HYDROLOGIC ASSESSMENT OF WELLHEAD PROTECTION IN THE VICINITY OF A ROOM-AND-PILLAR COAL MINE[1]

Perry M. Jones[2] and John L. Ellenberger[3]

Abstract: The U.S. Bureau of Mines is identifying and assessing various hydrogeologic and mining variables important in delineating wellhead protection zones around public supply wells in mining regions. As part of this study, researchers are monitoring hydrologic conditions between the Solar No. 7 Mine, an active underground coal mine, and three municipal wells in the borough of Stoystown, PA. Key variables important in determining the hydrologic interaction between mining activities and municipal water use have been monitored at the Stoystown field site. These variables include pumping rates and water levels in the three municipal wells, ground-water inflow rates into the mine, and water levels and water quality in three aquifer systems. The borough of Stoystown extracts on the average a total of 125,000 L (33,000 gal) per day from the three municipal wells. An average of 567,750 L (150,000 gal) per day of ground water is pumped from the Solar No. 7 Mine. Except in one monitoring well set which was undermined, no changes in water yield or quality in the municipal wells or the monitoring wells have been seen, thus far, that can be attributed to mining activity. Results from future model simulations will be used to demonstrate how the impact of mining on water quantity and quality can be taken into account in the delineation of wellhead protection zones, and how future mine planning can be incorporated into local wellhead protection programs.

Additional Key Words: wellhead protection, room-and-pillar coal mine, municipal pumping rates, ground-water inflow to mine workings.

Introduction

1986 Amendments to the Safe Drinking Water Act established the Wellhead Protection Program, a program designed to protect ground waters that contribute drinking water to public supply wells and wellfields (U.S. Environmental Protection Agency 1990). Under this program, State and local governments are required to establish wellhead protection areas (WHPA) around public well water supplies in their State based on reasonably available hydrogeologic information on ground-water flow, recharge, and discharge, and other information deemed necessary to adequately determine the WHPA. Within these protection zones, communities will develop management approaches and contingency plans, including the implementation of land use control measures, to prevent and limit the impact of any contamination of the water supply. Aquifers which serve as significant sources of public water supply systems are protected against diminution under regulations established through the Surface Mining Control and Reclamation Act (U.S. Code of Federal Regulations 1993).

The U.S. Environmental Protection Agency has outlined six possible methods for the delineation of WHPA's around public supply wells (U.S. Environmental Protection Agency 1987). These methods vary in complexity and cost. In principle, the method chosen for delineation should depend on the complexity of the hydrologic setting. However, owing to the limited availability of hydrologic information and the relatively high costs of collecting and analyzing detailed information, most communities and permitting agencies are forced to apply simple, less precise methods for delineating WHPA's. These simple methods usually do not take into account the various hydrological complexities found in mining areas, such as abandoned and active, surface and underground mine workings, longwall mining excavations, and mine dewatering, on the size and shape of capture zones of public supply wells used for delineating wellhead protection areas. When overly-simplified methods are applied in hydrologically complex settings, there is no assurance that delineated wellhead protection zones will adequately protect the water supply from mining-induced ground-water contamination, especially following mine abandonment and partial flooding. Protection zones need to be delineated accurately enough to effectively protect the water supply while minimizing control measures placed on local land users.

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Many well water supplies in the United States have been contaminated as a result of local and/or regional land use activities involving mining. Water from four municipal wells of the Milltown, MT, water system were found to have arsenic concentrations of more than four times the EPA maximum contaminant level for arsenic (0.05 mg/L) (Lambing 1991). These high arsenic levels were a result of the dissolution of mine tailings in the Milltown Reservoir, which were transported downstream in the Clark Fork River and its tributaries from the mining areas of Butte and Anaconda, MT. Several public water supplies in the Appalachian coal mining regions of Pennsylvania and West Virginia have either been contaminated by acid mine drainage or suffered significant decreases in well yields or total water loss owing to mine subsidence (American Water Works Association, 1992). The potential impact of nearby mining on drinking water supplies is currently a very strong concern in many mining communities throughout the United States (Shesky 1993, Thurston County (WA) Public Health and Social Services Department 1993).

