined streams sorted by mining method.

Mining Method	Length Undermined, mi
Longwall	63.9
Room and Pillar	49.8
Pillar Recovery	0
Total	113.7

VIII.B.4 – Compilation of Stream Investigation Reports

A stream investigation report was initiated in BUMIS, and in accompanying paper files at the CDMO, when a property owner, mining company, or PA DEP subsidence agents reported an incidence of flow loss or pooling. The PA DEP assigned each reported effect a claim number according to the year in which the report was filed and the order in which they were received. For example, the 12th reported problem in the year 2005 was assigned the number ST0512. Using a query tool, the University determined the total number of reported effects in BUMIS that occurred during the assessment time period. The date that the reported effect occurred and date of its final resolution are recorded in BUMIS.

The final resolution status has two possible outcomes: 1) Not Due to Underground Mining or 2) Resolved. If the PA DEP hydrologists, subsidence agents, and biologists determine that the reported effect is a result of surrounding land use, drought, or other factors unrelated to underground bituminous mining, the final resolution is Not Due to Underground Mining. During the current reporting period, 55 stream investigations occurred with 18 Resolved, 2 Not Due to Underground Mining, and 35 Not Yet Resolved (Table VIII-3).

Table VIII-3 - Status of all stream investigations at the end of the reporting period.

Resolution Status	Number
Final: Resolved	18
Final: Not Due to Underground Mining	2
Interim: Not Yet Resolved	35
Total	55

The Not Yet Resolved category was used when the investigation determined that the reported effects were indeed a result of underground mining. The mining company was required to submit mitigation and/or monitoring plan(s) to the PA DEP. The current requirement is that these mitigation plans must be submitted with the mining permit request. After approval of the mitigation and monitoring plans, the mining company must update the PA DEP on the progress and status of the stream(s). The PA DEP monitors the stream(s) closely during this time. Using flow and biology comparisons to either control streams or to pre-mining data from the same stream, the PA DEP makes the final determination if an effect is reported, and when, and if, the stream recovered. The investigation is then closed and the reported effect is Resolved. At the end of the assessment time period, not all reported effects had a final resolution status and for those streams where the investigation was still in progress, the final resolution status was listed as Not Yet Resolved. Figure VIII-3 shows the distribution of stream investigations sorted by mine and resolution status.

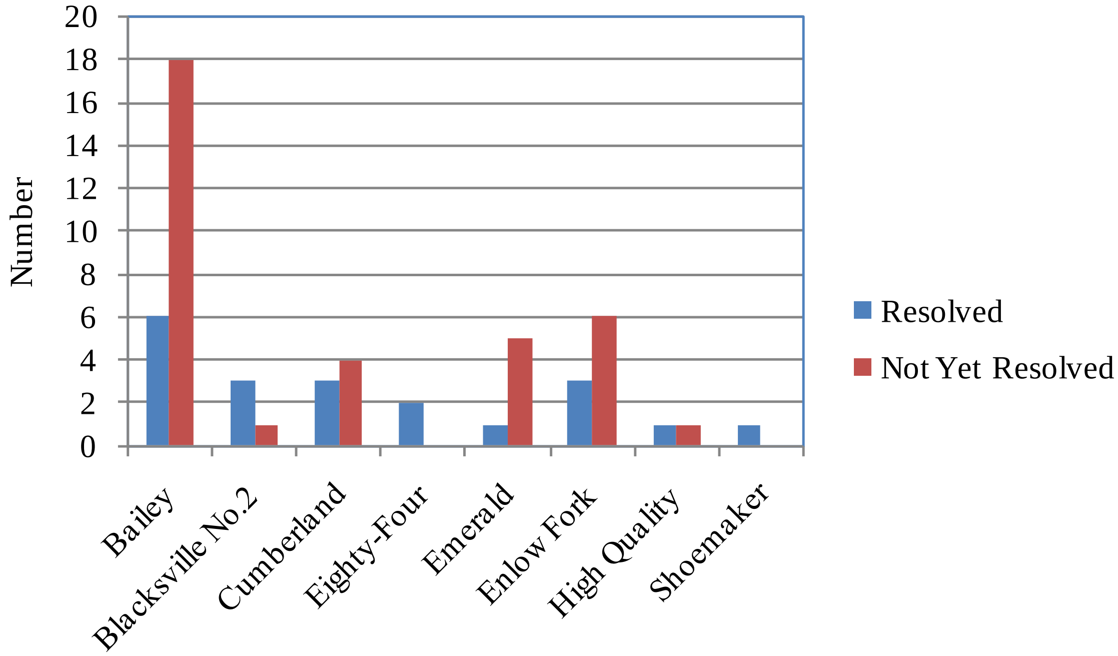


Figure VIII-3 – Distribution of stream investigations sorted by mine and resolution category.

BUMIS also contains the longwall panels where the effect occurred and the type of impact that occurred. In addition to searching BUMIS and the stream investigation files submitted by DEP hydrological and water pollution specialists at CDMO, the University also examined records associated with stream problem located at CDMO. When incomplete records were found, they were recorded as Not Yet Resolved. In 2007, PA DEP discontinued the use of stream investigation files if the mining company did not dispute a report of stream flow problems. Thus for the latter part of 2007 and all of 2008, there was much less information available for analysis.

An Excel spreadsheet was created to track reported stream effects by investigation number, mine type, dates of occurrence and/or resolution, type of effect, final resolution status, and actions taken by the PA DEP and mine operators. All information from BUMIS, from PA DEP staff-supplied spreadsheets, and from the paper files at CDMO was joined to UGISdb, and the relevant information was added.

VIII.B.5 – PA DEP Methodology for Assessing Impacts on Stream Flow

Stream impacts due to longwall mining conducted during the 3rd assessment period were of two types:

- impacts on flow, and
- impacts on the biological health of the stream.

During the third assessment period there was a major change in the methods for assessing flow and biological impacts. These are defined in PA DEP Bureau of Mining and Reclamation Technical Guidance Document (TGD-655) 563-2000-655 (PA DEP, 2005). On October 8, 2005, TGD-655 became the official guidance document. The PA DEP phased in the new stream protection requirements with the industry, over the next 12 – 18 months. This period allowed for the implementation of new ways in collecting biological data and increasing the frequency of stream flow measurements over areas of longwall panels. Thus, the flow data that exists for most of the streams undermined during the current reporting period does not meet the requirements of the TGD-655.

Prior to the TGD-655, potential impacts on flow were assessed following a period of little or no rain, so that the observed flow represented the ordinarily sustained flow through a combination of surface runoff and groundwater input, and was not simply a pulse of runoff following a rain event. The length of dry or pooling segments of a stream was calculated by using a handheld GPS unit to locate and measure the observed impact. (See Appendix D - Flow Observations Conducted by PA DEP Subsidence Agents / Biologists).

The reported impacts on flow for the eight longwall mines, for which full data are available, are summarized in Appendix E1. Averaged across the mines, for every mile of stream undermined, there were 0.63 reports of stream flow problems reported, i.e. roughly a 50-50 chance of a problem per mile of stream during the 3rd assessment period. By the end of the 3rd assessment period, of the 55 total reported effects in Appendix E1, 35 or 64-pct remained Not Yet Resolved (Table VIII-3).

Table VIII-4 - Stream investigations per mile of undermined stream sorted by mine.

Mine Name	Stream Undermined, mi	Total Investigations	Investigations per mile Undermined	Not Yet Resolved Investigations	Not Yet Resolved Investigations per mile Undermined
Bailey	17.2	24	1.4	18	1.0
Blacksville No.2	10.2	4	0.4	1	0.1
Cumberland	15.9	7	0.4	5	0.3
Eighty-Four	6.7	2	0.3	0	0.0
Emerald	11.8	6	0.5	6	0.5
Enlow Fork	25.4	9	0.4	6	0.2
High Quality	0.6	2	0.3	1	1.6
Shoemaker	0.1	1	10	0	0.0
Total / Average	87.9	55	0.63	37	0.42

For those stream problems that were Resolved, the time to resolution was determined (Appendix E1). The average time from original report filing to resolution was 688 days, with a standard deviation of 451 days and a median of 551. The minimum days to resolution for the 20 Resolved stream investigation cases was 136 and the maximum was 1,688.

Determinations of the extent of disruption to flow can be very difficult. Many of the streams in question are first and second order streams that exhibit highly variable flow with stretches in which flow typically ceases during the driest months. The time since a rain event and the long-term precipitation input can have substantial effects on the length and temporal duration of dry segments. Very little of the monitoring data presented by mining companies or the PA DEP allows definitive objective conclusions to be drawn. The PA DEP based its conclusions about the extent of the flow problems and involvement of mining-based subsidence and bedrock fracture on the best available evidence. That evidence included an impressive familiarity with the streams in the area, the coincidence of apparent decreases in flow with the period immediately following undermining, and the appearance of tension cracks, compression ruptures and pooling associated with the observed changes in flow. It was the opinion of the University that the conclusions drawn by the PA DEP about the effects of subsidence on stream flow were in general sound and well-reasoned. However, repeated pre- and post-mining monitoring in a way that would allow statistical comparisons could help preclude conflict and protracted legal proceedings. Indeed, the 2005 TGD-655 calls for the following:

- Weekly measurements six months prior to undermining,
- Daily measurements two weeks prior to undermining and continuing until the potential for impacts due to subsidence has passed, and
- Weekly measurement six months post undermining.

One example of such thorough data collection is shown in Table VIII-5 for Mount Phoebe Run, a stream above panels LW-49 and LW-50 of the Cumberland Mine. In the future, these detailed monitoring plans may allow for more robust accounts of flow impacts on undermined streams.

