NUMERICAL MODELING OF A LARGE MINED SYNCLINAL COAL BASIN, WESTMORELAND COUNTY, PENNSYLVANIA[1]

William R. Winters and Rosemary C. Capo[2]

Abstract. The Irwin Syncline bituminous coal basin has been extensively underground mined with numerous complexes (>95% mined over a 240 km^2 area; Pullman-Swindell, 1977). Earlier work in the Irwin Syncline demonstrated the benefit of dividing the basin into smaller sub-basins based on equilibrium flow conditions established over the past 30 years (Winters et al. 1999; Winters and Capo, in press). MODFLOW numerical modeling was undertaken to quantify the hydraulic relationships within the basin and to corroborate sub-basin delineation over time (~ 5-15 yrs) as post-mining equilibrium hydraulic conditions develop. Boundary conditions are imposed by (1) the coal outcrop, which limits hydraulic influence, (2) the low hydraulic conductivity of the coal seam floor (typically clay, $K \sim 10^{-8}$ cm/sec), and (3) large surface water bodies. Because of these constraints, recharge can be assumed to emanate primarily from infiltration through the overburden rocks. Basin discharge can be directly measured from the large discharges that developed following basin flooding.

In the Irwin basin, the overburden rocks range in thickness from 0 m at the outcrop to 200 m in the interior. Overburden units were modeled as four distinct hydraulic conductivity zones that correspond to classic mine subsidence profile models (Singh 1992). Initial model results indicated that mine water is discharging through the intervening overburden to the Youghiogheny River, which overlies the southwestern portion of the basin. To calibrate the model, 15 mine pool monitoring points from the 1970's were used to establish known hydraulic head elevations in the northern 2/3 of the basin. Hydraulic head elevations in the southern 1/3 were determined from current pumping elevations at two treatment plants in the area. Preliminary results from the calibrated model demonstrate the hydrologic impact of interior coal mine barriers on the flow regime and confirm that the largest discharges ($Q > 0.18$ m^3/s) are the dominant influence on the flow system. Future modeling efforts will concentrate on sensitivity analysis of recharge and other hydraulic parameters and on refinement of methods used for modeling the mine-void aquifer system.

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[2] William R. Winters is a Hydrologist with the US Dept of the Interior, Office of Surface Mining, 3 Parkway Center, Pittsburgh, PA, 15220 and a graduate student at the University of Pittsburgh. Rosemary C. Capo is Associate Professor of Geology and Planetary Science, 200 SRCC, University of Pittsburgh, PA, 15260.

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Introduction

The Irwin Basin was extensively mined over the past 150 years; it is an elongated boat-shaped structure encompassing 240 km^2 (Fig. 1). The Pittsburgh Coal seam forms the basin perimeter above the Youghiogheny River, which forms the southwestern boundary. Basin overburden thickness ranges from 0 m at the outcrop to >200 m in the basin interior. The strata consist of alternating shale, sandstone, and coal with lesser limestone beds throughout.

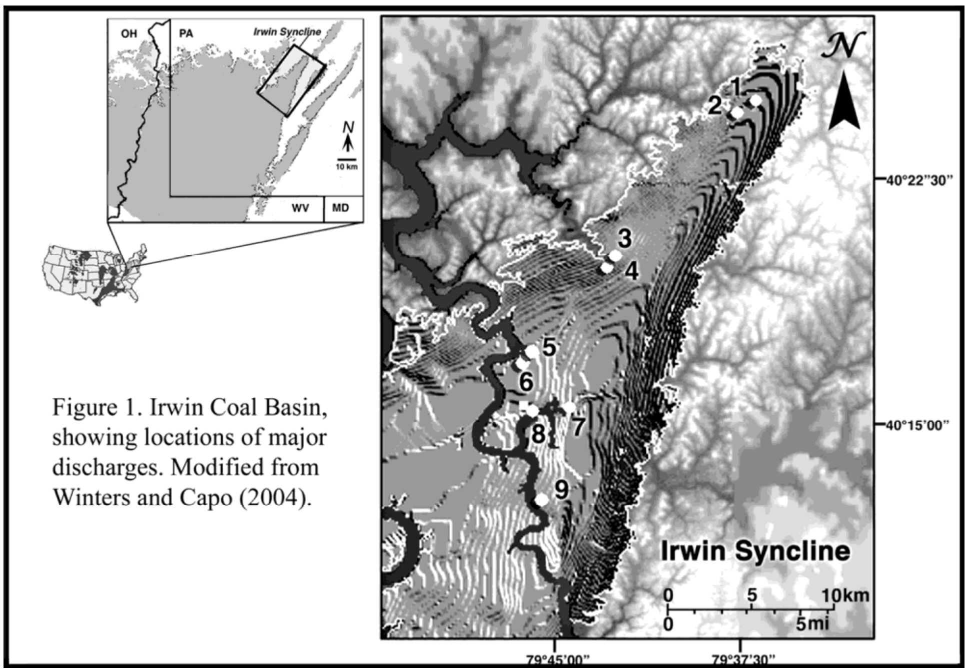

Figure 1. Irwin Coal Basin, showing locations of major discharges. Modified from Winters and Capo (2004).

