Section 3: Mining Operations

3.A – Overview

From August 21, 2013 to August 20, 2018 forty-nine (49) underground bituminous coal operations undermined 28,854 acres in Pennsylvania. These mines were owned and operated by 11 companies, and included three types of mines: longwall, room-and-pillar, and pillar recovery. Mines in the 5th assessment where higher in number but lower in the acres of mining compared to the 4th assessment period. Two new longwall mines started operating in Pennsylvania during the 5th assessment period, Harvey and Tunnel Ridge (Harvey Mine is a portion of Bailey Mine that was re-permitted). In addition, 10 new room-and-pillar mines opened during the 5th assessment. During this same period, 19 mines closed. As with the last assessments, most of the acreage mined is occurring in the Pittsburgh coalbed longwall mines of Washington and Greene Counties. Figure 3-1 shows all mining in longwall operations that occurred during the 5th assessment period.

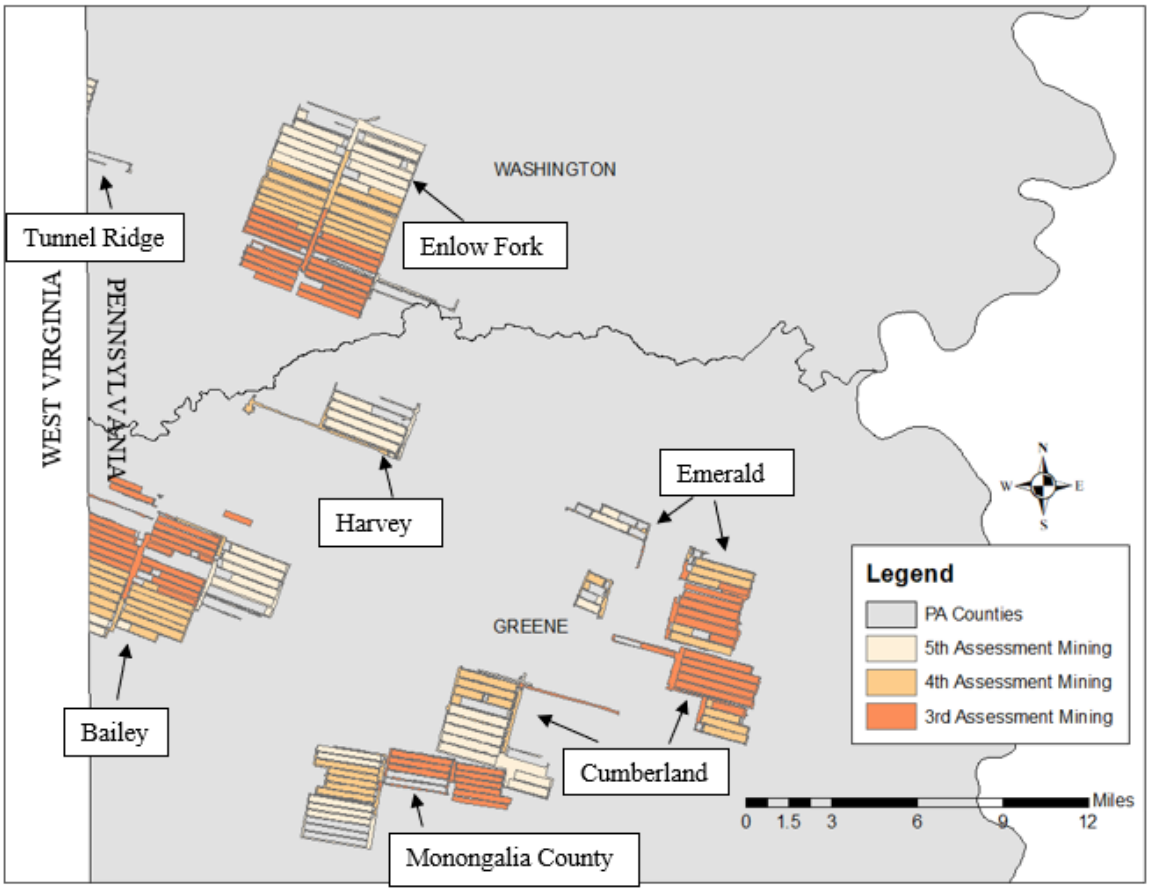

Figure 3-1. Map of all longwall mining extended during the 5th assessment period.

As specified in the scope of work (Appendix L), the University performed a detailed analysis of all active mines in the 5th assessment period from the data collected from the PADEP and mine operators. During this period, acres mined, mining type and method, operating company, and overburden were identified and analyzed.

3.A.1 – Disclaimer

Six-month mining maps near the end of the 5th assessment period were not available to the University. As a result, several areas (most notable the 10W panel of Monongahela County mine) are not included here. Likewise, areas mined in previous assessments but not logged in the Act 54 reports were added to the 5th assessment for completeness in future analysis. These mines were analyzed from a standpoint of mining type, acres mined, overburden, and impact occurring over the mines. Barbara 2, Brubaker, Gillhouser, Nolo, Penfield, Toms Run, Kimberly, and Twin Rocks AA. All had relatively small areas missed in the 4th assessment period and were added to the 5th assessment data.

3.B - Mines in Operation during the 5th Assessment

Of the 49 active mines during the 5th assessment period, seven were longwall mines, 37 room-and-pillar mines, and five pillar recovery mines. The active mines were determined by reviewing dates of mining on 6-month mine maps provided by the PADEP, the BUMIS database, and the Mine Safety and Health Administration (MSHA) Mine Data Retrieval System where quarterly miner employment rates are available. For longwall mining operations "Plus Maps" were used when applicable to determine the exact face position of the longwall mines during the assessment period.

3.B.1 – Types of Mining Operations

Each of the 49 mines are categorized as: a longwall mine, a room-and-pillar mine, or a pillar recovery mine. These three mine types represent all the types used for the extraction of underground bituminous coal in Pennsylvania. Given the requested analysis of subsidence impacts by mining type, differentiation between mine type and mining method provides essential clarity. Within a mine, different mining methods can be used. In a longwall mine, the room-and-pillar mining method is used for developing main, gate road, and bleeder entries. Within pillar recovery mine, room-and-pillar mining method is used to drive main entries and develop the sections where pillar recovery will occur. The pillar recovery mining method involves the extraction of specific coal pillars in a production panel. Room-and-pillar mines only uses the room-and-pillar development method. Table 3-1 shows the extraction ratio used by the different mining methods. The room-and-pillar developments have the lowest extraction ratio while longwall panels have a 100 % extraction ratio. The extraction ratio is important because the higher the extraction ratio, the higher the potential for subsidence and, in general, the more likely impacts will occur. The least amount of subsidence should be expected from room-and-pillar mines while longwall should have the greatest.

Table 3-1. Extraction ratio by mining method.

Mining Method	Extraction Ratio (Re)
Room-and-Pillar Developments	0.4 to 0.7
Pillar Recovery	0.7 to 1.0
Longwall	1.0

3.B.2 - Total Acres Mined

The 49 active mines mined 28,854 acres during the 5th assessment period (Table 3-2). The longwall mines mined 61.9 % of the total acreage and the pillar recovery mines had the least percentage, 8.7 %, of acres mined.

Table 3-2. Acres mined per mining type.

Mine Type	Total Acres Mined		
	3rd Assessment	4th Assessment	5th Assessment
Longwall	24,607 (64.3 %)	17,005 (54.3 %)	17,873 (61.9 %)
Room-and-Pillar	11,552 (30.2 %)	12,353 (39.4 %)	8,487 (29.4 %)
Pillar Recovery	2,097 (5.5 %)	1,984 (6.3 %)	2,494 (8.7 %)

Figure 3-2 compares the acres mined per mine type for each assessment period. The 3rd assessment period mined the most acres and the 5th assessment period mined the least. There was a large drop on acres mined in longwall mining from the 3rd assessment to the 4th assessment, but the acres did not drop in the 5th assessment. However, for room-and-pillar the acres decreased from the 4th to the 5th assessment period. The pillar recovery mines have had slight changes in acres mined but these values are not significant. One reason for the decrease in acres mined in both the longwall mines and the room-and-pillar mining is the rate of mining. In past assessment periods, the mine operators were often working seven days a week, 24 hours a day. Currently, most operations mine five days a week.

