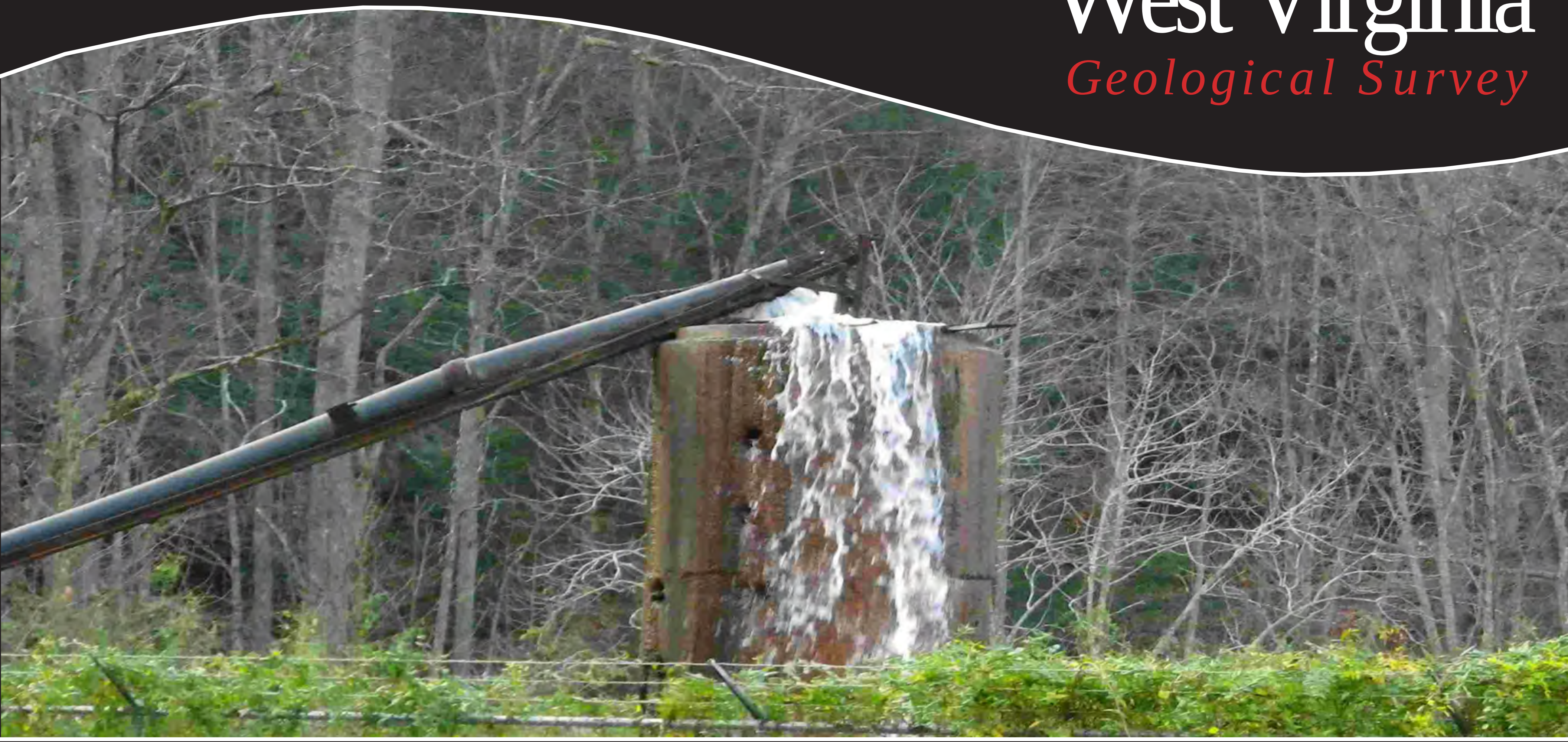
APPENDIX 10

West Virginia
Geological Survey



West Virginia Mine Pool Atlas

West Virginia

WEST VIRGINIA

West Virginia Mine Pool Atlas

Final Project Report
for the project period
January 1, 2010 through December 31, 2011

Submitted to:

West Virginia Department of Environmental Protection
601 57th Street SE
Charleston, WV 25304

Submitted by:

West Virginia Geological and Economic Survey
1 Mont Chateau Road
Morgantown, WV 26508-8079

Principal Investigator
Jane S. McColloch, Senior Geologist

Co-Investigators
Richard D. Binns, Jr., GIS Database Administrator
Bascombe M. Blake, Jr., Manager, Coal Programs
Michael T. Clifford, GIS Analyst
Sarah E. Gooding, Geologist and GIS Cartographer

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ABSTRACT

The West Virginia Mine Pool Atlas project was a two-year study by the West Virginia Geological and Economic Survey (WVGES) to evaluate abandoned coal mines as potential groundwater sources. This study was funded by the West Virginia Department of Environmental Protection (WVDEP). Although West Virginia receives an average of 44.31 inches of precipitation per year (SERCC, 2011) and is considered to have an abundant supply of water, much of West Virginia's precipitation runs off and leaves the state by way of its many streams. The remainder infiltrates the ground surface, but only a small fraction of this water recharges groundwater aquifers. One currently underutilized and frequently overlooked source of stored groundwater is abandoned coal mines. Recently, in the search for large water supplies to facilitate various processes, such as aquaculture, public supply, coal-to-liquid hydrocarbons, hydraulic fracturing water for gas wells, and power plant cooling, a realization has developed that these underground mine pools may be more of an asset than previously assumed.

This study, which addressed the potential for large volumes of groundwater storage based on mine void volume, was designed to facilitate prospecting for large volumes of water by identifying underground coal mines that have the potential to store large quantities of groundwater, especially those mines that are located below or near drainage. This study provides an initial attempt to locate all of the large mine pools in West Virginia stratigraphically and geographically and to estimate their potential volumes based on WVGES Coal Bed Mapping Program (CBMP) GIS data currently being developed to provide a modern, up-to-date picture of the State's coal resource base for various uses. These data include many mine maps that have been collected by the CBMP for many years.

Significant underground mining has taken place in 69 of 73 of West Virginia's mineable coal beds. Various information for the 69 coal beds, including mine polygons, coal cropline, structure contour of the elevation, and scanned mine maps, were visually examined to establish which areas had adequate data to determine the position of each mine relative to major drainage and to develop a tool to predict which mines could be partially or totally filled with groundwater.

Coal beds containing underground mines that were 500 acres or larger in area and located near or below drainage were considered major seams in this study, and 19 such seams were identified. Coal and mining information from the CBMP were used to generate maps and statistics about potential mine pools in these seams for the Mine Pool Atlas. As the individual CBMP data layers are dynamic rather than static, all results presented in this report are preliminary and are undergoing constant updating.

EXECUTIVE SUMMARY

The Mine Pool Atlas project was a two-year study funded by the West Virginia Department of Environmental Protection (WVDEP) to evaluate abandoned coal mines as potential groundwater sources. Although West Virginia receives an average of 44.31 inches of precipitation per year (SERCC, 2011) and is considered to have an abundant supply of water, much of West Virginia's precipitation runs off and leaves the state by way of its many streams. The remainder infiltrates the ground surface, but only a small fraction of this water recharges groundwater aquifers. One currently underutilized and frequently overlooked source of stored groundwater is abandoned coal mines. Recently, in the search for large water supplies to facilitate various processes, such as aquaculture, public supply, coal-to-liquid hydrocarbons, hydraulic fracturing for gas wells, and power plant cooling, a realization has developed that these underground mine pools may be more of an asset than previously assumed.

This study, which addressed the potential for large volumes of groundwater storage based on mine void volume, was designed to facilitate prospecting for large volumes of water by using available Coal Bed Mapping Program (CBMP) products to identify underground coal mines that have the potential to store large quantities of groundwater, especially those mines that are located below or near drainage. This study provides an initial effort to locate all of the large mine pools in West Virginia stratigraphically and geographically and to estimate their potential volumes based on the WVGES Coal Bed Mapping Program (CBMP) GIS data currently being developed to provide a modern, up-to-date picture of the State's coal resource base for various uses. These data include many mine maps that have been collected by the CBMP for many years.

Significant underground mining has taken place in 69 of 73 of West Virginia's mineable coal beds. Various information for these 69 coal beds, including mine polygons, coal cropline, structure contour of the elevation, and scanned mine maps, were visually examined to establish which areas had adequate data to determine the position of each mine relative to major drainage and to develop a tool to predict which mines could be partially or totally filled with groundwater

Coal beds containing underground mines located near or below drainage that were 500 acres or larger in area and located near or below drainage were considered major coal beds in this study, and 19 such coal beds were identified. CBMP coal and mining information were used to generate maps and statistics about potential mine pools in these coals for the Mine Pool Atlas.

The results of this investigation are summarized in this report; and maps and statistics potential mine pools of major coal beds reflect the status of CBMP work during the study. As the individual CBMP data layers are dynamic rather than static, all results presented in this report are preliminary and are undergoing constant updating.

The Mine Pool Atlas contains:

- General descriptions of major coal beds within each formation.
- Stratigraphic columns showing the position of all coal beds within each formation
- Tables showing the distribution of potential totally and partially flooded mines in each seam by mine footprint area and position with respect to drainage
- Tables showing the distribution of potential partially flooded areas of above and near drainage underground mines by coal bed
- Maps of coal beds in which potential partial and/or total flooding was present in mines that had areas of 500 acres or greater
    - Structure contour of elevation
    - Isopach (total bed thickness)
    - Seam overview
    - Extent of potential total flooding
    - Extent of potential partial flooding
- Overview tables for seams in which potential partial and/or total flooding were present in mines less than 500 acres in area

Much of the underground mining in the West Virginia has occurred above drainage. Examination of 9,539 mine polygons in 69 coal beds determined that 8,907 mines are above drainage; 325 near drainage, 178 are below drainage, and 129 are currently undetermined.

Study results showed that 99 mines, which exceed 500 acres in area, are generally located below drainage and are potentially totally flooded. These mines are located in 14 major coal beds:

- Pittsburgh coal in Ohio, Marshall, Monongalia, Marion, and Harrison counties
- Upper Freeport coal in Preston County
- Middle Kittanning coal in Preston and Barbour counties
- Coalburg coal in Wayne and Lincoln counties
- Peerless coal in Kanawha, Nicholas, and Mingo counties
- Number 2 Gas coal in Logan, Mingo, Boone, and Kanawha counties
- Powellton coal in Boone, Logan, and Mingo counties
- Lower Powellton coal in Mingo County
- Eagle coal in Nicholas, Fayette, Kanawha, Boone, Logan, and Mingo counties
- Sewell coal in Nicholas, Fayette, Raleigh, and Wyoming counties
- Beckley coal in Fayette, Raleigh, and Wyoming counties
- Pocahontas No. 6 coal in Raleigh County
- Pocahontas No. 4 coal in McDowell County
- Pocahontas No. 3 coal in Wyoming, McDowell, and Raleigh counties

Five hundred thirty-two mines exceeding 500 acres in area are potentially partially flooded; and 147 of these mines are located near drainage and 385 mines are above drainage. These mines are in 19 major coals. Fourteen of these coals also have mines that are potentially totally flooded and have been described above. These five coal beds have potentially partially flooded mines:

- Sewickley coal in Monongalia and Marion counties
- Bakerstown coal in Preston, Grant, and Tucker counties
- Number 5 Block coal in Braxton, Nicholas, Clay, Kanawha, Boone, Lincoln, Mingo, and Wayne counties
- Stockton coal in Braxton, Nicholas, Kanawha, Boone, Logan, Lincoln, and Mingo counties.
- Pocahontas No. 2 coal in Raleigh County.

Although efforts are made to use the best available data and locate mines as accurately as possible, mine locations should be considered approximate. The actual extent of mining may be unknown because final mine maps at the time of mine closure are not always available and not all underground mining has been documented by mine maps. The quality of mine maps is highly variable in the amount of detail and information presented. Some of the newer mine maps are available in digital form; however, many older mine maps have been photographically reduced from dimensionally unstable paper copies. Photographic reduction also introduced distortion due to lens geometry. Also, coal correlations may change with additional information. Active mines are not differentiated from recently closed mines in the CBMP database.

The extent of potential mine flooding is dependent on several factors, including mine orientation, mine entry location, proximity to other underground mines, and direction of groundwater flow. Groundwater pumping to enable underground mining can affect water levels in adjacent underground mines. The groundwater flooding potential for underground mines in one coal bed also may be affected by underground mining in stratigraphically lower coals. In general, once pumping ceases, the mines begin to flood.

The results of this study should be considered a “snapshot” rather than a finished product. New mines continually open in West Virginia and in adjoining states near the State’s borders. In addition, newly obtained mining coverages are being constantly updated in the CBMP GIS as new information becomes available. All of these factors reinforce the need for detailed site-specific studies to determine the presence of adequate water resources.

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INTRODUCTION

Purpose

The Mine Pool Atlas project was a two-year study funded by the West Virginia Department of Environmental Protection (WVDEP) to evaluate the potential of abandoned underground coal mines to serve as a source of large volumes of groundwater. Although West Virginia receives an average of 44.31 inches of precipitation per year (SERCC, 2011) and is considered to have an abundant supply of water, much of West Virginia's precipitation runs off and leaves the state by way of its many streams. The remainder infiltrates the ground surface, but only a fraction of this water recharges to groundwater aquifers. One currently underutilized and frequently overlooked source of stored groundwater is abandoned coal mines. This study, which addressed the potential for large volumes of groundwater storage based on mine void volume, is designed to facilitate prospecting for large amounts of water by identifying underground coal mines that have the potential to store large quantities of groundwater, especially those mines that are located below or near drainage. Recently, in the search for large water supplies to facilitate various processes, such as aquaculture, public supply, coal-to-liquid hydrocarbons, hydraulic fracturing water for gas wells, and power plant cooling, a realization has developed that these underground mine pools may be more of an asset than previously assumed.

This study, which addressed the potential for large volumes of groundwater storage based on mine void volume, was designed to facilitate prospecting for large volumes of water by identifying underground coal mines that have the potential to store large quantities of groundwater, especially those mines that are located below or near drainage. This study provides an initial attempt to locate all of the large mine pools in West Virginia stratigraphically and geographically and to estimate their potential volumes based on the West Virginia Geological and Economic Survey (WVGES) Coal Bed Mapping Program (CBMP) GIS data currently being developed to provide a modern, up-to-date picture of the State's coal resource base for various uses. These data include many mine maps that have been collected by the CBMP for many years.

Previous Work

The initial concept for this project was developed from a map showing estimated mine pool data for the Pocahontas No. 3 and Pocahontas No. 4 seams in southern West Virginia prepared by West Virginia Department of Environmental Protection (WVDEP, 2008). Several recent reports (Ziemkiewicz and Vandivort, 2004, Ziemkiewicz et al., 2004, and Donovan, 2004a, 2004b) have studied the extent of Monongahela Basin mine pool flooding based on water-level measurements within specific mines of the Pittsburgh coal in northern West Virginia and south western Pennsylvania. The hydrogeology of flooded and unflooded underground coal mines in the Upper Freeport seam in northern West Virginia and western Maryland has been reported in a reconnaissance mapping study by Morris et al. (2008).

METHODOLOGY

Underground mining has occurred in 69 of 73 of West Virginia's mineable coals. Coal bed and mining information for these beds including mine polygons, coal cropline, structure contour of the elevation, and scanned images of mine maps (WVGES, 2011) were examined to establish where adequate data existed to determine the position of each mine relative to major drainage where the potential for each mine to be partially or totally filled with groundwater to be determined.

To aid in understanding the potential of this water source for development, available WVGES CBMP data and models were used to determine which seams have mine voids capable of storing large quantities of groundwater. A dynamic, interactive Geographic Information System (GIS) was created to portray the location of mine pools that might provide large volumes of water for various private, public, and industrial uses. This GIS provided tools to estimate mine pool volumes. Figure 1 shows the status of work being conducted by CBMP (B.M. Blake, unpub. data, 2011).

Scope

The scope of the project was limited to the following tasks:

- Evaluation of each coal seam by region to determine which parts of the seam are above, near, and below major drainage.
- Estimate maximum mine pool volume of each seam assuming an average thickness based on WVGES CBMP GIS data and a 50 percent extraction rate—collapsed and uncollapsed mines would have essentially the same volume because additional voids are created in the crushed pillars and fractured overburden of collapsed mines.
- Develop map templates for use in the PDF atlas.
- Prepare maps of each major mine pool for PDF report.

The original scope included collection and evaluation of available water quality data. Unfortunately, much of the available water quality data were from treated mine water, and these analyses were not useful in determining in-situ water quality.

Mining Data

Data available from the ongoing CBMP used in this study include: mine polygons of approximately 9,500 underground mines; coal bed croplines; structure contours of the base of each coal bed; coal bed elevation raster data; and coal isopachs. As the individual data layers are dynamic rather than static and are subject to intermittent updating as new data warrant, all results presented in this report are preliminary and subject to change.

CBMP has digitized footprints of mine maps, and these mine polygons have been compiled to document the extent of underground mine works (Figure 2). Although efforts are made to use the best available data and locate mines as accurately as possible, mine locations should be considered approximate. The actual extent of mining may be unknown because final mine maps at the time of mine closure are not always available and not all underground mining has been documented by mine maps. The quality of mine maps is highly variable in the amount of detail and information presented. Some of the newer mine maps are available in digital form; however, many older mine maps have been photographically reduced from dimensionally unstable paper copies. Photographic reduction also introduced distorted due to lens geometry. Also, coal bed correlations may change with additional information. Active mines were not differentiated from recently closed mines in the CBMP database.

GIS Models

GIS models were used in this study to assist in determining the position of each mine with respect to drainage, the amount of potential groundwater flooding, and direction of groundwater flow.

The Watershed Model, which was used to determine groundwater flow direction, is a standard Esri© ArcMap™ 10.0 geoprocessing model that uses the Spatial Analyst™ Hydrology toolset to convert the CBMP coal bed elevation raster data into predictive hydrologic flow direction and flow accumulation rasters. From these generated datasets the model outputs generalized "stream" features which can be used to predict the direction of groundwater movement through mine voids relative to the coal outcrop. This model was run for all coal beds to aid in determining the extent of potential flooding in underground mines. An example of model output for the Sewell coal seam is shown in Figure 3.

The Mining Above/Below Drainage Model (MABD), which is a geoprocessing model (a series of standard ArcGIS™ tools executed in a certain order), was developed for this study to determine the position of mines with respect to drainage based on perennial stream elevations. Two versions of the MABD Model, the Major Drainage Elevation Model (MDEM) and the Perennial Drainage Elevation Model (PDEM), were generated by assigning USGS 7.5-minute quadrangle elevations to points selected from the National Hydrography Dataset (NHD). The MDEM selected points located within digitized perennial stream polygons; the PDEM selected points located along digitized perennial stream lines. The resolution of these digital elevation models (DEMs) were generated to 10 meters to match the CBMP seam elevation raster data. The coal elevation DEM was subtracted from the MDEM and the PDEM to indicate regions of the coal bed that lie above and below major drainage, these results were individually overlaid with the mine footprint to obtain the two versions of the final GIS layer of potentially flooded mine areas (Figures 4 and 5).

The effectiveness of the MDEM and PDEM models was tested by comparing the model output for 472 mines in the Sewell coal seam located in southern West Virginia with the results of the visual structure contour/cropline examination of the same underground mines (McColloch et al., 2011). The visual structure contour/cropline examination is the most effective method of identifying drainage position and potential extent of flooding in mines. The MDEM proved ineffective in predicting mine position with respect to drainage and potential extent of mine flooding. The PDEM is a fair predictive tool, but it is most effective in identifying potential flooding below drainage. The details of this comparison are presented in Appendix A.

Mine Pool Evaluation Process

- Establish which areas have structure contour and coal cropline coverages so that the position of each underground mine with regard to major drainage (above, near, or below), which allows the potential for each mine to be partially or totally filled with groundwater
- Evaluate position and likelihood of flooding for mines located in areas which have adequate coverages
- Visually examine each mine polygon by seam and assign attributes according to mine pool type, position with respect to drainage, availability of structure contour, availability of cropline, and potential extent of partial flooding

GIS Attribute Tables

To facilitate data analyses and map generation, six fields were added to the CBMP GIS attribute tables of the 69 coal beds that have been mined by underground methods:

- Mine pool type based on extent of potential flooding: 0=undetermined; 1=flooded; 2=not flooded; and 3=partially flooded
  - Undetermined represents underground mines located in areas with no structure contour and cropline coverages
  - Flooded represents underground mines that are located below drainage, and these mines have the potential to be totally filled with groundwater
  - Not flooded represents mines that are probably free draining
  - Partially flooded represents underground mines that have a configuration that would permit the accumulation of groundwater in specific areas that can range from very small to very large and these determinations are qualitative rather than quantitative
- Position with respect to drainage (0=undetermined; A=above; N=near; and B=below
  - Undetermined represents underground mines located in areas with no structure contour and cropline coverages
- Availability of structure contour (1=Yes; 2=No)
- Availability of cropline data (1=Yes; 2=No)
- Potential extent of flooding for partially flooded underground mines based on qualitative rather than quantitative
  - 1=very small potentially flooded area(s)
  - 2=small potentially flooded area(s)
  - 3=intermediate potentially flooded area(s)
  - 4=large potentially flooded area(s)
  - 5=very large potentially flooded area(s)
- Comment field

Mine Pool Volumetric Calculation Method

The CBMP Total Bed Thickness raster layer (totbed) is a 10 meter GRID layer that was the basis for vertical void measure estimates. This layer is produced using an Inverse Distance Weighted algorithm that interpolates grid values between actual coal bed thickness data as described by Wood et al. (1983). CBMP's mine footprint layer was the base used to determine the area covered by each mine void.

ArcMap™'s Spatial Analyst extension Zonal Statistics tool was employed to "sum" each 10 meter cell within a given mine polygon to calculate the total volume of the mine void. These data were output into a .dbf table (zonalstat).

The following mathematical formulas were used:

- Conversion of the Zonal Statistic result from inches/meters to cubic feet: ((SUM / 12) * 32.808399) * 32.808399

- Conversion of cubic feet to acre feet: cubic_ft / 43560

- Conversion of cubic feet to gallons: cubic_ft * 7.48051948

- Storage gallons were calculated as half of the estimated void gallons: (cubic_ft* 7.48051948)*0.5

- The average thickness of the cells intersected by the mine footprint polygon were calculated by taking the sum of the cell values divided by the count of cell selected.

Deliverables

The deliverables included: a final West Virginia Mine Pool Atlas report in electronic format; GIS geodatabases of WVGES's CBMP seam and mining coverages; and GIS map templates. This report includes: general description of major coal beds within each formation; the distribution of potential totally and partially flooded mines in each coal bed by mine footprint area and position with respect to drainage; estimated volume of groundwater contained in each mine pool; a five-map series for each of the 19 major coal beds identified by this study consisting of a structure contour map, an isopach map, a seam overview map, a map showing extent of potential total flooding, and a map showing extent of partial flooding; and overview tables for minor coal beds having potential mine void flooding.

Deliverable Data Layers Description

thickness_measures_location (points) — XY coordinates of coal measure location
thickness_measures_area (polygon) — 3 mile buffer of measure location used to determine "mapped" area of the coal bed as described in USGS Circular 891 (Wood et al., 1983)
structure (line) — coal elevation 40' contours
outcrop (polygon) — original coal resource area as currently mapped
mines (polygon) — underground mine footprints

- Apcard (poly_ID)
- Mine Name
- Company Name
- State Permit #
- WVGES Comment
- Seam Codes
- Stratigraphic Order
- Acres

mine_pool (polygon) — underground mine and zonal statistics tables concatenated
idwTotalBed (raster) — total bed thickness in inches 10 meter GRID
zonalstat (table) — volumetric calculation results

- Apcard (poly ID)
- Count — count of cells intersected by mine
- Area — total square meters of intersected cells
- Sum — total of cell thicknesses in inches
- Void Cubic Foot
- Void Acre Foot
- Void Gallons
- Storage Gallons
- Avgthk — average thickness of cells intersected by the polygon

Structure of the Report

Following evaluation, 19 major seams were identified for inclusion in the map section of the report. These are coal beds in which underground mines occur that have footprints equal to or greater than 500 acres in area and are near or below drainage. An area of 500 acres was chosen as the lower limit for inclusion in this report for two reasons: it would provide adequate potential storage to accommodate a large volume of groundwater; and the mine polygons printed on the map would be large enough to show annotation by attribute. Maps and statistics for each major mine pool presented in this report are limited to the coal and mining information available from the WVGES's CBMP during the period of this study.

The Atlas contains:

- A general description of principal coal beds within the group or formation
- Stratigraphic columns showing the position of the main named coal beds within each formation or group
- Table showing the distribution of potential totally and partially flooded mines in each seam by mine footprint area and position with respect to drainage
- Maps of coal beds that mines in which potential partial and/or total flooding is present in mines exceeding in 500 acres in area.
    - Structure contour of the base of each coal bed
    - Isopach (total coal bed thicknesses)
    - Seam overview
    - Extent of potential total flooding
    - Extent of potential partial flooding
- Overview tables for seams in which potential partial and/or total flooding is present in mines that are less than 500 acres in area

REGIONAL EVALUATION

Data for seams were reported by formation in stratigraphic order from youngest to oldest. A stratigraphic chart of Pennsylvanian coal-bearing strata is shown in Figure 6a. Stratigraphic columns of Pennsylvanian geologic units in Figures 6b–f show the stratigraphic position of named coal beds within each formation or group. The coal bed names shown in these figures are color coded: those in blue denote major seams in which potential totally and partially flooded underground mines exceeding 500 acres in area are present; those in orange correspond to other mineable seams in West Virginia; and those in black represent unmined coal beds.

Study data have been compiled and summarized in Tables 1 through 7. Names of major coal beds containing mines that have significant groundwater potential and exceed 500 acres in area are shown in boldface throughout the text and in Tables 1 through 7. Statistical data about potential totally flooded mines and potentially partially flooded mines are presented in Tables 1 and 2, respectively. Table 3 has information about potential totally and partially flooded mines by position with respect to drainage and by mine area. Tables 4 through 7 provide information about potential extent of partial flooding in above and near drainage mines by mine footprint area. Appendix B presents information about the 99 potential totally flooded underground mines that exceed 500 acres in area. Information about 532 potentially partially flooded underground mines having areas greater than 500 acres is presented in Appendix C. Overviews of 53 coal beds that did not meet the drainage position and area criteria for inclusion in the map atlas are presented in Appendix D.

The percentage of estimated maximum storage in million gallons (MMGal) of potentially totally and partially flooded underground mines of selected seams is shown in Figures 7a–c, respectively.

Elevations of the base of coal beds commonly serve as the basis for defining folds and faults in coal-bearing rock worldwide. Figure 8 shows the location of major structural features in the State.

Coal Bed Analyses by Formation/Group

Dunkard Group

The mainly Upper Pennsylvanian Dunkard Group (Figures 6a, b) contains 14 named coal beds. None of these coals have been mined by underground methods, and therefore, are excluded from further discussion.

Monongahela Group

The Upper Pennsylvanian Monongahela Group (Figures 6a, b) includes nine named coal beds of which four, the Waynesburg, **Sewickley**, Redstone and **Pittsburgh**, have been mined by underground methods. Coal beds that have the potential to contain large volumes of groundwater in mine voids are the **Pittsburgh** and **Sewickley** coals.

Waynesburg: The four underground mines in this seam are located in Monongalia County. All four mines are located above drainage and are potentially partially flooded by groundwater. These mines have limited potential for supplying water resources due to their small size and location above drainage.

Sewickley: This coal bed generally dips to the northwest in the area in which it is mined, and the minimum elevation of this coal is located in the Nineveh Syncline in Wetzel and Marshall counties (Figure 9a). The isopach map indicates the Sewickley bed (Figure 9b) ranges from 0 to 144 inches in thickness, with the thickest coal located in central Marion County. In areas where underground mining has occurred, this bed generally ranges in thickness from 36 to 96 inches.

Seventy-six underground Sewickley mines are located in Marion and Monongalia counties. Fifty-three mines are above drainage, 13 are near drainage, and ten are below drainage (Figure 9c). No below drainage mines greater than 500 acres in area currently occur in this seam (Figure 9d). Six near drainage mines exceeding 500 acres in area have potential partial flooding (Figure 9e). Average bed thicknesses of these mines range from 59.00 to 75.00 inches. Maps and statistical information about potential groundwater flooding of mines in this seam are shown in Figures 9c–e.

The presence of significant groundwater resources in underground Sewickley mines may be affected by underground mining in the stratigraphically lower Pittsburgh coal.

Potentially partially flooded underground mines in the Sewickley provide 100 percent of the estimated 22,809.16 million gallons (MMGal) of potential storage, and these Sewickley mines contain 1.65 percent of total potential storage and 2.23 percent of potential partial storage in underground mines of major coals (Figures 7a, c).