PA DEP has already used this detailed flow data to determine if future longwall panels will jeopardize flow in the undermined streams. An example of this was provided by the 4-East and 5-East panels in High Quality Mine. An unnamed tributary to Maple Creek ran across these panels and the PA DEP collected extensive pre-, during, and post-mining flow data from 2004 to 2007 (Table VIII-6). The flow data revealed that segments of the stream that were deemed perennial prior to mining were intermittent post-mining. Despite temporary augmentation which restored flow, the stream would go dry whenever the augmentation was turned off. When the mining company proposed to undermine a similar stream segment with the 6-East panel, the request went before an Environmental Hearing Board (The Board). The Board determined that "It is scientifically appropriate to consider the effect of mining on the 5-East watershed as a predictor of what would happen to the 6-East watershed if the 6-East Panel were longwall mined because the surface and subsurface characteristics and features of the two contiguous watersheds are very similar." (EHB Docket No. 2004-245-L). Based in large part on this data, the Board concluded that "the Department was correct in concluding that UMCO's longwalling would have permanently dewatered the previously perennial flow of the 6-East Stream." (EHB Docket No. 2004-245-L). The EHB ruling allowed High Quality to remove Panel 6-East as long as the area below the stream was mined using room-and pillar methods. Longwall mining was permitted in areas prior to and after the stream.

Table VIII-5 - Flow data (in gallons per minute) for Mount Phoebe Run in Cumberland Mine. Multiple monitoring stations are present and data is collected at least once a month. Additional data exists through February 28, 2006, however, only the following dates are shown as an example (Data from PA DEP stream investigation file ST0517).

Date	**SW 47**	**MT T2**	**MT 2**	**MT T3**	**MT 3**	**MT T6**	**SW 29**	**MT T7**	**MT 5**	**MT 6**	**MT T8**	**MT 7**	**MT 8**	**MT 9**	**S 22**
Oct.28, 2004	64	16	105	20	146	19	205	26	199	221	47	301	326	340	400
Nov.2, 2004	56			17	125		174	21	186	191	26		254	276	290
Nov.9, 2004	11	1	16	4	30	14	60	3	70	72	6	106	127	131	150
Nov.16, 2004	16			6	26		50	2	60	62	2	71	80	81	80
Nov.24, 2004	109	40	190	41	269	60	502	40	551	549	40	606	649	681	70
Dec.3, 2004	46			15	104		204	25	250	270	35	307	401	450	431
Dec.9, 2004	60	25	114	23	190	40	322	26	341	332	41	380	409	422	470
Dec.13, 2004	103			32	240		398	41	470	460	80		714	739	806
Dec.20, 2004	11	8	17	6	31	11	81	10	105	120	15	180	256	262	302
Dec.27, 2004	50			16	104		201	24	240	260	40		325	390	421
Jan.13, 2005	165	81	285	60	355	111	704	45	608	541	84	941	1,124	1,259	1,354
Jan.20, 2005	475			57	496	73	675	46	630	413	52		851	888	919
Jan.26, 2005	245		362	60	248	48	383	23	507	405	22	590	566	657	704
Feb.7, 2005	301	107	386	5	388	10	516	65	499	410	42	395	387	562	419
Feb.23, 2005	107	60	167	14	261	21	375	43	261	345	24	456	348	529	650
Mar.3, 2005	205			48	410	49	588	46	591	647	58	833	1,213	1,323	1,126
Mar.14, 2005	436	146	465	45	353	52	466	86	788	772	42	1,220	951	876	933

Table VIII-6 - Extensive flow data collected for an unnamed tributary to Maple Creek in High Quality Mine. Additional data exists through 2007, however, only the following dates are shown as an example.

DATE	Upstream Augmentation, gpm	4-East Panel Weir, gpm	Weir at 4-5 Gate, gpm	5-East Panel Weir, gpm
December 12, 2004	~ 60-70	40.4	44.8	44.8
December 23, 2004	~ 8-10	9.8	16.5	28.6
December 27, 2004	38	28.6	28.6	25.2
January 19, 2005	OFF	44.8	91.2	washed out
January 21, 2005	> 10	19.1	54.6	washed out
January 26, 2005	OFF			
February 1, 2005	OFF	0	~ 1	~ 3-4*
February 3, 2005	OFF	0	2	~ 3-4*
February 22, 2005	OFF	19.1		
February 28, 2005	OFF	16.5	36	40
March 7, 2005	OFF	22	65.6	65.6
March 17, 2005	OFF	14.1	22.7	36.2
March 22, 2005	OFF	5	14	14*
April 1, 2005	OFF		70	115
April 5, 2005	OFF	44.8	85.6	115
April 12, 2005	OFF	11	25.8	37.8
April 14, 2005	OFF	5.7	18.6	23.3*
April 18, 2005	OFF	1.7	8	8*
April 19, 2005	OFF	0.8	4.6	5.7*
April 20, 2005	OFF	< 0.1	1.2	3.8*
April 21, 2005	OFF	0	2.3	3.8*
April 25, 2005	OFF	0	Needs repaired	1.7*
April 26, 2005	OFF	0	3.8	0.84*
April 27, 2005	OFF	0	3.8	1.7*
April 28, 2005	OFF	0	1.7	0.5*
May 2, 2005	OFF	0	1.2	0.3*
May 4, 2005	OFF	0	1.2	0
May 5, 2005	OFF	0	0.15	0
May 6, 2005	OFF	0		0
May 9, 2005	OFF	0	0	0
May 10, 2005	OFF	0	0	0
May 11, 2005	OFF	0	0	0
May 13, 2005	OFF	0	0	0
May 16, 2005	OFF	0	0	0
May 17, 2005	OFF	0	0	0

* indicates flow that was below the mandated 25 gallons per minute.

Detailed flow data was crucial in the determination of impacts on streams and will be an important component of data collection for mining companies in the future.

VIII.B.6 – PA DEP Methodology for Assessing Impacts on Stream Biology

Prior to 2005, no specific biological assessment methods were required by law. Several variations of the EPA Rapid Bioassessment Protocols (http://www.epa.gov/owow/monitoring/rbp/ch07main.html) were used. As a result, most streams undermined prior to 2008 did not have biological data collected using TGD-655 methods. When applying for a permit revision or renewal, mining companies are now required to submit baseline, pre-mining stream assessments using the TGD-655 methodologies for streams with the potential for flow loss or pooling. While these methods were designed for low gradient streams, they have been successfully applied to both low and high gradient streams.

The TGD-655 provides precise and explicit methods for sampling stream macroinvertebrates and for calculating six scores:

- Taxa richness,
- Trichoptera richness,
- Percent of all taxa that are Ephemeroptera, Plecoptera and Trichoptera (% EPT),
- Percent taxa that are pollution/stress intolerant,
- Filterer-Collector + Predator Taxa Richness (FC+PR Richness), and
- Total Biological Score.

The Total Biological Score (TBS) is the average of the five preceding metrics in this list, after normalizing each to a 95th percentile statewide score. Any normalized score that exceeds 100 is set to 100. Normalized values of any of these measures in the range of 70 or higher indicate healthy streams with high biological use. These streams support healthy and productive fisheries. Macroinvertebrate scores are a good indicator of both ecological health and a productive fishery that is likely to attain its designated use.

Lack of existing data made most undermined streams, pre- and post-mining within-stream comparisons impossible. However, the University was able to use TGD-655 protocols to assess biological health of streams and compare the scores to a control stream when control stream data was available. The streams surveyed by the University are listed in Appendix D and the calculated macroinvertebrate TBS are provided

In a draft protocol document provided by the PA DEP, (PA DEP, 2005b) some guidance is provided for interpreting TBS. The aquatic life use attainment status is determined by comparing a stream segment survey's TBS to a bioregion-specific use attainment benchmark score. If the TBS of the surveyed stream segment is less than the benchmark score, the reach is not attaining aquatic life use. The suggested aquatic life use attainment benchmark scores for Bio-region 1, which includes the SW Appalachian Plateau where all the longwall mining in the Commonwealth occurred in the 3rd assessment period, is 50.1. This represents the lower 5th percentile of the distribution of TBS obtained from18 reference streams. Any stream not meeting the benchmark score was therefore at the extreme low end of TBS scores for streams in Bioregion 1. The benchmark was therefore a reasonable value for indicating streams that lost substantial biological function. It should be noted that the PA DEP provided this benchmark in a draft document and it represents good science; however, it should not be construed as PA DEP policy. The University provided this analysis because it is scientifically and statistically a well grounded comparative measure with a clear interpretive value.

In the presence of pollution or stress, all of the above measures are expected to decline. Thus a second means of interpreting the TBS was to compare pre- and post-mining TBS, or post-mining TBS with a designated non-undermined control stream. A score that was lower than 88-pct of the value of the pre-mining or control stream was deemed to have been impacted, according to the TGD-655.

VIII.B.7 – Choice of Streams Assessed by the University

Although a full assessment of the effects of underground mining on stream biology requires extensive pre-mining and extensive post-mining macroinvertebrate sampling, sampling at that level of intensity was not within the scope of work negotiated with the PA DEP. The University therefore set sampling priorities on the basis of two criteria.

VIII.B.7.a – Re-surveyed Streams from the 2nd Assessment Period

First, the PA DEP requested the University to re-survey a list of streams that remained problematic at the end of the 2nd assessment period. The University surveyed five streams for TBS and seven for flow. Many of the streams were not sampled due to access issues. Detailed reports of the University survey results are found in Appendix D. A summary of the results for the re-surveyed streams is presented in Appendix F1. For those re-surveyed streams for which macroinvertebrate data could be collected, the average TBS was 48.8. This mean score was below the bioregion 1 benchmark of 50.1. However, the standard deviation of the mean score is 6.2, thus overlapping the benchmark. The average TBS therefore indicated that on average the streams impacted in the 2nd assessment period were near, to slightly below, the benchmark for minimal biological attainment in Bioregion 1.