To address this concern, the U.S. Bureau of Mines is identifying and assessing various hydrogeologic and mining variables important in delineating wellhead protection zones around public supply wells in mining regions. As part of this study, researchers are monitoring hydrologic conditions between an active underground coal mine and the three municipal wells of the Borough of Stoystown, PA. In this study, researchers will demonstrate how the hydrologic impact of mining can be taken into account in the delineation of wellhead protection zones and how future mine planning can be incorporated into local wellhead protection programs.

Research Site

General Description

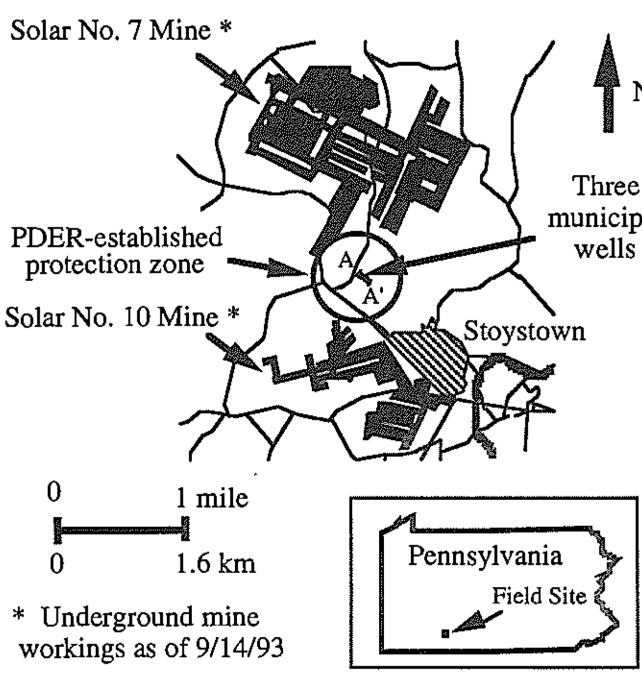

Figure 1. Plan view of field site.

The research site is located in Quemahoning Township of Somerset County, PA, just northwest of the borough of Stoystown, PA (fig. 1). The terrain is hilly with steep to moderate slopes, with a dominantly dendritic drainage pattern over the area. Topographic relief is approximately 167.6 m (550 ft). Land use consists mainly of rural dwellings and small agricultural croplands and grazing lands separated by small woodlots. Average precipitation for the Stoystown Area is roughly 104 cm (41 in) per year (National Oceanic and Atmospheric Administration, 1956-93).

Half of the 432 residents of Stoystown obtain their drinking water from three municipal wells located roughly 1.2 km (0.75 mile) northwest of the center of the borough (fig. 1). The three wells, denoted 6, 8, and 9, lie within a small stream valley less than 36.5 m (120 ft) apart (fig. 2). Wells 6, 8, and 9 are 79.25 m (260 ft), 92 m (302 ft), and 121 m (397 ft) in depth, respectively. The wells are open holes except for surface casings ranging in length from 12.2 to 12.8 m (40 to 42 ft) (fig. 2). The Pennsylvania Department of Environmental Resources (PDER) has established an 548.6-m (1,800-ft) radial protection zone around the three municipal wells to protect the water supply from any potential hydrologic impacts of mining (fig. 1).

Two active room-and-pillar underground coal mines, the Solar No. 7 and 10 Mines, are operating in the Upper Kittanning coal seam outside of the PDER-established protection zone (fig. 1). Average daily extraction rates for the Solar No. 7 and 10 Mines are 2,500 and 1,000 st, respectively (Lick 1991). At the location of the municipal wells, the Upper Kittanning coal seam lies 78 m (256 ft) below the land surface, 22.6 m (74 ft) above the Lower Worthington Sandstone.

The Upper Kittanning coal seam is present in each of the open holes of the three municipal wells (fig. 2). Local concern exists that the mining of the coal seam may impact the water quality and quantity in the three municipal wells.