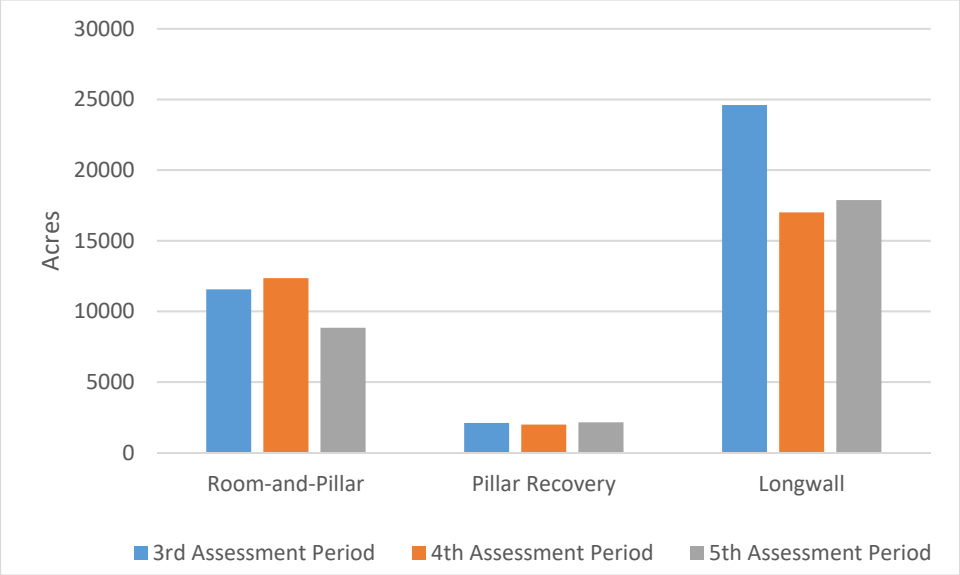

Figure 3-2. Area mined per assessment period for the three mine types.

As the subsidence impacts are analyzed on an ongoing basis, it is important to consider changes in mining activity that may influence the magnitude of subsidence impacts observed during the 5th assessment period. Over the last 15 years the total number of mines has been relatively constant, with a slight increase from the 4th to the 5th assessment period. However, while the number of mines has remained fairly constant, the acres of coal mined has decreased by 24.5 % (Figure 3-3).

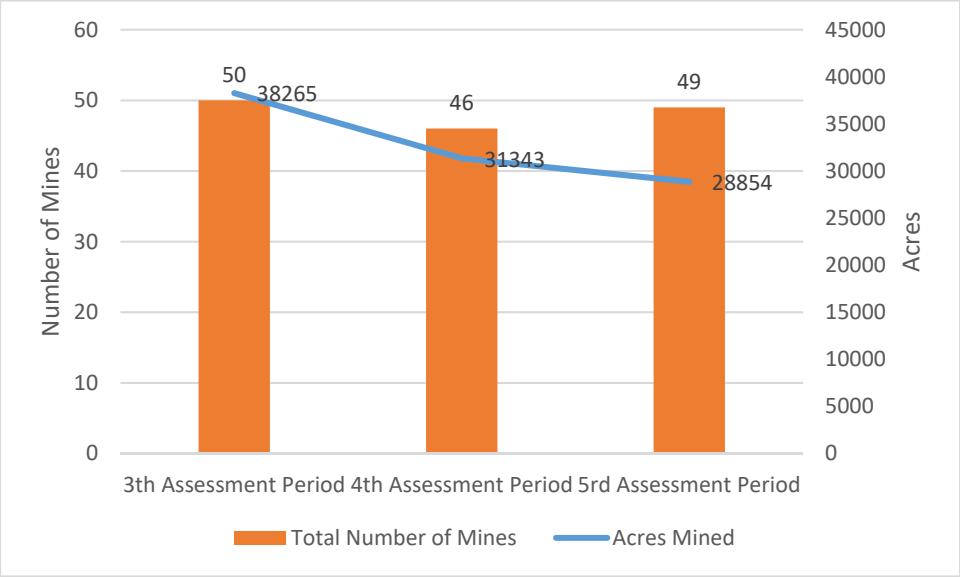

Figure 3-3. Total number of mines versus acres mined over the last 15-years.

3.B.3 - Mining Methods with expected Subsidence

It is especially important to track areas where pillar recovery and longwall mining methods occur, because this is where deformations and strains are projected to be greatest (Appendix D).

In the 5th assessment there were parts of 55 longwall panels mined, seven of these were still active as of August 20, 2018. Changes in panel characteristics were tracked and analyzed compared to impacts trends over the last 5-years.

The Longwall Mining Method: The longwall mining method (panels only) undermined 16,700 acres during the 5th assessment period. This extent of mining is summarized by panel in Table 3-3). The average panel width is approximately 1,400-ft and ranged between a minimum of approximately 1,000-ft and a maximum of approximately 1,600-ft. The average acres mined per day was approximately 1.13 with a minimum of 0.4 and a maximum of 2.21.

Table 3-3. Longwall panel size, shape, and mining history.

Mine	Panel	Start	End	Acreage	Acres/ day	Width	Length	Status*
Bailey	1L	7/28/14	6/29/15	371	1.10	1462	11049	C
	2L	7/14/15	6/17/16	503	1.48	1495	14359	C
	3L	6/27/16	2/13/17	400	1.73	1559	11458	C
	4L	2/27/17	9/5/17	419	2.21	1505	12154	C
	5L	10/9/17	8/6/18	410	1.36	1571	12162	C
	6L	8/20/18		40		1578		A
	16I	8/21/13	10/28/13	86	1.26	1483		C
	18H^	9/16/13	1/27/14	129	0.97	1484	4070	C
	19H^	6/16/14	10/6/14	106	0.95	1491	3397	C
Cumberland	61	8/21/13	9/17/13	17	0.63	1584		C
	62	10/4/13	6/15/14	398	1.57	1587	11026	C
	63	7/1/14	4/12/15	397	1.39	1570	11026	C
	64	4/17/15	1/7/16	399	1.51	1577	11070	C
	65	1/26/16	10/1/16	398	1.60	1575	11066	C
	66	10/19/16	6/14/17	398	1.67	1574	11079	C
	67	7/7/17	2/13/18	268	1.21	1557	7494	C
	68	2/22/18	8/20/18	245	1.37	1561		A
Emerald	D1	4/28/14	2/9/15	235	0.82	1387	7402	C
	D2	4/27/15	11/21/15	112	0.54	1379	3550	C
	E3	8/21/13	10/7/13	35	0.74	1454		C
	E4	11/9/13	4/30/14	146	0.85	1433	4455	C
Enlow Fork	E-24	8/21/13	1/15/14	191	1.30	1483		C
	E-25	12/17/13	12/31/14	316	0.83	1485	9203	C
	E-26	9/25/14	2/18/16	394	0.77	1485	11580	C
	E-27	5/1/15	9/19/16	415	0.82	1508	12152	C
	E-28	8/13/16	4/30/17	383	1.47	1527	11118	C
	E-29	7/10/17	7/8/18	374	1.03	1507	10838	A
	F-23	7/29/13	8/31/14	416	1.05	1495	12157	C
	F-24	5/21/14	4/17/15	416	1.26	1494	12162	C
	F-25	2/12/15	4/14/16	414	0.97	1487	12153	C
	F-26	4/7/16	8/7/17	421	0.86	1510	12155	C
	F-27	11/30/16	6/11/18	333	0.60	1513	9628	C
	F-28	3/12/18	8/20/18	65	0.40	1555		A
Harvey	1A	3/8/14	5/4/15	492	1.17	1495	14359	C
	2A	6/11/15	12/12/16	503	0.91	1483	14877	C
	3A	1/3/17	2/4/18	506	1.27	1486	13025	C
	4A	2/19/18	8/20/18	252	1.38	1455		A
Monongalia County	10W#	-	-	-	-	1102		A
	11W	4/19/17	12/31/17	298	1.16	1113	11836	C
	12W	4/25/16	2/14/17	300	1.02	1112	11831	C
	13W	2/8/15	3/29/16	294	0.71	1084	11826	C

	19W	5/6/14	2/2/15	285	1.05	1080	11828	C
	20W	5/6/14	2/2/15	298		1087	11944	C
Tunnel Ridge	4R	-	-	37	-	994	1790	C
	5R	-	-	46	-	1001	2198	C
	6R	-	-	68	-	1199	2690	C
	7R	-	-	81	-	1197	3174	C
	8R	-	-	77	-	1207	3017	C
	9R	-	-	91	-	1213	3487	C

*A=Active Panel; C=Completed Panel
^ - Partially mined in West Virginia
# - Panel 10W was mined in the 5th assessment period but no 6-month mining maps were received.