Redstone: This seam has been mined by underground methods in Barbour, Harrison, Lewis, Mason, Monongalia, and Upshur counties. Of the 218 underground mines in this seam, 207 are located above drainage, five mines are located near drainage, and six mines are located below drainage. These mines have limited potential to store significant volumes of groundwater.

Pittsburgh: The elevation of the base of this coal defines a series of south-southwest to north-northeast trending anticlines and synclines in northern West Virginia, and the lowest elevations of the Pittsburgh are found in the Nineveh, Burchfield, and Robinson synclines (Figures 8 and 10a).

The Pittsburgh bed ranges in thickness from 0 to more than 144 inches, and it generally exceeds 48 inches in thickness in many areas (Figure 10b). Although Figure 10b shows total coal bed thicknesses of greater than 144 inches in several small areas of eastern Gilmer County, more recent study indicates this information is erroneous. In areas where underground mining has occurred, the thickness of this bed generally ranges from: 72 to 120 inches in north-central West Virginia; 48 to 84 inches in the northern panhandle of West Virginia; and 36 to 84 inches in the western part of the state.

This coal has been extensively mined by underground methods in Barbour, Braxton, Brooke, Gilmer, Hancock, Harrison, Kanawha, Lewis, Marion, Marshall, Mason, Monongalia, Ohio, Preston, Putnam, Taylor, Upshur, and Wetzel counties. The Pittsburgh has a limited occurrence in Mineral County in the State's eastern panhandle where it has been removed through several generations of underground and surface mines. Mine polygons of 806 mines were examined, and 683 mines are above drainage, 79 are near drainage, and 44 are below drainage (Figure 10c). Twenty-two below drainage mines and one near drainage mine exceed 500 acres in area and are potentially totally flooded (Figure 10d). The average bed thicknesses of these mines range from 56.00 to 98.42 inches. Thirty-one near drainage mines exceed 500 acres in area and have potential partial flooding (Figure 10e). The average coal bed thicknesses of these mines range from 49.00 to 101.63 inches. Maps and statistical information about potential groundwater flooding of mines in the Pittsburgh are presented in Figures 10c–e.

Potentially partially and totally flooded underground mines in the Pittsburgh coal provide an estimated 423,453.52 MMGal of potential storage; and the potentially partially flooded underground Pittsburgh mines contain 51.87 percent of this potential storage. Potential storage in underground Pittsburgh mines accounts for 30.60 percent of total potential storage in underground mines of major seams (Figure 7a).The percentage of potential storage in potentially totally and partially flooded underground Pittsburgh mines represents 56.52 and 21.47 percent, respectively, of the total combined potential storage of mines in major coal beds (Figures 7b, c).

Conemaugh Group

The Upper Pennsylvanian Conemaugh Group (Figures 6a, c) includes 22 named coal beds. Three of these coals, the Elk Lick, **Bakerstown** and Mahoning, have been mined by underground methods. The **Bakerstown** coal is the only Conemaugh Group bed with significant potential to contain large volumes of groundwater in mine.

Elk Lick: This seam has been mined by underground methods in Grant, Lewis, Mineral, and Upshur counties, and 18 mines are present in this seam. All 18 mines are located above drainage. The mines in this seam are generally small in area and occur above local streams, offering limited potential for supplying water resources.

Bakerstown: Elevations of the base of this coal define a series of south-southwest to north-northeast trending anticlines and synclines in the western part of the eastern panhandle and north-central areas of West Virginia (Figure 11a). Most underground Bakerstown mines are located in Preston, Barbour, Tucker, and Grant counties where it has been preserved from erosion in the Ligonier, Belington, Kingwood, and North Potomac synclines (Figures 8 and 11a). The total bed thickness of the Bakerstown generally ranges from 24 to 84 inches, and the thickest part of the coal bed is located in northern Tucker County (Figure 11b).

Sixty-seven mines are located above drainage, and 52 of these mines are potentially partially flooded by groundwater (Figures 11c, e). Most of these mines are small and have limited potential for supplying water resources. No mines are located below drainage (Figure 11d). One near drainage mine located in Tucker County exceeds 500 acres in area and is potentially partially flooded (Figure 11e). The average bed thickness for this mine is 70.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 11c–e.

Potential flooding of underground mines in this seam may be affected by underground mining in the stratigraphically lower coals such as: the Upper Freeport in northeastern Tucker, northwestern Grant, and western Preston counties; and the Middle Kittanning in western Preston County.

Potentially partially flooded underground Bakerstown mines provide an estimated 4,600.06 MMGal of total potential storage, and these mines account for 0.33 percent of total potential groundwater storage and 0.45 percent of potential partial storage in underground mines of major seams (Figures 7a–c).

Mahoning: The five underground mines in this seam are located in Mineral County, and all five mines are above drainage. These mines have limited potential to provide water supplies because of their small size and position above drainage.

Allegheny Formation

The Middle Pennsylvanian Allegheny Formation (Figures 6a, d) includes 14 named coal beds; nine which have been mined by underground methods. The seams that have the greatest potential for containing large volumes of groundwater in mine voids are the **Upper Freeport** and **Middle Kittanning** coals in northern West Virginia and the **Number 5 Block** coal in southern West Virginia.

Upper Freeport: This coal bed has been folded into a series of south-southwest to north-northeast trending anticlines and synclines in the western part of the eastern panhandle and in north-central West Virginia (Figures 8 and 12a). Erosional remnants of the Upper Freeport occur along the Chestnut Ridge, Preston, and Blackwater anticlines. Most underground mines in this coal are located in Preston, Barbour, and Tucker counties, preserved in the Ligonier, Kingwood, Mount Carmel, and North Potomac synclines. In southeastern Marion, central Upshur, and northern Barbour counties, bedrock generally dips to the northwest (Figure 12a). Available data indicate the Upper Freeport ranges in thickness from 24 to 144 inches (Figure 12b). The thickest part of the coal bed is located in eastern Preston County.

Analysis of the 285 underground mines in the Upper Freeport (Figure 12c) show that 237 mines are located above drainage, ten are located near drainage, three are located below drainage, and 35 are located in areas with no structure contour and cropline coverages (Figure 12c). One below drainage mine in southwestern Preston County exceeds 500 acres in area (Figure 12d). Average bed thickness of this mine is 49.00 inches. One hundred ninety-two above drainage and 11 near drainage mines are potentially partially flooded (Figure 12e). Intermediate to very large areas of ten above drainage mines that exceed 500 acres in area are potentially flooded. Seven potentially partially flooded near drainage mines exceed 500 acres in area. The average bed thicknesses of these mines range from 51.00 to 97.24 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 12c–e.

Groundwater flooding in a few near and below drainage mines in Preston County may be affected by underground mining in the stratigraphically lower Middle Kittanning and Lower Freeport coal beds. Currently, potential for groundwater flooding has not been determined for underground Upper Freeport mines in Barbour and Upshur counties. A few of these mines are located above underground mining in the stratigraphically lower Middle Kittanning and Lower Freeport coals.

Potentially partially and totally flooded underground mines in the Upper Freeport coal provide an estimated 45,708.19 MMGal of total potential storage. Estimated potential partial storage is 97.42 perent of potential total storage in these mines. Total potential storage in this coal bed represents 3.30 percent of total potential storage in underground mines of major seams (Figure 7a). Estimated storage in potential totally and partially flooded Upper Freeport mines represent 0.33 percent and 4.35 percent storage, respectively, of major seams (Figures 7b, c).

Middle Kittanning: This coal bed has been folded into a series of south-southwest to north-northeast trending anticlines and synclines in north-central West Virginia (Figure 13a). Erosional remnants of the Middle Kittanning occur along the Chestnut Ridge Anticline (Figure 13a). In the areas where bed thickness data are available, this coal bed generally ranges in thickness from 0 to more than 144 inches (Figure 13b). In southwestern Preston County, underground mines in this coal are located in the Ligonier Syncline where the coal bed generally ranges in thickness from 24 to 108 inches (Figures 8 and 13a–b). Elsewhere, bed thickness in mined areas ranges from 24 to 72 inches in Barbour and Taylor counties and from 48 to 72 inches in Marion County.

Of the 43 underground mines in this seam, 22 are in areas where structure contour and/or cropline data are available. Eleven mines are located above drainage, six mines are near drainage and, five mines are below drainage (Figure 13c). The below drainage mines are potentially totally flooded by groundwater (Figure 13d); two of these mines exceed 500 acres in area and have average bed thicknesses of 51.00 and 74.50 inches. Ten above drainage and six near drainage mines are potentially partially flooded (Figure 13e). Three near drainage mines exceed 500 acres in area and have average bed thicknesses that range from 46.00 to 58.98 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 13c–e.

Currently, potential for groundwater flooding cannot be determined for underground Middle Kittanning mines in Barbour and Upshur counties as the CBMP products are not complete. A few mines in this seam are above underground mining in the stratigraphically lower Clarion coal bed in parts of north-central Barbour County and the Lower Kittanning in parts of central Upshur County.

Potentially partially and totally flooded underground mines in the Middle Kittanning provide an estimated 15,669.16 MMGal of total potential storage (Figure 7a). Estimated storage in potentially totally flooded Middle Kittanning mines is 50.72 percent. Potential storage in Middle Kittanning mines accounts for 1.13 percent of total potential storage in underground mines of major seams. This coal represents 2.20 percent and 0.75 percent storage in potential totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

No. 5 Block: This coal bed has been folded into several southwest-northeast trending anticlines and synclines (Figures 8 and 14a). Erosional remnants of the No. 5 Block are preserved along the southwest-northeast trending Warfield Anticline in southwestern West Virginia (Figure 14a). Southeast and northwest of the Warfield Anticline, many underground mines in this coal are located in the Handley Syncline and two unnamed synclines in Wayne and Lincoln counties. The thickness of this bed ranges from 0 to more than 132 inches, and the thickest coal is found in Nicholas County (Figure 14b). Bed thickness in areas of underground mining generally ranges from 24 to more than 132 inches (Figure 14b).

The No. 5 Block has been mined by underground methods in southwestern and central West Virginia. Mine polygons for the 429 underground mines in this seam were examined, and 416 of these mines are located above drainage and 13 near drainage (Figure 14c).

No potential totally flooded underground mines are present in this coal bed (Figure 14d). Three hundred forty-one of the above drainage mines and 12 of the near drainage mines are potentially partially flooded. One potentially partially flooded near drainage mine, which is located in eastern Lincoln County, exceeds 500 acres in area (Figure 14e). Average bed thickness in this mine is 69.00 inches. Additional information about potential groundwater flooding in this seam is presented in Figures 14c–e.

Potential groundwater flooding of above drainage underground mines in this coal in the Handley Syncline may be affected by underground mining of stratigraphically lower coals assigned to the underlying Kanawha Formation. In northern Nicholas, southern Braxton, and western Webster counties, underground mining in the Stockton lower split 2, Coalburg, and Winifrede coals may affect groundwater flooding in a few No. 5 Block mines.

Potentially partially flooded underground mines in the No. 5 Block coal provide an estimated 19,562.68 MMGal of total potential storage, and these mines account for 1.41 percent of total potential groundwater storage and 1.91 percent of potential partial storage in underground mines of major seams (Figures 7a, c).

Kanawha Formation

The Lower to Middle Pennsylvanian Kanawha Formation (Figures 6a, e) includes 42 named coal beds, and 31 have been mined by underground methods. The seven seams having the greatest potential to have mine voids containing large volumes of groundwater are the **Stockton**, **Coalburg**, **Peerless**, **Number 2 Gas**, **Powellton**, **Lower Powellton**, and **Eagle** coals. Nine hundred thirty-four mines have been identified in lower Kanawha Formation coal beds in southern West Virginia (Figure 6e), the Middle War Eagle, Bens Creek, Lower War Eagle, Glenalum Tunnel, Gilbert, and Douglas. For the most part, these mines are small in area, occur above drainage, and contain limited potential water supplies.

Stockton: Several southwest-northeast trending anticlines and synclines are defined by the structure contour of the base of this coal (Figures 8 and 15a). Erosional remnants of the Stockton are preserved along the southwest-northeast trending Warfield Anticline in southwestern West Virginia (Figure 15a). Many underground mines in this bed are located to the southeast of the Warfield Anticline in the Handley Syncline and a few are located on the northwest limb of the Warfield Anticline (Figure 15a). The Stockton ranges from 0 to more than 144 inches in bed thickness, and it obtains its thickest development in south-central Logan County (Figure 15b). Where it has been underground mined, the Stockton generally ranges from 24 to 144 inches thick (Figure 15b).

This coal has been mined by underground methods in southwestern and central West Virginia. Of the 160 mines in this seam, 157 are located above drainage and three are located near drainage (Figure 15c). No mines are located below drainage, and no mines are potentially totally flooded (Figure 15d). One hundred thirty-two of the above drainage mines and three near drainage mines are potentially partially flooded (Figure 15e). One potentially partially flooded near drainage mine, which is located in eastern Kanawha County, exceeds 500 acres in area. At this location, average bed thickness is 64.00 inches. Although potential flooding is generally limited to small areas in many of the smaller mines, intermediate to large areas of several larger mines could be flooded. Additional information about potential groundwater flooding in this seam is presented in Figures 15c–e.

Potential flooding particularly in above and near drainage Stockton mines in the Handley Syncline may be affected by many underground mines in stratigraphically lower coals beds assigned to the Kanawha formation (Figure 6e). In parts of western Boone, southern Braxton, and northern Nicholas counties, underground mining in the Coalburg will likely affect potential flooding in Stockton mines.

Potentially partially flooded underground mines in the Stockton coal provide an estimated 29,161.59 MMGal of total potential storage, and these mines account for 2.11 percent of total potential groundwater storage and 2.85 percent of potential partial storage in underground mines of major seams (Figures 7a, c).

Coalburg: Several southwest-northeast trending anticlines and synclines are defined by the structure contour of the base of this coal (Figures 8 and 16a). Erosional remnants of the Coalburg occur along the southwest-northeast trending Warfield Anticline in southwestern West Virginia (Figure 16a). The bed ranges in thickness from 0 to more than 144 inches, reaching a maximum thickness in northern Mingo County (Figure 16b). Available bed thickness data in areas of underground mining generally range from 24 to more than 144 inches (Figure 16b).

Underground mines in the Coalburg occur across most of southern West Virginia (Figure 16c). Data analysis was completed for the 298 mines for this seam; 287 mines are located above drainage, ten mines are near drainage, and one mine is below drainage (Figure 16c). One near drainage mine and one below drainage mine are potentially totally flooded. Two hundred sixty-five of the above drainage mines and nine of the near drainage mines are potentially partially flooded.

Most potential totally or partially flooded below and near drainage mines that exceed 500 acres in area are located in eastern Wayne and western Lincoln counties (Figure 16d, e). One potentially totally flooded below drainage mine exceeds 500 acres in area. The average bed thickness of this mine is 66.57 inches (Figure 16d). Two potentially partially flooded near drainage mines are greater than 500 acres in area, and the average bed thicknesses of these mines are 58.00 and 62.00 inches. Visual analysis indicates that large areas of these mines are potentially flooded (Figure 16e). Additional information about potential groundwater flooding in this seam is presented in Figures 16c–e.

Potential groundwater flooding of underground Coalburg mines may be affected in some areas by underground mining of stratigraphically lower coals from the Eagle to the Winifrede in the Handley Syncline; the Winifrede and Sewell coals in western Webster County; and the Winifrede and Eagle on the east limb of the Mann Mountain Anticline in western Nicholas County.

Potentially partially and totally flooded underground mines in the Coalburg coal provide an estimated 68,114.13 MMGal of potential storage; 88.44 percent of this estimated storage is in potentially partially flooded mines. This potential storage accounts for 4.92 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 2.18 percent and 5.89 percent storage in potential totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Winifrede: This coal has been widely mined by underground methods in Boone, Fayette, Kanawha, Logan, Mingo, Nicholas, Raleigh, Webster, and Wyoming counties. Mine polygons for the 283 mines in this seam were examined, and 281 mines are located above drainage and two mines are near drainage. The two near drainage mines are less than 500 acreas in area. Two hundred forty-four of the above drainage mines and the two near drainage mines are potentially partially flooded. The two near drainage mines are less than 500 acres in area. Although potential flooding would be limited to small areas in most of these mines, intermediate to large areas of several of the larger mines could be flooded.

Peerless: This coal generally dips to the northwest except in the vicinity of the southwest-northeast trending folds including the Warfield Anticline and the Handley Syncline and the north-northwest trending Mann Mountain Anticline (Figures 8 and 17a). The Peerless crops out on hillsides along the axis of the Warfield Anticline. Many underground mines in this coal are located southeast of the Warfield Anticline, and most of these mines are located above drainage. Ranging in thickness from 0 to more than 132 inches, this coal is thickest in southern Logan County (Figure 17b). Available bed thickness data in areas of underground mining generally range from 24 to 132 inches (Figure 17b).

Underground mining in this seam is present in southern and central West Virginia (Figure 17c) The Peerless often merges with the underlying No. 2 Gas coal which complicates analysis. Mine polygons for 284 mines were examined, and 229 mines are located above drainage, 12 near drainage, five below drainage, and 38 in areas where cropline and structure contour maps have not been completed (Figure 17c). Three mines above drainage, three mines near drainage, and five mines below drainage are potentially totally flooded (Figure 17d). Three potentially totally flooded below drainage mines exceed 500 acres in area. The average bed thicknesses of these mines range from 23.00 to 49.00 inches. Two hundred two above and nine near drainage mines are potentially partially flooded. One potentially partially flooded near drainage mine exceed 500 acres in area, and it has an average bed thickness of 38.00 inches. Visual analysis indicates that intermediate to very large areas of several large above drainage mines may be flooded (Figure 17e). Additional information about potential groundwater flooding in this seam is presented in Figures 17c–e.

Potential groundwater flooding of underground Peerless mines may be affected in some areas by underground mining of stratigraphically lower coals including: the No. 2 Gas, Powellton, Lower Powellton, and Eagle in parts of southern Logan and Mingo counties and the No. 2 Gas, Powellton, Lower Powellton, Eagle, and Little Eagle in parts of easternmost Boone, southernmost Kanawha, western Fayette, and northwestern Raleigh counties.

Potentially partially and totally flooded underground mines in the Peerless coal provide an estimated 53,219.45 MMGal of potential storage; 97.16 percent of this estimated storage is in potentially partially flooded mines. This potential storage accounts for 3.85 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 0.42 percent and 5.05 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

No. 2 Gas: This coal generally dips to the northwest except in the vicinity of the southwest-northeast trending folds including the Warfield Anticline and the Handley Syncline and the north-northwest trending Mann Mountain Anticline (Figures 8 and 18a). The No. 2 Gas crops out on hillsides along the axis of the Warfield Anticline. As noted above, the No. 2 Gas and Peerless beds often merge and are mined concurrently. Many underground mines in this coal are located in the Handley Syncline, and most of these mines are located near or below drainage. Ranging in thickness from 0 to more than 144 inches, this coal is thickest in northern Wyoming, western Raleigh, and southern Boone counties (Figure 18b). Bed thickness in areas of underground mining generally ranges from 24 to 132 inches (Figure 18b).

This seam has been mined extensively across southern West Virginia (Figure 18c), often in conjunction with the superjacent Peerless when the two beds merge. The examination of mine polygons for the 565 underground mines in this seam indicates 506 mines are located above drainage, 39 near drainage, and 15 below drainage (Figure 18c). Six mines above or near drainage and 15 mines below drainage are potentially totally flooded (Figure 18d). In Mingo, Logan, Boone, and Kanawha counties, two near and eight below drainage mines, which exceed 500 acres in area, are potentially totally flooded. The average bed thicknesses of these mines range from 42.08 to 76.00 inches. Visual analysis suggests 460 mines located above or near drainage are potentially partially flooded (Figure 18e). Twenty-three potentially partially flooded near drainage mines exceed 500 acres in area. The average bed thicknesses of these mines range from 19.00 to 77.93 inches. Although potential flooding would be limited to small areas in most of above drainage mines, intermediate to large areas of several large mines could be flooded. Statistical information about potential groundwater flooding in this seam is presented in Figures 18c–e.

Potential groundwater flooding of Number 2 Gas mines may be affected in some areas by underground mining of stratigraphically lower coals including: the Eagle, Powellton, and Lower Powellton in parts of Logan, Mingo, Wyoming, Boone, and McDowell counties; the Lower 2 Gas, Eagle lower split 1, Little Fire Creek in southernmost Logan County; the Eagle, Eagle A, and Bens Creek in northwestern Raleigh County; and the Powellton, Eagle, and Little Eagle in western Fayette and Nicholas counties.

Potentially partially and totally flooded underground mines in the No. 2 Gas coal provide an estimated 163,753.70 MMGal of potential storage; 89.78 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 11.84 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 4.64 percent and 14.37 percent storage in potential totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Powellton: This coal generally dips to the northwest except in the vicinity of the southwest-northeast trending folds including the Warfield Anticline and the Handley Syncline and the north-northwest trending Mann Mountain Anticline (Figures 8 and 19a). The Powellton crops out on hillsides along the axis of the Warfield Anticline. Many underground mines in this coal are located in the Handley Syncline, and most of these mines are located below or near drainage. Bed thickness of this coal ranges from 0 to more than 120 inches (Figure 19b). The thickest part of the coal bed is in southeastern Mingo County. In areas of underground mining, this bed thickness generally ranges from 24 to 96 inches.

This seam has been mined widely across southern West Virginia (Figure 19c). Mine polygons for the 321 mines in this seam have been examined, and 305 mines are located above drainage, seven near drainage, six below drainage, and three are not determined. One near drainage mine and the six below drainage mines are potentially totally flooded, and all of these mines exceed 500 acres in area (Figures 19c, d). Average bed thicknesses of these mines range from 46.00 to 69.00 inches. Two hundred sixty-one above and six near drainage mines are potentially partially flooded. Large to very large areas of two potentially partially flooded near drainage mines, which exceed 500 acres in area, may be flooded (Figure 19e). Average bed thicknesses of these two mines are 39.00 and 42.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 19c–e.

Potential groundwater flooding of Powellton mines may be affected in some areas by underground mining of stratigraphically lower coals including: the Lower Powellton, Eagle, and Eagle lower split 1 in parts of Mingo, Logan, Boone, and western Kanawha counties; and the Lower Powellton, Eagle, Little Eagle, Bens Creek, and Glenalum Tunnel in northwestern Raleigh, western Fayette, and southern Kanawha counties.

Potentially partially and totally flooded underground mines in the Powellton coal provide an estimated 36,180.12 MMGal of potential storage; and 67.89 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 2.61percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 3.22 percent and 2.40 percent storage in potential totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Lower Powellton: This coal generally dips to the northwest except in the vicinity of the southwest-northeast trending folds including the Warfield Anticline and the Handley Syncline and the north-northwest trending Mann Mountain Anticline (Figures 8 and 20a). The Lower Powellton crops out along the flanks of the Warfield Anticline. Ranging in thickness from 0 to more than 132 inches, this bed is thickest in southeastern Logan and northwestern Wyoming counties (Figure 20b). Bed thickness in areas of underground mining generally ranges from 24 to 84 inches (Figure 20b).

This coal has been mined widely across southern West Virginia (Figure 20c). Examination of the 119 mine polygons for this seam shows 112 mines are located above drainage, five near drainage, and two below drainage (Figure 20c). One above drainage and two below drainage mines are potentially totally flooded (Figure 20d). Two potentially totally flooded below drainage mines that are greater than 500 acres in area are located in Mingo County. The average bed thicknesses of these mines are 29.84 and 41.00 inches. Visual analysis suggests 103 mines located above or near drainage are potentially partially flooded (Figure 20e). Although potential flooding would be limited to small areas in most of these mines, large areas of two near drainage mines in Mingo County that exceed 500 acres in area could be flooded. The average bed thicknesses of these two mines are 34.00 and 46.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 20c–e.

Potential groundwater flooding of Lower Powellton mines may be affected in some areas by underground mining of stratigraphically lower coals such as: the Eagle in parts of Fayette, Kanawha, Logan, Mingo, Raleigh, and Wyoming counties; the Little Fire Creek in southeastern Logan County; and the Eagle lower split 1, Middle War Eagle, and Bens Creek in northwestern Wyoming County.

Potentially partially and totally flooded underground mines in the Lower Powellton coal provide an estimated 10,062.01 MMGal of potential storage; 87.71 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 0.73 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 0.34 percent and 0.86 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Eagle: Dip direction of this coal is generally to the northwest except in the vicinity of the southwest-northeast trending folds (Figures 8 and 21a). The Eagle crops out on hillsides along the flanks of the Warfield Anticline. Many underground mines in this coal are located in synclines northwest and southeast of the Warfield Anticline, and most of these mines are located below or near drainage. This bed ranges from 0 to more than 132 inches in thickness, and it is thickest in southern Boone County (Figure 21b). Bed thickness in areas of underground mining generally ranges from 24 to 96 inches (Figure 21b).

This seam has been mined widely across southern West Virginia (Figure 21c). Mine polygons for the 494 mines in this seam have been examined, and 414 mines are above drainage, 46 near drainage, 16 below drainage, and 18 are undetermined (Figure 21c). Four mines above drainage, five mines near drainage, and 16 mines below drainage are potentially totally flooded (Figure 21d). Eleven below drainage and two near drainage mines exceeding 500 acres in area are potentially totally flooded. The range of average bed thicknesses of these mines range from 33.31 to 62.00 inches. Three hundred sixty-three above and near drainage mines are potentially partially flooded, and visual analysis suggests large areas of 22 of these mines could be flooded (Figure 21e). Fifteen near drainage mines, which are potentially partially flooded, are greater than 500 acres in area and the average bed thicknesses range from 30.00 to 75.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 21c–e.

Potential groundwater flooding of Eagle mines may be affected in limited areas by underground mining of stratigraphically lower coal beds such as: the Little Eagle, Glenalum Tunnel, Bens Creek, and Beckley in parts of western Fayette and northwestern Raleigh counties; the Eagle lower split 1 and Bens Creek in northwestern Wyoming County; and the Middle War Eagle and Lower War Eagle in parts of southeastern Mingo and northwestern McDowell counties.

Potentially partially and totally flooded underground mines in the Eagle coal provide an estimated 105,126.15 MMGal of potential storage; and 77.64 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 7.60 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 6.52 percent and 7.98 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

New River Formation

The Lower Pennsylvanian New River Formation (Figures 6a, f) includes 20 named coal beds, and 14 have been mined by underground methods. The **Sewell** and **Beckley** seams have the greatest potential for containing totally or partially flooded mine voids. Mines in the other coal beds tend to be small, are generally above drainage, and therefore contain limited potential for storing significant volumes of groundwater.

Sewell: This coal bed generally dips to the northwest except in the vicinity of the southwest-northeast trending Pineville and Mullens anticlines, the north-northwest-south-southeast trending Mann Mountain Anticline, and the south-southwest-north-northeast trending Webster Springs Anticline (Figures 8 and 22a). Bed thickness ranges from 0 to more than 120 inches, and the thickest part of this coal bed is in north-central Raleigh County (Figure 22b). Available bed thickness data in areas of underground mining generally range from 24 to 84 inches (Figure 22b).

This seam has been mined by underground methods in McDowell, Wyoming, Raleigh, Fayette, Nicholas, Greenbrier, and Webster counties. The large mines in the Sewell, especially the ones below drainage, offer high potential for supplying water resources. The down dip areas of some of the large mines located near or above drainage also have potential for supplying water resources. Of the 599 mines in this seam, 415 are located in areas where structure contour and cropline data are available. Three hundred sixty-eight of these mines are above drainage, 31 near drainage, and 16 below drainage (Figure 22c). One near drainage mine and 16 below drainage mines are potentially totally flooded (Figure 22d); and 240 above drainage mines and 28 near drainage mines are potentially partially flooded (Figure 22e). Twelve potentially totally flooded below drainage mines exceed 500 acres in area and average bed thicknesses 37.00 to 57.00 inches. Thirteen potentially partially flooded near drainage mines exceed 500 acres in area, and average bed thicknesses for these mines range from 27.00 to 57.00 inches. Large areas of several above drainage mines exceeding 500 acres in area may be flooded. Statistical information about potential groundwater flooding in this seam is presented in Figures 22c–e.

Potential groundwater flooding of underground Sewell mines may be affected by underground mining of stratigraphically lower coal beds including: the Beckley in parts of Raleigh and Nicholas counties; the Welch, Beckley, Fire Creek, and Pocahontas 3 in parts of central McDowell County; the Beckley and Pocahontas 3 in parts of eastern Wyoming County; and the Fire Creek in parts of eastern Fayette, western Greenbrier, and southeastern Webster counties.