Because these streams were undermined well before the current TGD-655 was put in place in 2005, pre-mining TBS were not available for these streams. However, for six streams, measures of Taxa Richness and %EPT were available from pre-mining or post-mining surveys or both for comparison with the University's surveys. These are shown in Table VIII-7. In only one case was pre-mining data available, Laurel Run from the Emerald Mine. Unfortunately, this stream had ceased to flow when the University team attempted a survey. Of the remaining five streams for which post-mining biological metrics were available, all appear to be either holding constant since the post-mining surveys or increasing in biological diversity and function.

Table VIII-7 - Comparison of 3rd Assessment Period Stream Survey Metrics to Pre- and Post-mining Scores for Streams Impacted during the 2nd Assessment Period

WRDS Stream Code	Stream Name	Pre-mining Taxa Richness	Pre-mining % EPT	Post-mining Taxa Richness	Post-mining % EPT	Act 54 Taxa Richness[a]	Act 54-% EPT[a]
Bailey Mine							
32511	UT to Dunkard Fork	N/A	N/A	14	7	23	39
32600	Kent Run	N/A	N/A	9.5	47.4	17	59
Blacksville No.2 Mine							
41813	Roberts Run	N/A	N/A	14.7	35	16	25
Emerald Mine							
40432	Laurel Run	30	39	11[b]	Panel 8 – 64 Panel 9 - 5[b]	Dry	Dry
Enlow Fork Mine							
32708	Templeton Fork	N/A	N/A	18	31	26	27
32712	Rocky Run	N/A	N/A	11	27	11	18

[a] – Values represent observed values only and are not adjusted.
[b] – Post-mining data taken in June 2004.

VIII.B.7.b –Surveyed Streams from the 3rd Assessment Period

Second, the University surveyed a set of streams for which problems had been reported during the 3rd assessment period. In consultation with PA DEP, the University determined that the best approach was to obtain good sampling for a larger set of streams from one large mine, followed by a small number of samples from other mines. The Bailey Mine was among the most active during the 3rd assessment period and had the largest number of stream reported effects associated with it. In addition, a control stream was previously identified and macroinvertebrate data was collected. Therefore, the Bailey Mine was chosen for intensive sampling. A total of 17 streams were surveyed for macroinvertebrates (Appendix F2). Six surveyed streams were undermined by the Bailey Mine. The remainder was spread over the five next-largest longwall mines.

The average TBS in these streams was 46.1 with a standard deviation of 7.2. It is important to note that the TBSs were extremely variable. The scores ranged from a low of 13.3 to a high of 73.1. Overall, these streams were on average just below biological attainment. Bailey and Blacksville No.2 streams were also compared to the TBS obtained by PA DEP for their control streams, which had TBS of 76.3 and 62.6, respectively (Table VIII-8). The TGD-655 considers biological health to be unchanged from or restored to pre-mining levels if the scores are above 88-pct of the control stream value. These values were 67.1 and 55.1 for Bailey and Blacksville No.2, respectively. The mean of the six Bailey streams' TBS was more than two standard errors below the TBS for the control stream (mean = 50.5, std err = 7.9). Four of the six surveyed Bailey mine streams fell below the cutoff indicating adverse effects and failure to attain pre-mining levels, based on comparison to the control stream. The single surveyed stream from the Blacksville No.2 mine had a TBS above the critical 88-pct of its control stream's TBS. It was not considered adversely affected. Fully half of the streams surveyed fell below the Bioregion 1 cutoff for biological attainment. However, this cannot be attributed solely to mining effects, since there was no baseline comparison and multiple land use practices in the watershed can result low TBSs. During the course of the University's surveys, cattle and horses were observed watering in many of the streams. This not only caused changes in stream chemistry, but also increased sedimentation loads. In Appendix D, the surrounding land use around each stream surveyed for TBS is described in order to acknowledge that scores may have been impacted by agricultural practices.

Table VIII-8 - Comparison of 3rd Assessment Period Stream Survey Scores to Control Stream Scores.

WRDS Stream Code	Stream Name	Total Biological Score	Control Stream WRDS	Control Stream Total Biological Score	Score below which the stream is adversely affected	Adversely Affected
Bailey Mine						
32507	UT to Wharton Run	56.1	32542	76.3	67.1	Y
32530	Headley Hollow	68.8	32542	76.3	67.1	N
32532	UT to Dunkard Fork	73.1	32542	76.3	67.1	N
32596	UT N Fork of Dunkard Fork	27.2	32542	76.3	67.1	Y
32598	Polly Hollow	29.4	32542	76.3	67.1	Y
N/A	UT to Dunkard Fork	48.3	32542	76.3	67.1	Y
Blacksville No.2 Mine						
41728	Bulldog Run	58.0	41819	62.6*	55.1	N

* indicates that the TBS is an average of scores collected across multiple dates.

VIII.C – Summary

During the 3rd assessment period, nearly 114 miles of stream were undermined. For every two miles of stream undermined, there was an investigation of stream flow diminution or pooling, on average. By the end of the 3rd assessment period approximately one-third of these investigations had been resolved. Stream flow varies across seasons, across years, and even within seasons as a result of the vagaries of weather.

On average, a final resolution required 688 days. About half of the streams surveyed for macroinvertebrate diversity and composition had TBS below a PA DEP draft recommended cutoff for biological attainment for the SW PA Bioregion 1, indicating that one or more sources of perturbation have negatively influenced the TBS. Various land use practices, including underground mining, were likely sources of perturbation. Because most of the TBS scores obtained could not be compared to a pre-mining or control stream TBS, ascertaining the effect of mining per se was not possible. Although control streams for biological comparisons were designated for most, but not all, active longwall mines by the PA DEP, biological data was made available to the University for only two of these, Bailey and Blacksville No.2 Mines. The six stream surveys conducted for the Bailey Mine were statistically compared to that mine's control stream value. For the six Bailey Mine streams, the mean post-mining TBS was highly significantly below the control stream score (i.e. more than two standard deviation of the mean below the control TBS), indicating that recovery had not on average been attained. Two of these six streams were within the 12-pct difference of the control stream established by the TGD-655 as indicating recovery or maintenance of pre-mining biological health and have therefore substantially recovered. The other four were far from attainment. Comparison based on more limited biological data of post-mining Taxa Richness and %EPT scores with new surveys by the University indicated that there had been a mix of no improvement to substantial improvement since the post-mining surveys. There is substantial heterogeneity among streams, with about half the streams meeting PA DEP criteria for attainment of pre-mining biological scores.

The use of a single control stream, while understandable from a cost and time perspective, may not adequately represent the diversity of stream characteristics in the undermined area. It would be very useful to have pre-mining data for the undermined streams. More recent mining permits and permit revisions reflected a change in approach by the mining companies that was much more pro-active regarding the potential for mining-induced stream flow problems. The most recent permits, filed since the end of the 3rd assessment period, contained considerably more biological data for the streams to be undermined and this data was largely obtained following the TGD-655 protocols.

SECTION IX: Mining Effects on Wetlands - Recent Progress

IX.A – Overview

The PA DEP tasked the University with analyzing of the number, type and size of wetlands undermined during the 3rd assessment period. PA DEP originally intended for the University to analyze the number, types and sizes of wetlands that were impacted by mining operations using information from permit applications, operator reports, stream loss investigation files, wetland loss investigation files, and wetland impact reports submitted by the CDMO to the Bureau of Watershed Management. However, for two reasons this was not, in general, possible. First, very little documentation from these sources was provided during the seven months of document gathering by the University at CDMO. There were two documented mining related wetland impacts and subsequent investigations carried out by the CDMO during the 3rd assessment period: the wetlands over the 4B panel of Mine Eighty-Four and the wetlands over the 4R panel of the Blacksville No.2 Mine. Second, detailed information established through field surveys was only available in permit applications submitted after October 2007, and the wetlands identified in those permit applications were not yet undermined at the close of the 3rd assessment period. Since the availability of this information is crucial to future assessments of mining related effects on wetlands, this study had the following goals:

- Provide an inventory of known wetlands undermined during the 3rd assessment period.
- Evaluate the extent to which detailed and appropriate information was present in permit applications submitted after October 2007.

Wetlands provide a wide variety of human and ecosystem services. These include flood control, water purification through chemical transformations, chemical absorption and adsorption, sedimentation of particulate matter, groundwater infiltration and prevention of excessive runoff, diminution of surface flow velocity and consequent reduction in erosion, enhancement of biodiversity through provision of water, food and nesting habitat and habitat for fish, wildlife, and plants, many of which occur only in wetland habitats, as well as providing important services for domesticated animals (Committee on Characterization of Wetlands, 1995). As a consequence of the myriad values they provide, wetlands were protected by federal law from degradation or destruction through the Federal Water Pollution Control Amendments of 1972 (P.L. 92-500), commonly known as the Clean Water Act, amended in the Clean Water Act of 1977 and the Water Quality Act of 1987.

The Clean Water Act defined wetlands as -

> *"Those areas that are inundated or saturated by surface 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. Wetlands generally include swamps, marshes, bogs and similar areas."*

The predominance of longwall mining and the low prevalence of subsidence-associated surface water effects associated with room-and-pillar mining together resulted in wetland effects being associated entirely with longwall mining during the 3rd assessment period. As discussed in Section III, IV, and V, the greatest vertical subsidence basin occurs in the center of the mined panel, rising to the historical surface elevation over the adjacent gate road entries. The formation of a subsidence basin can affect wetlands in the following ways:

- Creation of new wetlands
  - First, the areas of greatest subsidence can be flooded by associated stream pooling, and low areas in the riparian zone can become wetlands as a result of associated flooding and/or shallower depths of soil saturation.
  - Second, even away from riparian zones, soils in subsidence areas can become saturated or inundated for all or part of the year because of the new proximity of the surface to the water table, and both hydric soils and typical wetland vegetation will subsequently develop.
- Loss of existing wetlands
  - The presence of elevated gateways and compression features, i.e. heaves and ridges, in areas that previously harbored wetlands.
  - The loss of groundwater through tension cracks resulting from the extension of bedrock layers during subsidence.