The Pillar Recovery Mining Method: The pillar recovery mining method is not extensively used in Pennsylvania. Three of the four mines practicing pillar recovery are extracting the Sewickley coalbed in Greene County. The other mine is extracting the Lower Kittanning coalbed in Indiana County. The full extraction or partial extraction of the pillars over a typical pillar recovery mining front has the potential to form a subsidence basin.

During the 5th assessment period, 275 acres of surface were undermined by the pillar recovery mining method. Pillar recovery accounts for less than one percent of the mining that occurred during the 5th assessment period. Table 3-4 shows that acres of pillar recovery had increased slightly from the Crawdad Portal B and 4 West Mines and had decreased slightly over in the Nolo and Prime 1 Mines.

Table 3-4. Total acres mine during the last three assessment for the pillar recovery mining method for pillar recovery mines in the 5th assessment.

Mine Name	**Pillar Recovery, Acres**		
	3rd	**4th**	**5th**
Nolo	50	23	14
Crawdad	86	75	84
4 West	9	127	137
Prime 1	0	36	18
Quecreek	0	8	22

The Room-and-Pillar Mining Method: The two most likely causes of surface subsidence above room-and-pillar developments are long-term pillar instability and floor heave caused by pillars punching into the floor:

> *Long-term pillar instability*: This occurs when the strength of the coal pillars (S_p) is exceeded by overburden pressure (σ_p). If the calculate Factor of Safety drops below one, there is a potential for pillar failure. In the unlikely event that multiple pillars fail, subsidence may occur, especially at low overburdens. The overburden pressure is a function of the weight of the overburden rock and the extraction ratio, as shown below. It

is possible that long-term pillar instabilities are at least partially responsible for the subsidence impacts over inactive mines (Sections 4.D.4; 5.D.4; 6.D.3).

$$Safety\ Factor\ (SF) = S_p/\sigma_p\sigma_p = \frac{\sigma_i}{(1 - Re)} = \sigma_v * \frac{(pl1 + rw)^2 - (pl2 + rw)^2}{(pl1 * pl2)^2}$$

Where: $\sigma_v = h$ x 1.1
h = depth of mining
pl = pillar dimension
rw = room width

Pillar punching: Pillar punching or floor heave, occurs when pillars are pressed into weaker layers, often claystone, in the mines' floor. There were no known occurrences of pillar punching during the 5th assessment period. However, the University is only able to identify pillar punching if it is noted on the 6-month mining maps or further information is provided by the PADEP.

3.B.4 – Age of Mining Operations

Since the close of the last assessment period in August 2013 there have been 11 new mines opened in the 5th assessment period. Ten of the mines are room-and-pillar mines: Brush Valley, Coral Graceton, Kojancic, Kingston-West, Cass 1, Crooked Creek, Maple Springs, North Fork, Acosta, and Cresson Mines. The Tunnel Ridge longwall mine also mined in Pennsylvania for the first time during the 5th assessment period. The remaining mines have been active in previous assessment periods. Figure 3-4 shows the ages of the mines from 1994 when the PADEP started tracking mining for Act 54 until the present. There are six mines in the 5th assessment that have been active since the 1st Act 54 Assessment; five longwall mines, Bailey, Enlow Fork, Emerald, Monongalia County (previously known as Blacksville 2) and one room-and-pillar mine, Darmac 2.

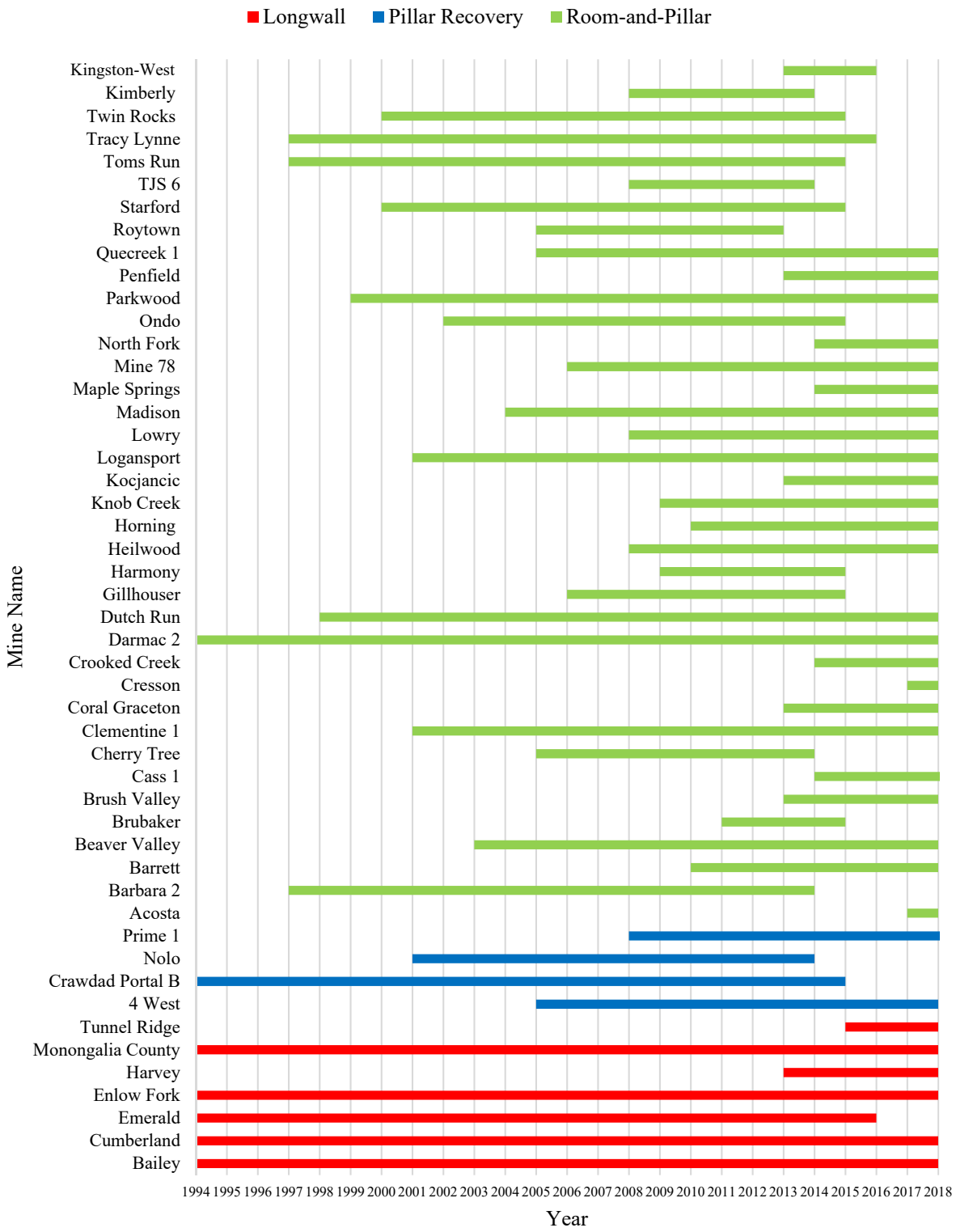

Figure 3-4. Active years of mines operating during the 5th assessment period. NOTE: this analysis shows only mines that operated during the 5th assessment, and only goes back in time to the passage of Act 54 in 1994.

There were 19 mines that ceased operations during the 5th assessment period. Four of the pillar recovery operations stopped mining prior to the end of the 5th assessment period, including Prime No. 1, Crawdad Portal B, Nole, and 4 West, as well as the Emerald longwall mine, and fourteen room-and-pillar mines: Harmony, Kimberly, TJS 6, Gillhouser, Roytown, Cherry Tree, Ondo, Twin Rocks, Starford, Tracy Lynn, Toms Run, and Barbara 2, Kingston-West, and Brubaker. Figure 3-5 shows how many mines ceased operations over the last three assessment periods. The fewest mines closed in the 4th assessment (11 mines).