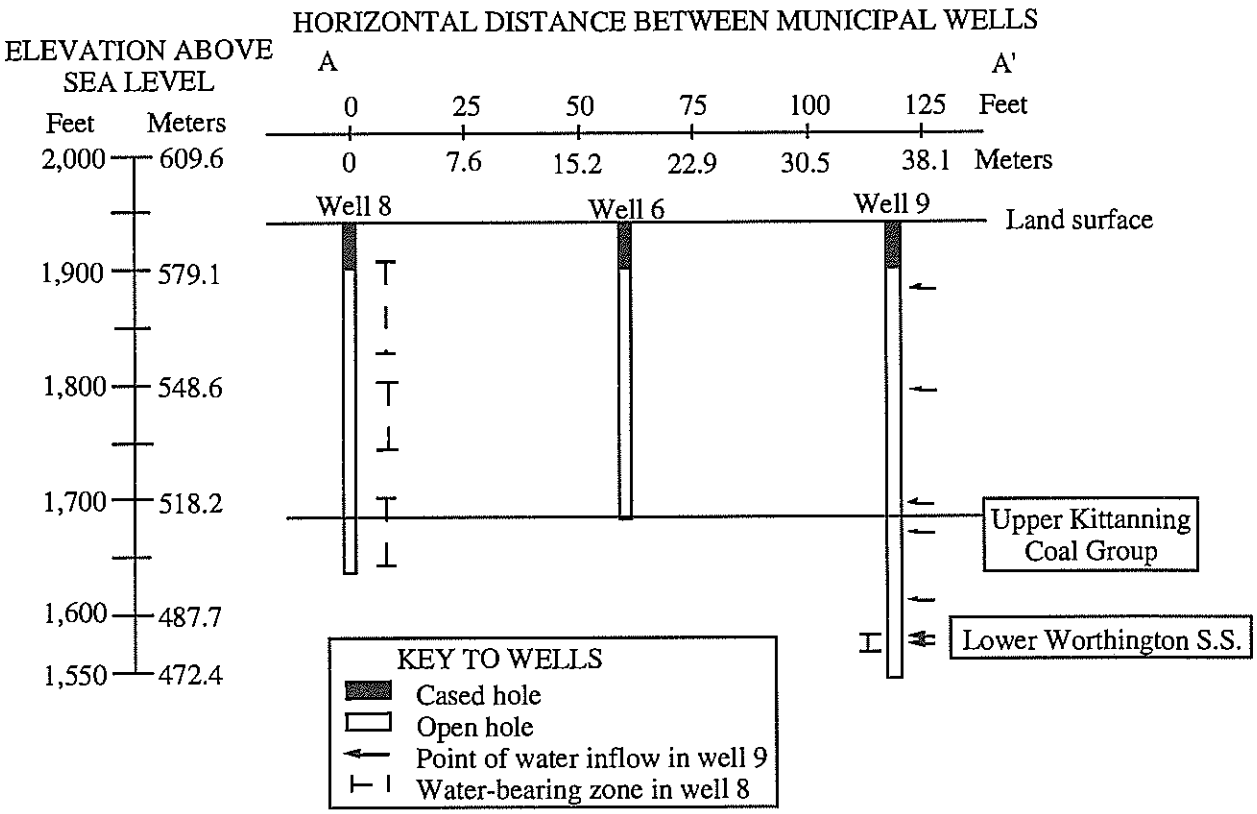

Figure 2. Vertical cross section of Stoystown municipal wells.

Active mining in the Solar No. 7 Mine is proceeding along the 1,800-ft radial protection zone surrounding the municipal wells, while active mining in the Solar No. 10 Mine is more than 1.6 km (1.0 mile) from the municipal wells, heading in a southwesterly direction away from the municipal wells. Therefore, initial hydrologic assessment has focused on the hydrologic impacts of the Solar No. 7 mine. The hydrologic impacts of the Solar No. 10 Mine are being assessed in a separate study.

Key variables important in assessing the hydrologic interaction between mining activities and municipal water are the pumping rates, water levels, and water quality in the three municipal wells, ground-water inflow and pumping rates at the Solar No. 7 Mine, and water levels and water quality in local ground-water flow systems. Each of these variables is currently being monitored and assessed at the site.

