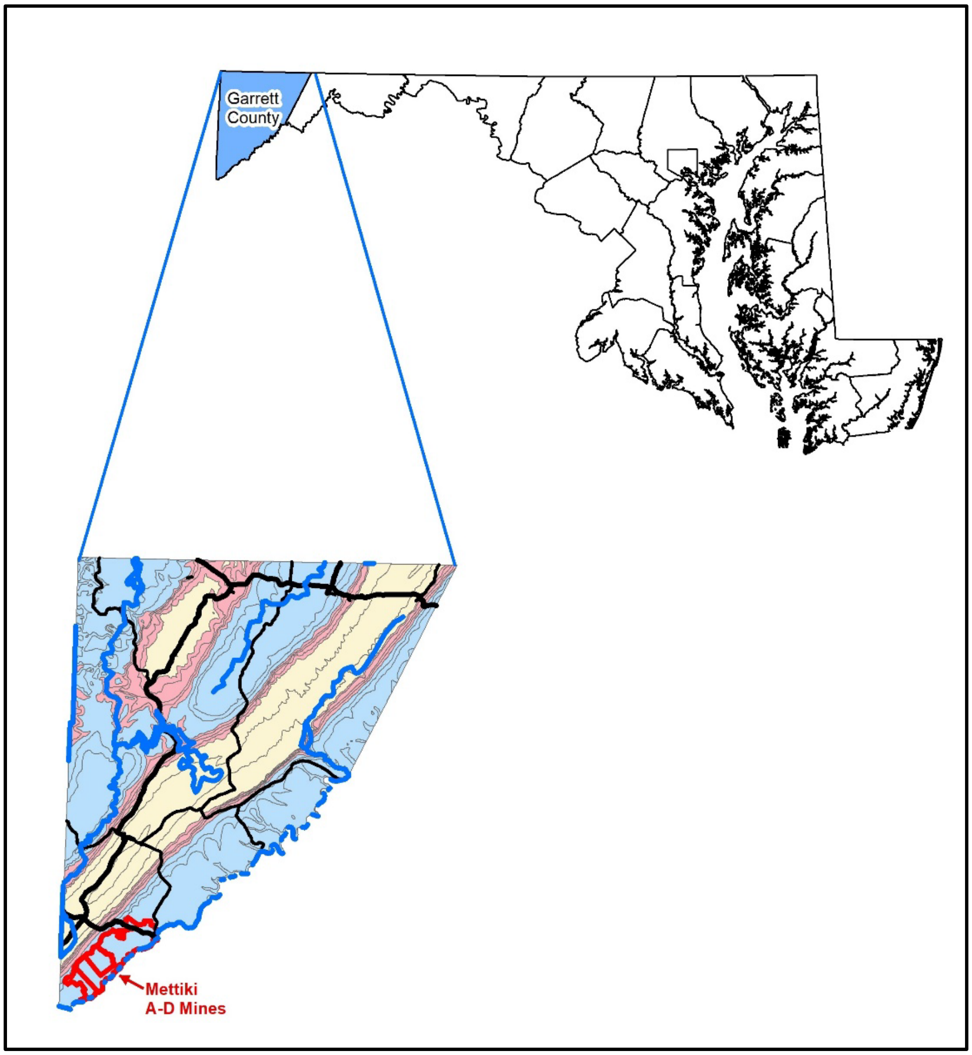
HYDROLOGICAL IMPACTS CAUSED BY DEWATERING OF THE METTIKI D-MINE, GARRETT COUNTY, MARYLAND



Maryland Department of the Environment

1800 Washington Blvd

Baltimore, MD 21230

May 2022

Department of the Environment

Water and Science Administration

Water Supply Program

Gregory Busch, Manager

HYDROLOGICAL IMPACTS CAUSED BY DEWATERING OF THE METTIKI D-MINE, GARRETT COUNTY, MARYLAND

by

Patrick A. Hammond

2022

CONTENTS

ILLUSTRATIONS

Figure

Table

CONVERSION FACTORS AND SYMBOLS

Multiply	by	to obtain
Length		
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
square foot (ft^2)	0.0929	square meter (m^2)
square mile (mi^2)	2.59	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (l)
gallon (gal)	3.785×10^{-3}	cubic meter (m^3)
Discharge Rate		
gallon per minute (gpm)	3.785	liter per minute (l/min)
Production Rate		
gallon per day (gpd)	3.785×10^{-3}	cubic meter per day (m^3/d)

Annual average use gallons per day = gallons per day average (gpd avg)
Use during the month of maximum use =-gallons per day maximum (gpd max)

Use of notation: As close as possible, the original scientific or mathematical notations of any papers discussed have been retained, in case a reader wishes to review those studies.

