HOME

Modelling of Mine Flooding in the Pittsburgh Coal Basin, USA

B R Leavitt[1], J J Donovan[2], A J Morris[2] and E Werner[2]

ABSTRACT

Coal mining in the Pittsburgh coal seam, in the eastern United States, began in the late-1700s. Since that time numerous mining technologies have been used throughout the basin. Environmental concerns, particularly mine discharge quality, have only been considered since the early-1970s. During the last 20 years, many of the larger underground mines have closed and are now either flooding or already flooded. In order to understand the consequences and potential future effects of this flooding, mine mapping of the basin has been compiled utilising a geographic information system (GIS) with an emphasis on locating barrier pillars between mines. Mine flooding has been monitored at numerous sites utilising pressure transducers and data loggers. These data have been combined with historical data from mining companies and structure contour maps to yield chronological flooding maps of the basin from 1980 to present. Utilising these maps and the indicated flooding rates, future discharge locations have been identified along with estimates of when these discharges are likely to occur. Related work has identified barrier pillar hydraulic conductivities and vertical infiltration rates as a function of overburden thickness. All of this information has been integrated into a groundwater flow model that simulates mine flooding. This model is useful in defining mine to mine interactions as the various mines fill with water, and the testing of various flooding scenarios. The model will be used in evaluating mine discharge rates and evaluating the options for regional mine drainage treatment.

INTRODUCTION

Mining in the Pittsburgh coal

The Pittsburgh coal seam has been described as the single most valuable mineral deposit in the world. This coal deposit is located in parts of Pennsylvania, Ohio and West Virginia. (Figure 1) Mining of this resource began in 1761 across the Monongahela River from the city of Pittsburgh (Leavitt, 1999). During the past 240 years, it is estimated that 56 per cent of the coal has been mined (Ruppert, 2001).

Environmental aspects of underground coal mining

Acid mine drainage (AMD) has been a chronic problem in the basin. During the 1950s to the early-1970s, the pH of the Monongahela River at the Lock and Dam # 8 near point Marion, ranged from three to five. (United States Geological Survey, 2003) It was customary at that time to discharge mine water directly to rivers and streams without regard to the resulting environmental impact. With the advent of the Clean Water Act in 1972, AMD treatment plants were constructed and placed in operation. By the end of the decade, the pH of the Monongahela River had returned to the mid seven range. (United States Geological Survey, 2003) During the last 20 years, a number of mines have ceased operation and either have flooded, or are flooding. During the same time period, the sales price of coal has declined, thus putting financial pressure on the remaining coal mine operators. The combination of high costs, low sales price, and depleting reserves has led the various state and federal government agencies to become concerned that the water treatment burden would no longer be born by the coal industry, and that AMD would again degrade the waters of the Monongahela River. Based on preliminary data, more than 58.5 million cubic metres of mine water per year are discharged from the existing mines; 50.1 per cent of this water is untreated. A total of 5136 tons of iron are produced and 26.5 per cent of this is untreated.

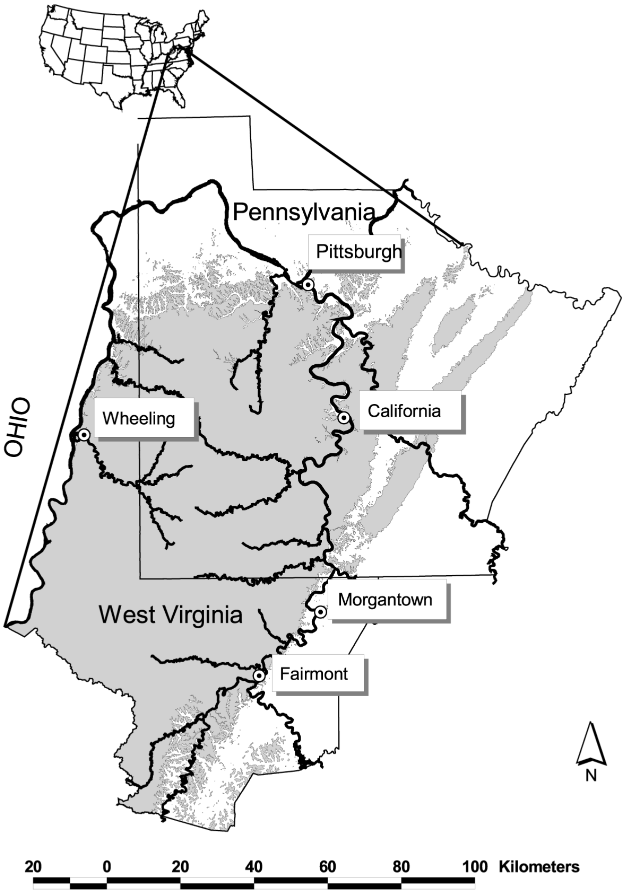

FIG 1 - Location map.

