UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. KRUG, Secretary
BUREAU OF MINES
JAMES BOYD, Director

Technical Paper 727

WATER POOLS IN PENNSYLVANIA ANTHRACITE MINES

By
S. H. ASH, W. L. EATON, KARL HUGHES, W. M. ROMISCHER
AND J. WESTFIELD

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1949

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 55 cents

CONTENTS

ILLUSTRATIONS

TABLES

WATER POOLS IN PENNSYLVANIA ANTHRACITE MINES[1]

By S. H. Ash,[2] W. L. Eaton,[3] Karl Hughes,[4] W. M. Romischer,[5] and J. Westfield [6]

INTRODUCTION

Factual data regarding water impounded in underground pools and in abandoned stripping excavations are necessary to solve the critical water problem confronting the Pennsylvania anthracite industry (*1, 2, 3, 4, 14, 17*).[7]

Past mining practices have allowed surface water to enter both active and abandoned mine workings and to accumulate in mines now in operation; such water has to be pumped to the surface or drained by gravity through drainage tunnels. Active mines are thus burdened with water infiltrating from abandoned mines in addition to that normally present in the active mines. As more mines are abandoned, for whatever cause, the problem becomes cumulatively more serious with regard to both economics and safety.

A report of the Pennsylvania Department of Internal Affairs, Bureau of Mines, for 1897 states, on page 34:

> It should also be noticed that bodies of water had accumulated in parts of abandoned mines before duplicate surveys of the same were required by law, and, as a result, we have today to contend with bodies of water, the exact location and position of which are not correctly known.

Since that date, over 50 years ago, the implications of the foregoing comment have grown tremendously. At that date, seemingly, pools of water were present only in abandoned mines; however, many abandoned mines are now full of water to the overflow point, and enormous water pools are present in parts of active mines.

Because of the abandonment and inundation of mines from 1927 to the present, only 40 percent of the minable anthracite measures of the Western Middle field are available to active collieries (*2*). Recent production of anthracite, even with the war and postwar demands, has been less than two-thirds that of the peak production years during the early 1920's.

---

1 Work on manuscript completed September 1948.
2 Chief, Safety Branch, Health and Safety Division, Bureau of Mines, Washington, D. C.
3 Civil engineer, Anthracite Flood Prevention Section, Health and Safety Division, Bureau of Mines, Wilkes-Barre, Pa.
4 Mining engineer, Anthracite Flood Prevention Section, Health and Safety Division, Bureau of Mines, Wilkes-Barre, Pa.
5 Engineer in charge, Anthracite Flood Prevention Section, Health and Safety Division, Bureau of Mines, Wilkes-Barre, Pa.
6 Former engineer in charge, Anthracite Flood Prevention Section, Health and Safety Division, Bureau of Mines, Wilkes-Barre, Pa.
7 Italicized numbers in parentheses refer to items in the bibliography at the end of this report.

DEPLETION OF ANTHRACITE RESERVES

Depletion of anthracite reserves has reached an advanced stage (*30*); the actual depletion is greater than the theoretical depletion figures (*6*) based upon the proportion of total reserves actually removed from the ground. A large proportion of anthracite reserves included in the original estimate of 1893 is unminable (*7*) because areas of many beds have been found to be of less-than-minable thickness; because anthracite has been lost through mine fires; because the proximity of adjacent beds often makes it unsafe and uneconomical to mine all the beds; because some reserves must be left in place to prevent subsidence under rivers, highways, cemeteries, churches, schools, other public buildings, and valuable surface improvements; because some reserves must be left in place for barrier pillars, shaft pillars, and slope pillars; and because some reserves are now inundated or threatened with inundation.

The largest loss is the reserves now submerged by water pools or likely to be inundated (*7*) by the enlargement or overflow of present pools because of increased inflow of water over present pumping capacity. Because the anthracite that has been removed to date included a large proportion from the readily minable beds and from those beds that produce anthracite having the most attractive appearance from a sales standpoint, mining will be increasingly difficult, and waste will grow in future mining (*8*).

Comparatively few abandoned mines in the anthracite region of Pennsylvania have no reserves. Usually, abandonment and subsequent inundation of reserves came about because the cost of pumping mine water made mining unprofitable. Virtually all abandoned mines except drift mines have some reserves that may or may not be minable if the mine-water problem is solved; this depends upon the relation between the value of the anthracite reserves and the cost of unwatering and reopening the mine workings.

TECHNOLOGIC INVESTIGATION OF WATER POOLS BY THE BUREAU OF MINES

Research concerning underground water pools was first undertaken by the Bureau of Mines in 1945 as part of the technologic investigation of the anthracite mine-water problem. This revealed that some of the larger mining companies had collected information on underground water pools in their own mines and adjacent mine workings; however, no attempt was made to compile information on all the underground water pools in the respective anthracite fields (Northern, Eastern Middle, Western Middle, and Southern).

Factual data on the underground water pools in the Northern and Southern fields were collected during the fiscal year ended June 30, 1945 (*9*); in the Western Middle field during the fiscal year ended June 30, 1946 (*6*); and in the Eastern Middle field during the fiscal year ended June 30, 1947 (*7*). Additional data were obtained on the underground water pools in the Northern field during the fiscal year ended June 30, 1948.

The importance of suitable barrier pillars to prevent underground mine water from flowing from one mining property into another was studied during the fiscal years ended June 30, 1946 (*6*) and June 30, 1947 (*7*).

Potential hazards to life and property and the engineering and economic problems present when surface water is allowed to collect in abandoned stripping excavations were investigated during the fiscal year ended June 30, 1948.

The information covered in this report was obtained by studying geological maps and cross sections, mine maps, mine cross sections showing mine workings, and other pertinent data obtained from anthracite-mining companies. This report includes maps, plans, cross sections, and longitudinal sections of the underground water pools, the number of water pools in each field, the altitude of the surface of the water in each pool, the volume of water in each pool, and the position and altitude of overflow points where the water from one pool can flow into another pool or into active mine workings. Such data are necessary for a comprehensive understanding of the anthracite mine-water problem so it can be solved.

ACKNOWLEDGMENTS

The authors acknowledge their indebtedness for aid in the collection of data for this report to: Officials of mining companies in the anthracite region; the anthracite mine inspectors of the Pennsylvania Department of Mines; the Anthracite Institute; the various water companies throughout the anthracite region; the engineers of the Federal Bureau of Mines; and D. O. Kennedy, mining engineer of the Bureau of Mines, who reviewed the manuscript.

PRECIPITATION AND INFILTRATION OF SURFACE WATERS

Mine water originates as precipitation; however, a constant relationship has not been established between the volume of precipitation in the anthracite region and that of the water entering from the surface into the mine workings. Infiltration following the same volume of precipitation in a given area in which the physical surface conditions remain unchanged will vary greatly because of climatic conditions. Therefore, it is difficult to evaluate the benefits that have been derived from any work that has been done toward preventing or minimizing the infiltration of surface waters or to show definite economies to be derived from projects intended to reduce the inflow into the mine workings by diverting the run-off into impervious conduits, such as flumes, ditches, and pipes.

Over a long period of years, some mine operators have vigorously attempted to control infiltration of surface water; but, in spite of these efforts, the volume of surface water that infiltrates into the mines has trended upward. Local improvements in surface drainage facilities updoubtedly have resulted in reducing the quantity of water infiltrating into the mines, and future projects designed for that purpose will continue to do so. There is little doubt that, in every instance, water retained on the surface and diverted to surface drainage channels has been handled more economically than it would have been by pumping from the mines. However, it is impossible to present data to substantiate an estimate of actual or relative benefits as applicable to any definite project.

PRECIPITATION IN PENNSYLVANIA ANTHRACITE REGION

Table 1 shows the annual precipitation for 18 years as recorded at gaging stations in the anthracite region at Wilkes-Barre and Scranton in the Northern field, Hazleton in the Eastern Middle field, Shamokin and Mahanoy City in the Western Middle field, and Pottsville in the Southern field. The yearly precipitation recorded ranges from a minimum of 26.12 inches at Scranton in 1930 to a maximum of 61.17 inches at Hazleton in 1945. The average annual precipitation at individual stations ranges from 36.73 inches at Scranton to 47.13 inches at Pottsville. The average for the six stations for the entire 18-year period is 42.40 inches.

Rainfall records from 1930 to 1947 show frequent extremely heavy local precipitation during short periods. For example, 19.81 inches of rainfall, of which 7.83 inches fell in less than a 24-hour period, was recorded at Mahanoy City in July 1947. At Wilkes-Barre, 6.07 inches of rain fell in 24 hours between noon of July 31 and noon of August 1, 1946. At Mahanoy City, 10.3 inches of rainfall was recorded in one week during May 1942.

Maximum values of precipitation are important in the anthracite region because pumping facilities must be based upon maximum values rather than on mean values. Pumping and drainage facilities, including reserve sump capacity, must be able to handle the maximum inflow of water that occurs from flash floods, which are prevalent. Sudden flooding of mine workings has occurred, sometimes with loss of life, but always with loss of wages and anthracite production and with considerable expense to the mine owners for unwatering and reopening the mines.

TABLE 1.—*Precipitation in anthracite region (inches)*

Year	Northern field		Eastern Middle field	Western Middle field		Southern field	All fields (average)
	Wilkes-Barre [1]	Scranton [2]	Hazleton [3]	Shamokin [4]	Mahanoy City [5]	Pottsville [6]	
1930	26.60	26.12	29.86	29.82	35.02	30.61	29.67
1931	30.03	30.54	37.07	30.31	35.02	33.03	32.67
1932	34.21	34.01	46.15	39.01	47.99	48.18	41.59
1933	40.80	43.10	54.64	52.36	59.30	59.75	51.66
1934	34.68	34.07	45.27	44.71	48.43	46.50	42.28
1935	35.77	44.21	42.53	40.12	47.80	45.21	42.61
1936	32.84	37.27	37.56	40.45	50.10	45.92	40.69
1937	39.79	40.92	49.31	45.06	54.01	54.78	47.31
1938	40.89	37.90	32.42	44.04	56.02	52.87	44.02
1939	32.94	29.23	41.13	37.25	38.59	42.17	36.89
1940	39.47	38.65	47.72	47.80	48.22	52.08	45.66
1941	29.31	27.28	38.05	32.32	32.58	35.57	32.52
1942	38.99	41.59	56.25	49.82	53.14	57.75	49.59
1943	39.23	32.52	44.68	45.63	52.34	46.43	43.47
1944	30.76	31.87	38.41	43.04	31.80	42.20	36.35
1945	53.84	53.71	61.17	51.17	52.18	58.19	55.04
1946	35.10	36.72	46.36	38.70	43.78	40.75	40.24
1947	46.58	41.46	56.66	45.81	59.00	56.31	50.97
Average	36.77	36.73	44.74	42.08	46.96	47.13	42.40

Taken from the records of:
[1] Scranton-Spring Brook Water Co.
[2] U. S. Weather Bureau.
[3] Hazleton Water Authority.
[4] Roaring Creek & Bear Gap Water Co.
[5] Anthracite Water Co. Observation taken at observatory wastehouse run dam. U. S. Weather Bureau (1944–47).
[6] Philadelphia & Reading Coal & Iron Co.

In 1936 the Lackawanna River overflowed its banks in Duryea, Pa.; the water inundated the Hallstead mine of the Kehoe-Berge Coal Co. and several contiguous mines operated by other companies. Although no lives were lost, 6,000 mine workers were made idle for a considerable period; all pumping equipment was lost; and an immense volume of water had to be pumped to the surface. At the time of the flood, unemployment of miners in the anthracite region was a serious social problem. In consideration of the cost to the anthracite-mining companies to recondition the mines, and to permit employment of the affected workmen, the Commonwealth of Pennsylvania furnished the pumps, other equipment, and power to unwater the mines. Probable recurrence of such floods constitutes a major item in the problem of mine-water control. Some attempts have been made to establish ratios between precipitation, run-off, and infiltration for small, isolated areas over monthly or yearly periods (*17, 24*), but no data exist to correlate these factors during flash floods.

The wide differences in precipitation from year to year and from locality to locality during the past 18 years are characteristic of this region. As can be seen on figure 1, showing the average precipitation in the region, the recorded annual precipitation has gradually increased. The inflow of water into the mine workings throughout the region has increased steadily, but it is extremely difficult to correlate these figures.

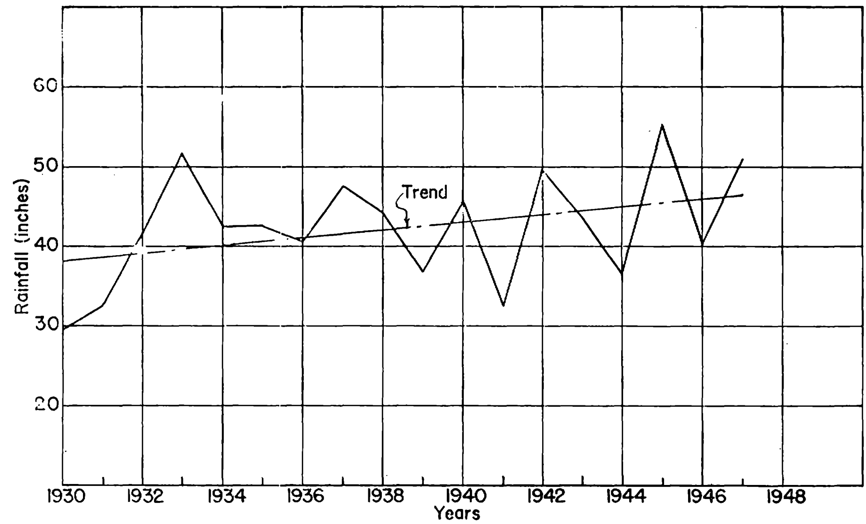

FIGURE 1.—Average precipitation based on readings from six stations in the anthracite region.

INFILTRATION OF SURFACE WATERS INTO MINES

The volume of water entering into mine workings during and after any period of precipitation varies greatly in adjoining basins, and even in adjoining collieries in the same field, because of differences in the condition of the strata as affected by the progress of the extraction of the anthracite, particularly that from the uppermost beds. The ratio between run-off and infiltration varies for each period of precipitation in any given area because of variables in the rate of precipitation, duration of storms, rate of evaporation that depends upon the temperature and humidity, transpiration dependent upon the season and the amount of vegetable life, status of the water table, frost that seals crevices in the ground, and the presence of anchor ice that would seal the bottoms of streams.

Surface water that infiltrates into underground mine workings can be attributed to the following sources:

1. Stream-bed leakage.
2. General surface leakage.
3. Barrier-pillar seepage.

STREAM-BED LEAKAGE

Leakage from the beds of streams is an important source of water that infiltrates into mine workings. Every stream crossing the coal measures loses some of its water, which eventually enters underground mine workings. Because the loss at any particular point is usually small and the distance between the point where the water left the stream and the point where it entered into the mine workings may be great, it is impossible to measure accurately the amount of such leakage or to apply corrective measures, except in small streams.

Natural stream beds are pervious; however, streams must continue to serve as the ultimate discharge points for mine pumps and underground drains, unless some other means are utilized. Stream beds are less pervious than the ground surrounding them because mining operations directly underneath the streams have been conducted so as to prevent or to minimize breaks in the rock strata underlying the streams; moreover, water escaping from the channels of rivers and streams enters into the mine workings through fissures and cracks caused by subsidence, through bedding planes in the rock strata, through natural cleavage planes, and through faults.

Although many small apertures in the rock strata become sealed with silt and sludge, numerous openings are made by mining subsidence. A large volume of water infiltrates into the mine workings through these openings in the 750 miles of stream beds crossing the anthracite measures (*6*).

Water pumped or drained from a mine and conducted to a natural surface watercourse is not necessarily confined to this watercourse but may contribute to the volume of water that must be pumped from some other mine situated farther downstream.

The addition of a relatively small volume of water, such as the discharge from a pump or the flow from a mine drift or drainage tunnel, does not necessarily increase the leakage that will occur from a stream channel in a given distance. Stream leakage is a function of the number and size of openings lying within the wetted perimeter of the stream channel, rather than the quantity of water flowing in the stream. The leakage will not increase unless the volume of water added to the stream is enough to increase appreciably the cross section of the stream channel in contact with the water (*26*). A noticeable increase in the depth of water flowing in the channel of a river or stream after a heavy rain will denote an increase in leakage because of the increase in the wetted perimeter (*26*) of the stream channel.

The "Buried Valley of the Susquehanna River," which extends from Coxton to West Nanticoke in the Wyoming region of the Northern field and covers an area of approximately 37 square miles, is a constant source of water that infiltrates into underlying mine workings and presents a hazard of inundation of mine workings in this area. This ancient channel, now filled with clay, sand, and gravel deposits 50 to 300 feet in depth, lies below the level of the present river bed and has a very irregular-shaped rock bottom (*6*). The mining that has been done underneath the buried valley has been conducted with great care to avoid breaking the rock cover, but infiltration of water occurs along the lines of bedding planes and through the natural interstices in the rock strata, allowing water from the river and the lower reaches of its tributaries to enter mine workings.

Many of the smaller streams lose all their water soon after crossing the outcrop of the lowest anthracite bed when they enter the area that overlies the coal measures. These streams carry water throughout their original length only during periods of heavy run-off. Throughout the greater part of the year, their entire flowage, ranging from a few gallons to several thousand gallons per minute, infiltrates into the mine workings (*7*).

A study of larger streams (*7*) shows a very marked decrease in flow between the outcrop of the anthracite measures and the confluence of these streams with the main stream at almost all periods when relatively low water permitted comparable observations. However, at the same stages of water, such decrease did not occur when the bed of the stream was sealed by anchor ice.

Wherever a definite zone of leakage has been established, the stream beds have been made impervious to a large extent by stream-bed paving or by carrying the water over the broken pervious ground by means of a flume. However, much of the loss of water occurs in minute leaks over the entire length of the stream bed traversing the anthracite measures.

GENERAL SURFACE LEAKAGE

Rock fissures, cave-ins, fissures in outcrops, and strippings, either on the flood plains of streams or on drainage areas, provide easy ingress to a large proportion of the surface water that infiltrates into both active mines and abandoned mine workings. Strippings especially contribute heavily to this infiltration of water because of the removal of overburden and because of the longitudinal extent of strippings along the outcrops of the anthracite beds. Many fissures and cave-ins are not visible on the surface because they are hidden under refuse banks or are partly filled with dirt; nevertheless these openings contribute much to water seepage.

The dry beds of thousands of small former watercourses are good evidence of the general disturbance of the surface of the ground that has followed extraction of the anthracite beneath them. The operating companies have dug ditches and built flumes to divert into natural stream channels the run-off after a rainstorm from permeable areas. However, that part of the precipitation that would have become ground water and later drain into these small watercourses now infiltrates into mine workings and thus leaves these watercourses dry.

SURFACE-DRAINAGE CONTROL

Large sums of money are spent each year (*17*, *24*, *31*) by anthracite-mining companies to prevent surface water from entering into active and abandoned mines, using the following methods:

1. The construction and maintenance of flumes and ditches to intercept and conduct water to natural courses, thus bypassing to some extent outcrops, rock fissures, strippings, mine openings, and cave-ins through which water might enter the underground mine workings.
2. Back-filling cave holes and stripping excavations with impervious material to an established hydraulic gradient that will guarantee natural drainage.
3. Cleaning and widening stream channels to provide free flow of water in the streams.
4. Lining stream beds with concrete or rubble masonry (stone and mortar) to prevent infiltration through the stream beds.
5. Silting stream beds to render them impervious.

RELATION BETWEEN INFILTRATION OF SURFACE WATERS AND PUMPING OF MINE WATERS

The total volume of water discharged annually from active and abandoned mines in the anthracite region by pumping and drainage tunnels exceeds 200 billion gallons (*31*).

Pumping of large volumes of water is required as a result of normal mine operations; however, large volumes must be pumped for coal-preparation purposes and other functions. To operate many anthracite mines, the mining companies are burdened at present with the cost of handling water from some abandoned mines. Many underground pools and abandoned stripping excavations are so situated that the water in them either cannot be made tributary to present pumping or drainage facilities or cannot be handled with the pumping facilities available. Some of these pools threaten the adjoining active mines if the overflow from the pools is not controlled. Any interruption of the operation of the pumps, for even a few days, or a sudden inflow of water in excess of the pumping capacity might drown out a pumping plant, create a new pool, or enlarge an existing pool, with further loss of reserves and of employment for mine workers.

Data regarding individual pumping plants placed in basins from which all drainage is disposed of by pumping indicate that, while there is some reduction in water handled during dry years, such as 1944 and 1946, as compared with the quantity pumped during wet years, such as 1945 and 1947, the general trend is upward in all instances.

Table 2 shows the total volume of water pumped, the total underground production, and the ratio of water pumped to underground production for a large mining company.

The trend of the volume of water pumped from the mines is increasing, because of increasing water load and decreasing production. This increase in water load is attributed to the breakage in the strata caused by the extraction of anthracite.

Possibly the worst factor in connection with an abandoned mine is the failure to maintain surface drains or other works designed to minimize infiltration. The operator of the adjacent mine is not familiar with what has been done and has no legal right to enter such premises; consequently, the infiltration of surface water in this area increases.

BARRIER PILLARS

To obtain a better picture of the relation of water pools to the anthracite mine-water problem, it is necessary to understand the part played by the barrier pillars that separate abandoned or flooded mine workings (*5*).

A barrier pillar in the Pennsylvania anthracite region is a portion of an anthracite bed that is left unmined along the property line or lines of adjoining properties, or between mines, or between parts of mines. Its principal function is to act as a dam to prevent water that has accumulated in a mine from suddenly breaking into an adjacent mine or into adjacent mine workings and causing loss of life, property, or both.

TABLE 2.—*Net tons of water pumped to surface to net tons of anthracite produced underground by a large company in the Southern field*

Year	Net tons of water	Net tons of anthracite	Ratio of tons of water to tons of anthracite
1938	85, 843, 275	4, 097, 232	21. 0
1939	45, 453, 212	3, 880, 776	11. 7
1940	47, 224, 828	4, 002, 532	11. 8
1941	46, 667, 583	3, 862, 500	12. 1
1942	82, 663, 342	3, 661, 048	22. 6
1943	96, 337, 136	3, 834, 987	25. 1
1944	86, 316, 387	3, 454, 660	25. 0
1945	134, 340, 160	3, 228, 088	41. 6
1946	98, 586, 138	3, 601, 278	27. 4
1947	99, 284, 000	3, 436, 285	28. 9
Total	822, 716, 061	37, 059, 386	22. 2

If dependable barrier pillars had been maintained at many mines, now abandoned because of depletion of reserves or other reasons and allowed to fill with water, such mines would not present a menace. Additional water would flow as ground water or flow to surface-drainage channels, and no water problem would exist in many instances, except for a small amount of seepage (*19*, *31*).

Unfortunately, barrier pillars often are of inadequate design, were often robbed, and were frequently pierced by openings. As a consequence, the condition of barrier pillars in many abandoned mines and parts of active mines is unknown, and almost every abandoned mine constitutes a water problem for mines adjoining it.

MINE INSPECTORS' FORMULA FOR BARRIER PILLARS

Article III, section 10, of the Anthracite Mining Laws of Pennsylvania (1891) reads thus:

It shall be obligatory on the owners of adjoining coal properties to leave, or cause to be left, a pillar of coal in each seam or vein of coal worked by them, along the lines of adjoining property, of such width that, taken in connection with the pillar to be left by the adjoining property owner, will be a sufficient barrier for the safety of the employees of either mine in case the other should be abandoned and allowed to fill with water; such width of pillar to be determined by the engineers of the adjoining property owners together with the inspector of the district in which the mine is situated, and the surveys of the face of the workings along such pillar shall be made in duplicate and must practically agree. A copy of such duplicate surveys, certified to, must be filed with the owners of the adjoining properties and with the inspector of the district in which the mine or property is situated.

An arbitrary rule for determining the width of barrier pillars, adopted by a number of mining companies and the State mine inspectors of Pennsylvania anthracite districts, is known as the "mine inspectors' formula for barrier pillars." The rule is as follows:

Multiply the thickness of the coal bed, in feet, by 1 percent of the depth below the drainage level, and add to this five times the thickness of the coal bed, (*12*).

This rule can be written in formula, as follows:

$$W=(T\times 0.01\times H)+5T,$$

where

W= width of barrier pillar, in feet;
H= depth below drainage level, or hydrostatic head, in feet; and
T= thickness of the bed, in feet.

The drainage level of a mine as defined above is that altitude above which water will not rise. It is the overflow point and may be the collar of a shaft or slope or the point at which an outside tunnel or drift intersects the coal measures. It may also be an opening in a barrier pillar that allows water to drain from one mine into another.

Thus, according to this rule, for an anthracite bed 6 feet thick and 400 feet below the drainage level the barrier pillar should be

$$(6\times 0.01\times 400)+(5\times 6)=54 \text{ feet wide.}$$

To determine the widths of barrier pillars, other conditions besides the thickness of the bed and the vertical distance below the drainage level are considered by engineers of the mining companies and the State mine inspectors. The nature of the bed in which the barrier pillar is to be established must be considered carefully. If it is crushed by folding or is friable, a pillar designed according to the "mine inspectors' formula" may not be satisfactory. Although it may not fail through collapse, its seepage factor may be too high; this often results in excessive pumping for a company operating a mine adjacent to one that is filled with water.

The geologic structure of the coal measures where the barrier pillars are to be established must be studied carefully. It is evident that a barrier pillar established in an area in which a fault is present may prove useless. Water might readily flow along the fault and pass from one side of the barrier pillar to the other.

The dip of the bed also plays an important part in determining the width of a barrier pillar, whether the proposed pillar is perpendicular to the strike of the coal measures or parallels it.

Where the beds are flat, or nearly so, and not friable or faulted, the width of the barrier pillar is generally determined by applying the "mine inspectors' formula." Figure 2 illustrates the form of columnar section obtained where barrier pillars are designed strictly in accordance with this formula. It shows that the strata composing such a barrier between mine workings would be of doubtful stability where beds are completely extracted adjacent to the barrier pillars.

Where the beds dip steeply, the results obtained from the formula are arbitrarily increased by the engineers and the State mine inspectors according to their judgment and experience.

The method generally employed to mine steeply dipping beds is to drive tunnels through the rock strata and anthracite beds perpendicular to the strike so as to intersect all the beds in the area. A gangway, or entry, is then driven in each bed from the tunnel. The rooms

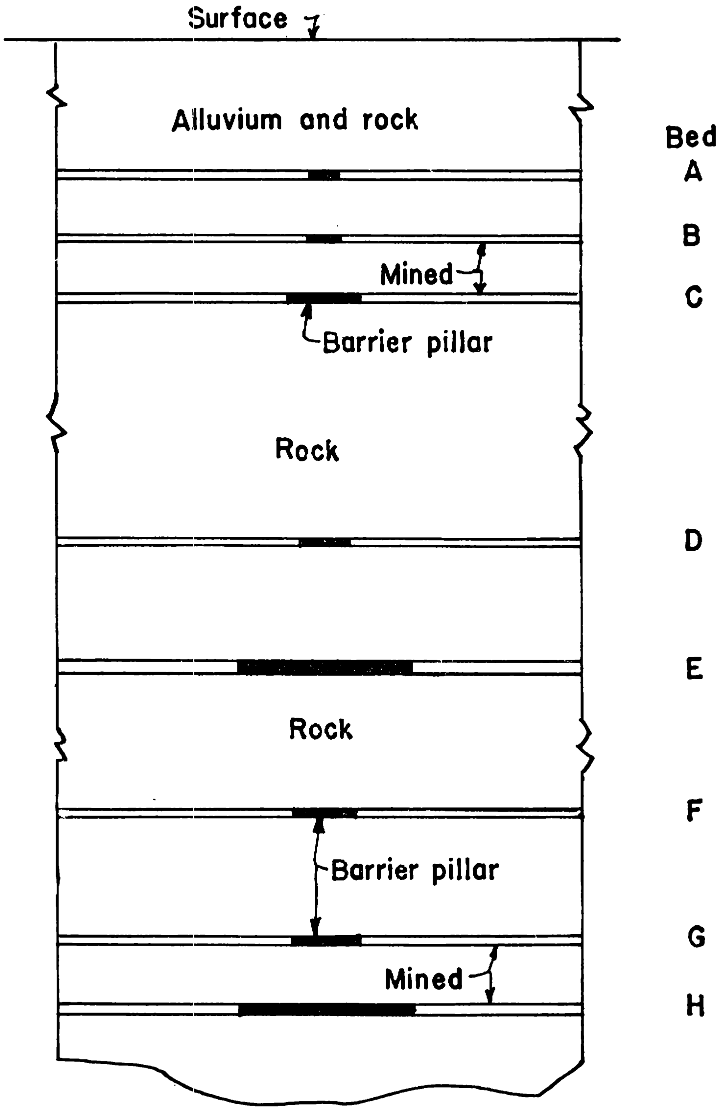

FIGURE 2.—Columnar section through theoretical barrier; gently dipping beds.