Methodology

A 24 layer Groundwater Vistas model was assembled using layers 7.5 m (25 ft) thick. The model was divided into five zones corresponding to mine subsidence theory (Kendorski 1994) (Fig 2): (1) the *mined coal seam*, (2) a *cave zone* with fractures propagating to a height of 2 to 10 times the mined thickness, (3) the *fractured zone*, 10 to 24 times the mined thickness, (4) an *aquiclude zone*, and (5) a *surface zone*.

Forty-three rows were used to simulate basin width (305 m; 1000 ft) with 112 columns simulate length (305 m; 1000 ft) for a total of 115,584 cells. Inactive/no-flow cells were used to simulate basin geometry in the x-y plane and also along the basal unit to simulate the synclinal plunge. Coal barriers were placed at sub-basin divides. Cross-sectional model thickness is 185 m (600 ft) with a bottom elevation of 185 m (600 ft) above mean sea level (AMSL) and maximum topographic elevation of 365 m (1200 ft) AMSL corresponding to actual in situ elevations.

No-flow boundary conditions were assigned to the basin periphery at the Pittsburgh Coal outcrop on the top and sides of the model. River boundary conditions were assigned to layer 17 (245 m /800 ft AMSL) to simulate actual Youghiogheny River elevation. The nine discharge points (Fig. 1) were assigned as pumping wells in the model layer corresponding to discharge elevation and physical location. The discharge rate was based on average flow measured at each discharge location. Model convergence was determined to be 3 cm (0.1 ft) head difference between successive iterations; convergence was achieved in 155 iterations. Seven Pennsylvania Department of Environmental Resources Operation Scarlift mine pool monitoring points were used as calibration points for this modeling effort. Table 1 shows relevant model parameters.

Table 1. Parameters for model layers, assuming confined aquifer conditions. **K** = hydraulic conductivity, (ft/day); **S** = storativity (dimensionless); $\mathbf{S_y}$ = specific yield (dimensionless); **n** = porosity (%).

Layer	K_x	K_y	K_z	S	S_y	n	Aquifer Zone
1	0.1	0.1	0.005	0.05	0.1	0.15	Surface
2	0.001	0.001	0.0015	0.005	0.15	0.20	Aquiclude
3	0.05	0.05	0.01	0.005	0.15	0.25	Fractured
4	700	700	700	0.005	0.15	0.20	Delmont/Export Void
5	0.5	0.5	0.5	0.001	0.15	0.20	Coal Barrier
6	500	500	500	0.001	0.15	0.20	Irwin Void
7	500	500	500	0.001	0.15	0.20	Marchand Void
8	100	100	100	0.001	0.15	0.20	Banning Void

Model Results

Preliminary results for the Irwin basin indicate that steep gradients form along competent mine barriers, effectively creating sub-basins within the larger mined basin (Fig. 2). Water flow does occur across competent barriers; this result reinforces the importance of lithological integrity when considering barriers for future mines. The largest mine discharges control the dynamics of the equilibrium flow regime. Earlier work suggested water entered the basin in the northern reaches, moved along the basin plunge and exited in the lower portions of the Irwin basin. However, modeling indicates that the underlying mine voids have a greater affect on the overall flow system than previously understood.