PURPOSE OF THIS STUDY

The purpose of this study is to map the existing underground mine areas in the Pittsburgh coal seam; determine the location of coal barriers and mine interconnections; measure the water level or current discharge volume in the various mines or mine complexes; develop a mine flooding model for the basin; identify the chemistry of the mine water and its changes over time; identify future mine discharges including their location, flow rate, chemistry and time of occurrence. The interim results of the study of the mine chemistry and its evolution are being reported separately at this conference and are not included here.

---

1. Consulting Hydrogeologist, 2776 S-Bridge Road, Washington PA 15301, USA.

2. Department of Geology and Geography, West Virginia University, Morgantown WV 26506-6300, USA.

METHODS

GIS mapping of mined coal

Historic mine mapping in the Pittsburgh Basin has been based on mine specific coordinate systems. Larger operators occasionally used a single coordinate system for their various mines but these were still proprietary systems. If all of these maps were to be presented, they had to be located in a single coordinate system. Since mining in the basin has spanned over two centuries, the mine mapping ranges from non-existent to stylised, to draft, to digital. Older maps, on paper or velum, may not have maintained their dimensional stability and consequently must be adjusted back to their original size. Maps also exist at different scales; where possible we tried to obtain maps at a scale of 1:4800. However, it has been necessary to use maps ranging from 1:1200 to 1:12 000.

Mine maps were obtained from State and Federal map repositories, library archives, and coal mining companies. The West Virginia Geologic and Economic Survey provided many mine outlines that they had developed. Maps were scanned utilising large format scanners at a resolution of 200 dots per inch (dpi). Once scanned, it was often necessary to merge the scanned images so that the entire mine, or a large portion of it, could be represented by a single file. Once scanned, the image is georeferenced using the geographic information system (GIS). These scanned, merged, and referenced images represent very large computer files frequently exceeding of 200 megabytes for each mine. With these file sizes, it is not feasible to represent all of the mining in tag image file format (TIFF). Consequently, each mine outline is digitised along with the barrier pillars indicated on the map and any internal pillars greater than about two hectares in size.

Field location of mine-map features by GPS

Georeferencing is the process of locating a scanned image in space. Underground mines are particularly difficult to locate because they have few surface features that can be used for reference. Two methods were used for the georeferencing; the preferred method is to obtain coordinates utilising the Global Positioning System (GPS). A handheld GPS receiver is taken into the field to those places where the mine and the surface have an identifiable point in common. Typically, these are shafts, power boreholes, pump holes, and drift or slope entries. In this study a Garmin™ etrex Legend with wide area augmentation system (WAAS) real time correction was utilised. With this unit, accuracies of two to five metres were usually obtained, and 239 points have been located in the study area. The second method is to match surface features shown on the underground mine map to the same feature found on the USGS topographic quadrangle. Typically, these are road intersections and streams. This method is more problematic due to the quality of the surface mapping on the older mine maps and the mapping error in the 7.5 minute quadrangles. However, if mining surface features no longer exist, then georeferencing to the 7.5 minute quadrangles is the only alternative. For the purpose of this project, we are using Universal Transverse Mecator (UTM) with NAD27 as the datum. NAD27 is used because that is the same datum as the topographic quadrangles published by the US Geological Survey. Using these techniques 322 mine outlines are currently in the database, encompassing 341 264 hectares of mined land.

Water level monitoring

Since mines tend to fill with water from the lowest part of the mine to the highest it is possible to monitor the flooding process by drilling monitoring wells and measuring the water level in the well. Access to water level data has been obtained in three ways, well and or data access has been provided by mining companies, abandoned wells have been located and monitoring wells have been drilled. In total, 29 well monitoring points have been established along with 60 mine discharge points. Water levels are monitored periodically using an electric water level probe, and at most sites water levels are recorded hourly using Global Water™ model 14 recording pressure transducers. Water levels for discharging mines are assumed to be at or near the elevation of the discharge.