Potentially partially and totally flooded underground mines in the Sewell coal provide an estimated 70,722.33 MMGal of potential storage; and 71.73 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 5.11 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 5.54 percent and 4.96 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Beckley: This coal generally dips toward the northwest (Figure 23a). Coal bed thickness ranges from 0 to more than 144 inches, and this coal bed is thickest in western Raleigh County, northern Wyoming County, and central McDowell County (Figure 23b). In areas where underground mining has taken place, bed thickness generally ranges from 24 to 84 inches (Figure 23b).

Underground mines in the Beckley are located in Raleigh, Wyoming, McDowell, Mercer, and Greenbrier counties (Figure 23c). Of the 271 mines in this seam, 112 are located in areas where cropline data are currently available. Ninety-six of these 112 mines are located above drainage, ten near drainage, and six below drainage. The six below drainage mines, which are located in Raleigh County, are potentially totally flooded; and five exceed 500 acres in area (Figure 23d). Average bed thicknesses for these mines range from 49.00 to 70.75 inches. Seventy-seven above drainage mines and ten near drainage mines are potentially partially flooded. Four potentially partially flooded near drainage mines are greater than 500 acres in area; one is located in north-central Raleigh County and three are in southern McDowell County (Figure 23e). Average bed thicknesses for these mines range from 35.00 to 54.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 23c–e.

Potential groundwater flooding of underground Beckley mines may be affected by underground mining of stratigraphically lower coal beds including: the Fire Creek and Pocahontas Nos. 7, 6 upper split 1, 6, 4 and 3 in parts of Raleigh County; the Fire Creek and Pocahontas Nos. 6, 4, and 3 in parts of eastern Wyoming County; the Fire Creek, Little Fire Creek and Pocahontas Nos. 6, 4, and 3 in parts of McDowell County; and the Fire Creek and Pocahontas No. 3 in westernmost Mercer County.

Potentially partially and totally flooded Beckley seam underground mines provide an estimated 25,975.14 MMGal of potential storage; 51.88 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 1.88 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 3.47 percent and 1.32 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Fire Creek: Underground mines in this seam are located in McDowell, Mercer, Wyoming, Raleigh, Fayette, Greenbrier, Pocahontas, and Webster counties. Of the 459 mines in this seam, 411 are located in areas currently without completed structure contour and cropline maps. Four hundred ten of these mines are above drainage, none near drainage, and one below drainage. The below drainage mine is less than 500 acres in area. These mines are mostly small and have limited potential to store large volumes of groundwater.

Pocahontas Formation

The Lower Pennsylvanian Pocahontas Formation (Figures 6a, f) includes 12 named coal beds of which eight have been mined by underground methods. The seams having the greatest potential for totally and partially flooded mine voids are the **Pocahontas No. 2**, **Pocahontas No. 3**, **Pocahontas No. 4**, and **Pocahontas No. 6**.

Pocahontas No. 6 upper split 1: Underground mining of this seam has taken place in Wyoming, Raleigh, and Mercer counties. Of these 65 mines, 45 mines are located in areas in which CBMP mapping has been completed. Forty-four of these 45 mines are located above drainage, and one mine is located near drainage. Twenty-three above drainage mines and one 115.09-acre near drainage mine are potentially partially filled by groundwater.

Pocahontas No. 6: This coal generally dips to the northwest; however, the southwest-northeast trending Mullens and Pineville anticlines in Wyoming County and the Boggs Knob Anticline and an unnamed syncline locally affect dip direction in easternmost Fayette County (Figures 8 and 24a). Where data are available in parts of Fayette, Raleigh, and Wyoming counties, ranges from 0 to more than 96 inches (Figure 24b). In the areas where underground mining has occurred, this coal bed is generally 24 to 72 inches thick (Figure 24b).

The 262 underground mines in this seam are located in southern West Virginia (Figure 24c). Forty-one mines are located in areas where no structure contour and cropline coverages are currently available. One hundred ninety-nine mines are located above drainage, 16 near drainage, and four below drainage (Figure 24c). The four below drainage mines and two small above drainage mines are potentially totally flooded by groundwater (Figure 24d), and one of these mines exceeds 500 acres in area. The average bed thickness of this mine is 31.00 inches. One hundred twelve above drainage mines and 16 near drainage mines are potentially partially flooded by groundwater (Figure 24e). Eight of the potentially partially flooded near drainage mines are greater than 500 acres in area and average bed thicknesses of these mines range from 27.00 to 37.00 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 24c–e.

Areally extensive underground mines in the stratigraphically lower Pocahontas No. 3 coal may affect groundwater flooding in Pocahontas No. 6 underground mines in southern Raleigh, western Mercer, eastern Wyoming, eastern McDowell, and northern Summers counties.

Potentially partially and totally flooded underground mines in the Pocahontas No. 6 provide an estimated 19,883.69 MMGal of potential storage; and 94.32 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 1.44 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 0.31 percent and 1.83 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Pocahontas No. 5: This coal has been mined by underground methods in McDowell, Mercer, and Raleigh counties. Of the 26 mines in this seam, 25 are located in areas in which structure contour and cropline data are currently available. All underground mines in this seam area located above drainage, and 15 of them are potentially partially flooded by groundwater. The down dip areas of four of these mines are partly located in Virginia where potential flooding is more likely to occur.

Pocahontas No. 4: This coal generally dips to the northwest; however, the southwest-northeast trending Pineville, Mullens, and Dry Fork anticlines locally affect dip direction in areas of Raleigh, Wyoming, and McDowell counties (Figure 25a). Erosional remnants of the Pocahontas No. 4 occur along the southwest-northeast trending Dry Fork Anticline in southeastern McDowell County. Available data indicate bed thickness ranges from 0 to more than 144 inches, and the thickest part of the coal bed is in southeastern McDowell County where it has been mined basically to exhaustion. In the areas where underground mining has occurred, this coal bed is generally 24 to 108 inches thick (Figure 25b).

Underground mining in this seam has taken place in McDowell and Wyoming counties (Figure 25c). Of the 58 mines in this seam, 55 are located in areas where structure contour and cropline data have been completed. Thirty-nine mines are located above drainage, nine near drainage, and seven below drainage (Figure 25c). Seven below drainage mines are potentially totally flooded, and six of these are greater than 500 acres in area (Figure 25d). These six mines have average bed thicknesses ranging from 28.50 to 67.47 inches. Thirty-one of the above drainage mines and 9 of the near drainage mines are potentially partially flooded (Figure 25e). Four potentially partially flooded near drainage mines exceed 500 acres in area, and large to very large areas of these mines could be flooded. The average bed thicknesses of these four mines range from 45.28 to 78.27 inches. Statistical information about potential groundwater flooding in this seam is presented in Figures 25c–e.

In parts of central and southeastern McDowell County and eastern Wyoming County, groundwater flooding of underground mines in the Pocahontas No. 4 will likely be affected in areas where underground mines in the Pocahontas No. 3 are present less that 100 feet below.

Potentially partially and totally flooded underground mines in the Pocahontas No. 4 coal provide an estimated 50.432.56 MMGal of potential storage; and 64.42 percent of estimated storage is in potentially partially flooded mines. This potential storage accounts for 3.64 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 4.98 percent and 3.18 percent storage in potentially totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Pocahontas No. 3: This coal generally dips to the northwest; however, the southwest-northeast trending Pineville, Mullens, and Dry Fork anticlines locally affect dip direction in areas of Raleigh, Wyoming, and McDowell counties (Figure 26a). Erosional remnants of the Pocahontas No. 3 occur along the southwest-northeast trending Dry Fork Anticline in southeastern McDowell County. Isopach maps for the Pocahontas No. 3 were not available at the time of this writing. However, data indicate that the Pocahontas No. 3 ranges in thickness from 0 to more than 120 inches.

This seam has been mined extensively by underground methods in Wyoming, McDowell, Raleigh, Mercer, and Summers counties (Figure 26c). Of the 299 mines in this seam, 280 are located in areas in which structure contour maps are currently available; however, cropline data are available for the areas in which these mines are located. Two hundred thirty-two of these mines are located above drainage, 35 near drainage, and 13 below drainage (Figure 26c). In areas where structure contour coverages are available, visual analysis indicates 13 below drainage mines are potentially totally flooded (Figure 26d) and 178 above drainage mines and 33 near drainage mines are potentially partially filled by groundwater (Figure 26e). Twelve potentially totally flooded mines exceed 500 acres in area, and average bed thicknesses of these mines range from 35.00 to 67.00 inches. Twenty-two potentially partially flooded near drainage mines exceed 500 acres in area, and average bed thicknesses of these mines range from 38.08 to 80.58 inches. Statistical information about potential groundwater flooded in this seam is presented in Figures 26c-e.

Potentially partially and totally flooded underground mines in the Pocahontas No. 3 coal provide an estimated 161,086.42 MMGal of potential storage 80.14 percent of estimated storage is in potentially flooded mines. This potential storage accounts for 11.64 percent of total potential storage in underground mines of major seams (Figure 7a). This coal represents 8.87 percent and 12.62 percent storage in potential totally and partially flooded mines, respectively, of major seams (Figures 7b, c).

Pocahontas No. 2: This coal bed dips to the northwest (Figure 27a). Where data are available, this bed is generally 24 to 36 inches thick (Figure 27b), and it is thickest in southern Raleigh County. In areas where underground mining has taken place, bed thickness generally ranges from 24 to more than 36 inches (Figure 23b).

The 15 underground mines in this seam are located in McDowell, Mercer, and Raleigh counties(Figure 27c). Fourteen mines are located above drainage, and one mine is located near drainage (Figure 27c). No potentially totally flooded below drainage mines are present in this coal bed (Figure 27d). Six of these 14 above drainage mines have very small to small areas that are potentially partially filled by groundwater. Large areas of the potentially partially flooded near drainage mine, which exceeds 500 acres in area, is located in southern Raleigh County. The average coal bed thickness of this mine is 31.00 inches (Figure 27e). Statistical information about potential groundwater flooding in this seam is presented in Figures 27c–e.

Potentially partially flooded underground mines in the Pocahontas No. 2 coal provide an estimated 947.09 MMGal of total potential storage, and these mines account for 0.09 percent of total potential groundwater storage and 2.85 percent of potential partial storage in underground mines of major seams (Figures 7a–c).

DISCUSSION

In this study 8,907 of the 9,539 mine polygons examined represented above drainage underground mines. The potential for total or partial flooding in these mines is less certain than it is for near and below drainage mines. These above drainage mines are in coal beds that crop out on hillsides and hilltops. Perched aquifers above local drainage have a more limited areal extent than the unconfined and confined aquifers associated with near and below drainage mines. The degree of certainty about extent of potential flooding of mine voids is greatest in below drainage mines and least in above drainage mines.

Although below and near drainage mines have a greater potential for flooding, storage in above drainage mines should not be overlooked. Statewide public water supply data was analyzed as part of this study to determine which water sources were associated with underground mines. Twenty-seven public water supplies, which are located in Boone, Kanawha, Logan, Mingo, Fayette, Greenbrier, McDowell, Raleigh, and Wyoming counties, were identified as being associated with underground mines in these nine coal beds: Stockton; Winifrede; Fire Clay; No. 2 Gas; Sewell; Beckley; Fire Creek; Pocahontas No. 4; and Pocahontas No. 6. Ten of these public water supplies are springs formed where old works crop out and 17 are wells drilled into old mines. Twenty-two are located above drainage and four are located near drainage, mostly in potential partially flooded mines; and one is located below drainage.

An important finding of this study is the recognition that total estimated potential storage in the Pittsburgh mine pools surpasses that of mine pools in each of the other major coal beds including the No. 2 Gas, Pocahontas No. 3, Eagle, and Sewell. This fact is due to the wide areal extent of this coal bed, its position with respect to major drainage, and its greater average thickness.

This study addressed the potential for large volumes of groundwater storage in underground mines based on mine void volume. Determining the actual extent of groundwater flooding in specific underground mines requires more in depth studies. Recent studies of the extent of mine pool flooding iin the Monongahela Basin, which are based on water-level measurements within specific mines of the Pittsburgh coal bed in northern West Virginia and southwestern Pennsylvania (Ziemkiewisc and Vandivort, 2004, Ziemkiewisc et al., 2004, and Donovan, 2004a, 2004b), have provided insight into the formation of mine pools. Ziemkiewisc et al. (2004) noted that the amount of hydraulic connection between adjacent mines was affected by barrier pillar geometry and thickness and the leakage rate through barrier pillars. Donovan (2004a) reported instances in which groundwater pumping in inactive or closed mines adjacent to an active mine was used to control mine pool elevations to minimize leakage into the active mine. The assumption that all inactive below drainage mines are flooded can be misleading. Donovan (2004b, p. 38) noted that the Valley Camp 1 mine, which is a below drainage mine in the Pittsburgh coal in Brooke County, "... has been closed for over 20 years, the fact that the mine is dry indicates that there is very little inflow to this mine ...."

Multiple seam mining may also affect groundwater flooding in underground mines. In the Monongahela Basin mine flooding study, Donovan (2004a, p. 98) reported that "vertical infiltration to underground mines of the Pittsburgh coal seam is influenced by three principal factors: (a) depth, (b) the presence or absence of overlying Sewickley mining, and (c) status of flooding." Underground mining of multiple coal beds has occurred in many areas of the State. For example, underground mines are present in 14 Kanawha Formation coal beds in the Handley Syncline in southwestern West Virginia, and mines in multiple seams overlap in several areas. Many of the underground mines in this area could be totally or partially flooded, but fracturing of overburden in overlapping mines may affect potential flooding, especially in mines of the upper coal beds. The hydrologic interaction between mines in more than one seam is beyond the scope of this project, and actual determination of mine flooding should be investigated on a case by case basis.

CONCLUSIONS

The total potential storage in the Pittsburgh seam surpasses that of other major seams such as the Number 2 Gas, Pocahontas No. 3, Eagle, and Sewell. The main reasons are the wide lateral extent of this seam and its greater average thickness.

Much of the underground mining in the West Virginia has occurred above drainage. The examination of 9,539 mine polygons of mining in 69 seams determined 8,907 mines are above drainage; 325 are near drainage, 178 are below drainage, and 129 are currently undetermined.

Ninety-nine mines in 14 major seams are potentially totally flooded and are generally located below drainage. These mines are located in these seams in the following counties:

- Pittsburgh seam in Ohio, Marshall, Monongalia, Marion, and Harrison counties
- Upper Freeport seam in Preston County
- Middle Kittanning seam in Preston and Barbour counties
- Coalburg seam in Wayne and Lincoln counties
- Peerless seam in Kanawha, Nicholas, and Mingo counties
- No. 2 Gas seam in Logan, Mingo, Boone, and Kanawha counties
- Powellton seam in Boone, Logan, and Mingo counties
- Lower Powellton seam in Mingo County
- Eagle seam in Nicholas, Fayette, Kanawha, Boone, Logan, and Mingo counties
- Sewell seam in Nicholas, Fayette, Raleigh, and Wyoming counties
- Beckley seam in Fayette, Raleigh, and Wyoming counties
- Pocahontas No. 6 seam in Raleigh County
- Pocahontas No. 4 seam in McDowell County
- Pocahontas No. 3 seam in Wyoming, McDowell, and Raleigh counties

Potential partial flooding was present in 532 mines; 147 mines are located near drainage and 385 are above drainage. Nineteen seams contain potentially partially flooded mines; these seams include the 14 listed above that also have potentially totally flooded mines. Potential partially flooded mines present in the five other seams are located in these counties:

- Sewickley seam in Monongalia and Marion counties
- Bakerstown seam in Preston, Grant, and Tucker counties
- No. 5 Block seam in Braxton, Nicholas, Clay, Kanawha, Boone, Lincoln, Mingo, and Wayne counties
- Stockton seam in Braxton, Nicholas, Kanawha, Boone, Logan, Lincoln, and Mingo counties.
- Pocahontas No. 2 seam in Raleigh County.

Although efforts are made to use best available data and locate mines as accurately as possible, mine locations should be considered approximate. The actual extent of mining may be unknown because final mine maps at the time of mine closures are not always available and not all underground mining has been documented by mine maps. The quality of mines maps is highly variable in the amount of detail and information presented. Some of the newer mine maps are available in digital form; however, many older mine maps have been photographically reduced from dimensionally unstable paper copies. Photographic reduction also introduced distortion due to lens geometry. Also, coal correlations may change with additional information. Active mines are not differentiated from recently closed mines in the CBMP database.

The extent of potential mine flooding is dependent on several factors, including mine orientation, locations of mine entries, proximity to other underground mines, and direction of groundwater flow. Groundwater pumping to enable underground mining can affect water levels in adjacent underground mines. Mine flooding in one seam also may be affected by underground mining in stratigraphically lower coals. In general, once pumping ceases, the mines begin to flood.

The results of this study should be considered a "snapshot" rather than a finished product. New mines continually open in West Virginia and in adjoining states near the State's borders. In addition, newly obtained mining coverages are being constantly updated in the CBMP GIS as new information becomes available. All of these factors reinforce the need for detailed site-specific studies to determine the actual presence of adequate water resources.

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MINE POOL ATLAS

FIGURES

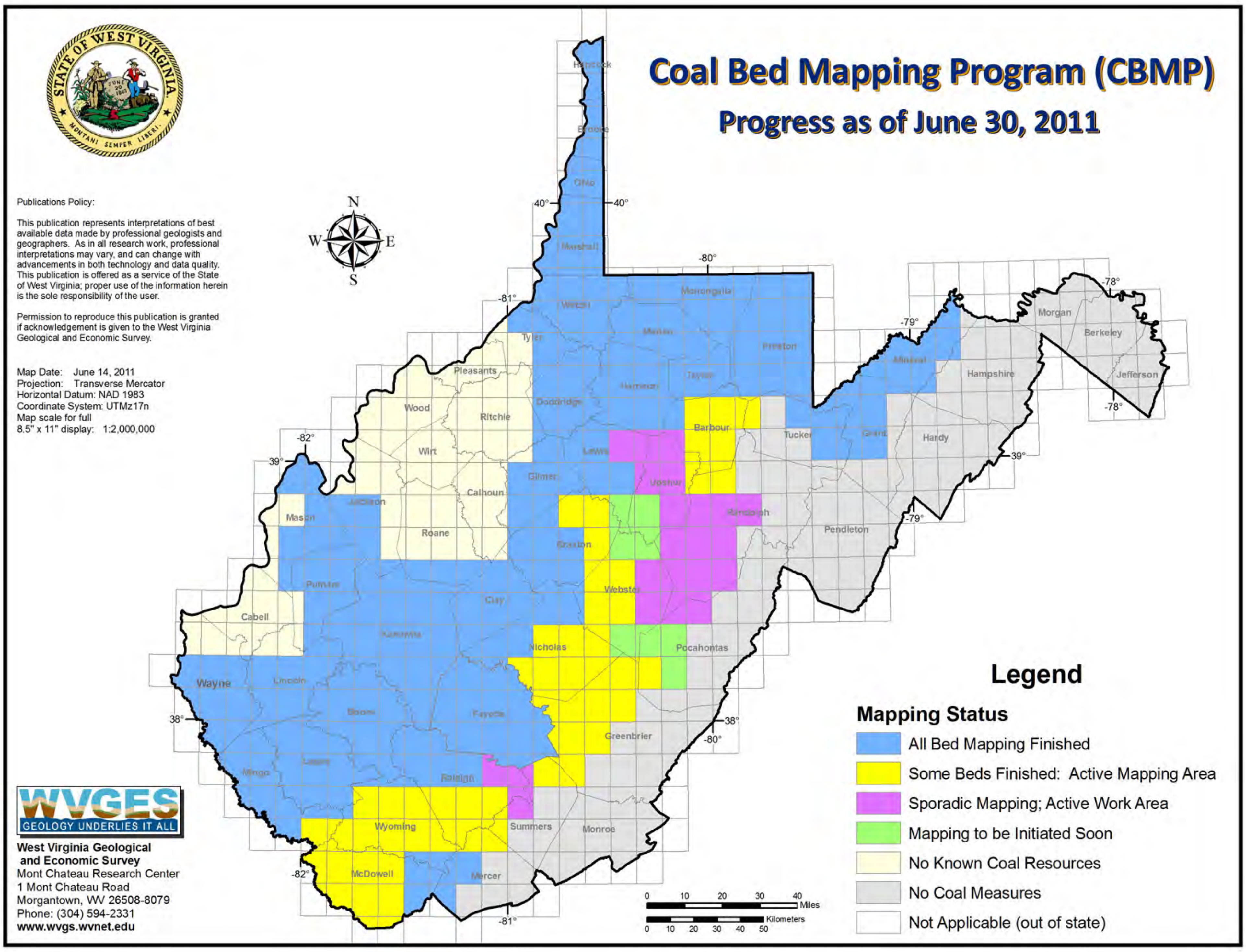


Figure 1. **Status of coal bed mapping by the WVGES CBMP as of June 30, 2011 (B.M. Blake, unpub. data, 2011)**

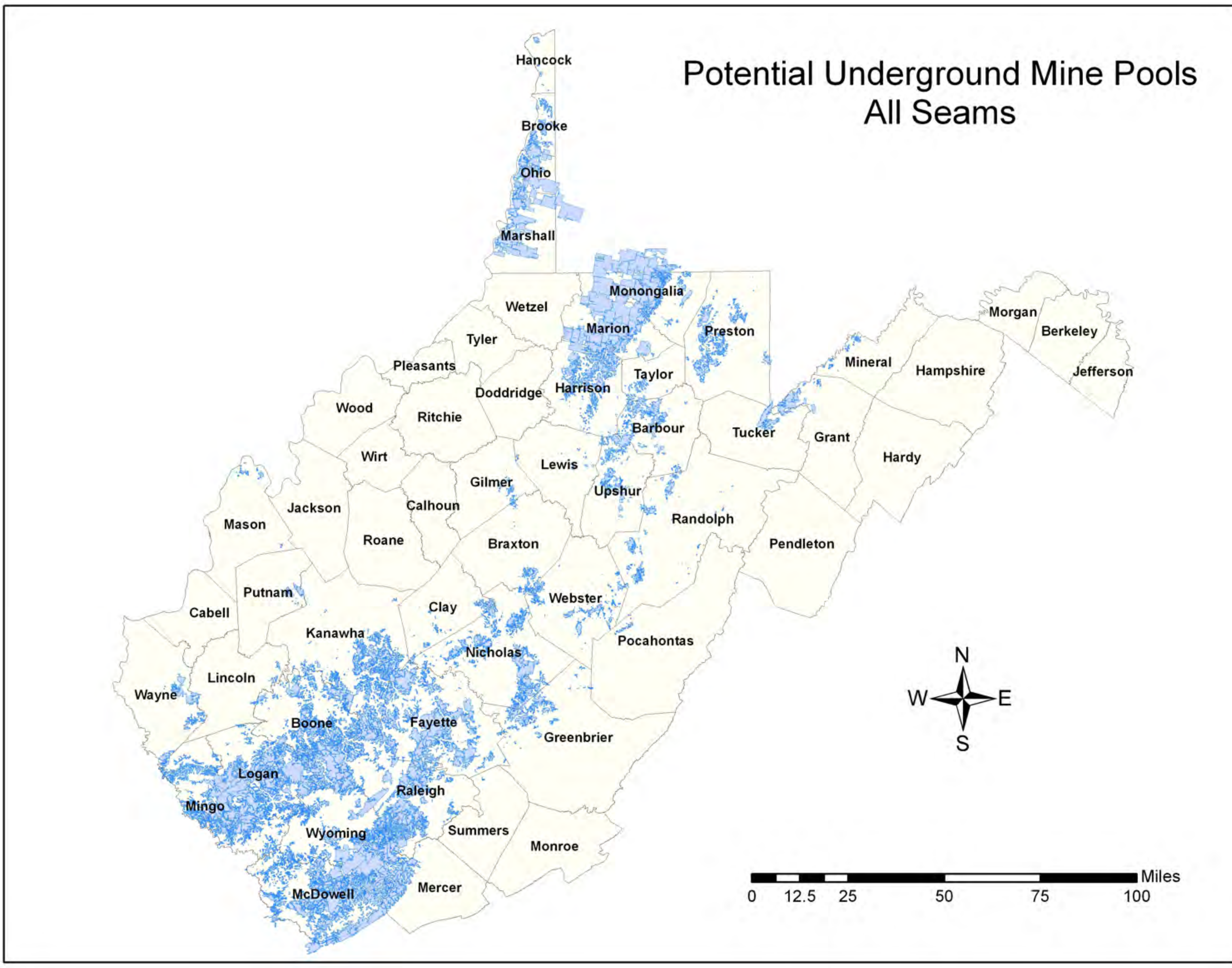


Figure 2. Footprints of all documented underground mines in West Virginia coal seams delineate areas of potential mine pools (WVGES, 2010).

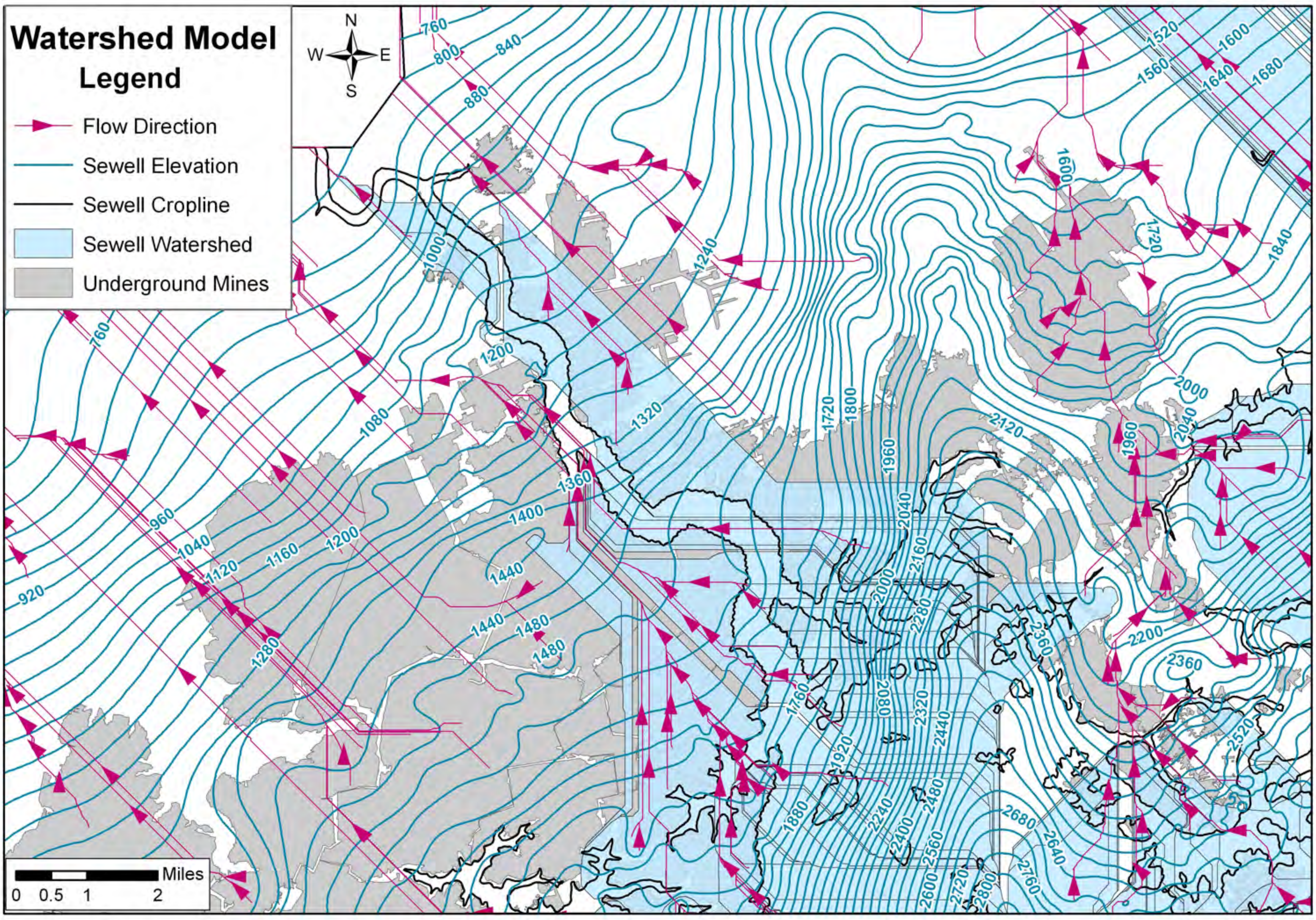


Figure 3. Watershed model output shows predicted direction of groundwater flow through mine voids in the Sewell coal bed on the Fayetteville 7.5-minute topographic quadrangle and surrounding area. The blue watershed area represents water flow from mines contributing to surface water flow. Red arrows show flow direction. This model was run for all coal beds having available input data to aid in determining extent of potential flooding in underground mines.

