VIII. Potential Impacts from Underground Mining

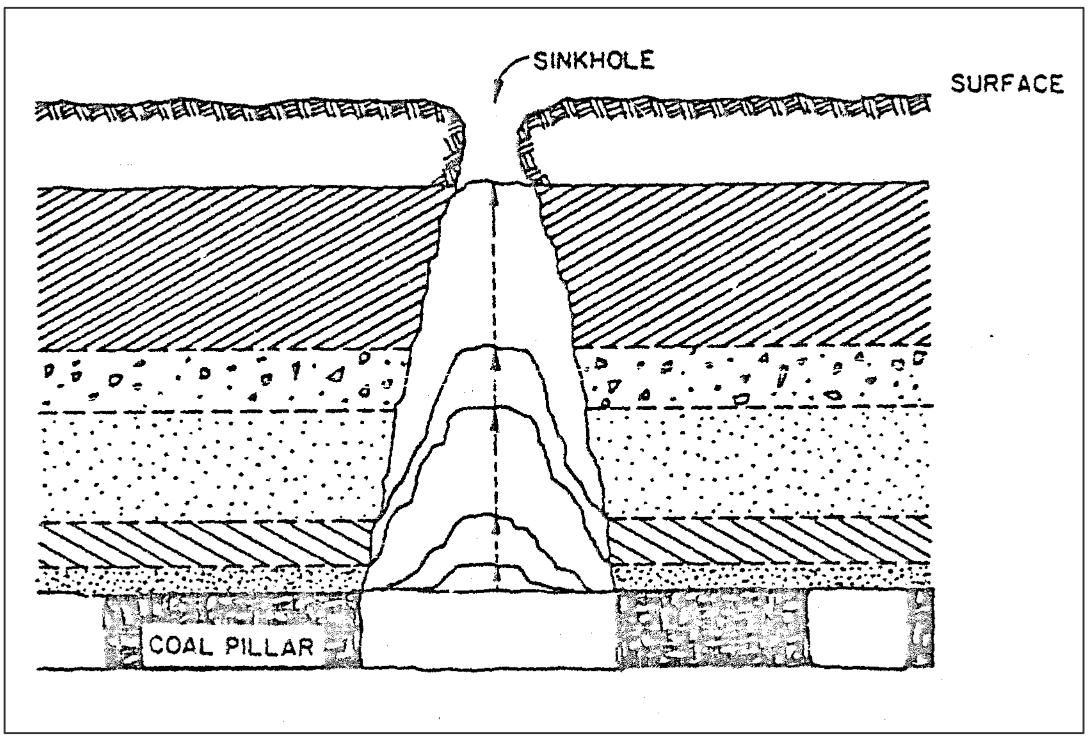
Mine Subsidence – An Overview

In order to consider potential impacts of underground mining on overlying structures, water resources, and surface land, it is first necessary to have some understanding of the mechanics of mine subsidence.

Mine subsidence can be defined as movement of the ground surface as a result of readjustments of the overburden due to collapse or failure of underground mine workings. Surface subsidence features usually take the form of either sinkholes or troughs.

Sinkhole subsidence is common in areas overlying shallow room-and-pillar mines. Sinkholes occur from the collapse of the mine roof into a mine opening, resulting in caving of the overlying strata and an abrupt depression in the ground surface (see Figure VIII.1).

Figure VIII.1
Sinkhole Subsidence Feature above an Underground Mine Entry



The majority of sinkholes usually develop where the amount of cover (vertical distance between the coal seam and the surface) is less than 50 feet. This type of subsidence is generally localized in extent, affecting a relatively small area on the overlying surface. However, structures and surface features affected by sinkhole subsidence tend to experience extensive and costly damages, sometimes in a dramatic fashion. Sinkhole subsidence has been responsible for extensive damage to numerous homes and property throughout the years. Sinkholes are typically associated with abandoned mine workings, since most active underground mines operate at depths sufficient to preclude the development of sinkhole subsidence. In accordance with the current regulations, the Department will not authorize underground mining beneath structures where the depth of overburden is less than 100 feet (30.5 m), unless the subsidence control plan demonstrates that proposed mine workings will be stable and that overlying structures will not suffer irreparable damage.

Subsidence troughs induced by room-and-pillar mining can occur over active or abandoned mines. The resultant surface impacts and damages can be similar, however the mechanisms that trigger the subsidence are dramatically different. In abandoned mines, troughs usually occur when the overburden sags downward due to the failure of remnant mine pillars, or by punching of the pillars into a soft mine floor or roof. It is difficult, if not impossible, to predict if or when failure in an abandoned mine might occur, since abandoned mines may collapse many decades after the mining is completed, if the mine workings were not designed to provide long-term support.

Longwall mining and room-and-pillar with retreat mining are high-extraction mining techniques, designed to induce concurrent subsidence. These methods may cause the overburden to sag, thus creating a subsidence trough over active mine workings. The resultant surface impact is a large, shallow depression or basin in the ground, which is usually circular or elliptical in shape, depending primarily on the geometry of the mine workings.

The subsidence impacts associated with active longwall mining operations are experienced more frequently than impacts from room-and-pillar operations in Pennsylvania because of the high production rates associated with longwall operations, the large zones of full coal extraction, and immediate overburden collapse. (A review of Department records applicable to the five-year report period suggests that approximately 60% of subsidence incidents are associated with active mining operations and the remaining 40% with abandoned mining operations). A more detailed discussion on subsidence above longwall panels is presented below.