Estimation of flooding levels

Mining greatly increases the hydraulic conductivity of the coal seam. This degree of interconnection is illustrated in the Jordan mine. Two monitoring wells exist in this mine about 7900 metres apart, yet the measured water level difference between these two locations is less than two metres during non-pumping conditions. Barring excessive roof collapse or subsidence, this high conductivity zone allows the extrapolation of the water level observed in the monitoring well throughout the mine. The extrapolation of the measured water level is continued until the mine barrier is reached. Utilising this technique combined with known mine interconnections, flooding maps can be generated. Currently, 86 mines have flooding data available. The mines in the database have been separated into groups depending on their flooding status. Table 1 shows the mine status. These data indicate that 71.5 per cent of the basin flooding status is known. As additional water level data are obtained these statistics will be modified.

TABLE 1

Distribution of mined area.

Status	Hectares	Per cent
Active	67 821.5	19.9
Draining	16 552.3	4.8
Flooding	159 565.5	46.8
No data	97 324.6	28.5
Total	341 263.9	100

RESULTS

Distribution of mine flooding

The distribution of mine flooding is influenced by one global factor. It is the relationship of the coal seam to the surface topography. This relationship expresses itself in several ways. The primary influence is on the location and direction of mining. Initial mining in the basin occurred at the coal outcrop due to its easy access and identifiable location (Leavitt, 1999). Mining at these sites was conducted in an up dip direction so that water would freely drain from the mines. Mining of this type was dominant in the northern part of the basin and along the major drainages specifically the Ohio River North of the town of Wheeling, West Virginia, the Monongahela River valley North of California, Pennsylvania and the east side of the Monongahela River south of this point. The hydrologic effect of this mining is a predominance of unflooded, freely draining mines. Drainage from these mines is dominated by persistent low pH conditions with significant amounts of dissolved iron and particularly aluminium.

As transportation, mine ventilation, and mine dewatering improved down-dip mining became practical and thus the structure of coal had a direct influence on the ability of mines to flood (Leavitt, 1999). Many of these mines began production between 1900 and 1950 and most have closed between 1980 and 2002. Most of these mines are located in the interior of the basin west of the Monongahela River and east of the Ohio River and are at a lower elevation than either of these regional drainage systems. Drainage from these mines is dominated by an initial low pH and high metals content followed by a transition to a neutral pH net alkaline water with iron levels below 200 mg/L.

Mine to mine interactions

Although down-dip mining was practiced early in the 20th century, mine dewatering continued to be a problem for the mine operators. Mine to mine interconnections were frequently made to facilitate water removal. As recently as the 1950s, these interconnections were endorsed by the State of Pennsylvania in order to reduce the potential for impounded mine water to threaten the safety of the miners. (Pennsylvania Department of Mines, 1950) Where these interconnections exist significant flow can occur between mines with the result that two or more mines may behave as one flooded unit.