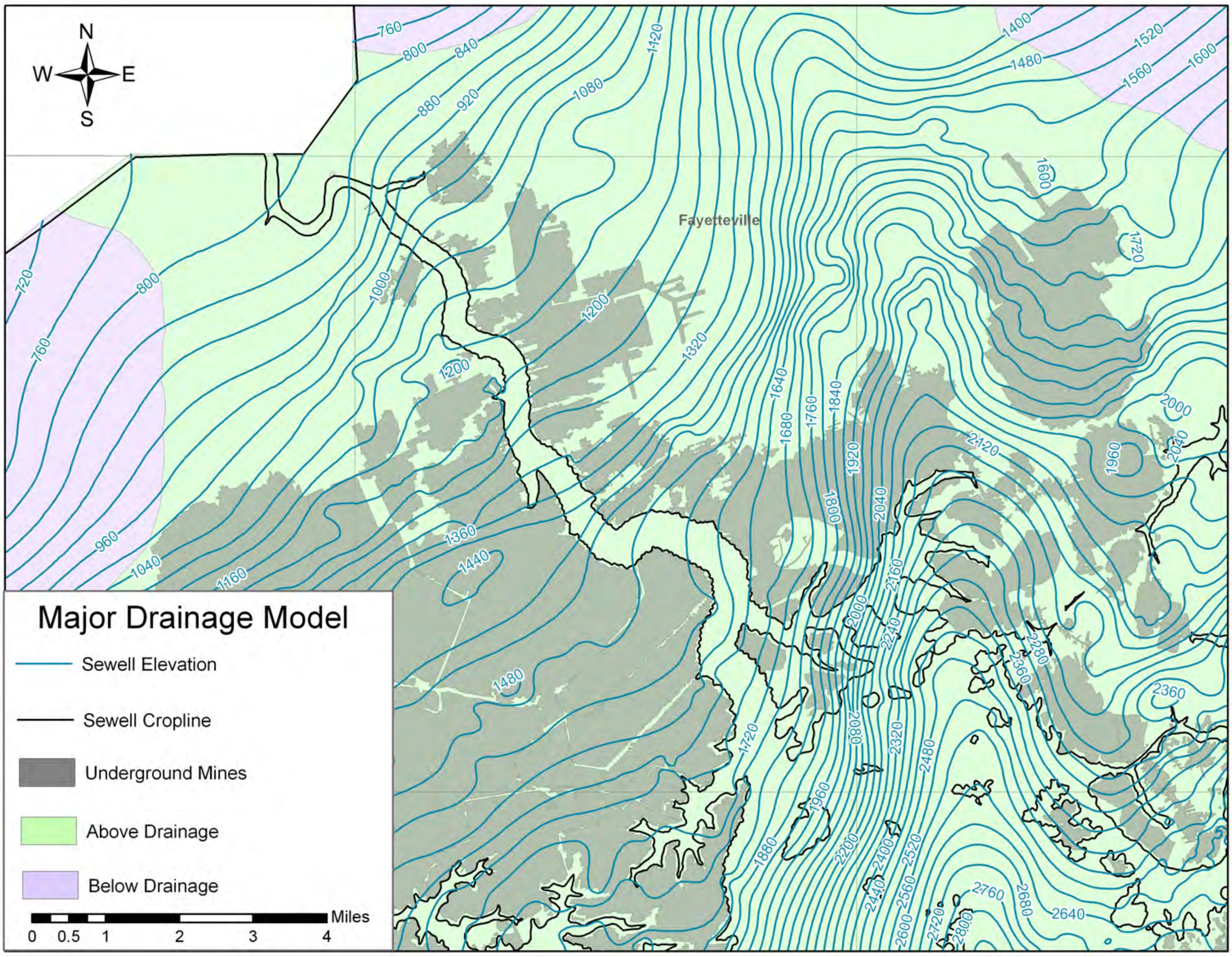


Figure 4. Major Drainage–Mining Above/Below Drainage (MABD) model output shows areas of the Sewell coal bed that lie above and below major drainage on the Fayetteville 7.5-minute topographic quadrangle and surrounding area. This model, which was developed to determine mine position with respect to drainage based on perennial stream elevations, generated a Major Drainage Elevation Model (MDEM) by assigning USGS 7.5-minute quadrangle elevations to points selected from the National Hydrography Dataset (NHD) that are located within digitized perennial stream polygons.

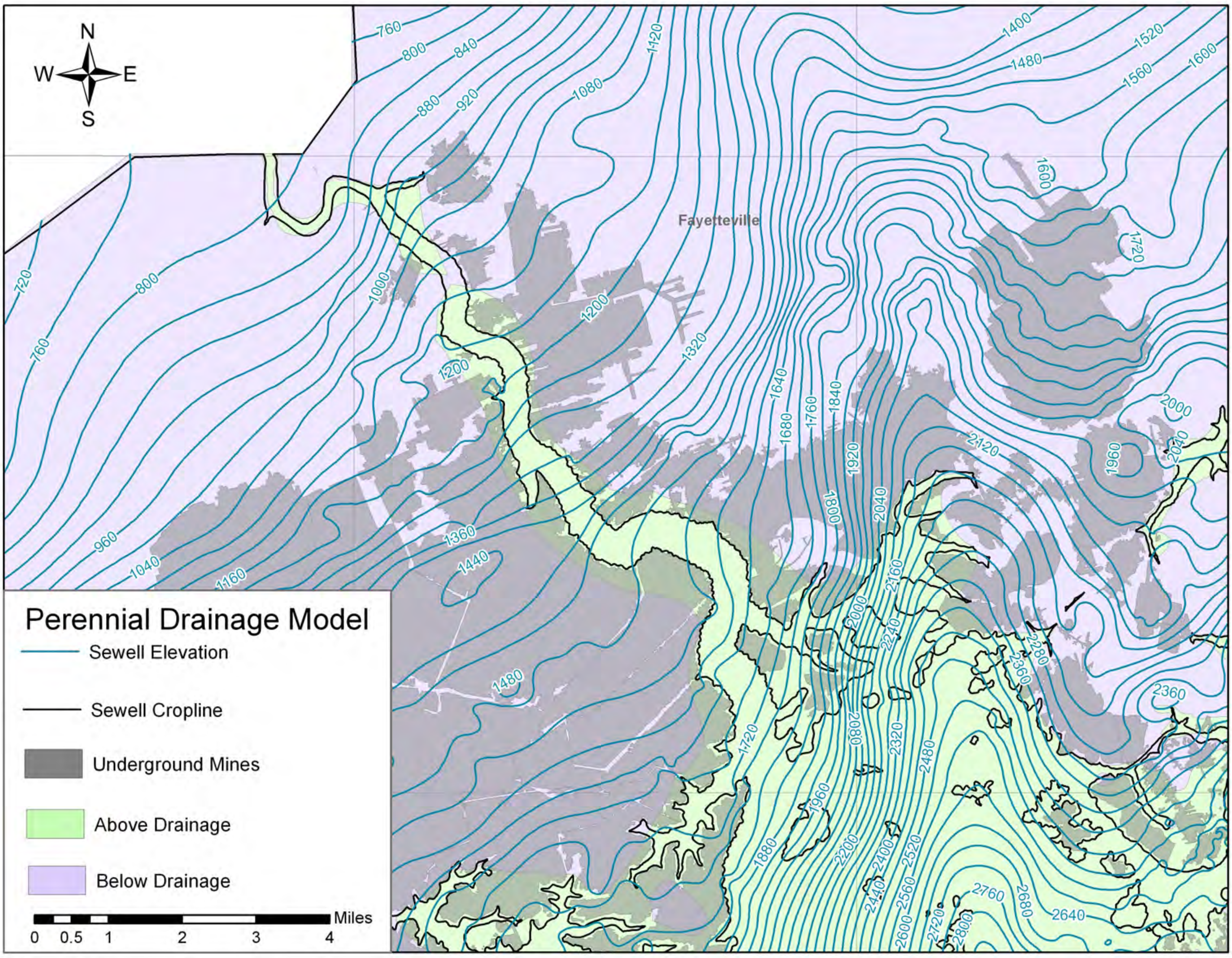


Figure 5. Perennial Drainage –Mining Above/Below Drainage model output shows areas of the Sewell coal bed that lie above and below perennial drainage on the Fayetteville 7.5-minute topographic quadrangle and surrounding area. This model, which was developed to determine mine position with respect to drainage based on perennial stream elevations, generated a Perennial Drainage Elevation Model (PDEM) by assigning USGS 7.5-minute quadrangle elevations to points selected from the National Hydrography Dataset (NHD) that are located along digitized perennial stream lines.

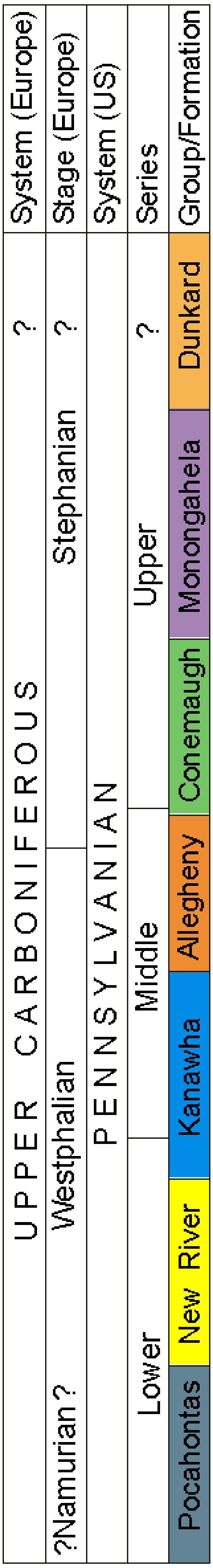


Figure 6a

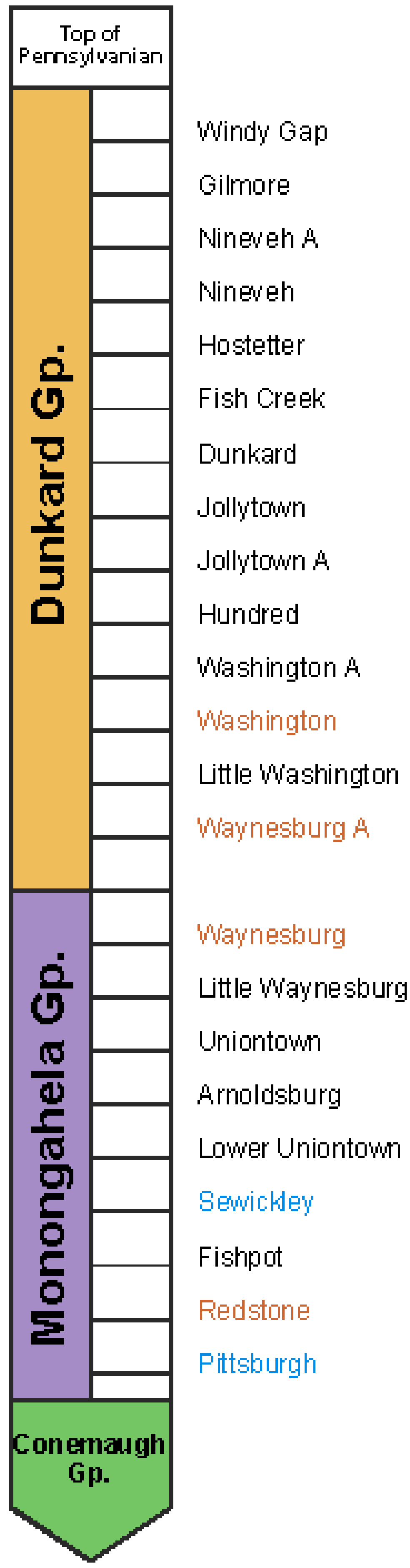


Figure 6b

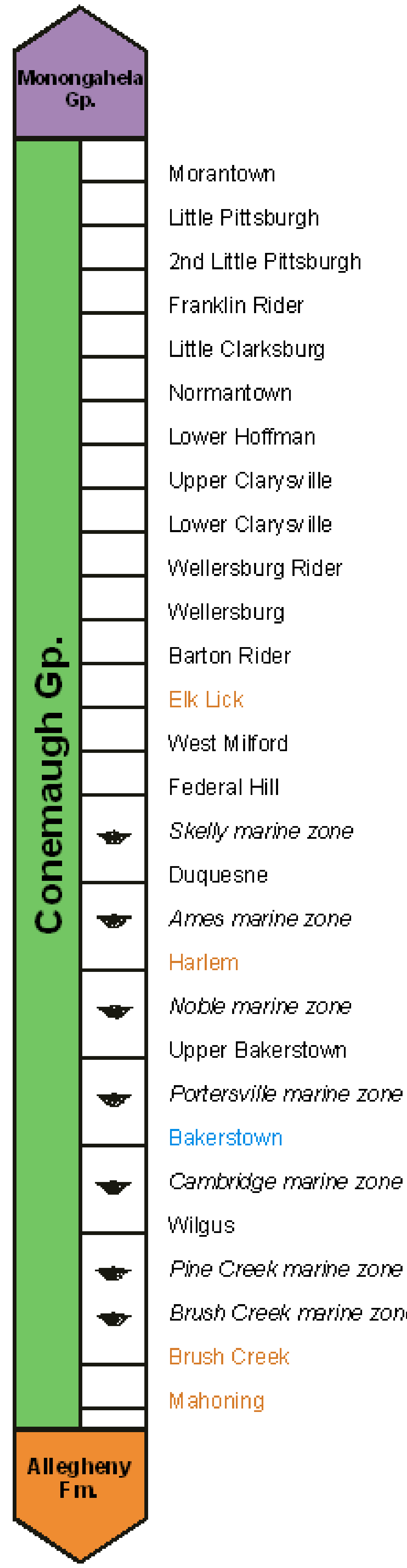


Figure 6c

Figure 6. Stratigraphic chart and columns of the Pennsylvania coal-bearing strata in West Virginia: (a) stratigraphic chart shows age and stratigraphic position of groups/formations; (b) stratigraphic column of the Dunkard and Monongahela Groups; (c) stratigraphic column of the Conemaugh Group; (d) stratigraphic column of the Allegheny Formation; (e) stratigraphic column of the Kanawha Formation; and (f) stratigraphic column of the New River and Pocahontas Formations. The names of the 19 major seams identified in this report, mineable coal beds, and named unmined coal beds are shown in blue, orange, and black, respectively.

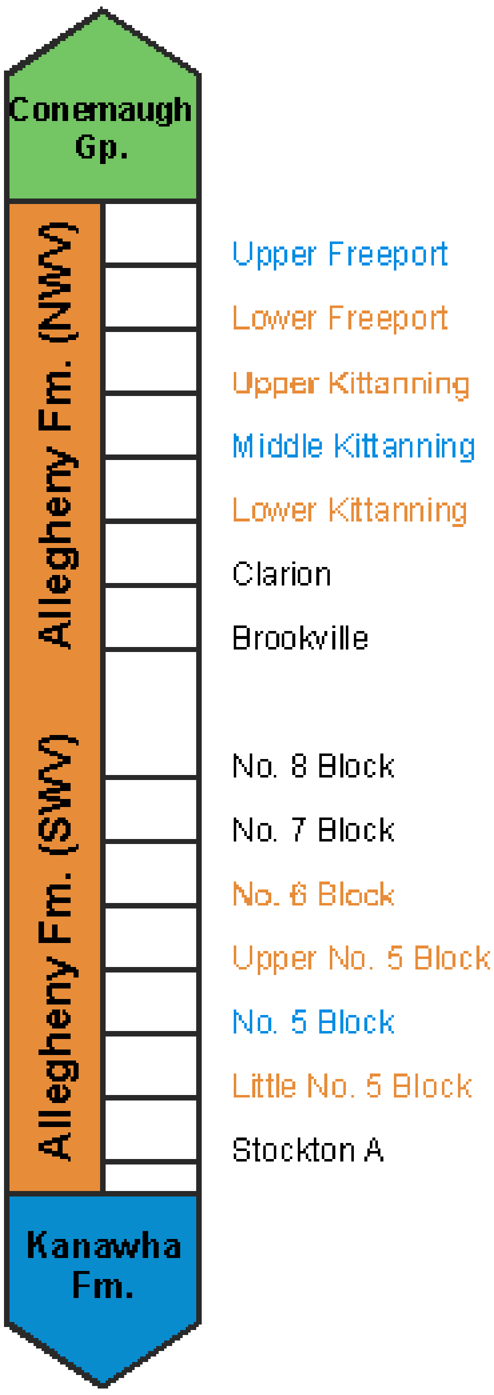


Figure 6d

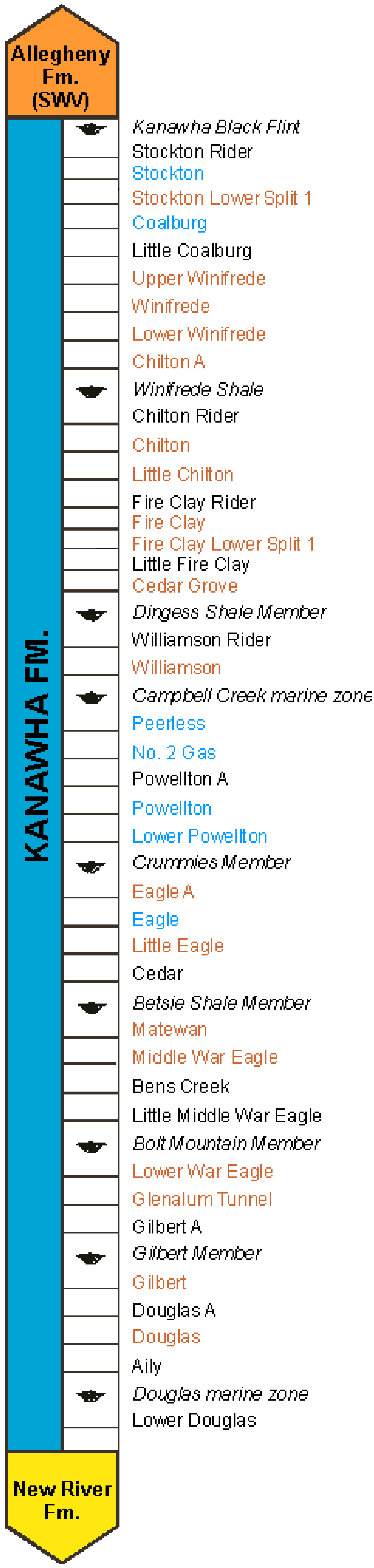


Figure 6e

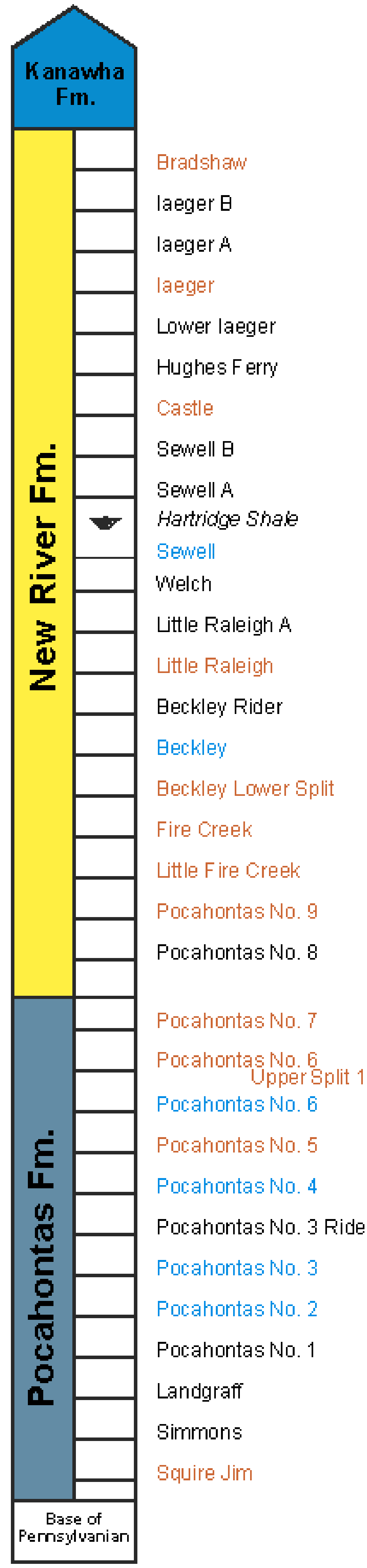


Figure 6f

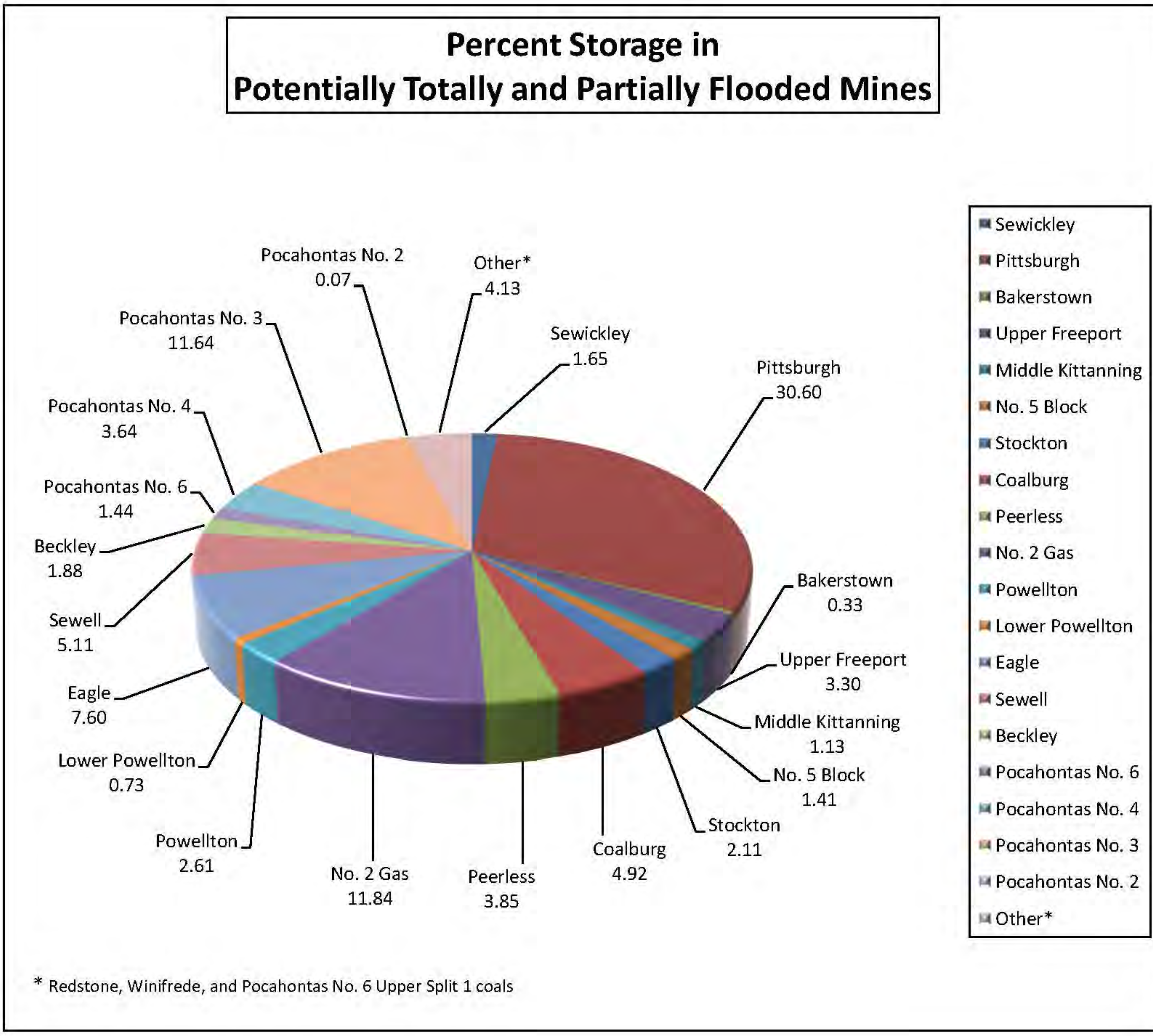

Percent Storage in
Potentially Totally and Partially Flooded Mines
Pocahontas No. 2
0.07
Other*
4.13
Pocahontas No. 3
11.64
Sewickley
1.65
Pittsburgh
30.60
Pocahontas No. 4
3.64
Pocahontas No. 6
1.44
Beckley
1.88
Sewell
5.11
Bakerstown
0.33
Upper Freeport
3.30
Eagle
7.60
Middle Kittanning
1.13
Lower Powellton
0.73
No. 5 Block
1.41
Stockton
2.11
Powellton
2.61
No. 2 Gas
11.84
Peerless
3.85
Coalburg
4.92
Sewickley
Pittsburgh
Bakerstown
Upper Freeport
Middle Kittanning
No. 5 Block
Stockton
Coalburg
Peerless
No. 2 Gas
Powellton
Lower Powellton
Eagle
Sewell
Beckley
Pocahontas No. 6
Pocahontas No. 4
Pocahontas No. 3
Pocahontas No. 2
Other*
* Redstone, Winifrede, and Pocahontas No. 6 Upper Split 1 coals