Subsidence above Longwall Panels

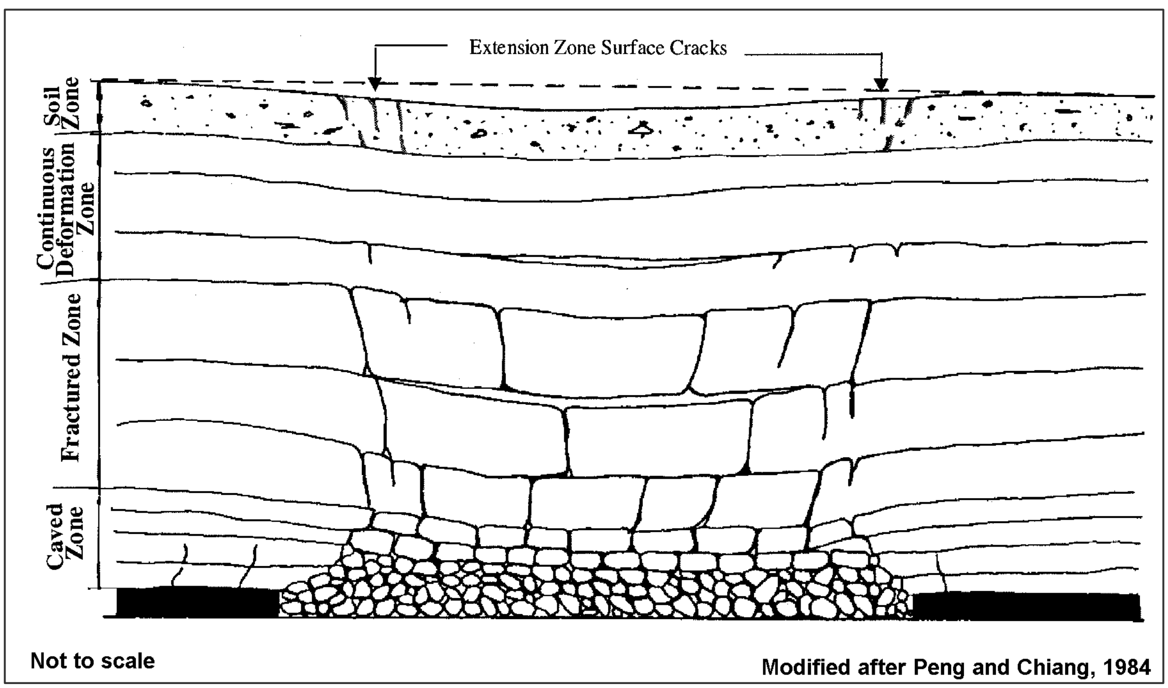
In longwall mining, 100% of the coal is removed within the confines of a “panel” which typically is several hundred feet wide and several thousand feet long. As the mining takes place, the overburden and the overlying ground surface subside. The phenomenon of subsidence can be understood by studying three characteristics of the process: the behavior of the overburden (*overburden movement*), the shape of the final subsidence trough or basin (*final subsidence profile*), and surface movements that occur concurrently with the mining operation (d*ynamic subsidence*).

Overburden Movement

Considerable research has been conducted to define the physical impacts of underground mining on the overlying rock mass. Much of the knowledge gained regarding rock fracturing above mine voids has come from studies of changes to groundwater flow characteristics above mines. The water-bearing capabilities and permeability of the overburden are heavily fracture-dependent and therefore give a good picture of the postmining fracture density and interconnectedness.

The response of the overburden can generally be divided into four zones. Zone 1 is a highly rubbleized, *caved zone* typically extending upward 6 to 10 times the coal seam thickness. Zone 2 is a *fractured zone* defined by massive block-type caving and vertical fracturing typically extending 24 to 30 times the coal seam height. Zone 3 is a zone of increased groundwater storage with dilated fractures (*dilated zone or continuous deformation zone*) and horizontal movements along weak-strong rock interfaces typically extending 30 to 60 times the seam thickness. Zone 4 is a *surface extension zone* where surface cracks typically open along the margins of the panel and above the working face of the panel (see Figure VIII.2). These surface cracks may open as the longwall face passes beneath the surface and close as the face moves away. Some researchers define an additional zone above zone 3 where the rock mass is constrained and there is no significant impact on groundwater movement or storage (develops where the mine is deeper than 60 times the seam thickness plus the depth of surface extension zone fracturing) (Hasenfus et.al., 1988; Peng, 1992; Kendorski, 1993).