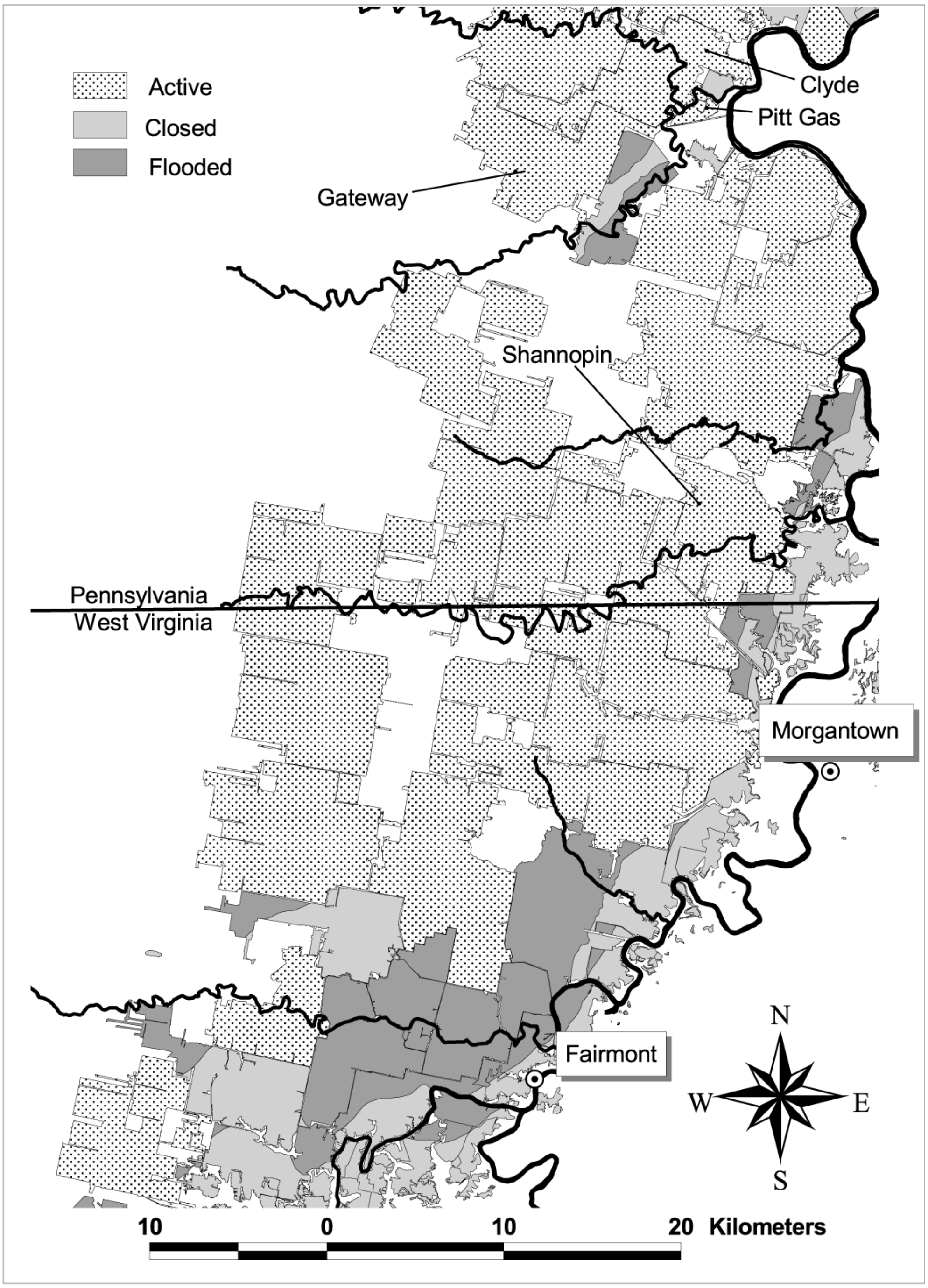

FIG 2 - Mine flooding 1980.

Beginning in the 1930s, mine safety laws began to require improved barrier pillars between mines (Leavitt, 1999). These pillars were designed according to the Ashley formula in order to prevent catastrophic failure between a flooded mine and an active mine. This formula requires 20 feet of coal plus an additional width of coal equal to four times the height of the coal seam plus one tenth of the potential hydraulic head (Leavitt, 1999). Where these barrier pillars exist they form a significant restriction to mine flooding. Heads in excess of 280 feet have been observed across mine barrier pillars. Despite this restriction, water leakage from mine to mine through the barrier pillars can have a significant effect on mine flooding rate.

Visualisation of transient mine flooding

In order to visualise the sequence of mine flooding the GIS outline of each mine, for which water level data are available, was cut along the appropriate structure contour into flooded and unflooded sections. The water level utilised is as of 31 December for each calendar year represented. Using historical data combined with data obtained by this project we have been able to document much of the flooding history of the basin. Figures 2 to 4 show the sequence of mine flooding in the southeastern part of the basin based on these data for years 1980, 1990 and 2000 respectively.