(chambers, or breasts) are then driven from the gangway. The area comprising the gangway and rooms driven from it that is mined from a given tunnel is called a level. There may be one or a number of these levels, depending on the size of the mine and the depth of the synclinal axis of the measures.

The width or size of the barrier pillar applying to barrier pillars in the respective beds that are mined on a given level, where the beds dip steeply, is based upon the thickness of the thickest bed intersected by the tunnel and is calculated by the "mine inspectors' formula." In a given level, this width applies to all the beds, irrespective of their thickness; therefore, it is the width to be maintained between the given tunnel and the bottom of the tunnel next above.

As the barrier-pillar width applying to the beds mined on each level is calculated by the "mine inspectors' formula," and as the thickness of the thickest bed is approximately the same in each level, the cross section of the strata constituting a barrier between the mine workings adjacent to the barrier assumes the form of a pyramid by becoming wider with each successive level of lower altitude.

OFFSET BARRIER PILLARS

Mining companies have not always respected the outer limits of established barrier pillars. For one reason or another, mine workings occasionally have been extended into barrier pillars. This practice was more prevalent in the early days of the industry than at present and generally occurred when mining operations on one side of the barrier pillar extended to the barrier pillar before those on the opposite side.

Where mining is conducted near a barrier pillar that has previously been weakened by mine workings on the opposite side of the barrier pillar, and especially if these older workings contain water, it is necessary to stop mine workings short of the agreed limits for the barrier pillar to keep a safe distance from the damaged or weakened barrier pillar to establish an adequate new barrier. This is one of the factors in the establishment of what are known as offset barrier pillars.

When mining operations are conducted in more than one anthracite bed, the barrier pillars separating adjacent mines in which the same beds are mined are not always placed in a vertical plane but are offset.

There are reasons why barrier pillars may be offset from each other. The ownership of the beds may be different and property lines may overlap; the beds may have been mined at different times; or an overlying bed may have been considered nonminable at the time an underlying bed was extracted, and the extraction of the underlying bed caused damage to the overlying bed or beds, which were mined at a later date.

The offsetting of barrier pillars is open to criticism, because a number of potentially dangerous conditions can result, especially if the barrier pillars are expected to act as dams. As a consequence, no protection is provided that will prevent water from flowing into mine workings on either side of the barrier pillar if the mine workings are interconnected by broken strata.

In 1931, a section of a mine in the Western Middle anthracite field was flooded because the strata between two anthracite beds fissured between offset barrier pillars. The Bottom Split of the Mammoth bed was worked from mine H and was abandoned and allowed to fill with water. The Buck Mountain bed underlies the Bottom Split of the Mammoth bed and is worked from mine G. The strata between the Bottom Split of the Mammoth bed and the Buck Mountain bed are 144 feet thick and are composed of sandstone, conglomerate, and two unmined anthracite beds. The barrier pillar in the Bottom Split of the Mammoth bed and the barrier pillar in the Buck Mountain bed are offset 800 feet, as shown in figure 3.

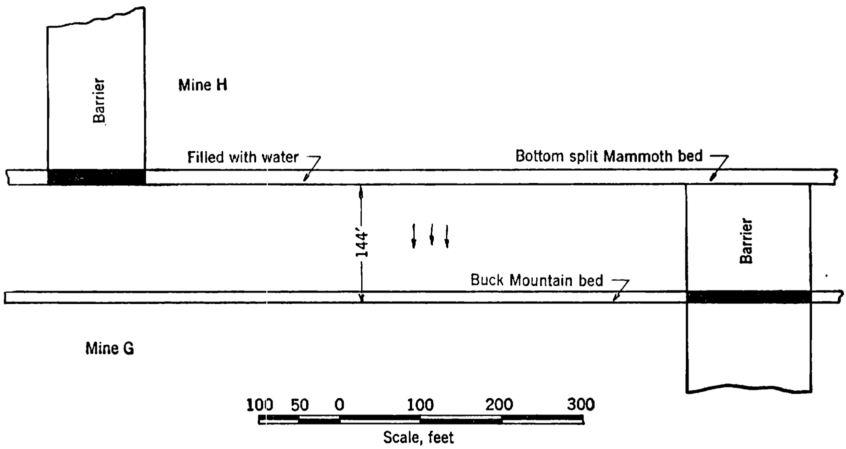

FIGURE 3.—Cross section showing failure of rock strata between offset barriers.

On September 30, 1931, a fire boss, while making a preshift examination in the Buck Mountain bed of mine G, noticed an unusual volume of water flowing along the gangway. The water was rising rapidly, and he realized that his escape would be cut off. He immediately started to climb the chambers and make his way to the shaft through old workings. On reaching the shaft, he notified the officials that water was flooding the mine. A large group of men were working in another section of the mine. Men were sent to warn them of the danger and to instruct them to return to the surface. All the men reached the surface safely; but, in escaping from the mine, some had to wade through water that reached their hips.

Investigation proved that the strata between the Bottom Split of the Mammoth bed and the Buck Mountain bed had fissured in the area between the offset barrier pillars and allowed water from the abandoned workings in the Bottom Split of the Mammoth bed to flow into mine workings in the Buck Mountain bed. As a consequence, the purpose of the barrier pillar was destroyed, a group of men nearly lost their lives, and a large quantity of anthracite was lost.

EFFECT OF BOOTLEG MINING ON BARRIER PILLARS

Bootleg mining has caused considerable damage to barrier pillars in numerous instances, especially in the Western Middle and Southern fields, where the beds dip steeply and easily accessible barrier pillars have been left along the outcrop.

814153°—49——3

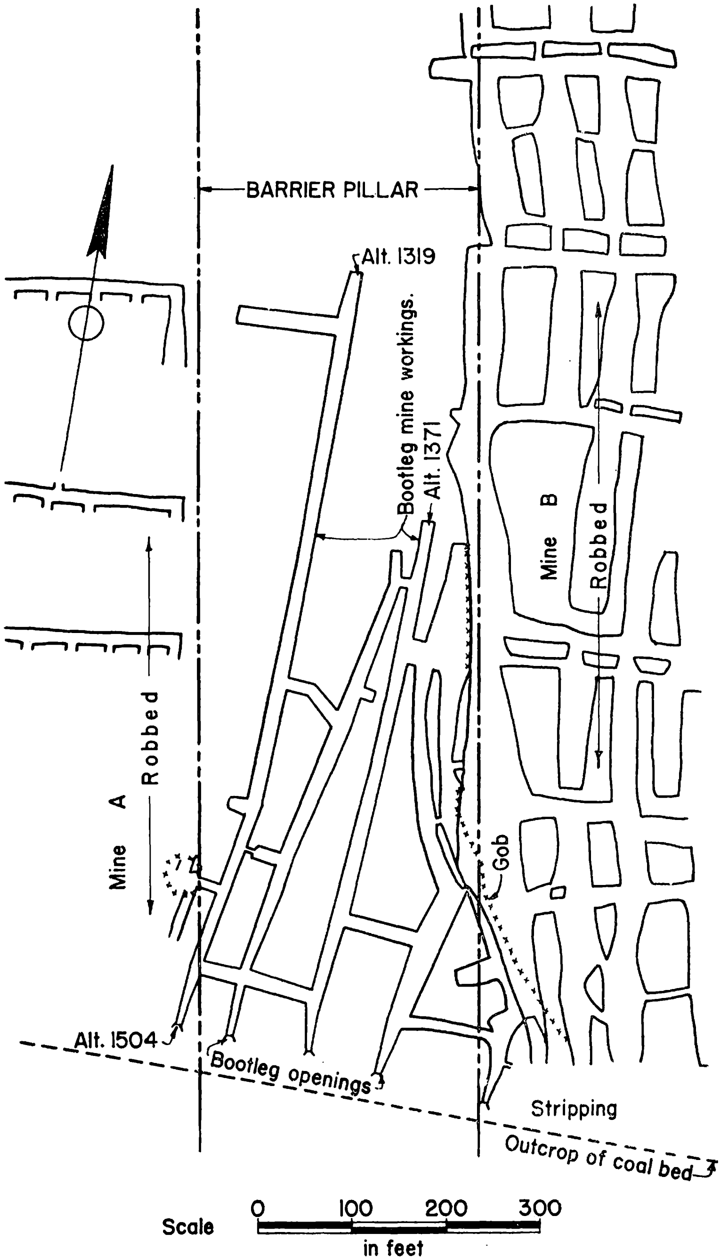

FIGURE 4.—Damage done to barrier pillar by bootleg-mine workings.

When mining in a barrier pillar, bootleg operators drive a slope or series of parallel slopes from the outcrop down the dip in the barrier pillar. Short gangways and rooms, or breasts, are then driven from the slope or slopes. The barrier pillar is mined and punctured in many places, with the result that its usefulness as a barrier pillar is destroyed from the outcrop to the bottom of the slope, as shown in figure 4.

In some instances the mine on either side of a barrier pillar or the mines on both sides are partly filled with water, and bootleg mining

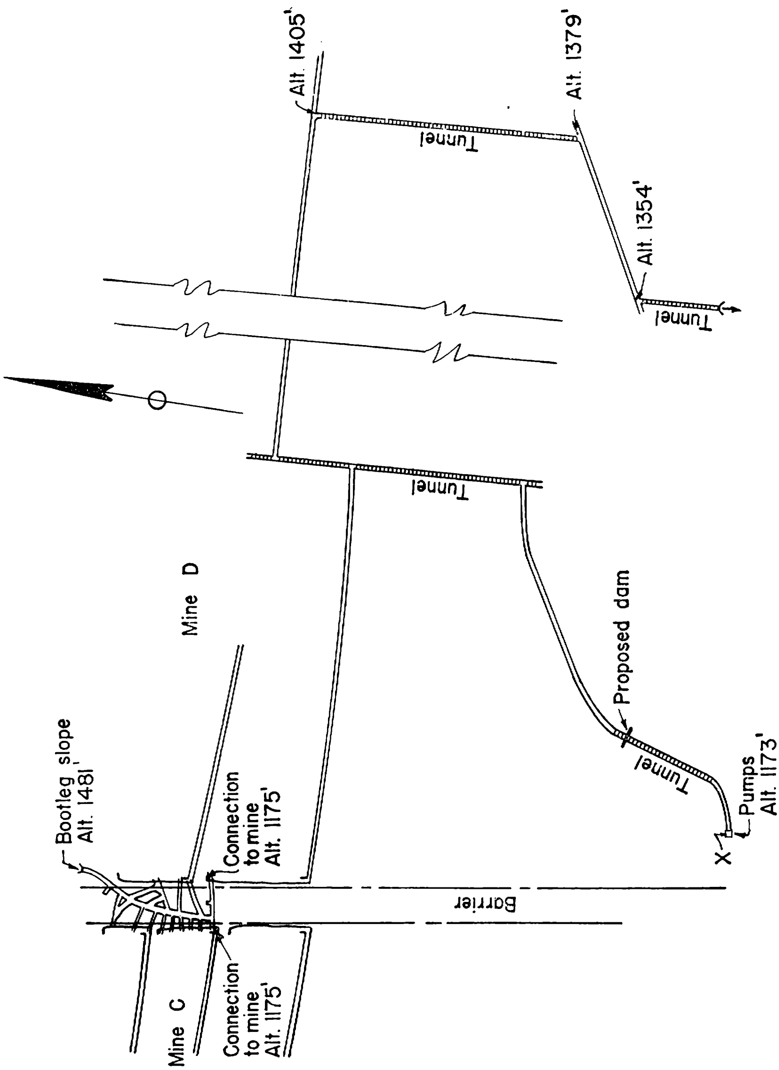

FIGURE 5. Barrier pillar destroyed by bootleg mining.

is conducted in the barrier pillar down to the altitude of the water. After this occurs, the water in the mine on either side of the barrier pillar cannot rise above this altitude without causing unnecessary pumping in the mine on the opposite side of the barrier pillar.

Figure 5 shows a barrier pillar between two active mines that was destroyed by bootleg mining. Mine D, on the east side of the barrier pillar, contains a coal basin that has a drainage area of 4 square miles. The water from this basin flows through a rock tunnel to a pumping station situated in another basin at point X, from where the water is pumped to the surface. The company operating mine D planned to erect a dam in the tunnel connecting the mine workings in the north and south basins to allow the mine workings in the north basin to fill with water to 1,405 feet altitude, the altitude of a drainage tunnel through which the water would flow to the surface. Erection of this dam would have made it unnecessary to pump the water that collected in the north basin, which has an area of 4 square miles. This plan had to be abandoned because the barrier pillar between mines C and D was punctured at 1,175 feet altitude by bootleg mining. If the water in mine D is allowed to rise above 1,175 feet altitude, it will flow into mine C, where it has to be pumped to the surface against a greater hydrostatic head than is necessary in mine D.

STATUS OF BARRIER PILLARS

The increase in the number and size of the underground water pools throughout the anthracite fields is to a large degree the result of the nondependability of numerous existent barrier pillars to serve as dams between adjoining mining properties.

Where a barrier pillar acts as a dam between an active mine and an inactive mine that is gradually filling with water, the mining company often considers such a barrier pillar unsafe as a protection against a hydrostatic head that is more than a definite figure. In such an active mine, boreholes are driven through the barrier pillar at strategic points. Valves are attached to the boreholes to control the hydrostatic pressure against the barrier pillar. At critical points the barrier pillars have been strengthened by large blocks of masonry, reinforced concrete, hydraulic back filling, or a combination of these means of protection.

When it becomes necessary to drain water from an abandoned mine into an active mine in order to operate with safety in the active mine, the pumping costs of the active mine rise sharply. Some mining companies pump water from six to eight abandoned mines, so that the hydrostatic pressure against barrier pillars in active mines can be maintained at a safe figure. Where barrier pillars have been punctured, the water from abandoned mines must be handled to prevent inundation of active-mine workings.

Research to date regarding the size and position of barrier pillars and the condition of existent barrier pillars makes it apparent that uncertainty exists in the minds of those concerned, not only as to the method by which the size of a barrier pillar is determined, but also as to the stability of a barrier that is to serve as a dam.

The question of barrier pillars is intimately associated with the question of ground movement (mining subsidence, "squeezes," and rock bursts). Unless mining operations are conducted so as to prevent a squeeze or rock burst (bump) affecting a barrier pillar, there is no assurance that even the stability of the barirer pillar, having the correct size to serve as a dam, can be maintained (*8, 11, 18, 20, 28, 29, 32, 34*).

FORMULA FOR CALCULATING SIZE OF BARRIER PILLARS

Barrier pillars that are considered to be dams and designed as such have been discussed by Ash and Eaton (*5*). It was found by trial calculation that a barrier or dam having a trapezoidal cross section, with a top width of 50 feet, arbitrarily chosen, and a base width of 0.45 of the height would be stable. Such a barrier will not be damaged by mining subsidence if the angles that its sides make with the vertical equal or exceed the angles of draw.

The term "angle of draw" means the angle of intersection of the draw line and a vertical line. The term "draw line" means the line from the edge of the barrier pillar in a bed in which anthracite is extracted to the edge of a surface area that may be affected by mining subsidence. The angle of draw varies widely, as reports in the literature show (*11, 20, 22, 23, 25, 34*), and should not be assumed to be less than 10° (*5, 25*).

Figure 6 shows the cross section of a barrier, designed to act as a dam, superimposed on the cross section of an actual stepped barrier situated in the Southern field. The stepped barrier roughly follows the shape of the trapezoidal barrier having sides that are 12° to the vertical; however, the stepped barrier is smaller than the trapezoidal barrier, the difference in size increasing as the depth of the mine increases. Figure 6, and other examples studied, show that, in the Southern field, recently designed barrier pillars practically conform in size, particularly in volume, to those proposed by Ash and Eaton (*5*).

Mining practice supports the opinion that any rule or formula for determining the size of a barrier pillar is to be regarded merely as a guide. No rule can possibly serve in all instances; however, a barrier pillar is of vital importance where it must serve as a dam to protect a mine and the persons employed therein.

The prevention of failure of a barrier pillar that is acting as a dam requires a remedy that leaves no question of doubt. Such a remedy requires the use of a simple calculation by which the width or size of a barrier pillar can be determined without attempting to connect the thickness of the bed and the width of the barrier pillar, by means of a formula.

A barrier as designed by Ash and Eaton (*5*) to resist safely a hydrostatic head of 2,000 feet, which is the approximate depth below the drainage level in any mine at present developed in the anthracite region, has the following dimensions: Depth, 2,000 feet; top, 50 feet; and base, 900 feet. The sides of the barrier have a slope of 12° to the vertical.

Considering the cross section of such a barrier, formulas have been developed to determine the width or size of a barrier pillar in a bed, regardless of the thickness of the bed and its inclination, or dip (*5*). These formulas are as follows:

All measurements of distance are expressed in feet, and

A = the width, on the plane of the bed, of the portion of the barrier pillar on the rise side of the property line;

B = the width, on the plane of the bed, of the portion of the barrier pillar on the dip side of the property line;

$L = A + B$ = the width or size of the barrier pillar;

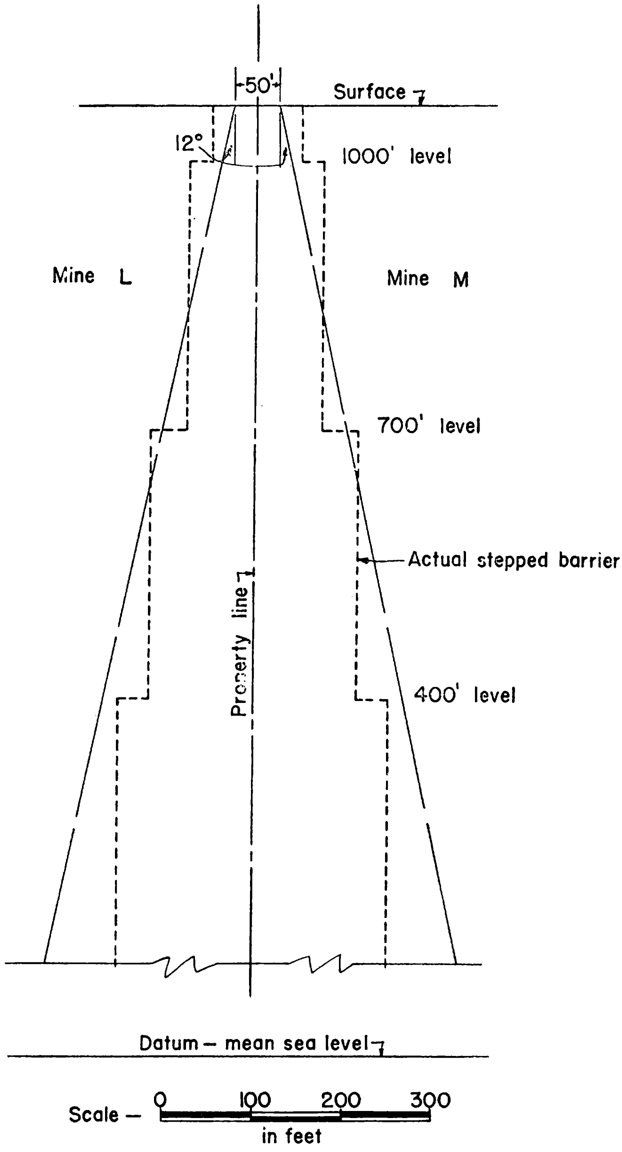

FIGURE 6.—Cross section of a barrier designed to act as a dam superimposed on an actual stepped barrier.

C = the horizontal width of the barrier, or dam, as measured on the surface or at the drainage level; this is considered to be 50 feet, which the authors believe should be the minimum width of the top of a barrier that acts as a gravity dam;

D = the vertical distance, or depth, between the property line on the surface and the trace of the property line on the floor (bottom, or footwall) of the bed;

d_{rise} = the horizontal distance from the property line to the floor of the bed, where the bed outcrops at some point on the rise side of the property line on the top of the barrier, or dam;

d_{dip} = the horizontal distance from the property line to the floor of the bed, where the bed outcrops at some point on the dip side of the property line on the top of the barrier;

θ = the angle that the nonparallel sides of the cross section of the barrier make with the vertical, where the barrier has a top that is 50 feet wide and has a depth or no more than 2,000 feet. This angle is taken as 12° for a barrier, so that it can serve as a gravity dam;

φ = the dip of the bed.

Where the bed does not outcrop within the limits of the top of the barrier, or dam, and the property line and barrier pillar are parallel to the strike of the bed, the following formulas are applicable when

$$C = 50 \text{ feet, and } \theta = 12°,$$

$$A = \frac{24.45 + 0.208D}{\sin(102° - \varphi)},$$

$$B = \frac{24.45 + 0.208D}{\sin(78° - \varphi)},$$

and

$$L = A + B = (24.45 + 0.208D)\left[\frac{1}{\sin(102° - \varphi)} + \frac{1}{\sin(78° - \varphi)}\right].$$

If the inclination of the bed is zero (a flat bed), or $\varphi = 0$,

$$A = B = 25 + 0.213D,$$

and

$$L = A + B = 50 + 0.426D.$$

Where the bed outcrops on the rise side of the property line on the top of the barrier, or dam,

$$A = \frac{d_{\mathrm{rise}}}{\cos\varphi},$$

and

$$B = \frac{24.45 + 0.208D}{\sin(78° - \varphi)}.$$

Where the bed outcrops on the dip side of the property line on the top of the barrier, or dam,

$$A = 0,$$

and

$$B = \frac{24.45 - 0.978\, d_{\mathrm{dip}}}{\sin(78° - \varphi)}.$$

Where the property line and barrier pillar are perpendicular to the strike of the bed, the portions, A and B, of the base of a given cross section of the barrier are of equal magnitude with respect to the vertical plane of the property line regardless of the thickness of the bed, its inclination, and whether or not it outcrops.

The depth D, or vertical distance between the surface or drainage level and a definite point that is formed by the intersection of a given vertical cross section of the barrier and the trace of the property line on the plane of the floor of the bed, is equal to the vertical distance from the surface to the floor of the bed, which is considered as being flat. In other words, φ is considered as being zero at the above-mentioned point in the bed. If we let

$$C=50 \text{ feet and } \theta=12°,$$

then

$$A=B=25+0.213D.$$

The mine-property owner is interested in knowing how much of the given bed must be left on his side of the property line. Widths A and B of the portions of the barrier pillar can be calculated by whichever formula applies to the problem; however, the real values of the widths A and B can also be determined from graphs shown in figure 7 and figure 8 (*5*).

As an example: Consider the vertical depth D to be 1,000 feet and the dip (φ) of the bed to be 45°; then, from figure 7 we find that A is 276 feet; similarly, from figure 8 we find that B is 425 feet.

UNDERGROUND WATER POOLS

Often pools of water are present in abandoned mines because no one is financially interested in removing them. The water has accumulated because pumping was stopped. The operator of the adjoining active property takes just enough action to protect his own property and the lives of his workmen, which is all that he is justified in doing. The water in the abandoned property then accumulates to the altitude prescribed, usually in conjunction with the State mine inspectors for the district, as assuring the safety of the adjacent active mine. If this active mine in turn ceases operation for any reason whatsoever, the same procedure is followed, resulting in enlargement of the pool and possibly a rise in the altitude of the surface of the water.

Pools in inactive mine workings of active mines usually are formed when the inflow of water exceeds the pumping capacity. When the rising water has come to rest or has been brought to rest, arrangements are made to handle the inflow from the higher altitude rather than to unwater a basin that has been flooded and may be flooded again. Consequently, pumps are installed to control the water at this altitude, and action to lower the water is deferred. This procedure is perfectly logical because removing a body of water in a basin is a slow, tedious, and expensive operation. Also, more often than not, the operators of the active mine cannot assume the added operational expense of pumping and the capital outlay for additional new equipment.

In some instances, pools of water have been purposely created in parts of active mines having barrier pillars that separate the active mines from abandoned mines filled with water. These pools have a stabilizing effect and reduce the hydrostatic pressure exerted on the barrier pillars by the water in the abandoned mines.

Advantages, other than deferring and reducing the cost of pumping, that are presented as arguments for delay in unwatering flooded mine workings are: The removal of fire hazards; no ventilation and inspection of old workings; and improved ventilation in the workings not flooded because of reduction in the size of the area that must be ventilated.

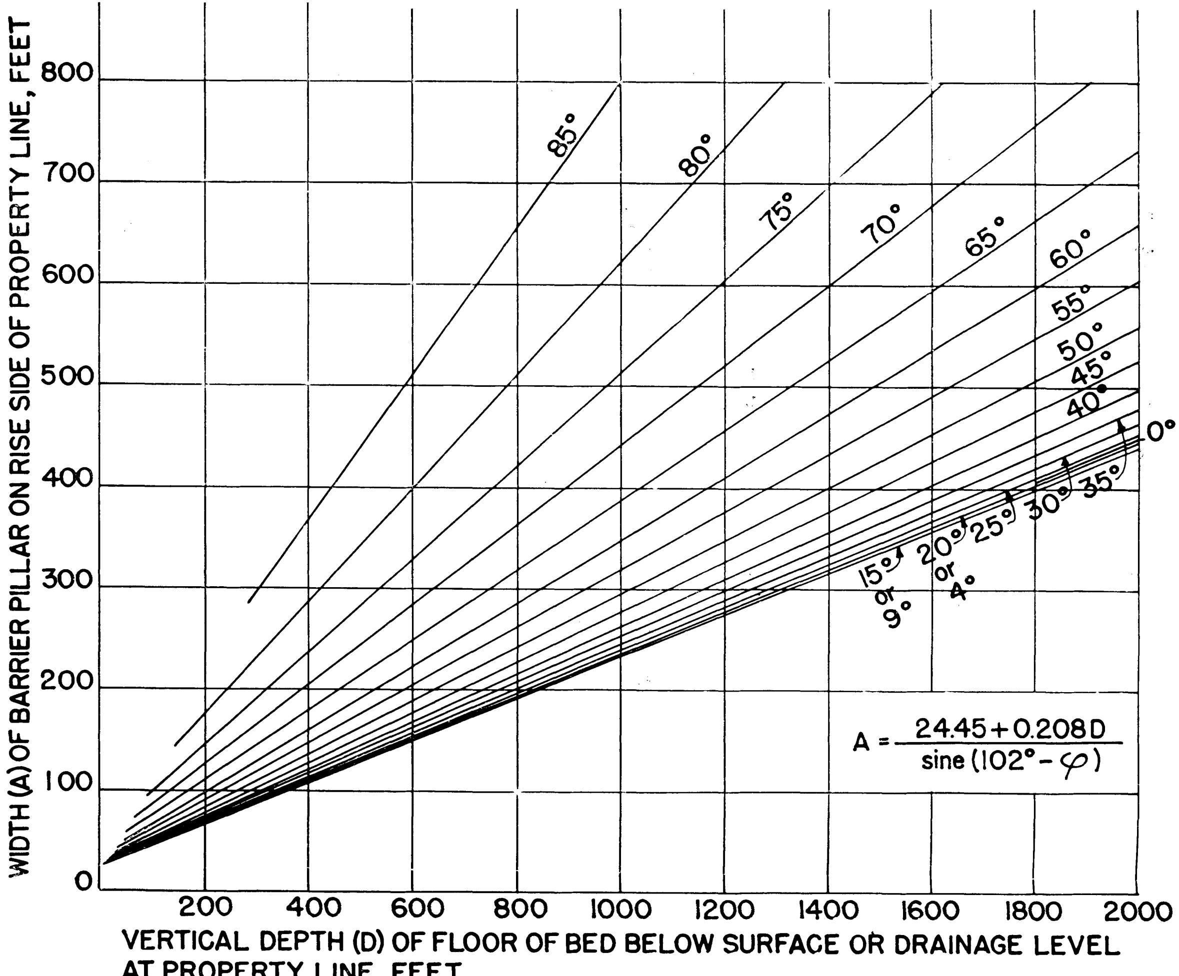

FIGURE 7.—Widths of portions of barrier pillar on rise side of property line, where bed does not outcrop on top of barrier, or dam, and barrier pillar and property line parallel strike.