Figure VIII.2
Overburden Movement above a Longwall Panel

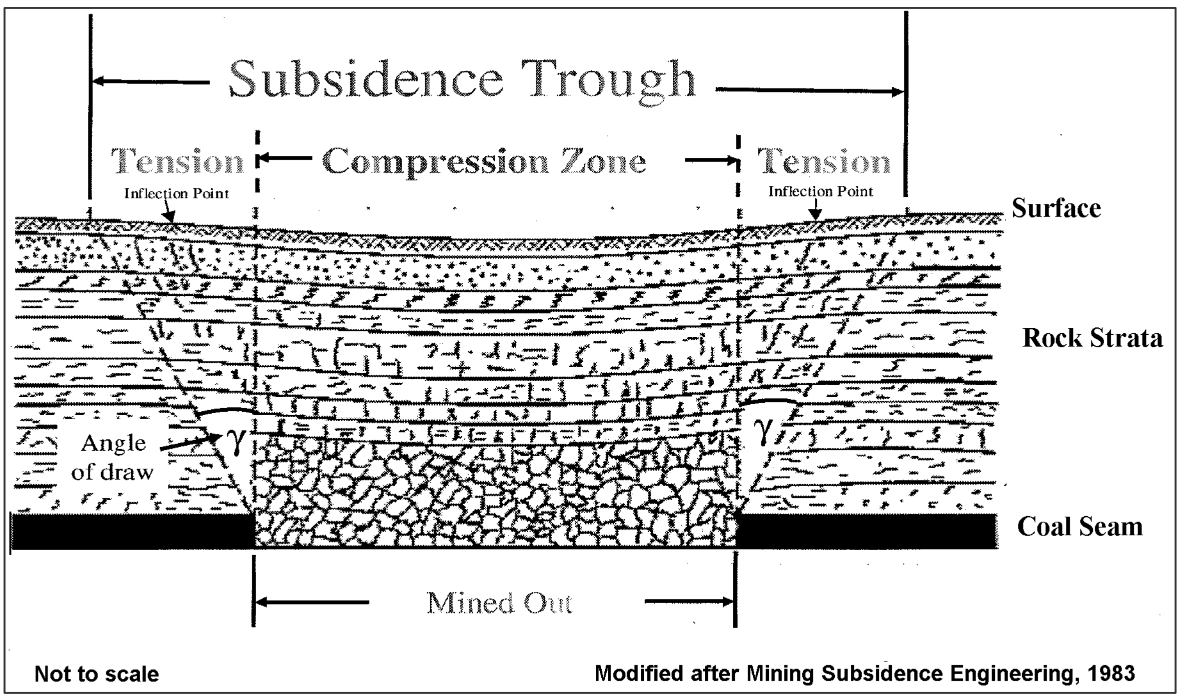


Various researchers use different vertical distances to mark the transition points. However, the numerous independent studies paint a similar composite picture of the vertical fracture profile above longwall panels.

Final Subsidence Profile

The subsidence trough present upon completion of mining a longwall panel is referred to as the final subsidence profile. In longwall mining, final subsidence troughs tend to be elliptical in shape. The surface area within a subsidence trough is normally larger than the area of the extracted coal seam (see Figure VIII.3). The angle formed between a vertical line projected upward from the edge of the extracted area which caused the subsidence and a line connecting the limit of subsidence on the surface with the edge of the extracted area is referred to as the angle of draw (?). The Department's staff has observed typical angles of draw in southwestern Pennsylvania in the range of 15 to 25 degrees. Angles outside of this range have been observed occasionally.

Figure VIII.3
Cross-section of Subsidence Trough Showing Angle of Draw, Compression Zone, Tension Zone, and Inflection Points



Ground movements within a subsidence trough have both vertical and horizontal components. Downward vertical movement usually occurs at all areas within the trough. The vertical movement is usually greatest at the center, and it progressively decreases at points along the trough profile until the limit of the affected surface area is reached. The Department's investigators have also observed instances where slight "heave" or upward movement has occurred.

Horizontal movement or displacement also occurs within the subsidence trough, as points on the surface tend to move horizontally toward the center. For adjacent points near the center, the horizontal distance between points is reduced resulting in compressive strains at the surface. The amount of compression decreases at points further from the center as the distance between neighboring points is reduced by lesser amounts, until a position is reached where the compression is zero. No horizontal movement will be experienced at this location. This position in the trough is referred to as the inflection point. Beyond this, the distance between neighboring points is increased, resulting in tensile strains on the surface. The inflection point also represents the location where the shape of the subsidence profile changes from concave to convex.

The areas of compressive and tensile strains within the subsidence trough are known as the *compression* and *tension* zones, respectively. The compression zone makes up the central portion of the subsidence trough, and develops above the center of the area of failure within the mine. The tension zone makes up the remainder of the subsidence trough, and usually extends beyond the collapsed area within the mine.

The relationships between the width and length of the longwall panel, the thickness of the mined coal seam, and the type and thickness of the overburden play an important role in the development of a subsidence trough. When longwall subsidence occurs, the maximum vertical movement occurs at the center of the longwall panel. In theory, when the length and width of the panel reach a critical size, subsidence at the center of the trough will reach a maximum possible value. Once this panel size is exceeded (supercritical situation), multiple points along the profile will subside this maximum amount and the subsidence trough will have a flat-bottomed central area (see Figure VIII.4). The maximum amount of subsidence will not increase regardless of how wide or long the panel becomes. Conversely, if the extraction area is less than this critical value, the maximum possible theoretical subsidence will not be achieved, and the resulting profile will be shallower and will not flatten out in the center.

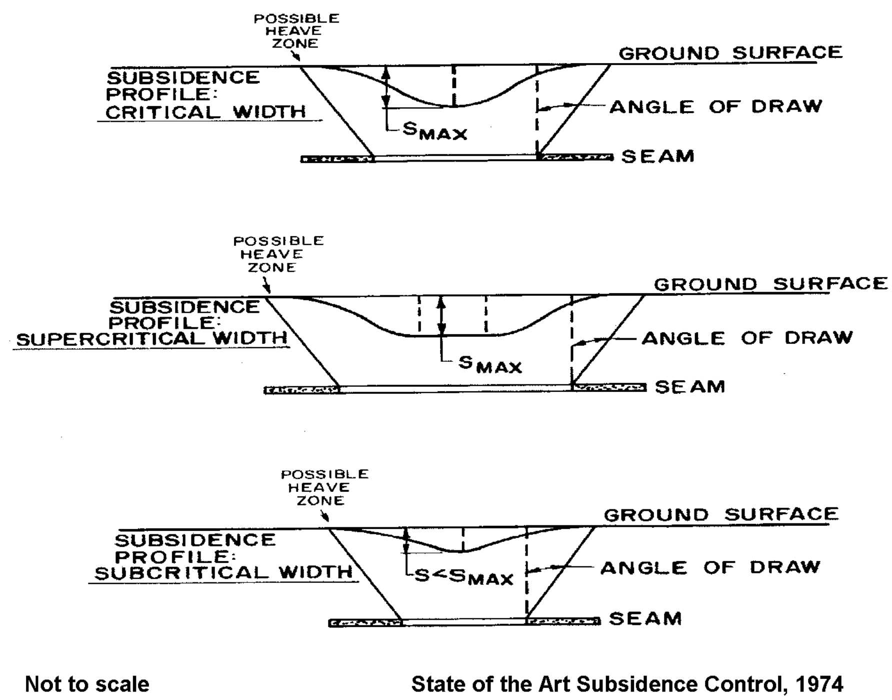
Since the width of the panel is the shorter dimension, it plays the primary role in the determination of the maximum amount of subsidence. Critical width occurs when the width of the extracted area is in the range of 0.9 to 2.0 times the depth of cover (Peng, 1992). Extremely wide panels operating under shallow cover conditions will result in supercritical profiles, with a central area being relatively flat. Narrow panels operating under deep cover conditions will result in subcritical profiles, causing subsidence values less than the theoretical maximum.