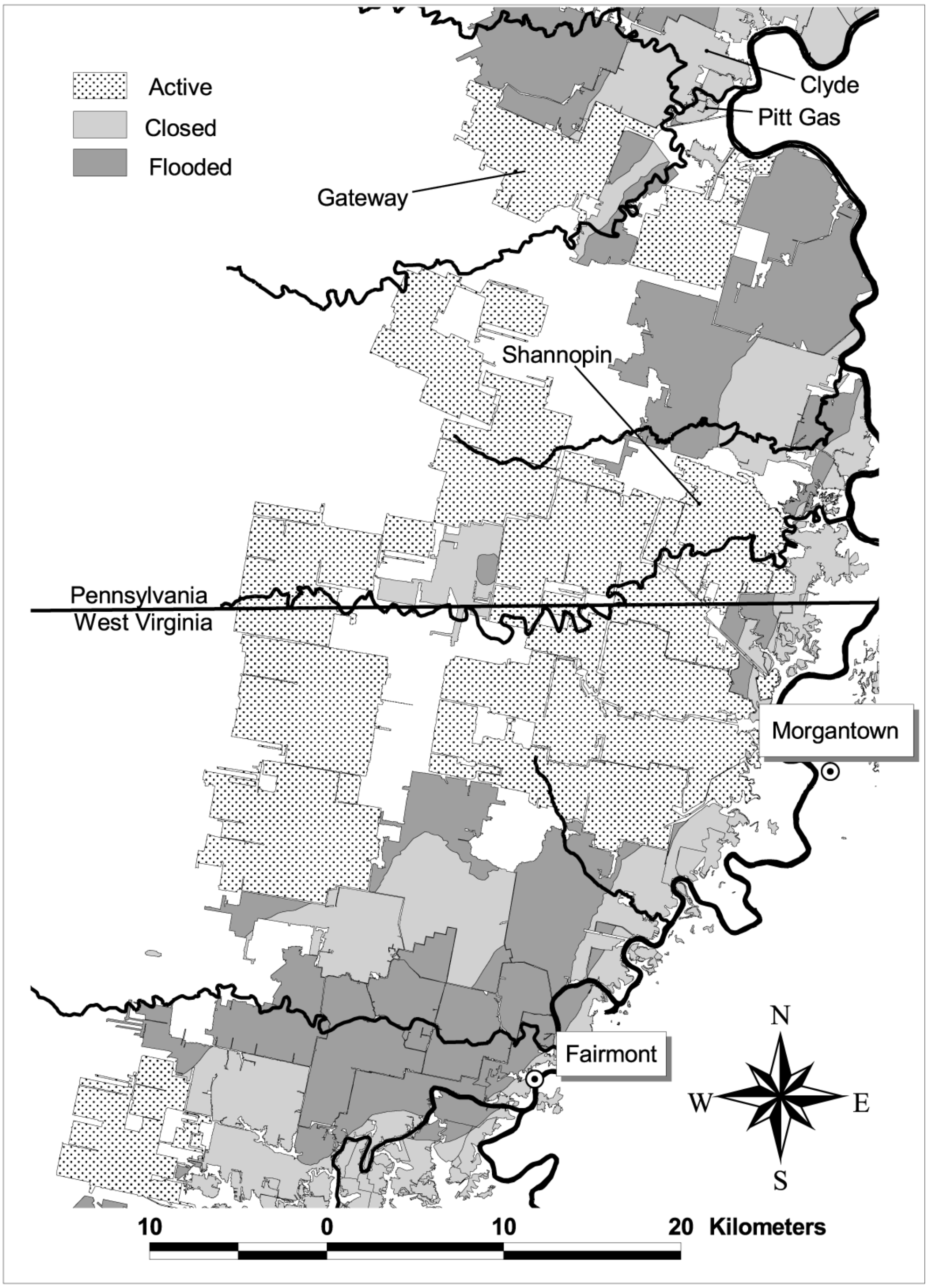

FIG 3 - Mine flooding 1990.