Figure 7a

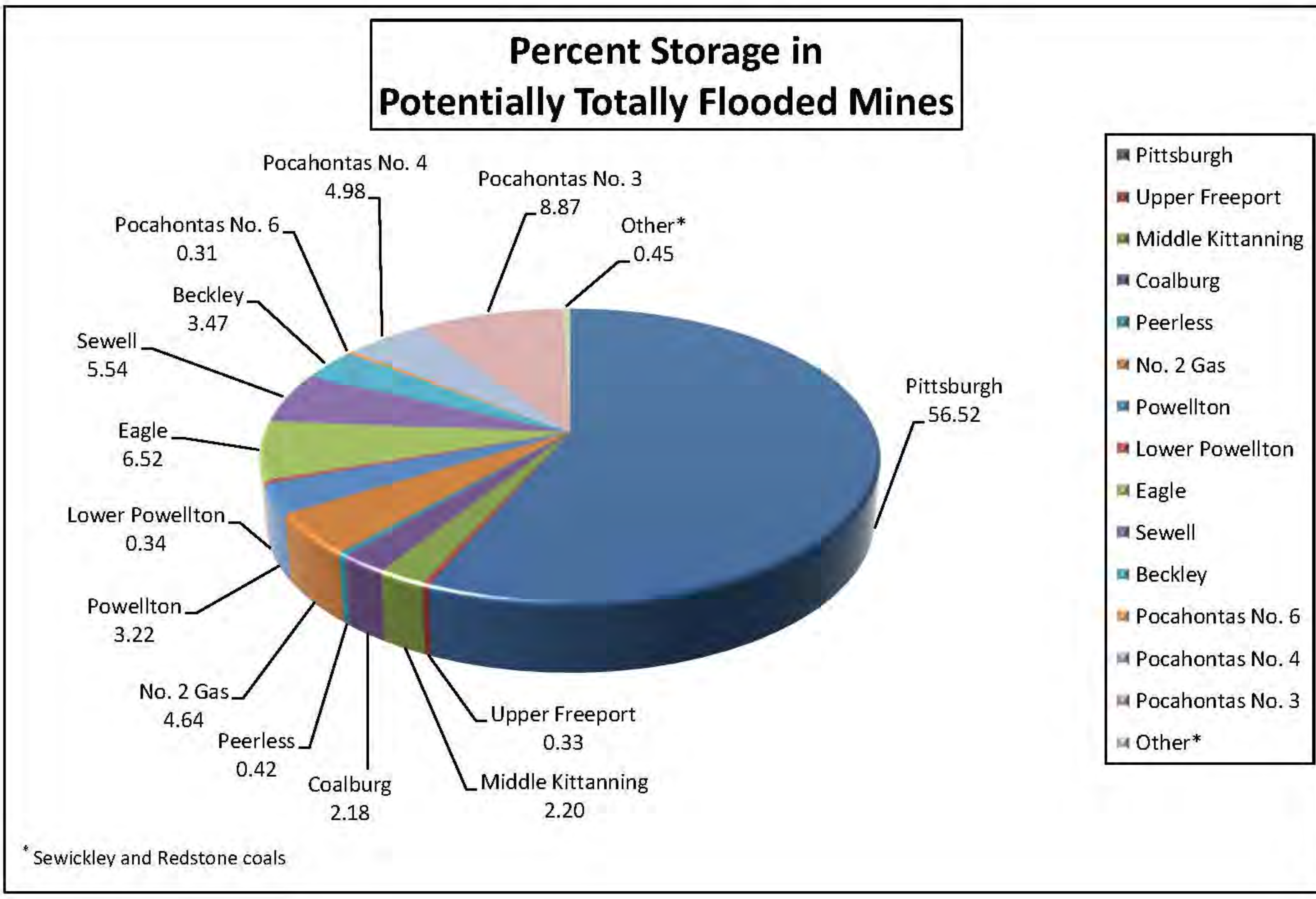
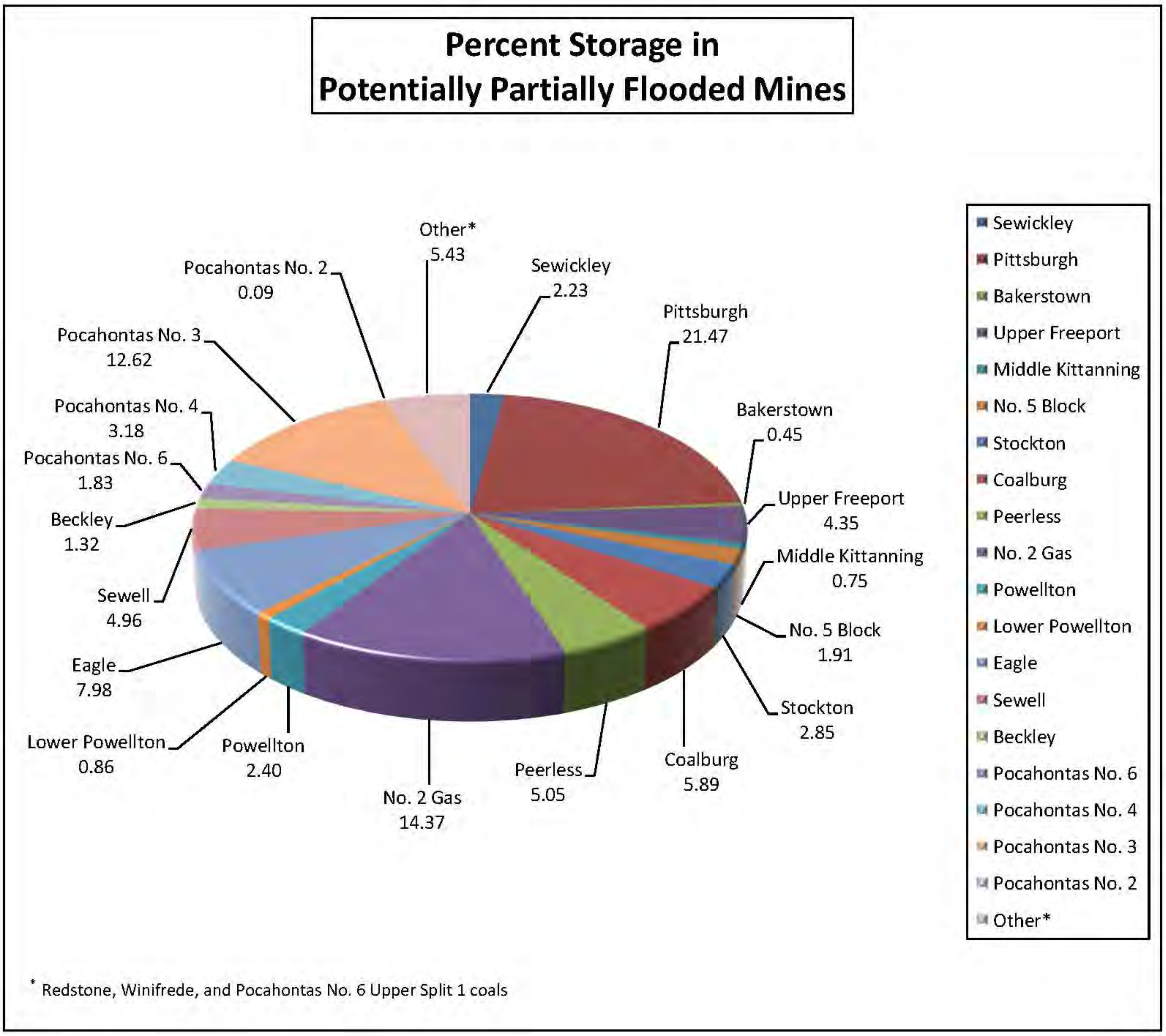
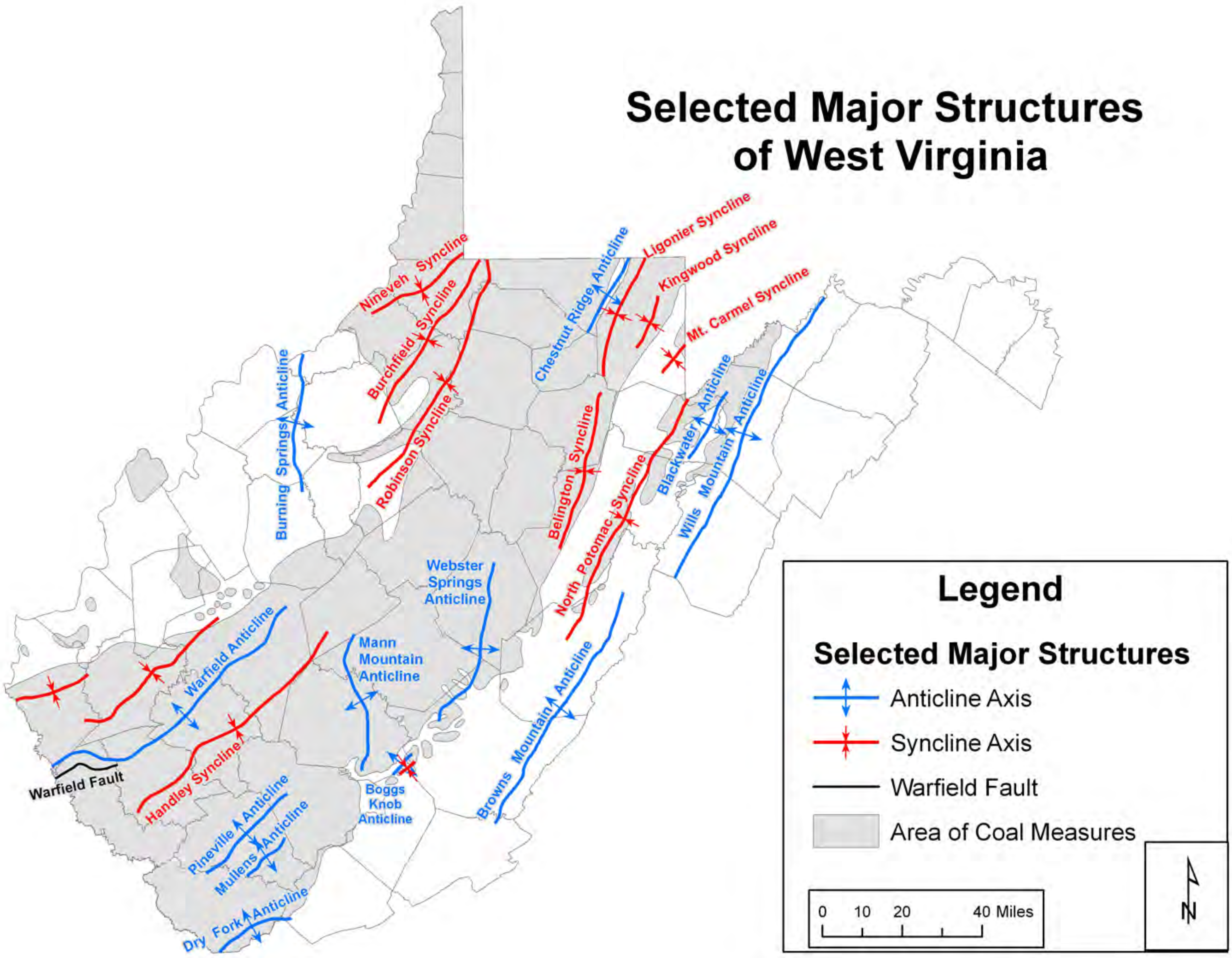

Percent Storage in
Potentially Totally Flooded Mines
Pocahontas No. 4
4.98
Pocahontas No. 3
8.87
Other*
0.45
Pocahontas No. 6
0.31
Beckley
3.47
Sewell
5.54
Eagle
6.52
Lower Powellton
0.34
Powellton
3.22
No. 2 Gas
4.64
Peerless
0.42
Coalburg
2.18
Middle Kittanning
2.20
Upper Freeport
0.33
Pittsburgh
56.52
Pittsburgh
Upper Freeport
Middle Kittanning
Coalburg
Peerless
No. 2 Gas
Powellton
Lower Powellton
Eagle
Sewell
Beckley
Pocahontas No. 6
Pocahontas No. 4
Pocahontas No. 3
Other*
* Sewickley and Redstone coals

Figure 7b



Percent Storage in Potentially Partially Flooded Mines
Other* 5.43
Sewickley 2.23
Pittsburgh 21.47
Bakerstown 0.45
Upper Freeport 4.35
Middle Kittanning 0.75
No. 5 Block 1.91
Stockton 2.85
Coalburg 5.89
Peerless 5.05
No. 2 Gas 14.37
Powellton 2.40
Lower Powellton 0.86
Eagle 7.98
Sewell 4.96
Beckley 1.32
Pocahontas No. 6 1.83
Pocahontas No. 4 3.18
Pocahontas No. 3 12.62
Pocahontas No. 2 0.09
Sewickley
Pittsburgh
Bakerstown
Upper Freeport
Middle Kittanning
No. 5 Block
Stockton
Coalburg
Peerless
No. 2 Gas
Powellton
Lower Powellton
Eagle
Sewell
Beckley
Pocahontas No. 6
Pocahontas No. 4
Pocahontas No. 3
Pocahontas No. 2
Other*
* Redstone, Winifrede, and Pocahontas No. 6 Upper Split 1 coals

Figure 7c



Selected Major Structures of West Virginia
Nineveh Syncline
Burchfield Syncline
Robinson Syncline
Burning Springs Anticline
Chestnut Ridge Anticline
Ligonier Syncline
Kingwood Syncline
Mt. Carmel Syncline
Belington Syncline
North Potomac Syncline
Blackwater Anticline
Wills Mountain Anticline
Webster Springs Anticline
Mann Mountain Anticline
Warfield Anticline
Warfield Fault
Handley Syncline
Boggs Knob Anticline
Browns Mountain Anticline
Pineville Anticline
Mullens Anticline
Dry Fork Anticline
Legend
Selected Major Structures
Anticline Axis
Syncline Axis
Warfield Fault
Area of Coal Measures
0 10 20 40 Miles
N

Figure 8

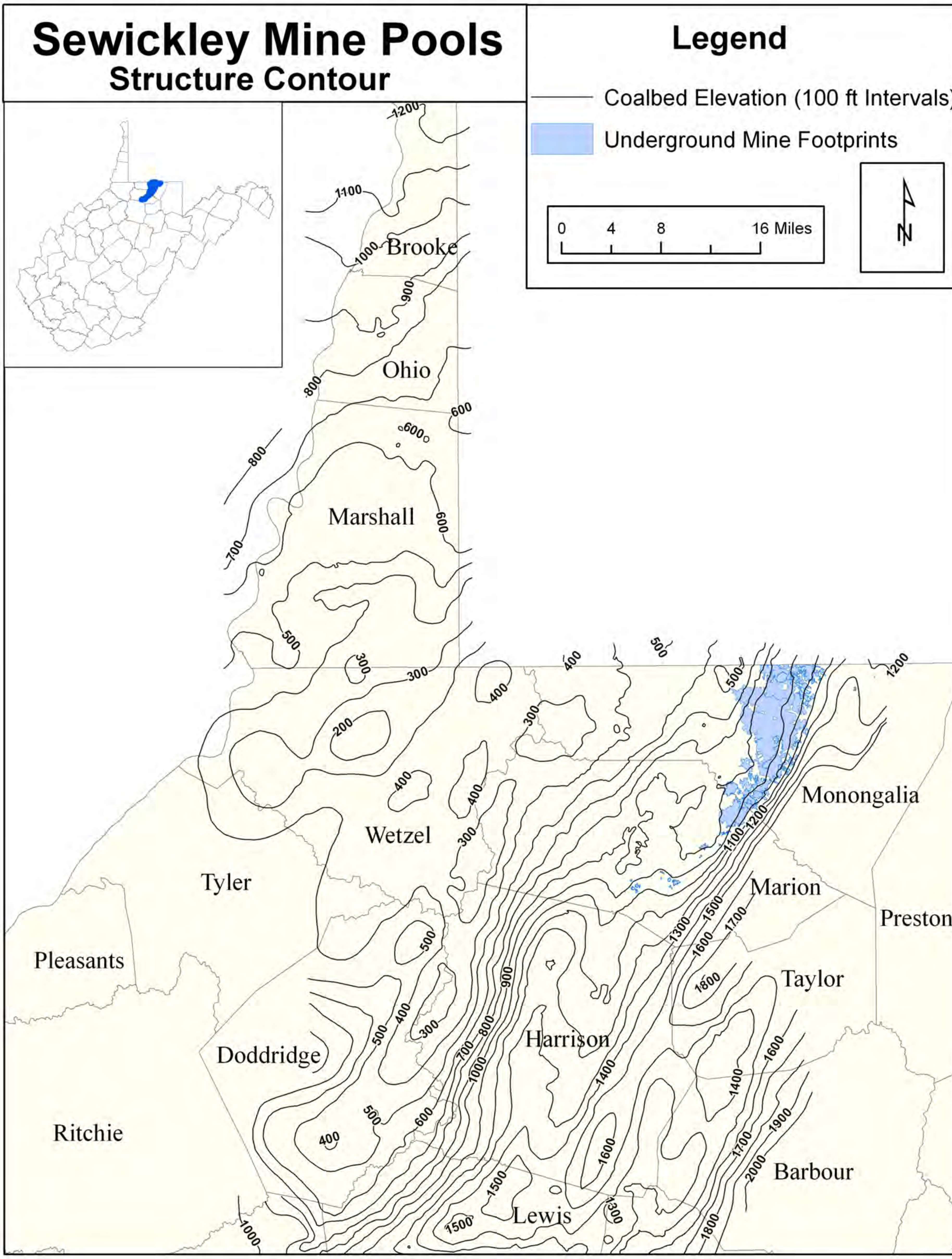

Sewickley Mine Pools
Structure Contour
Legend
Coalbed Elevation (100 ft Intervals)
Underground Mine Footprints
0 4 8 16 Miles
N
Brooke
Ohio
Marshall
Wetzel
Tyler
Pleasants
Doddridge
Ritchie
Harrison
Lewis
Monongalia
Marion
Preston
Taylor
Barbour

Figure 9a

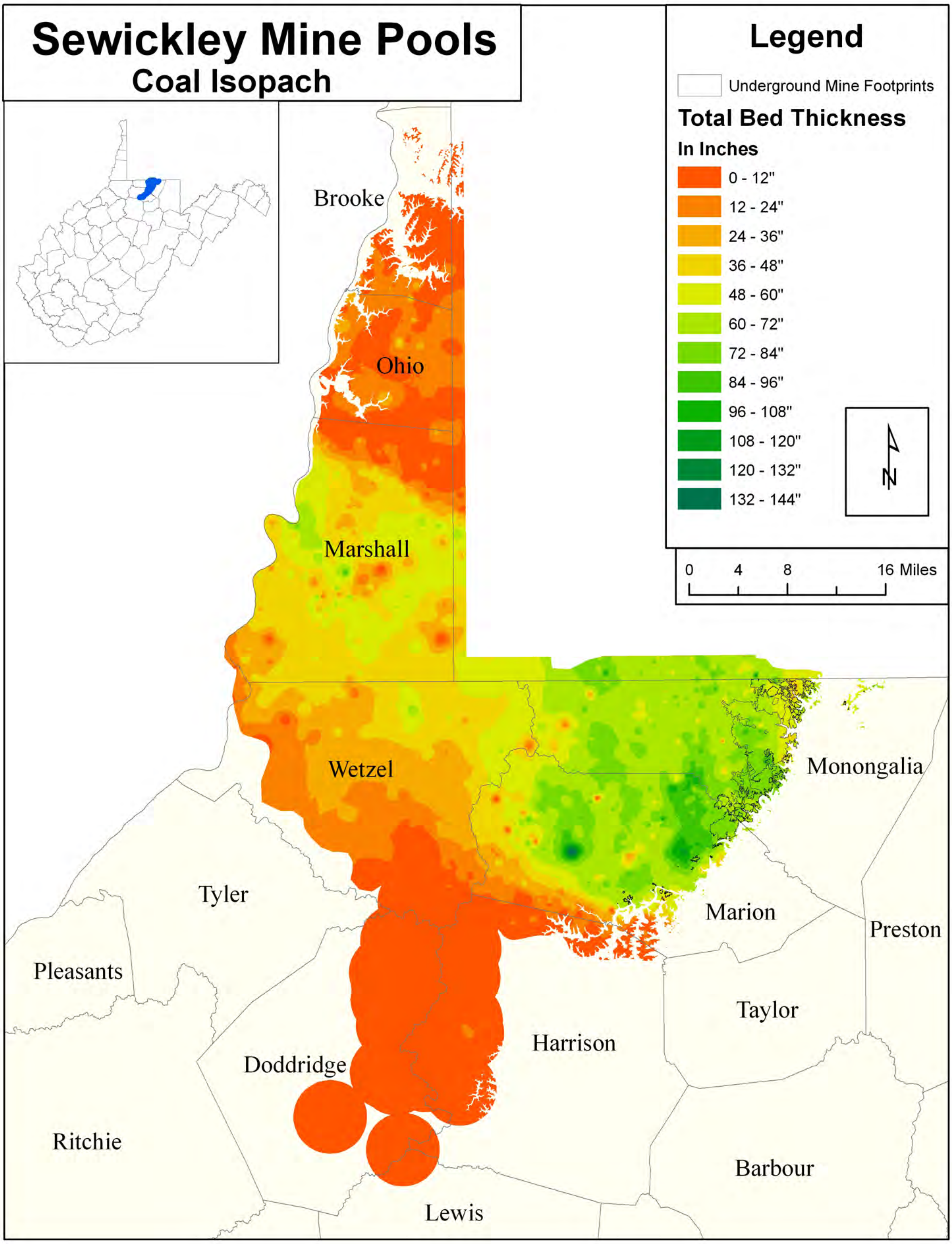
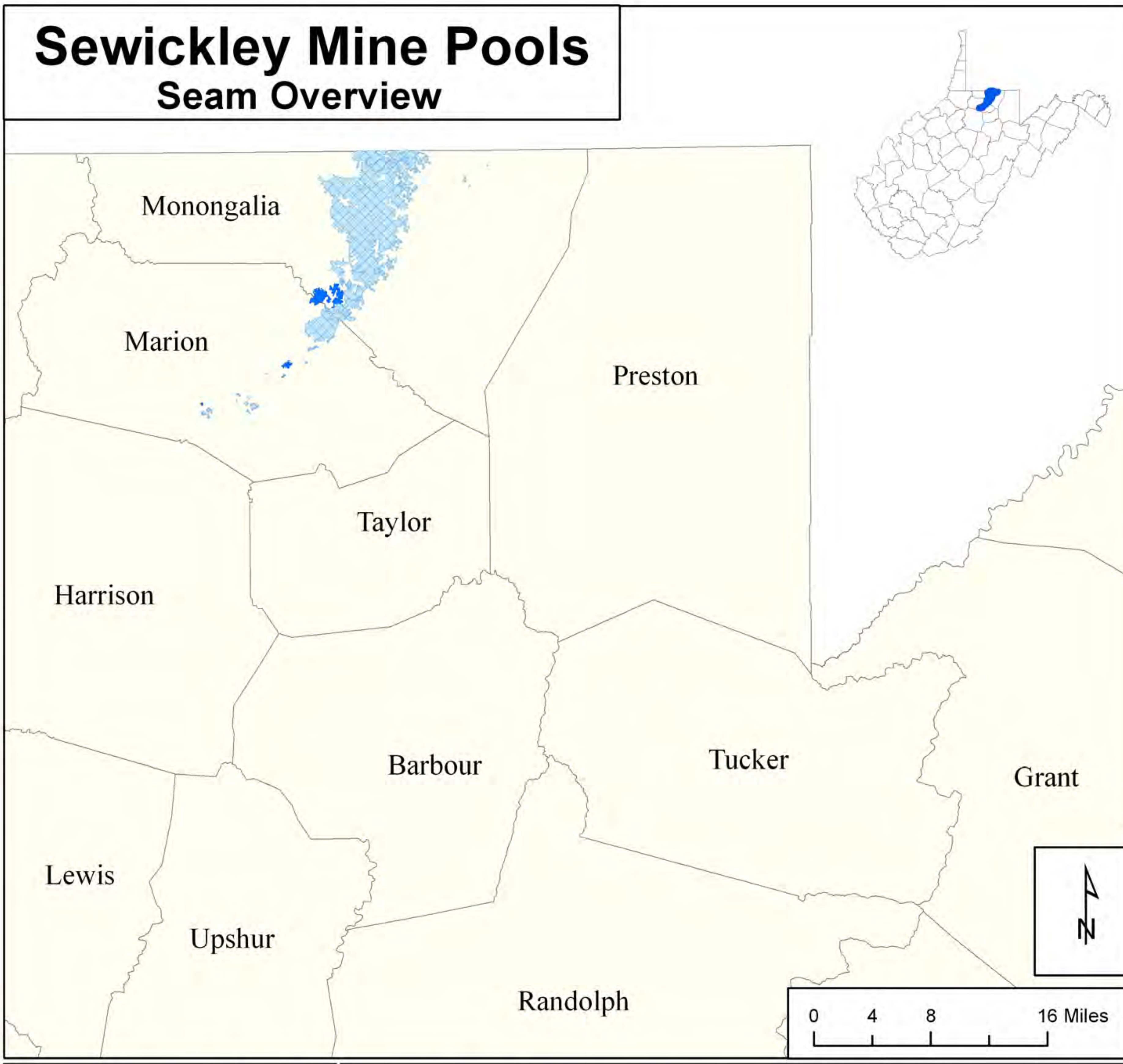

Sewickley Mine Pools
Coal Isopach
Legend
Underground Mine Footprints
Total Bed Thickness
In Inches
0 - 12"
12 - 24"
24 - 36"
36 - 48"
48 - 60"
60 - 72"
72 - 84"
84 - 96"
96 - 108"
108 - 120"
120 - 132"
132 - 144"
N
0
4
8
16 Miles
Brooke
Ohio
Marshall
Wetzel
Monongalia
Tyler
Marion
Preston
Pleasants
Taylor
Harrison
Doddridge
Ritchie
Barbour
Lewis

Figure 9b

Sewickley Mine Pools
Seam Overview



Legend

Position

- Above drainage
- Near drainage
- Below drainage

Potential Extent of Flooding

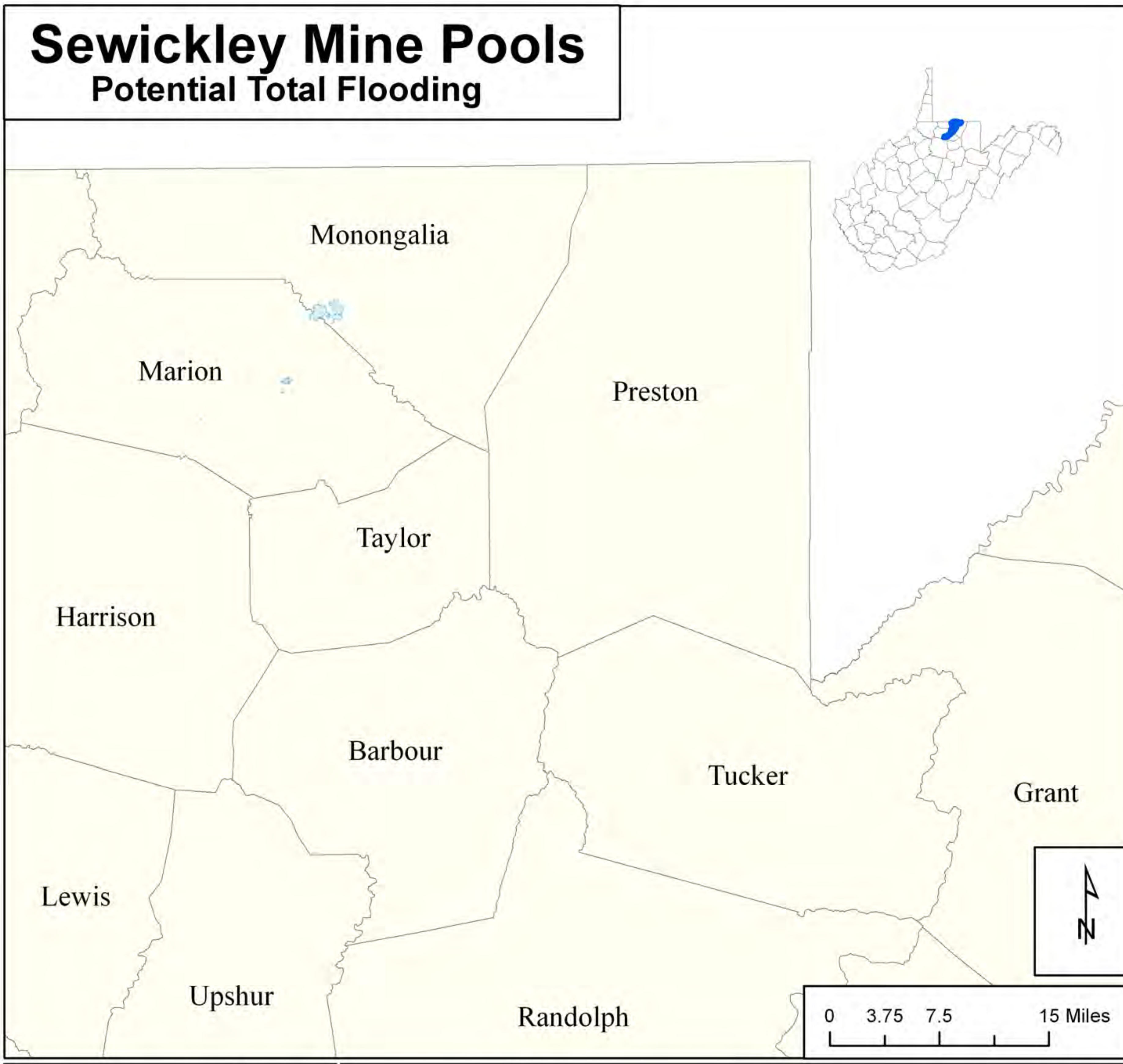
- Undetermined
- Flooded areas unlikely
- Partially flooded
- Totally flooded

Sewickley Mine Pool Statistics

	Undetermined	Potentially flooded areas unlikely	Potentially partially flooded	Potentially totally flooded
No. of Mines	0	5	61	10
Mean coal bed thickness (feet)	0.00	5.08	5.03	5.73
Min. footprint area (acres)	0.00	0.15	0.03	0.01
Max. footprint area (acres)	0.00	5.47	12,846.57	494.35
Mean footprint area (acres)	0.00	2.31	405.83	109.84
Median footprint area (acres)	0.00	0.87	18.05	9.40
Total footprint area (acres)	0.00	11.56	24,755.47	1,098.45
Estimated void volume (acre feet)	0.00	28.69	69,988.21	3,223.36
Max. potential storage (million gallons)	0.00	9.35	22,809.16	1,050.49