It should be noted that both the width and length of the longwall panel must be taken into consideration. Since most longwall panels are thousands of feet long, the profile along the longitudinal axes of the panel is nearly always supercritical. Profiles along the width of a longwall panel may be subcritical, critical, or supercritical depending on the width/depth ratio.

Dynamic Subsidence

All to often, property owners are only concerned with the location of their structure or surface feature relative to the final subsidence basin associated with the longwall panel. That is, a homeowner may know his structure is located at the center of the panel, therefore he believes he will only be impacted by forces within the compression zone. However, the development of a subsidence trough is a progressive event. When a longwall panel begins operation, initial surface subsidence will result in a subcritical basin. As the panel advances, the basin reaches critical dimensions, and ultimately flattens out as supercritical conditions are reached. A structure may initially be located in the tension zone of the basin as the panel approaches, causing a pulling of the structure towards the longwall face. Foundation cracks and separations at structural interfaces may occur as a result of the dropping and stretching of the ground surface. In addition, the structure may become out of level and plumb, tilting towards the approaching longwall face.

Figure VIII.4
Critical, Supercritical, and Subcritical Widths



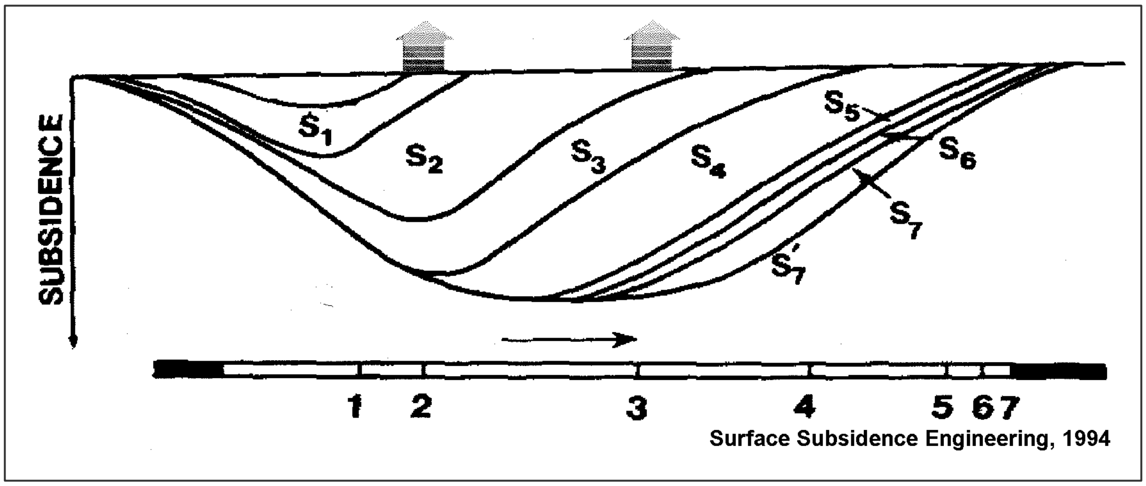
Not to scale State of the Art Subsidence Control, 1974

As the face advances to areas below and beyond the structure or feature, the ground surface may then be in compression since it is now located near the center of the existing subsidence basin. Cracks and separations, which previously appeared, may now close only to give way to new cracks, and perhaps buckling of foundation walls. The structure or feature may also return to its previous state of level and plumb relative to the longitudinal axis of the panel.

As the longwall face advances well beyond the structure or feature, the ground surface may again go into tension, particularly for structures located near the starting edge of the longwall panel.

This changing of the ground surface as the longwall passes through a given area is referred to as dynamic subsidence (see Figure VIII.5). Cracks in the surface land and structures may open and close as the "wave" passes through. This is particularly common in shallow cover situations where the surface may actually be located in the fracture zone, or within a relatively thin bending zone. In some cases, attempts to repair foundation cracks or road cracks with incompressible materials while the structure or feature is in tension have resulted in buckling of the wall or road when the ground goes into compression and the cracks attempt to close.

Figure VIII.5
Development of Dynamic Subsidence Profiles as the Face Advances



Potential Impacts of Longwall Subsidence on Surface Land and Structures

Based on the foregoing discussion, it is evident that the impacts of longwall mining on structures, surface features, or the ground surface depend on a number of factors. Primary factors that influence subsidence-induced ground movements include the thickness and physical properties of the overburden, the size and shape of the longwall panel, the thickness and inclination of the coal seam being mined, and the surface topography. If detailed information is available regarding these factors, subsidence profiles can be predicted with a reasonably high degree of accuracy.