Municipal Water Quantity and Quality

Daily pumping rate and number of pumping hours vary among the three municipal wells. Daily pumping schedules for these wells varies seasonally. In general, only two of the wells are pumping at any time. A pressure/flow data-logging system was installed on each well to monitor average hourly water levels and pumping rates in the municipal wells.

The borough of Stoystown extracts on the average a total of 125,000 L (33,000 gal) per day from the three municipal wells. Under the highest water demands of 1993, the three wells pumped 257,400 L (68,000 gal) per day in July. Well 6 is pumped continuously at flow rates varying from 24.6 to 30.3 L (6.5 to 8 gal) per minute, while water levels in the well vary little from 9.75 to 12.2 m (32 to 40 ft) below the top of the well casing (table 1). This pumping scenario changes little on a seasonal and annual basis. Any water level fluctuations in well 6 appear to be due to seasonal changes in ground-water recharge rates from seasonally variable precipitation rather than to changes in pumping conditions in the two other municipal wells.

Well 8 is normally pumped over 1- to 2-h intervals four times a day, allowing water levels to recover for 4 to 5 h between pumping intervals (table 1). Pumping rates in this well during the first few minutes of pumping can be as high as 121.1 L (32 gal) per minute, decreasing to 75.7 L (20 gal) per minute after the first hour of pumping, and gradually decreasing to 53 to 60.6 L (14 to 16 gal) per minute at the end of the 2-h pumping intervals. Average drawdown during these 2-h pumping periods is 30.5 m (100 ft), but can be as much as 38.1 m (125 ft), returning back to the water level before pumping after 2 h of recovery.

Table 1 - Common Daily Pumping Schedules For Stoystown Municipal Wells *

Pumping parameter	Well 6	Well 8	Well 9
Length of Pumping Periods (h)..................	24	1-2	2-3
Pumping Rates (Lpm).........................	24.6-30.1	75.7-121.1	94.6
Number of Pumping Periods.......................	1	4	4
Length of Recovery Periods (h)..................	0	4-5	3-4
Total Pumping (h).......	24	4-8	8-12
Total Water Pumped (L)			
Minimum...................	35,400	23,600	45,400
Maximum...................	43,300	47,200	68,100

Well 9 is normally pumped at a constant rate of 94.6 L (25 gal) per minute over 2- to 3-h intervals four times a day, allowing 3 to 4 h for water level recovery (table 1). Water levels decline at a much slower rate in well 9 than in well 8 during pumping, only dropping between 12.2 to 15.2 m (40 to 50 ft) during the 2- to 3-h pumping period, with water levels varying between 85.3 and 106.7 m (280 and 350 ft). This indicates that well 9 is pumping from a better source of water quantity than well 8. Unlike well 8, well 9 can be pumped at a rate of 94.6 L (25 gal) for several days without becoming dry. Water level monitoring of wells 6 and 8 during 48-h constant discharge tests conducted in well 9 in this study and by Casselberry (1990) indicated no water level declines in the two shallower wells during pumping of the deeper well. No changes in the water levels of wells 6 and 9 were seen during constant discharge tests conducted in well 8, indicating no interaction between the wells. However, the tests conducted in well 8 lasted only 2 to 3 h, possibly not long enough to see the impact of pumping on local water levels.

Table 2 - Average ionic concentrations in waters from Stoystown municipal wells. *

Chemical parameter	Well 6	Well 8	Well 9
Calcium.........................	36.2	35.4	7.1
Iron, total.......................	0.37	0.04	< 0.01
Magnesium....................	10.7	10.5	2.0
Sodium...........................	18.7	22.7	85.5
Hardness (Ca, Mg) (mg/l as $CaCO_3$)...........	134	132	26
pH.................................	8.2	8.1	8.6
Alkalinity to pH 4.5 (mg/l as $CaCO_3$)...........	142	138	200
Sulfate............................	20	16	< 5

* Measurements are in mg/L unless otherwise specified.