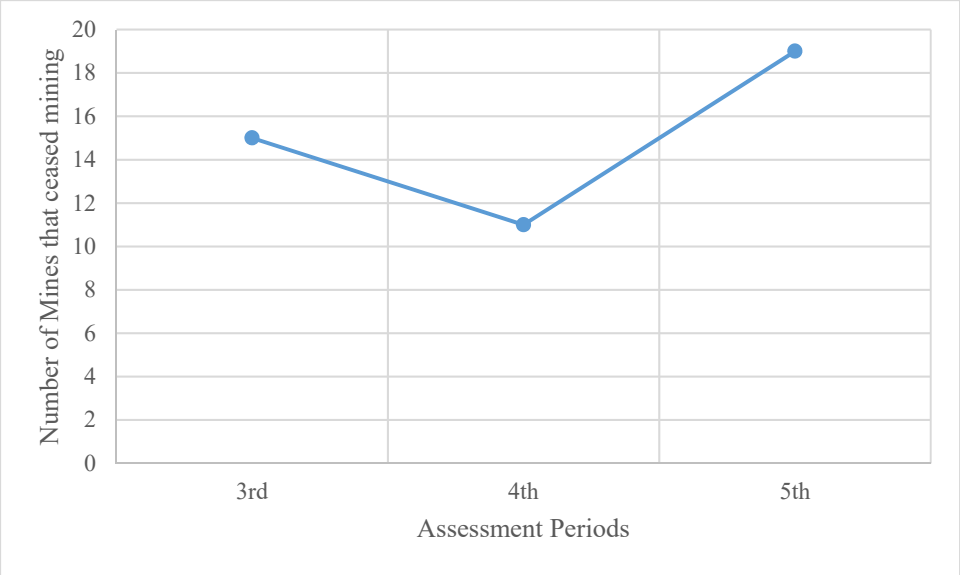

Figure 3-5. Number of mines closed per assessment period.

3.B.5 – Companies Operating Mines

The 49 active mines are owned by eleven operators (Table 3-5). Rosebud Mining Company operates 28 mines (57 %) of all mines active during the 5th assessment period, 27 mines are room-and-and pillar mines and one (Nolo mine) is a pillar recovery mine. The remaining 10 room-and-pillar mining operations are split between Rox Coal (4), LCT Energy (3), AK Coal Resources (1), C&D Mining (1), and Wilson Creek (1). The remaining four pillar recovery mines are owned by Dana Mining Company (3) and Rox Coal (1). The seven longwall mines are divided among 4 operators. CONSOL Energy operated three longwall mines, Contura LLC operators two, and the Monongalia Coal Company and Tunnel Ridge LLC both operated one longwall mine each.

Table 3-5. Active mines in the 5th Assessment sorted by mining company.

Company	Mine(s)	#	Acreage
AK Coal Resources	North Fork	1	540
C & D Mining	Kingston-West	1	69
CONSOL Energy	Bailey Deep, Enlow Fork, Harvey	3	11,382
Contura LLC	Cumberland, Emerald Deep	2	4,206
Dana Mining Co.	4 West, Crawdad Portal B, Prime 1	3	1,969
LTC Energy	Brubaker, Cass 1, Maple Springs	3	728
Monongalia Coal Co.	Monongalia County	1	2,053
Rosebud Mining Co.	Barrett Deep, Beaver Valley, Brush Valley, Cherry Tree, Clementine 1, Coral Graceton, Cresson, Crooked Creek, Darmac 2, Dutch Run, Gillhouser, Harmony, Heilwood, Knob Creek, Kojancic, Logansport, Lowry, Madison, Mine 78, Nolo, Ondo, Parkwood, Penfield, Starford, TJS 6, Toms Run, Tracy Lynne, Twin Rocks	28	6,970
Rox Coal Co.	Barbara 2, Horning, Kimberly, Roytown, Quecreek 1	5	660
Tunnel Ridge LLC	Tunnel Ridge	1	231
Wilson Creek Co.	Acosta	1	45
Total		49	28,854

The number of mines and the percentage of total acres mined for each company are shown in Figure 3-6. Rosebud Mining Company had the most mines (28 or 57.1 %) but mined only 6,970 acres, or 24 %, of the total area undermined during the 5th assessment period. Conversely, CONSOL Energy had the largest percentage of acres mined (11,382 acres, or 40.6 %) with only three longwall mines. The remaining longwall mine operators, Contura LLC, Monongalia Coal Company, and Tunnel Ridge LLC, extracted a combined 23 % of the acres mined.

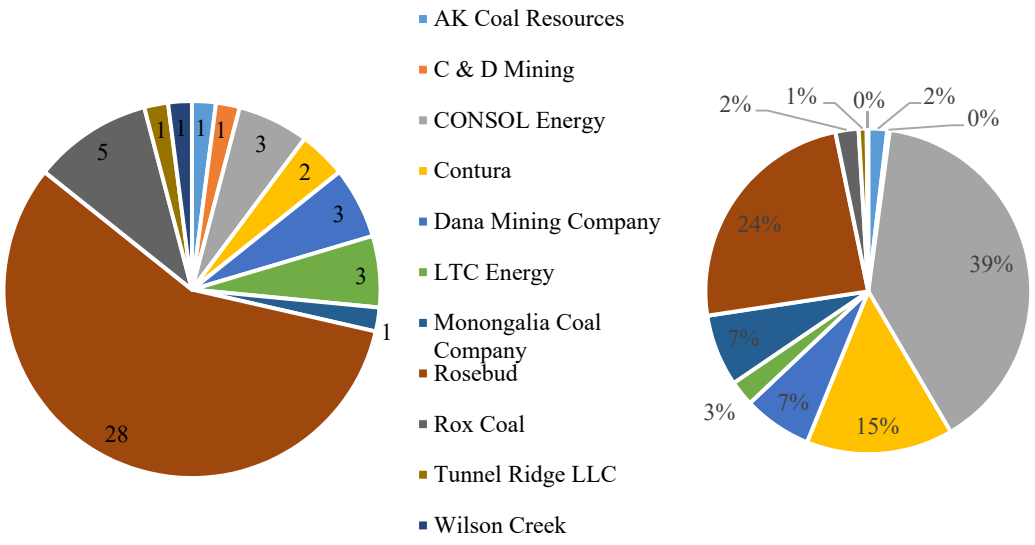

Figure 3-6. The number of mines (left) and percentage of total acres (right) mined by each company.

3.B.6 – Mine Operations by Counties

When evaluating subsidence impacts, documentation of the spatial distribution of these causes is essential to legislators who serve undermined areas or those interested in comprehensive assessment of mining in the Commonwealth. There were 37 room-and-pillar mines, five pillar recovery mines, and seven longwall mines. All mines operated in ten Pennsylvania counties: Greene, Washington, Somerset, Indiana, Beaver, Cambria, Clearfield, Armstrong, Jefferson, and Westmoreland. In the 3rd assessment there were also ten counties with active mining, while in the 4th assessment there were seven. All counties with mines in the 5th assessment period also had mining in the 3rd or 4th assessment except for Westmoreland County. Figure 3-7 outlines all counties that had active mining during the 5th assessment period. More specific descriptions of the distribution of mining among counties is included in Appendix E.