Until October 2005, reporting on wetlands in mining company permit applications lacked clear guidelines. As a result, mining companies and their environmental consultants used a variety of standards and approaches, making standardized assessment of the types, size and number of undermined wetlands difficult, as well as hampering the ability to determine the effects of undermining on wetlands.

In response to the difficulty of ensuring wetlands protection without clear regulation and policy, the PA DEP included guidance for wetland identification, assessment of damage to wetlands, and procedures for mitigation or replacement in the TGD-655 (PA DEP, 2005). This document stipulated the following responsibilities on the mining companies for wetlands protection:

- All mining must be planned to ensure that no net loss of wetlands will occur,
- Any adverse effects on wetlands must be mitigated in accord with the guidance provided by the Technical Guidance Document 363-0300-001 (PA DEP, 1997),
- Wetlands above the area to be mined must be delineated and monitored as a part of the permitting and re-permitting process.

In addition, the PA DEP responsibilities can be briefly summarized as follows:

- Verify mining company predictions regarding wetland delineation and prediction of adverse effects,
- Ensure requirements for pre- and post-mining assessments are included in the permit applications,
- Make sure that requisite monitoring and reporting of wetland conditions occurs during and post mining by the mining companies,
- Make certain that mitigation plans are adequate and all mitigation obligations are adequately carried out, and
- Consult with other state and federal regulatory and management agencies where appropriate.

The TGD-655 specifies that mining companies must follow the wetlands guidelines within 24 months after the official implementation of the TGD. Thus, mining permit applications and revisions submitted after October 8, 2007 were subject to the requirements contained therein. This date is only about 10 months prior to the end of the 3rd assessment period, so the mining that took place during the 3rd assessment period was not subject to the TGD-655's requirements. There was therefore, as in the 2nd assessment period, little to report.

In the event that the mining company, a citizen, or a PA DEP agent had identified an apparent adverse effect on a wetland, the PA DEP followed much the same investigative procedure as with stream flow investigations. If underground mining was determined to be the likely cause of an adverse wetland impact, the mining company was required to submit a mitigation plan, if one was not included as a part of the mining permit. The mitigation plan must meet the criteria established in the TGD-655. A bond was also posted in association with the mitigation plan. The DEP was responsible to see that the stipulated post-mitigation monitoring indicated in the mitigation plan had been successfully completed. This monitoring was required by the Wetland TGD-655 to continue for five years following mitigation. The University found one case (4R panel, Blackville No.2) in which mitigation was conducted and the wetland investigation was resolved during the 3rd assessment period.

IX.B – Data Collection

IX.B.1 – Inventory of undermined wetlands during the 3rd assessment period

The University coverage of wetlands undermined during the third assessment period was entered into UGISdb. Data were gathered from multiple sources, but primarily from the National Wetland Inventory (NWI) (ttp://www.fws.gov/wetlands/Data/Mapper.html). Additional data was collected from mining companies and the associated environmental consulting firms, and from the Pennsylvania Environmental Council. All longwall mines, with the exception of the Shoemaker Mine where very little mining occurred within Pennsylvania, were assessed. Whenever possible, the acreage of the wetland and its U.S. Fish and Wildlife standard classification codes (Cowardin et al., 1979) were included.

A total of 79 undermined wetlands occupying 93.9 acres were identified across six of the largest active longwall mines (Appendix G1). Four extensive Riverine wetlands, varying in size from 7.0 to 16.7 acres, were all classified as R5UBH. Riverine defines a wetland type largely comprised of unclassified perennial vegetation with unconsolidated bottom and permanently flooded. All other classified wetlands were Palustrine. The Palustrine includes all nontidal wetlands dominated (> 30-pct) by trees, shrubs, emergent, mosses or lichens. Thirty-nine were classified as less than 30-pct vegetative cover and unconsolidated bottom (PUB), 21 were classified as showing emergent vegetation (PEM; Figure IX-1, one of these was a mix of emergent vegetation and scrub/shrub), five were forested (PFO), one was scrub/shrub (PSS), and nine were not classified (Table IX-1). The unclassified wetlands were very small, averaging 0.14 acres in size.

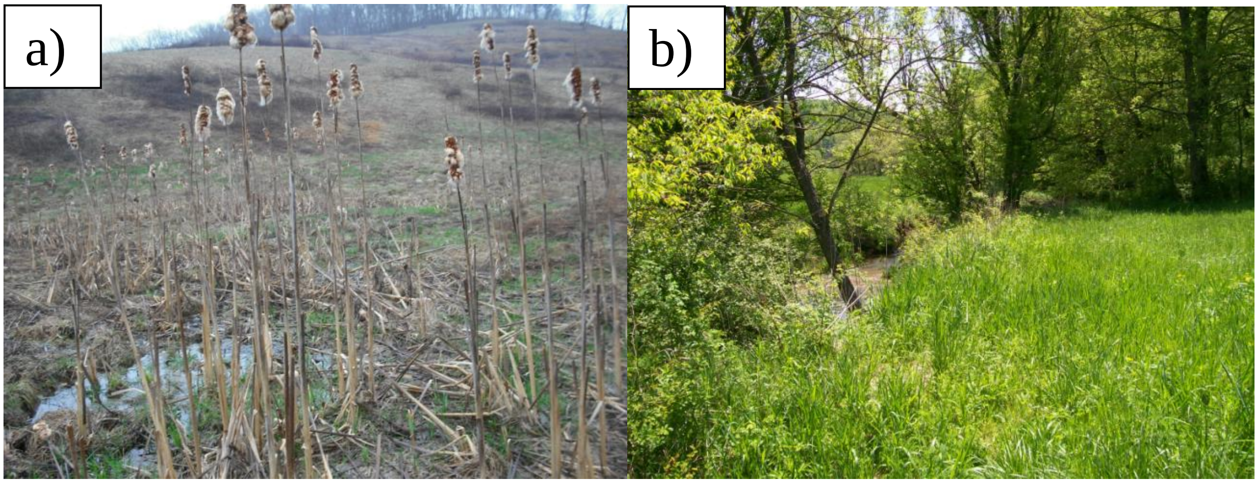


Figure IX-1 - Examples of palustrine emergent wetlands around two undermined streams:a) Unnamed tributary to Frosty Run over Emerald Mine and b) Dutch Run over Cumberland Mine. These wetlands are characterized by the dominance of rooted, herbaceous vegetation (Photographs courtesy of A. Hale).

Table IX-1 - Undermined wetlands, 3rd assessment period, sorted by type.

Wetland Type	Number	Total Acres	Percent	Average Size
PEM	21	24.13	25.7	1.14
PSS	1	0.54	0.6	-
PFO	5	8.78	9.3	1.76
PUB	39	16.44	17.5	0.42
R5UBH	4	42.72	45.5	10.68
Unknown	9	1.39	1.4	0.14
Total	79	93.9	100	

Caution should be used in comparing wetland data across mines. It is not clear that the same standards were used to delineate wetlands for all mines, and differing sources of data were available for the different mines. The information provided is meant only to provide a general picture of the frequency of wetlands, their major types and their sizes.

A single wetland loss investigation report was available to the University (PA DEP, 2009). The report was submitted to the CDMO compliance manager on June 15, 2009 by a PA DEP Water Pollution Biologist 2, based on his field and office research regarding a complaint by the landowner's family that a wetland and spring on their property had been diminished shortly after being undermined. The report was thoroughly documented. The DEP biologist who authored the report has made use of all available data, including the results of his own field investigations, together with his extensive experience, to reach his conclusions. He concluded that the wetland has been fed primarily by three small unnamed streams, the most important of which arose largely from a spring that has also served as the water supply for the landowner's home. The DEP biologist presented evidence that:

- The flow in the spring and the tributary was indeed diminished,
- The wetland had decreased in both its saturation and in the area inhabited by wetland indicator plant species, based on a comparison of pre-mining delineation and PA DEP delineation as a part of the investigation,
- The timing of the diminution of flow was coincident with undermining,
- This wetland was within an area where tensile stresses from the formation of the subsidence basin over the gate road entries / panel transition could have produced tensile cracking. These open fractures could be responsible for loss of surface and groundwater, and
- The adverse effects on the wetland were very likely to have been caused by undermining.

According to PA DEP officials, this investigation was closed. The Department had a Memorandum of Understanding with the Bureau of Water Quality protection (PA DEP, 2007) that allowed the operator to contribute funds to the Pennsylvania Wetland Replacement Project instead of conducting wetland mitigations (TGD 563-0200-003). The amount of the contribution was directly related to the size of the impact to the wetland. In regards to the previously identified wetland, the mine operator impacted 0.213 acres of the wetland area, so as per the MOU, they paid $2,500 into the fund.

A wetland gain investigation report over Blacksville No.2 was also available to the University. Prior to mining, a floodplain over the 4R panel near Roberts Run supported a hay field. While this area was likely inundated after large precipitation events due to high flow in Roberts Run, it did not support a wetland. However, after reports from a property owner were made to the PA DEP, a wetland delineation was conducted on July 12, 2003. After testing three separate test sites, consultants determined that the area now supported wetland vegetation, hydric soils, and was inundated. Thus, the former hayfield was designated as a wetland. To mitigate this wetland gain, the mining company proposed a regrading plan in a permit revision to restore the area to its former use. This plan included the following:

- Establishing proper drainage from a spring at the north end of the wetland into Roberts Run,
- Stripping the topsoil on the wetland and replacing it with fill from the Roberts Run restoration project to achieve a proper grade to prevent pooling,
- Stabilizing the Roberts Run stream banks to prevent future flooding of the wetland area, and
- Creating a ditch to catch run-off from the nearby road and prevent it from entering the wetland area.

