THE FUTURE OF MINE-WATER DISCHARGES FROM UNDERGROUND COAL MINES OF THE PITTSBURGH COAL BASIN, WV-PA[1]

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Abstract. Numerous underground coal mines in the Pittsburgh coal basin of West Virginia and Pennsylvania have closed in the period 1980-2003. Of an estimated 1000+ once-active mines, only 11 are currently active, most relatively deep in the basin. These closures have caused flooding of mines and caused new discharges of mine water, of which all are either currently flooding or pumped and treated by mine operators or state agencies.

This newly-created aquifer is a series of semi-interconnected compartments formed by mines separated by barrier pillars of 25->400 feet thickness. The leakage rate through barrier pillars is quite variable spatially and may be either very high (with hydrologically open conditions between adjacent mines) or very low (creating relatively isolated "pools" of one or more mines). Due to this fact and to the various closure dates of mines, the flooding history is complex with mines at a wide variety of water levels and flooding extents. However, experience shows that most mines near the Monongahela River flood within 10 years or less, and thus a new "equilibrium state" is expected to be attained by about 2015. At this time, flooding of most mines will be complete and an estimated 53,000 gpm (85,479 acre-ft/year) of mine discharge – both treated and untreated – will flow into the Monongahela watershed from below-drainage mines. This is in addition to an additional 8000 gpm estimated from above-drainage free-draining mines. At this time, the flooded Pittsburgh coal will become the largest spatially-continuous high-yield aquifer exclusive of Cambro-Ordovician karst aquifers in the Northern Appalachian region.

The locations of discharge from mines are known for 2003, subject to limitations of data availability, and may be speculatively projected for year 2015, subject to numerous assumptions and future circumstances. It is expected that all of the new discharges will require active treatment for metals removal to prevent discharge to the Monongahela and Ohio river watersheds. This resource of treated water may be utilized for other purposes, such as commercial development and aquaculture.

Additional Key Words: Mining hydrogeology, groundwater

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Introduction

Underground coal mines in many cases fill with water to some degree following closure. A number mines have extensive dry areas because they are located above surface drainage; these are capable of producing acidic water for many years. Some, however, extend well below stream levels and, when they fill with water to a new equilibrium after mining, may have very little of their area exposed to air circulation. Such is the case for many mines of the Pittsburgh coal basin (Leavitt et al., 2003). The Pittsburgh coal is a high-sulfur, bituminous seam that has been mined since the 19th century and its reserves are currently nearly 50-60% depleted. The number of mines in this basin is in excess of 1000, yet only 11 mines currently remain active. Numerous large deep mines largely or entirely below surface drainage closed between 1980 and 2003. The result of these closures has been a sequence of flooding events that demonstrate well the nature of mine flooding progress in a complex coal basin with numerous mines. The flooding of mines in this area also illuminates the fact that new discharges which arise from these mines will, ultimately, become a permanent fixture of the hydrologic landscape. The hydrogeology of this region is dominated by bedrock aquifers in which all flow is through fractures, creating aquifers of relatively low permeability (Schubert, 1980; Stoner et al., 1987). The style of aquifer created by deep mining is two or more orders of magnitude higher in hydraulic conductivity than these native fractured rocks, and in addition receives much higher recharge rates in areas of shallow mining (McCoy, 2002).

It is the purpose of this paper to (a) quickly review the mine flooding history of the Pittsburgh basin, (b) estimate what the long-term hydrologic condition of the basin will be in year 2015, a target date for most mines currently flooding to reach post-closure hydraulic "steady-state", and (c) to examine some of the implications of this flooding with respect to water availability for other purposes (e.g., commercial applications and aquaculture).