814153—48 (Face p. 20)

814153°—49—4

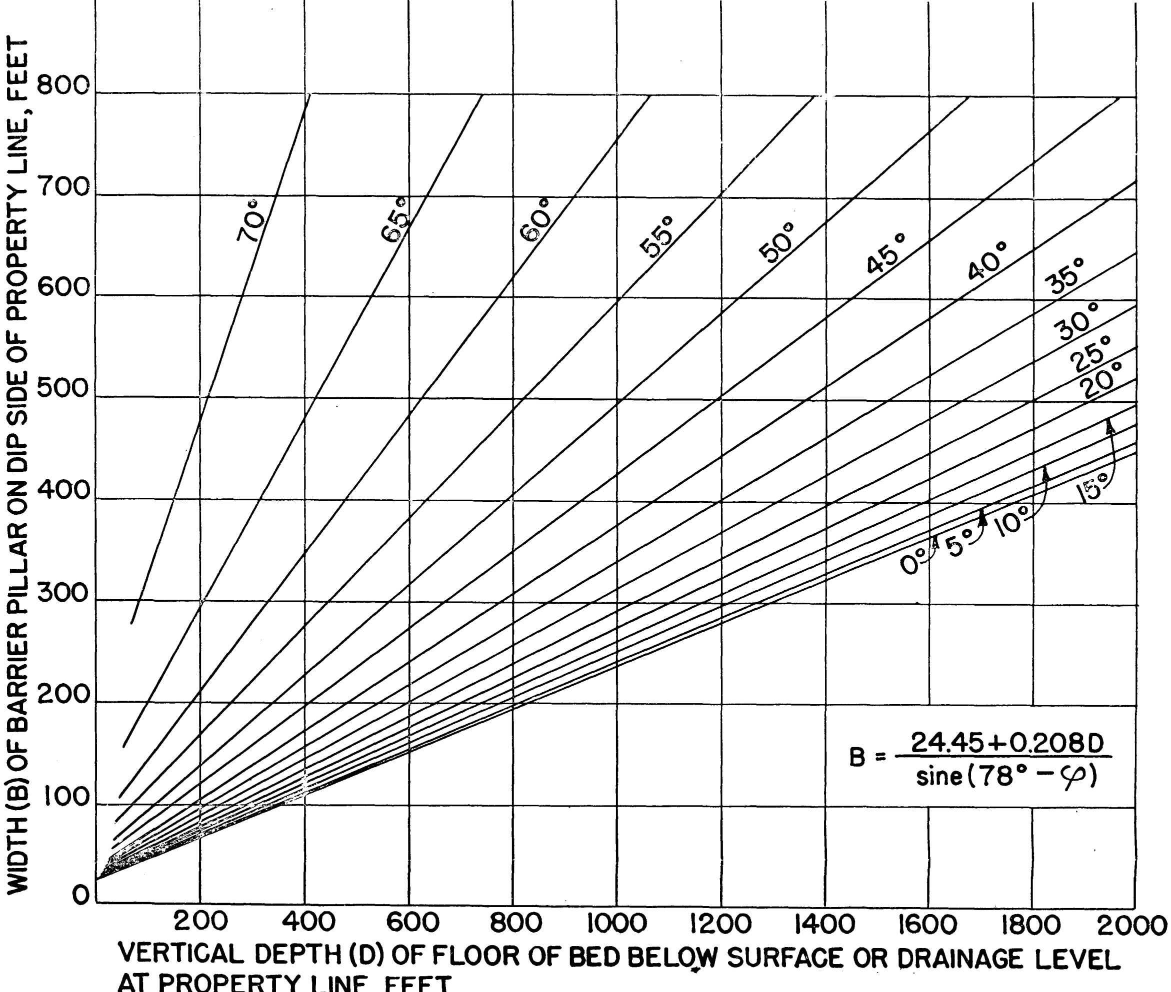

FIGURE 8.—Widths of portions of barrier pillar on dip side of property line, where bed does not outcrop on top of barrier, or dam, and barrier pillar and property line parallel strike.

814153—48 (Face p. 21)

The productive coal measures in the anthracite region of Pennsylvania are in four distinct fields, as shown in figure 9. The earliest record of a mine being abandoned and allowed to fill with water concerns a mine in the Southern field that was closed in 1856. Table 3 shows the growth in the number of underground water pools by 5-year periods from 1 in 1856 to 159, containing 91 billion gallons of water, in 1948.

At present, the Northern field has the most acute water problem; this field produces more than one-half the present total output. The Eastern Middle field does not have as serious a problem as the other fields because, with a large expenditure of capital in the early 1890's, drainage tunnels were driven that indicate a way to solve the water problem in other sections. The Northern and Eastern Middle fields, which have the shortest life, have the greatest density of population (*3*).

TABLE 3.—*Progressive growth in number of underground water pools by 5-year periods, from 1855 to 1948*

Period	Northern field	Eastern Middle field	Western Middle field	Southern field	Total
1855–1859				1	1
1860–1864				1	1
1865–1869					
1870–1874				1	1
1875–1879			2	1	3
1880–1884					
1885–1889				3	3
1890–1894		2	2	1	5
1895–1899	2	1	1	2	6
1900–1904		2	4	1	7
1905–1909		2	1		3
1910–1914	1	3			4
1915–1919	1	1		1	3
1920–1924	3	2			5
1925–1929		6	10	3	19
1930–1934	10	4	16	10	40
1935–1939	13	2	13	5	33
1940–1944	6	2	9	1	18
1945–1948	3	4			7
Total	39	31	58	31	159

TYPES OF POOLS

The underground water pools considered in this report include:

1. Pools in abandoned mines that have no anthracite reserves and are filled with water to the overflow point. These may be a hole or break in a barrier pillar, a drainage tunnel that connects two basins and allows water to flow from one basin to the other, or an overflow point at the surface of the ground.

2. Pools in abandoned mines that have no reserves and in which the water has not reached the altitude of natural overflow. The altitude of the water in the pool is controlled by pumping or by drainage through boreholes to maintain the hydrostatic head below a definite figure against a barrier pillar that is considered unsafe.

3. Pools in abandoned mines having reserves that, although inundated, would be minable if the mines were unwatered and the threat of inundation economically removed.

4. Pools in active workings in which lower levels are allowed to fill with water so that pumping, necessary to keep the active workings free from water, can be done from the surface of the pool instead of from the basin, thus lowering the cost of pumping by reducing the hydrostatic head.

5. Pools in active mines having reserves that, although inundated, would be minable if the water problem were solved.

This report does not cover sumps having facilities by which the water can be removed, or bodies of water in local dips or basins from which water is normally removed during active mining operations by means of gathering pumps or drainage boreholes, which have become blocked through lack of maintenance.

NORTHERN FIELD

The Northern field is a canoe-shaped syncline, in large part with flat bottom and rather steep dips on the margins that extend along the slopes of mountain ridges that mark the outcrop of the conglomerate and other hard strata below the anthracite measures. This trough is 62 miles long, with a maximum width of 5 miles, extending in a northeasterly direction from Shickshinny to Forest City. The anthracite measures cover an area of approximately 176 square miles.

For much of its course, the basin is wide and flat-bottomed, but in most of the region west of Wilkes-Barre it contains subordinate folds and faults, some of them of considerable magnitude and complexity. Although these structural complexities add considerably to the cost of mining and cause some loss of anthracite, they add materially to the tonnage of anthracite available (*13*).

Although there are some local folding and faulting, in general the center of the trough is wide and flat-bottomed, with gradually increasing dips that become quite steep as the limbs of the syncline approach the outcrops. Faults and minor dislocations, in general, parallel the main course of the basin, but some are diagonal to it. The topography of the area is a wide, rolling valley, with sides rising not quite as steeply as the underlying anthracite measures.

In the deepest part of the field, near Wilkes-Barre, the total thickness of the anthracite measures is approximately 2,000 feet, with 18 workable beds of anthracite having an aggregate thickness of 100 feet. From this point to the northeast and the southwest, the thickness of the anthracite-bearing strata decreases as the altitude of the bottom bed rises in each direction along the synclinal axis of the basin.

The lowest anthracite bed outcrops near Shickshinny at the western end of the field. At Askam, near Wilkes-Barre, this bed at its lowest point is 1,500 feet below sea level, thence rises in a northeasterly direction along the synclinal axis to 700 feet below sea level at Kingston; 200 feet above sea level at Pittston; and 500 feet above sea level at Old Forge, from where it again plunges to slightly below sea level at Olyphant. At Archbald the main axis of the basin is displaced to the north; and, from there, the basin becomes much more shallow until it rises to the outcrop near Forest City at the eastern end of the field.

Along the flanks of the Northern field, the lowest anthracite bed outcrops mostly on the mountain slopes on each side of the syncline

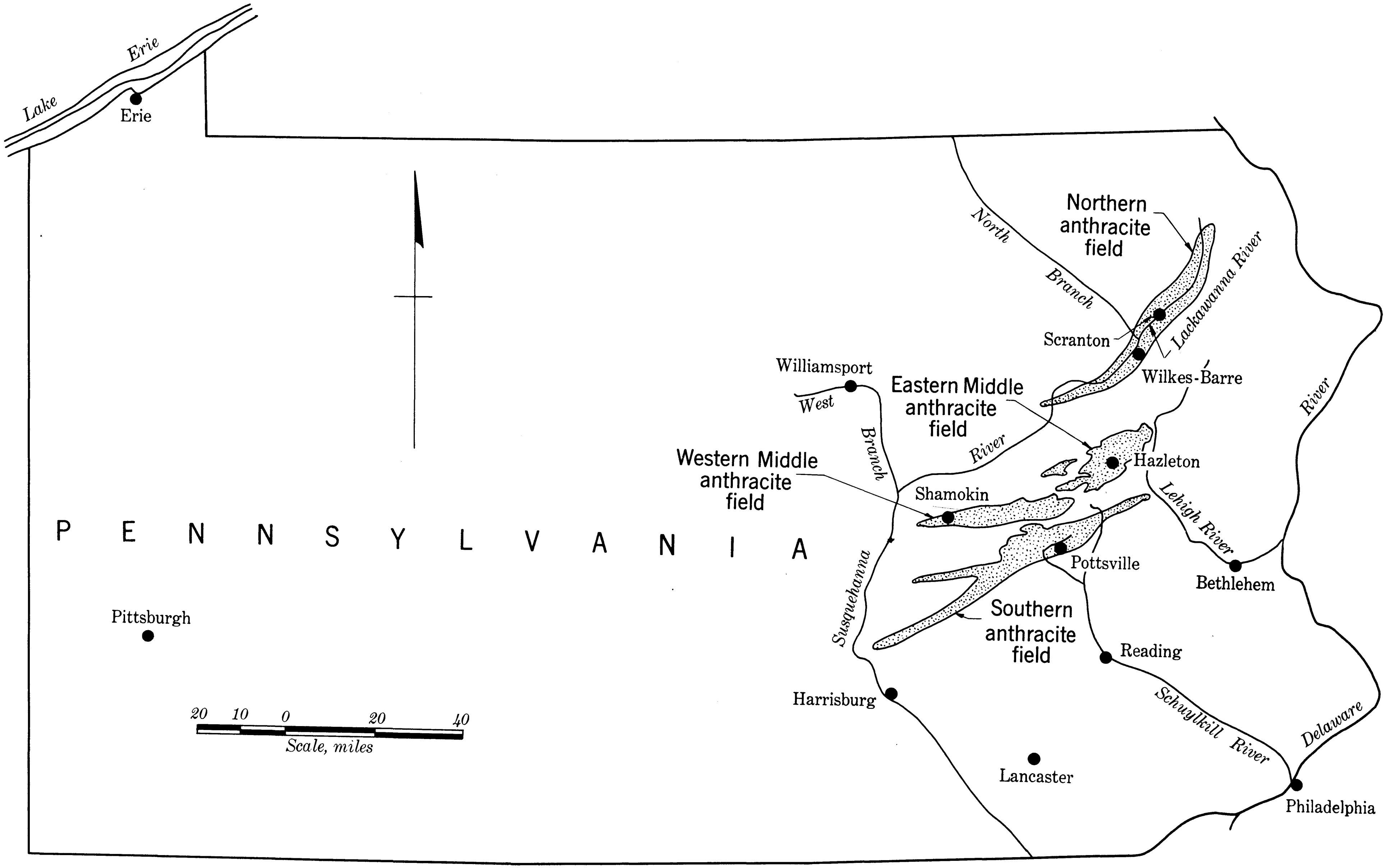

FIGURE 9. Vicinity map showing four anthracite fields.

814153 O - 49 (Face p. 22) No. 1

Pool No.	Colliery	Altitude of surface (feet)	Altitude of lowest level (feet)	Altitude of water (feet)	Altitude of basin in lowest bed (feet)	Water in workings (gallons)	Location of overflow
1	West end	500.0	300.0	500.0	300.0	237,270,000	Overflows to surface.
2	do	500.0		500.0			
3	do	800.0	400.0	800.0	400.0		
4	Grand Tunnel	520.0	−207.0	150.0	−1,500.0	108,190,000	Pumped to surface Overflow to Avondale (break in barrier) at Red Ash 350.
5	Gaylord	546.0	−300.0	220.0	−1,200.0	186,770,000	To Nottingham 3 6-inch boreholes through barrier at 202 Red Ash. Overflow to Nottingham through break in barrier at Red Ash 250.
6	Kingston Coal Co	567.0	−590.0	160.0	−900.0	850,000,000	Pumped to surface. Deep-well pump. Kingston No. 4 shaft. Overflow to Loree through break in barrier at Baltimore 170.
7	East Boston	567.0	−400.0	160.0	−900.0		Break through barrier at 160. 11 feet to Kingston Coal Co.
8	Black Diamond	567.0	−200.0	160.0	−800.0		To East Boston through 12-inch boreholes at Ross 99.
9	Forty Fort	560.0	−300.0	−170.0	−700.0	150,000,000	Active colly. To Black Diamond break in barrier at Red Ash 370.
10	Baltimore	554.0	−927.0	60.0	−927.0	511,940,000	Pumped to surface Hollenback colliery (piped through barrier). Overflow to Hollenback at Baltimore 270.
11	Mineral Spring	600.0	−247.0	340.0	−600.0		Flows to Baltimore colliery at Baltimore bed 270.
12	Peach Orchard	580.0	−591.0	278.0	−700.0		Flows to Baltimore colliery. Crack in barrier at Baltimore bed 278.
13	Maltby	560.0	−110.0	122.0	−300.0	250,000,000	Active collieriery. Being dewatered.
14	Pa. Coal Co. No. 14	560.0		125.0	−150.0	380,500,000	Pumped to surface. Pennsylvania No. 14.
15	Pa. Coal Co. No. 6	558.0	−60.0	45.0	−60.0	77,000,000	Pumped to No. 14. Boreholes through barrier.
16	Schooley	556.0	−25.0	120.0	−25.0	425,000,000	Pumped to surface Schooley shaft.
17	Clear Spring	577.0	105.0	454.0	105.0	1,865,200,000	Leaks through strata.
18	Seneca	567.0	100.0	356.0	100.0		To Barnum borehole through barrier Clark 316.
19	Pa. Coal Co. No. 9	580.0	105.0	177.0	165.0		Pumped to surface.
20	Greenwood	753.0	533.0	603.0	325.0	413,500,000	Pumped to surface Greenwood No. 1 shaft. Overflow to National (break in barrier) No. 2 Dunmore at 615.
21	Pyne	850.0	412.0	475.0	300.0	148,500,000	Overflows to Holden pumps at Clark 475.
22	Mount Pleasant, west side	920.0	401.0	416.0	200.0	312,030,000	To Sloan water shaft at Clark bed 416.
23	Mount Pleasant, east side	808.0	200.0	315.0	200.0		To Bellevue No. 2 Dunmore 315 (break in barrier).
24	Oxford	808.0	200.0	315.0	200.0		Part of Mount Pleasant, east side pool.
25	Pine Brook	711.0	300.0	455.0	200.0		To Bellevue No. 2 Dunmore, 2 8-inch boreholes, at 397. Overflow to Manville colliery at 473, No. 2 Dunmore.
26	do	690.0	430.0	490.0	200.0	4,356,000	To Bellevue boreholes. Rock strata between No. 2 and No. 3 Dunmore at 435. Overflow 500, No. 2 Dunmore to Pine Brook.
27	Diamond	694.0	227.0	405.0	227.0	406,742,000	Pumped to surface Diamond No. 2 shaft. Overflow to Mount Pleasant, east side, New County bed at 514 (break in barrier).
28	Marvine	744.0	42.0	250.0	42.0	924,470,000	Pumped to surface Marvine shaft. Overflow to Storrs colliery. Clark 320.
29	Richmond	727.0	160.0	300.0	70.0		Overflows to Marvine 384, Dunmore No. 3.
30	Storrs-Cayuga	773.0	−5.0	235.0	−5.0	967,932,000	Pumped to surface. Overflow to Marvine colliery. Clark 320.
31	Price-Pancoast	750.0	25.0	310.0		216,480,000	Overflows to Marvine, 2 10-inch boreholes Dunmore No. 3 at 310.
32	Johnson	757.0	12.0	486.0	12.0	196,813,000	To Olyphant at 420 upward (weak barrier).
33	Lackawanna	777.0	175.0	734.0	100.0	753,723,000	Overflows to surface Jerome shaft 777.
34	Ontario	933.0	586.0	933.0	100.0		Seeps to Lackawanna through barrier. Wet-weather overflows to surface by tunnel at 933.
35	Peck shaft-Sterrick Creek	820.0	220.0	320.0	220.0	68,000,000	Pumped to surface, deep-well pumps.
36	Riverside-Gravity Slope	822.0	520.0	822.0	520.0	1,792,700,000	Overflow slope to surface at 822.
37	Jermyn	925.0	720.0	925.0	650.0	4,045,000,000	Overflow slope to surface at 925.
38	Carbondale	1,022.0	915.0	953.0	915.0	27,847,000	Kept below 953 by deep well pumps at Carbondale No. 3.
39	Clinton-Forest City	1,384.0	1,100.0	1,384.0	1,100.0	701,875,000	Overflow to surface at 1380 slope.
	Total					16,021,838,000	

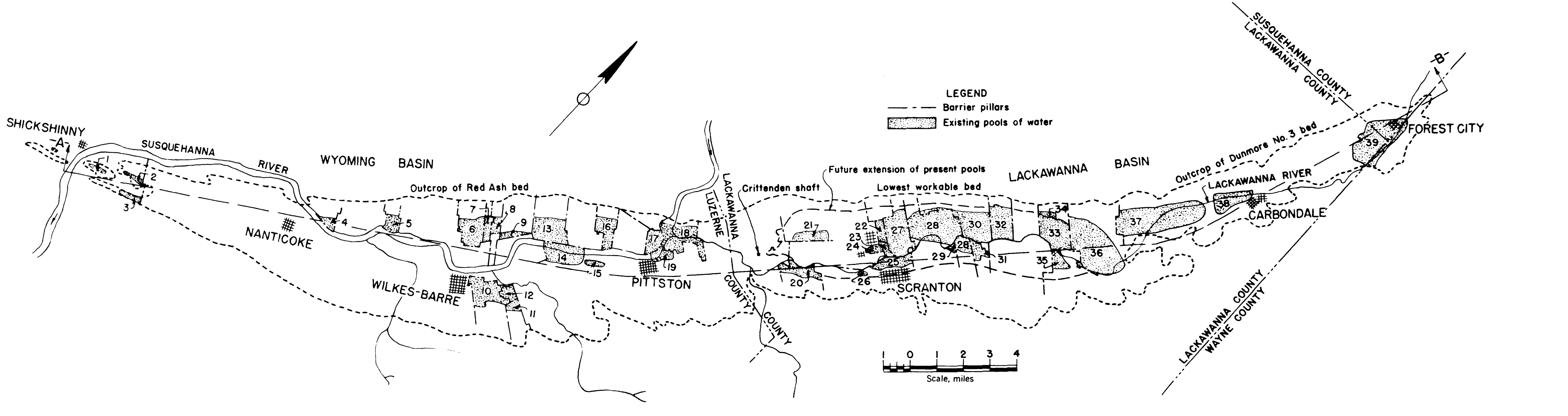

FIGURE 10.—Map of underground pools impounded in Northern anthracite field.

814153 O - 49 (Face p. 22) No. 2

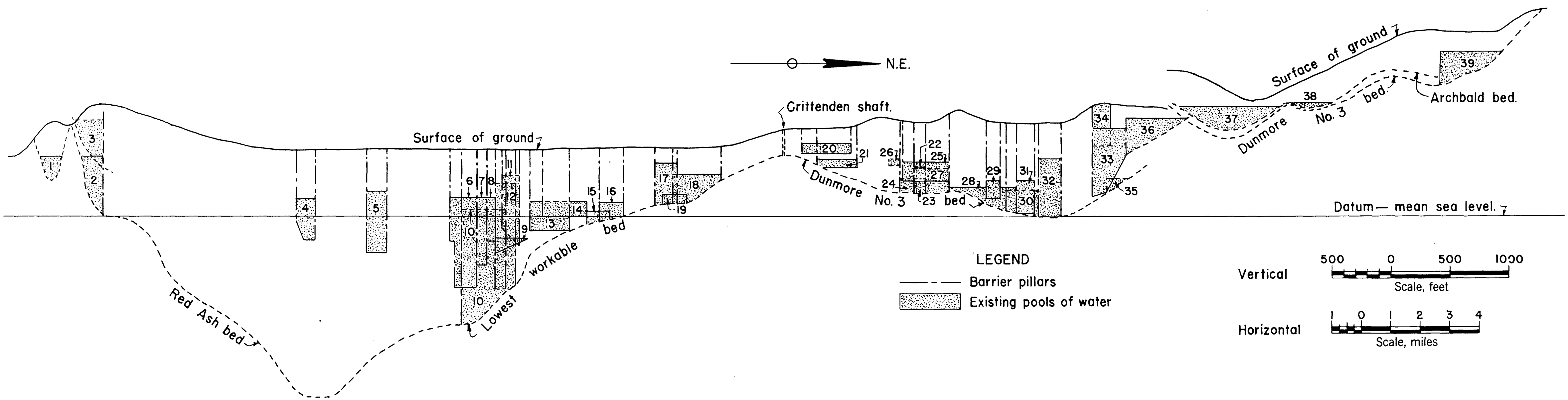

FIGURE 11.—Northern anthracite field, showing longitudinal section along line A–B.

at altitudes ranging from 1,000 feet at Shickshinny to 1,800 feet at Forest City.

The Northern field is divided into two basins, the Wyoming Basin and the Lackawanna Basin, by a structural saddle near Old Forge, where the altitude of the lowest bed along the synclinal axis is approximately 500 feet.

Water originating in underground workings in the Lackawanna Basin cannot pass this saddle and flow into the mine workings in the Wyoming Basin until a large number of mines in the Lackawanna Basin, which extends from the saddle at Old Forge to a barrier pillar northeast of Dickson City, become inundated to the altitude (500 feet) of the saddle. However, if the water rises above the 500-foot altitude it would flow to the center of the Wyoming Basin at Askam, from whence the water would have to be handled with an increase of 400 percent in static head and a corresponding increase in the cost of pumping.

A review of the history of the mine-water problem in the Northern field indicates that the water impounded in the underground pools is not generally the result of any preconceived plan but is a condition for which the present operating companies are not responsible. It is expected that further encroachment of water will occur in this area.

At the present rate of depletion, the reserves in the Lackawanna Basin will be virtually exhausted within 15 years, and the abandoned mine workings will be inundated. The resultant overflow of mine water into the Wyoming Basin will be disastrous to mines in this area unless a solution of this phase of the mine-water problem is underway within the next 5 years.

Nearly half of the present anthracite production comes from the Northern field, and approximately half of the mine employees in the anthracite industry reside in this area.

Thirty-nine underground pools containing 16 billion gallons of water are present in the Northern field, as shown in the legend for figure 10, which gives the pertinent data concerning the impounded water in underground pools in the Northern field.

Figures 10 and 11, a plan map and a longitudinal section, respectively, of the Northern field, show the pools of impounded mine water in this field.

Within the past year, mining has been completed in three separate areas near the easterly end of the field, namely: Clinton-Forest City; Riverside-Gravity Slope; and Jermyn. These abandoned mines have been allowed to fill with water, except for small areas lying above the drainage level. Overflow portals have been constructed through which the mine water now flows to the surface. This dispensed with three large pumping plants. Moreover, efficient barrier pillars prevent the water in these mines from flooding adjacent mines.

The Lackawanna (Jerome shaft) and Greenwood collieries are abandoned mines protected by adequate barriers that have overflow portals. However, because of leakage through pervious surface wash, low-head pumps are in use to hold the altitude of the surface of these pools below the leakage points. The pumps at Jerome shaft are of the deep-well type (*17*).

EASTERN MIDDLE FIELD

The Eastern Middle field consists of a number of comparatively small basins, the synclinal axes of which are parallel and trend easterly and westerly. Most of the basins lie above the natural drainage horizon of the nearby surface areas. The area covered by the anthracite measures in this field is approximately 33 square miles. The basins are relatively long and narrow and separated by broad areas immediately underlain by the several members of the Pottsville conglomerate, which contains no anthracite (*16*). The anthracite measures in this area are discontinuous because the crests of the anticlinals of the anthracite measures have been eroded away.

A large volume of mine water in this field is drained to the surface through tunnels (*7*). Most of the underground water pools in this field lie below the altitude of the drainage tunnels.

Table 4 lists the major drainage tunnels in the Eastern Middle field, with pertinent data concerning these tunnels.

Numerous mine openings, such as slopes, drifts, and short tunnels, also serve for drainage purposes. Despite these facilities, 31 underground water pools are present in the Eastern Middle field and contain 4 billion gallons of water.

Figure 12 is a plan map of the Eastern Middle anthracite field, showing pools of impounded mine water and the major drainage tunnels in this field.

Figures 13 to 18 are typical cross sections through water pools in the Eastern Middle anthracite field.

The legend for figure 12 gives the pertinent data concerning the impounded water in underground pools in the Eastern Middle anthracite field.

The pools are in the basins that are not drained by tunnels or because the overflow points of the pools lie below the altitude of the drainage tunnels. The water in some pools in abandoned mines is confined by barrier pillars. To maintain a hydrostatic pressure at a safe figure in order that adjacent mines can be operated, the water in the pools is pumped to the surface or drained through boreholes in the barrier pillars into sumps of active mines, from where it is pumped either to the surface or to drainage tunnels.

Pool No.	Colliery	Altitude of surface (feet)	Altitude of lowest level (feet)	Altitude of water (feet)	Altitude of basin in lowest bed (feet)	Water in workings (gallons)	Location of overflow
1	McCauley Mt. Basin	1,510	1,260	1,510		50,688,000	Overflows to surface at 1,510 altitude.
2	Gowen No. 16 slope	1,220	801	956	819	34,200,000	Drainage tunnel to surface, 956 altitude.
3	Coxe-Gowen	980	604	822	504	92,602,000	Pumped to surface.
4	Coxe-Deringer	980	654	822	600	91,584,000	Underground connection (tunnel) to Coxe-Gowen.
5	Black Ridge	1,350	1,210	1,350	1,210	159,603,000	Overflows to surface at 1,350 altitude.
6	West Woodside Basin	1,582	1,461	1,582		68,120,000	Overflows to surface at 1,582 altitude.
7	East Woodside Basin	1,832	1,612	1,832		85,313,000	Overflows to surface at 1,832 altitude.
8	Upper Lehigh West Basin	1,680	1,540	1,680		425,502,000	Overflows to surface at 1,680 altitude.
9	Upper Lehigh East Basin	1,655	1,540	1,655		25,746,000	Overflows to surface at 1,655 altitude.
10	Highland No. 6	1,607	1,470	1,607		243,288,000	Overflows to surface at 1,607 altitude. (Surface pool, 60 acres.)
11	Pond Creek	1,569	1,433	1,569		94,879,000	Overflows to surface at 1,569 altitude.
12	Harleigh	1,515	1,206	1,440		3,802,000	Jeddo drainage tunnel.
13	Jeddo No. 7 Fish Tail Slope	1,515	1,391	1,508		26,136,000	Overflows to surface at 1,508 altitude.
14	Jeddo No. 4 Slope B	(1)	848	1,092		485,273,000	Jeddo drainage tunnel.
15	{Cranberry No. 8 Slope Basin {Harwood James Tunnel }	1,720	1,238	1,335	1,238	53,478,000	James Tunnel to Harwood South Basin.
16	Harwood South Basin	1,640	1,049	1,204	1,049	17,696,000	Overflows to Cranberry No. 11 plane basin.
17	Harwood Back Basin	1,732	1,574	1,732	1,574	53,823,000	Overflows to surface at 1,732 altitude.
18	Cranberry No. 11 Plane Basin	1,620	1,000	1,130	880	28,967,000	Borehole in barrier pillar to Hazleton Basin.
19	Hazleton Basin	1,575	645	865	420	18,618,000	Pumped to Jeddo drainage tunnel, 1,082 altitude.
20	Diamond Basin	1,575	645	865	420	61,875,000	Pumped to Jeddo drainage tunnel, 1,082 altitude.
21	Stockton Basin	1,600	600	1,117	600	576,906,000	Jeddo drainage tunnel.
22	Hazle Brook	1,568	1,185	1,526		481,200,000	Pumped to surface, 1,568 altitude.
23	Buck Mountain Stripping	1,598	1,558	1,598		11,880,000	Overflows, 1,598 altitude.
24	Audenried	1,700	1,100	1,220	1,050	41,844,000	Audenried drainage tunnel.
25	Spring Brook	1,740	1,192	1,228	1,192	5,880,000	Boreholes in barrier pillars to Audenried drainage tunnel.
26	Tresckow	1,760	1,123	1,265	1,123	17,280,000	Audenried drainage tunnel.
27	Tresckow No. 21 Slope	1,760	1,310	1,489	1,310	84,240,000	Will overflow to Tresckow.
28	Spring Mountain	1,702	1,275	1,425	1,275	49,200,000	Pumped to surface.
29	Coleraine	1,620	1,082	1,326		67,860,000	Borehole in barrier pillars to Beaver Meadow.
30	Evans	1,650	1,276	1,446		20,160,000	Do.
31	Silver Brook	1,620	1,105	1,540	{No. 1, 1,100 {No. 2, 1,190	683,000,000	Air hole to surface 1,540 altitude.
	Total					4,160,643,000	

[1] Inside slope.