The plan was approved on January 5, 2005 by the PA DEP and work began in April 2005. The area was inspected in July 2005 by PA DEP officials who were satisfied with the work and determined that the project was complete.

IX.B.2 – Increased rigor of wetland inventories since 2007

Since late 2007, permit revisions and new permits have included much more extensive and precise delineation of wetlands. Each permit application filed since that time included precise geo-referenced delineation of the geographic extent of all wetlands in a GIS coverage. While these coverages were in digital form in the mining companies' records, PA DEP was unprepared to accept them in digital form and required that paper maps be submitted.

Since the permit applications submitted in late 2007 and beyond, were not undermined in the 3rd assessment period, the University did not include them in this report. However, one new permit application was investigated and the wetland coverages included in its permit maps were examined. These new applications were extraordinarily precise and thorough in their wetland delineations. The University collected data from the maps provided with this permit revision application for Enlow Fork Mine panels E12 to E18 and F12 to F18 as an illustration. In these 14 panels, 19.9 acres of wetlands were delineated, compared to the 11.0 acres identified for the entire undermined area from the 3rd reporting period (Appendix G2). Fifty-seven wetlands were identified in the permit revision application, whereas only 23 were identified for the entirety of the undermined part of Enlow Mine in the 3rd reporting period. The University also found a report of that meticulously assessed the size and location of wetlands at the Cumberland mine. This 2004 study estimated 63.6 acres of wetlands (Appendix G3). This new estimate showed a dramatic increase over the NWI generated 3.1 acres of wetlands for the Cumberland Mine (Appendix G1).

One reason for this significant increase in the number of wetlands identified was that the 3rd reporting period inventory of wetlands relied heavily on the NWI database of registered wetlands. It was well known that forested wetlands and small wetlands have often gone unrecorded in the NWI database. The University observed the flags and tapes used by mining company consultants to mark their spatial delineations in some areas. Wetlands, as small as a few hundredths of an acre, are now being delineated. These wetland data now being included in mining permits appear to identify every wetland no matter how small and are providing an accurate classification of wetland type. This should provide the necessary material to assess adverse effects of mining on wetland characteristics and function.

IX.C – Summary

While mining permits prior to 2007 contained very uneven data on wetland inventories in the areas to be undermined, both of the wetland reported effects did have pre-mining data. Using this data, newly gathered data, and other available information, the PA DEP was able to determine that the areas were impacted by underground mining.

A total of 93.9 acres of wetlands were identified as having been undermined during the 3rd assessment period. This total was largely based on the NWI. Since the NWI missed many of the smallest wetlands, University estimates of the number and total acreage of wetlands undermined during the 3rd reporting period are therefore conservative.

TGD-655 became effective in October of 2005. This document specified a sound and precise protocol for delineating all wetlands within an area of planned mining. All permit applications submitted 24 months after the effective implementation date of the TGD-655 were required to have used this protocol to supply the wetland information in the application. Thus all permit applications submitted after October 2007 contained excellent wetlands pre-mining data that inventoried all wetlands down to sizes of a few hundredths of an acre.

SECTION X: Discussion, Summary, and Conclusions

X.A – Discussion

The previous nine sections described in-detail the various important aspects of underground bituminous coal mining and its impact on structures, water supplies, land, streams, and wetlands. Much of the report was dedicated to explaining how impacts occur and documenting how mining operations complied with the legislative mandates set forth in ACT 54. This was summarized by examining the compliance actions by the numbers and kinds of reported effects still unresolved from the 2^{nd} assessment period and that occurred during the 3^{rd}. This analysis, by its nature, examined how effectively the mining operations and PA DEP contributed to compliance actions. The key questions answered were: what impacts have occurred, how have these impacts been resolved, and how long has it taken to resolve them?

The protocols for assessing structures, water supplies and land reported effects are relatively robust and have remained constant over the 3^{rd} assessment period. Protocols for assessing streams and wetlands changed significantly (Section VIII and IX). For this reason, the discussion on compliance assessment focuses on structures, water supplies, and land reported effects.

X.A.1 - Structure, Water Supplies, and Land Reported Effects

This is what was reported regarding structures, water supplies and land reported effects:

- Of the 275 reported effects that occurred during the 2^{nd} assessment period, 212 were resolved and the remaining 63 had Interim Resolution in place at the end of the 3^{rd} assessment period.
- 1,247 reported effects occurred during the 3^{rd} assessment period. Thirty-nine were found at closed mines, the other 1,208 occurred at 36 of the 50 active mines studied in this report. Fourteen mines did not have a reported effect.

X.A.1.a - 2^{nd} Assessment Period

The 275 reported effects unresolved at the end of the 2^{nd} assessment were distributed over 15 active and 10 closed mining operations (Figure X-1). The active mines accounted for 143 reported effects while the closed mines had 132 (Appendix B2). Impacts to water supplies accounted for the most reported effects with 244 (88.7-pct of the total), followed by structures with 26 (9.5-pct) and land with 5 (1.8-pct). Resolutions occurred in 212 cases with 93.4-pct or 198 classified as Company Liable. Only 14 Company Not Liable cases occurred. Lastly, 63 Interim Resolutions from the 2^{nd} assessment period remained at the end of the 3^{rd} assessment period.

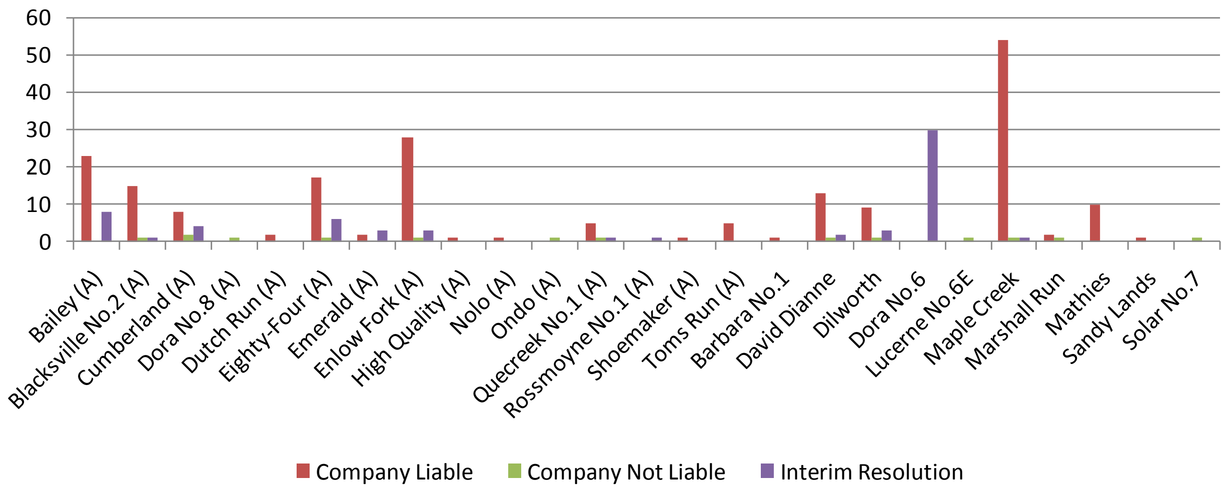


Figure X-1 – Number of Company Liable, Company Not Liable, and Interim Resolutions for the 25 mines where reported effects occurred but were not resolved in the 2nd assessment period. Note: The (A) indicates active mines.

A projection of reported effects liability was made by examining the resolution trends of the 2nd assessment cases resolved during the 3rd (Table X-1). Projecting past trends forward yielded 257 Company Liable reported affects and 18 Company Not Liable.

Table X-1 – Projected resolution status of all reported effects from the 2nd assessment period.

	Reported Effect (2nd)*			
Resolution	**Actual**	**Actual Percent**	**Projected**	**Projected Percent**
Company Liable	198	72.0	257	93.4
Company Not Liable	14	5.1	18	6.6
Interim Resolution	63	22.9	0	0

* - 2nd refers to occurring in the 2nd assessment period.

The average days to achieve one of the four major categories of resolutions for all 275 reported effect was 1,711 with a standard deviation of 889 (Table X-2). The median number of days was 1,797. The median value is used as a measure of location when a distribution, such as this one, is skewed. The median is a useful tool to reduce the importance attached to outliers, i.e. in this data there were a small percent of cases still litigation that tended to skew the average values. Reported effects with a final resolution of Company Liable had an average of 1,426 days and a median of 1,435. Company Not Liable cases had less days with an average of 945 and a median of 412. Interim resolutions at the end of the 3rd assessment period have the highest days with an average of 2,777 and a median of 1,867. Clearly, these 63 cases represented some of the most difficult to resolve. Thirty of these cases were associated with the Dora No.6 Mine flooding incident discussed in Section IV.L of the Conte and Moses report (2005). The Dora No.6 Mine was a room-and-pillar mine in the Lower Kittanning Coalbed where 39 water supplies had sulfate levels in the range of 250-mg/l, indicating the supplies were influenced by mining operations. Thirty of the 39 were found in BUMIS where the Interim Resolution reported "Treatment system installed by DEP-BAMR (Bureau of Abandoned Mine Reclamation)." Since these impacts are being mitigated by a state agency, they should not be used to assess industry compliance. A revised Interim Resolution, minus the Dora No.6 cases, at the end of the 3rd assessment period showed an average of 2,477 days and a median of 2,545 (Table X-2).