Methodology

The dataset presented here are a series of maps of mine flooding, generated from a combination of information sources on a conventional GIS platform. The compiled information includes mine outlines, representing the perimeter of each mine; mine pillars, representing interior blocks of coal >20 hectares in area; the coal outcrop location; and structure contours on the bottom elevation of the coal bed. Full details of the procedure are laid out in Leavitt et al. (2003). The most critical element of mine mapping for hydrogeological purposes is maintaining the spatial integrity of coal barrier pillars, which influence the degree of hydraulic connection between adjacent mines and separate individual mine "pools" (portions of the mine aquifer constrained within individual mines that are hydraulically insulated from those of surrounding mines) from their neighbors (Luo et al., 2001; McCoy et al., 2003). The leakage rate through barrier pillars is quite variable spatially and may be either very high (with hydrologically open conditions between adjacent mines) or very low (creating relatively isolated “pools” of one or more mines). Barrier pillars range in thickness from about 25 feet to in excess of 400 feet, and mines must be located to extreme accuracy for these barrier widths to be correctly preserved. Therefore, the mapping was constrained to preserve the geometry and thickness of these barriers as a first priority. Original or duplicate mine maps of scale 1:12,000 or better were used to map the form of the barrier pillars between mines, and these were then used to constrain mine outline location in transferring them from mine maps to vector form.

Utilizing these map representations of barriers and mine outlines, maps of the approximate extent of mine flooding were estimated using historical water level information, either collected by the authors or compiled from a variety of sources. Flooding maps, showing the extent of saturated vs unsaturated conditions on the mine floor, were established for 1980 and 2003. The maps were constructed using straightforward extrapolation of the surveyed mine-water hydraulic head from the point of measurement to all surrounding portions of that particular mine. While there is some variation of hydraulic head within individual mines, it is normally very small in range (<10 feet), due to the very high hydraulic conductivity of the mine aquifer, and the flooding extents of most mines would be relatively insensitive to such minor variations. For some mines, no well hydraulic head data were available, and the flooded area in the mine was inferred from the hydraulic head of the discharge from that particular mine.

The 2003 mine flooding extent was modified to estimate the approximate extent of flooding in year 2015. This projection was not difficult inasmuch as all but about 10 mines were already at a fully-flooded and/or equilibrium hydraulic configuration in 2003. These ten mines fall in two categories: (a) mines that are in 2003 partially flooded and continuing to flood; and (b) anticipated mine closures within the next few years of present. Although the flooding of any specific mine is completely dependent on local conditions, experience has shown that most mines in this portion of the basin, close to the Monongahela River, take less than 10 years to fully flood (Donovan et al., 2003); therefore, the mapped flooding for year 2015 shows the estimated fully-flooded levels of all mines that are either currently flooding or expected to close within the next few years after 2003. It should be recognized that the flooding estimates for 2015 are projections, subject to uncertainties related to the equilibrium water levels the flooded mines attain and to how water management in the basin proceeds.

Mine discharge amounts (in gallons per minute) were also estimated based on field measurements for untreated discharges during 2002-2003 and on reported pumping rates of treatment plants. The discharges shown here exclude above-drainage mines; they represent only mines which are at least partially below-drainage with flooded areas of about 200 acres or greater. For year 2015, discharge rates are extrapolated from the 2003 data, with estimated values for new discharges. The new Flaggy Meadows treatment plant near Everettville, WV, is estimated to increase to 5000 gpm, accounting for the discharges of three mines in West Virginia that are currently flooding and will be fully flooded by about 2005. The Colvin Run plant (Garrard's Fort, PA) was reduced to 500 gpm because the Dilworth mine to the north stopped pumping into it in early 2003. The Crucible-Nemacolin mines may possibly show some new discharge associated with closure and flooding of the Dilworth mine to the west, into which they are interpreted to have leaked water when it was active. The Gateway-Mather-Pitt Gas mines are expected to converge in their flooding to form a new discharge in an unknown location along Ten Mile Creek, in year 2005 or earlier. This discharge may also cause increased pumping rate in the neighboring Clyde mine, for the same reason as the potential Crucible-Nemacolin discharge. The Mathies mine, currently discharging 115 gpm, is expected to show an approximate 500 gpm increase, when the main portion of this mine floods and merges with the small pool that now exists. And the Maple Creek, Dilworth, and Shannopin mines are expected to develop new discharges by that time. Estimates of the magnitudes of these discharges were based either on existing pumping during active operations or, for mines for which no discharge estimates were available, the predictive equation of McCoy (2002), based upon the proportion of the mine shallower than 100 meters of cover above the top of the coal.