HYDROLOGICAL IMPACTS OF MINE DEWATERING AT THE METTIKI D-MINE, GARRETT COUNTY, MARYLAND

by

Patrick A. Hammond

KEY RESULTS

This study describes the hydrologic impacts due to dewatering of the Mettiki Coal Corporation D-Mine in southwestern Garret County, Maryland, while coal was extracted by longwall mining techniques. It is a follow-on study to two Maryland Geological Survey (MGS) reports on changes in mining activity and hydrologic conditions in the three adjacent permit areas (Mines A-B-C) covering the period 1978-1984 that were mined using room-and-pillar methods. Dewatering of the four mines reached a maximum of an annual average of 12 million gallons per day during the wet year of 2003. The maximum number of acres undermined increased from 1650 acres in 1984 to 7267 acres in 2006, that included 212 acres in West Virginia after the North Branch of the Potomac River was undermined. After that mining ceased and water withdrawals declined to 0.8 Mgd but pumping increased to 8-9 Mgd to maintain the mine pool elevation at a level to prevent breakouts and discharges of poor-quality water to the river.

A review of available records indicated that 38 water supplies were replaced, and one spring box repaired, which was 39% of the water supplies on inventory, while there were only three replacements of 46 (6.5%) wells drilled in the D-Mine area prior to its development. No correlation could be found between impacted water supplies and topographic position; however, water supplies with overburdens greater than 500 feet were less impacted that those where the overburden was less than 500 feet. Where distances could be determined, 21 of 33 water supplies were between 1000 and 2000 feet of mining when impacts occurred, while 7 were between 2000 and 4500 feet of mining. A community ground water supply was developed for the Town of Gorman in 1996-97 to replace a surface water supply from Mount Storm, West Virginia. Water lines were later extended along Wilson-Corona Road and U.S. Route 50 in 2003 and Table Rock Road in 2007 to serve an estimated 17 customers whose water supplies were impacted by mining activity. When these homeowners were added to the existing inventory, it is then estimated that 50% of the individual water supplies in the D-mine area were impacted.

The U.S. Geological Survey (USGS) installed five well clusters, with wells in 4 or 5 depth intervals from a minimum of 85 feet deep to a maximum of 832 feet deep. There were relatively gradual long-term water level declines in the interval below the upper Freeport coal seam at sites 1-3 that started prior to mining in the A-mine area that appears to have been related to dewatering of the North Branch Mine in West Virginia. In the A-Mine area, the greatest drawdowns occur in the intermediate intervals at sites 1 & 2 (200-400 feet), while the least drawdowns occur in the shallow interval (less than 100 feet). At site 3, the drawdowns were less than those at site 1 and 2. At site 4, there were sharp declines in water levels of about 50 feet in all zones, except the interval just above the coal, which had a long-term gradual decline of less than 30 feet. At site 5, the water level decline in the deep interval was greater than 600 feet. In the intermediate intervals, the declines were about 200 feet and less than 60 feet in the shallow intervals. While drawdowns in domestic water wells can be shown to occur when distance to mined intervals were less than 4500 feet, there was some evidence that mining activity at distances of greater than one mile may have affected water levels in the USGS monitoring wells.

Early stream flows (prior to 1986) were augmented by mine discharges to all streams. In 1990, the annual average flows in McMillan Fork declined by about 20%, after being undermined by the D-Mine. Flows recovered rapidly in 2006, upon the end of mining and when pumpage declined by >90%. Flows in the North Fork of Sand Run were stable until 2004, when mining between the A and D mines commenced, after which the flows declined about 40%, at which point the record ends. There were no apparent declines in flows in Laurel Run, until that record ends in 2003.

Biological sampling in 2001 indicated that the fish habitat in McMillan Fork was impaired, probably due to the lack of adequate streamflow. Both the benthic and fish habitats were impaired in the North Fork of Sand Run during the same period, but that was a period when flows in the creek were minimally impacted by mining activity. The impairment was probably related to the small drainage area at the sampling point or stream embeddedness. Treated acid mine discharge (AMD) in the South Fork of Sand Run allowed it to be stocked with rainbow trout. Shields Run, just downstream of the confluence with McMillan Fork, was sampled in 2010 and there was no evidence that the stream was impaired. The drainage area was 2+ times greater than and the flow 3 times more than that of McMillan Fork. It is then possible that the higher flows in Shields Run were the reason that the stream was not impaired. While flows were not an issue with Laurel Run, the stream was impaired in 2007. The most likely reason was the low pH in the stream due to acid mine drainage from the Kempton Mine in West Virginia.