Table X-2 - Summary of days to achieve various resolutions of reported effects occurring during the 3rd assessment period at active and inactive mines.

Reported Effects (2nd)	Average, days	Standard Deviation, days	Median, days	Min., days	Max., days	Number
All Active and Closed Mines	1,711	889	1,797	63	3,572	275
Company Liable	1,426	698	1,435	199	3,271	198
Company Not Liable	945	949	412	63	2,684	14
Interim Resolution	2,777	457	3,108	1,867	3,572	63
Interim Resolution without Dora No.6	2,477	456	2,545	1,867	3,572	33
Outstanding	-	-	-	-	-	0

* - 2nd refers to occurring in the 2nd assessment period.

All of the 63 Interim Resolutions were classified as water supply loses. Thirteen Interim Resolutions categories are shown in Table X-3. Typically the resolution path to a water supply reported effect was multi-step. Temporary water was supplied and then the logistics of providing a long term solutions was investigated and agreed upon by the landowner. Often a period of monitoring was required to assess when the impact had stabilized its influence on the water supply. In addition, this process often required O&M determinations which were time consuming. It is difficult to know which step or process took the most time because a reported effect may have multiple Interim Resolutions. Therefore, the Interim Resolution found in BUMIS will depend, in part, on the step it currently occupied when the data base was queried.

Table X-3 – Average and median values of days for 63 water supply Interim Resolutions sorted by resolution type.

Interim Resolution (2nd assessment period)	Average, Multiple Cases, days	Median, days	One Case, days	Number
Agreement Pending	-	-	1,965	1
Implementing Water Supply Replacement Plan	2,528	2,528	-	2
In Litigation	2,220	2,220	-	2
In Negotiation	2,364	2,364	-	2
O&M Review	2,828	2,976	-	5
O&M Bond Requested	2,543	2,861	-	3
Pending Owner Approval	2,849	2,849	-	5
Public Water/O&M Pending	1,996	1,979	-	3
Temporary Water/Awaiting Public Water	2,412	2,597	-	3
Temporary Water	-	-	1,867	1
Well, Spring/O&M Pending	2,172	2,108	-	5
Water Supply Replacement Plan Under Development	-	-	3,572	1
Treatment system installed by DEP-BAMR	3,108	3,108	-	30

X.A.1.b - 3rd Assessment Period

The 1,247 reported effects were distributed over 36 of the active mining operations (Active Mines -1,208 reported effects) while 16 closed mines accounted for another 39 (Appendix B1).

For the 3rd assessment period, water supplies accounted for the most reported effects with 683 (54.8-pct of the total), followed by structures with 456 (36.6-pct) and land with 108 (8.6-pct). Resolutions occurred in 896 cases with 621 being classified as Company Liable and 275 as Company Not Liable (Table X-4). Lastly, there were 262 Interim resolutions and 89 Outstanding Resolutions at the end of the 3rd assessment period. The projection of mining operations liability towards reported effects was again made using trends established above for the 2nd assessment cases resolved during the 3rd (Table X-1). Projecting past trends forward yielded 949 Company Liable reported affects and 298 Company Not Liable.

Table X-4 – Number of actual and projected resolution status for all reported effects from the 3rd assessment period.

	Reported Effect			
Resolution (3rd)*	**Actual**	**Actual Percent**	**Projected**	**Projected Percent****
Company Liable	621	49.8	949	93.4
Company Not Liable	275	22.1	298	6.6
Interim Resolution	262	21.0	0	0
Outstanding Resolution	89	7.1	0	0

* - 3rd refers to occurring in the 3rd assessment period
** - from 2nd assessment projections

The average days to achieve one of the major categories of resolutions and sorted by impact class are shown in Table X-5. Reported effects with a final resolution of Company Liable and Company Not Liable have relatively low median values ranging from 145 to 348 days. Unresolved cases, i.e. Interim and Outstanding Resolutions at the end of the 3rd assessment period, have relatively high median values ranging from 249 to 593 days.

Table X-5 - Summary of days to achieve various resolutions of reported effects occurring during the 3rd assessment period at active and inactive mines sorted by impact class.

Resolution Category	Impact Class	Average, days	Standard Deviation, days	Median, days	Min., days	Max., days	Number
All Active and Closed Mines		293	336	168	0	1,662	1,247
Company Liable	Structures	246	281	151	0	1,253	301
	Water Supplies	293	348	146	0	1,615	270
	Land	249	279	158	0	1,253	50
Company Not Liable	Structures	153	191	84	0	851	59
	Water Supplies	112	145	64	0	930	179
	Land	147	209	56	0	1,048	37
Interim Resolution	Structures	348	278	266	21	1,054	72
	Water Supplies	535	403	382	8	1,662	174
	Land	371	287	249	85	901	16
Outstanding	Structures	490	387	484	33	1,492	24
	Water Supplies	451	460	288	1	1,662	60
	Land	530	354	593	89	933	5

The 12 most used final resolutions used during the 3rd assessment period are shown in Table X-6. Company Purchase Property had the least amount of days to resolution, averaging 66 days with a median of two. This indicates that the decision to buy, on the company's part, and sell, on the owner's part, was made relatively soon after a reported effect was filed. The PA DEP was able to establish Not Due to Underground Mining (Company Not Liable) in an average of 126 days with a median of 66. Conversely, Agreements (Company Liable) between the company, land owners, and the PA DEP averaged 323 days with a median of 249. The final resolutions that took the most days were Compensation and Public Water Supply averaging 395 and 463 respectively with median values of 373 and 448.

Table X-6 - Summary of days to achieve various resolutions of reported effects occurring during the 3rd assessment period at active and inactive mines sorted by impact class.

Resolution Category	**Average, days**	**Standard Deviation, days**	**Median, days**	**Min., days**	**Max., days**	**Number**
Not Due to Underground Mining	126	163	66	0	1,048	237
Agreement	323	302	249	0	1,253	192
Company Purchased Property	66	148	2	0	934	132
Compensation	395	263	373	0	1,219	78
Repair & Resolved	276	314	154	0	1,222	76
Public Water Supply (Wells/Spring)	251	322	94	0	1,197	65
Undisclosed & Unspecified	343	396	133	0	1,221	36
Water Supply Recovered	168	263	92	0	1,116	19
Public Water Supply (Public)	463	448	343	0	1,490	18
Withdrawn	164	154	167	0	535	14
No Actual Problem	70	92	18	0	223	10
No Liability	158	315	45	0	930	8

Lastly, the skewed nature of the data was evaluated by examining the relative distribution in the form of percentiles for the nine most common final resolution categories (Table X-6). A percentile is the value of a variable below which a certain percent of observations fall. For example, for the nine final resolution categories shown in Figure X-2, the 80th percentile is the value below which 80-pct of the observations are found. This value was approximately 600. So for the most common resolutions 80-pct of all cases were solved in the first 600 days after the date of occurrence. During this timeframe, PA DEP made sure the case was valid, the impact was stabilized and an amicable resolution between the coal operation and property owners was reached. It also highlights reason why other 20-pct of the cases were taking longer.

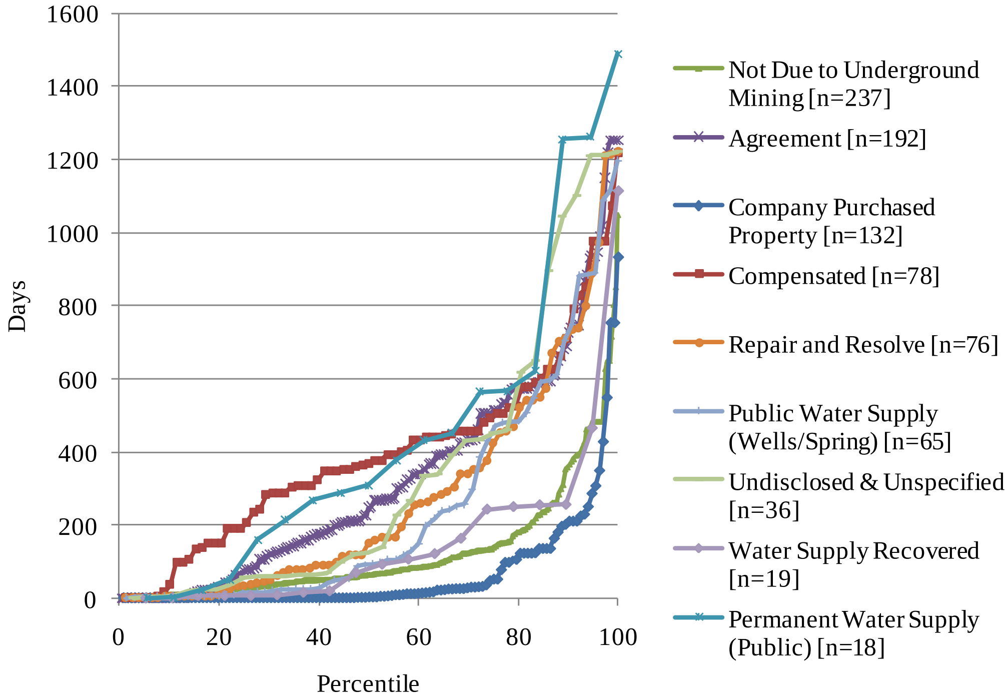


Figure X-2 - Distribution of days to final resolution for nine of the most common categories.