Potential Impacts on Surface Lands

Following are general observations of Department staff regarding impacts on surface lands that may be affected by longwall mining:

- Ground cracks are common in the tension zone of the final subsidence basin regardless of the depth of mining.
- Ground cracks parallel to the longwall face are common above shallow mines resulting from the dynamic subsidence, however these cracks tend to close as the face passes beneath and beyond the surface area.
- In areas that are prone to landslides it is common for slips to occur, particularly in areas within the tension zone.
- Drainage of flat-lying areas can be adversely impacted. Changes in surface contours may cause low-gradient streams to pond and flood adjacent surface lands, sometimes creating wetlands or enlarging existing wetlands.

Potential Impacts on Structures

Damages to structures are generally classified as cosmetic, functional, or structural. Cosmetic damage refers to slight problems where only the physical appearance of the structure is affected, such as cracking in plaster or drywall. Functional damage refers to situations where the structure's use has been impacted, such as jammed doors or windows. More significant damages that impact structural integrity are classified as structural damage. This would include situations where entire foundations require replacement due to severe cracking of supporting walls and footings.

When considering impacts of longwall mining on structures, the following factors are also relevant:

- Size and shape of the structure
- Orientation of the structure relative to the longwall panel
- Age and current condition of the structure
- Design of the structure
- Quality of construction
- Thickness and type of soils beneath and adjacent to foundations

All three classifications of damages have been observed in structures that have been subjected to longwall mine subsidence. Some structures have been undermined with little or no noticeable impacts. At the other extreme, extensive cracking of foundation walls and footings and extreme tilting have required replacement of entire foundations. The following is a summary of general observations by Department staff regarding homes and buildings damaged by longwall mine subsidence.

- Structures within the central portion of the final subsidence trough may experience damage caused by the compression of the ground surface. Foundation walls below grade may buckle inward, and compressive forces may push walls and support posts out of plumb.
- Structures located within the tension zone of the final subsidence basin tend to tilt toward the center of the panel. They also tend to be damaged by tension or stretching of the

ground surface. Cracks in foundation walls, floors, and separations between structures and building components within a structure are common.

- Large structures (dwellings, barns, and commercial buildings) tend to sustain more damage than smaller structures (garages, sheds, and outbuildings).
- Structures with their long axes oriented parallel to the direction of the longwall face advance tend to sustain greater damage than structures with their long axes oriented perpendicular to the direction of face advance.
- Structures over shallow mines tend to sustain more severe damage than similar structures over deep longwall mines
- Structures located over shallow mines tend to experience greater damage from dynamic subsidence as opposed to comparable structures located over deeper mines. For example, the structure may be located at the center of the panel and may be perfectly level and plumb in the final subsidence basin, however the impacts of the dynamic subsidence may have caused extensive foundation damage requiring complete foundation replacement.
- It is common for cracks to open and close, and for subgrade walls to buckle and then return to normal during the dynamic subsidence phase.
- Cracks resulting from a structure's location in the tension zone of the final subsidence basin tend to remain open.
- Buckling of walls resulting from a structure's location in the compression zone of the final subsidence basin do not return to their original condition.
- Structures with pre-existing damage tend to sustain more damage than comparable structures without pre-existing damage.
- Damages tend to be concentrated in areas of weakness in a structure. Examples of such areas are windows, doorways, and areas where building components are not properly structurally connected, as well as areas where previous damages exist. It is common for existing cracks to lengthen and become wider, especially for cracked foundation walls and footings.

Potential Hydrologic Impacts of Underground Mining

Underground mine openings can intercept and convey surface water and groundwater. When excavated below the water table, mine voids serve as low-pressure sinks inducing groundwater to move to the openings from the surrounding saturated rock. The result is the dewatering of nearby rock units via drainage of fractures and water-bearing strata in contact with the mine workings. There is also the potential for impacts to more remote water-bearing units and surface water bodies depending on the degree of hydrologic communication. The extent and severity of the impact on the local surface water and groundwater systems depends on the depth of the mine, the topographic and hydrogeologic setting, and the hydrologic characteristics of the adjacent strata. Additionally, the amount and extent of mine subsidence-related changes to the rock mass govern the impacts of underground coal mining on surface water and groundwater.

In the flat-lying sedimentary rocks of southwestern Pennsylvania, underground mining is routinely accompanied by rock fracturing, dilation of joints, and separation along bedding planes. Rock movements occur vertically above the mine workings and at an angle projected away from the mined-out area. Mining-induced fracturing within this angle can result in hydrologic impacts beyond the margins of the mine workings. The zone along the perimeter of the mine that experiences hydrologic impacts is said to lie within the "angle of dewatering" or "angle of influence" of the mine. Angle of influence values of 27 to 42 degrees have been reported for the coalfields of northern West Virginia and southwestern Pennsylvania (Carver and Rauch, 1994; Tieman and Rauch, 1991).

These changes to the rock mass can change the water transmitting capabilities of the rock by creating new fractures and enlarging existing fractures. This typically results, at least temporarily, in detectable changes in permeability, storage capacity, groundwater flow direction, groundwater chemistry, surface-water/groundwater interactions, and groundwater levels. Depending on the ratio of overburden to seam thickness and the type of mining, measurable surface subsidence may occur. As previously discussed, this surface movement ranges in type from broad troughs approximating the area of coal extraction (typical of longwall mining) to complete collapse of overburden from the mine to the surface, e.g., sinkhole subsidence (generally associated with shallow room-and-pillar mining).