Figure 9c

Sewickley Mine Pools
Potential Total Flooding



Legend

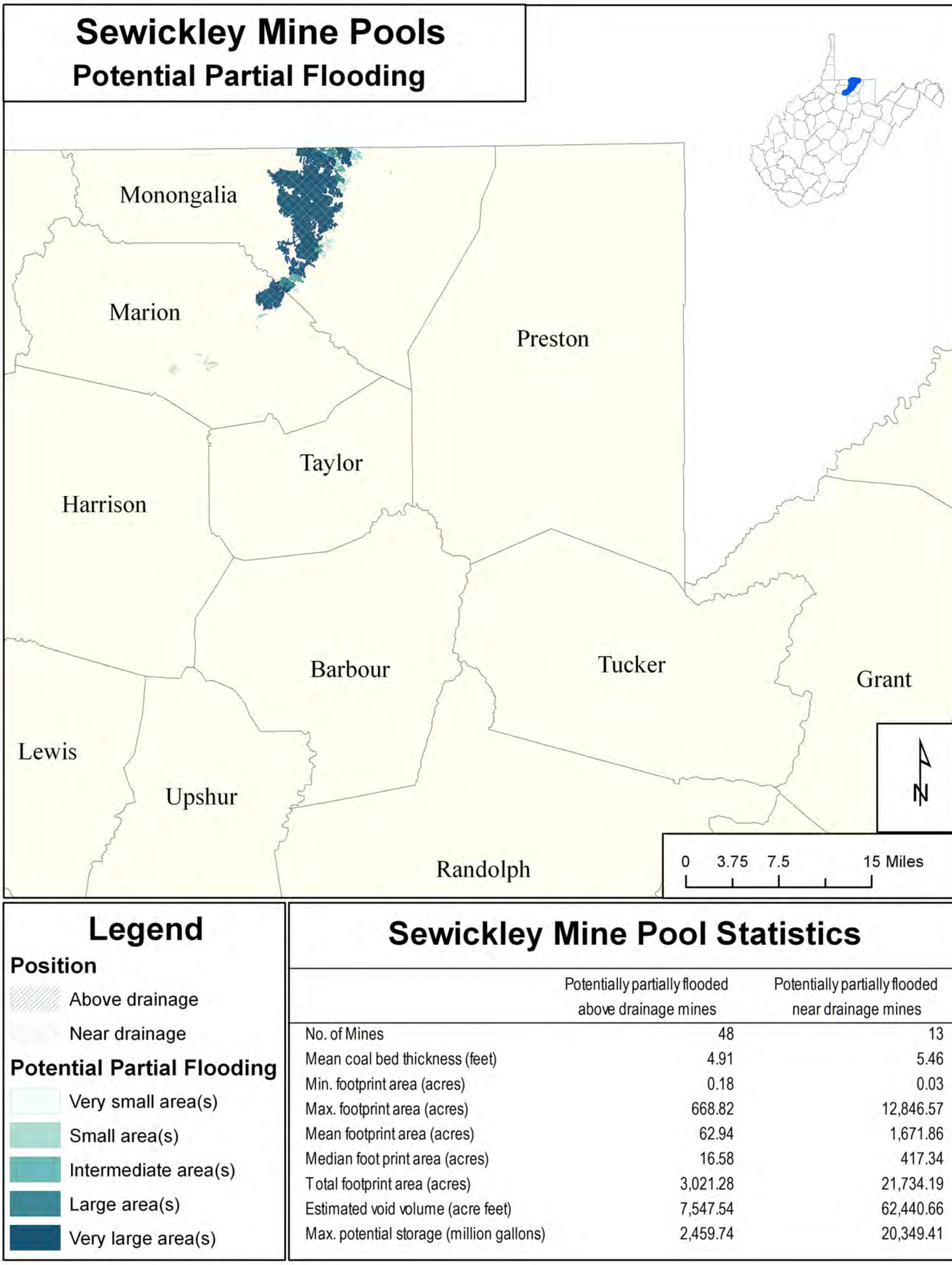
Position
- Above drainage
- Near drainage
- Below drainage

Storage in Million Gallons
- 0.000 - 5,000
- 5,001 - 10,000
- 10,001 - 15,000
- 15,001 - 20,000
- 20,001 - 25,000
- 25,001 - 30,000

Sewickley Mine Pool Statistics

	Potentially totally flooded above drainage mines	Potentially totally flooded near drainage mines	Potentially totally flooded below drainage mines
No. of Mines	0	0	10
Mean coal bed thickness (feet)	0.00	0.00	5.73
Min. foot print area (acres)	0.00	0.00	0.01
Max. foot print area (acres)	0.00	0.00	494.35
Mean foot print area (acres)	0.00	0.00	109.84
Median foot print area (acres)	0.00	0.00	9.40
Total foot print area (acres)	0.00	0.00	1,098.45
Estimated void volume (acre feet)	0.00	0.00	3,223.36
Max. potential storage (million gallons)	0.00	0.00	1,050.49

Figure 9d



Sewickley Mine Pool Statistics

	Potentially partially flooded above drainage mines	Potentially partially flooded near drainage mines
No. of Mines	48	13
Mean coal bed thickness (feet)	4.91	5.46
Min. footprint area (acres)	0.18	0.03
Max. footprint area (acres)	668.82	12,846.57
Mean footprint area (acres)	62.94	1,671.86
Median foot print area (acres)	16.58	417.34
Total footprint area (acres)	3,021.28	21,734.19
Estimated void volume (acre feet)	7,547.54	62,440.66
Max. potential storage (million gallons)	2,459.74	20,349.41

Figure 9e

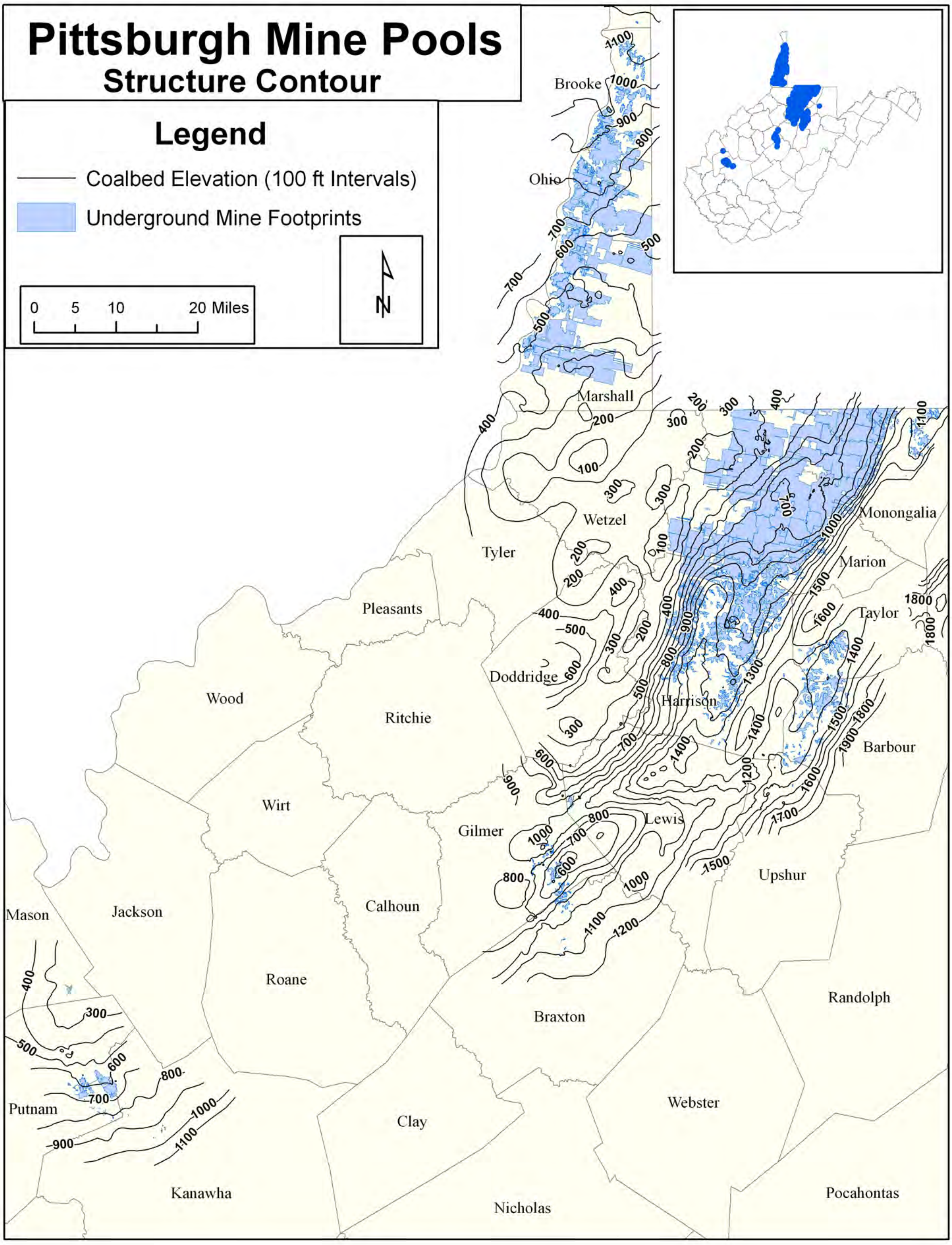

Pittsburgh Mine Pools
Structure Contour
Legend
Coalbed Elevation (100 ft Intervals)
Underground Mine Footprints
0 5 10 20 Miles
N
Brooke
Ohio
Marshall
Wetzel
Tyler
Monongalia
Marion
Taylor
Pleasants
Doddridge
Harrison
Barbour
Wood
Ritchie
Wirt
Gilmer
Lewis
Upshur
Mason
Jackson
Calhoun
Roane
Randolph
Braxton
Putnam
Webster
Clay
Kanawha
Nicholas
Pocahontas

Figure 10a

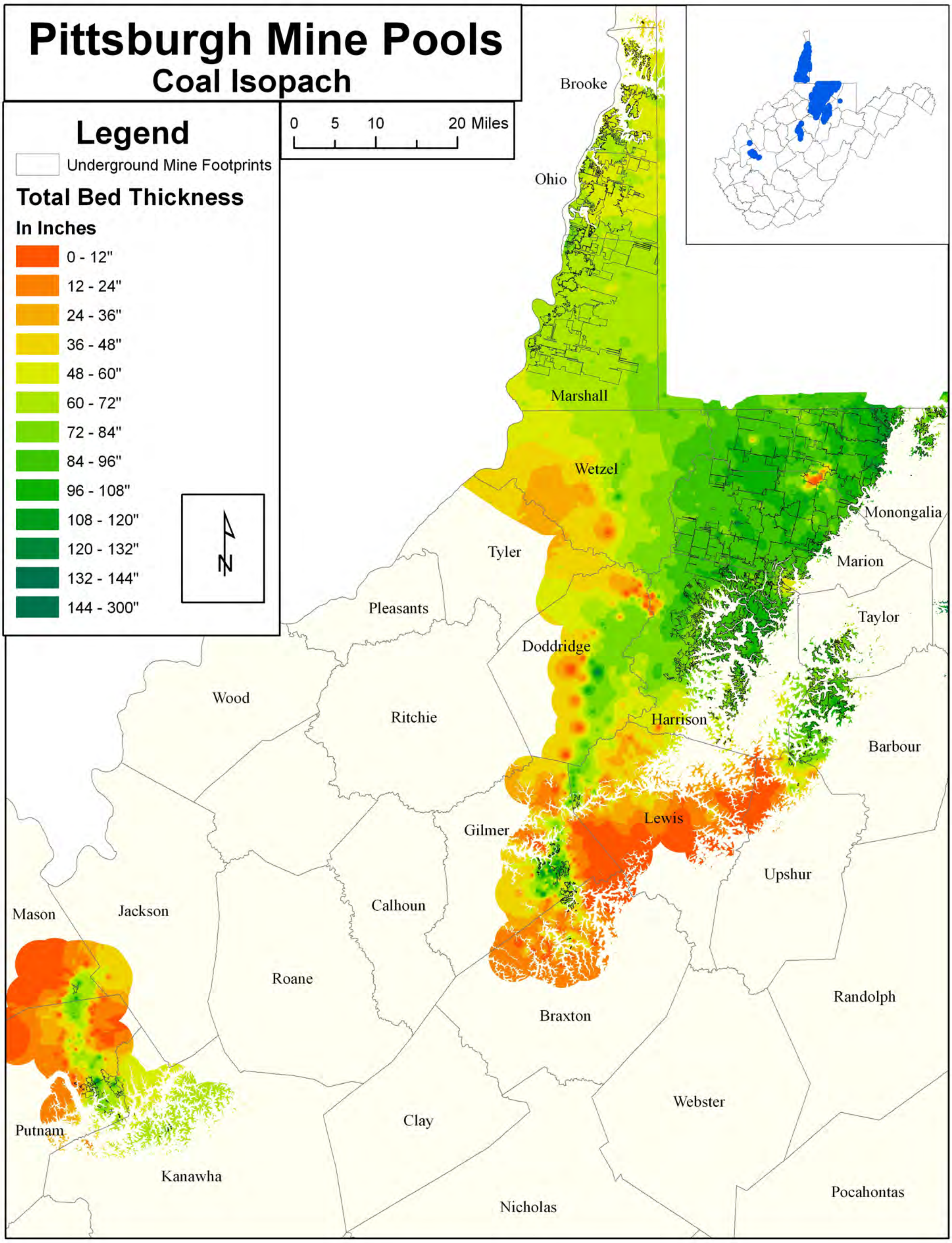
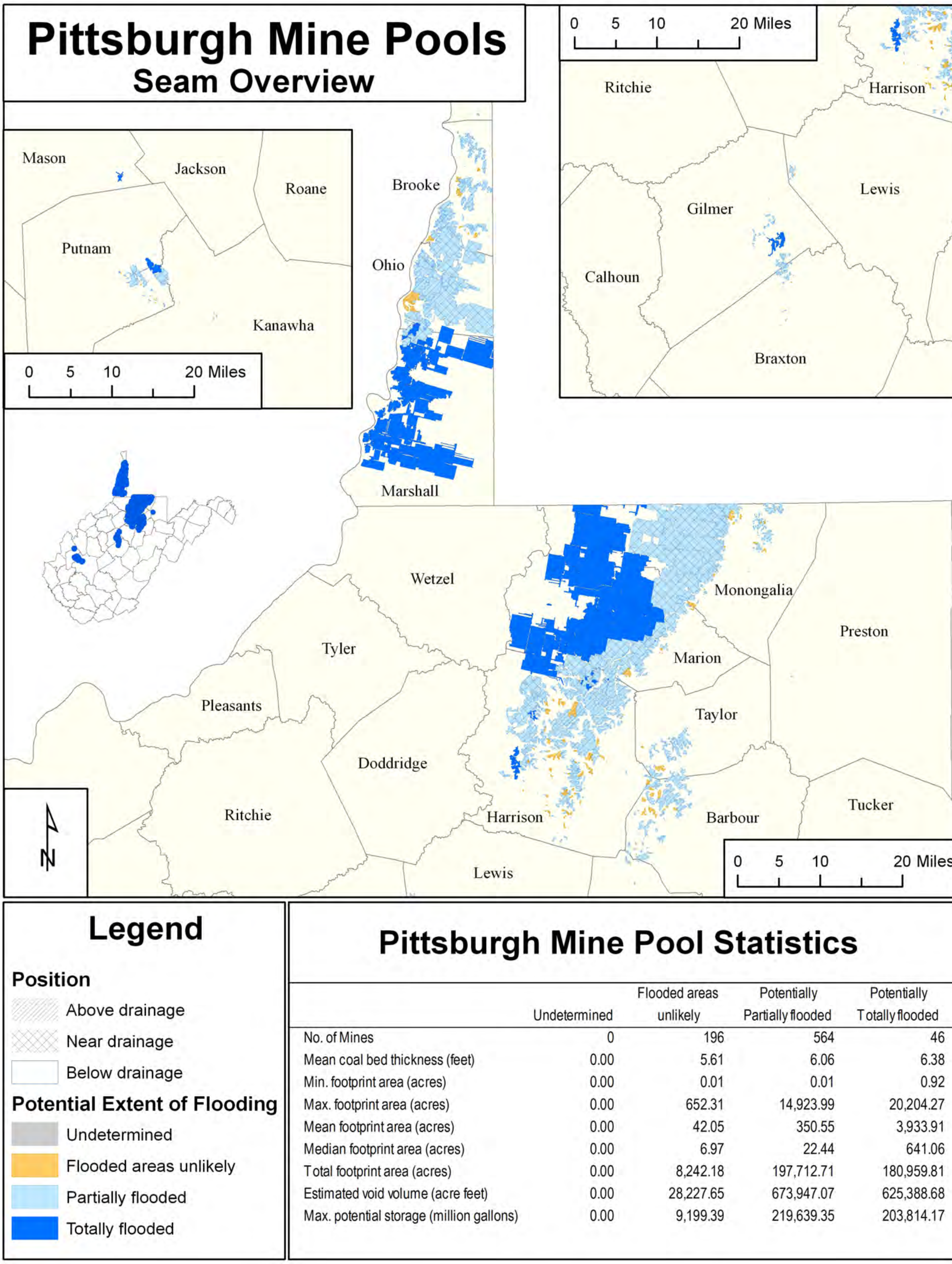

Pittsburgh Mine Pools
Coal Isopach
Legend
Underground Mine Footprints
Total Bed Thickness
In Inches
0 - 12"
12 - 24"
24 - 36"
36 - 48"
48 - 60"
60 - 72"
72 - 84"
84 - 96"
96 - 108"
108 - 120"
120 - 132"
132 - 144"
144 - 300"
0 5 10 20 Miles
N
Brooke
Ohio
Marshall
Wetzel
Monongalia
Marion
Tyler
Pleasants
Taylor
Doddridge
Wood
Ritchie
Harrison
Barbour
Gilmer
Lewis
Upshur
Mason
Jackson
Calhoun
Roane
Randolph
Braxton
Putnam
Clay
Webster
Kanawha
Nicholas
Pocahontas

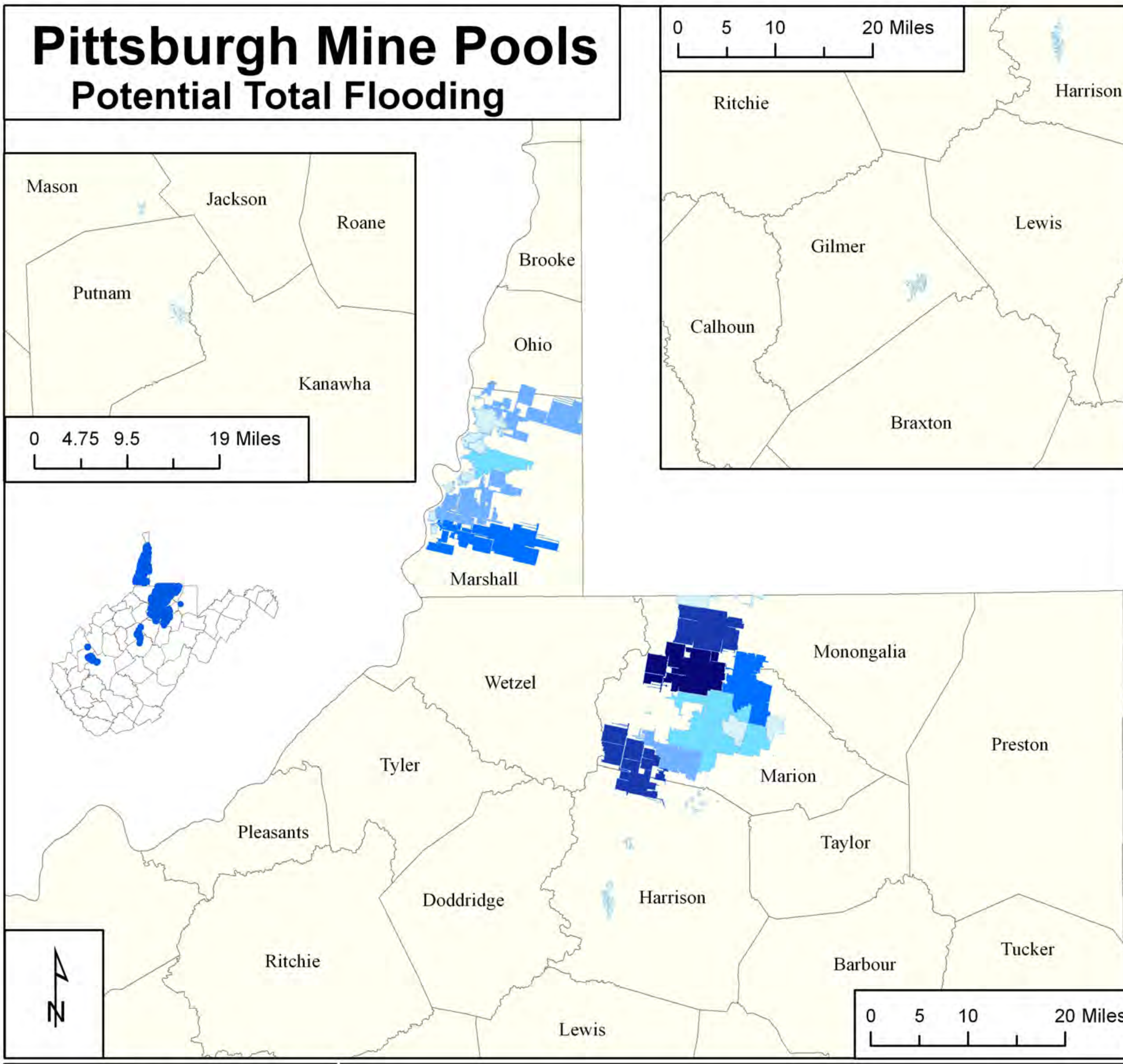
Figure 10b



Pittsburgh Mine Pool Statistics

	Undetermined	Flooded areas unlikely	Potentially Partially flooded	Potentially Totally flooded
No. of Mines	0	196	564	46
Mean coal bed thickness (feet)	0.00	5.61	6.06	6.38
Min. footprint area (acres)	0.00	0.01	0.01	0.92
Max. footprint area (acres)	0.00	652.31	14,923.99	20,204.27
Mean footprint area (acres)	0.00	42.05	350.55	3,933.91
Median footprint area (acres)	0.00	6.97	22.44	641.06
Total footprint area (acres)	0.00	8,242.18	197,712.71	180,959.81
Estimated void volume (acre feet)	0.00	28,227.65	673,947.07	625,388.68
Max. potential storage (million gallons)	0.00	9,199.39	219,639.35	203,814.17

Figure 10c



Legend

Position

- Above drainage
- Near drainage
- Below drainage

Storage in Million Gallons

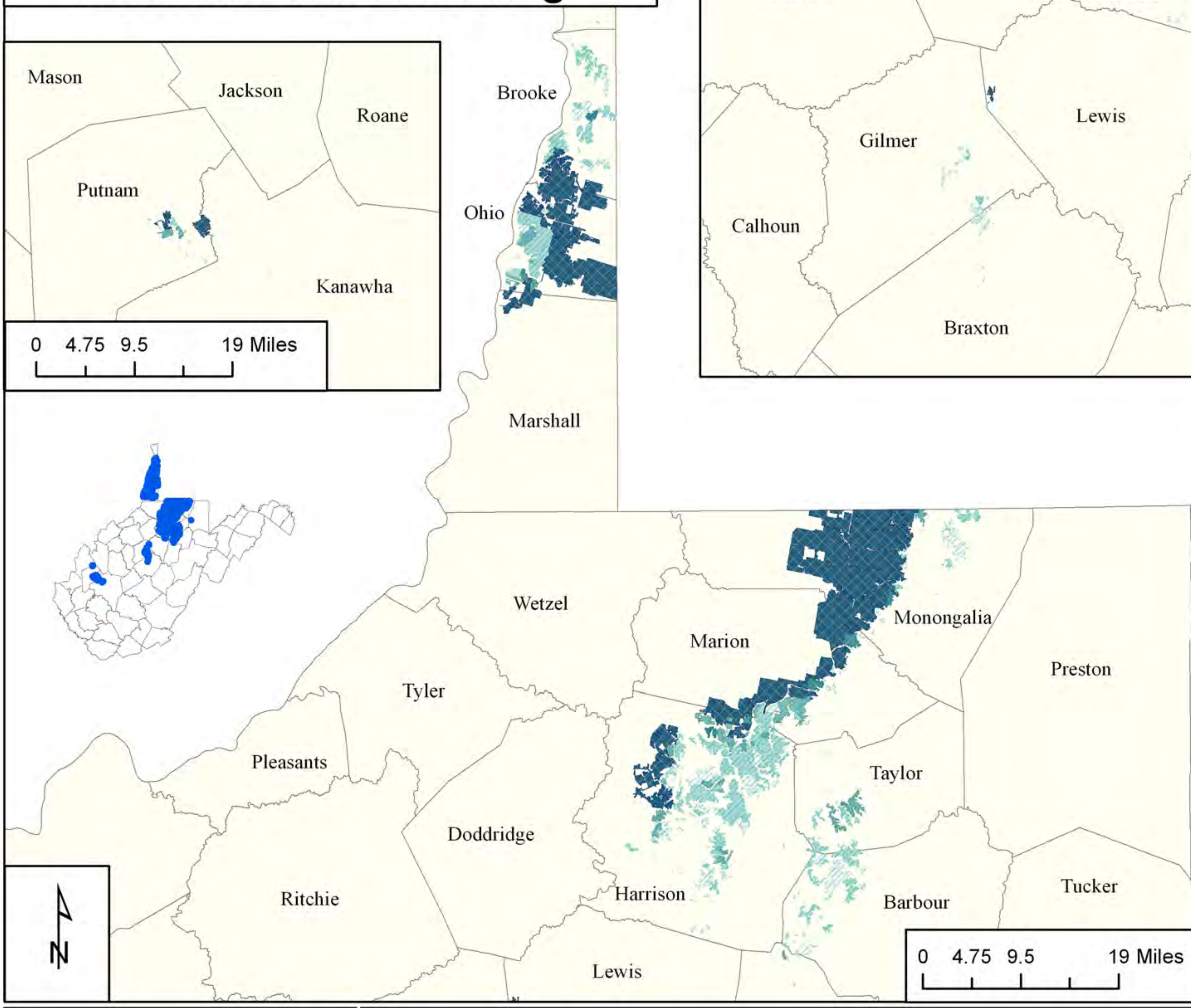
- 0.000 - 5,000
- 5,001 - 10,000
- 10,001 - 15,000
- 15,001 - 20,000
- 20,001 - 25,000
- 25,001 - 30,000

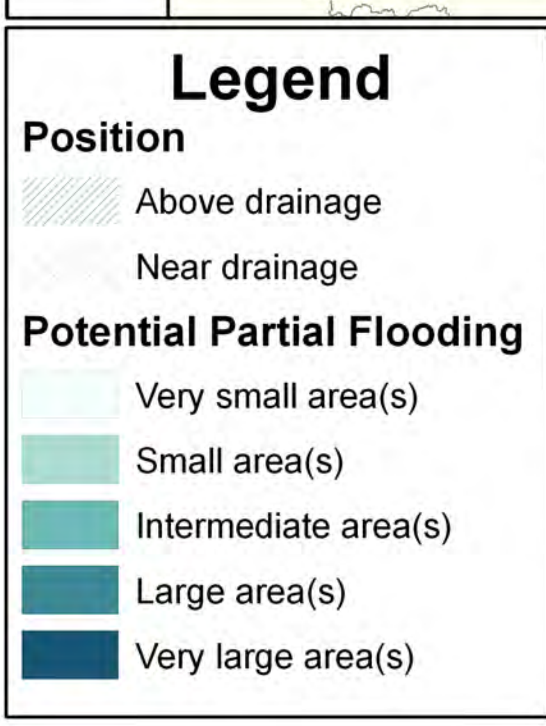
Pittsburgh Mine Pool Statistics

	Potentially totally flooded above drainage mines	Potentially totally flooded near drainage mines	Potentially totally flooded below drainage mines
No. of Mines	0	2	44
Mean coal bed thickness (feet)	0.00	7.22	6.34
Min. foot print area (acres)	0.00	166.86	0.92
Max. foot print area (acres)	0.00	1,126.20	20,204.27
Mean foot print area (acres)	0.00	646.53	4,083.34
Median foot print area (acres)	0.00	646.53	641.06
Total foot print area (acres)	0.00	1,293.06	179,666.75
Estimated void volume (acre feet)	0.00	4,341.23	621,047.45
Max. potential storage (million gallons)	0.00	1,414.81	202,399.36

Figure 10d

Pittsburgh Mine Pools
Potential Partial Flooding





Pittsburgh Mine Pool Statistics

	Potentially partially flooded above drainage mines	Potentially partially flooded near drainage mines
No. of Mines	487	77
Mean coal bed thickness (feet)	5.95	6.76
Min. footprint area (acres)	0.01	0.16
Max. footprint area (acres)	3,935.43	14,923.99
Mean footprint area (acres)	140.54	1,678.85
Median foot print area (acres)	16.14	197.87
Total footprint area (acres)	68,441.16	129,271.55
Estimated void volume (acre feet)	212,639.06	461,308.01
Max. potential storage (million gallons)	69,299.07	150,340.28