X.A.2 – Comparison of the 3rd Assessment with the 2nd

In almost every category, more mining and more impacts were measured during the 3rd assessment in comparison to the 2nd. For example, 34,051 acres and 3,033 properties were undermined in the 2nd assessment compared to 38,256 acres and 3,587 properties in the 3rd. That is a 12-pct increase in acres and an 18-pct increase in properties. Room-and-pillar mining with and without pillar recovery more than doubled, increasing from 6,544 to 13,649 acres. The number of structures inventoried increased from 3,656 to 3,787. Less longwall mining occurred, dropping by 11-pct from 27,507 acres to 24,607. The total number of water suppliers undermined was not mentioned in the 2nd assessment report so a comparison could not be made.

Reported effects related to structures, water supplies, and land, increased 14-pct from 1,090 to 1,247. Structure reported effects increased 31-pct from 348 to 456, water supplies remained virtually the same, and land reported effects increase 86–pct from 58 to 108. The University could not determine all the factors that might have influenced these increases, but mining in more populated areas is one possible reason. Another could be better record keeping practices.

The length of streams undermined were virtually the same over the two assessment periods (113.7 miles in the 3rd and 115.5 miles in the 2nd). However, the length of streams over longwall panels dropped by 10-pct (97 miles in the 2nd and 88 miles in the 3rd). During this same period the number of stream investigation reports more than doubled, rising from 22 to 55. These trends clearly indicate a greater effort by companies and the PA DEP to more accurately characterize the flow and the biological health of streams. The total acres of wetlands undermined increased from 77.8 in the 2nd assessment to 93.9 in 3rd (Figure X-3). As stated in the Section IX, these totals will likely increase in magnitude as more efforts are made by the mining operations to adequately characterize wetlands.

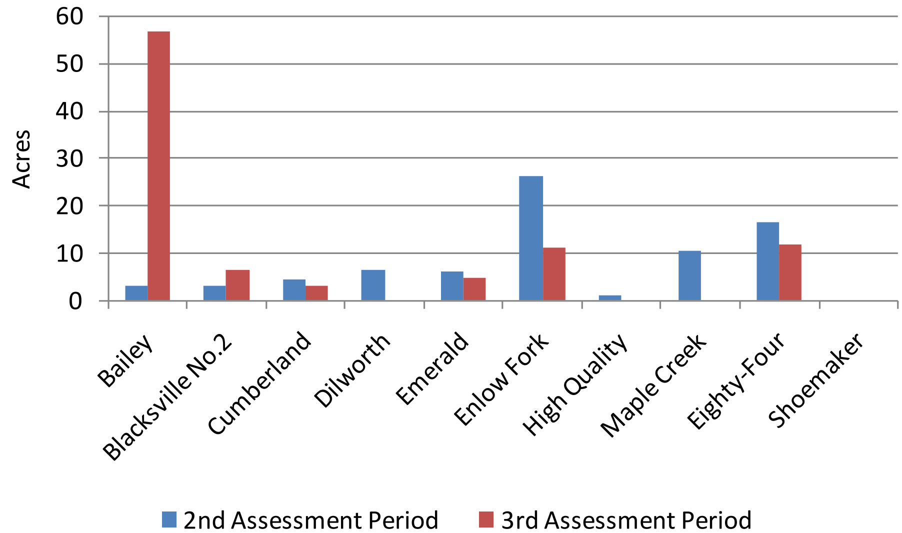


Figure X-3 - Acres of wetlands for the 2nd and 3rd Assessment periods sorted by mine.

X.B – Summary

The University was contracted in 2009 to conduct the 3rd assessment, covering the period from August 21, 2003 to August 20, 2008 (*3rd assessment period*). The following are summary statistic developed from each of the previous nine sections. For a more detailed summary, see the Summary Points at the end of each section.

X.B.1 - Inventory of Mining Related Activity

- 50 underground bituminous mines operated in Pennsylvania
  - 36 room-and-pillar mines
  - 8 longwall mines
  - 6 room-and-pillar mines with pillar recovery
- 38,256 acres of surface land undermined
  - By mine type
    - 24,607 acres of land (64.3-pct of total) by longwall mines
    - 11, 552 acres (30.2-pct) by room-and-pillar mines
    - 2,097 acres (5.5-pct) by pillar recovery mines
  - By mining method
    - 20,375 acres (53.3-pct of total) from the longwall
    - 17,605 acres (46.0-pct) from room-and-pillar (also includes main, gate road, and bleeder entries at longwall mines)
    - 276 acres (0.7-pct) from the pillar recovery
- 3,587 surface properties undermined
  - 1,738 properties (48.5-pct) from room-and-pillar mines
  - 1,572 properties (43.8-pct) from longwall mines

    - 277 properties (7.7-pct) for pillar recovery mines
- 6 coalbeds mined
    - Pittsburgh
        - Thickest and most persistent
        - 8 longwall mines in Greene and Washington Counties
        - 1 room-and-pillar mine (Ridge) in Armstrong County
    - Sewickley
        - 5 room-and-pillar with pillar recovery mines in Greene County
    - Upper and Lower Freeport and Kittanning
        - 36 room-and-pillar mines
        - 8 different counties (Armstrong, Beaver, Cambria, Clearfield, Elk, Indiana, Jefferson, and Somerset)

X.B.2 – Inventory of Structures Impacts

- 3,735 inventoried structures undermined
- 31 different feature types recognized
    - 1,502 were dwellings, 593 garages, 357 barns, 264 sheds, 230 trailers, 169 outbuildings, 95 buildings, 35 silos, 32 pools, and 21 septic systems
    - Less frequent but yet notable structural features included cemeteries, towers, churches, schools, bridges, and dams
- 1,856 structures from longwall mines,
    - 427 reported effects from longwall mines,
    - 352 final resolution taking an average of 238 days,
    - 63 cases with Interim Resolution
    - 12 had no interim or final resolution at the end of the 3rd assessment period with an average length of time of 689 days
- 1,879 structures from room-and-pillar mines (with and without pillar recovery)
    - 29 reported effects
    - 7 final resolution of Company Not Liable with an average days to resolution of 107
    - 18 interim resolution
    - 3 outstanding
- Mitigation measures practiced
    - Banding, bracing, bridging, trenching, and cribbing

X.B.3 – Inventory of Water Supplies Impacts

- 2,789 wells, springs, and ponds were undermined
    - 1,212 from room-and-pillar mines
    - 1,502 from longwall mines
    - 75 from pillar recovery mines
- 683 reported effects were associated with the undermined water supplies
    - 238 from room-and-pillar mines
    - 20 from room-and-pillar with pillar recovery mines
    - 397 from longwall mines

  - 28 from post-closure mines
  - 267 classified as Company Liable
  - 182 classified as Company Not Liable
  - 234 classified as unresolved where an Interim Resolution or Outstanding resolution existed at the end of the 3rd assessment period
  - 212 of the 244 unresolved cases from the 2nd assessment were resolved. The remaining 32 were still unresolved as of August 20, 2008
  - 74-pct of reported effects were associated with water supply diminution
  - 66-pct of the reported effects were resolved as of the end of the assessment period
  - 34-pct of cases were still awaiting a final resolution
  - 57-pct, of resolved cases were Company Liable
- The number of days associated with water supply cases
  - 143 days required for a final resolution for room-and-pillar mines
  - 115 days for room-and-pillar with pillar recovery mines
  - 274 days for longwall mines
  - 259 days for closed mines
  - 12 cases exceeding three years without a final resolution

X.B.4 – Inventory of Land Impacts

- 108 land reported effects
  - 87 had final resolutions, taking an average of 206 days
    - 57-pct, or 50 assigned as Company Liable
    - 43-pct, or 37 assigned as Company Not Liable
  - 13 active and closed mines
    - 9 longwall mines with 88.9-pct of reported effects
    - 4 room-and-pillar mines with 11.1-pct of reported effects
  - 21 did not have a final resolution as of August 20, 2008
    - 18 with an Interim Resolution
    - 3 with Outstanding reported effect
- 5 additional land reported effects remained unresolved from 2nd assessment period

X.B.5 – Inventory of Stream Impacts

- 113.7 miles of streams undermined
  - 87.9 miles (77.3-pct of total) for longwall mines
  - 21.2 miles (18.6-pct) for room-and-pillar mines
  - 4.6 miles (4.1-pct) for room-and-pillar mines with pillar recover
- 55 stream investigation were made by the PA DEP
  - Twenty of these investigations were resolved during the 3rd assessment period
  - For every two miles of stream undermined, there was an investigation of stream flow diminution or pooling (average)
  - 688 day for a final resolution (average)
- Approximately half of the streams surveyed for macroinvertebrate diversity and composition had TBS below a PA DEP recommended indicating a negative influence on the TBS.

  - Various land use practices were the likely source of the negative influence with underground mining as the most likely but other practices such as agriculture were also present
  - It is not possible to compare these values with pre-mining conditions since no TBS scores are available, therefore, ascertaining the effect of mining per se was not possible
- 6 stream surveys at the Bailey Mine could be statistically compared to that mine's control stream value
  - Average post-mining TBS was highly significantly below the control stream score (i.e. more than two standard deviation of the mean below the control TBS), indicating the stream had not, on the average, attained recovery
  - 2 streams were within the 12-pct difference of the control stream indicating recovery or maintenance of pre-mining biological health and had therefore substantially recovered
  - 4 streams were far from attaining recovery

X.B.6 – Inventory of Wetlands Impacts

- 93.9 acres of wetland were measured
- 85 wetlands identified
- These numbers were developed, for the most part prior to the new TGD and therefore will undoubtedly increase as more detailed wetland assessments occur in the future

X.B.7 – Inventory of Impacts to I79

- 9 longwall panels were extracted under I79
- Observed features
  - Tension type distress features, i.e. longitudinal and transverse cracking, began to impact the highway immediately prior to and during the undermining of the highway by the longwall face
  - Compression type distress features, i.e. blowups or heaving, were more common after the longwall face had passed underneath the highway
- Some of the effects were transitory – associated with the passage of the dynamic subsidence wave
  - Successfully managed through traffic controls and temporary support measures
- Some of the impacts were permanent
  - Addressed through routine road maintenance such as milling, patching, repaving, and straightening guardrails
- Preemptive action was taken to prevent a potential catastrophic differential subsidence event of the bridges carrying I79 over Mooney (Tower) Road
- Over 19 million dollars was spent by PennDOT to monitor and rehabilitate sections of I79 impacted by longwall mining

X.C – Conclusions

Underground bituminous coal mining is a large and significant industry within the Commonwealth of Pennsylvania with a legacy of environmental consequence. For example, every day 13.5 acres of land are undermined by longwall mining. Laws and regulations have been promulgated requiring companies involved in this industry to remedy mining damage caused to homes, businesses, and land, replace impaired water supplies, and repair impacts to streams and wetlands. The regulations and technical standards set by the PA DEP have been put in place to assure that coal operations comply with ACT 54 of the Bituminous Mine Subsidence & Land Conservation Act and other related legislation. These regulations and standards require operations to address impacts when a mining permit is submitted and as permits are modified and extended. One of the special provisions of ACT 54 is the requirement by the PA DEP to produce an assessment of the surface impacts of mining every five years, hence this report.