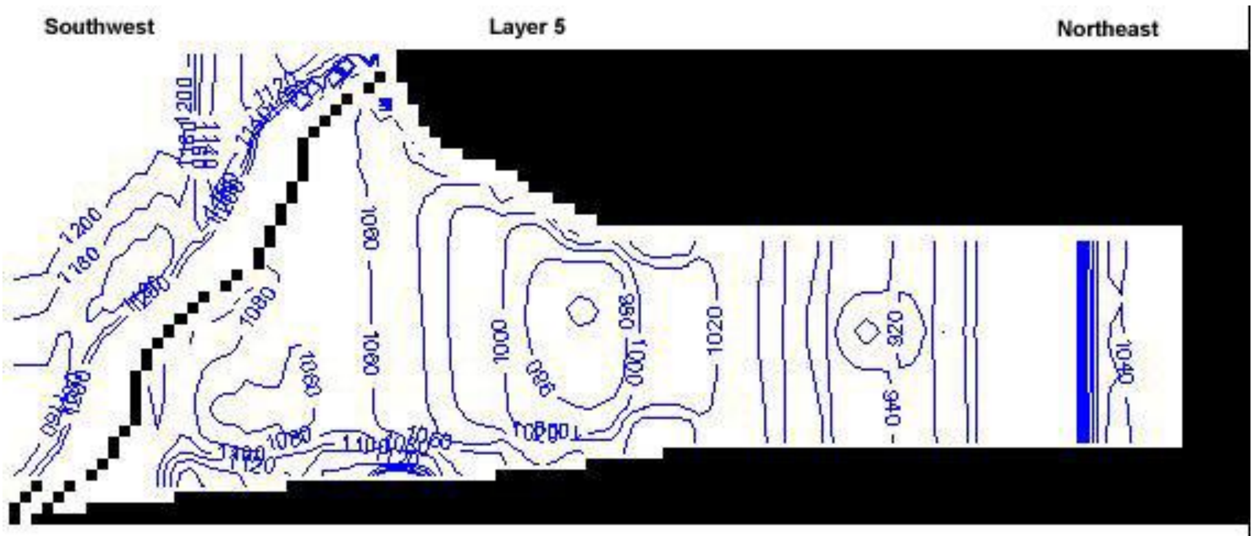

Figure 2. Potentiometric map of the Pittsburgh coal seam in the Irwin basin in the Groundwater Vista model. Contour interval is 20 ft.

Prior to installation of the Banning and Euclid treatment facilities in the Banning Mine complex, the Banning sub-basin discharged water along the flood plain adjacent to the Youghiogheny River. Currently, pumping keeps the mine pool at or below river elevation in the lower section of the sub-basin but modeling suggests that mine water is discharging to the river in areas away from the pumping wells. It is also evident that the underlying mine voids act as a large underdrain for the entire Irwin coal basin. Downward hydraulic gradients are evident throughout much of the basin, but modeled hydraulic head indicates that strata overlying the mine voids are capable of supporting water wells. Field reconnaissance substantiates this result.

Individual mine pool velocity varied according to location along the respective flow path (Fig. 3). Mine water velocities were greatest in areas closest to the discharge and slowest toward the back end of each respective sub-basin.

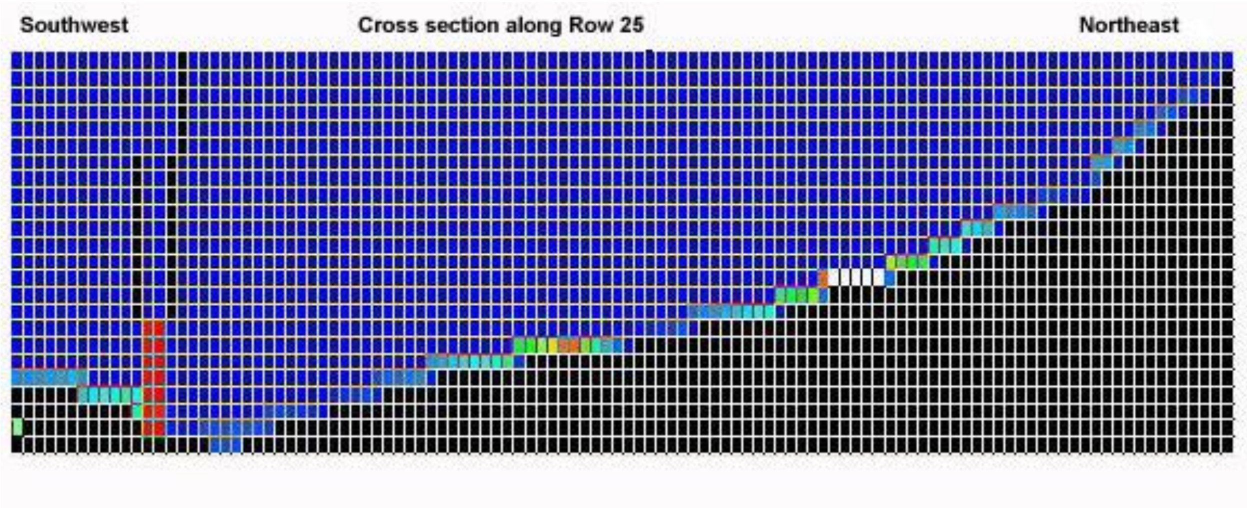

Figure 3. Color flood image of velocity along the longitudinal profile of the Irwin Basin Groundwater Vistas model. Velocities (ft/day): White >20; Red 18-20; Orange 16-18; Yellow 14-16; Lime-green 9-14; Aqua 4-7; Dark Blue 0-3.

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