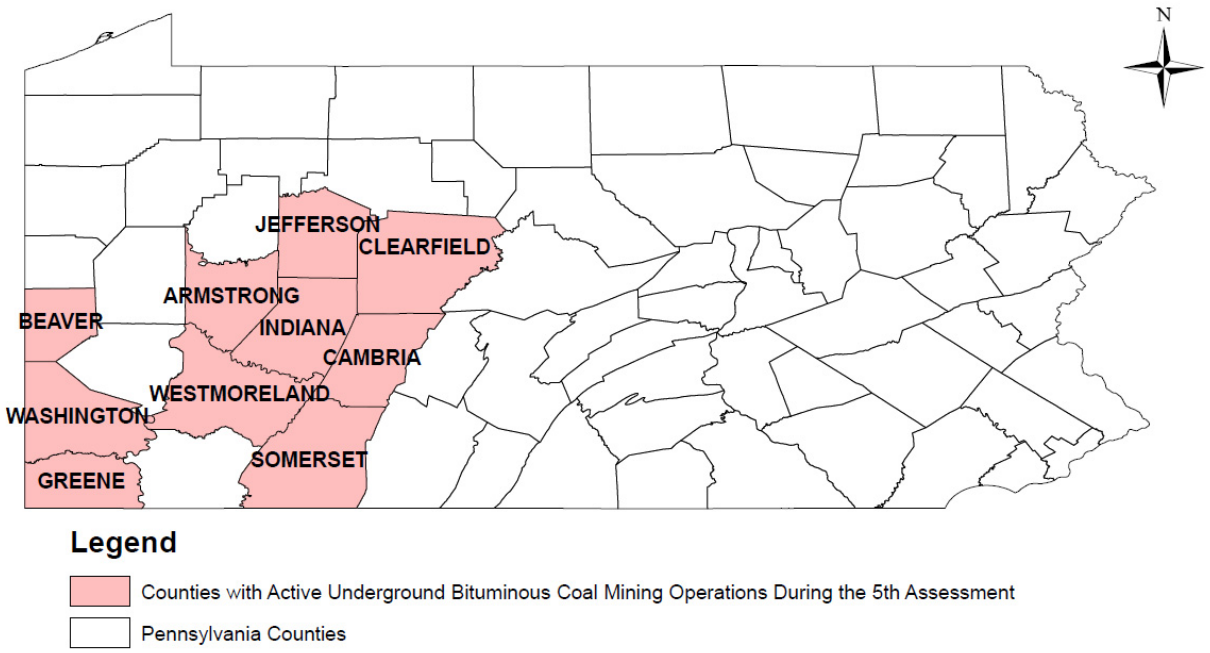

Figure 3-7. Counties mined in the 5th assessment period.

3.B.7 – Room-and-Pillar Mining Operations

Thirty-seven room-and-pillar mines were active during the 5th assessment period (Table 3-6). This number increased slightly from the 3rd and 4th assessment periods which had 34 and 36 active room-and-pillar mines, respectively.

Table 3-6. Thirty-seven room-and-pillar mines with operating company, coalbed, county, and Mine Code information.

	Mine	**Operating Company**	**Coalbed**	**County**	**Mine Code**
1	Acosta	Wilson Creek	Middle Kittanning	Somerset	Au
2	Barbara 2	Rox Coal	Lower Kittanning	Somerset	Bb
3	Barrett	Rosebud Mining Co.	Lower Kittanning	Indiana	Br
4	Beaver Valley	Rosebud Mining Co.	Upper Freeport	Beaver	Bv
5	Brubaker	LTC Energy	Lower Kittanning	Somerset	Bu
6	Brush Valley	Rosebud Mining Co.	Lower Kittanning	Indiana	Bs
7	Cass 1	LTC Energy	Lower Freeport	Somerset	Ca
8	Cherry Tree	Rosebud Mining Co.	Upper Freeport	Clearfield	Ch
9	Clementine 1	Rosebud Mining Co.	Lower Kittanning	Armstrong	Cl
10	Coral Graceton	Rosebud Mining Co.	Lower Freeport	Indiana	Co
11	Cresson	Rosebud Mining Co.	Lower Freeport	Cambria	Cr
12	Crooked Creek	Rosebud Mining Co.	Upper Freeport and Upper Kittanning	Indiana	Ck
13	Darmac 2	Rosebud Mining Co.	Upper Freeport	Armstrong	Dm
14	Dutch Run	Rosebud Mining Co.	Upper Freeport	Armstrong	Dr
15	Gillhouser	Rosebud Mining Co.	Lower Freeport	Indiana	Gh
16	Harmony	Rosebud Mining Co.	Upper Freeport	Clearfield	Hy
17	Heilwood	Rosebud Mining Co.	Brookville and Lower Kittanning	Indiana	Hw
18	Horning	Rox Coal	Lower Freeport	Somerset	Hd
19	Knob Creek	Rosebud Mining Co.	Upper Kittanning	Indiana	Kc
20	Kojancic	Rosebud Mining Co.	Lower Kittanning	Jefferson	Kj
21	Logansport	Rosebud Mining Co.	Lower Freeport	Armstrong	Lg
22	Lowry	Rosebud Mining Co.	Lower Kittanning	Indiana	Ly
23	Madison	Rosebud Mining Co.	Upper Freeport	Cambria	Ma
24	Maple Springs	LTC Energy	Lower Kittanning	Somerset	Ms
25	Mine 78	Rosebud Mining Co.	Upper Kittanning	Somerset	M7
26	North Fork	AK Coal Resources	Middle Kittanning	Somerset	Nf
27	Ondo	Rosebud Mining Co.	Lower Kittanning	Indiana	Od
28	Parkwood	Rosebud Mining Co.	Upper Freeport	Armstrong	Pa
29	Penfield	Rosebud Mining Co.	Lower Kittanning	Clearfield	Pf
30	Roytown	Rox Coal	Upper Kittanning	Somerset	Rt
31	Starford	Rosebud Mining Co.	Lower Kittanning and Middle Kittanning	Cambria	St
32	TJS 6	Rosebud Mining Co.	Upper Freeport	Armstrong	T6
33	Toms Run	Rosebud Mining Co.	Upper Freeport	Indiana	Tr
34	Tracy Lynne	Rosebud Mining Co.	Lower Kittanning	Armstrong	Tl
35	Twin Rocks	Rosebud Mining Co.	Lower Freeport	Cambria	Tw
36	Kimberly	Rox Coal	Lower Kittanning	Somerset	Kr
37	Kingston-West	C&D Mining Co.	Upper Freeport	Westmoreland	Ki

3.B.8 –Pillar Recovery Operations

There were five pillar recovery mines in the 5th assessment period. This number decreased slightly from the six pillar recovery mines in the 3rd assessment period and five in the 4th assessment period. The Quecreek had the largest area of pillar recovery with 355 acres. Table 3-7 shows the active pillar recovery mines during the 5th assessment period.

Table 3-7. Five pillar recovery mines with operating company, coalbed, county, and Mine Code information.

	Mine	Operating Company	Coalbed	County	Mine Code
1	4 West	Dana Mining Co.	Sewickley	Greene	Fw
2	Crawdad Portal B	Dana Mining Co.	Sewickley	Greene	Cd
3	Nolo	Rosebud Mining Co.	Lower Kittanning	Indiana	No
4	Prime 1	Dana Mining Co.	Sewickley	Greene	Pr
5	Quecreek 1	Rox Coal	Upper Kittanning	Somerset	Qc

3.B.9 – Longwall Operations

Seven longwall mines were active during the 5th assessment period. Table 3-8 shows the coalbed and county locations of all the longwall mines. The total number of longwall mines did not change from the 4th assessment period although one mine closed, Mine Eighty-Four, and one West Virginia mine began extracting coal in Pennsylvania. Tunnel Ridge Mine has its portal in West Virginia but parts of five panels cross the border into Pennsylvania (Figure 3-8). The Tunnel Ridge Mine has extensive reserves in Pennsylvania. All mines expect for Enlow Fork and Tunnel Ridge were in Greene County. The Bailey and Enlow Fork Mines are among the largest producers of coal east of the Mississippi (U.S. Energy Information Agency, 2019)

Table 3-8. Seven longwall mines with operating company, coalbed, county, and Mine Code information.