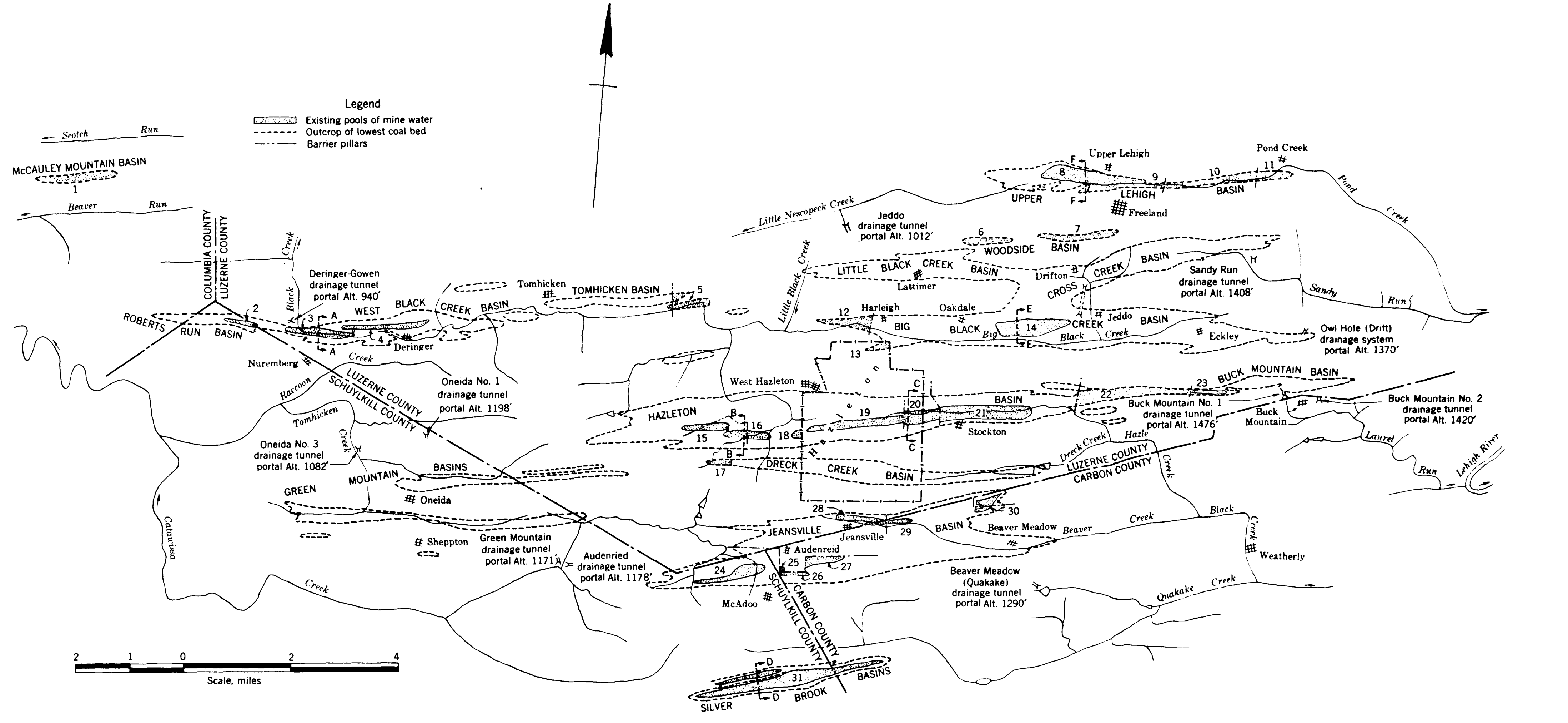

FIGURE 12.—Map of underground pools impounded in Eastern Middle anthracite field.

TABLE 4—*Major drainage tunnels, Eastern Middle field*

Name of tunnel	Company	Length (feet)	Drainage		Drainage basin
			From—	To—	
Audenried	Glen Alden Coal Co	17,000	Audenried	Catawissa Creek	Susquehanna River.
Buck Mountain Mo. 1	Coxe Bros. & Co., Inc	1,570	Buck Mountain, Nos. 1 and 2 Basins	Laurel Creek, then to Lehigh River	Delaware River.
Buck Mountain No. 2	do	1,650	Buck Mountain, No. 2 Basin	do	Do.
Deringer-Gowen	do	1,800	Gowen Basin	Big Black Creek	Susquehanna River
Green Mountain	Glen Alden Coal Co	4,155	East end of South Green Mountain Basin.	Catawissa Creek	Do.
Jeddo Tunnel system	G. B. Markle & Co Jeddo Tunnel Co	43,477	Little Black Creek Basin Big Black Creek Basin Cross Creek Basin Hazleton basin	Little Nescopcek Creek	Do.
Oneida No. 1	Coxe Bros. & Co., Inc	5,150	North Green Mountain Basin	Tomhicken Creek	Do.
Oneida No. 3	do	7,040	West end of South Green Mountain Basin.	do	Do.
Owl Hole drainage system (drift in coal bed).	do		East end (Big Black Creek Basin)	Sandy Run, then to Lehigh River	Delaware River.
Quakake (Beaver Meadow)	do	5,487	Beaver Meadow mine	Quakake Creek, then to Lehigh River	Do.
Sandy Run	M. S. Kemmerer & Co	1,900	Sandy Run mine	Lehigh River	Do.

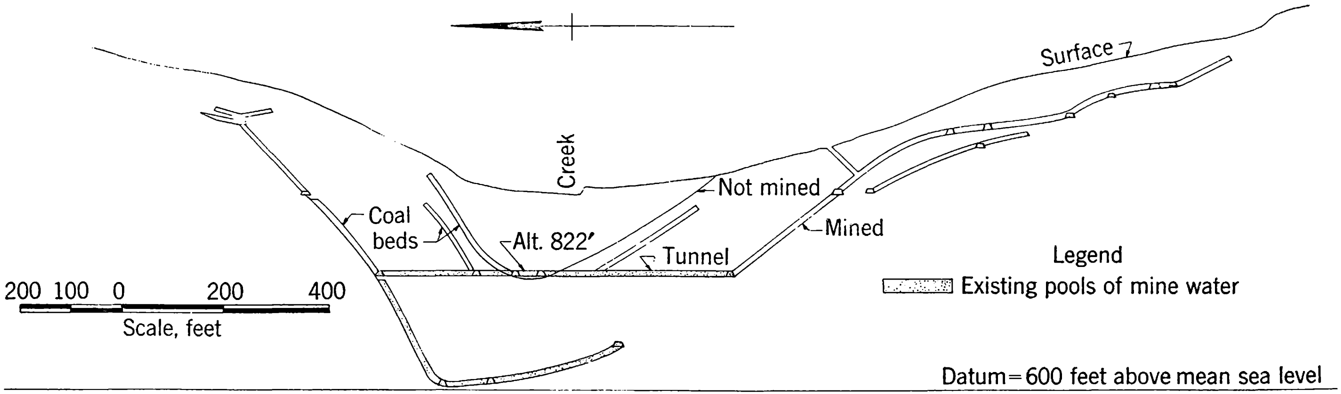

FIGURE 13.—Eastern Middle anthracite field, cross section on line A–A.

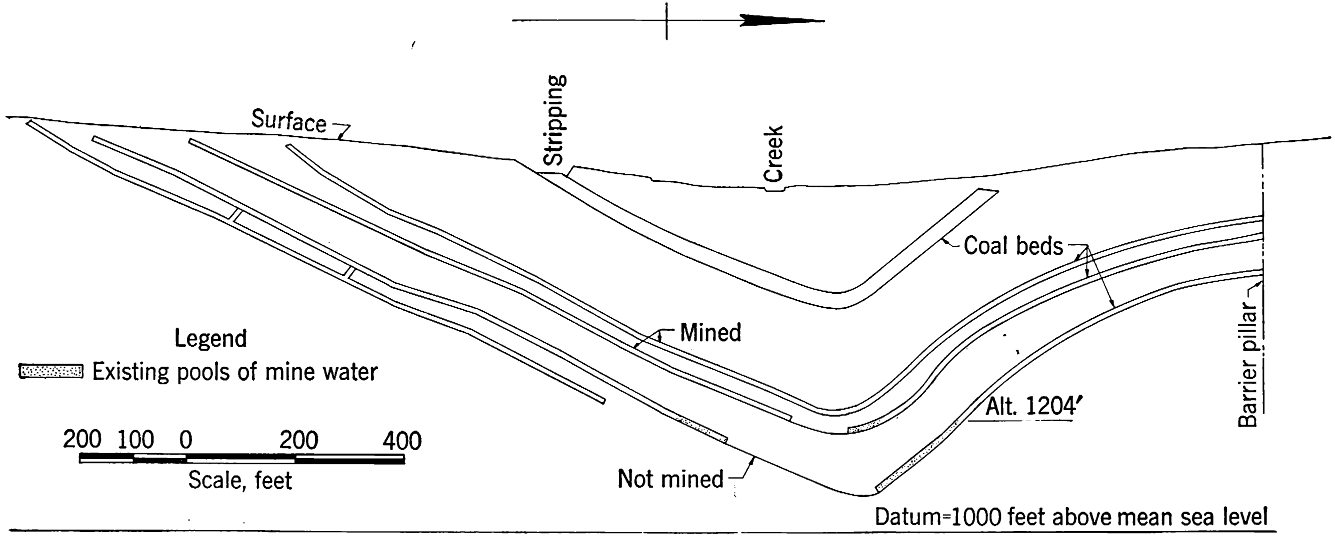

FIGURE 14.—Eastern Middle anthracite field, cross section on line B–B.

814153°—49——5

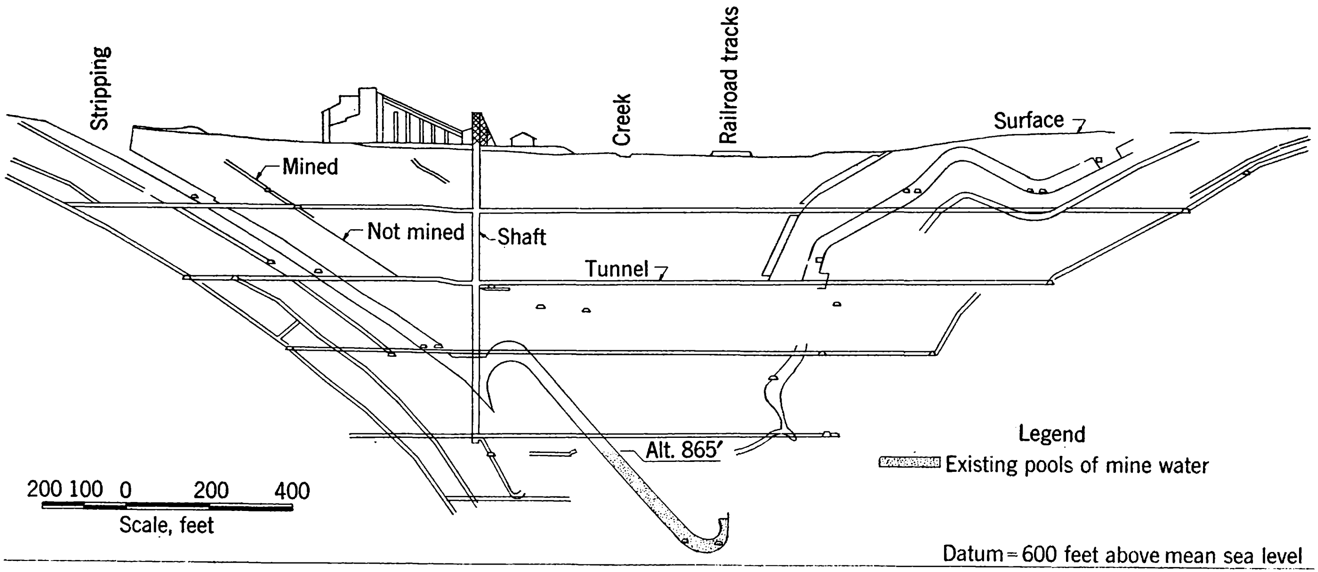

FIGURE 15.—Eastern Middle anthracite field, cross section on line C–C.

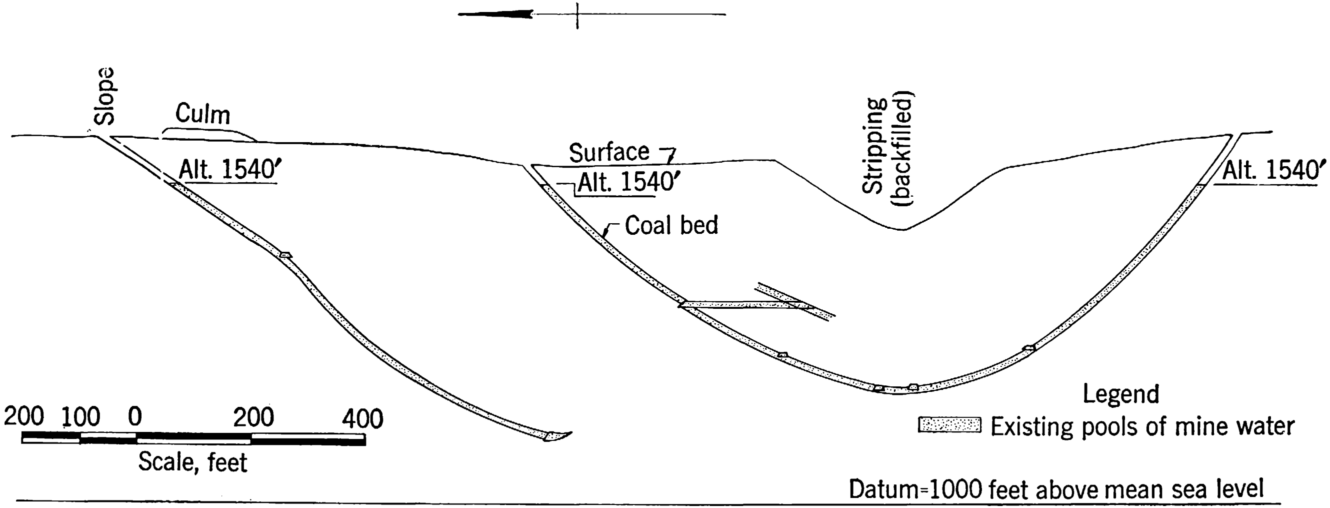

FIGURE 16.—Eastern Middle anthracite field, cross section on line D–D.

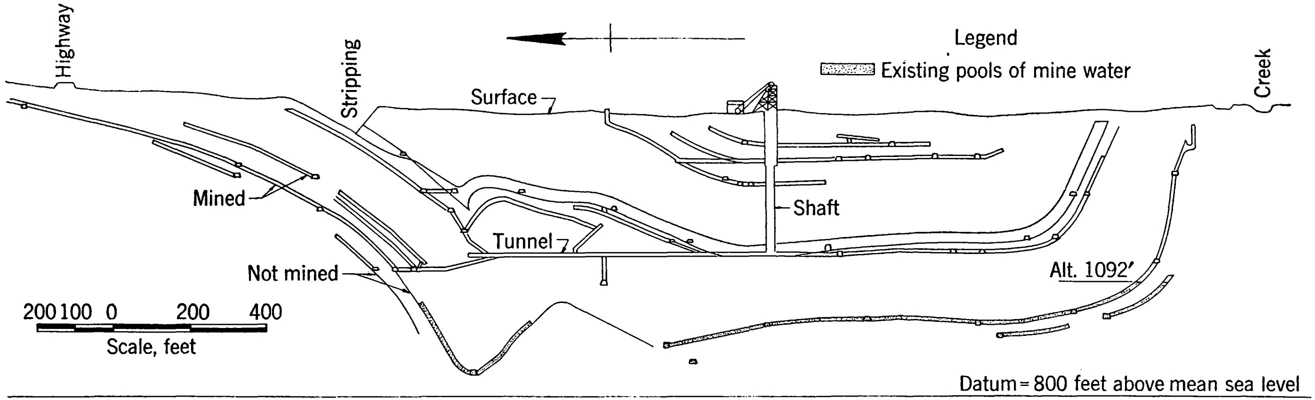

FIGURE 17.—Eastern Middle anthracite field, cross section on line E–E.

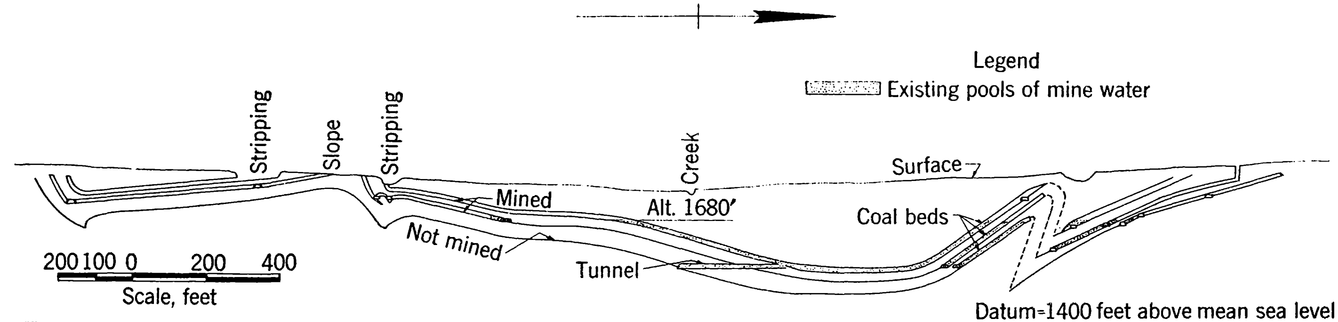

FIGURE 18.—Eastern Middle anthracite field, cross section on line F–F.

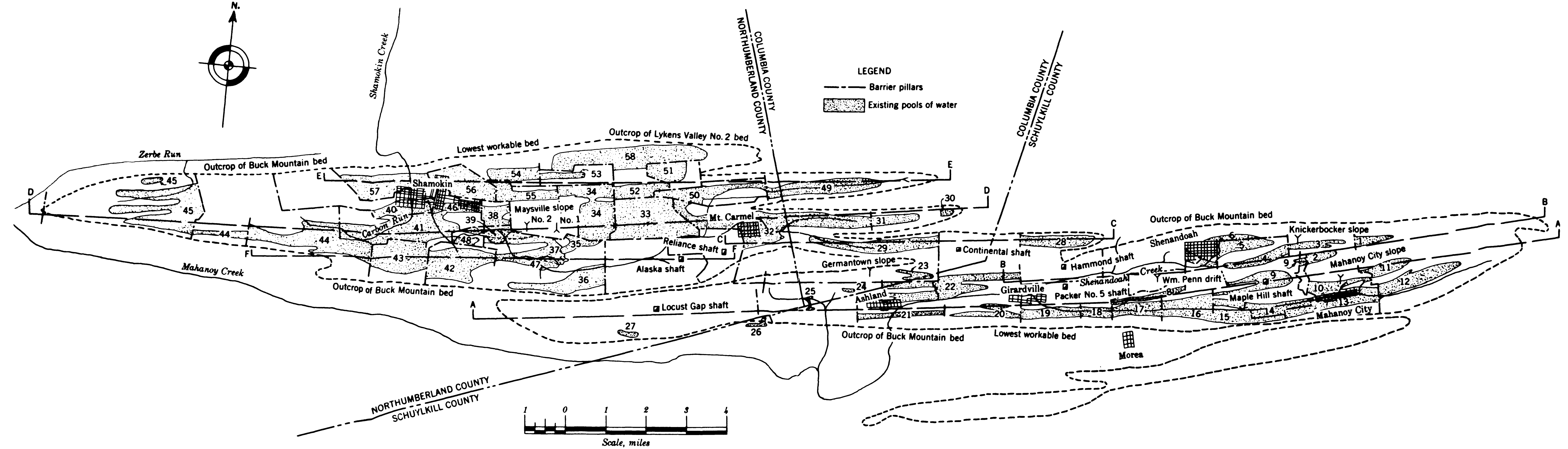

FIGURE 19.—Map of underground pools impounded in Western Middle anthracite field.

Pool No.	Colliery	Altitude of surface (feet)	Altitude of lowest level (feet)	Altitude of water	Altitude of basin in lowest bed (feet)	Water in workings (gallons)	Location of overflow
	Park No. 1		880.0	1,172.0	200.0		Active colliery. Pumps on first and second levels.
1	Springdale	1,335.0	1,172.8	1,172.0		243,600,000	Pumps on shaft level for Springdale washery.
	Park No. 2		880.0				Through drill holes to Park No. 1—second level pumps.
2	North Mahanoy	1,305.0	528.4	[1] 715.0		75,000,000	To Maple Hill shaft-level pumps; sections of colliery active.
3	Knickerbocker	1,327.0	506.0	589.0		52,453,000	Active colliery. Pumps on 2½ level.
4	Shenandoah City	1,316.0	476.0	881.0		397,068,000	Through strata and drill holes to Maple Hill No. 1 shaft level pumps.
5	Indian Ridge	1,264.0	739.0	915.0		423,829,000	Over anticline to Shenandoah City.
6	Kehley Run	1,379.0	831.0	[2] 881.0 [3] 996.0		23,733,000	To Kohinoor at 881.0 and to Indian Ridge at 996.0.
7	West Shenandoah		376.1	607.7		210,643,000	Through drill holes to Maple Hill No. 6 slope pump plant.
	Kohinoor	1,225.0	244.0	610.0			Overflows to West Shenandoah.
8	East Bear Ridge	1,139.0	680.0	1,139.0	120.0	475,300,000	Water level tunnel.
9	Maple Hill	1,251.0	160.1	443.1		486,073,000	Active colliery; pumps on borehole slope and No. 1 shaft.
	Maple Hill, east side		503.0	553.0		13,731,000	No. 1 shaft level pumps.
10	Mahanoy City	1,337.0	427.0	662.0		258,492,000	Active colliery; pumps on underground shaft.
11	Primrose	1,507.0	850.0	1,000.0	400.0	164,500,000	To Mahanoy City colliery; through 24-inch boreholes and pillars.
12	Buck Mountain	1,570.0	670.0	1,250.0	670.0	1,987,000,000	Surface breach. East of Mahanoy City Borough +1,250.
13	Tunnel Ridge	1,292.0	368.0	970.7	−320.0	798,890,000	Pumps on St. Nicholas slope.
14	St. Nicholas	1,236.0	128.3	970.7	−460.0	1,138,551,000	Do.
15	Boston Run	1,245.0	−29.1	970.7	−60.0	735,020,000	Pumps on Gilberton shaft.
16	Gilberton	1,138.0	−66.0	975.0	−400.0	1,868,240,000	Do.
17	Lawrence	1,160.0	147.0	973.0		2,126,919,000	McTurk's water-level drift.
18	West Bear Ridge	1,178.0	370.0	986.0	45.0	584,700,000	Through pillar to Girard colliery.
19	Girard	1,083.0	450.0	986.0	−32.0	839,600,000	Water-level tunnel.
20	Preston No. 3	1,062.0	434.0	948.0	W. (−1,100′) E. (+190′)	570,646,000	Water-level drift west of Girardville.
21	Tunnel	993.0	11.0	872.0	W. (−1,300′) E. (−1,100′)	617,080,000	Water-level tunnel south of Ashland.
22	Bast	1,154.0	16.1	757.0	W. (−1,600′) E. (−1,100′)	3,678,788,000	Deep-well pumps. Bast pumping station.
23	Big Mine Run	1,110.0	725.0	989.0		120,351,000	Overflow to Bast colliery.
24	Cambria (Potts)	1,110.0	1,010.0	1,085.0		32,340,000	Overflow to Potts colliery.
25	Potts	1,177.9	9.0	251.0	W. (−970′) ℄ (−1,200′)	3,131,000	Third level; colliery active above third level.
26	Lavelle Coal Co.	1,135.0	849.0	1,135.0	−1,000.0	21,628,000	Top of rock slope.
27	Helfenstein	1,173.0	996.0	1,173.0	−500.0	51,840,000	Water-level tunnel.
28	Raven Run	1,500.0	980.0	1,360.0	850.0	380,000,000	Top of water shaft.
29	Centralia	1,530.0	700.0	1,000.0	700.0	300,800,000	Drainage tunnel.
30	Midvalley No. 11	1,698.0	1,490.0	1,644.0	1,490.0	56,200,000	Surface.
31	Midvalley No. 3	1,550.0	760.0	1,212.0	350.0	130,100,000	Through No. 1 tunnel to Midvalley No. 2 basin.
32	Sayre (including Sioux)	1,170.0	580.0	920.0	360.0	1,138,000,000	Flows to Pennsylvania colliery through borehole ℄ 640.0.
33	Pennsylvania	1,140.0	80.0	888.0	−700.0	2,135,800,000	Pump at Pennsylvania shaft.
34	Scott	1,056.0	−73.0	886.0	−750.0	1,207,500,000	Pump at Scott shaft.
35	Excelsior No. 3 Slope Basin		807.0	960.0		176,985,000	Overflow to Greenback.
36	Enterprise and Excelsior	1,037.7	449.2	865.0	W. (500.0) E. (430.0)	867,750,000	Enterprise No. 3 slope pumps.
37	Corbin	963.6	324.0	873.0		354,075,000	Greenback drift.
38	Buck Ridge No. 2:						
	Main slope	946.0	257.0	824.0		176,580,000	Air hole south of main slope.
	No. 7 slope	806.0	728.0	803.0		9,936,000	Air hole.
	No. 4 slope	830.0	740.0	830.0		21,024,000	Top of slope.
	Water-level tunnel	820.0	537.0	820.0	−380.0	24,300,000	Water-level tunnel.
39	Greenback and Bear Ridge No. 1	1,010.9	52.4	775.0		282,000,000	Water-level drift north of Big Mountain shaft.
40	Neilson	739.0	−474.0	730.0	−1,280.0	41,341,000	Shaft.
41	Henry Clay	849.0	18.0	770.0	−1,550.0	1,318,750,000	Central pump slope.
	Stirling	860.0	158.0	770.0	−1,550.0	1,368,570,000	Do.
42	Big Mountain	869.0	321.0	869.0	−1,250.0	822,862,000	Top of shaft.
43	Burnside	905.0	183.0	770.0	−1,250.0	1,102,855,000	Central pump slope at Stirling.
44	Bear Valley:						
	Rock slope	1,190.0	750.0	770.0	−1,100.0		
	No. 1 shaft	980.0		770.0	−1,100.0	1,324,000,000	Do.
	No. 2 shaft	986.0	300.0	770.0	−1,370.0		
45	North Franklin	925.0	315.0	870.0	−160.0	1,597,266,000	Top of Tender slope.
46	Royal Oak	840.3	364.0	770.0	−30.0	93,513,000	Central pump slope at Sitrling.
47	Excelsior No. 1 Under Slope		740.0	948.0		172,683,000	Water-level drift.
48	Buck Ridge No. 1		520.7	789.0		16,200,000	Top split vein off dip tunnel.
49	Midvalley Nos. 1-2 basins	1,350.0	622.0	1,163.0	300.0	303,330,000	Holmes vein drift.
50	Richards	1,164.0	154.0	1,076.0	−500.0	1,637,000,000	To Black Diamond coillery (seepage through pillars).
51	Richards water level tunnel	1,164.0	650.0	1,070.0	450.0	118,300,000	To Greenough or Colonial.
52	Greenough	1,298.0	453.0	1,070.0	−600.0	297,600,000	To Richards.
53	Hickory Ridge	1,204.0	670.0	690.0	−250.0	19,000,000	To Hickory Swamp; No. 9 slope active.
54	Hickory Swamp	1,063.0	388.0	650.0	−500.0	104,500,000	To Luke Fidler; No. 5 slope active.
55	Colbert	1,006.0	206.0	800.0	−600.0	302,100,000	To Luke Fidler.
56	Luke Fidler	843.0	−788.0	542.0	−1,100.0	615,000,000	To Glen Burn.
57	Glen Burn	723.0	−363.0	430.0	−1,700.0	1,169,400,000	Active colliery; pumped to surface from 443.0 elevation.
58	Natalie	1,372.0	750.0	1,083.0	100.0	608,000,000	To Greenough.
	Total					38,292,286,000	

[1] Average. [2] Buck. [3] Others.

WESTERN MIDDLE FIELD

The Western Middle field covers an area of approximately 120 square miles, is 42 miles in length from Delano on the east to Trevorton on the west, and is 2 to 5 miles in width (*2*). This field consists of a series of irregularly shaped parallel basins. In some localities the anthracite beds dip steeply, whereas in others the beds are quite level because of the broad and open folding of the anthracite beds and the asymmetrical shape of the cross sections of some of the basins.