Introduction

The State of Maryland is in the Mid-Atlantic region of the eastern United States and includes much of the major Washington-Baltimore metropolitan complex, where about 5 million people live. Most of the metropolitan area is served by surface water from the Potomac River and the Baltimore City reservoir system.

There have been about 100 known private wells of more than a total of 200,000 wells, impacted by groundwater withdrawals in the fractured rock aquifers of central and western Maryland, and all those water supplies have been effectively replaced. There have been about 400 water use permits issued to large users in the fractured rock aquifers of the State or those withdrawing more than an annual average of 10,000 gpd. Only a few permittees have caused unreasonable impacts, of which more than 90% can be attributed to withdrawals by Poolesville and Taneytown municipal wells, and dewatering of the Mettiki Coalmine, all in consolidated sedimentary rock formations, and dewatering of limestone quarries. The impacts associated with these withdrawals were successfully mitigated, primarily because they occurred in formations where it is relatively easy to drill and complete replacement wells.

Location of Study Area

The Mettiki Coal Mine is in the southwest corner of Garrett County, Maryland, Figure 1, on the Appalachian Plateau and is part of the Upper Potomac Coalfield. The region consists primarily of generally gently folded consolidated sedimentary shale, siltstone, and sandstone units. It is in an area of alternating synclines (Pennsylvanian outcrops) and anticlines (Devonian outcrops) oriented in northeast to southwest directions, with the mine located in a syncline along the Upper Potomac River basin. Coal is extracted from the Pennsylvanian Upper Freeport coal seam.