	Mine	Operating Company	Coalbed	County	Mine Code
1	Bailey	CONSOL Energy	Pittsburgh	Greene	By
2	Cumberland	Contura LLC	Pittsburgh	Greene	Cu
3	Emerald	Contura LLC	Pittsburgh	Greene	Em
4	Enlow Fork	CONSOL Energy	Pittsburgh	Washington	Ef
5	Harvey	CONSOL Energy	Pittsburgh	Greene	Hr
6	Monongalia County	Monongalia Coal Co.	Pittsburgh	Greene	Mo
7	Tunnel Ridge	Tunnel Ridge LLC	Pittsburgh	Washington	Tu

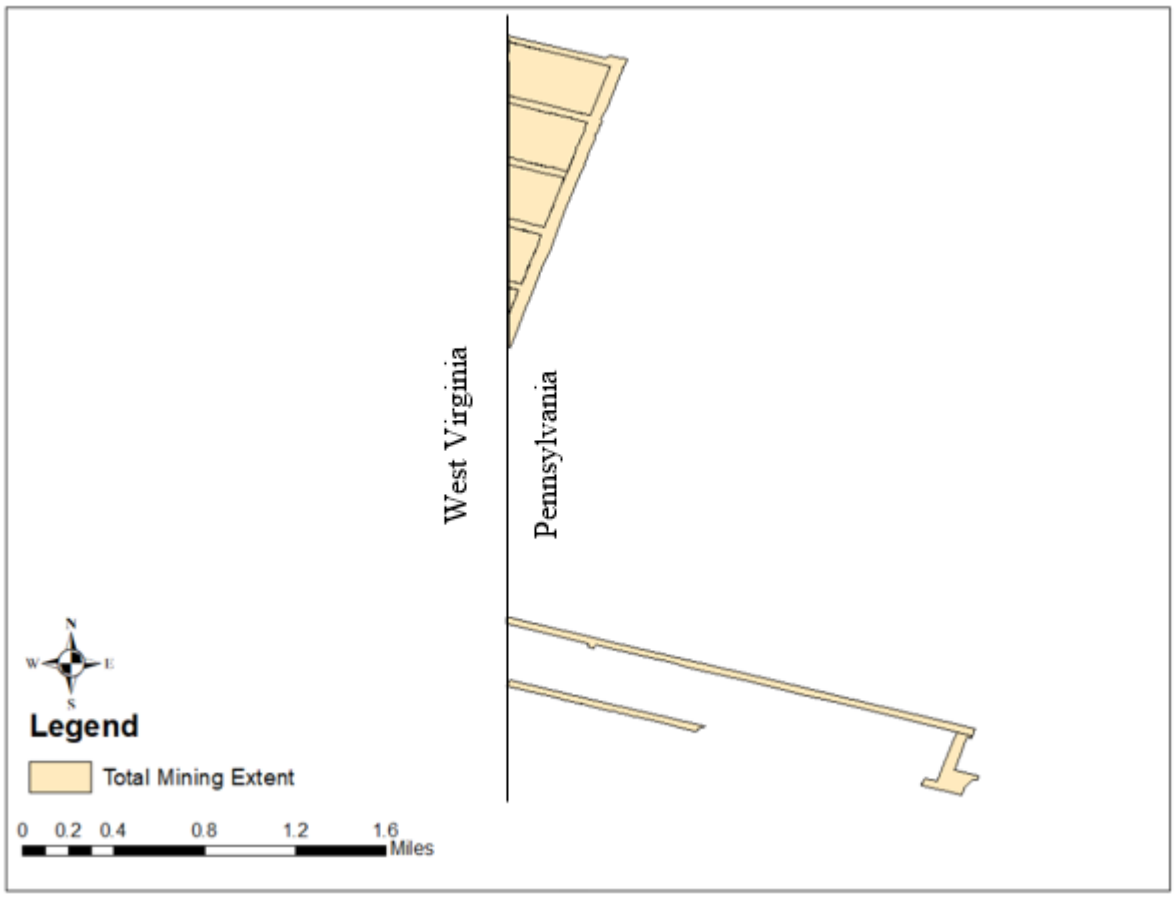

Figure 3-8. Tunnel Ridge mining in Pennsylvania.

3.C - Stratigraphic Influences on Mining (Mining in Different Coalbeds)

Documentation of the distribution of mining during the 5th assessment period among Pennsylvania's coal beds are provided in Appendix E

3.D - Variations in Overburden

As outlined in Appendix D, overburden is a very important factor in prediction of the formation of a subsidence basin and therefore the pattern and magnitude of subsidence impacts. More importantly, it is a defining variable in the delineation of the RPZ. Therefore, documentation of overburden in the context of ongoing mine activity, is a fundamental part of evaluating subsidence impacts. Over the 49 active mines during the 5th assessment, the absolute minimum overburden was around 23-ft in the Madison Mine while the absolute maximum was 1,290-ft in the Monongalia County longwall mine. The lowest overburdens, those less than 100-ft, are typically associated with areas near the mine's portals.

3.D.1 – Overburden Categories

For the purposes of this report, three overburden categories were established: shallow, average, and deep overburden. These categories were established from data collected from each active

mine during the 5th assessments where the maximum, minimum, average, and standard deviation of the overburden were measured. The average category included all mines whose average overburden fell within a standard deviation of the mean of all the mines. These overburden categories were then applied to each of the three mine types. Table 3-9 shows the categories developed during the 5th assessment period for each mining type. The longwall mines have the deepest range for average overburden, while room-and-pillar mines have the shallowest.

*Table 3-9. Overburden categories in the 5th assessment period. **

Type of Mine	Overburden Category		
	Shallow, ft	**Average, ft**	**Deep, ft**
Longwall	< 705	705 to 907	> 907
	2 mines	4 mines	1 mine
Room-and-Pillar	< 295	295 to 425	> 425
	11 mines	17 mines	11 mines
Pillar Recovery	< 432	432 to 552	> 552
	2 mines	2 mines	1 mine

**The room-and-pillar mines total more than 38 because the mines that mined more than one coalbed are analyzed by overburden of each coalbed they mined, so they appear twice.*

There were 23 mines that had average overburden, 13 with deep overburden, and 15 with shallow overburden in the 5th assessment period (Table 3-9). The average overburden for longwall mines was 810-ft, for room-and-pillar mines it was 360-ft and for pillar recovery 492-ft. For a given amount of vertical subsidence, lower overburden mines would be expected to produce more dramatic impacts.

Table 3-10 shows the overburden categories for each of the mining types over the last 15-years. A notable trend can be seen in the shallow overburden category. In each of the mining types, the minimum value for the shallowest overburdens has increased.

Table 3-10. Overburden categories for each mining type, by mining assessment period.

Type of Mine	Overburden Category								
	Shallow, ft			Average, ft			Deep, ft		
	3rd	4th	5th	3rd	4th	5th	3rd	4th	5th
Longwall	< 525	< 627	< 705	525 to 850	627 to 939	705 to 907	> 850	> 939	> 907
Room-and-Pillar	< 185	< 200	< 295	185 to 397	200 to 562	295 to 425	> 397	> 562	> 425
Pillar Recovery	< 185	< 200	< 432	185 to 397	200 to 562	432 to 552	> 397	> 562	> 552

3.D.2 – Longwall Mine Overburden

The seven longwall mines in the 5th assessment extracted some of the deepest coal in Pennsylvania. The overburden ranged from as shallow as 416-ft in parts of the Enlow Fork Mine to 1,293-ft in the Monongalia County Mine (Table 3-11). From Table 3-10 above, Enlow Fork

and Tunnel Ridge fall under the shallow category while Monongalia County is categorized as deep. The average overburden for all seven longwall mines was 810-ft with a standard deviation of 125-ft.

Table 3-11. Overburden characteristics for the seven longwall mines.

Mine	Avg.	SD*	Min	Max	Category
Bailey	890.7	150.7	511.5	1269.6	Average
Cumberland	893.6	102.5	616.5	1191.6	Average
Emerald	734.8	79.5	449.4	894.8	Average
Enlow Fork	634	93.1	416	850	Shallow
Harvey	870.9	95.4	688.7	1258.2	Average
Monongalia County	977.2	123.9	743.3	1293.1	Deep
Tunnel Ridge	642.8	61	470.8	723.1	Shallow

*SD - Standard Deviation

Figure 3-9 graphs the values of the maximum, minimum, and standard deviation of overburden values for each of the longwall mines. This graph shows that two distinct groupings. The shallower group comprised of Enlow Fork, Emerald, and Tunnel Ridge, and the deeper group comprised of Monongalia County, Bailey, Cumberland, and Harvey.