The various underground mining techniques have distinctly dissimilar impacts on local water resources. In short, the impacts of room-and-pillar subsidence tend to be localized, irregular, and often long delayed; whereas those of longwall subsidence are immediate, pervasive, systematic, and ultimately predictable (Booth, 1997). Therefore, the following sections outlining potential impacts to surface and groundwater resources are arranged by mining method.

The following sections review some general aspects of mining-induced impacts to water resources. However, the impacts of mine subsidence on surface and groundwater flow quantity and quality are not easily generalized.

"…The enhancement of the overburden hydraulic conductivity due to mining is neither uniform nor well-defined. Predicting impacts is difficult and there is no such thing as a 'typical' hydrogeologic setting or mine site." (Parizek and Ramani, 1996)

Potential Impacts on Streams and Surface Waters

The impacts of underground mining on surface waters can range from no noticeable impact to appreciable diminution, ponding, and/or diversion. The formation of subsidence-induced cracks, surface depressions, and/or sinkholes at the bottom of, or adjacent to, surface water bodies, such as streams, ponds, and lakes can lead to complete or partial loss of water due to leakage to the underlying strata. The resultant changes in surface slope can adversely impact drainage along irrigated fields, canals, sewers, and natural streams (Bhattacharya and Singh, 1985).

<u>Room-and-pillar Mining</u>

Room-and-pillar mining is generally less disruptive to nearby surface waters than high-extraction methods. Individual openings have only minimal localized draining impacts due to self-supporting roof members which span the opening to form a compression arch, with the support pillars serving as abutments. This "pressure arch" limits not only the deformational, but also the hydraulic influence of the opening (Booth, 1986). As additional entries are driven, the resultant network of intersecting drains act as a planar underdrain inducing downward leakage from overlying units. However, due to its built-in system of support pillars and limited mining-induced fracturing, significant drainage is typically limited to near-mine units.

Many detrimental impacts of room-and-pillar mining take years or even decades to occur as weak coal pillars deteriorate over time (Sgambat, 1980). Deteriorating or under-sized pillars that fail over time result in vertical extension of mine-induced fracturing. Dewatering impacts under these conditions can reach to a few hundred feet above the mine collapse areas (Rauch, 1985).

Rauch (1985) provides the following description of the dewatering impacts of room-and-pillar mining in the north central Appalachians.

"…Typically the greatest groundwater inflow rates occur near the working face of the mine where groundwater is being drained from storage, especially from fractures in mine roof rocks. In older mine sections, long term groundwater recharge to the mine is under more or less steady state conditions, originating ultimately from infiltration of precipitation or surface water. … This water typically enters the mine along rock fractures that intersect the mine ceiling, especially along vertical fracture zones . …Groundwater inflow is especially great in areas of mine ceiling collapse due to the leaving of too little roof rock support or to weak ceiling rock where fracture zones intersect the mine.

This drainage to room-and-pillar mines dewaters some overlying aquifers. The extent of this drainage is best determined from studies of water wells and springs overlying the mines. In general, significant dewatering extends to 20 to 100 feet vertically above drained room-and-pillar mines, but is usually restricted to within about 40 feet vertically of these mines."

"Localized, significant hydraulic impacts of deep headings and uncollapsed room-and-pillar mines will be seen in shallow aquifers only in areas (such as fracture zones) where vertical hydraulic connections are naturally high or where the mine itself is very shallow" (Booth, 1986). Shallow room-and-pillar mining (within 200 feet (61 m) and particularly within 100 feet (30.5 m) of the surface) drastically increases the likelihood of significant impacts to surface waters. This results from the mining's proximity to shallow, open fractures and unconsolidated surface material. Hobba's (1993) report on room-and-pillar mining in northern West Virginia found that,

"… mining and subsidence cracks increase hydraulic conductivity and interconnection of water-bearing rock units, which in turn cause increased infiltration of precipitation and surface water, decreased evapotranspiration, and higher base flows in some small streams…. Both gaining and losing streams were found in mined areas."

In deep settings, the impacts tend to be minimal. Bruhn and Speck (1986) reported the following impacts from room-and-pillar mining conducted beneath 600 feet of overburden in northern West Virginia.

"… Structurally, the overburden strata were little affected by the introduction of entries and cross cuts into the panel. Subsidence was virtually nil. Piezometric levels remained at their pre-mining elevations except (presumably) near mine level. Measured piezometric level variations were minor and no more than might be expected from seasonal variations…"

Room-and-pillar with retreat and Longwall Mining

High-extraction mining can potentially produce profound changes to nearby surface water resources. These impacts generally occur either by direct draining of groundwater to the mine or by mining-induced groundwater storage increases to near-surface aquifers. The caving, fracturing or bending behavior of the rock mass within a given zone depends on the characteristics of an individual stratum and its location relative to other strata.

Studies conducted above longwall mines by researchers at West Virginia University have provided insight into mining-induced impacts to streams. Dixon and Rauch (1988) observed stream depletion associated with longwall mining at three mine sites in West Virginia. Dewatering was less severe at mines with greater overburden thickness. Recovery times for stream flow ranged from eight months to five years. Tieman and Rauch (1987) found that streams located above regional base level and undermined by longwall panels less than two and one-half years old were partly to completely dewatered during base-flow conditions. They found that streams located above regional base level and also above panels at least three years old had normal flow. Water lost from streams did not penetrate to the mine, but instead migrated downward through probable subsidence fractures to near regional base level, where it migrated laterally through a sandstone unit to discharge at a master stream over the mine. Carver and Rauch (1994) drew the following conclusions regarding impacts to streamflow based on their study of a longwall mine in West Virginia.