Figure 10e

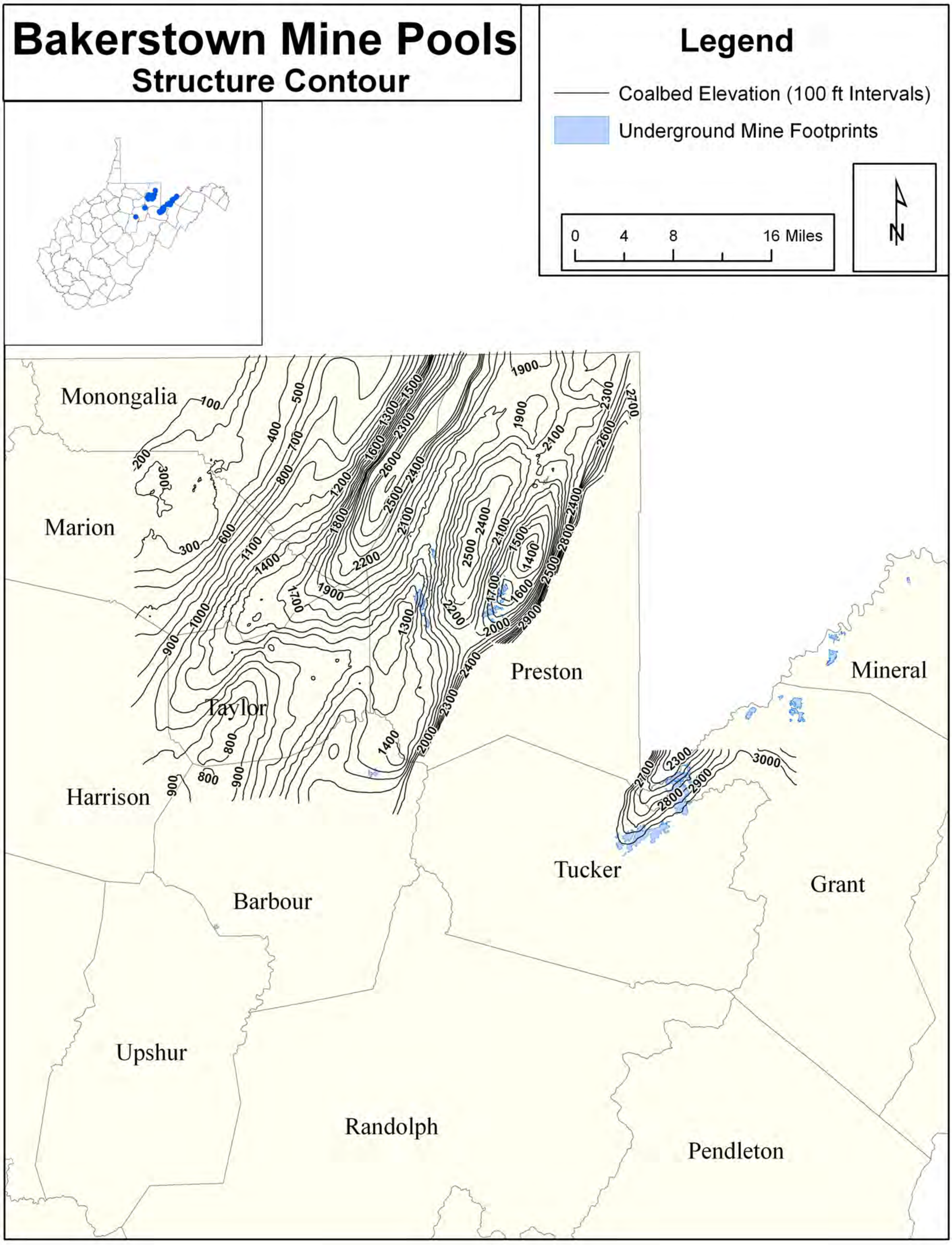
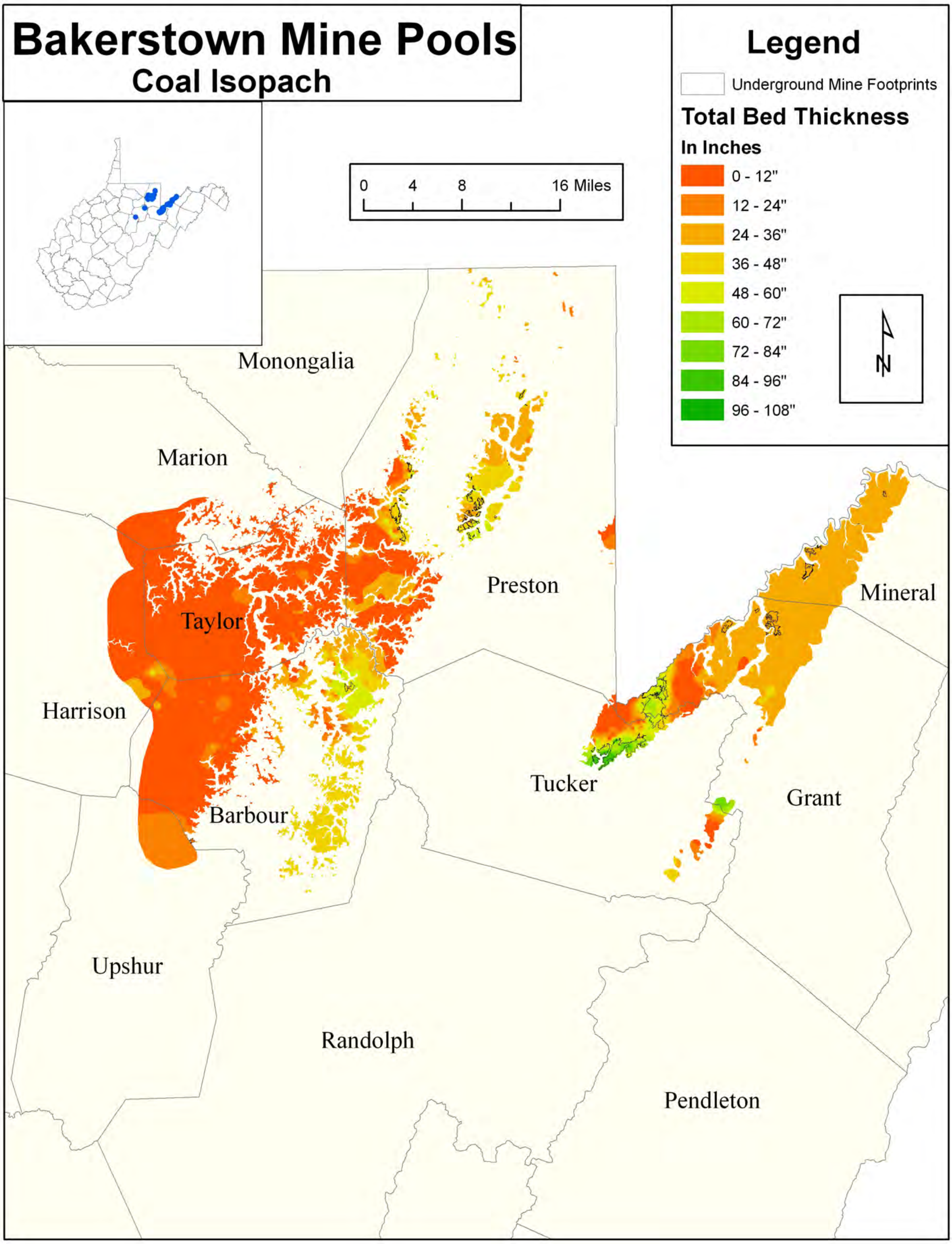

Bakerstown Mine Pools
Structure Contour
Legend
Coalbed Elevation (100 ft Intervals)
Underground Mine Footprints
0 4 8 16 Miles
N
Monongalia
Marion
Harrison
Taylor
Preston
Mineral
Tucker
Grant
Barbour
Upshur
Randolph
Pendleton

Figure 11a

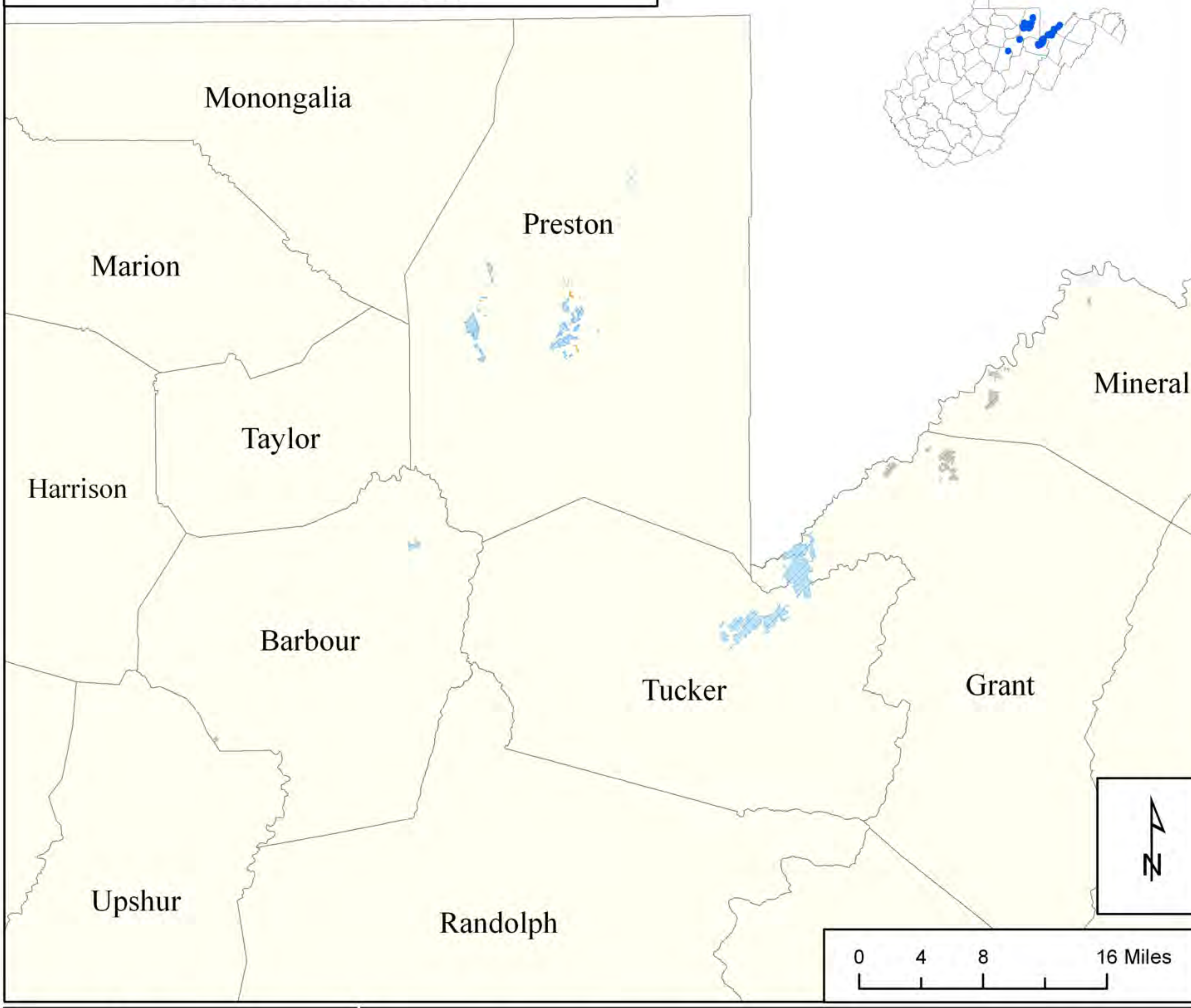


Bakerstown Mine Pools
Coal Isopach
Legend
Underground Mine Footprints
Total Bed Thickness
In Inches
0 - 12"
12 - 24"
24 - 36"
36 - 48"
48 - 60"
60 - 72"
72 - 84"
84 - 96"
96 - 108"
0 4 8 16 Miles
N
Monongalia
Marion
Taylor
Preston
Mineral
Harrison
Tucker
Barbour
Grant
Upshur
Randolph
Pendleton

Figure 11b

Bakerstown Mine Pools

Seam Overview



Legend

Position

- Above drainage
- Near drainage
- Below drainage

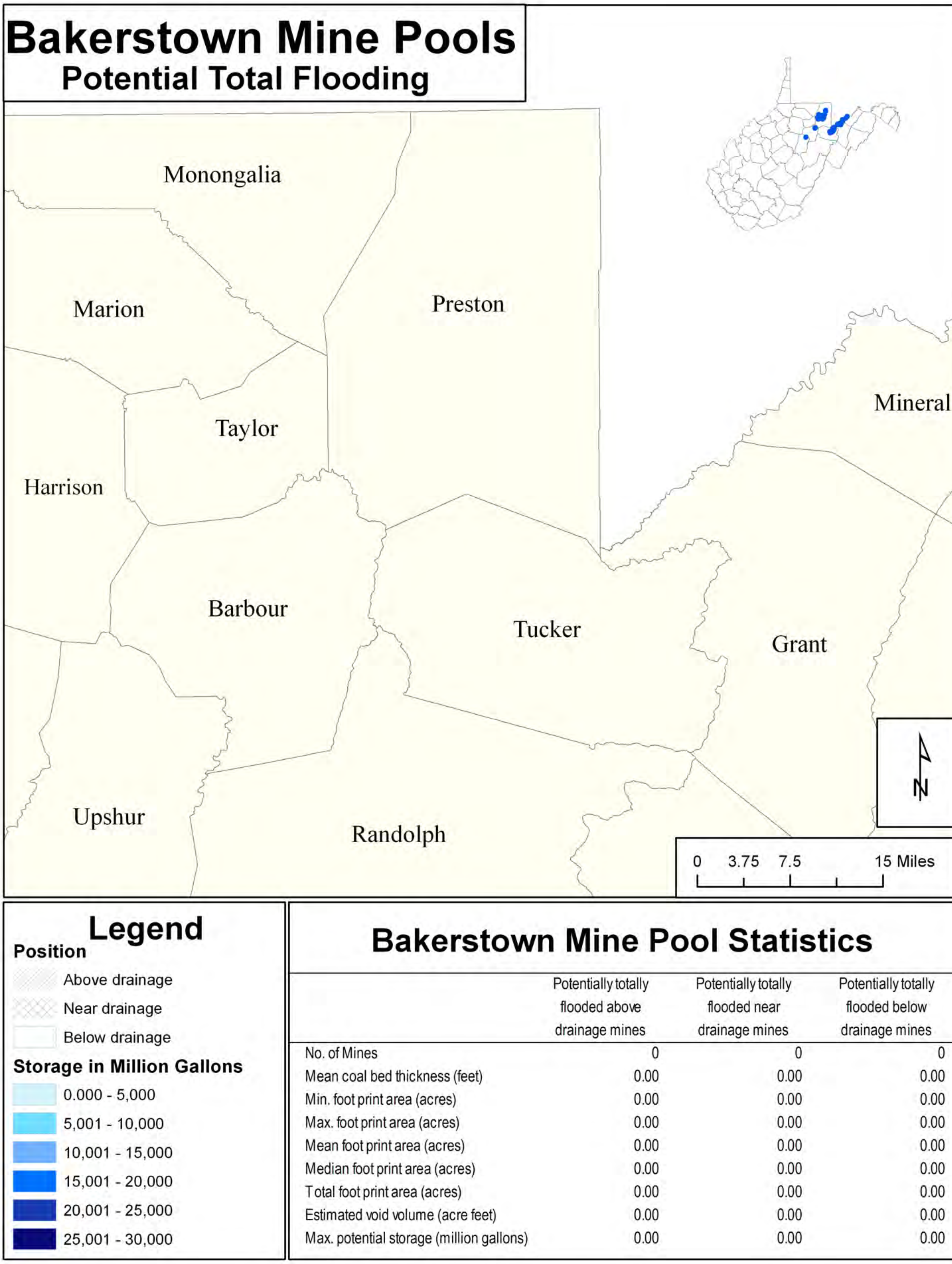
Potential Extent of Flooding

- Undetermined
- Flooded areas unlikely
- Partially flooded
- Totally flooded

Bakerstown Mine Pool Statistics

	Undetermined	Potentially flooded areas unlikely	Potentially partially flooded	Potentially totally flooded
No. of Mines	15	15	54	0
Mean coal bed thickness (feet)	2.82	2.56	3.24	0.00
Min. footprint area (acres)	0.53	0.14	0.17	0.00
Max. footprint area (acres)	314.63	14.35	1,952.97	0.00
Mean footprint area (acres)	98.07	2.68	122.52	0.00
Median footprint area (acres)	39.89	1.36	24.26	0.00
Total footprint area (acres)	1,470.99	40.18	6,616.09	0.00
Estimated void volume (acre feet)	2,290.51	49.56	14,114.95	0.00
Max. potential storage (million gallons)	746.48	16.15	4,600.06	0.00

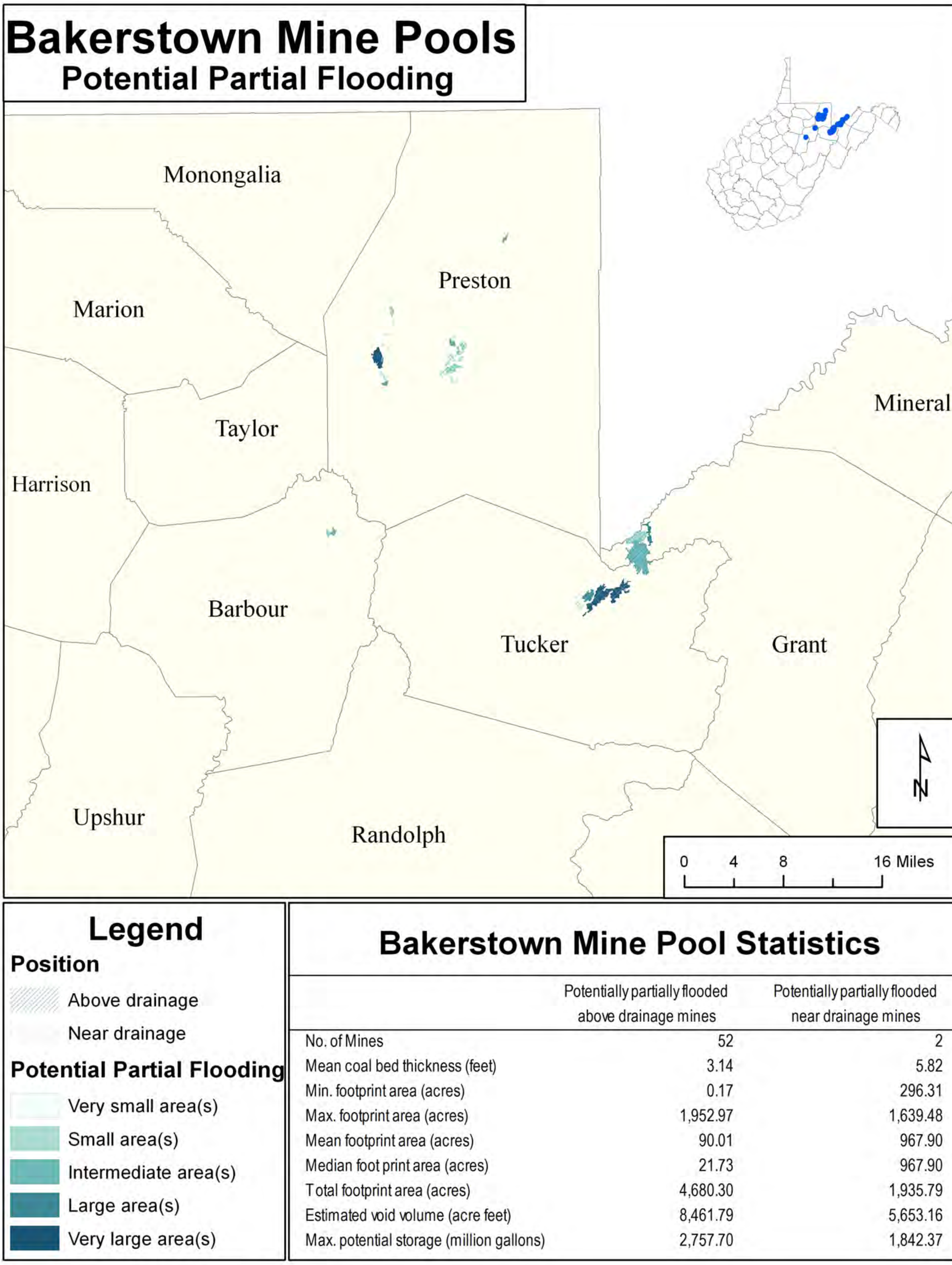
Figure 11c



Bakerstown Mine Pool Statistics

	Potentially totally flooded above drainage mines	Potentially totally flooded near drainage mines	Potentially totally flooded below drainage mines
No. of Mines	0	0	0
Mean coal bed thickness (feet)	0.00	0.00	0.00
Min. foot print area (acres)	0.00	0.00	0.00
Max. foot print area (acres)	0.00	0.00	0.00
Mean foot print area (acres)	0.00	0.00	0.00
Median foot print area (acres)	0.00	0.00	0.00
Total foot print area (acres)	0.00	0.00	0.00
Estimated void volume (acre feet)	0.00	0.00	0.00
Max. potential storage (million gallons)	0.00	0.00	0.00

Figure 11d



Bakerstown Mine Pool Statistics

	Potentially partially flooded above drainage mines	Potentially partially flooded near drainage mines
No. of Mines	52	2
Mean coal bed thickness (feet)	3.14	5.82
Min. footprint area (acres)	0.17	296.31
Max. footprint area (acres)	1,952.97	1,639.48
Mean footprint area (acres)	90.01	967.90
Median foot print area (acres)	21.73	967.90
Total footprint area (acres)	4,680.30	1,935.79
Estimated void volume (acre feet)	8,461.79	5,653.16
Max. potential storage (million gallons)	2,757.70	1,842.37

Figure 11e

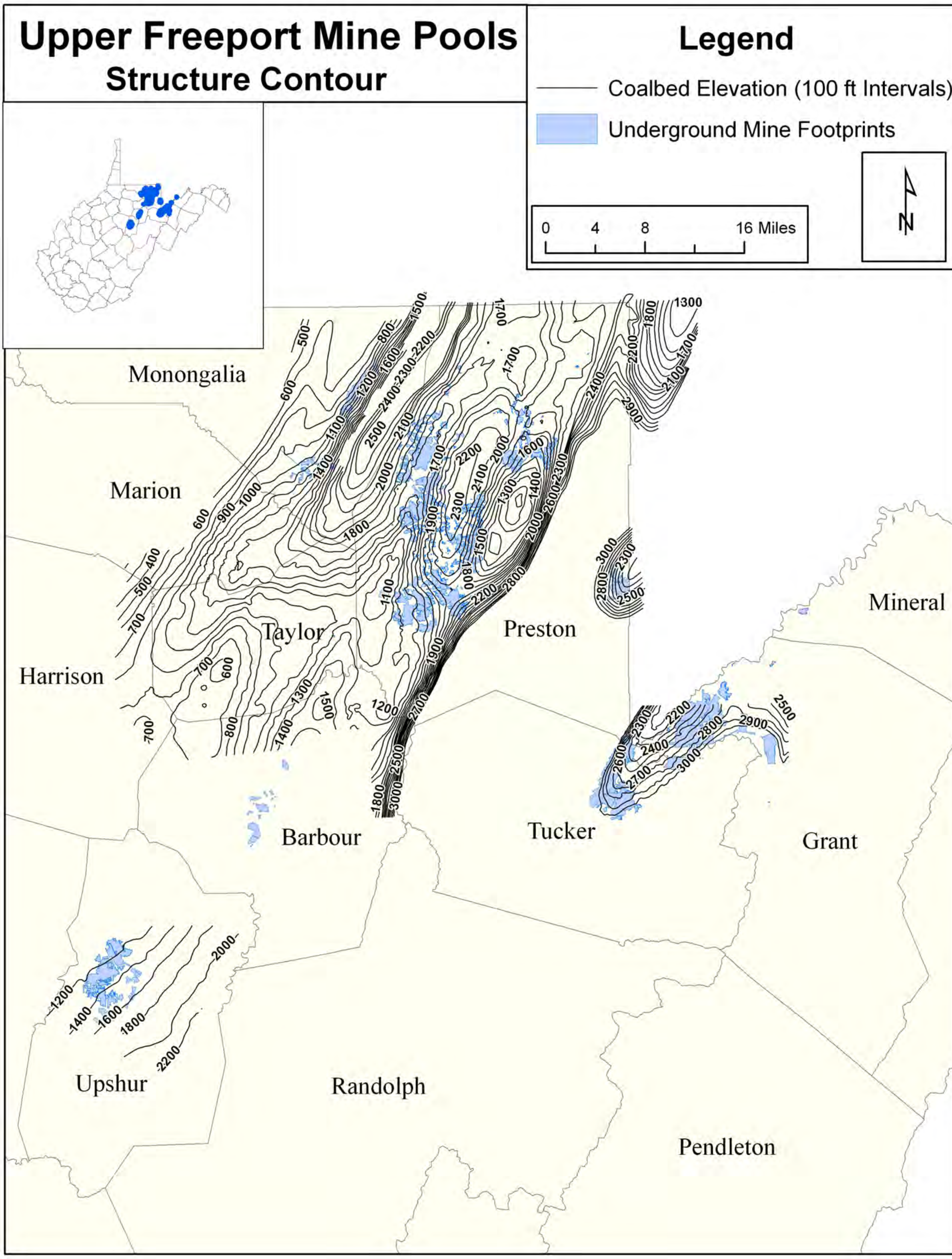

Upper Freeport Mine Pools
Structure Contour
Legend
Coalbed Elevation (100 ft Intervals)
Underground Mine Footprints
0 4 8 16 Miles
N
Monongalia
Marion
Harrison
Taylor
Preston
Mineral
Barbour
Tucker
Grant
Upshur
Randolph
Pendleton

Figure 12a

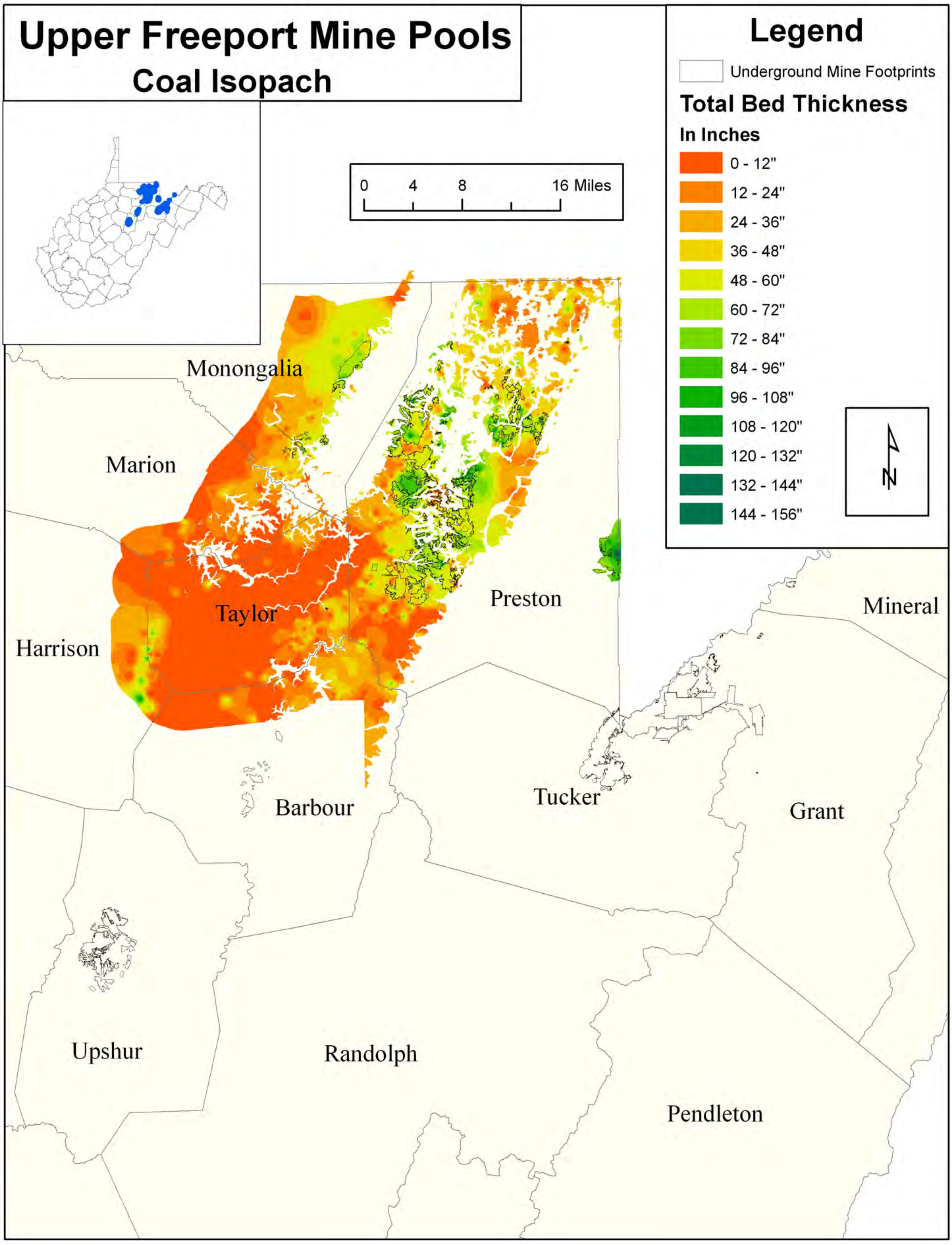
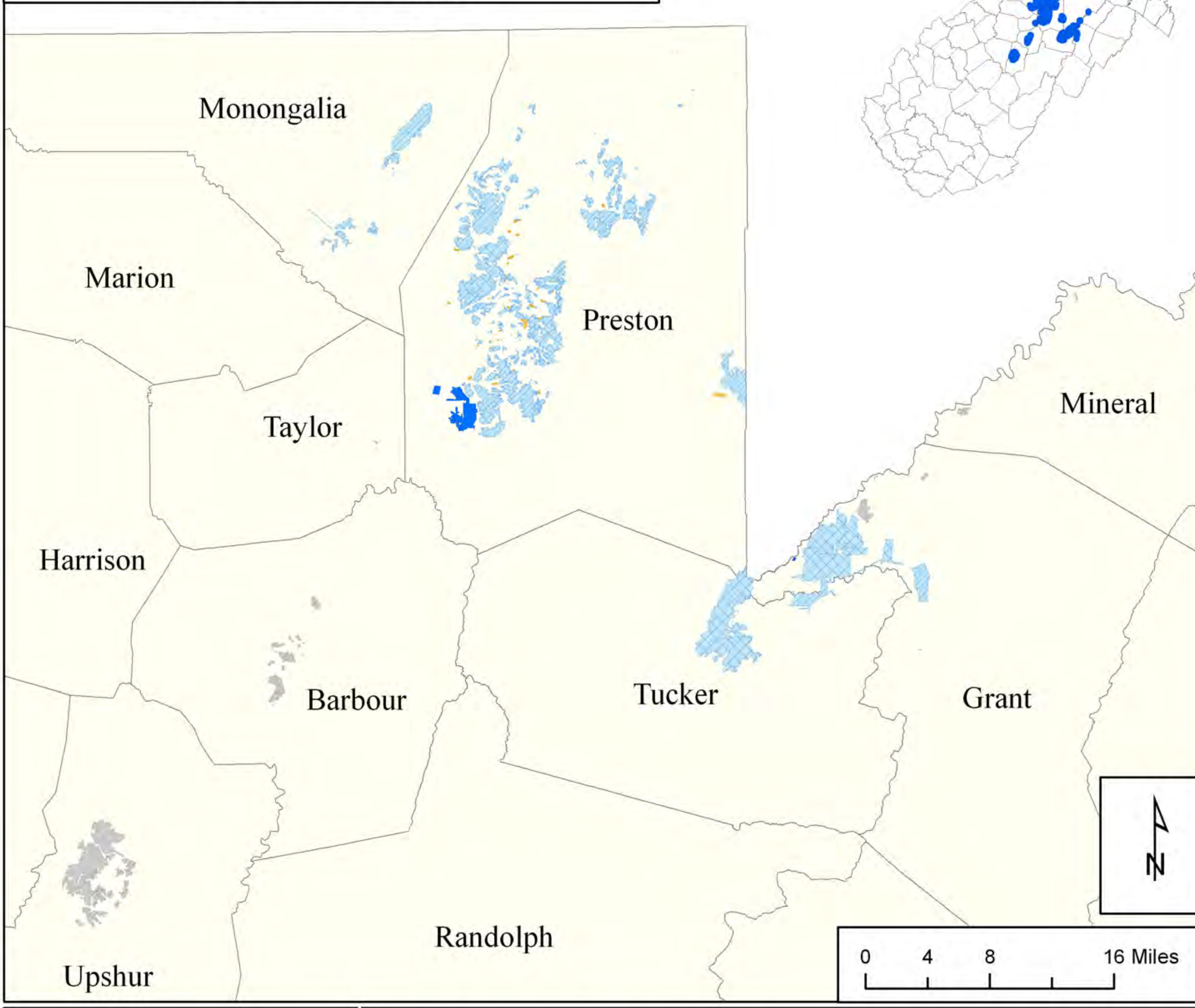