Dissolved ion concentrations in waters from the three wells indicate that the two shallower wells obtain their water from a common source, relatively shallow bedrock aquifers, while water from well 9 is a much softer water, with lower concentrations of sulfate and iron (table 2).

Solar No. 7 Mine - Water Inflow and Pumping

Active mining in the Solar No. 7 Mine is occurring in two different sections of the mine near the 1,800-ft protection zone: sections north-to-northeast of the municipal wells and sections northwest of the wells (fig. 3). During the first 9 months of 1993, an average total of 34,200 mt/month (37,600 st/month) of coal was extracted by these two sections. In both sections of the mine, pillars are currently not being extracted, minimizing any immediate subsidence impact on the local hydrology. No future plans for mining these pillars exist.

An average of 567,750 L (150,000 gal) of ground water is pumped from the Solar No. 7 Mine on a daily basis. This average value is more than four times the average daily pumping of ground water from the Stoystown three municipal wells (125,000 L). Pumping rates from the mine vary seasonally between 473,125 L (125,000 gal) to 1,514,000 L (400,000 gal) per day. Higher pumping rates occur in spring as snowmelt occurs, while the lower pumping rates occur in the summer and winter. Water pumped from the mine is discharged to a treatment pond, where lime is added to reduce the water's acidity. Once treated, the water is discharged to a local stream.

A large amount of the ground water entering the mine is produced from abandoned sections of the mine located below local stream valleys. Roughly 50% of the workings in the mine have been secondary-mined and abandoned, with 10% of these abandoned workings lying below stream valleys. Total water inflow into abandoned sections lying below stream valleys varies seasonally from 151,000 to 492,000 L/d (40,000 to 130,000 gal/d), with an average inflow of 306,000 L (80,800 gal) per day. Although only accounting for 5% of the spatial extent of the mine, these abandoned sections account for roughly 54% of the ground-water inflow into the mine. Water flowing into these abandoned sections of the mine is thought to be produced from fractured bedrock systems located above the mined coal seam.

The rate of water inflow along active and abandoned sections of the mine is low compared to the abandoned sections of the mine below stream valleys. The roof and walls of the accessible sections of the mine are very dry, indicating that the water is being produced from aquifer systems lying below the mined coal seam.

Local Hydrogeology

Constant discharge flow tests conducted during and after well construction indicated that water from the two shallowest municipal wells, Nos. 6 and 8, is obtained mostly from shallow bedrock aquifers lying above the Upper Kittanning coal seam, while well 9 obtains most of its water from the deeper Worthington Sandstone aquifer located below the Upper Kittanning coal seam (Casselberry 1990). Using drawdown analyses developed by Theis (1935) and Jacob (1950), transmissivity values obtained from these flow tests ranged from 57 to 125 L/d/m (49 to 108 gal/d/ft) for bedrock aquifers lying above the mined coal seam, while transmissivity values for the Lower Worthington Sandstone lying below the mined coal seam varied from 798 to 2725 L/d/m (692 to 2,362 gal/d/ft).

In order to monitor flow conditions in these two different ground-water flow systems, four sets of monitoring wells were installed between the Solar No. 7 Mine and the three municipal wells. These well sets are labeled A, B, C, and D on figure 3. Three of these well sets were positioned within the established protection zone, while the fourth set was located half the distance between the municipal wells and the protection zone within a stream valley. Each set contains three wells constructed to monitor three different aquifer systems: upper fractured bedrock aquifers above the Upper Kittanning coal seam, the Upper Kittanning coal seam, and the lower Worthington Sandstone Aquifer. The wells in each set are less than 15 m (50 ft) from one another and are only opened to one of the three different aquifer systems. Water levels and water quality are being monitored in each well set on a weekly and bimonthly (every two months) basis, respectively.