Flooding of the Pittsburgh coal, 1980-2003

Year 1980

Fig. 1 shows the extent of mine flooding in year 1980, as well as discharges believed to have been present at this time (yellow circles). The magnitude of the discharge is indicated by the size of the circles, although the discharges have been estimated based on observations in 2001-2003. All of these discharges total to an estimated 33,000 gpm and represent primarily untreated discharges of mines closed prior to this time. The discharges are concentrated mainly in the area south and east of Pittsburgh. There were an estimated 30 active mines at this time.

The mine outlines shown in this figure date to year 2003 and are thus an over-estimation of the area of the active mines in this figure. The mapping for closed mines is accurate.

Year 2003

Fig. 2 shows the extent of mine flooding in the beginning of year 2003, as well as all discharges of flooded mines known at present (orange circles). The white circles are retained from discharges which originated prior to 1980. There were at at this time 11 active mines and relatively few (11) in which the extent of flooding is still increasing.

The new discharges as of year2003 total 45,000 gpm and are concentrated in the Washington PA, Waynesburg PA, and Morgantown WV areas. All these are pumped and treated at mine drainage treatment plants for removal of metals.

Year 2015

Fig. 3 shows the projected extent of mine flooding in the beginning of year 2015, as well as projected new discharges that will have likely evolved between 2003 and 2015 (red circles). The orange and white circles of the earlier discharges are retained from previous figures. There are projected at this time to be 8 active mines and relatively no mines that are still flooding. However,