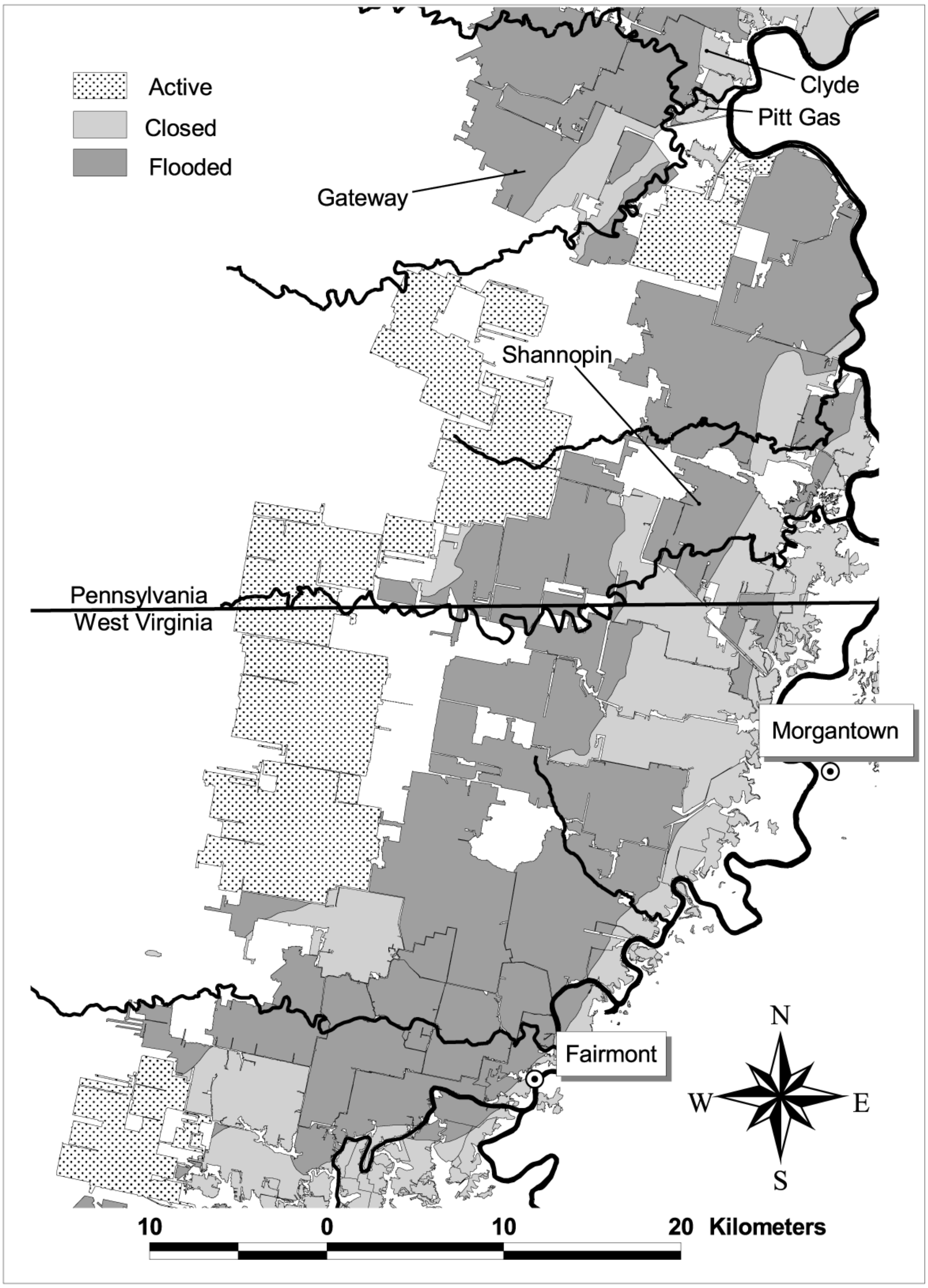

FIG 4 - Mine flooding 2000.

Identification of potential discharges

Water discharge from a flooding mine is first anticipated at the lowest surface elevation above the mine. This may be a mine opening such as a drift entry or it may be a stream where the stress relief fracture system provides a conduit between the mine and the surface. If the first connection is not adequate for the volume of mine water to be discharged then the water level in the mine will continue to increase until a dynamic equilibrium is achieved. Such a situation was observed near Fairmont, West Virginia. In 1996, the flooding of mine #38 resulted in a discharge into the bottom of Buffalo Creek. This discharge discoloured the water, but the volume was insufficient to control the amount of inflow the mine was receiving. The water level continued to rise and a second discharge was anticipated from an old pump borehole. Discharge was prevented when a siphon was built to transfer the water into an adjacent mine.

Future mine flooding scenarios

Water level data obtained during this project has been used to identify future discharges from flooding mines. Of particular interest are the Shannopin Mine and the Clyde, Gateway, Pit Gas complex.