In consequence of the abandonment and inundation of collieries from 1927 to present, only 40 percent of the anthracite measures of the Western Middle field is available to active collieries (*2*). To operate their active mines, the mining companies are burdened with the almost insurmountable problem of handling water from abandoned mines. Some mining companies pump water from six to eight abandoned mines, so as to maintain the hydrostatic pressure against barrier pillars at a safe figure. To insure continuance of operation of 5 of its active mines, 1 operating company handles water from 12 abandoned mines.

There are 58 underground pools containing 38 billion gallons of water in the Western Middle field.

Figure 19 is a plan map of the Western Middle field, showing pools of impounded mine water.

Figures 20 to 25 are longitudinal sections through the underground water pools in the Western Middle field.

The legend for figure 19 gives the pertinent data concerning the impounded water in underground pools in the Western Middle field.

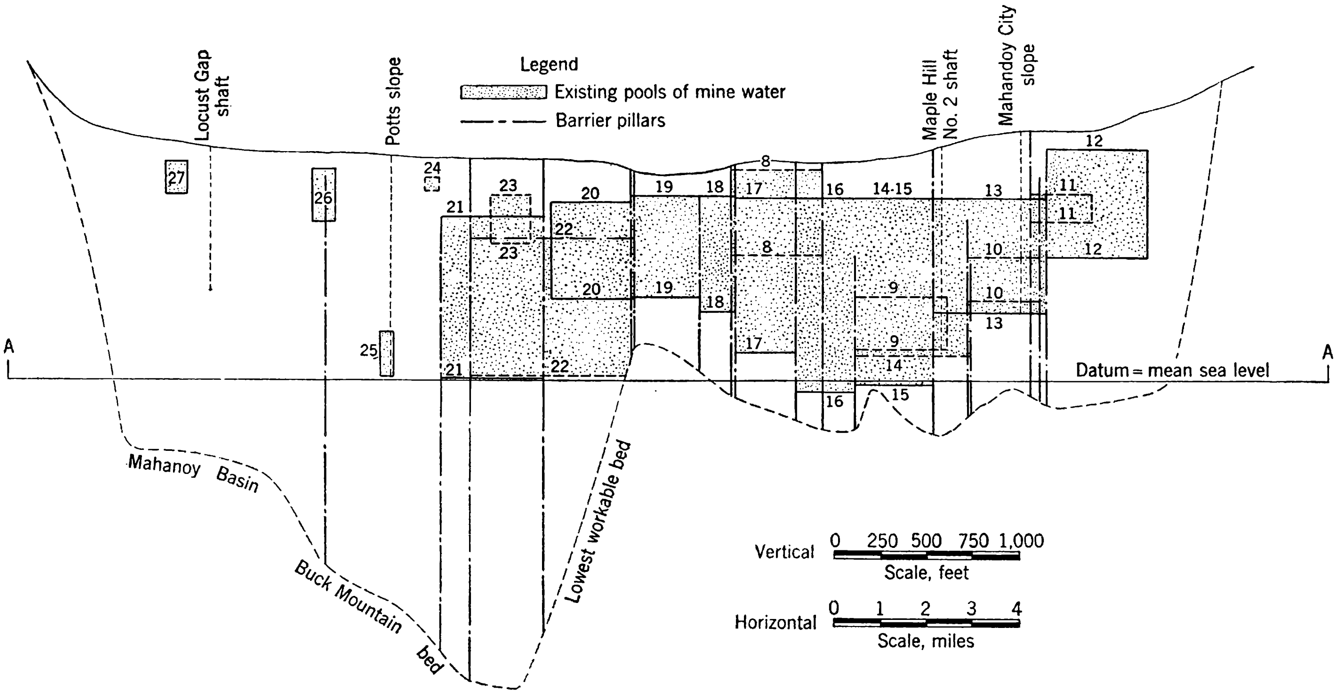

FIGURE 20.—Western Middle anthracite field, longitudinal section on line A-A.

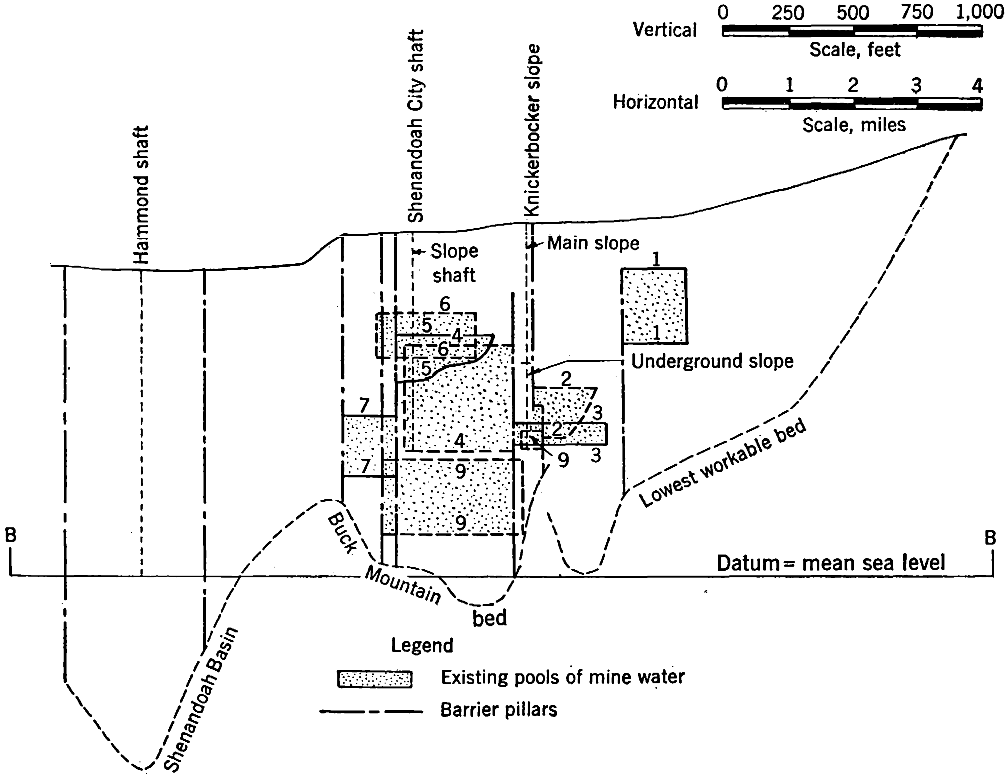

FIGURE 21.—Western Middle anthracite field, longitudinal section on line B–B.

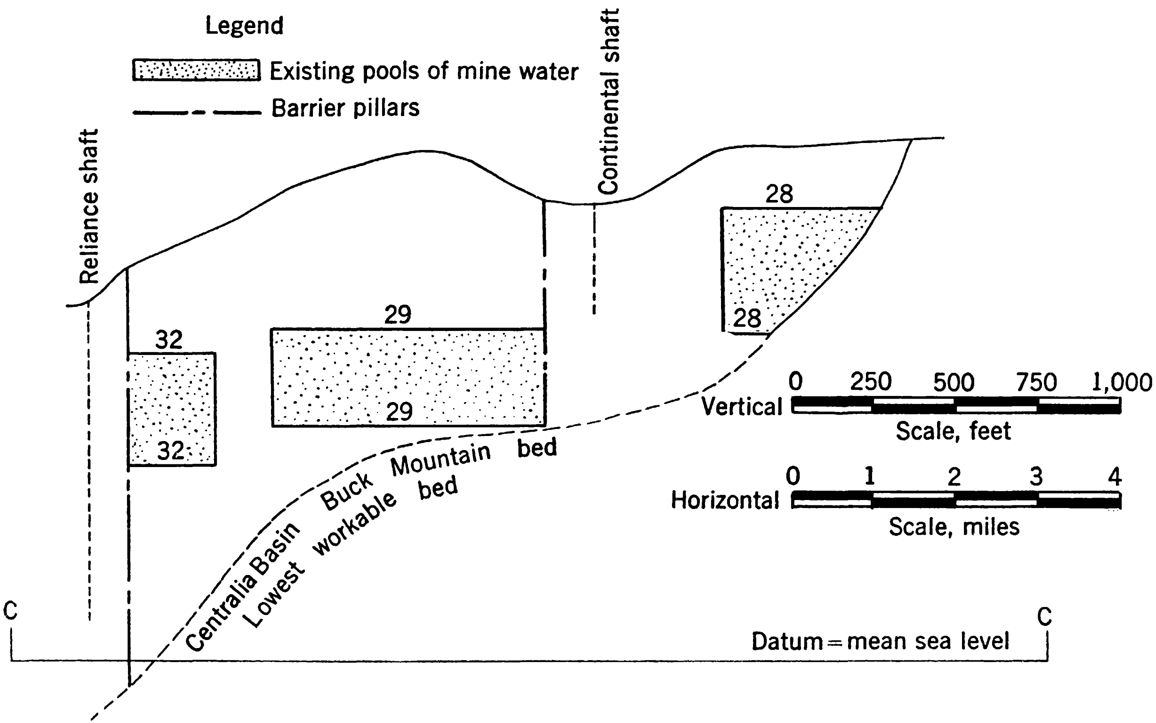

FIGURE 22.—Western Middle anthracite field, longitudinal section on line C–C.

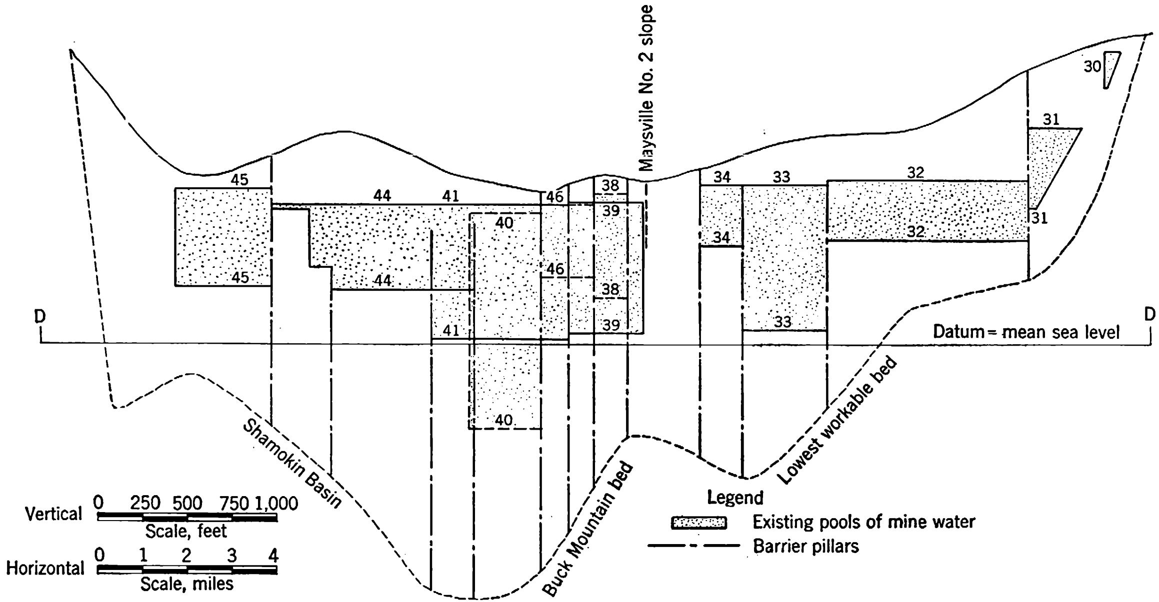

FIGURE 23.—Western Middle anthracite field, longitudinal section on line D–D.

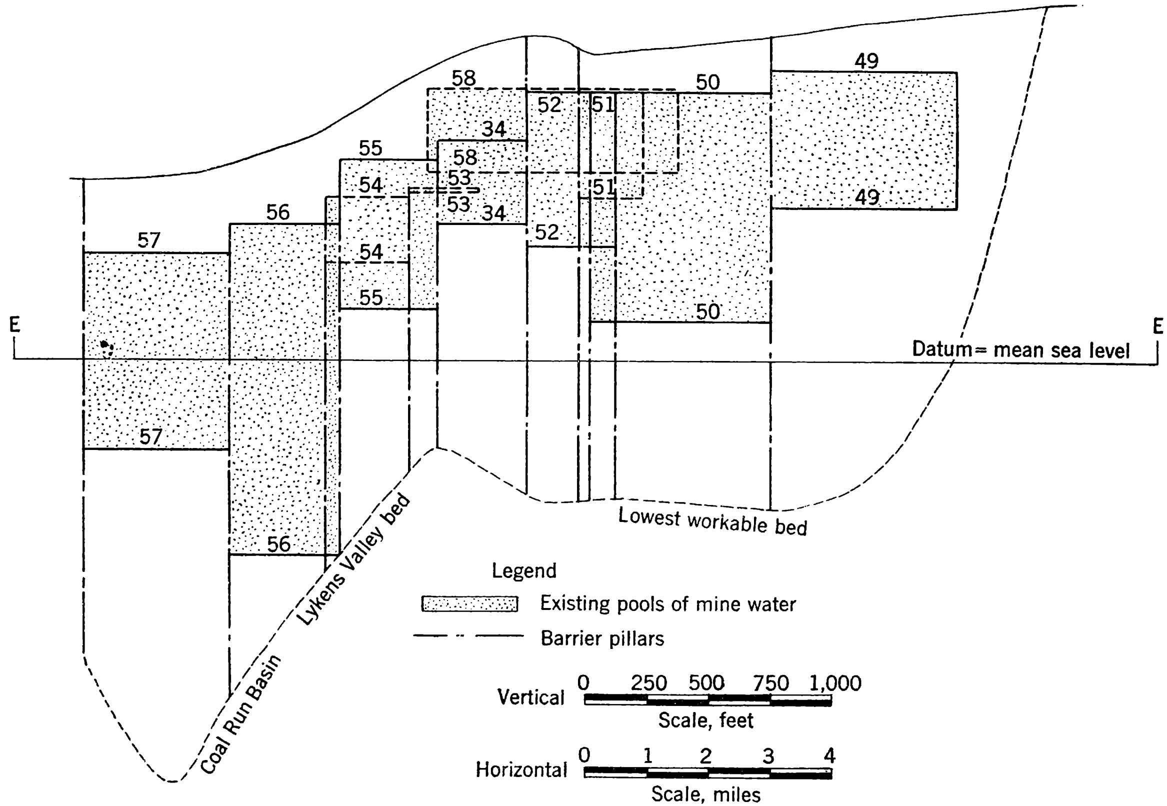

FIGURE 24.—Western Middle anthracite field, longitudinal section on line E–E.

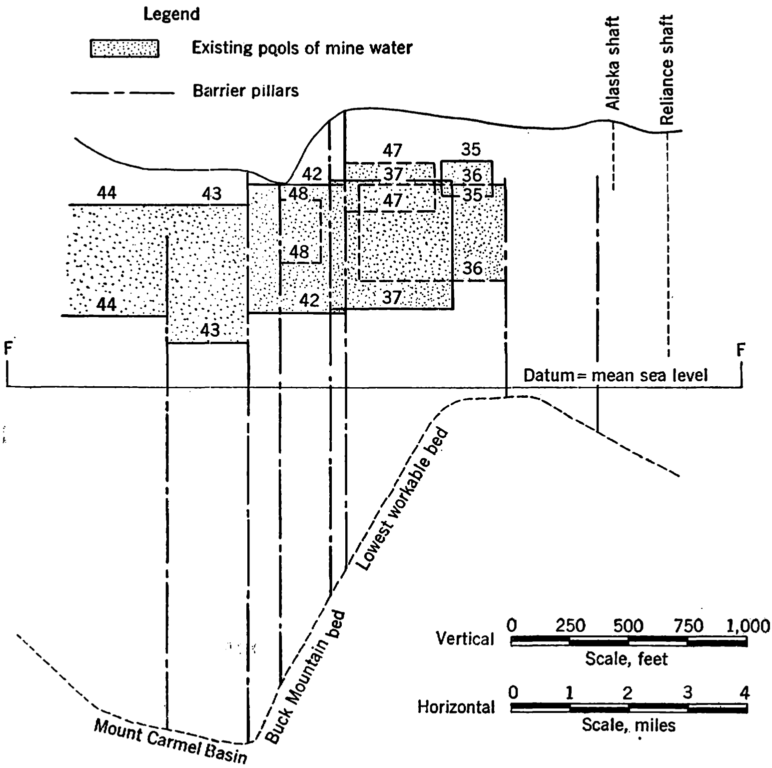

FIGURE 25.—Western Middle anthracite field, longitudinal section on line F–F

SOUTHERN FIELD

The Southern field extends from Mauch Chunk on the east to the Susquehanna River on the west, a distance of 70 miles. At its widest point, near Pottsville, the field extends 6 miles north and south. The area covered by the anthracite measures is 200 square miles.

The geologic structure of the Southern field is more complicated than that of any other portion of the anthracite region. This field has a greater columnar thickness of anthracite measures contained within the synclinals, which are generally of less width in proportion to their depth than is contained in most of the synclinals in the other three fields. The dips of the limbs of the synclinals and the anticlinals are generally much steeper than elsewhere (*16*). Moreover, the basins are long, narrow, and relatively deep.

The anthracite beds on the limbs of the basins dip steeply and extend to considerable depth. In the vicinity west of Pottsville, the beds are believed to extend to a depth of approximately 3,000 feet below sea level or approximately 4,000 feet below the surface of the ground, as shown by the Geological Survey of Pennsylvania on maps and cross sections of the Southern anthracite field.

The largest tonnage of reserves of anthracite lies in the Southern field, where mining conditions are the most difficult. The workings of abandoned mines are confined to the limbs of the beds near the surface. Large reserves of anthracite underlie the abandoned mine workings. Before a great part of the reserves in the Southern field can be developed and extracted, abandoned workings must be unwatered and kept drained (*2*).

In the period between 1923 and 1940, abandonment of mines in the Southern field had resulted in flooding 60 square miles (30 percent of the field) (*17*). Fortunately, abandonment of mines has not imposed additional expense for pumping on the mines still operating, although the extension of developments unquestionably will make necessary either handling additional water from abandoned mines or suspension of operations if economic conditions will not justify the assumption of additional pumping costs (*2*).

Thirty-one underground pools containing 32½ billion gallons of water are present in the Southern field.

Figure 26 is a plan map of the Southern anthracite field, showing pools of impounded mine water.

Figures 27 to 29 are longitudinal sections through the underground water pools in the Southern anthracite field.

The legend for figure 26 gives pertinent data concerning impounded water in underground pools in the Southern field.

Pool No.	Colliery	Altitude of surface (feet)	Altitude of lowest level (feet)	Altitude of water (feet)	Altitude of basin in lowest bed (feet)	Altitude of Pottsville Basin (feet)	Water in workings (gallons)	Location of overflow
1	Tamaqua Lands, S. D.	951.0	531.0	950.0	E. (−400.0) W. (−520.0)	−1,150.0	800,000,000	No. 2 drift, drainage holes, high mines drifts.
2	Tamaqua Lands, N. D.		492.0	784.0	E. (−250.0) W. (−450.0)		312,000,000	Allen colliiery drifts.
3	Mary D	982.0	382.0	823.0	℄ 550.0	−1,150.0	400,000,000	Water level drift east of Bell colliery.
4	Kaska	941.0	−209.0	832.0	℄ −650.0		600,000,000	Boreholes.
5	Silver Creek	951.0	68.4	814.5			1,774,000,000	Drift east of breaker.
6	Eagle Hill	815.5	−223.9	680.0	−700.0	−1,800.0	727,000,000	Diamond Drift at Sineys Crossing.
7	Palmer Vein	902.5	99.3	694.0			400,000,000	Water-level drift.
8	Bear Ridge	767.0	310.0	668.0			40,000,000	Do.
9	Pine Forest	780.0	214.0	560.0	−650.0		419,000,000	Pump at St. Clair Coal Co.
10	Wadesville	821.2	65.0	732.0	E. (−700.0) W. (−850.0)	−2,150.0	3,582,000,000	Concrete pipe at St. Clair shaft.
11	Pottsville East	738.4	−839.0	713.0			125,000,000	Drift at East mines.
12	Pine Knot No. 1	949.0	208.0	682.0	℄ 800.0		600,000,000	Pump at Pine Knot No. 2 shaft.
13	Thomaston	1,032.0	375.0	871.0			784,000,000	Overflows to Pine Knot.
14	Richardson		374.0	871.0	℄ −350.0		625,000,000	Overflows to Thomaston.
15	Glendower	1,370.0	436.0	815.0	E. (O) W. (+700.0)		403,000,000	Pump at Buck Mount slope.
16	Buck Run (old)		457.0	871.0	E. (+250.0) W. (+1035.0)		477,000,000	Overflows to Thomaston.
17	Buck Run (dam basin)		1,080.0	1,203.0	1135.0		53,000,000	Overflows to Buck Run (old).
18	Lytle	1,035.0	−460.0	+3.0	E. (−600.0) W. (−300.0)		795,000,000	Fifth level, Lytle shaft.
19	Phoenix Park		−17.0	728.0	−1600.0	−3,050.0	2,054,000,000	Drainage tunnel.
20	Otto	963.2	−194.5	830.0	−1250.0	−3,250.0	2,265,000,000	Peach Mountain airhole.
21	Middle Creek	979.7	195.0	980.0	−1300.0	−2,800.0	700,000,000	Shaft.
22	Blackwood	1,024.0	548.0	819.0			35,000,000	Water-level tunnel.
23	Colket	1,080.0	462.0	945.0	−2200.0		513,000,000	Do.
24	Good Spring No. 3	1,274.0	522.0	1,152.0			471,000,000	Tracy airhole No. 22.
25	Good Spring No. 1	1,456.0	476.0	1,198.0	−1400.0		915,000,000	Tracy airhole No. 119.
26	Westwood		497.0	1,260.0	−1900.0		253,000,000	Top of slope.
27	New Lincoln		476.0	1,171.0			145,000,000	Water-level tunnel.
28	R. Creek and E. Franklin		277.0	972.0			890,000,000	Do.
29	Lincoln	1,361.0	68.0	960.0	−1400.0	−1,400.0	1,938,000,000	Rowe tunnel.
30	Brookside	1,410.0	−409.0	906.0	−1400.0		1,944,000,000	Valley View tunnel.
31	{Williamstown	1,317.0	−500.0	897.0	−2100.0	}	7,330,000,000	Short Mountain shaft.
	{Lykens	897.0	−1,292.0	897.0	−1900.0			
	Total						32,469,000,000	

Figure 26.—Map of underground pools impounded in Southern anthracite field.

816153 O - 49 (Face p. 38) No. 1

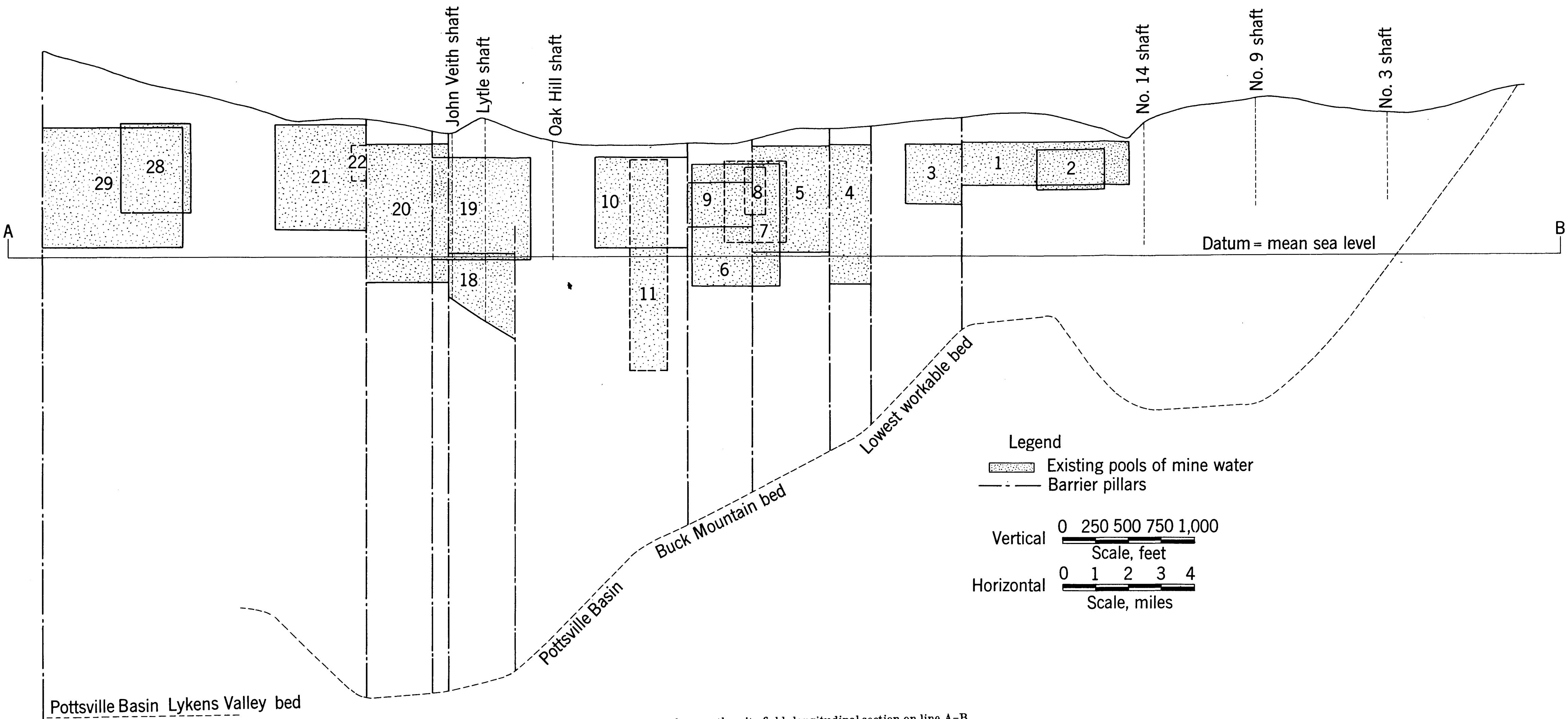

FIGURE 27. Southern anthracite field, longitudinal section on line A–B.

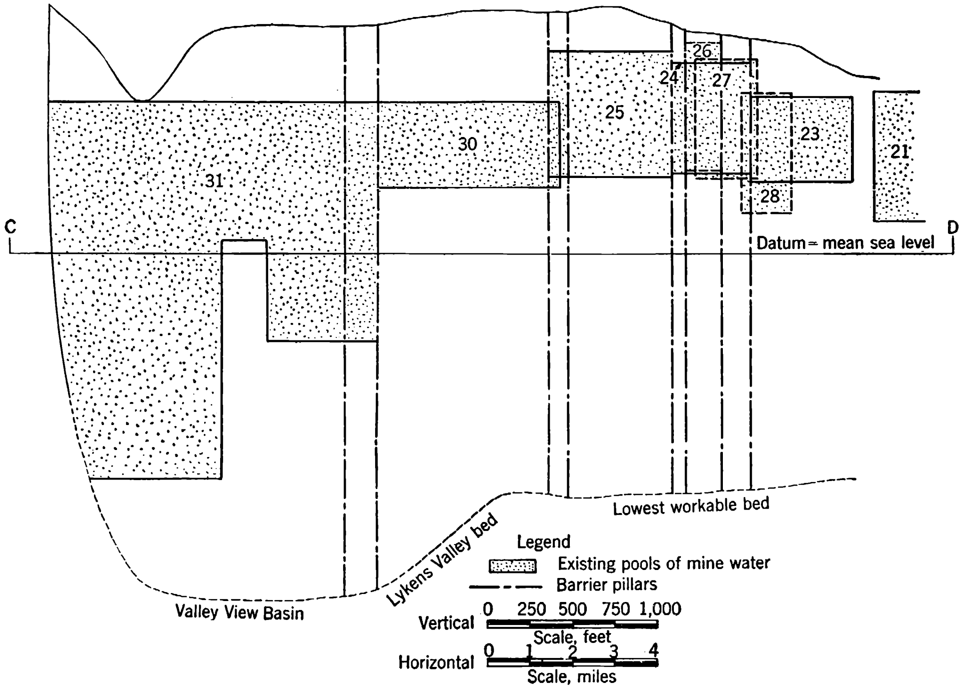

FIGURE 28.—Southern anthracite field, longitudinal section on line C–D.