Upper Freeport Mine Pools
Coal Isopach
Legend
Underground Mine Footprints
Total Bed Thickness
In Inches
0 - 12"
12 - 24"
24 - 36"
36 - 48"
48 - 60"
60 - 72"
72 - 84"
84 - 96"
96 - 108"
108 - 120"
120 - 132"
132 - 144"
144 - 156"
0 4 8 16 Miles
N
Monongalia
Marion
Harrison
Taylor
Preston
Mineral
Barbour
Tucker
Grant
Upshur
Randolph
Pendleton

Figure 12b

Upper Freeport Mine Pools
Seam Overview



Legend

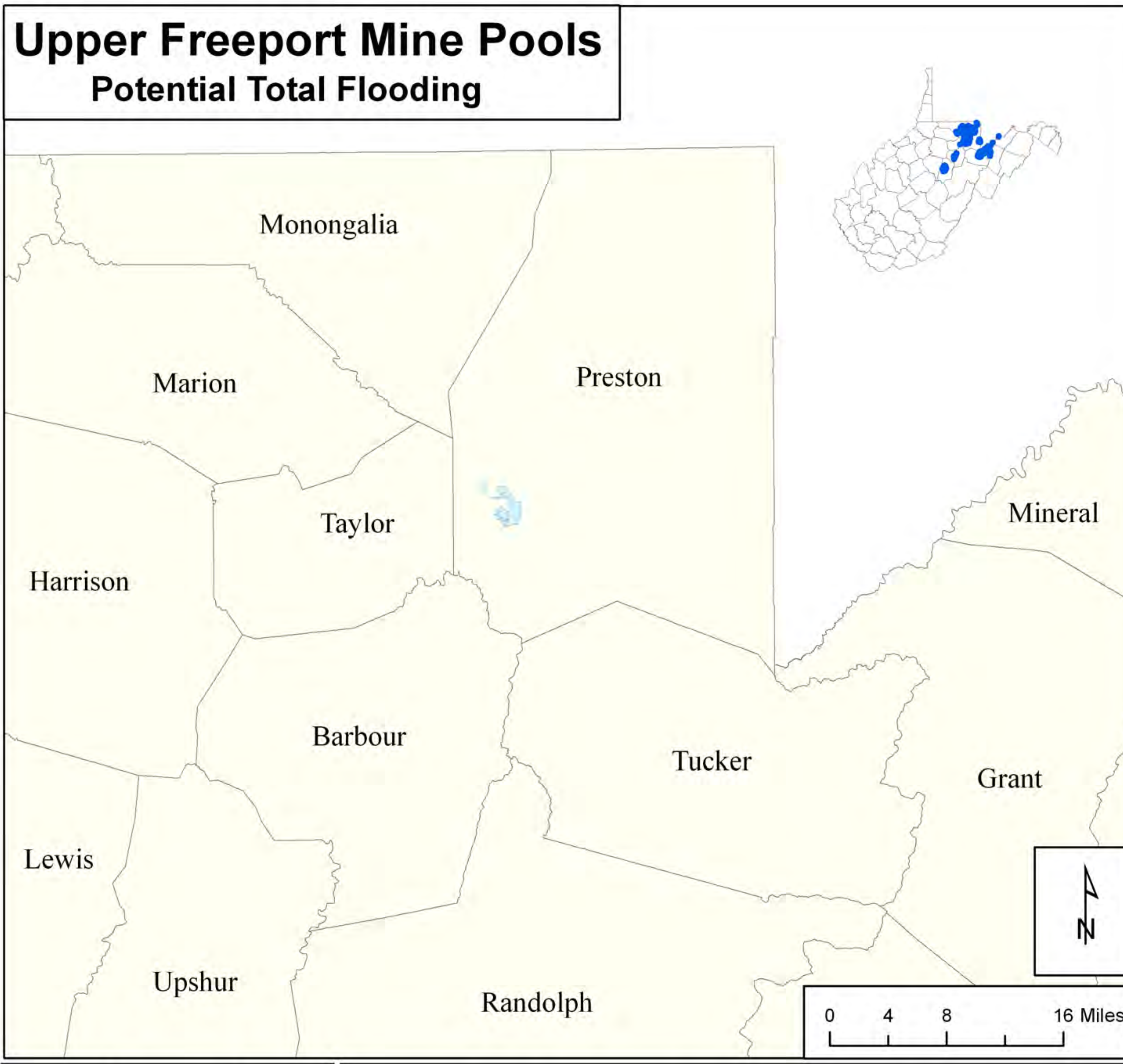
Position
- Above drainage
- Near drainage
- Below drainage

Potential Extent of Flooding
- Undetermined
- Flooded areas unlikely
- Partially flooded
- Totally flooded

Upper Freeport Mine Pool Statistics

	Undetermined	Potentially flooded areas unlikely	Potentially partially flooded	Potentially totally flooded
No. of Mines	35	45	202	3
Mean coal bed thickness (feet)	2.07	4.72	4.75	5.27
Min. footprint area (acres)	0.01	0.01	0.04	17.38
Max. footprint area (acres)	2,421.33	105.38	7,005.07	1,592.89
Mean footprint area (acres)	243.10	9.44	222.10	582.25
Median footprint area (acres)	91.39	2.27	26.50	136.47
Total footprint area (acres)	8,508.48	424.77	44,864.77	1,746.75
Estimated void volume (acre feet)	14,506.28	1,019.81	136,630.31	3,621.87
Max. potential storage (million gallons)	4,727.60	332.36	44,527.82	1,180.37

Figure 12c



Legend

Position

Position

- Above drainage
- Near drainage
- Below drainage

Storage

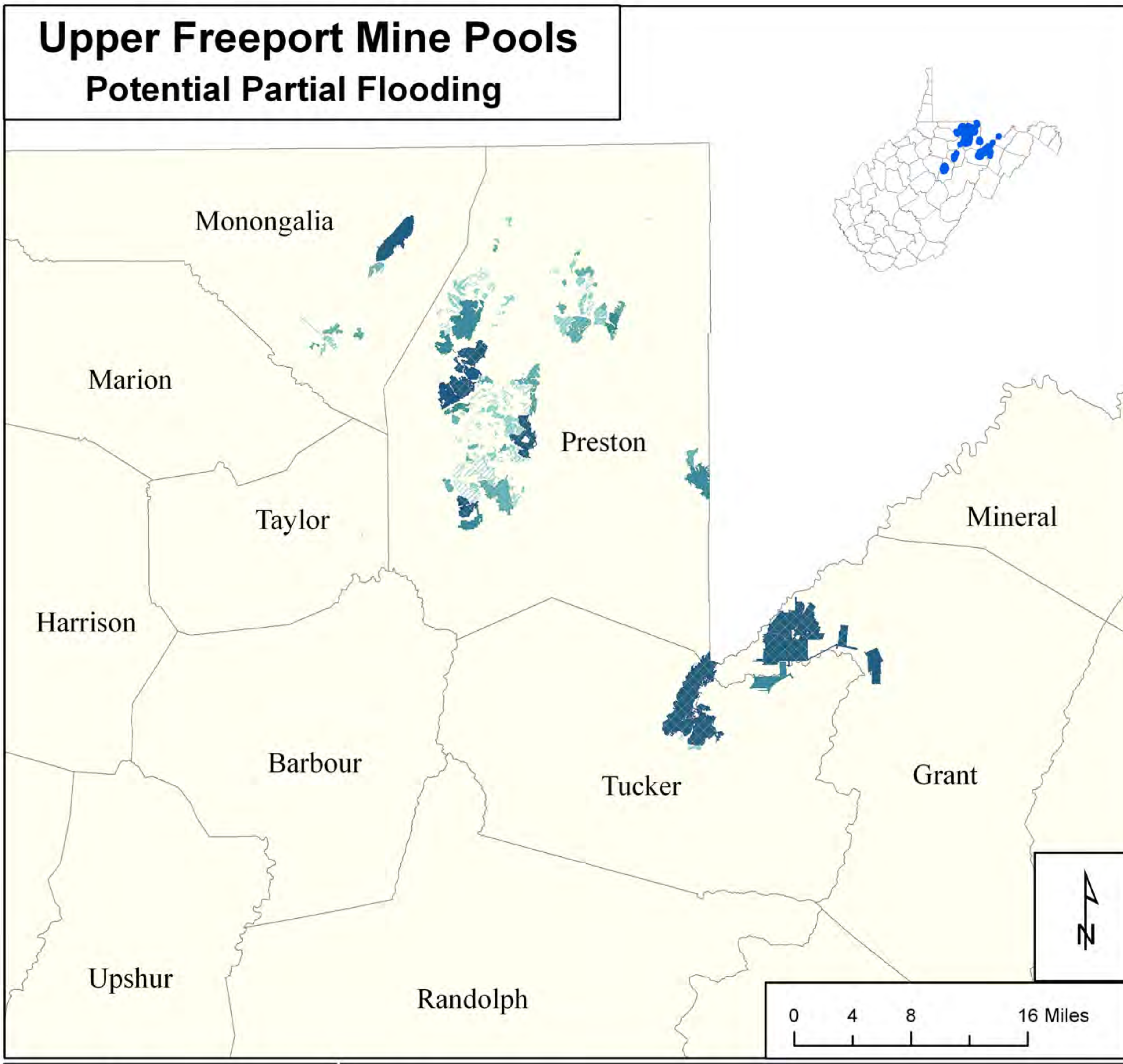
Storage in Million Gallons

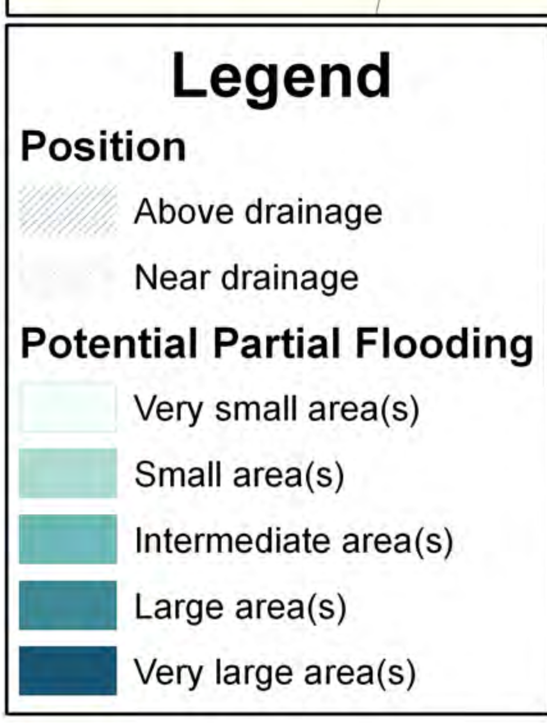
- 0.000 - 5,000
- 5,001 - 10,000
- 10,001 - 15,000
- 15,001 - 20,000
- 20,001 - 25,000
- 25,001 - 30,000

Upper Freeport Mine Pool Statistics

	Potentially totally flooded above drainage mines	Potentially totally flooded near drainage mines	Potentially totally flooded below drainage mines
No. of Mines	0	0	3
Mean coal bed thickness (feet)	0.00	0.00	5.27
Min. foot print area (acres)	0.00	0.00	17.38
Max. foot print area (acres)	0.00	0.00	1,592.89
Mean foot print area (acres)	0.00	0.00	582.25
Median foot print area (acres)	0.00	0.00	136.47
Total foot print area (acres)	0.00	0.00	1,746.75
Estimated void volume (acre feet)	0.00	0.00	3,621.87
Max. potential storage (million gallons)	0.00	0.00	1,180.37

Figure 12d





Upper Freeport Mine Pool Statistics

	Potentially partially flooded above drainage mines	Potentially partially flooded near drainage mines
No. of Mines	192	10
Mean coal bed thickness (feet)	4.68	5.99
Min. footprint area (acres)	0.04	101.92
Max. footprint area (acres)	2,252.09	7,005.07
Mean footprint area (acres)	130.35	1,983.84
Median foot print area (acres)	23.17	1,155.12
Total footprint area (acres)	25,026.41	19,838.36
Estimated void volume (acre feet)	67,755.36	68,874.95
Max. potential storage (million gallons)	22,081.47	22,446.35

Figure 12e

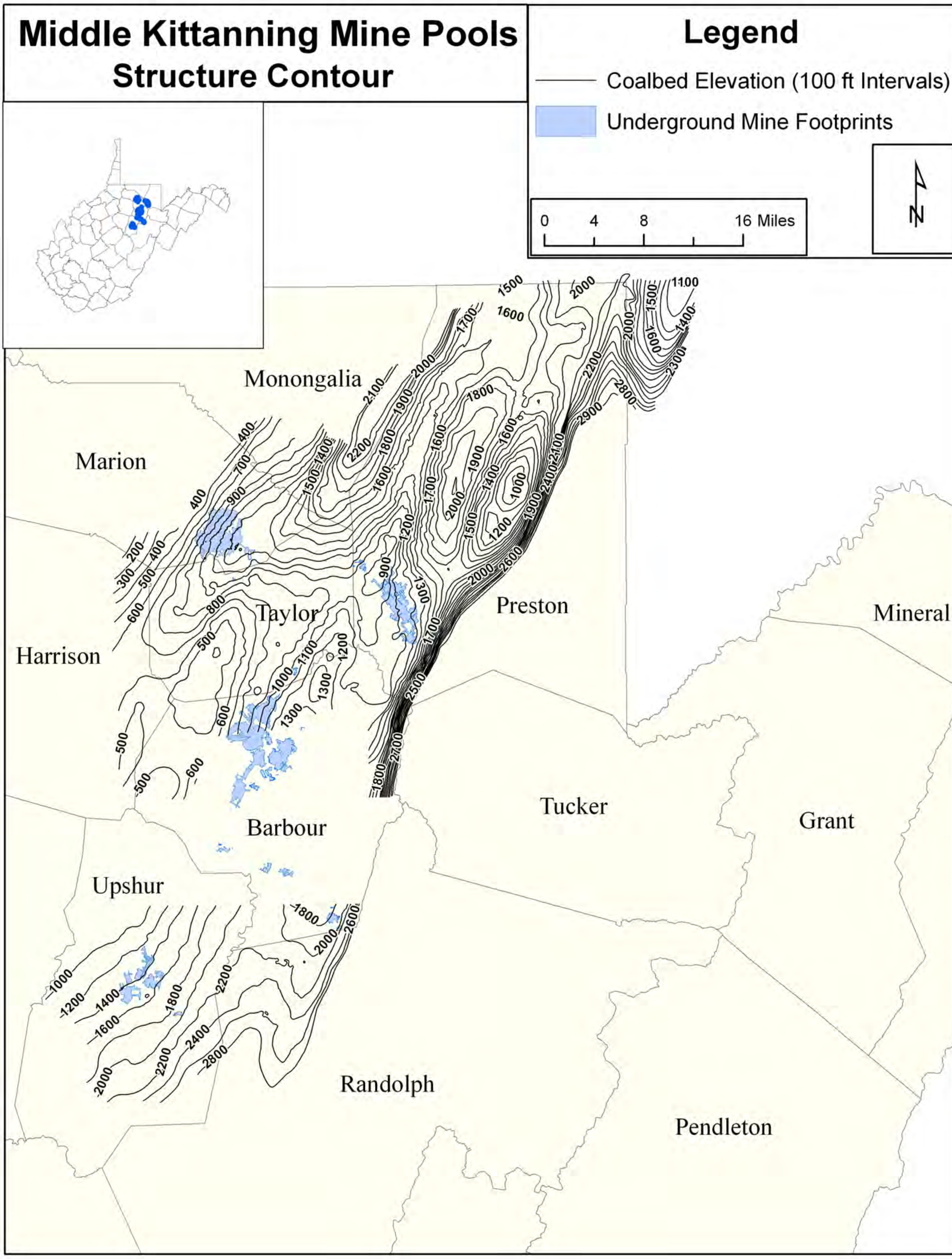

Middle Kittanning Mine Pools
Structure Contour
Legend
Coalbed Elevation (100 ft Intervals)
Underground Mine Footprints
0 4 8 16 Miles
N
Monongalia
Marion
Harrison
Taylor
Preston
Mineral
Tucker
Grant
Barbour
Upshur
Randolph
Pendleton

Figure 13a

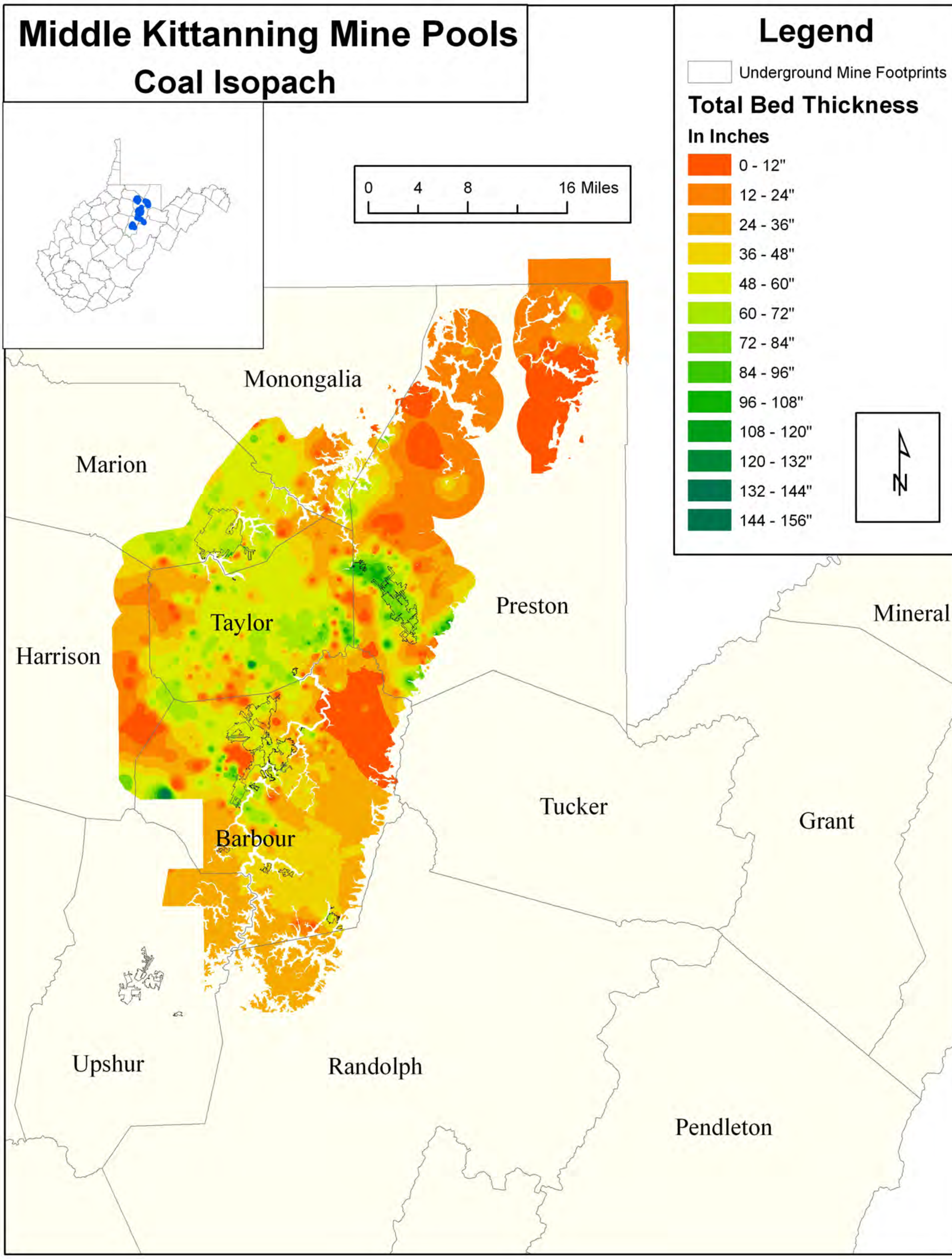
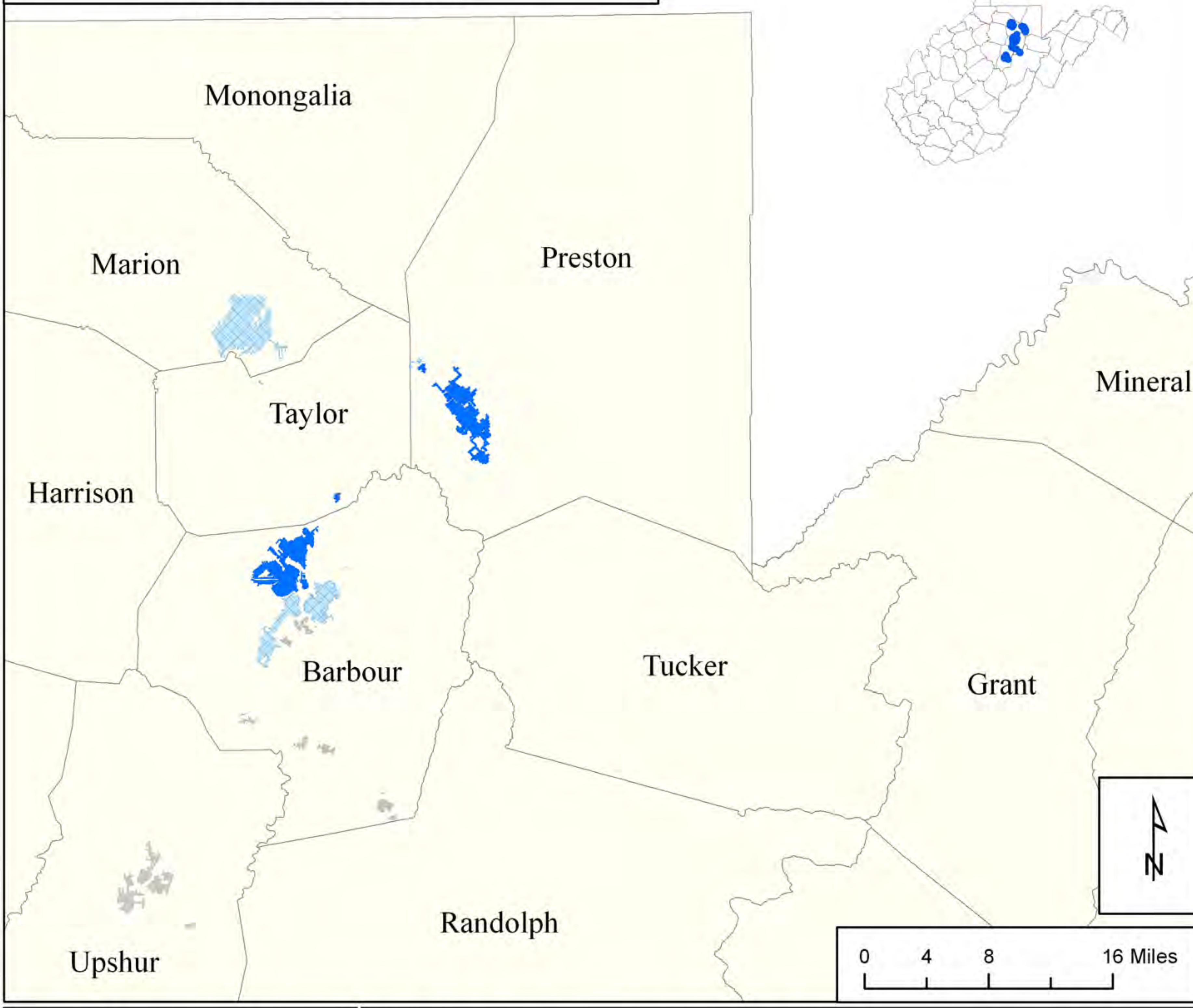

Middle Kittanning Mine Pools
Coal Isopach
Legend
Underground Mine Footprints
Total Bed Thickness
In Inches
0 - 12"
12 - 24"
24 - 36"
36 - 48"
48 - 60"
60 - 72"
72 - 84"
84 - 96"
96 - 108"
108 - 120"
120 - 132"
132 - 144"
144 - 156"
0 4 8 16 Miles
N
Monongalia
Marion
Taylor
Harrison
Preston
Mineral
Tucker
Grant
Barbour
Upshur
Randolph
Pendleton

Figure 13b

Middle Kittanning Mine Pools
Seam Overview



Legend

Position

- Above drainage
- Near drainage
- Below drainage

Potential Extent of Flooding

- Undetermined
- Flooded areas unlikely
- Partially flooded
- Totally flooded

Middle Kittanning Mine Pool Statistics

	Undetermined	Potentially flooded areas unlikely	Potentially partially flooded	Potentially totally flooded
No. of Mines	21	1	16	5
Mean coal bed thickness (feet)	4.16	4.75	5.05	5.39
Min. footprint area (acres)	0.31	0.83	0.06	81.75
Max. footprint area (acres)	1,039.10	0.83	6,191.64	4,755.03
Mean footprint area (acres)	180.83	0.83	643.78	1,879.00
Median footprint area (acres)	88.02	0.83	2.99	172.19
Total footprint area (acres)	3,797.35	0.83	10,300.50	9,395.02
Estimated void volume (acre feet)	8,137.69	1.94	23,692.48	24,387.17
Max. potential storage (million gallons)	2,652.07	0.63	7,721.38	7,947.78

Figure 13c