"…Subsidence from longwall mining typically reduced stream discharge for two to three years. Panels positioned beneath upland catchment areas and not under streams caused no apparent stream dewatering…. Monitored stream reaches within the angle of draw zone of an adjacent panel did not normally become dewatered for panels older than 2.3 years. However, stream reaches in basins less than 200 acres in size often experienced dewatering for up to 3.1 years after undermining…. After two to three years since mine subsidence occurred recovered streams display lower high base flow and higher low base-flow discharge, or more uniform base-flow discharge, compared to unsubsided streams…. Water diverted from affected streams and supplies remained in the shallow groundwater flow system and probably did not penetrate deeper than local base level, as shown by the reported low groundwater inflow rate to the mine and by the most impacted streams having returned to "normal" flows downgradient. The lost waters probably moved downgradient as underflow through shallow aquifers and then returned to streamflow in unsubsided or recovered areas."

One important aspect of overburden movement relative to high-extraction mining's potential impacts to surface waters is the formation of surface extension zone fractures. An extension zone forms at panel edges and at the traveling panel face and is most pronounced near the surface. Surface extension zone fractures are typically 50 to 100 feet (15 to 30.5 m) deep. This near-surface zone of increased permeability and storativity can result in shallow aquifer and surface water impacts even where overburden to seam ratios are considerable and there is no direct avenue for drainage to the mine.

Peng et.al. (1994) included the following description of stream impacts due to longwall mining in West Virginia. Their study documented subsidence-induced ponding along stream valleys.

> "… When a coal seam is extracted under a surface stream, the stream water may form migratory ponds following the surface waves created by the dynamic surface subsidence process. If a thin overburden exists, the water in a migratory pond may fall into the surface dynamic cracks as it travels across the longwall panel. After the surface has reached the final subsidence stage, the migratory ponds will cease moving and stop near the chain pillar area and form a stationary pond. Loss of water may occur in a stationary pond, because it is located in the high-tension zone (or surface crack zone) where secondary permeability increases. …"

From a watershed perspective there appears to be a relationship between groundwater interception by high-extraction mining and base-flow recharge to streams. Cifelli and Rauch (1986) studied a high-extraction mining operation in north-central West Virginia and concluded that base-flow streams were significantly impacted where at least ten percent of their watershed was undermined and subsided, and had dried up where at least 25 to 30 percent of their watershed was so affected.

Potential Impacts on Wells and Springs

<u>Room-and-Pillar Mining</u>

Wells and springs in proximity to room-and-pillar mining have the potential of being adversely impacted. Commonly the mechanism is direct draining of groundwater to the mine. Generally, where the support pillars are stable, these impacts are localized. Dewatering typically extends to 20 to 100 feet (6 to 30.5 m) above the mine workings. Wells that terminate at depths greater than 100 feet (30.5 m) above the mine roof are generally safe. In cases where support pillars fail, additional subsidence may result in more extensive fracturing. In these instances impacts may be up to 200 (61 m) or even 300 feet (91.5 m) above the mine roof. Subsidence impacts may be extended where mining is close to vertical fracture zones.

<u>Longwall and Room-and-Pillar with Retreat</u>

The severity of impacts to groundwater sources above high-extraction workings depends on the distance of the groundwater source above the mine workings, the topographic setting of the water supply, and the overburden lithology. Typically groundwater within the caved zone and all or part of the fractured zone will drain directly to the mine. Wells drawing water from these zones will generally be severely impacted. If the overburden is thick enough, a zone of dilated fractures may develop above the fractured zone. Water levels within this dilated zone typically drop during undermining. The strata in this dilated zone are deformed but there is no widespread development of vertical fractures. The groundwater within the dilated zone therefore does not usually drain to the mine level although water levels may drop due to increased storage. Hill and Price (1983) found that temporary water losses from the upper fractured zone and dilated zone occur primarily due to increased fracture porosity, leading to lowered water levels and increased groundwater storage at these levels. The majority of research indicates that impacts to supplies within the upper fractured zone and the dilated zone are temporary. In fact, the postmining water-bearing capabilities of these units are often enhanced due to the larger fracture apertures. For a typical coal seam in southwestern Pennsylvania, the zone of partial to complete overburden dewatering extends between about 120 and 400 feet (37 to 122 m) above the mine (Rauch, 1985). The most extensive dewatering and least recovery for wells occurs near the centers of longwall panels where subsidence fracturing is most severe. The most pronounced dewatering of springs appears to be over longwall panel and mine edges in the extension fracturing zones (Coe and Stowe, 1984; O'Steen, 1982; Rauch et.al., 1984). Impacts from near-surface extension zone fractures tend to be localized. However, in cases where mining is shallow, the extension zone fractures may intersect deeper subsidence fractures and result in direct avenues to the mine.

Rauch (1985) presents the following description of impacts due to high-extraction mining.

"… any water level drops were temporary for aquifers located at least 400 feet above a mine. Water levels and yields for such wells returned to normal after subsidence was complete. However, studies by Booth (1984) and Coe and Stowe (1984) indicate that partial to complete dewatering has occurred for aquifers as much as 600 to 700 feet above deep mines in the Kittanning and Pittsburgh coal seams respectively with little apparent recovery of water level after mining. … Exceptions to general aquifer dewatering trends also exist in the opposite sense. Wells located within 100 to 150 feet of a stream may retain water in close vertical proximity (as close as 175 feet) to Pittsburgh coal deep mines. Apparently influent stream conditions keep these wells recharged with water to compensate for well leakage to the deep mines."