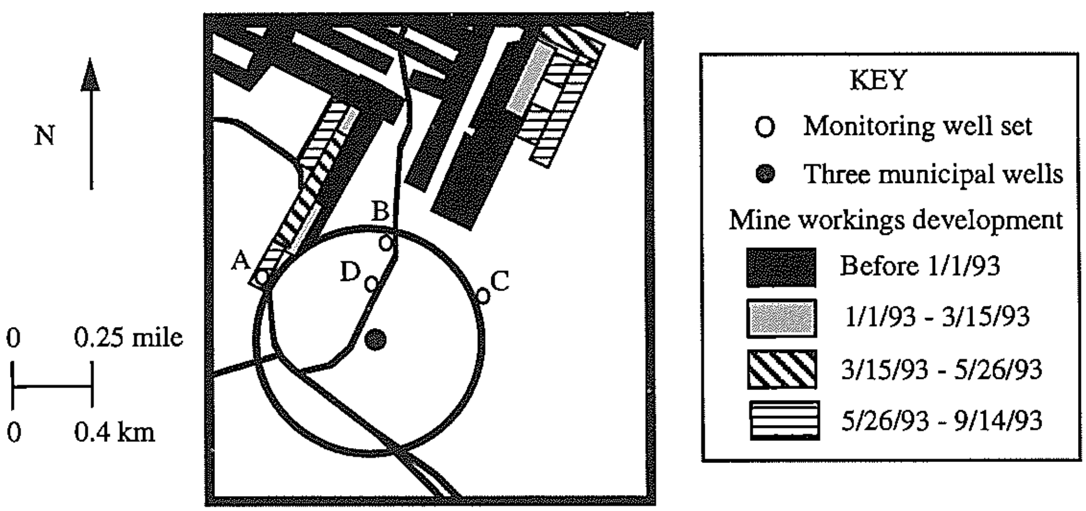

Figure 3. Locations of monitoring well sets and Solar No. 7 Mine workings development in 1993.

Water levels in three of the four monitoring well sets indicated that hydraulic head conditions in the Upper Kittanning Coal unit are lower than in the Lower Worthington Sandstone, suggesting a possible upward flow of ground water from the sandstone to the coal unit. This conclusion is supported by the observation that most of the water entering the active sections of the Solar No. 7 Mine not beneath valley settings is produced from aquifer systems lying below the coal seam. Vertical pressure gradients in these three well sets vary among the sets and over time, ranging from 0.05 to 2.04 m (2 to 80 in) of water pressure per meter of elevation difference between the coal seam and the sandstone unit.

Average water levels in fractured aquifers above the coal seam in all of the well sets are higher than water levels in the Upper Kittanning coal seam and the Lower Worthington Sandstone, indicating flow downward in aquifers lying above the coal seam. Water quality analyses of the monitoring wells opened to aquifers above the coal seam are quite similar to chemical analyses of water from municipal wells 6 and 8, indicating common sources of water.

When pumped, wells opened to the Lower Worthington Sandstone (one well in each set) are very slow to recover, some taking weeks to months to fully recover. Slow water levels recoveries are seen in the Lower Worthington Sandstone monitoring wells of well sets located in both hillside and valley settings. These slow recoveries suggest that the sandstone at these locations is less permeable than at the location of municipal well 9. Well 9 could be intercepting a highly permeable fracture system located within the sandstone unit, with recharge potentially coming from shallow fractured units. Since water levels in the monitoring wells are much slower to recover than water levels in the municipal wells, the monitoring wells opened to the Lower Worthington Sandstone do not appear to intercept this fracture system. Future hydrologic and geochemical testing, such as isotopic dating of waters, may provide further insight into the difference between the permeability encountered in the monitoring wells as contrasted to the municipal supply wells.

Impact of Mining on the Local Hydrogeology

On June 10, 1993, 336 days after the wells were drilled, monitoring well set A was undermined. This well set is located northwest of the municipal wells along the established protection zone (fig. 3). As it undermined the well set, the mine cutting through the well opened to the Upper Kittanning Coal seam. A 30.5-m (100-ft) pillar was established around the other two wells in the set to protect their integrity. Following undermining, water entered the mine from the floor, indicating that the source of this inflowing water was below the coal seam.