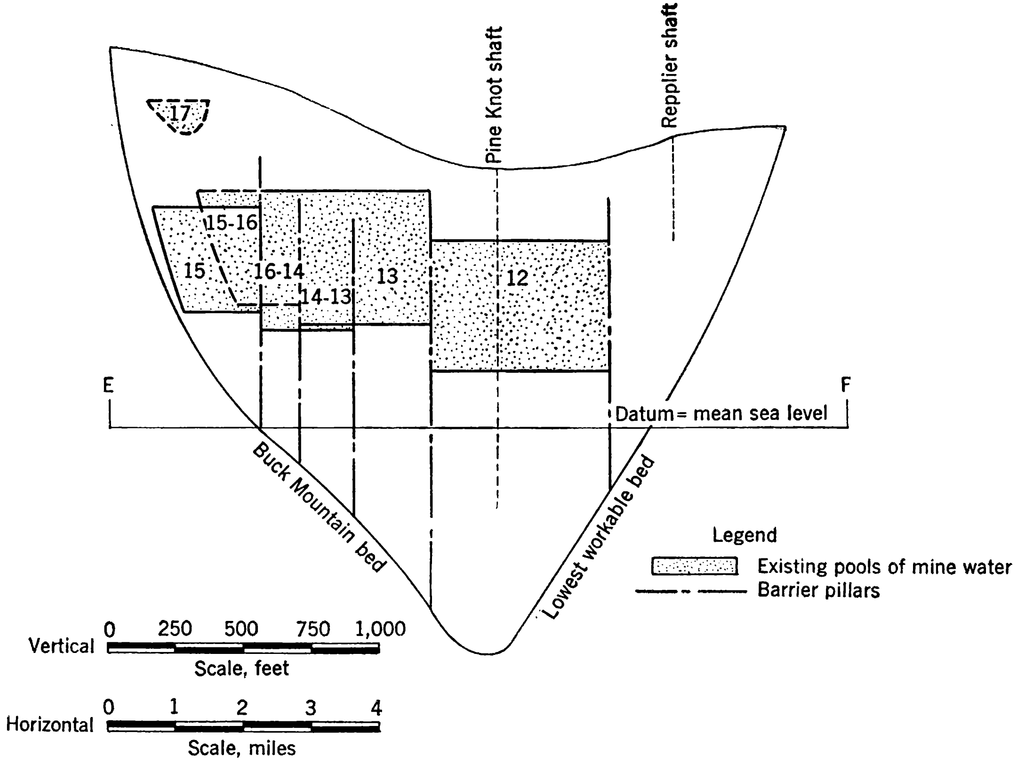

FIGURE 29.—Southern anthracite field, longitudinal section on line E–F.

BOOTLEG OPERATIONS

In addition to the underground water pools listed in the separate anthracite fields, hundreds of small pools are present in abandoned bootleg mines. These constitute a menace to future mining, not necessarily because of the volume of water impounded, but because it is impossible to obtain information in regard to the size and position of the pools. Thousands of these small mines, or "holes," have been opened from the outcrops and other areas where only a thin mantle of overburden is present. No record exists of the work done in the great majority of these holes. In many instances, the openings to these small-mine workings have soon become obliterated because of caving and other physical changes in the landscape. When this occurs, it is impossible to obtain data on the extent and direction of the underground workings. Many of these mines were opened in the outcrops of virgin beds and were only operated during dry weather, or as long as the miner could keep the mine workings free of water with the simple equipment available and then abandoned. Some of these workings penetrated the anthracite beds several hundred feet before being flooded. Many of these small mines are not connected to the underground workings of other mines and are filled with water, which cannot be pumped to the surface of the ground because the portals are closed by roof falls.

Many workers in bootleg mines have had narrow escapes, and a few have lost their lives by drowning when their mine unexpectedly broke into older mine workings filled with water.

Before the anthracite lying below crop holes that are filled with water can be safely extracted, it is necessary to know the exact position and extent of the flooded mine workings.

CALCULATION OF VOLUME OF IMPOUNDED WATER

Information on underground water pools was obtained by studying geological maps and cross sections, mine maps, cross sections showing mine workings, and other information obtained from mining companies. The following procedure was employed to obtain detailed information:

A complete list was prepared of all active mines and known abandoned mines that contained underground water pools. This list was compiled from information obtained from the mining companies and the Pennsylvania Department of Mines. Each mine was studied separately. To determine the extent of a water pool, the altitude of the surface of the water in an accessible mine opening was ascertained. The extent of the inundated mine workings in each bed was then determined and outlined on separate plan maps. Some of the underground water pools studied were found to extend into 17 or 18 beds and into 2 or 3 anthracite basins. The longitudinal extent of the water pools in each bed was measured from the plan maps. The transverse extent of the pools could not be measured from the plan maps because of the steep dips of many of the beds; therefore, the transverse extents were measured from selected cross sections. The thickness of each bed was ascertained from maps, borehole records, and mining records.

To determine the volume of water contained in the pools in the mine workings, as shown by maps and cross sections, a factor of 40 percent of the total area mined was used. Mining records show that recovery (in percentage), or the anthracite actually produced from mining operations, varies in each mine and often in the same bed in different parts of the same mine. In some mines, only first-mining has been conducted; in others the pillars have been extracted and the mine workings are standing open, or some mine workings have caved, or have been partly closed by squeezes; and in others the original openings have been back-filled by hand-pack or hydraulic methods.

Where mines have been flooded to extinguish mine fires or abandoned mines have been unwatered, the mining records show that the volume of water contained in the mine workings was 40 percent of the total original volume of the mine workings that had been flooded, whether the area had been first-mined, robbed, or hand-packed. The figure of 40 percent is conservative, errs on the safe side, and was employed to determine the quantity of water impounded in all underground water pools in all fields.

Because of the irregular shape of an underground water pool, an adaptation of the average end-area method was employed to determine the volume of water in each bed in a mine. The longitudinal distance between adjacent cross sections of the mine was measured from the plan map. The transverse width of the pool in a block between two cross sections is the average width of the bed as measured on these two end sections. The volume of water in this block was then determined by use of the following formula (*6*):

$$Q = L \times W \times T \times 7.50 \times 0.40,$$

where

Q = quantity, in gallons;
L = length (longitudinal distance), in feet;
W = average width of pool between cross sections, in feet;
T = thickness of bed, in feet;
7.50 = number of gallons to a cubic foot; and
0.40 = percentage factor (area of mine flooded).

The sum of the individual volumes between the cross sections equaled the total volume of water in the mine workings of that bed. The sum of the totals for each bed included in the pool gives the total water content for that pool and is the figure shown in these tabulations.

Other pertinent information on water pools, such as the altitude of the overflow points, the altitude of the lowest mine workings, and the altitude of the bottom of the basins of the beds, as shown on the legend for each field, was obtained from mine maps and cross sections.

Barrier pillars, as shown on the map of the underground water pools in each anthracite field, are not intended to indicate the width of the barrier pillars but are shown as lines to indicate the property lines or approximate position of the center line of the barrier pillars.

WATER POOLS IN ABANDONED STRIPPING EXCAVATIONS

An investigation regarding water impounded in stripping excavations in the Northern, Eastern Middle, Western Middle, and Southern anthracite fields of Pennsylvania was conducted in the spring of 1948 to procure factual data on water pools in abandoned stripping excavations so as to determine the quantity of water in the pools and to what extent they affect safe operation of active anthracite mines and future underground operations.

Table 5 lists 141 surface water pools containing 2.3 billion gallons of water in abandoned stripping excavations examined in the course of the investigation. This list does not include all the water pools in abandoned stripping excavations, but it does include most of them and is representative of some conditions that exist in all.

Shallow pools formed in stripping excavations by run-off from local rainstorms or spring thaws are not considered because of their temporary nature; moreover, such pools disappear during an extended dry period. Only pools that are considered to be present the year round are tabulated.

Many new pools were being formed and old ones were being filled or drained by numerous active stripping operations at the time of the investigation. This was especially true in the Southern and Western Middle fields. Some of these surface pools are small; others are veritable lakes. A few are situated near villages or are visible from public highways; but, by far, most of them are found only by diligent search among spoil banks and numerous abandoned stripping excavations.

TABLE 5.—*Water pools in abandoned stripping*

NORTHERN

Index No.	Date of collection of sample (1948)	Number of pools in group	Name of coal basin or colliery	Name of bed	Direction of dip	Date of completion of stripping	pH	Free acidity as $CaCO_3$ p. p. m.
1	May 12	1	Clinton	Grassy Island	South	1928	7.0	0
2	May 10	3	Jermyn	Archbald	North	1946	6.6	0
3	May 7	1	Maltby	Nine Foot	South	1941	6.3	0
4		1	Franklin	Red Ash	North	1947		
5	May 6	2	Newport Anticlinal.	Bottom George	South	1941	3.0	203
6	do	1	Glen Lyon	Hillman	do	1933	4.4	20
Total		9						

EASTERN MIDDLE

Index No.	Date of collection of sample (1948)	Number of pools in group	Name of coal basin or colliery	Name of bed	Direction of dip	Date of completion of stripping	pH	Free acidity as $CaCO_3$ p. p. m.
1	Mar. 23	1	Upper Lehigh No. 5.	Buck Mountain	North and south.	1920	3.4	25
2		1	Upper Lehigh North.	do	South	1918		
3		1	Upper Lehigh South.	do	North	1918		
4	Mar. 18	1	Freeland	do	do	1932	6.4	0
5	Mar. 23	2	Highland—Pond Creek.	do	South	1920	3.7	38
6	May 26	4	Woodside	do	North and south.	1935	4.5	10
7	do	1	South Virgin Basin.	do	do	1946	4.9	5
8	do	2	Buck Mountain	do	South	1946	4.9	5
9	do	1	Buck Mountain No. 4.	do	North and south.	1935	4.3	5
10	do	1	Buck Mountain No. 7.	do	do	1930	4.3	5
11	do	1	Buck Mountain No. 6.	do	North	1915	4.1	20
12	June 1	1	Black Ridge	Mammoth	South	1914	3.4	30
13	do	1	Tomhicken	do	North and south.	1945	3.7	140
14	do	1	do	Wharton		1937	3.1	105
15	do	1	do	Gamma	North	1945	4.1	10
16	do	1	Derringer	Buck Mountain	South	1942	5.3	0
17	May 26	1	Porters Swamp	do	North and south.	1926	6.1	0
18	do	1	Hazle Brook	Mammoth	South	1910	6.1	0
19	do	1	Stockton	do	do	1943	6.0	5
20	Mar. 25	2	Humboldt	Buck Mountain	North	1946	4.8	0
21	June 3	3	do	do	South	1935	5.1	0
22	May 17	4	Quakake	Lykens	North and south.	1946	5.2	0
23	June 1	1	Beaver Meadow	Wharton	South	1947	5.2	0
24	do	1	do	Buck Mountain	do	1947	6.0	0
25	Mar. 17	1	Silver Brook	Mammoth	do	1902	3.3	50
Total		36						

See footnotes at end of table.

excavations in the anthracite region

ANTHRACITE FIELD

Total acidity as $CaCO_3$, p. p. m.	Content of pool, million gallons	Approximate altitude of surface of water (feet)	Outlet	Classification of workings [1]	Contaminating influences [2]	Effect of pool on present or future mining	Remarks
3	6.0	1,415	Seepage	C	1, 2	None	Complete extraction.
0	(3)	927	To mines	B		do	Do.
5	.5	1,050	Through broken strata to mines.	A-A	1, 2, 3, 4	do	Local basin. Complete extraction.
	.5	825	Seepage	D	1, 2	Must unwater.	Given bed incompletely extracted.
282	2.2	740	None	A	1, 2, 3, 4	do	Underlying beds unmined.
48	4.6	900	Borehole to underground workings.	D	1, 2, 3, 4	do	Do.
	13.8						

ANTHRACITE FIELD

Total acidity as $CaCO_3$, p. p. m.	Content of pool, million gallons	Approximate altitude of surface of water (feet)	Outlet	Classification of workings [1]	Contaminating influences [2]	Effect of pool on present or future mining	Remarks
53	1.8	1,780	To surface	C	1, 2	None	Local basin. Complete extraction.
	112.5	1,780	do	C	1, 2	do	Do.
	.6	1,740	do	C	1, 2	Must unwater.	Local basin. Extraction incomplete.
0	.2	1,700	None	D	1, 2	do	Extraction incomplete.
70	8.4	1,780	To surface	B	1, 2	do	Do.
15	(3)	1,832	do	B	1, 2	do	Do.
10	28.0	1,440	do	A-A	1	None	Local basin. Complete extraction.
10	1.2	1,500	Seepage	C	1, 2, 4	Must unwater.	Extraction incomplete.
20	3.2	1,431	Through borehole	C	3	do	Local basin. Complete extraction, but threatens adjacent workings.
20	.9	1,487	Seepage	C	2, 3	do	Local basin. Incomplete extraction, and threatens adjacent workings.
40	36.2	1,598	do	C	1, 2, 4	None	Local basin. Complete extraction. Adjacent basin robbed.
55	(3)	1,350	To surface	B	1, 2	Must unwater.	Given and underlying beds. Extraction incomplete.
155	.1	1,155	Borehole to mine workings.	C	1, 2, 4	do	Extraction incomplete.
140	1.4	1,215	None	A	1, 2	do	Given and underlying beds unmined.
40	.2	1,200	do	A	1, 2, 4, 5	do	Do.
10	4.2	1,200	do	A	5	do	Given bed unmined.
5	1,224.0	1,535	Over barrier to mine workings.	A	2	do	Completely extracted. Adjacent property, extraction incomplete.
2	(3)	1,540	To underground pool.	B	2	do	Given and underlying beds. Extraction incomplete.
20	.8	1,575	To surface	A		do	Given and underlying beds unmined.
8	80.0	1,780	do	A		do	Given bed unmined.
5	30.0	1,780	None	A		do	Do.
10	75.0	1,732	To surface	A-A		Must partly unwater.	Adjacent property. Extraction incomplete.
5	3.7	1,540	None	A-A	2	Must unwater.	Given and underlying beds unmined.
5	8.0	1,550	To surface	A-A	2	do	Given bed unmined.
80	(3)	1,540	To mine workings	B	1, 2, 4, 5	None	Given bed exhausted. Underlying beds robbed.
	1,620.4						

TABLE 5.—*Water pools in abandoned stripping*

WESTERN MIDDLE

Index No.	Date of collection of sample (1948)	Number of pools in group	Name of coal basin or colliery	Name of bed	Direction of dip	Date of completion of stripping	pH	Free acidity as $CaCO_3$ p. p. m.
1	Mar. 25	1	Buck Mountain Village.	Mammoth	North and south.	1946	4.3	5
2	do	1	Mahanoy—Vulcan.	Holmes	do	1946	3.0	110
3	do	1	Locust Mountain No. 9.	Mammoth	do	1930	5.3	0
4		1	Continental	Buck Mountain	South	1937		
5		1	Germantown	Mammoth	do	1947		
6		2	do	Orchard	do	1940		
7		1	do	Holmes	do	1946		
8	Apr. 5	1	Aristes	Buck Mountain	North and south.	1934	4.2	3
9	do	1	Aristes—Midvalley No. 14.	do	do	1941	4.3	8
10	do	1	Centralia	do	Underlap	1939	4.8	0
11	do	1	Natalie—Susquehanna.	Mammoth	North and south.	1938	4.1	5
Total		12						

SOUTHERN

Index No.	Date of collection of sample (1948)	Number of pools in group	Name of coal basin or colliery	Name of bed	Direction of dip	Date of completion of stripping	pH	Free acidity as $CaCO_3$ p. p. m.
1	Apr. 9	1	Reevesdale	Diamond	North	1948	4.6	0
2	do	1	do	Primrose	do	1948	2.7	240
3	do	2	do	Buck Mountain	do	1948	3.4	120
4	do	1	do	Holmes	South	1945	3.4	50
5	Apr. 7	1	do	Orchard	do	1942	6.8	0
6	do	1	do	Primrose	do	1946	3,2	150
7	Apr. 9	1	Tuscarora	do	North and south.	1948	5.1	0
8	do	1	do	Diamond	South	1848	6.6	0
9	do	1	do	Holmes	Local—south	1945	4.5	3
10	do	2	do	do	South	1945	4.9	0
11	do	1	do	Orchard	do	1944	3.7	45
12	Apr. 20	1	do	do	North	1944	3.8	30
13	do	1	do	Local Pocket	North and south.	1945	3.5	100
14	Apr. 27	1	do	Holmes	South	1947	3.3	40
15	Apr. 20	1	do	Local Pocket	North and south.	1945	3.0	475
16	do	1	do	do	do	1945	4.0	20
17	do	1	do	Diamond	South	1946	6.6	0
18	do	1	do	Holmes	do	1941	4.2	15
19	do	1	do	Orchard	do	1943	3.2	160
20	do	1	do	Holmes	do	1943	2.9	350
21	Apr. 23	1	do	Tracy	do	1941	2.8	710
22	do	1	Mary D	Seven Foot	do	1947	4.0	20
23	do	2	do	Diamond	do	1944	3.5	100
24	do	1	do	Orchard	do	1944	4.0	15
25	do	2	do	Primrose	do	1947	6.2	0
26	Apr. 27	1	do	Diamond	do	1948	4.0	8
27	do	1	do	Seven Foot	do	1948	3.9	10
28	do	2	Brockton		do	1947	5.5	0
29	do	1	Middleport		North	1947	4.5	0
30	do	1	do	Mammoth	do	1947	4.0	3

See footnotes at end of table.

excavations in the anthracite region—Continued

ANTHRACITE FIELD

Total acidity as $CaCO_3$, p. p. m.	Content of pool, million gallons	Approximate altitude of surface of water (feet)	Outlet	Classification of workings [1]	Contaminating influences [2]	Effect of pool on present or future mining	Remarks
25	18.0	1,380	Seepage	C	1, 2	Must unwater.	Given and underlying beds incompletely extracted.
160	29.2	1,310	To surface	C	1, 2	do	Do.
8	108.0	1,685	do	A-A	1	None	Local basin. Complete extraction.
	.1	1,548	None	C	1, 2	Must unwater.	Extraction incomplete.
	.1	986	do	C	1, 2	do	Do.
	1.2	1,265	To surface	A	1, 2, 4	do	Given bed unmined. Underlying beds incompletely extracted.
	.1	1,436	do	A	1	do	Do.
20	56.0	1,660	Pumped to Centralia breaker.	A	1	None	Extraction complete.
30	84.0	1,645	Flows to Midvalley breaker.	C	1, 2	Must unwater.	Extraction incomplete.
10	15.7	1,565	To surface	A	1, 2	do	Extraction incomplete on adjoining property.
25	75.0	1,330	Seeps through railroad fill.	A	1, 2	do	Given and underlying beds unmined.
	387.4						

ANTHRACITE FIELDS

Total acidity as $CaCO_3$, p. p. m.	Content of pool, million gallons	Approximate altitude of surface of water (feet)	Outlet	Classification of workings [1]	Contaminating influences [2]	Effect of pool on present or future mining	Remarks
15	2.9	1,055	None	A	1, 2	Must unwater.	Given and underlying beds unmined.
460	7.5	1,022	do	A	1, 2	do	Do.
175	1.2	1,217	do	D	1, 2, 4	do	Incomeplte extraction.
75	2.2	960	To surface	C	1, 2	do	Do.
0	1.4	990	None	D	2	do	Given and underlying beds unmined.
230	2.7	980	Seepage	C	1, 2	do	Incomplete extraction.
8	7.0	907	None	A	1, 2	do	Given and underlying beds unmined.
0	3.0	900	To surface	A		do	Do.
25	15.0	880	Seepage	A	1, 2	do	Do.
5	.6	880	do	A	2	do	Do.
65	.9	840	To surface	A	1, 3	do	Do.
75	.3	845	None	A	1, 3	do	Do.
165	3.0	815	do	A	1, 4	do	Do.
83	.5	900	do	A	1, 2	do	Do.
725	.4	810	do	A	1, 5	do	Do.
50	11.2	780	To surface	A	1	do	Do.
3	1.5	805	do	C	1	do	Given and underlying beds incompletely extracted.
45	.6	830	None	C	1, 3	do	Do.
210	1.5	795	do	A	1, 3	do	Given and underlying beds unmined.
565	.5	780	To surface	A	1, 2	do	Do.
1,060	1.3	762	do	A	1, 2, 3	do	Do.
40	.3	1,045	None	C	1, 2, 4	do	Given and underlying beds incompletely extracted.
150	3.9	880	Seepage	C	1, 2	do	Do.
30	1.9	828	To surface	B	1	do	Do.
3	2.6	842	do	A		do	Given and underlying beds unmined.
10	1.9	878	Seepage	C	2	do	Given and underlying beds incompletely extracted.
13	6.3	880	None	A	2	do	Given and underlying beds unmined.
8	3.4	800	do	A	2		Information not available.
10	.3	920	do	A	2, 4		Do.
5	.1	1,280	do	A	2	do	Given and underlying beds unmined.

TABLE 5.—*Water pools in abandoned stripping*

SOUTHERN

Index No.	Date of collection of sample (1948)	Number of pools in group	Name of coal basin or colliery	Name of bed	Direction of dip	Date of completion of stripping	pH	Free acidity as $CaCO_3$ p. p. m.
31	Apr. 27	1	Middleport	Primrose	North	1947	4.3	0
32	do	1	do	Orchard	do	1947	4.4	0
33	do	1	Middleport-Sharp Mountain.	Mammoth	do	1947	5.1	0
34	May 14	2	Eagle Hill	Tracy	South		4.8	15
35	do	1	do	Clinton	do		6.3	0
36	June 3	1	do	Diamond	Inverted	1945	3.4	20
37	May 21	1	Pottsville	Peach Mountain	South	1946	4.0	8
38	do	1	do	Little Tracy	do	1946	4.2	3
39	do	1	do	Tracy	do	1946	4.2	5
40	do	1	do	Clinton	do	1946	4.7	0
41	do	1	do	Tracy	North	1946	5.2	0
42	do	1	do	Peach Mountain	do	1945	7.3	15 alk.
43	May 25	3	Sharp Mountain	Tracy	South	1941	6.8	5 alk.
44	do	3	do	Holmes	do	1941	6.5	0
45	Apr. 29	1	Pine Knot	Primrose	do	1946	6.6	0
46	do	1	do	Mammoth Bottom Split.	North	1946	4.6	0
47	do	1	Hechserville	Mammoth Top Split.	do	1947	4.5	3
48	do	1	Swatara	Diamond	South	1946	3.9	10
49	do	1	do	Peach Mountain	do	1946	6.7	0
50	May 20	1	Glendower	Mammoth Bottom Split.	North and south.	1948	6.0	0
51	Apr. 30	1	Rousch Creek	Skidmore	South	1947	6.1	0
52	do	1	Fishing Creek	Mammoth Top Split.	do	1945	5.1	0
53	May 21	1	Tower City	Little Diamond	do	1946	4.9	5
54	do	1	do	do	North	1946	4.4	0
55	do	1	do	Orchard and diamond.	do	1946		
56	Apr. 7	2	Brookside-Lykens Valley.	Red Ash	do	1946	5.3	0
57	Apr. 15	1	Intermediate Basin over Tower City.	Diamond and Little Diamond.	South	1947	4.7	0
58	May 21	1	Tower City	Tracy	North	1946	7.0	neutral
59	Apr. 15	2	Intermediate Basin over Tower City.	Orchard	South	1947	4.4	3
60	do	2	do	Primrose	do	1947	2.8	255
61	do	1	do	Holmes	do	1947	4.3	5
62	May 20	1	Tower City	Mammoth Top and Middle.	North	1947	3.3	110
63	Apr. 30	1	do	Holmes	do	1946	3.9	3
64	do	1	do	Little Diamond	South	1945	3.8	48
65	Apr. 15	1	do	Primrose	do	1947	4.6	0
66	Apr. 30	2	do	do	North	1945	5.0	3
67	Apr. 7	3	Goodspring	Little Diamond	do	1946	4.1	20
68	Apr. 15	1	Valley View	Mammoth Top and Middle.	South	1946	4.1	5
Total		84						
Total all fields.		141						

[1] Workings classified as follows:
A. Virgin area—reserves beneath the pit.
A–A. Stripping—excavated to bottom of basin of given bed.
B. Connected directly to underground water pool.
C. Connected to underground workings by openings that are now choked and impermeable.
D. A pillar exists between pit and underground workings in the same bed.

excavations in the anthracite region—Continued

ANTRACITE FIELDS—Continued

Total acidity as $CaCO_3$ p. p. m.	Content of pool, million gallons	Approximate altitude of surface of water (feet)	Outlet	Classification of workings [1]	Contaminating influences [2]	Effect of pool on present or future mining	Remarks
5	1.9	1,110	To surface	A	2	Must unwater.	Given and underlying beds unmined.
3	.5	1,075	None	A	1	do	Do.
3	1.3	1,240	do	A	1	do	Do.
35	.4	690	Seepage	------	1, 2	do	Underlying beds unmined.
5	.4	690	do	------	1, 2	do	Do.
95	15.0	650	To surface	A	1, 2, 5	do	Do
20	5.5	705	do	A-A	1, 2, 3, 4, 5	do	Do.
25	2.2	710	do	A	1, 2, 3	do	Do.
30	1.8	710	do	A	1, 2, 3	do	Do.
15	2.7	735	do	A	1, 2	do	Do.
5	1.3	730	do	A	1, 2	do	Do.
15 alk.	10.0	890	do	C	1, 2, 4	do	Do.
2 acid	6.8	1,090	Seepage	A	2	do	Underlying beds imcompletely extracted.
0	5.0	1,090	do	A	2	do	Do.
0	1.3	1,060	None	C	----------	do	Given and underlying beds incompletely extracted.
5	.2	1,175	do	C	----------	do	Do.
20	.7	1,150	do	C	1, 2	do	Do.
50	.6	790	do	C	----------	do	Do.
0	9.2	1,000	To surface	A	1	do	Given and underlying beds unmined.
5	12.0	1,315	Through spoil bank.	A	----------	do	Do.
0	1.1	1,320	To surface	A	1	do	Do.
4	1.5	1,060	None	A	1	do	Do.
18	24.0	1,340	do	A	2	do	Do.
5	15.9	1,380	do	A	2	do	Do.
--------	8.4	1,360	do	A	4	do	Do.
5	2.2	1,440	To surface	A	1, 2	do	Given bed unmined.
8	14.4	1,360	None	A	1, 2	do	Given and underlying beds unmined.
Neutral	16.9	1,275	do	A	1, 2	do	Do.
15	13.4	1,455	do	A	1, 2	do	Do.
520	1.9	1,445	do	A	1, 2	do	Do.
15	1.3	1,380	do	A	1, 2	do	Do.
175	16.2	1,398	Seepage	A	1, 2	do	Do.
22	4.8	1,410	To surface	A	1, 2	do	Do.
70	1.6	1,405	do	A	1, 2	do	Do.
10	1.1	1,400	None	A	1, 2	do	Do.
12	7.9	1,410	do	A	1, 2	do	Do.
45	4.9	1,310	To surface	A	1, 2	do	Do.
20	2.7	1,145	None	A	1, 2	do	Do.
--------	304.9	------	------	------	------	------	------
--------	2,326.5	------	------	------	------	------	

[2] Contaminating influences noted as follows:
1. Carbonaceous material in spoil bank, run-off from spoil bank drains into pit.
2. Anthracite and other carbonaceous material exposed in walls, ends, or bottom of pool.
3. Drainage from mine-rock bank, breaker-refuse bank, or ash bank.
4. Incomplete backfilling with carbonaceous material.
5. Drainage of wash water from preparation plant.

[3] Included in estimate of underground pool content.

Figures 30 to 50 inclusive show abandoned stripping excavations that contain water. This group includes a general view of a stripped area (fig. 32) in which stripping operations have been completed; two

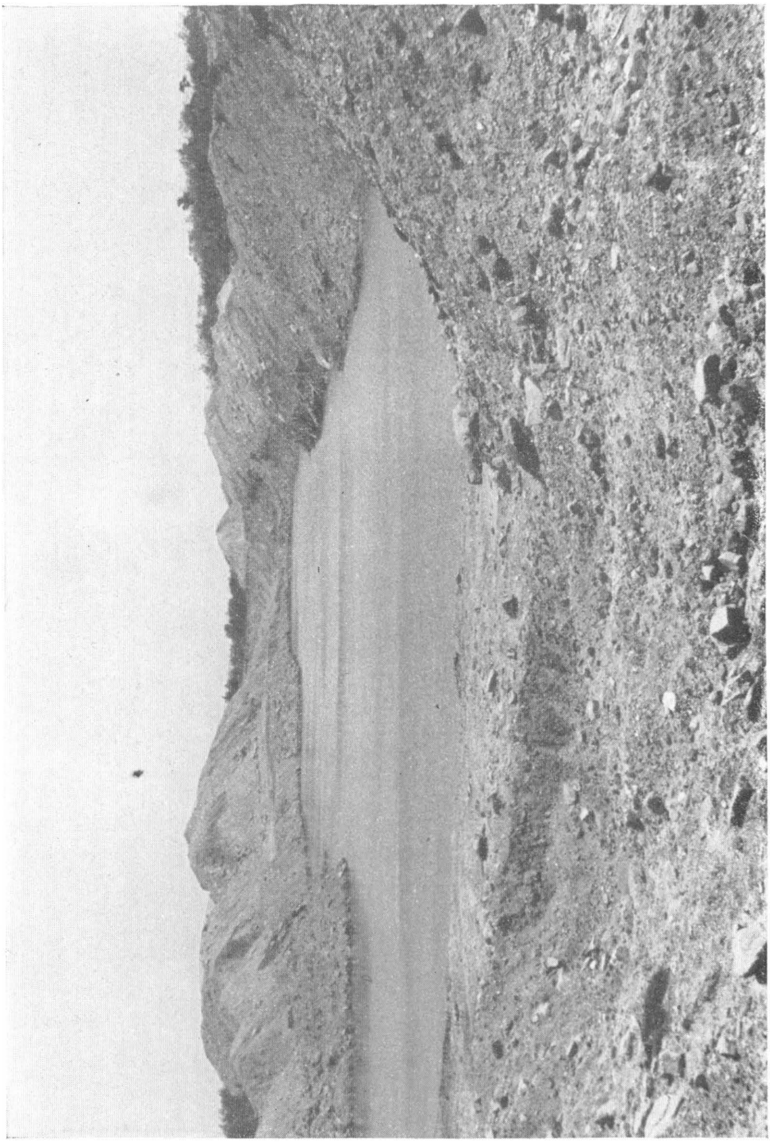

FIGURE 30.—Lykens-bed stripping, Quakake Mountain, near Beaver Meadow, Eastern Middle field.

pictures (figs. 44 and 45) of active stripping operations, and a picture (fig. 50) showing an underground water pool overflowing through an outcrop fall.