The Shannopin mine is located west of the Monongahela River (Figure 5) and has a mined area of 3409 hectares. All of the mining at Shannopin was conducted using room and pillar full extraction techniques. A monitoring well was drilled into a mined-out section in the down-dip portion of the mine. Water level data from this well are shown in Figure 6. GIS software was used to overlay the USGS 7.5 minute topographic quadrangle map on the georeferenced mine map. With this overlay, the lowest surface opening of the mine was identified at elevation 825 feet mean sea level (msl). The water level in Shannopin as of 31 December 2002 was 770.72 feet msl. The rate of mine flooding is affected by both the rate of water inflow and the volume of coal extracted at that point along the strike of the coal seam. Based on the apparent inflow rate and the remaining mine area, it is anticipated that Shannopin will begin to discharge in early-2005.

Water level records from the Gateway mine indicate that the mine began to flood slowly in 1991. However, after May 1997, the flooding rate accelerated. Figure 7 is a graph of this flooding. The acceleration in flooding is attributed to inflow from the adjacent Clyde mine to the north. Based on estimates of the remaining mine void volume, Clyde may be contributing as much as 9.5 cubic metres per minute. As the water level in Gateway reaches Clyde's overflow point it is anticipated that increased pumping will be necessary in Clyde in order to maintain its water level below the discharge point. This increase in pumping is expected to begin in 2003.

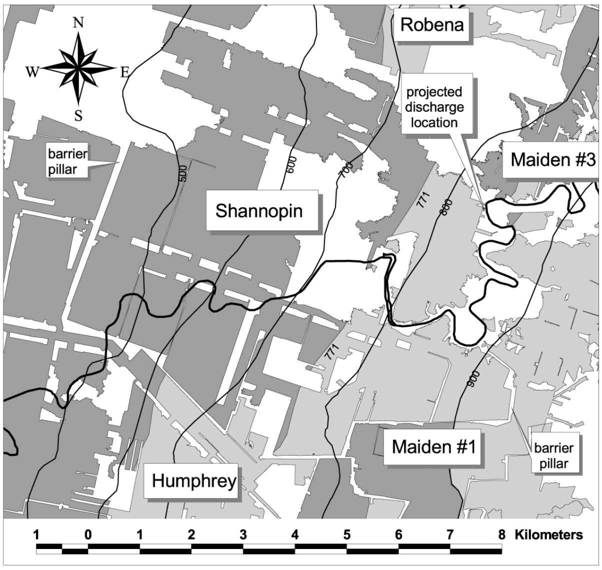

FIG 5 - Shannopin mine.

DISCUSSION AND CONCLUSIONS

Regional mapping of mines has been done periodically in printed format however, no publicly available mine flooding maps have been generated for the basin. Once generated, printed maps become rapidly obsolete due to continued mining in the operating mines, and continued changes in water level in the flooding mines. The use of a GIS model, such as the one presented here, allows for rapid update of both the mining and water level data. This mapping, once completed, can be made available electronically to reduce the delay from data collection to map generation.

The flooding maps generated by this study allow for both environmental impact evaluation as well as resource analysis. The flooding sequence maps allow for rapid identification of potential mine discharge location. This mapping allows for the calculation of flooded mine volumes per unit time which can then be used to generate an estimate of mine inflow rate/discharge volume. The inflow rate can be used to project when the discharge is likely to occur. The discharge location, volume, and timing can then be combined with water quality data so that water treatment facilities can be designed and built in time to prevent surface water contamination. Thus far, two mines have been identified that are expected to discharge in the near term.