Wells in monitoring well set A were pumped for water sampling purposes several times prior to the workings intercepting the well set on June 10 (336 days after drilling) (fig. 4). Significant decreases in water levels associated with this pumping were seen in all three of the wells between 230 and 245 days after well drilling (fig. 4). Because of these pumping events, water levels in these wells had not fully recovered prior to undermining.

As the mine approached the well set, water level decreases associated with the approaching workings were seen in the wells monitoring the Upper Kittanning coal seam and the upper bedrock aquifers on May 11, 1993, 30 days before the workings intercepted the well (fig. 4). On that date, the workings had approached within 122 m (400 ft) of the well set. Water levels in the upper bedrock aquifer well declined 1.5 m (5 ft) from May 11 to May 27 (322 days after drilling). This well was pumped for water sampling on May 27 (fig. 4). Following pumping, water levels in the upper bedrock aquifer well recovered to levels seen prior to May 11. Water levels in the Upper Kittanning coal well continued to decline after May 11, dropping 8.5 m (28 ft) over the 30 days prior to the workings intercepting the well (fig. 4). Before the well was actually cut by mining equipment, 8 m (26 ft) of water was standing in the Upper Kittanning coal well. Water levels in wells monitoring the Upper Kittanning coal seam and the upper bedrock aquifers in other well sets remained constant during the month of May, indicating no relationship between the recorded water declines and seasonal fluctuations in the local water levels.

Water levels in both the upper bedrock aquifers lying above the coal seam and the Lower Worthington Sandstone continued to rise during recovery from pumping as the mine passed through the well set (336 days after drilling) (fig. 4). Also the rate of water level recovery from pumping in both wells did not change following undermining, indicating that the workings did not have a long-term impact on the upper fracture bedrock aquifers and any impact on the Lower Worthington Sandstone at the time of well interception. Inflow rates and water levels in the monitoring wells will continue to be monitored and assessed over time to see if water levels in the wells return to pre-pumping levels.