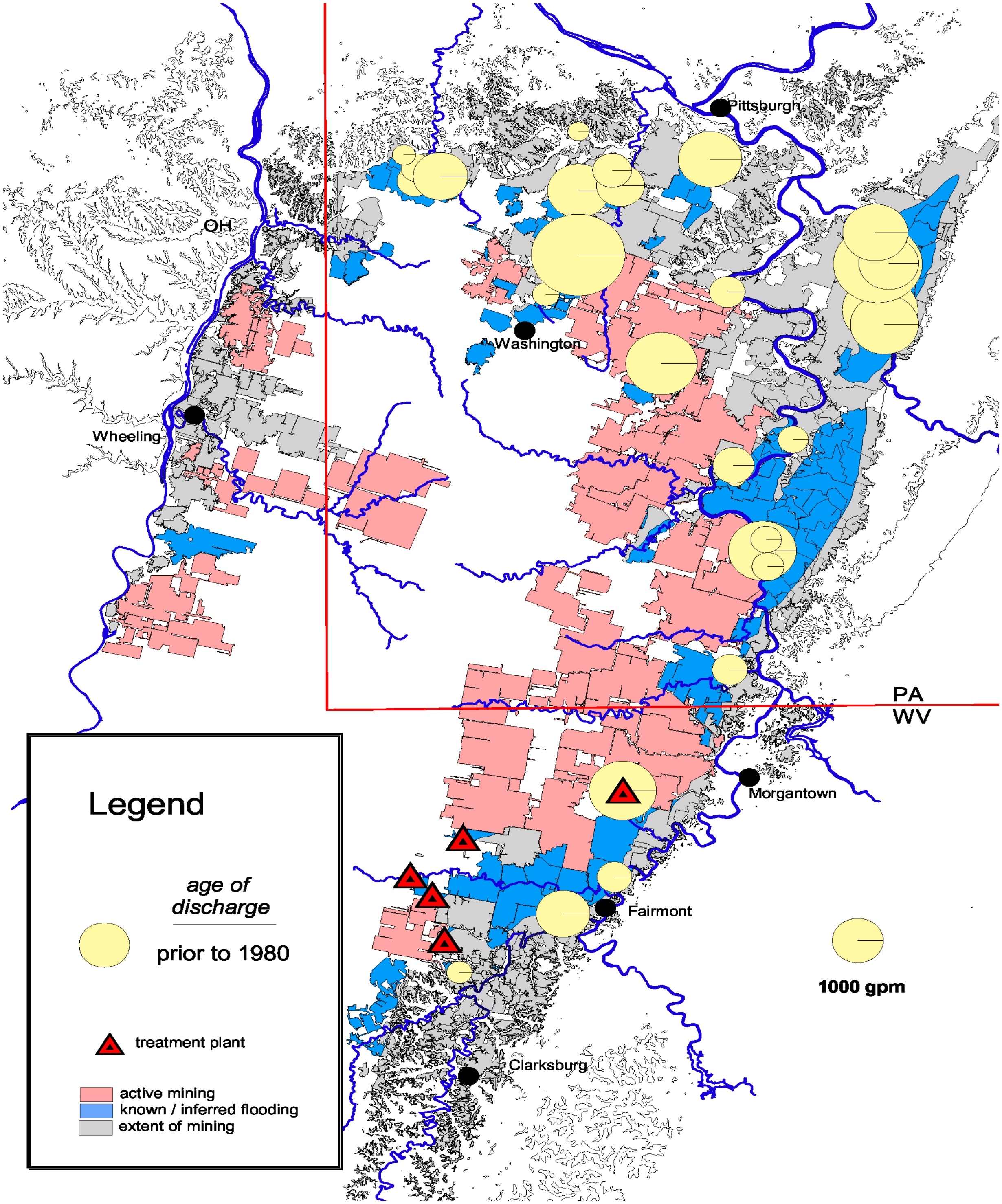

Figure 1. Extent of mine flooding and mine discharge locations/magnitude in year 1980. Base of mine outlines from year 2003 mapping.