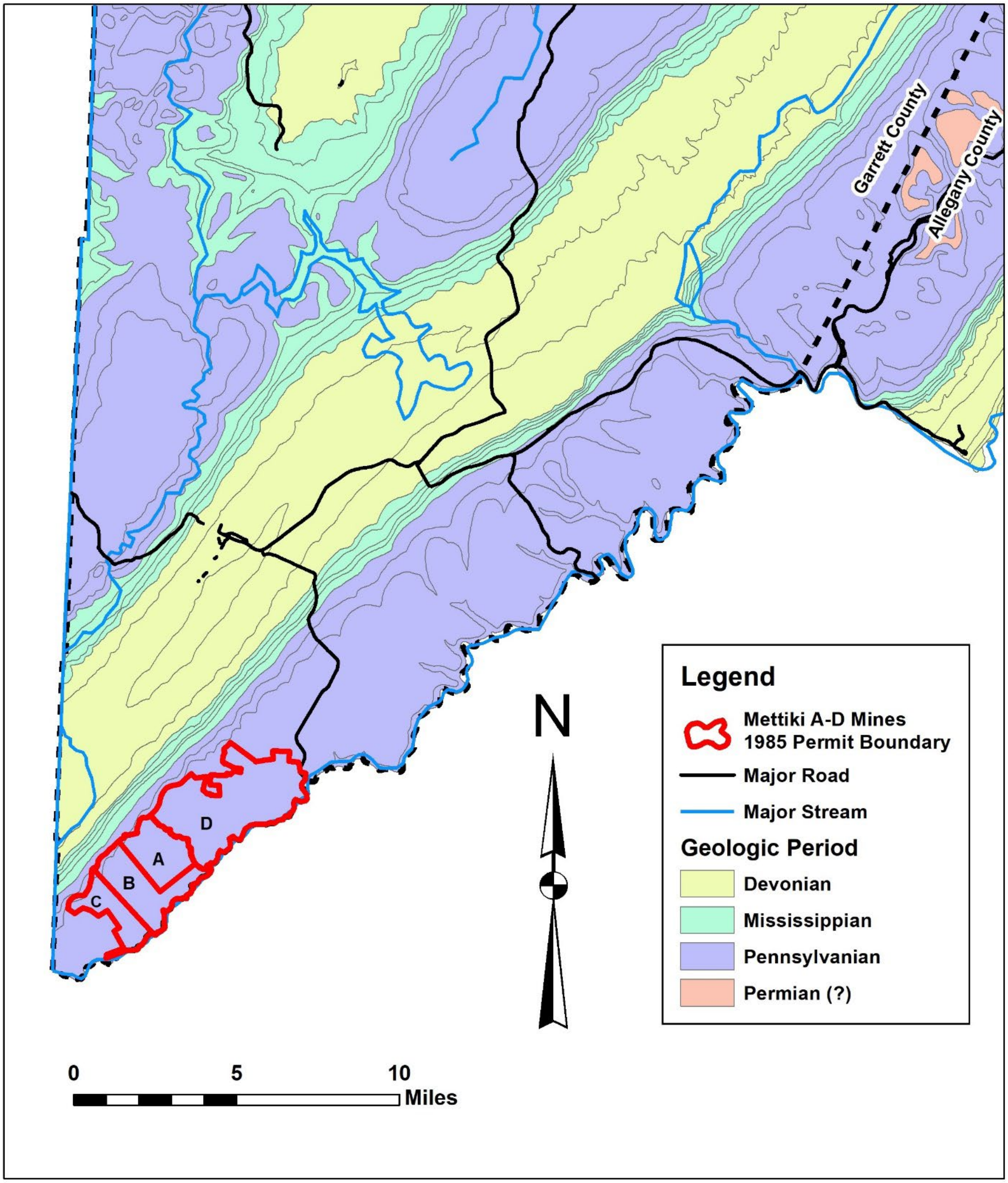


Figure 1. Location map of the study area

The History of Coal Mining in Maryland

The earliest coal mines in Maryland appeared as early as 1782 at the mouth of Georges Creek, in Allegany County, Lyons and Jacobsen (1981). Initially, production was on a small scale, only supplying local customers; but, during the mid-1800s coal production became commercially important, after construction of Baltimore and Ohio Railroad (1842) and the Chesapeake & Ohio Canal (1850) allowed substantial amounts of coal to be transported out of the region to serve the rapidly growing Washington-Baltimore area. Annual coal production first reached 1 million tons in 1865 and ultimately peaked at 5.5 million tons in 1907, nearly all of it coming from the Pittsburgh coal seam in the Georges Creek basin, shortly after the construction of the Hoffman drainage tunnel. It remained relatively high until the post-World War I recession and the following Great Depression, as well as its replacement as a fuel by petroleum sources, along with the depletion of the Pittsburgh and other thick coal seams, causing production to decline to about 2 million tons. By the early-1950's only about 500,000 tons were being mined; but, shortly after that period the construction of coal-fired power plants revived the coal industry and caused production to again reach about 1.5 million tons by the early-1970s. At that point, the deep mines in the Georges Creek basin were depleted and strip mining was the chief method used to extract the coal. Increasing oil prices during the 1970s caused coal production to increase, reaching a peak of 4.5 million tons in 1981. Much of the coal came from deep mines, especially after with opening of the Mettiki mine in 1977, when Garrett County became the major source of coal in the state. Ultimately, a peak of 5.8 million tons was produced in 2005, of which 3.3 million tons were from the deep mines in Garrett County. Production declined fairly rapidly from that point, reaching 2.2 million tons in 2013; first due to the closure of the Metttki mine, which had been producing about 3 million tons/year, and then by increased competition by natural gas production from fractured shale formations, primarily the Marcellus Shale.

The first mining law in Maryland was the Mine Act of 1876 and following amendments, regulating the working and proper ventilation of coal mines, were primarily concerned with those aspects of mine safety and operations that could prevent mine accidents and disasters. Costly in terms of the severity and amount of land disturbed, strip mining began within the region during the 1940s. No state law governed that type of operation until 1955, when the Strip Mining Laws of Maryland went into effect and addressed issues associated with reclamation, conservation and revegetation of lands disturbed by open-pit mining. This was followed by the federal Surface Mining Control & Reclamation Act of 1977, with assignment of primacy of control to the State of Maryland in 1980, which was designed to protect lands from the environmental hazards of surface mining, including maintenance of a proper hydrologic balance. In the case of the Mettiki mine permit application, the Maryland Bureau of Mines (MDBOM) had no authority that specifically required replacement of impacted water supplies; however, a regulation was applied that required correction of the effects of any material damage or diminution of land values due to mining, which was determined to include the loss of a water supply.