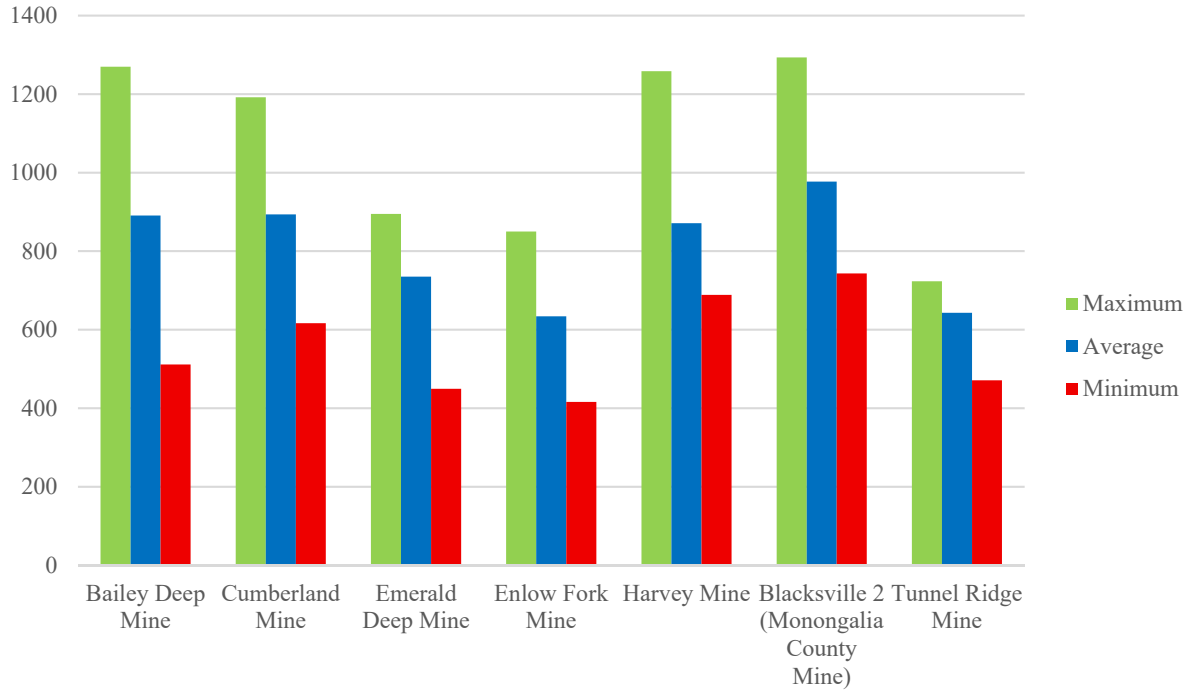

Figure 3-9. The distribution in overburden within each of the seven longwall mines.

3.D.3 – Room-and-Pillar Overburden

The 37 room-and-pillar mines in the 5th assessment were significantly shallower than the longwall mines. The minimum overburden was typically greater than 100-ft. But one mine, Madison, had less than 100-ft near their mine portals. The maximum overburden was 945-ft over the Tracy Lynne Mine (Table 3-12). The average overburden for all room-and-pillar mines was 360-ft with a standard deviation of 122-ft.

Table 3-12. Overburden Characteristics for room-and-pillar mines.

Mine Name	Seam*	Avg.	SD**	Max.	Min.
Acosta	Middle Kittanning	222.5	150.7	304.7	94.9
Barbara 2	Lower Kittanning	276.7	102.5	504.1	106.3
Barrett	Lower Kittanning	507.5	79.5	613.7	241.2
Beaver Valley	Upper Freeport	300	93.1	319.9	182.4
Brubaker	Lower Kittanning	302.8	95.4	412.1	66.1
Brush Valley	Lower Kittanning	456.5	123.9	584.2	229.1
Cass 1	Lower Freeport	327.1	61	401.5	102.3
Cherry Tree	Upper Freeport	440.2	120.1	636.3	357.7
Clementine 1	Lower Kittanning	395	86.9	508	291
Coral Graceton	Lower Freeport	262.8	19.7	386	149.1
Cresson	Lower Freeport	136.1	14.31	165.3	77.7
Crooked Creek	Upper Freeport	337.3	42.1	524.3	186.8
	Upper Kittanning	447.8	118.7	575.1	183.3
Darmac 2	Upper Freeport	402.2	63.2	564.1	204.2
Dutch Run	Upper Freeport	315	94.1	470.8	135.8
Gillhouser	Lower Freeport	410.9	61.4	522.6	271.1
Harmony	Upper Freeport	311.9	61.5	423.8	172
Heilwood	Brookville	699.7	62	771.1	634.5
	Lower Kittanning	393.3	68.1	518.3	202.6
Horning	Lower Freeport	192	49.7	204.7	172.8
Knob Creek	Indiana	258	59.84	389.1	98.4
Kojancic	Lower Freeport	321.3	24.8	679	257
Logansport	Lower Freeport	503	80	679	257
Lowry	Lower Kittanning	395.3	76.9	777	285.7
Madison	Upper Freeport	277.8	64.2	419.3	23.2
Maple Springs	Lower Kittanning	316	72.1	499	182
Mine 78	Upper Kittanning	583.1	46.5	800.9	399.8
North Fork	Middle Kittanning	231.9	61.9	435.5	101.7
Ondo	Lower Kittanning	330.9	23.9	505.9	101.5
Parkwood	Upper Freeport	347	65.6	615	102
Penfield	Lower Kittanning	547.1	10.2	615.2	394.7
Roytown	Upper Kittanning	343.2	56.4	351.5	337.6
Starford	Middle Kittanning &Upper Kittanning	450.7	84.3	545.7	384.1
TJS 6	Upper Freeport	202.4	117	316.7	122.9

Toms Run	Upper Freeport	549.7	60.8	866.7	337
Tracy Lynne	Lower Kittanning	516.3	96	945.7	310.98
Twin Rocks	Lower Freeport	303.6	91	387.3	208.8
Kimberly	Lower Kittanning	183.8	50.9	275.5	83.4
Kingston-West	Upper Freeport	237.5	90.19	314.9	77.2
Total		360	122	502.2	203.7

*For Crooked Creek and Heilwood, the overburdens for the different seams mined are calculated and classified individually, instead of calculating the overburden for the mine.

**SD = Standard Deviation

The distribution of the average overburden of all 37 mines can be seen in Figure 3-10. Heilwood has the highest overburden and Cresson the least. There are 11 mines in the deep category, 11 shallow mines, and 18 average overburden mines.

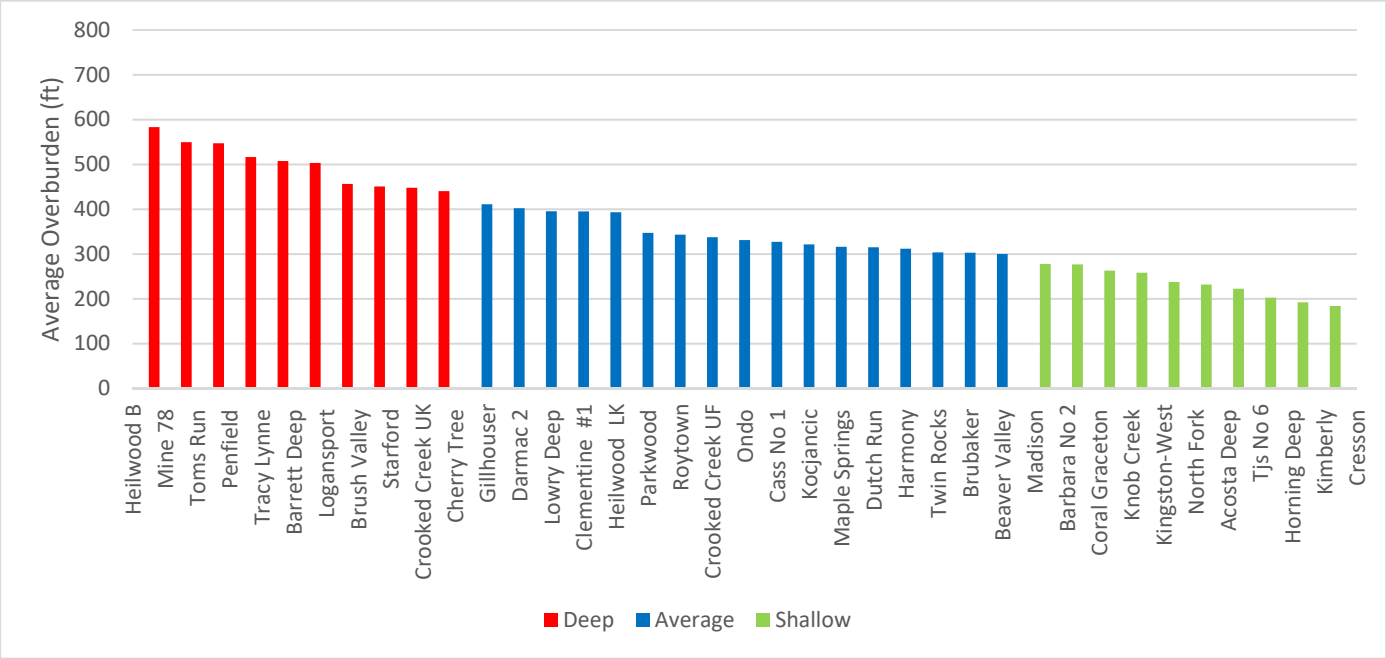

Figure 3-10. Distribution of average overburdens for the 38 room-and-pillar mines. Note that Crooked Creek and Heilwood appear twice, as the overburdens for different coalbeds are calculated and categorized separately.