Leavitt and Gibbens (1991) reviewed the response of 174 domestic wells to longwall coal mining in southwestern Pennsylvania, northern West Virginia, and southeastern Ohio. Their research focused on groundwater sources in the dilated zone and the near surface (extension zone) area. Of the 174 sources of water, 99 (57%) were adversely impacted by mining. Thirty-seven of the 99 impacted water supplies were temporarily affected, recovering without intervention. The remaining 62 supplies required intervention. Of this group, 57 supplies (92%) suffered from water quantity problems. Drilled wells exhibited the fewest impacts, with 68 % of the original 137 sources ultimately returning to service. Of the 14 dug wells involved, 65% were affected, 43 % ultimately returned to service. Fifty-seven percent of the 22 springs were unaffected or resumed flow in their original location. In a number of locations they found that after a spring ceased to flow, a new spring developed downslope from the original site. This was attributed to a redistribution of groundwater flow in the near surface.

Pennington et.al, (1984) conducted research on the impacts of longwall mining on shallow and deep overlying aquifers in western Pennsylvania. Their study found shallow water-bearing zones that were isolated from mining impacts due to the presence of aquitards in the rock strata overlying the mine. An aquitard is a zone of low permeability relative to surrounding rock units. When aquitards are located far enough above the mine workings to avoid fracturing they can retain their flow retarding properties and serve to protect shallower water resources. Pennington's findings relative to groundwater supply impacts include the following:

" …Water levels in deep wells encountered significant declines which were closely related in space and time to the mining front.

The shallow aquifer zone is isolated from major impacts caused during mining by an aquitardal layer which retained its confining properties during and after subsidence.

The postmining water level in most deep wells remained below premining levels. However, a slight to complete water level recovery occurred in most deep wells after the water level declines associated with the passage of the mining front. This recharge-discharge equilibrium was reached within two months after mining termination.

Shallow domestic wells encountered no significant impact from nearby longwall mining during the monitoring period. Besides occurring as a very localized phenomenon, dewatering of the shallow aquifer zone was minimized by aquitardal layers.

Deep well water production over the mine panel would be greatly affected by the mining operation. In several wells, dewatering of the deep aquifer zone decreased water levels beyond the well depths…"

Matetic and Trevits (1990) studied impacts to a series of groundwater monitoring wells located across two longwall panels in Greene County, Pennsylvania. Their findings included:

" … Well yield and specific capacity for wells located beyond the current panel…(approximately 500 to 1700 feet) appear to be unaffected by mining.

…Dramatic water level fluctuations, for wells located in the current panel occur when the longwall face is less than one overburden thickness from the well. Water level fluctuations and ultimate water loss occur before the process of subsidence is completed. Fluid level recovery appears to also begin prior to completion of the subsidence process…

A loss of water may only be a temporary condition, fluid level recovery was observed in most of the wells… Furthermore, a loss of water does not imply that all of the water contained in the overburden rock mass has been lost to the gob (caved) zone. Water lost from upper zones may be confined at some deeper level below the bottom of the well…"

In studies conducted in Greene County, Pennsylvania, Stoner (1983) observed that water pressure declines became smaller as the separation between the mine and well bottoms became greater, that hydraulic heads dropped above longwall panels where they did not above room-and-pillar operations, and that partial recovery of water levels occurred after mining. Moebs and Barton (1985) reported that in 150-foot (46-m) wells penetrating a shallow aquifer over a longwall mine 750 – 1000 feet (228 – 305 m) deep, water levels declined greatly (> 100 feet) on the panel's centerline, but only slightly on the periphery and not at all at 580 to 1270 feet (177 to 387 m) outside the subsidence area.

Booth (1990) provided the following summary of the hydrologic impacts of high-extraction mining on shallow aquifers.

"…subsidence above deep longwall and pillar-extracted mines can affect shallow aquifers without drainage to the mine, by altering near-surface hydraulic properties and the hydrologic balance through fracturing. The major results are lowered heads (affecting well and springs) because of increased porosity, leakage from aquifers to lower drainage levels, and altered hydraulic gradients, particularly in upland recharge areas. In discharge areas, these effects are less severe, but head losses through direct drainage to the mine are more likely. Subsidence can also have positive effects by increasing well yields…"

In summary, aquifers and water supplies are generally partially to totally dewatered within the caved and fractured zones above subsided deep mines. These supplies routinely show no short-term recovery. Supplies located higher in the subsidence profile (upper fractured zone and dilated zone) tend to suffer only partial and temporary water losses (Rauch, 1989).

Other Causes of Impacts on Structures and Water Supplies

There are many factors that cause damages to structures other than mine subsidence. Most structures have some degree of damage even prior to mining. Most property owners are not fully aware of the condition of their home and property since they do not generally conduct routine and thorough inspections.

Some of the more common reasons for structural damages other than mine subsidence are:

- Settlement of soils due to the weight of surface loads
- Landslides and soil creep
- Shrinking and swelling of soils
- Freezing and thawing of soils
- Surface and subsurface erosion
- Poor construction methods
- Structural deterioration due to age, lack of maintenance, or misuse
- Structural movements

Likewise, there are numerous causes, both natural and man-induced, that can mimic the impacts seen from underground mining near water supplies. Naturally occurring impacts to well yield include:

- drought (affects springs also)
- plugging of the well screen via incrustation
- plugging of the well screen by iron bacteria
- clogging of the well due to improperly sized well screen and migration of fines into the well.
- clogging of the well resulting from corrosion of well screen

Man-induced causes include:

- increased groundwater withdrawals (new wells in area)
- nearby surface mining activities

Additionally, water quality complaints must be investigated with an appreciation of ambient groundwater quality. In large areas of the bituminous coalfields indicator parameters for mine drainage, such as iron and manganese, occur naturally at concentrations above drinking water limits.

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