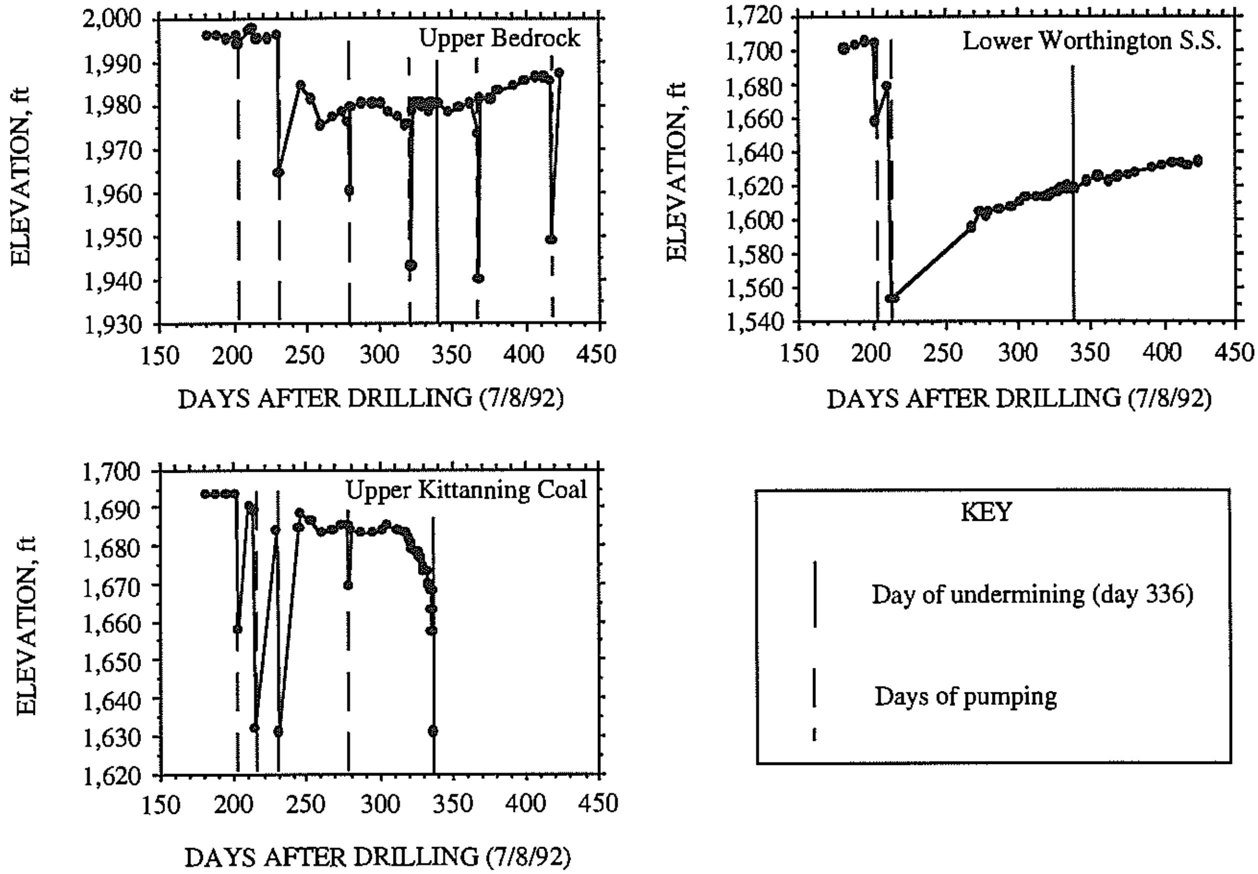

Figure 4. Water levels in monitoring well set mined through by Solar No. 7 Mine.

Water Quantity and Quality Implications of Mining on Wellhead Protection

As defined in the Safe Drinking Water Act, wellhead protection areas are "the surface and subsurface area surrounding a water well or wellfield, supplying a public water system, through which contaminants are reasonably likely to move toward and reach such water well or wellfield" (U. S. Environmental Protection Agency 1987). This definition addresses wellhead protection as a method of protecting public well water supplies from potential water quality problems. In mining regions, wellhead protection has to address both potential water quantity and quality problems that may occur as mine workings are developed and eventually abandoned.

Thus far, wellhead protection at the Stoystown field site has focused on water quantity issues as the size and shape of the capture zone for the mine changes with the advancement of workings. Water quality will become a more important issue as workings are abandoned and allowed to flood. As flooding occurs, the amount and residence time of ground water in the mine will increase, increasing the amount of water/mineral contact. Pyrite and other iron sulfide minerals present in the coal seam will be dissolved at a higher rate, increasing the acidity of the water present in the mine. Although the abandonment of the Solar No. 7 Mine is not planned for the near future, the potential hydrologic impact of future abandonment, as well as the current impacts of mining, needs to be accounted for in the current analysis of wellhead protection zone delineation.

At the Stoystown research site, average daily water inflow rates in the Solar No. 7 Mine are more than four times the average daily water extraction from Stoystown's three municipal wells. Inflow rates are expected to increase as the mine workings advance under local stream valleys north of the municipal wells. Water level and water quality will continue to be monitored in the well sets as the workings advance around the 1,800-foot protection zone. In particular, collected water quality data will be used to assess the impact of flooded mine workings on ground-water quality. Water level and quality data from the municipal wells and monitoring well sets indicate that mining in the Solar No. 7 Mine has had no immediate impact on the Stoystown water supply. Thus far, no changes in water yield or water quality in the municipal wells or the monitoring wells, except for the undermined well set A, have been seen that can be attributed to advancing mine activity or water pumping from the mine.

Collected hydrologic information is currently being used in the Bureau's hydrologic model, Mineflow, to simulate the capture zones of the mine workings and the municipal wells and particle transport from abandoned, flooded workings. Changes in the size and shape of these capture zones will be assessed as mine workings continue to be developed in the area and new municipal pumping scenarios are implemented. The potential impact of future flooding of the Solar No. 7 Mine on the municipal water supply quality will also be addressed through a series of model simulations. Results from these model simulations will be used to demonstrate how the hydrologic impact of mining can be taken into account in the delineation of wellhead protection zones and how future mine planning can be incorporated into local wellhead protection programs.

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