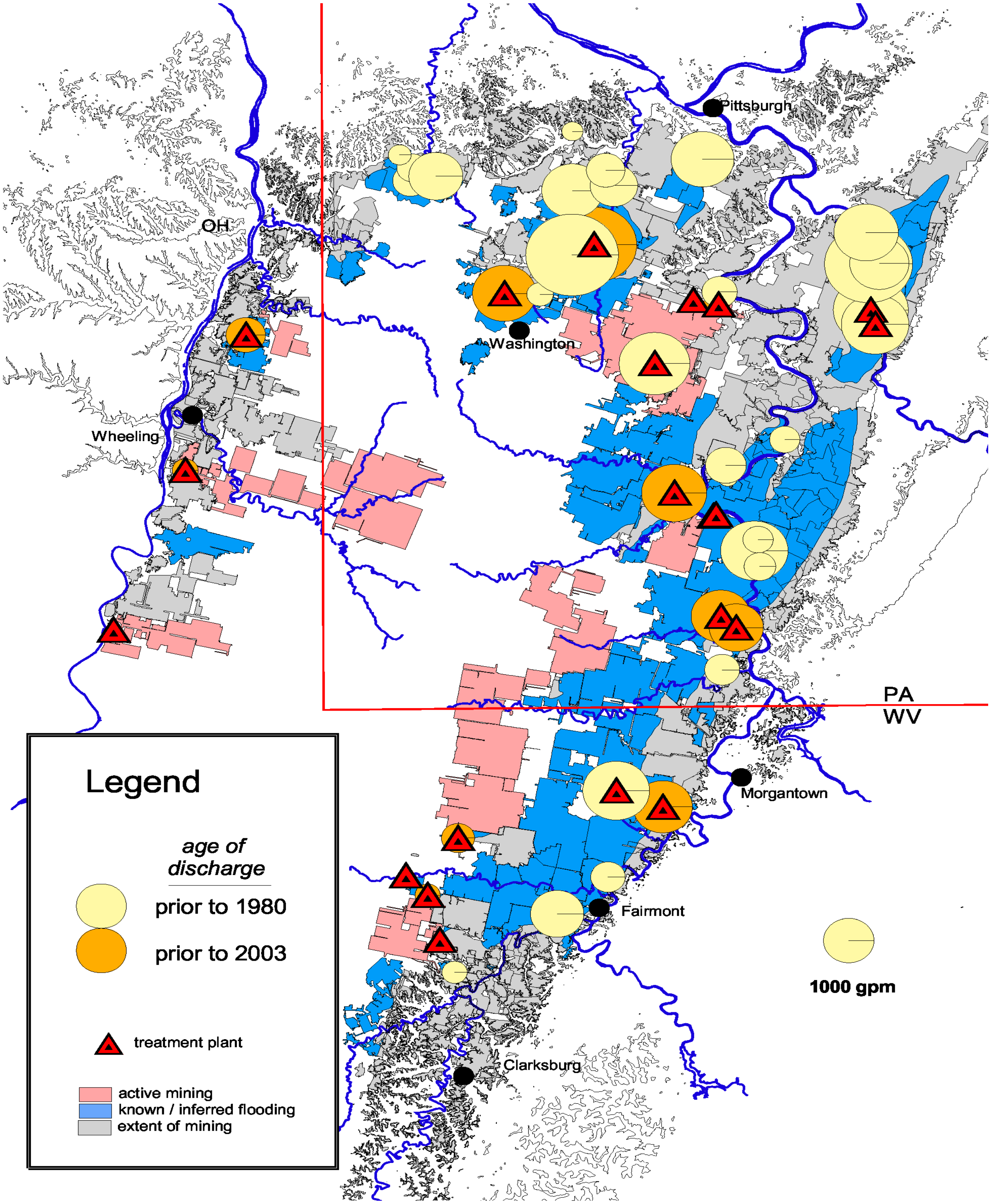

Figure 2. Extent of mine flooding and mine discharge locations/magnitude in year 2003. Base of mine outlines from year 2003 mapping.