3.D.4 – Pillar Recovery Overburden

The pillar recovery mines had a higher average overburden than the room-and-pillar mines but was less than the longwall mines. Quecreek had the shallowest overburden at 190-ft while 4 West had the deepest overburden of 919-ft (Table 3-13). 4 West was classified as deep, but Quecreek is in the shallow overburden category. The average overburden for pillar recovery mining was 492-ft with a standard deviation of 60-ft.

Table 3-13. Overburden characteristics of the pillar recovery mines.

Mine	Avg.	SD*	Min	Max	Category
4 West	592	120	324	919	Deep
Crawdad	438	87	266	649	Average
Nolo	425	20	364	474	Shallow
Prime 1	513	14	457	554	Average
Quecreek	357	68	190	513	Shallow

*SD - Standard Deviation

The overburden distribution Figure 3-11 shows that the 4 West Mine had higher overburden than the remaining pillar recovery mines. Nolo (14 acres) and Prime 1 (18 acres) do not have as large of a large spread between the minimum and maximum overburden probably because both had very small pillar recovery areas during the 5th assessment period.

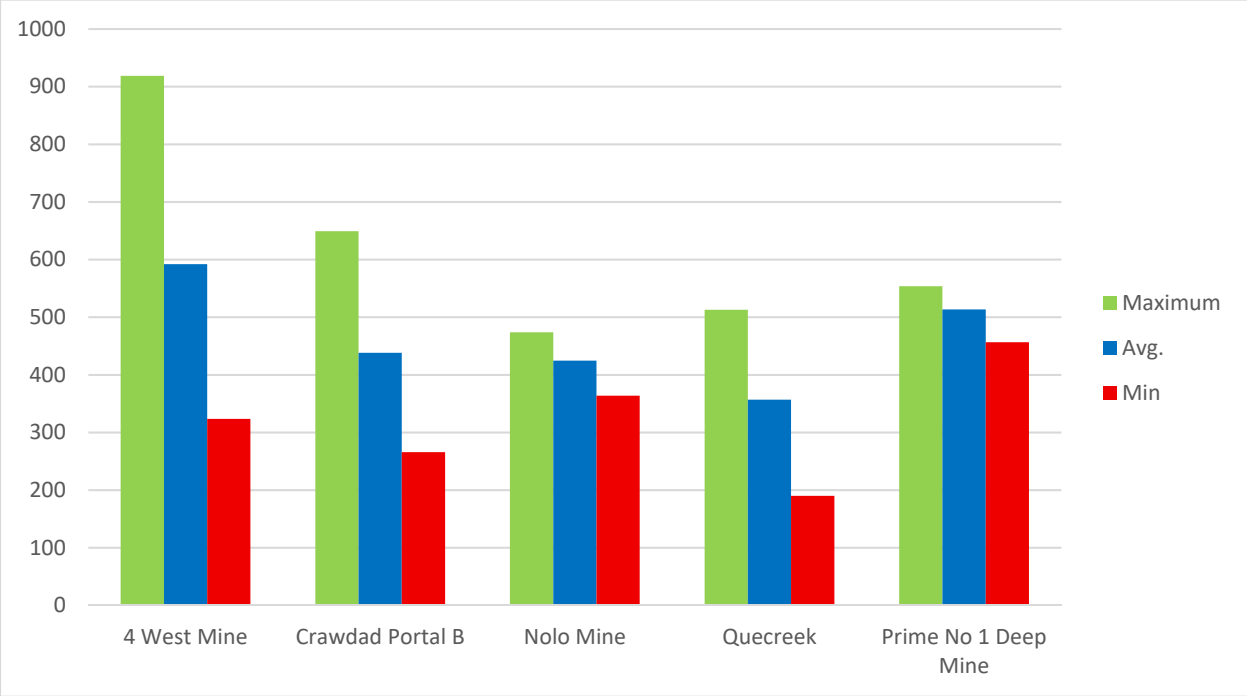

Figure 3-41. The distribution in overburden within each of the five pillar recovery mines.

3.E – Future Mining Trends

Analysis of current impacts is fundamental to development of means and methods to avoid future subsidence impacts. Appendix E examines ongoing trends in the spatial distribution of mining and the interaction of the trends with geology and technology to estimate future mining activity in Pennsylvania.

3.F – Summary

In the 5th assessment period there were 49 active mines whose conditions were tracked from August 21. 2013 to August 20, 2018. There were seven longwall mines, 37 room-and-pillar mines, and five pillar recovery mines. A total of 28,854 acres were mined, with longwall mining accounting for 62 % of the total, room-and-pillar 29 %, and pillar recovery 9 %. The following are key observations made by the University of the mining that occurred in the 5th assessment period:

- Three different mining types were analyzed: longwall, room-and-pillar, and pillar recovery mines. Within these mining types three mining methods were employed: longwall panel extraction, room-and-pillar developments, and pillar recovery mining.
- Longwall mining had the greatest extraction ratio (Re=1), pillar recovery had a slightly lower extraction ration (Re=0.7 to 1), and room and pillar had the lowest extraction ratio (Re=0.4 to 0.7). The higher the extraction ratio, the more likely it is for subsidence to occur.
- There was a 7 % decline in area mined from the 4th assessment to the 5th assessment. The decline in acres mines from the 3rd assessment to the 4th assessment was due to the decrease in longwall mining, but in the 5th assessment room-and-pillar mining had the largest decrease in the mining types.
- During the 5th assessment period two new longwall mines opened operations in Pennsylvania, Harvey and Tunnel Ridge.
- The Bailey and Enlow Fork Mines combined continue to be one of the largest producers of underground bituminous coal east of the Mississippi river.
- There were 15 mines that closed from the 4th to the 5th assessment period.
- Rosebud Mining Company had the most mining operations in the 5th assessment period, all room-and-pillar mines.
- CONSOL Energy mined the most acres, 11,382 acres, from their Bailey, Enlow Fork, and Harvey longwall mines.
- Greene County had the most mining, 46.5 % of the acres mined during the 5th assessment period.
- Eight different coalbeds in the Pittsburgh and Allegheny formations were mined.
- All longwall mines were in the Pittsburgh coalbed, making it the most productive coalbed in the 5th assessment period.
- Three pillar recovery mines were in the Sewickley coalbed in the Pittsburgh formation, while the remaining pillar recovery mines and all room-and-pillar mines were distributed over six coalbeds in the Allegheny formation.
- Each mining type had three overburden categories, shallow, deep, and average.
- There were 14 mines that had shallow overburden and 13 mines with deep overburdens. There was an increase in the number of mine mining extreme overburden conditions (i.e. the shallow and deep overburden) from the 4th to the 5th assessment period.
- The longwall mining rate has decreased from the 4th assessment to 3,500 acres/year during the 5th assessment period.

- Technology advances continue to shape the way that longwall mining is conducted in Pennsylvania
- At current mining rates and conditions, 40 years of longwall mining remain in the Pittsburgh coalbed of Pennsylvania.
- The next assessment period, the average overburden for the Pittsburgh longwall mines is expected to increase by 5 %.

References

U.S. Energy Information Administration (2019) "Pennsylvania State Energy Profile" https://www.eia.gov/state/print.php?sid=PA