The History of Water Appropriation or Use Regulations in Maryland

The Water Appropriations Act of 1933 created regulatory authority over the appropriation of surface and ground waters for any use (with significant exemptions, especially for subdivisions, and municipal and agricultural users). The Well Drillers Law was passed in 1945 and addressed the issue of licensing well drillers. It also required permits before and completion reports after drilling of any water well, providing a wealth of data on the ground waters of the State. The permitting system for well drillers and water appropriations was one of the earliest such programs in the nation. The 1933 law had been essentially largely ignored until about 1957, when the “Regulated Riparian” system for surface waters was adopted. At that time, the “American Rule” or Reasonable Use Doctrine governed groundwater use in the State, which states that a landowner has the right only to a reasonable and beneficial use of the waters upon his land. The reasonable use theory does not prevent the proper, non-wasteful consumption of such waters for the development of land for mining, allowing the underground waters of neighboring properties to be interfered with or diverted. In 1988, the water use regulations were modified based on the Restatement (second) of Torts, Section 858, which requires replacement of impacted water supplies, with some restrictions. They also require consideration of the aggregate and cumulative changes of new and future appropriations, and their contributions to future degradation of the State’s waters, provisions which are used to protect the hydrologic balance of the State’s water resources. Note that the major changes occurred after severe to extreme droughts (1930-32, 1954-55 and 1986-88). In addition, the present study grew out of the Wolman Commission report (2008) following the droughts of 1998-1999 and 2001-2002.

Methods of Investigation

Hydrologic data used in the present study were collected at the Mettiki mine by the USGS at five nested well sites and four stream flow monitoring gages. Mine timing/advancement maps provided by the operator were used to determine the proximity of mining activities when significant declines or recovery of groundwater levels were observed. Automated computer programs were used to calculate annual base flow from mean-daily stream flow records. Three stream gages were located on streams overlying the D-Mine site and a fourth was on Laurel Run in the A-Mine area. Ratios of the annual base flow derived at those sites were compared to the base flow at an unregulated gage outside of the area influenced by dewatering of the mine, to determine the potential impacts to stream flow caused by mining activity. Maryland Biological Stream Survey (MBSS) data were collected from stream overlying the mine to determine the potential impacts to aquatic habitat by mining activities.

In 1985, the mine operator was required to conduct an inventory of private water supplies within 1000 feet of the proposed area of the D-mine. While the operator was required to notify the State of any water supplies potentially disrupted by mining operations and replace any that were determined to be unreasonably impacted, there were no specific directions on how to track the complaints and impacts. The operator did maintain reasonably complete records of the receipt and nature of complaints, and the action taken to resolve the problems. In most of 23 complaints on record, the mine replaced the water supply without question. In five cases, the operator asked the Maryland Bureau of Mines (MDBOM) to decide as to the cause of the disruption to an individual water supply. A review of well completion reports indicated that about 29 water supplies were replaced, or wells were deepened after the commencement of mining operations. In some cases, there was a conflict between the driller's report and the operator's record, so the drilling company was asked to indicate if the mine had paid for the replacement well. The well completion reports often, but not always, included a street address. The 1985 inventory was accompanied by a map showing well and spring locations and property boundaries. Using the inventory map, well completion report information and State property records, reasonably accurate locations were found for the replacement water supplies.

Previous Studies

In 1986, the Mettiki Coal Corporation applied for mining and water appropriation permits to extend its existing mining operations to the then proposed 5743-acre D-mine area. Neither the mining operator nor, initially, the State agencies expected negative impacts to groundwater supplies or streams to occur, primarily due to sufficient cover and the potentially confining nature of the local aquifer. Notwithstanding these evaluations, the applicant did present a mitigation plan by which any private water supplies that were disrupted by mining activity would be restored or replaced. In preparation for a contested case administrative hearing in 1988 on the proposed use, a review of the literature was conducted by the Maryland Water Resources Administration (MDWRA), to determine what additional data or information that the operator might be required to submit.

The first study in the review was the recently published paper, Duigon and Smigaj (1985), on the hydrologic effects of coal mining at Mettiki's A-C mines, immediately southwest of the proposed Mine D site. At USGS site 1 in that paper, there were large drawdowns, up to several hundred feet, in all four wells in that cluster, with no long-term recoveries. These responses occurred as the mine face, developed by room and pillar methods, but prior to retreat, approached to within 800 feet of the wells. Site 1 was located along a fracture trace, indicating that the mine and well cluster may have been connected by a natural fracture, since no induced fractures would have been present due to collapse mining operations. Of special interest was that the water level in the shallowest (115-foot) well declined by 80 feet. This was evidence that some of the mostly, shallow, private water supplies in the area might be unreasonably impacted by the mining activity. Those water supplies were identified by an inventory conducted by the operator, to include all of those within 1000 feet of the proposed mine permit area.