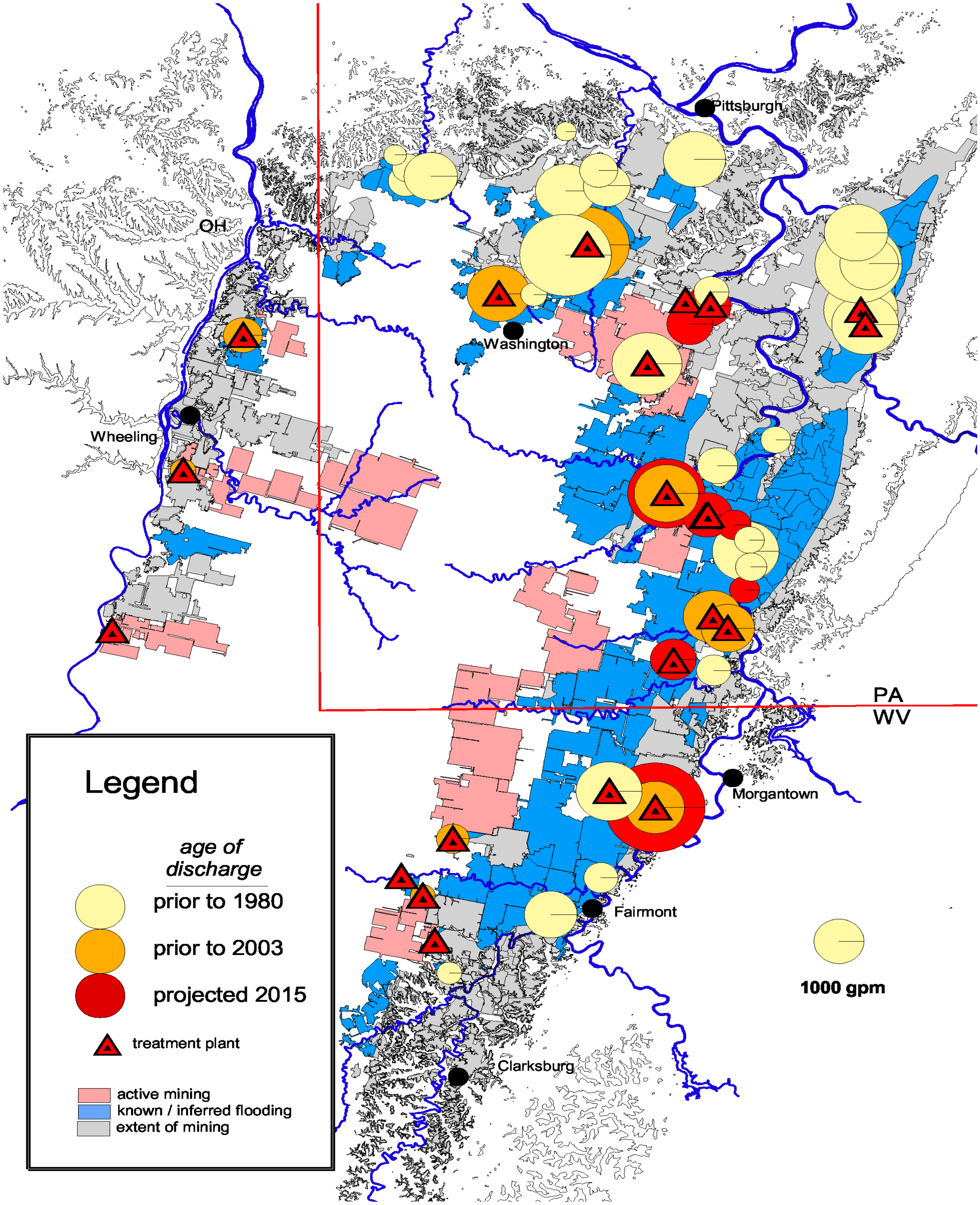

Figure 3. Projected extent of mine flooding and mine discharge locations/magnitude in year 2015. Base of mine outlines from year 2003 mapping.

this projection is very much subject to future mining conditions and is assumed for the sake of this projection.

The new discharges by 2015 – less robustly known than those for 2003 and earlier -- total 53,000 gpm and cover a wide area between Pittsburgh and Fairmont, WV. An extensive number of mine drainage treatment plants will be required to control the impacts of these new discharges. Fig. 3 shows 22 active AMD plants as of 2003, and in some locations, new or larger plants may be required. Alternately, diversion schemes to move water from one or more mines to existing large treatment plants may become a preferred strategy for controlling the mine water.

The total 2015 discharge in the basin from treatment plants is projected to be 27,000 gpm, assuming that all new discharges are served by water treatment plants. This is about triple the amount of such water available in year 1980.

The equilibrated Pittsburgh mine aquifer

In 2015, the "new" aquifer will behave as most natural aquifers do. It will be supported by spatially-distributed recharge and have multiple points of discharge. Once all flooding is complete and water levels in all portions of the aquifer cease rising, it is expected there will be annual fluctuations in water level driven by seasonality, but an overall balance between recharge and discharge. At this point, the aquifer will be at a new hydrologic equilibrium.

There will continue to be deep mining in the basin at greater depth than the flooded mines shown in Figure 3. However, these mines will (by design) have sufficiently thick barriers to greatly limit the amount of barrier leakage into them, especially when they themselves flood and reduce hydraulic gradients with neighboring mines. In addition, these mines are sufficiently deep that their rate of recharge will always be far lower than those mines that are shown as flooded. Thus although mining continues in deeper parts of the basin, these mines will never contribute appreciably (or likely even detectably) to the flow rate of discharges from the shallow mines.

The current (2003) area (1.24 million acres, or 1941 square miles) and total discharge (53,000 gpm) of mines on the eastern and northern sides of the basin make this the highest-yield continuous aquifer in the region, excepting the carbonate aquifers of the Cambro-Ordovician rocks of the folded Ridge and Valley Physiographic Province to the east. The aquifer is about 39% flooded, representing an estimated 1.36 trillion gallons of water in storage. Flooding by the year 2015 will not appreciable increase the flooded area of the basin (a 6% increase) but will substantially (by 18%) increase its discharge.

This paper and its discussion have focused primarily on the eastern and northern sides of the valley. While some mines on the western (Ohio valley) side are known to be partially or wholly flooded, less is known about details of the hydrogeology in this region. No orphan mine discharges of any substantial magnitude are known for the Pittsburgh coal on this side of the basin, and only three treatment plants (two from active mines) are operating. Therefore, the conclusions of this paper pertain only to the eastern and northern portions of the basin. The Ohio Valley side appears to be taking a longer timeframe for flooding to be accomplished.

Summary and Conclusions

The Pittsburgh mine aquifer is in mid- to late-age of its flooding history, and is expected to largely equilibrate to a new steady state by the year 2015. At this time, flooding will have completed on the eastern and northern sides of the basin, and there will be an estimated 41 discharges of any appreciable size from flooded below-drainage mines. A number of these in the northern portion of the basin are quite old discharges and largely untreated, but more recent flooding has created or will create new discharges between Washington PA and and Fairmont WV, all of which to date have been treated for metals removal. These new treated discharges represent a potential water resource for commercial and aquaculture development.

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