Underground bituminous coal mines vary in size and in their manner of operation. Longwall mines are large, averaging 3,505-acres of surface land in size and mining at a rate of a little more than 58-acres/month. Several of these longwall operations were among the most productive underground coal mines in the US. The average longwall overburden was 687-ft. The High Quality Mine is classified as shallow (338-ft) and the Blacksville No.2 as deep (887-ft). The other six longwalls in this study are classified as average overburden. This data implied that a high percentage of impacts were expected with the extensive areas mined by longwall panels.

The average room-and-pillar mine undermined 321-acres of surface land and mined at a rate of a little more than 5-acres/month. The average overburden for these mines was 276-ft. Based on their overall overburden characteristics, 26 mines were classified as average, five as shallow, and five as deep. The average size of room-and-pillar mines with pillar recovery was 46-acres, representing about 15-pct of the total area mined for these six mines. The individual pillar recovery sections were relatively small, typically less than 1000-ft in length. These areas were mainly contained within production panels with overburden averaging 378-ft. Unlike longwall mines, these room-and-pillar mines generally didn’t have subsidence impacts, especially since the pillar recovery method accounted for such a small portion of the total.

X.C.1 - How are Structures Impacted?

Twenty-three percent of the 3,735 structures located over longwall panels had reported effects. The topographic condition of the structure, i.e. hill top, hillside, or valley bottom, didn’t have a significant influence on reported effects. Conversely, only 1.5-pct of the structures over room-and-pillar mines had reported effects. This was largely due to the pervasive use of “safe” pillar designs that minimizes unplanned mine subsidence.

However, pillar failure was the overwhelming cause of the 21 reported effects cases listed in BUMIS for room-and-pillar mines. The University analyzed the stability characteristics of pillars systems and found them to be adequate. Minor changes in the assumed conditions can significantly increase the risk for unstable conditions in the pillars and adjacent roof and floor strata. For example, floor heave on a wide scale is capable of producing a local subsidence basin.

The most notable structure impact was the Ryerson Station Dam in Greene County. The dam was never undermined. DCNR and the mine operator had an agreement to leave a block of solid coal underneath the dam. The PA DEP investigated the impacts and, in 2010, concluded that damage was caused by longwall mining at the Bailey Mine.

X.C.2 - How are Water Supplies Impacted?

Approximately one-quarter (683) of the 2,789 water supplies undermined had reported effects. Longwall mining accounted for 58.1-pct and room-and-pillar mines, with and without pillar recovery, account for the remaining 41.9-pct. With water supplies, impacts typically can be attributed to the formation of the subsidence basin but they can also occur in room-and-pillar mines, especially when these mines are relatively shallow. The topographic character of the surface did have an influence. Approximately 80-pct of water supplies remained viable after being undermined for all settings except for shallow hilltops where the impact rate was 75-pct and deep valley bottoms with 100-pct viability.

The relationship between the structures distance from a longwall panel and the reported effects provided insight as to what resolution outcome can be expected as the distance from mining increases. Approximately 77-pct of company liable impacts occurred within the 35-deg projection angle (RPZ). Nearly 86-pct of cases outside of the RPZ were determined as Company Not Liable. The final resolution of Repaired and Pre-Mining agreements occurred most often when structures were located very near to a longwall panel (< 35-deg). Conversely, when the projection angle was large (> 35-deg), companies more often resorted to purchasing properties as a final resolution.

For longwall mines the water supplies located over the mid or quarter-panel regions of the panel were 22 and 21-pct likely to be impacted, respectively. When located over the gate roads or outside of mining the likelihood of impact decreased to 18 and 17-pct, respectively. There was no data that would suggest that the shallow aquifer systems above deep longwall panels were being lost to mine inflow. Lastly, headwater springs were no more likely to be impaired by subsidence than any of the other water supplies undermined by longwall mining. However, any impairment to springs in headwater areas can have a significant impact on the biological health of the streams they are contributing to.

X.C.3 - How are Lands Impacted?

The 3,735 properties produced 108 reported effects for a rate of occurrence averaging less than 3-pct. Properties over longwall mines had a reported effects rate of 6.3-pct. Room-and-pillar mines, with and without pillar recovery, had close to zero (0.02) land reported effects. Therefore, land reported effects occurred mainly at longwall mines. The University identified 76 land reported effects that were classified into five categories: *mass wasting, tension cracks, settlements, compression ruptures, and unknown*.

- 37, or 48.7-pct, cases with tension cracks varying in scale and impact,

- 20, or 26.3-pct, cases with mass wasting ranging from large landslides hundreds of feet across (estimated from PA DEP photographs) to small mass soil movements that produced hump, rolls, and slips in the surface,
- 12, or 1.58–pct, settlement cases often disrupting drainage patterns resulting in ponding of water in fields, pastures, and residential lawns.
- 7, or 9.2–pct, cases of unknown cause.

Compression ruptures were found in steep-sided valley stream bottoms over the Bailey, Blacksville No.2, Cumberland, and Enlow Fork Mines that often trend in a Northwest to Northeast direction. These compression rupture features were caused by significant levels of horizontal stresses found in Pennsylvania's near-surface strata. Stress concentrations can be locally influenced by the shape and orientation of the stream valley and the physical properties of the bed rock strata. When compression ruptures occurred, they had an adverse impact on land in general and streams in particular.

X.C.4 - How are Interstate Highways Impacted?

I79 was impacted through traffic restrictions over recently mined longwall panels through:

- Vertical curvature and reduced sight distances of the highway, and
- Expenditure of over 19 million dollars to monitor and rehabilitate sections of the highway.

However, traffic flow was safely maintained at all times and no driving related injuries were reported as a result of longwall mining. The majority of the damages noted consisted of longitudinal cracking, mainly along the edges of the highway, and heaving, mainly along transverse joints. The vast majority of highway deformations were transient, i.e. occurring over relatively short periods of time (7 months). As a result, highway monitoring and rehabilitation efforts were concentrated over a relatively short span of time for each panel mined. Therefore, it was more cost effective to allow longwall mining to proceed than to condemn the coal needed to provide support for the highway.

X.C.5 - How are Streams Impacted?

All stream impacts have occurred over longwall mines. The length of streams undermined by longwall mines actually decreased from 97 miles during the 2nd assessment period to approximately 87.9 miles in the 3rd. At the same time the number of stream investigations more than doubled from 22 to 55. This increase is, in part, due to the greater emphasis being placed by the PA DEP to monitor stream conditions and to initiate investigations when impacts are discovered.

During the 3rd assessment period, a new protocol was implemented for examining the biological health of a stream. Its purpose is to help determine when streams are impacted and when they have been restored to their pre-mining states. Currently, there isn't enough pre-mining data to adequately determine which streams have been impacted and to what degree these impacts have occurred. As noted, the TBS values generated by this study do indicate that several streams have had negative impacts to their biological diversity when compared to a local control stream where mining has not occurred. However, the use of a single control stream for each mine may not adequately represent the diversity of stream characteristics in the undermined area.

The issue associated with controls streams should not be a problem in the future since new mining permits and permit revisions must contain pre-mining TBS values. Assessing stream impacts during the permit approval process requires the mining companies to take more pro-active approaches. This involves implementing mitigation controls that will help to retain flow and promote biologic diversity.

X.C.6 - How are Wetlands Impacted?

While this question can't be adequately addressed in this report, the necessary protocols to answer it in the future have been implemented during the 3rd assessment period. The recent permit revisions for longwall mines that have been submitted to the PA DEP reflect these changes. The 93.9 acres of wetlands identified in this study will likely increase in magnitude as more efforts are made by the mining operations to adequately characterize wetlands.

X.C.7 - Is ACT 54 working and is there Compliance?

The University understands that hardships are being experienced by citizens when their properties are undermined and impacts occur. The State legislature has put into place legislation from which regulations and standards have been developed to make sure these citizens are compensated.

The University has determined that for structures, water supplies, and land reported effects, 80-pct of all cases were solved in the first 600 days after the date of occurrence. The PA DEP is tasked to make sure that each case is handled in a fair manner and that the best scientific data available is used to resolve the reported effect. These processes take time. The system in-place that achieves a successful resolution in 80-pct of the cases in the first 600 days seems adequate. However, the other 20-pct of the case are lingering for much longer time frames and efforts should be continually made to resolve these cases.

The University further believes that the PA DEP has implemented appropriate protocols to assure that mining companies mitigate impacts to streams and wetlands undermined in the future. The efforts to remediate these impacts by mining companies are in many cases significant and will hopefully have the intended outcome.

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