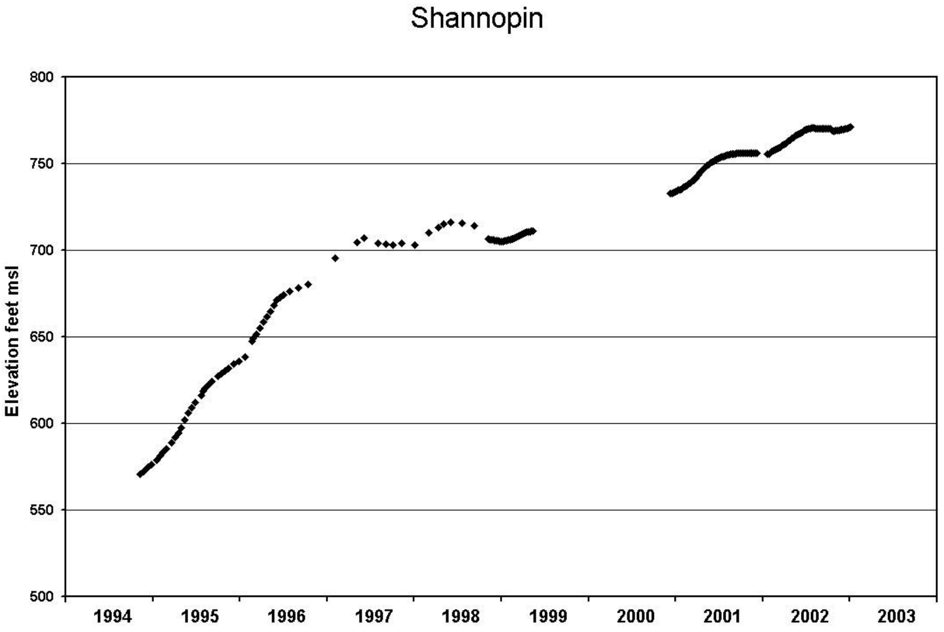

FIG 6 - Shannopin hydrograph.

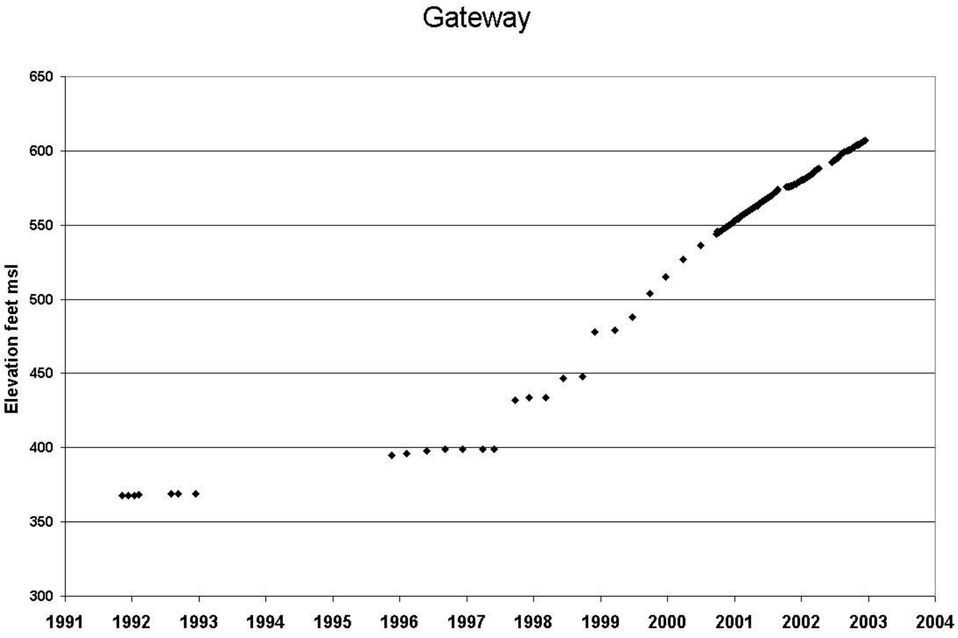

FIG 7 - Gateway hydrograph.

Although considerable effort has been expended in georeferencing the available mapping, there remains a wide range in map accuracy. While some mine locations may be accurate to a few metres, other mines may be out of place by as much as 30 metres. In other locations mapping may not be available even though the coal has been removed. Due to these uncertainties, the maps presented here should not be used for mine subsidence related activities.

ACKNOWLEDGEMENTS

Funding for this work was provided by the US Department of Energy, National Energy Technology Laboratory, and by the US Environmental Protection Agency.

REFERENCES

Leavitt, B R, 1999. Mine flooding and barrier pillar hydrology in the Pittsburgh basin, in *Proceedings Pittsburgh Coal Conference*, September.

Pennsylvania Department of Mines, 1950. Bituminous mining laws of Pennsylvania, Harrisburg, Pennsylvania.

Ruppert, L F, 2001. Chapter A—Executive summary—Coal resource assessment of selected coal beds and zones in the northern and central Appalachian Basin coal regions, in Northern and Central Appalachian Basin Coal Regions Assessment Team, 2000 resource assessment of selected coal beds and zones in the northern and central Appalachian Basin coal regions: US Geological Survey Professional Paper 1625–C, CD-ROM, version 1.0.

United States Geological Survey, accessed 2003. http://waterdata.usgs.gov/nwis/qwdata site number 03063000 water quality data for the Monongahela River at Point Marion, Pennsylvania 1957 - 1976.