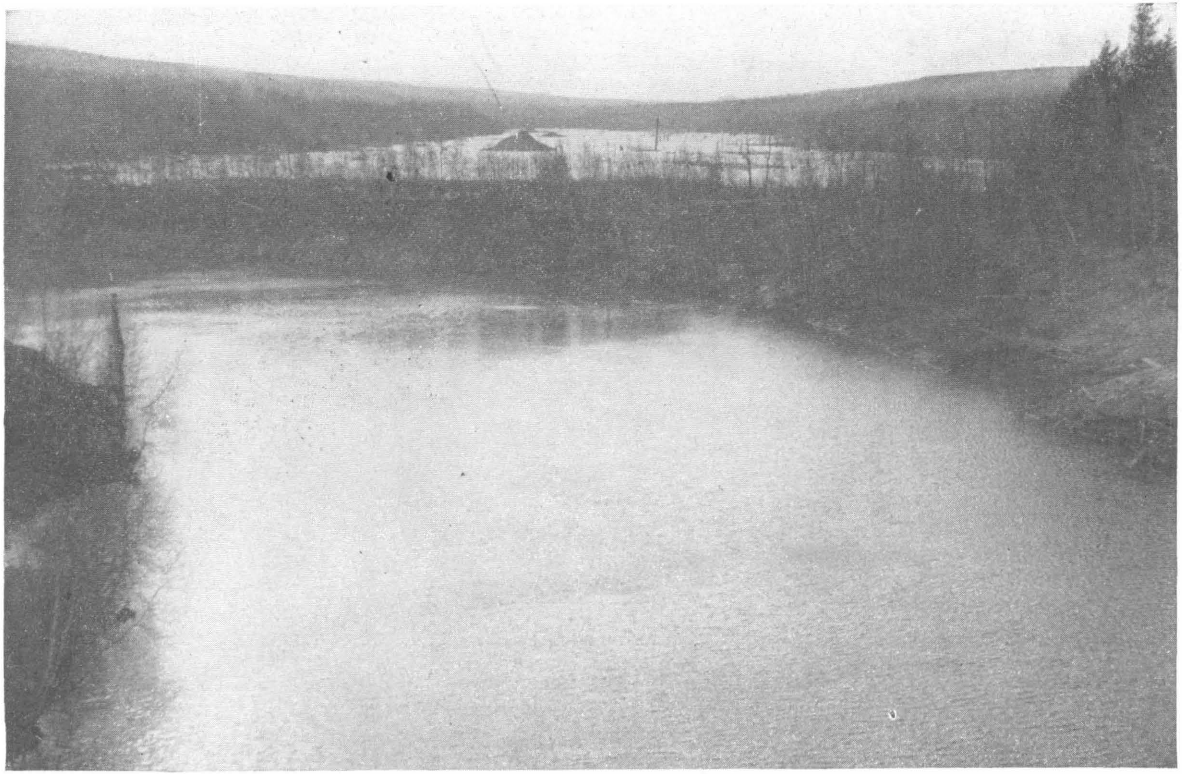

FIGURE 31.—Pond Creek stripping (surface pool in background), Eastern Middle field.

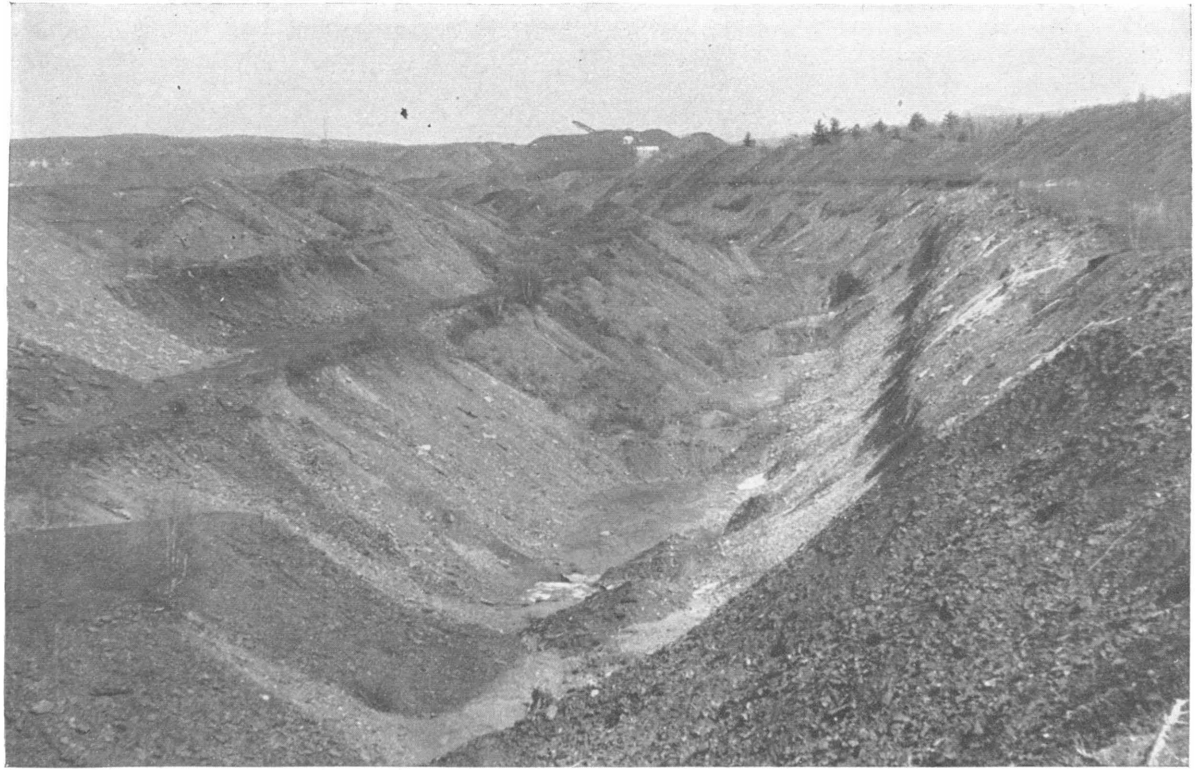

FIGURE 32.—General view of stripped area near Oakdale, Big Black Creek Basin, Eastern Middle field.

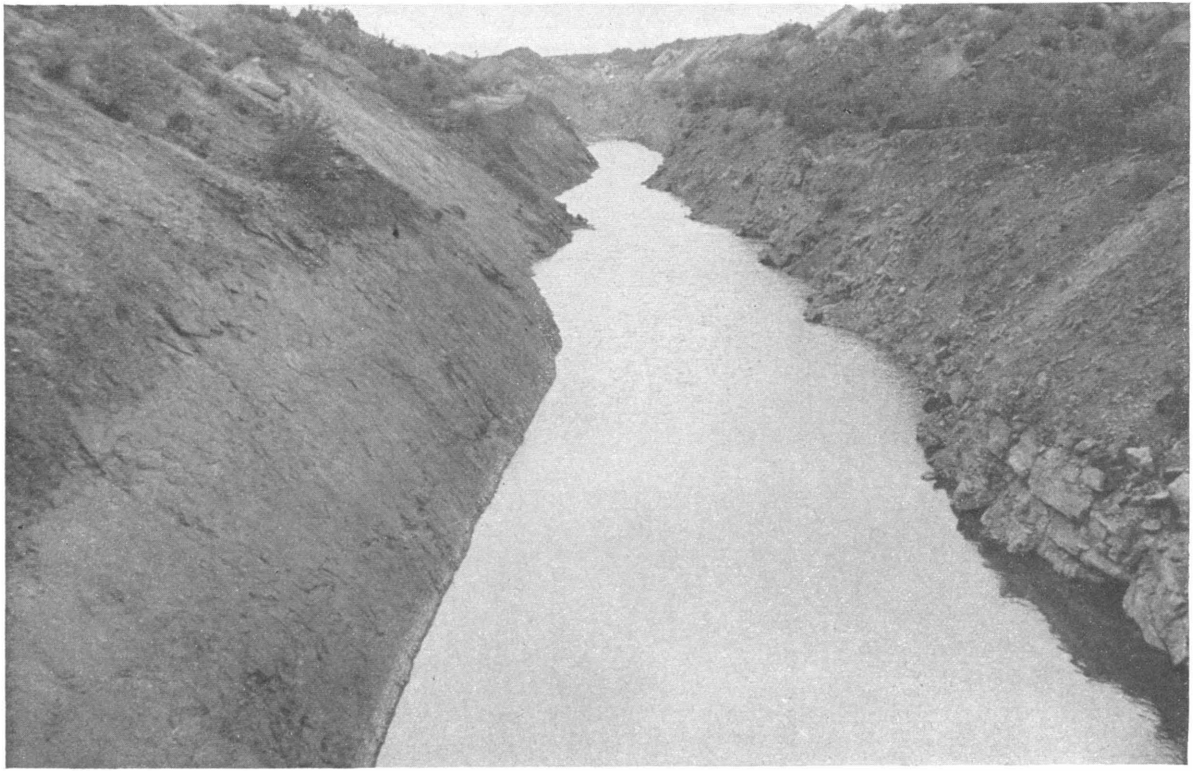

FIGURE 33.—Buck Mountain bed ,South Dip stripping, near Humboldt ,Eastern Middle field.

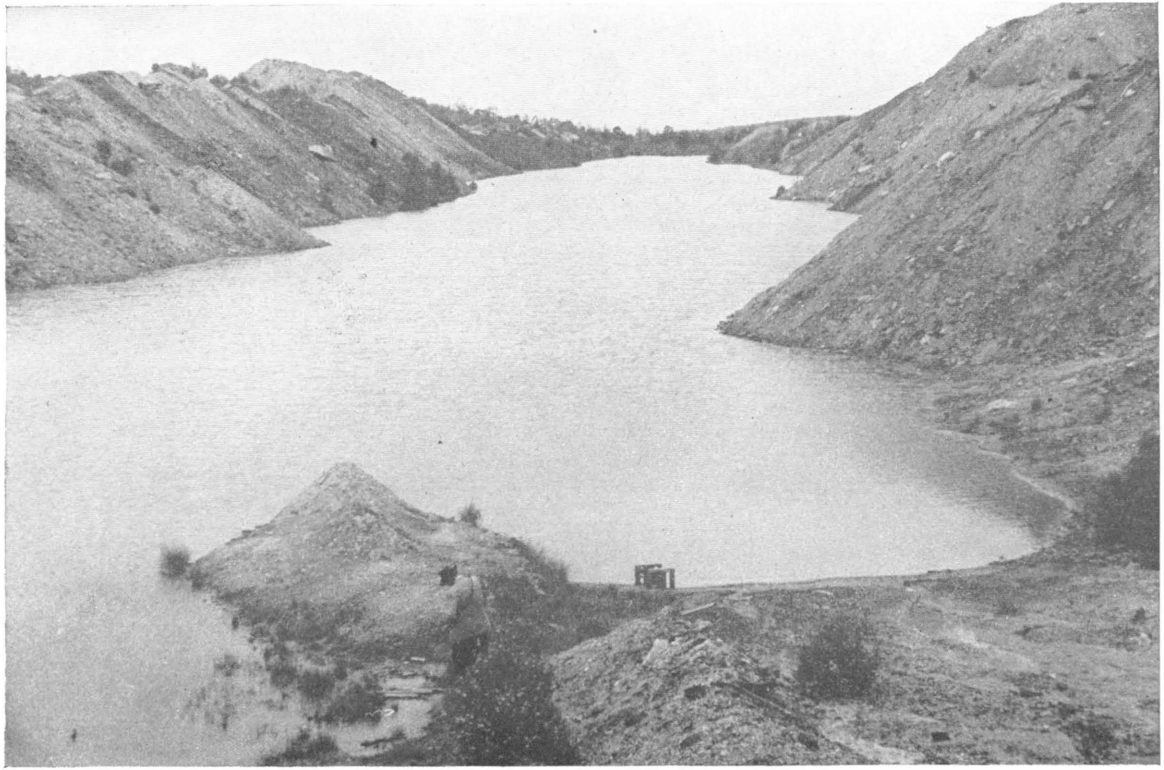

FIGURE 34.—Buck Mountain bed, North Dip stripping, near Humboldt, Eastern Middle field.

FIGURE 35.—Mammoth-bed stripping, near Silver Brook, Eastern Middle field.

FIGURE 36.—Mammoth-bed stripping at Black Ridge, Eastern Middle field.

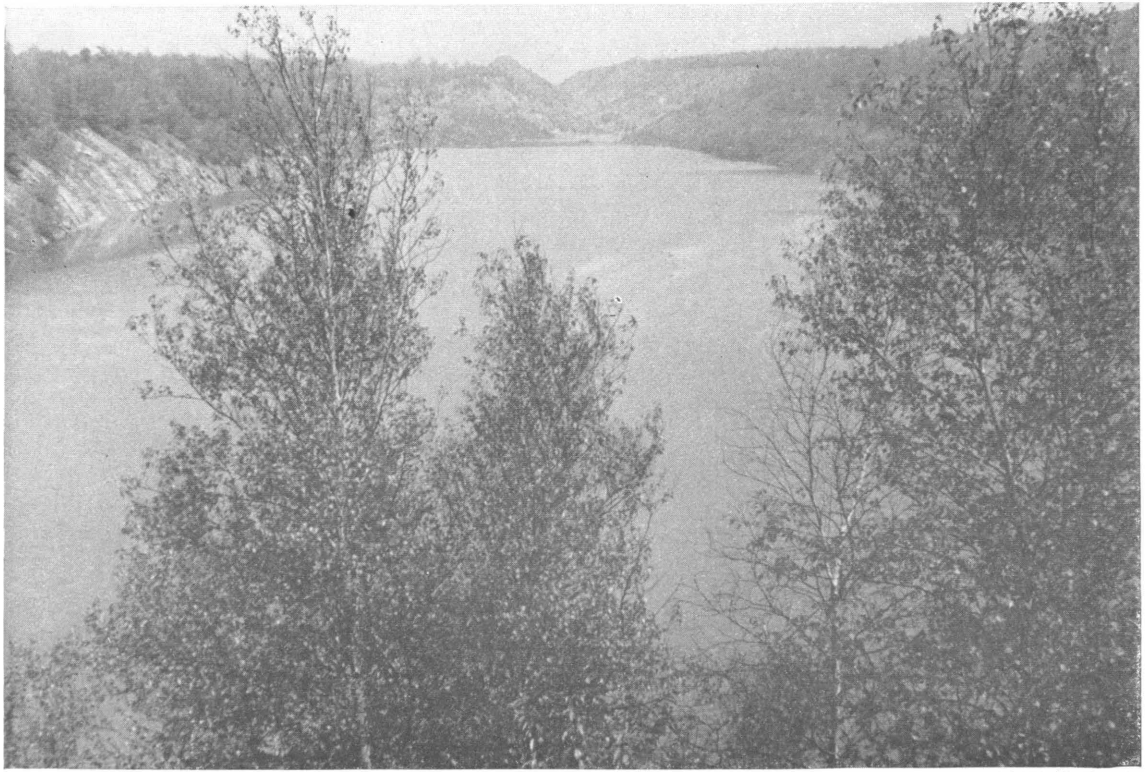

FIGURE 37.—Buck Mountain-bed stripping, Porter's Swamp, Eastern Middle field.

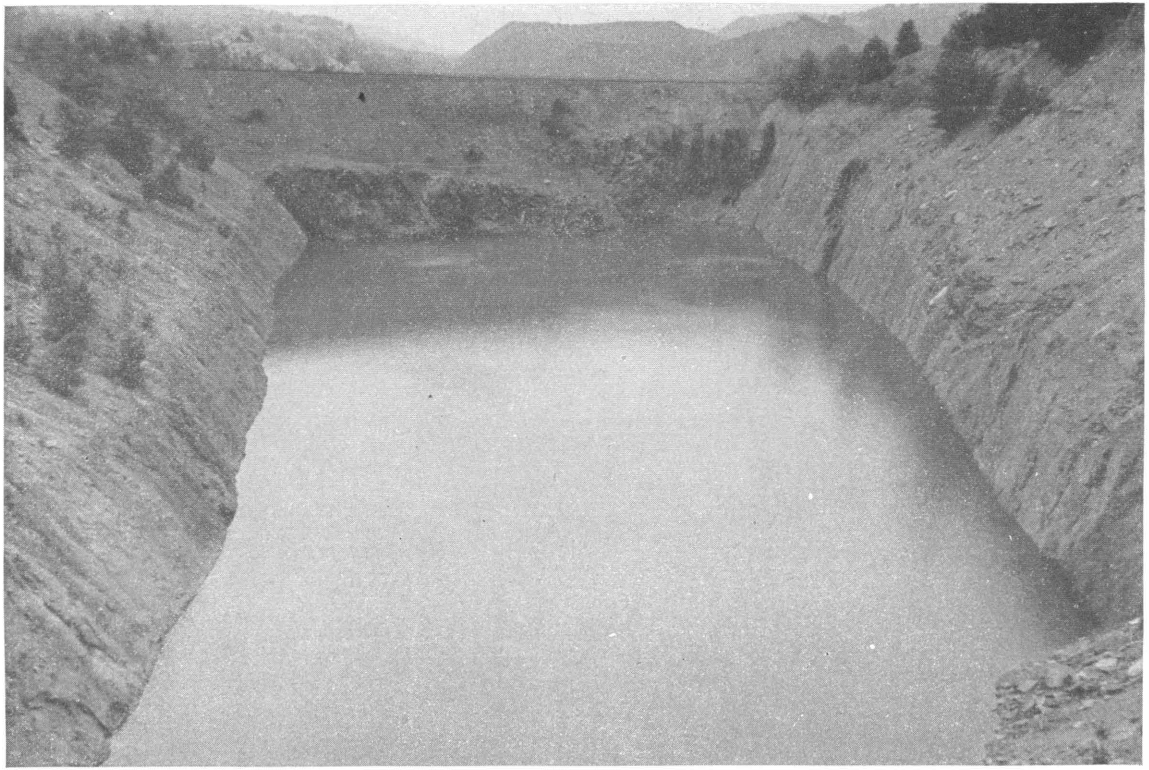

FIGURE 38.—Mammoth-bed stripping, near Natalie, Western Middle field.

FIGURE 39.—Mammoth bed, Buck Mountain Village stripping, near Mahanoy City, Western Middle field.

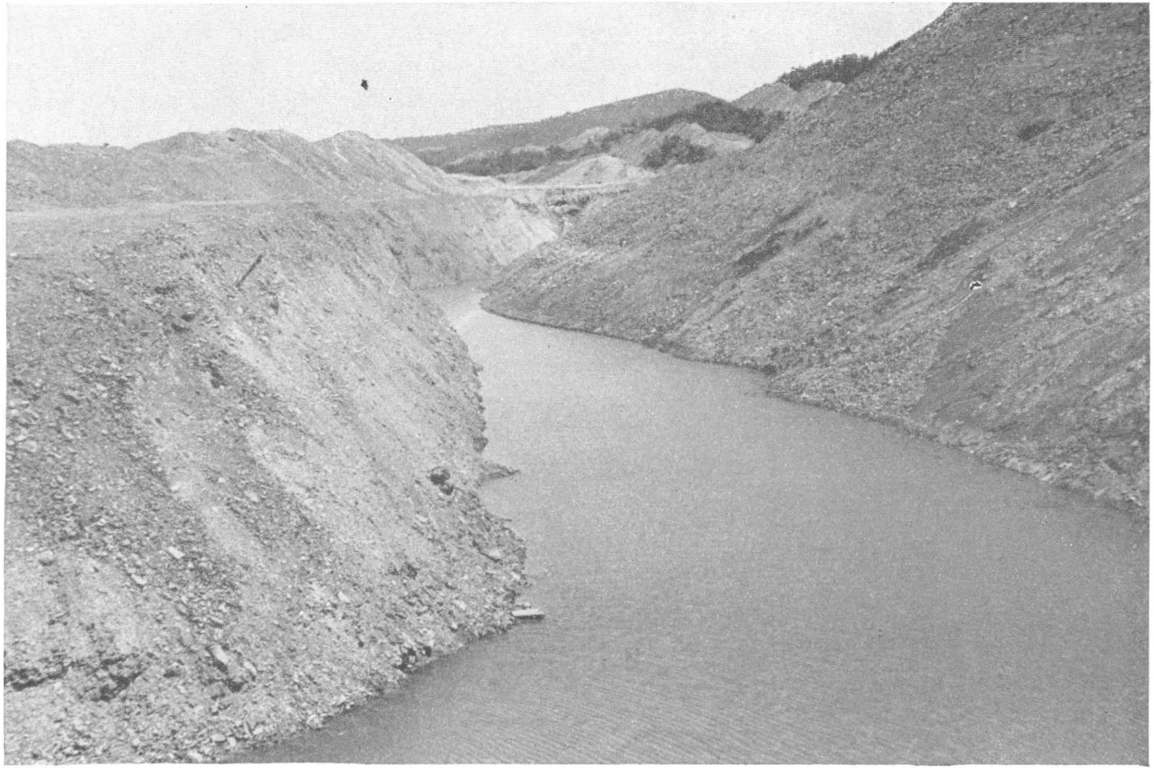

FIGURE 40.—Vulcan stripping, Holmes bed, near Mahanoy City, Western Middle field.

FIGURE 41.—Buck Mountain stripping, Midvalley Basin, near Aristes, Western Middle field.

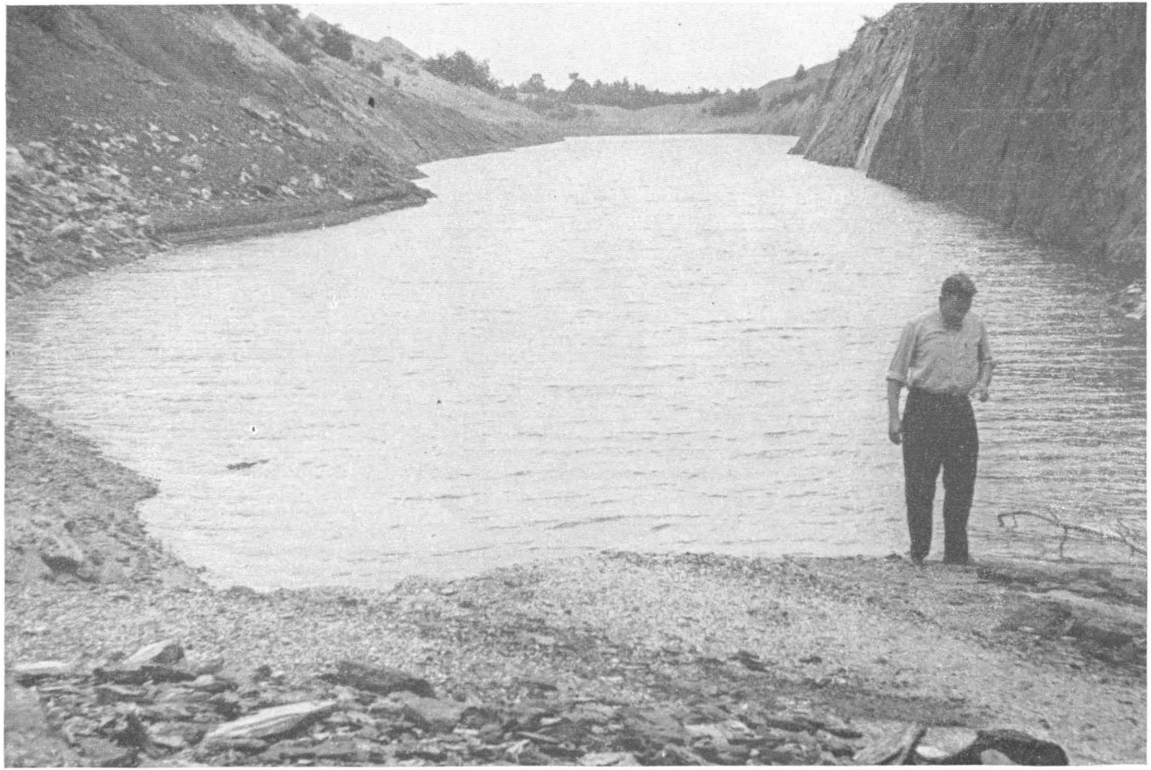

FIGURE 42.—Buck Mountain stripping, north and south dip, near Aristes, Western Middle field.

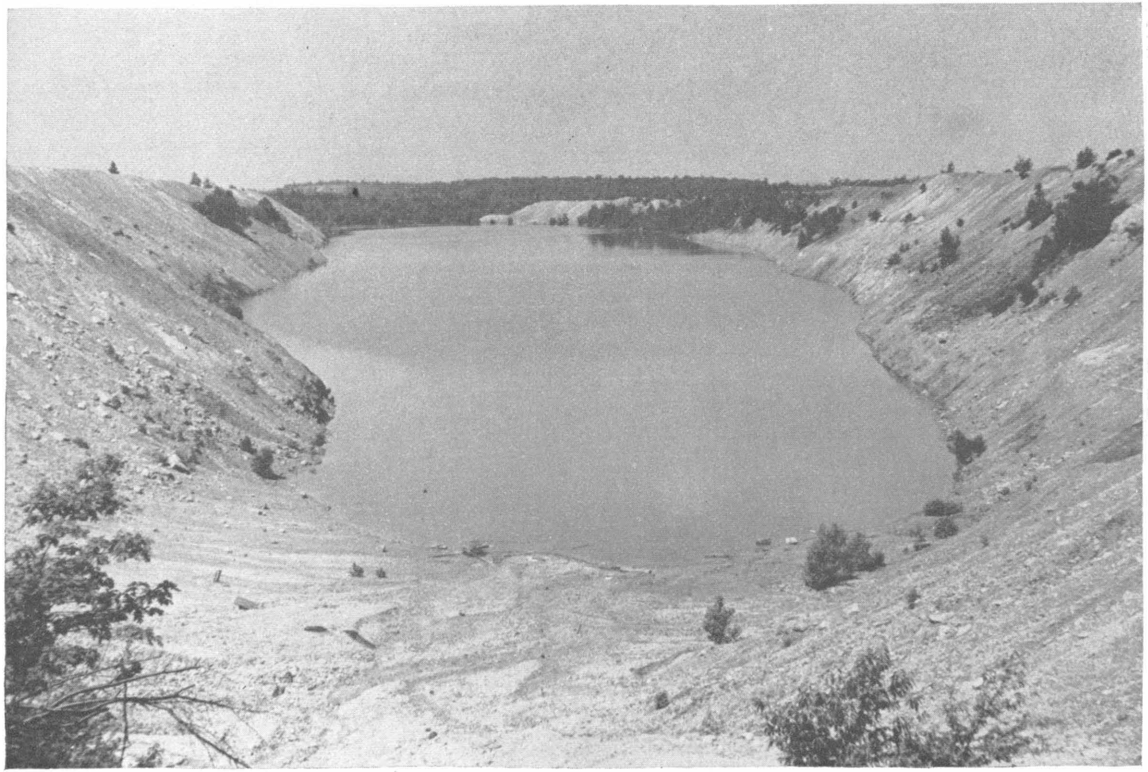

Figure 43.—Mammoth-bed stripping, Locust Mountain No. 9, near Shenandoah, Western Middle field.

FIGURE 44.—Active stripping in Diamond bed, Tower City Basin, Southern field.

FIGURE 45.—Active stripping in Mammoth bed, near Minersville, Southern field.

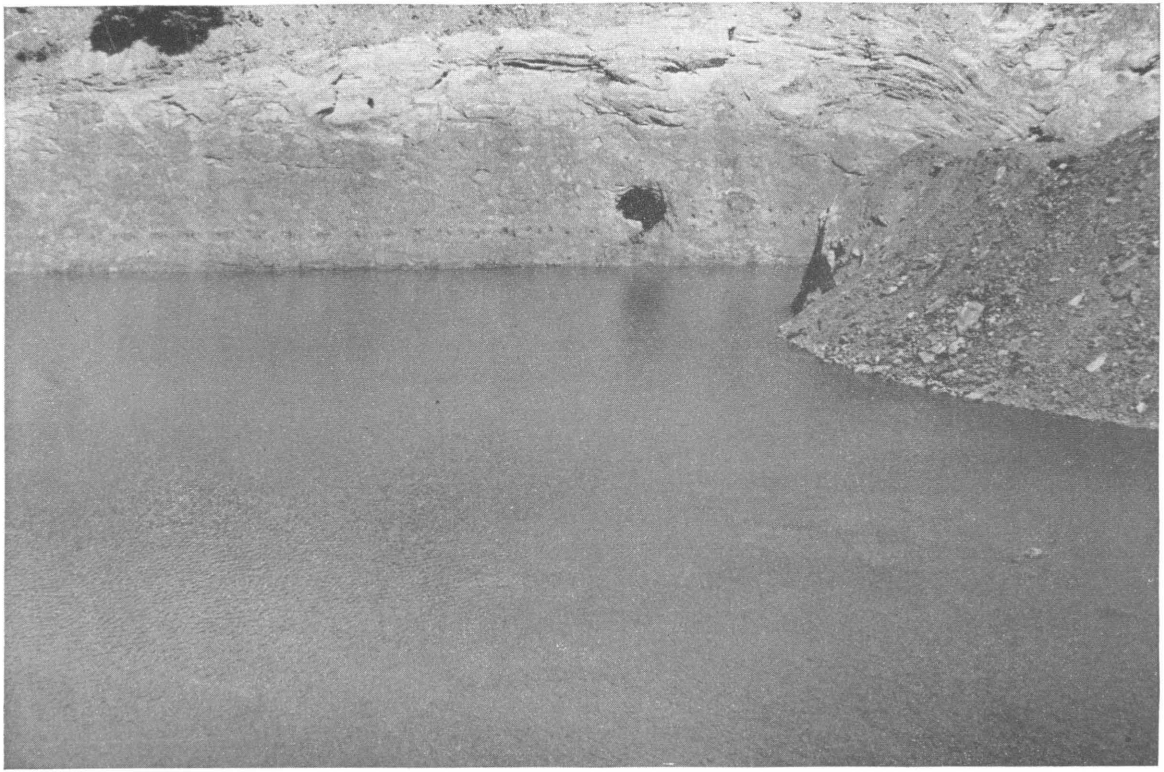

FIGURE 46.—Holmes Pocket stripping, near Tuscarora, showing underground tunnel discharge into pool, Southern field.

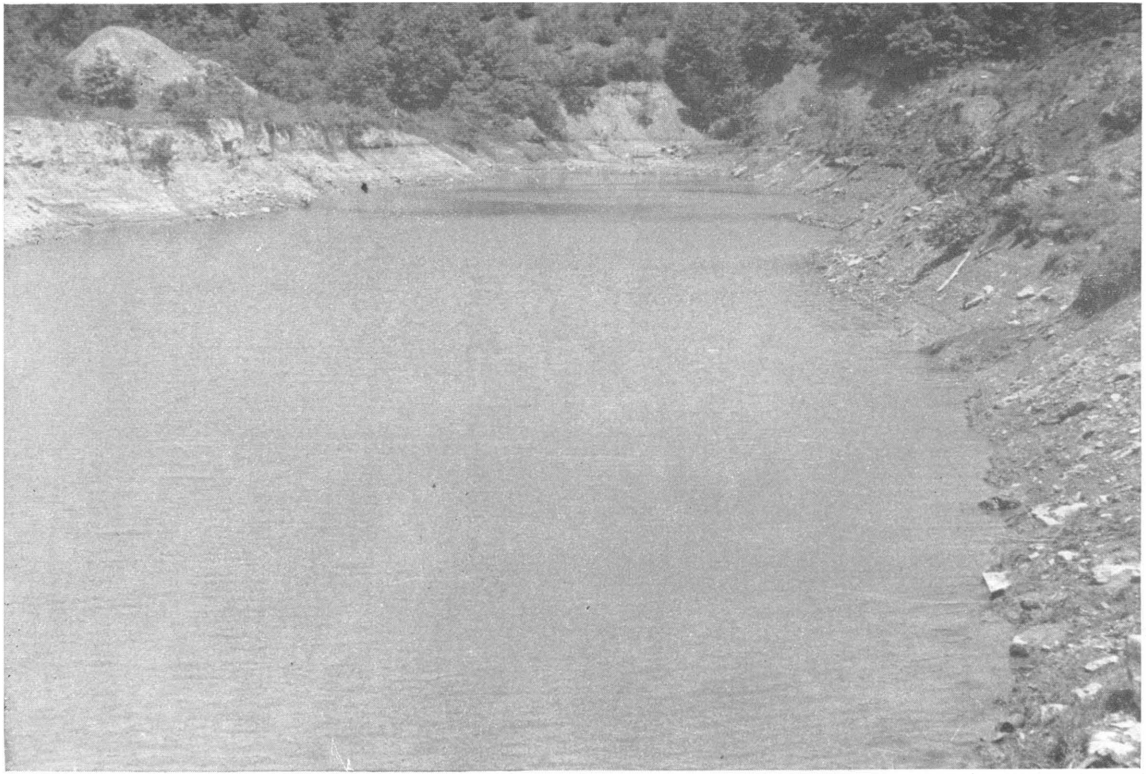

FIGURE 47.—Orchard-bed stripping, near Mary D Village, connected to underground workings, Southern field.

FIGURE 48.—Diamond-bed (Spoon-end) stripping, Tower City Basin, Southern field.

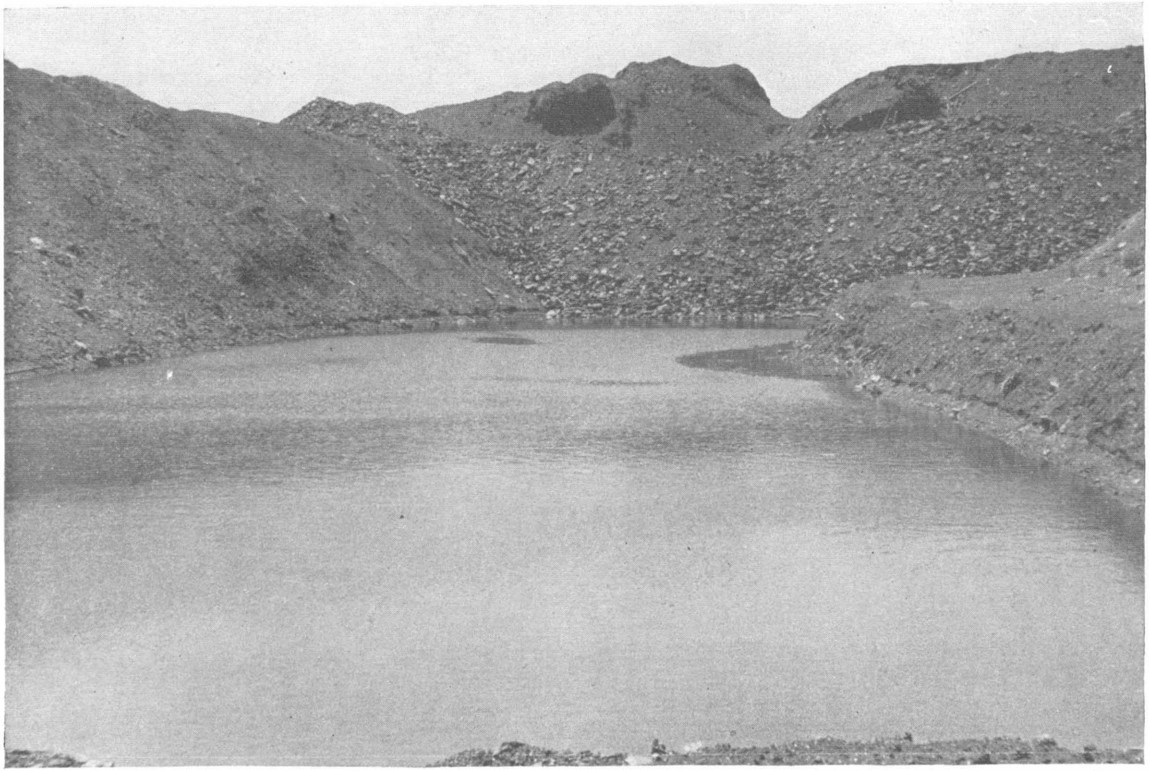

FIGURE 49.—Orchard No. 2-bed stripping, near Mary D Village, Southern field (carbonaceous slate and coal in spoil bank).

FIGURE 50.—Underground water pool overflowing to surface through outcrop fall at Mary D colliery, Southern field.

TYPES OF POOLS

In table 5 the surface water pools in the stripping excavations are classified according to the nature of the ground in which the excavation was made, as follows:

Class A comprises all those excavations in which a virgin anthracite bed has been stripped at the outcrop or at the crest of an anticlinal and the anthracite has been removed as far down the dip as was economical by the equipment available. The anthracite left in place (solid anthracite) presumably will be mined in the future by underground methods. Dependable surveys have been made of the bottoms of relatively few of these pits. No mining should be done in the beds below such pits before some provision has been made for removal of the water in the pits, by pumping, draining, or back-filling the pits to the extent that water will not collect in a pool.

Class A–A comprises pools in an excavation made where the spoon end of a virgin bed has been removed all the way to the bottom of the local basin. This excavation may be deep. Subsequent mining in subjacent beds may result in opening fissures in the footwall of the stripping excavation that contains the water and thereby allow the water to enter into the new workings. To remove this hazard, no mining should be done in the subjacent beds below these pits before water in the stripping excavations is removed.

Class B comprises surface pools in the stripping excavation directly connected with an underground water pool. The water seen in the pool listed is merely a portion of the water in the underground water pool and presents no additional hazard or problem.

Class C comprises pools found in abandoned stripping excavations that originally were connected to underground workings; but, at present, no open connection exists. The passageway connecting the underground workings and stripping becomes choked by boulders and gravel falling into it from the spoil bank, by loose rock from the walls of the stripping excavation, by partly back-filling the stripping excavation, by caves in the old mine workings, or by a combination of the foregoing causes. Clay and silt particles held in suspension by the water infiltrating through the clogged passageway complete the seal by filling the interstices with fine material. The water remains in these pools indefinitely. Other pools that are connected to underground workings have the connecting passageway clogged with material to the extent that the water drains through to the underground workings slowly and, during an extended dry period, these pools may disappear entirely or nearly so. Still other pools in this classification are bodies of water that drain through broken or fissured ground. Pools of water in stripping excavations in this classification are a distinct hazard to active underground mining operations beneath them. There is no assurance against the sudden failure of the seal between the pool and the underground workings and resultant rush of water from the pool into the underground mine workings.

Class D comprises surface water pools in abandoned stripping excavations in which a pillar of anthracite (in situ) is between the stripping excavations and the underground workings. These pools can be drained easily by tapping them by means of boreholes from the nearest underground mine workings.

In addition to the abandoned stripping excavations that contain water throughout the year, hundreds of abandoned stripping excavations are present; these contain fairly large pools of water after spring thaws or torrential rainstorms for a period ranging from a few days to a few weeks. These normally dry stripping excavations, when they contain water, are a menace to underground mining operations for the same reasons as explained for surface water pools under class C. After every wet period, an inspection should be made of these stripping excavations to ascertain whether or not they contain enough water to constitute a hazard to underground mine workings.

NORTHERN FIELD

In the Northern field, only nine small pools of surface water in stripping excavations were found. Three of these are in the town of Jermyn and are being back-filled. Less anthracite has been recovered by stripping methods in this field, and fewer surface water pools are present than in any of the other three anthracite fields. A much larger proportion of the anthracite composing the beds near their outcrop had been removed by underground methods before modern stripping methods and equipment were developed. Moreover, many of the anthracite beds in this field outcrop beneath the water-bearing deposits of the Buried Valley of the Susquehanna River, and the beds are thinner and therefore not adaptable to the stripping method of mining (*27*).

EASTERN MIDDLE FIELD

In the Eastern Middle field, 36 surface water pools were found in abandoned stripping excavations. These pools contain 1,620 million gallons of water. Some of the largest surface pools are situated in this field. Included among these are the pools at Porter's Swamp, Humboldt, and Beaver Meadow. The water in the large pools at Silver Brook and Black Ridge (Conyngham Pass) is not included in this estimate of the amount of water in surface pools in stripping excavations because these pools are connected directly to an underground pool, and the water in them is recorded with the water in the underground water pools. The reason many immense pools are found in this field may be explained by the fact that the Eastern Middle field consists of a number of separate comparatively small basins. The anthracite beds composing the spoon ends of the plunging synclines that form these basins have all been removed by stripping methods and the huge excavations are filled with water.

WESTERN MIDDLE FIELD

In the Western Middle field, 12 surface water pools are present in abandoned stripping excavations. These pools contain 387 million gallons of water.

SOUTHERN FIELD

In the Southern field, 84 surface water pools were found in abandoned stripping excavations. These pools contain 305 million gallons of water. The great number of stripping excavations found in this field is due to the large quantity of anthracite available at the outcrop of many anthracite beds. The anthracite measures are in multiple folds and produce a basin and range structure. Many of the crests of the anticlinals (ridges) have been eroded to the extent that the steeply dipping limbs of the beds are exposed at the surface of the ground. The surface water pools found in this field are relatively small. The proportion of stripping excavations with water in them as permanent surface pools is the same as in the other fields.

CALCULATION OF VOLUME OF WATER IN POOLS

The volume of water in stripping excavations was calculated by the adaptation of the average end-area method as explained on pages 42 and 43.

ACIDITY OF WATER IN ABANDONED STRIPPING EXCAVATIONS

As part of the investigation of pools in stripping excavations, the acidity of the water in these pools was determined.

The collection of samples of the water contained in abandoned stripping excavations and the determination of *p*H, free acidity, and total acidity of these samples were performed by engineers of the Anthracite Flood Prevention Section, Bureau of Mines, Wilkes-Barre, Pa. The methods described in Technical Paper 710, Acid Mine Water in the Anthracite Region of Pennsylvania (*15*), were employed.

It can be readily seen that, particularly when a dragline is employed to do the stripping, the material lying nearest the surface in the area to be strip-mined (usually mantle and overburden) finds its way to the bottom of the spoil bank. The carbonaceous material in the dark shales and anthracite waste that is found in the bottom of the pit remains near the top of the spoil bank after it is excavated.

Associated with the anthracite and carbonaceous wall rocks are sulfur-bearing compounds. Important among these are the iron sulfides, pyrite and marcasite. These minerals occur as finely disseminated crystals in the anthracite and the wall rocks and as bands along the bedding planes of the wall rock. As long as these sulfur-bearing compounds (minerals) remain in place (unmined) and the moisture and air do not come in contact with them, no chemical reaction will take place. However, if these minerals are exposed to air and water, the oxidation of the pyrite and the marcasite can be explained by chemical reactions occurring in three stages (*21, 33*):

Stage 1:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4.$$

The iron sulfide minerals are oxidized by air in the presence of water to produce a nearly colorless solution of ferrous (iron) sulfate and some sulfuric acid.

Stage 2:

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O.$$

The ferrous sulfate and part of the sulfuric acid combine with additional oxygen to form ferric (iron) sulfate.

Stage 3:

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4.$$

The ferric sulfate hydrolyzes to form a reddish-brown precipitate and additional sulfuric acid.

The above reactions occur quite readily in porous spoil banks. During a heavy rain, the spoil banks are nearly saturated with oxygen-bearing rain water. This water descends through and drains from the spoil banks, carrying with it dissolved sulfates. As the water seeps down through the spoil bank, moist air enters the pores of the material to replace the water. This is an ideal condition for further oxidation.

The above reactions also take place over the surface of the wall rocks or anthracite in place, or anywhere the sulfide minerals are exposed to the chemical action of the oxygen in the air in the presence of water by faults, fissures, or fracturing of the beds.

Table 5 shows that the water samples taken from stripping excavations are markedly less acid in character than samples taken from mine-water discharges and from drainage tunnels in the anthracite region in 1941 and 1946, as determined by Felegy, Johnson, and Westfield (*15*).

Almost all of the samples taken from stripping excavations may be characterized as slightly acid. Only two samples, both taken in the Southern field, show any trace of alkalinity; and only five, all taken in the Southern field, are markedly acid.

The processes that produce acidity in both surface pools in abandoned stripping operations and underground water pools are the same, namely, oxidation and leaching of the sulfides by infiltration of surface water.

The relatively slight acidity of the water in abandoned stripping excavations as compared with the higher acidity of the water in the underground water pools may be explained as follows: The percentage of the material in the spoil banks containing sulfides is small; only part of the water that leaches the sulfides from the spoil banks may reach the pools in the abandoned strippings; furthermore, the water in the pools is diluted by water from surface drainage.

The relatively higher acidity of underground mine water compared with the acidity of the water in abandoned stripping excavations may be explained in general by the following factors: The sulfide-bearing material available to water percolation is of much greater extent; drainage of oxygen-bearing surface water into mines is a more continuous process compared with the intermittent addition of rainfall to surface pools; and any seepage from pools in abandoned stripping excavations into mine workings provides the opportunity for increasing the acidity of this water by additional exposure to sulfide-bearing strata. Ordinarily, underground accumulation of acid-bearing water is not subjected to appreciable dilution.

The relatively slight acidity of the water in abandoned stripping excavations as shown in table 5, taken in conjunction with the relatively higher acidity of the mine-water discharges shown in tables 8 and 9 of Technical Paper 710 (*15*), and the acidity or alkalinity of the rivers that drain the anthracite region, as shown in table 4 of Technical Paper 710, would indicate that the drainage from the stripping excavations have little affect upon the acidity of the surface drainage in the anthracite region.

TABLE 6.—*Anthracite produced from strip pits and total anthracite produced from 1942 to 1946, inclusive, from the four anthracite fields of Pennsylvania (in net tons)*

Year	Northern field		Eastern Middle field		Western Middle field		Southern field		All fields		Percentage mined from strip pits
	Strip pits	Total [1]	Strip pits	Total [1]	Strip pits	Total [1]	Strip pits	Total [1]	Strip pits	Total [1]	
942	1, 639, 001	29, 461, 775	1, 138, 967	5, 977, 286	3, 023, 783	13, 922, 202	3, 269, 182	10, 918, 253	9, 070, 933	60, 279, 516	15. 1
1943	1. 352, 509	27, 862, 196	1, 088, 969	6, 496, 674	2, 612, 436	13, 300, 902	3, 922. 976	12, 886, 128	8, 976, 890	60, 545, 900	14. 8
1944	1, 651, 910	28, 330, 531	1, 104, 573	6, 309, 311	3, 173, 376	13, 645. 716	5, 009, 591	15, 268, 588	10, 939, 550	63, 554, 146	17. 2
1945	1, 640, 888	24, 238, 347	1, 011, 025	5, 347, 361	3, 201, 318	11, 980, 289	4, 121, 361	13, 186, 597	9, 974, 592	54, 752, 594	18. 2
1946	2, 621, 399	27, 162, 185	1, 144, 526	5, 340, 100	4, 243, 911	13, 932, 816	4, 827, 006	13, 964, 683	12, 836, 842	60, 399. 784	21. 3
Average											17. 3

[1] Underground, strip pits, culm banks, and river dredging.

TRENDS IN STRIPPING OPERATIONS

The increased size and greater efficiency of excavating equipment that has been developed in recent years have effected a revolutionary change in methods of mining anthracite amenable to strip-mining methods.

The largest dragline used in the anthracite region is a walking-type machine with a bucket capacity of 25 cubic yards and a 180-foot boom. A machine of this type and size was first placed in operation during the latter part of 1944.

Many portions of the anthracite beds situated along the outcrop of steeply dipping limbs of anticlinals or synclinals and spoon ends of basins that were formerly unprofitable to mine by stripping and could be mined only inefficiently and at extremely high cost by underground methods have become profitable to mine by utilizing modern stripping methods and equipment.

Table 6, data taken from the Bureau of Mines Minerals Yearbooks, 1942–46, inclusive, shows the anthracite mined in net tons in the four anthracite fields from strippings and the total amount, in net tons, of anthracite recovered from underground, strippings, culm banks, and river dredging.

The percentage of anthracite recovered from strippings from 1942 to 1946, inclusive, is 15, 15, 17, 18, and 21 percent, respectively. A steady increase in tonnage of anthracite recovered by stripping is shown on this table for 1942 to 1946, inclusive.

SUMMARY

The principal factor that threatens to cut short the life of the anthracite industry, to curtail production, and to affect the economic structure of the people and business dependent on anthracite for their livelihood is the inundation of anthracite mines.

Factual data on pools of water, underground and in abandoned stripping excavations, are necessary to assist in solving the water problem. This paper covers pertinent data available relating to such pools in the anthracite mines of Pennsylvania, as follows:

1. Pools in abandoned mines that have no anthracite reserves and are filled with water to the overflow point.
2. Pools in abandoned mines that have no reserves and in which the water has not reached the altitude of natural overflow.
3. Pools in abandoned mines having reserves that, although inundated, would be minable if the mines were unwatered and the threat of inundation could be economically removed.
4. Pools in active workings in which lower levels are allowed to fill with water so that pumping, necessary to keep the active workings free from water, can be done from the surface of the pool instead of from the basin, thus lowering the cost of pumping by reducing the hydrostatic head.
5. Pools in active mines having reserves that, although inundated, would be minable if the water problem were solved.

An advanced stage of depletion of anthracite reserves has been reached. A large proportion of the anthracite included in the original estimate of reserves is now unminable because of water impounded in underground mines and abandoned stripping excavations.

Active mines are now burdened with infiltration of water from abandoned mines in addition to the water that collects as a result of their own activities. In consequence of the abandonment of collieries from

1927 to the present, less than 40 percent of the anthracite measures in the Western Middle field is available to active collieries. Some mining companies pump water from six to eight abandoned mines, so that the hydrostatic pressure against barrier pillars in active mines is maintained at a safe figure.

Although some mine operators have put forth constantly increasing efforts to control infiltration of surface waters; nevertheless, the total volume of water infiltrating into mine workings shows an upward trend owing to the progressive disturbance to the surface of the ground caused by mining operations.

Infiltration of surface water is attributable to the following sources: Stream-bed leakage, general surface leakage, and barrier-pillar seepage.

To control infiltration some mining companies have:

1. Constructed and maintained flumes and ditches.
2. Back-filled cave holes and stripping excavations.
3. Cleaned and widened stream channels.
4. Lined stream beds across known pervious areas.
5. Silted stream beds.

The volume of water removed from mines in the anthracite region annually by means of pumping and through drainage tunnels exceeds 200 billion gallons. Ninety-one billion gallons of water is impounded in 159 pools in the underground mine workings that are not tributary to present drainage systems, and 2.3 billion gallons of water is impounded in 141 pools in abandoned stripping excavations.

Any interference with operation of the pumping plants for even a few days, or a sudden inflow of water in excess of the pumping capacity, can possibly flood a pumping plant and form a new pool or enlarge an existent pool.

Hundreds of very small underground water pools are present in the anthracite region that have resulted from bootleg mining, on which no data have been obtained. These constitute a hazard to future mining in many places.

Water impounded in many abandoned stripping excavations must be removed to permit mining of adjacent and underlying reserves; however, such pools do not constitute an appreciable additional source of stream pollution.

BIBLIOGRAPHY

1. Ash, S. H. The Water Problem in the Pennsylvania Anthracite Mining Region. Paper presented at the fall meeting of the Anthracite Section, Am. Inst. Min. and Met. Eng., Wilkes-Barre, Pa., Oct. 25, 1940, 12 pp.
2. ———. A Major Problem in the Pennsylvania Anthracite Region. Proc. 32d ann. conv., Mine Inspectors' Inst. America, 1941, pp. 127–146.
3. ———. Water Problem in the Pennsylvania Anthracite Mining Region. Bureau of Mines Inf. Circ. 7175, 1941, 11 pp.
4. ———. Flood Prevention and Control in the Anthracite Region of Pennsylvania. Am. Min. Cong. Jour., vol. 32, No. 3, March 1946, pp. 32–34, 36.
5. Ash, S. H., and Eaton, W. L. Barrier Pillars in the Anthracite Region of Pennsylvania. Am. Inst. Min. and Met. Eng. Tech. Pub. 2289, Class F, Coal Technol., November 1947, 20 pp.
6. Ash, S. H., and Others. Flood-Prevention Projects at Pennsylvania Anthracite Mines, Progress Report for 1945. Bureau of Mines Rept. of Investigations 4109, 1947, 64 pp.
7. ———. Flood-Prevention Projects at Pennsylvania Anthracite Mines, Progress Report for 1946. Bureau of Mines Rept. of Investigations 4288, 1948, 51 pp.

8. Ash, S. H., and Westfield, James. Back-Filling Problem in the Anthracite Region as It Relates to Conservation of Anthracite and Prevention of Subsidence. Bureau of Mines Inf. Circ. 7342, 1946, 18 pp.
9. ————. Flood-Prevention Projects at Pennsylvania Anthracite Mines. A Preliminary Study. Bureau of Mines Rept. of Investigations 3868, 1946, 25 pp.
10. Ashmead, Dever C. Water Pumped from the Mines of the Anthracite Region of Northeastern Pennsylvania. Trans. Am. Geophys. Union, 18th Ann. Meeting, 1937, pp. 498–504.
11. Briggs, Henry. Mining and Subsidence. Edward Arnold & Co., London, 1929, 215 pp.
12. Coal Miners Pocketbook. 12th Ed., 1928, p. 645.
13. Darton, N. H. Some Structural Features of the Northern Anthracite Coal Basin, Pa. Geol. Survey Paper 193–D, 1940, 81 pp.
14. Edwards, Dean G. Public Interest and Welfare as Affected by the Anthracite Mine-Drainage Problem. A report prepared for the Anthracite Mine-Drainage Subcommittee of the Susquehanna Drainage-Basin Committee, National Resources Planning Board, Jan. 14, 1941, 9 pp.
15. Felegy, E. W., Johnson, L. H., and Westfield, James. Acid Mine-Water in the Anthracite Region of Pennsylvania. Bureau of Mines Tech. Paper 710, 1948, 49 pp.
16. Geological Survey of Pennsylvania. Annual Report for 1885.
17. Griffith, Edward. Mine-Drainage Practice in the Anthracite Region of Pennsylvania. Trans. Am. Inst. Min. and Met. Eng., vol. 168, 1946, pp. 127–144.
18. Griffith, Wm., and Conner, Eli T. Mining Conditions Under the City of Scranton, Pa. Bureau of Mines Bull. 25, 1912, 89 pp.
19. Hedley, A. M. The Water Problem in Southwest Durham; Survey of Surface Streams. Coll. Guardian, Mar. 11, 1938, p. 448.
20. Herbert, C. A., and Rutledge, J. J. Subsidence Due to Coal Mining in Illinois. Bureau of Mines Bull. 238, 1927, 59 pp.
21. Hinkle, M. E., and Koehler, W. A. The Action of Certain Microorganisms in Acid Mine-Water Drainage. Am. Inst. Min. and Met. Eng. Tech. Publ. 2381, Class F, Coal Technol., May 1948, 5 pp.
22. Lane, W. T., and Roberts, J. H. The Application of the Mines (Working Facilities and Support) Act, 1923—part II. Coll. Guard., Aug. 17, 1928, vol. 137, No. 3529, pp. 627–628.
23. ————. Vol. 137, No. 3530, Aug. 24, 1928, pp. 723–724.
24. Lutz, Walter S. and Griffiths, J. T. Arrangements for Handling Mine Water in the Scranton-Olyphant Section of the Northern Anthracite Field. Trans. Am. Inst. Min. and Met. Eng., vol. 168, 1946, pp. 145–154.
25. Maize, E. R., Thomas, Edward, and Greenwald, H. P. Studies of Roof Movement in Coal Mines. Bureau of Mines Rept. of Investigations 3562, 1941, 11 pp.
26. Merriman, Mansfield. Treatise on Hydraulics. 10th ed., revised, 1916, p. 272.
27. Minerals Yearbook, 1944. U. S. Department of the Interior, p. 941.
28. Montz, H. W., and Norris, R. V. Subsidence from Anthracite Mining and Surface Support. Trans. Am. Inst. Min. and Met. Eng., Coal Div., 1930, pp. 98–134.
29. Moore, W. H., and Powell, E. T. Mining Anthracite on Pitching and Flat Seams Over Mined-Out Areas. Trans. Am. Inst. Min. and Met. Eng., Coal Div., vol. 149, 1942, pp. 16–28.
30. National Resources Committee. Energy Resources and National Policy. U. S. Government Printing Office, Washington, D. C., 1939, p. 119.
31. Roos, George A. Mine Drainage in the Anthracite Region. Min. Cong. Jour., vol. 31, No. 6, June 1945, pp. 32–34, 50.
32. Rutledge, J. J. Examples of Subsidence in Two Oklahoma Coal Mines. Trans. Am. Inst. Min. and Met. Eng., vol. 69, 1923, pp. 403–433.
33. Snyder, Raymond H. Effects of Coal Strip Mining Upon Water Supplies, Jour. A. W. W. A., Western Pennsylvania Section, Am. Water Work Assoc., June 12, 1947, pp. 751–769.
34. Young, L. E., and Stoek, H. H. Subsidence Resulting from Mining. Univ. of Illinois Eng. Exp. Sta. Bull. 91, 1916, 205 pp.

O