Hoirtdahl (1988) was a follow-on study at the Mettiki mine. Water level data were presented from four observation wells (FA 26-29) drilled by the mine operator in the area to be mined. Water levels initially declined sharply by about 140 feet in FA 26 to more than 200 feet in FA 28 (when the well went dry) in early 1981, after the wells were undermined. Lesser drawdown occurred in FA 29 in early 1981 (80 feet) and FA 27 in middle 1982 (30 feet);

however, both of those wells also went dry. Seasonal variations in water levels were greater post mining than before mining, indicating that there was probably a better connection after mining between the source of recharge and the strata in which the wells were completed. In addition to site 1, well clusters were drilled by the USGS at sites 2 and 3. Neither well cluster 2 nor cluster 3 were undermined during the first or second study periods. Water levels measurements were continued at sites 1, 2 and 3, as well as sites 4 and 5 located in the D-mine area. The water fluctuations at USGS sites 1-5 for the full periods of record will be discussed in detail later in the present study.

Green et al. (1986) was a study of a longwall mine site near Waynesburg, in southwestern Pennsylvania. Eleven, 150-foot, observation wells were located near four longwall panels. Green et al. (1986) presented well profiles that were related to topography and each mining panel. Water levels in the wells and precipitation were measured over the period of the longwall mining. The following trends or observation were noted during the MDDNR review of the paper. Few of the wells had drastic declines that could be analogous to seriously impacted private water supplies in an area. One notable exception was well 1, which went dry with a long-term decline in the water level of more than 100 feet. Three other wells had drawdowns of 30 to 60 feet, with limited to rapid recoveries. The wells over longwall centerlines had the greatest declines in water levels. Many of the water level declines appeared to be related to average or below average precipitation. Four of the five wells showing the sharpest declines and slowest recoveries were located on topographic high points. The fifth was at an intermediate elevation. Two of the three wells least effected by mining were in topographic lows, while the third was on a chain pillar or support structure. Neither fracture trace analyses nor maps were presented in the Green et al. (1986) study, and the location of a well relative to a mine face could only be approximated. Knowledge of these factors might have helped determine whether a hydrologic response was due to either natural or induced fractures.

Stoner (1983) studied the hydrogeologic effects of mining at three active sites in Greene County, southwestern Pennsylvania. One observation well, with its bottom 90 feet above the coal seam, had a long-term decline of 180 feet while retreat mining was used in recovery of the coal. A second well, with its bottom 240 feet above the coal seam, where room and pillar methods were in place, had no significant declines in its water level that were not due to drought effects. A third well, with its bottom 608 feet above the coal seam, had a 7-foot decline and rapid recovery of its water level as it was undermined by a longwall panel.

Hill and Price (1983) investigated the effects caused by mining of a selected longwall panel in western Pennsylvania. Seven deep and four shallow monitoring wells were completed for that study. The deep wells were drilled to 250 feet or about 300 feet above the coal seam. The shallow wells were drilled to 75 feet or about 475 feet above the coal seam. Three deep wells and one shallow well were located along the centerline of the panel. Three deep wells and one shallow well were placed near the edge of the panel. One shallow well was placed just outside the panel. As a control point, one shallow and deep well each were located ¾ of a mile from the study panel. The deep wells along the centerline dropped more than 200 feet as the mine face passed under the wells, with partial recovery after about one month. The drawdown in the one shallow well was about 30 feet, with nearly full recovery after about two months. The response to mining by the wells along the panel edge was like those along the centerline, except that the drawdowns were about ½ less. There appears to have been no response to mining by the any of the wells outside of the panel.

Booth (1986) studied the effects of the extraction of coal from two longwall panels at the Lancashire No. 20 mine, in Cambria County, Pennsylvania. The coal was mined at depths of 300 to 800 feet and water levels were measured in shallow domestic wells. Nine of those wells were in the vicinity of longwall panel G4-G6. Their depths were 90 to 205 feet, and they were located between 380 and 5200 feet from the panel. The vertical separation between the mine and well bottom of the wells was 470 to 610 feet. Water levels declines of 5 to 15 feet were noted in all the wells within 1300 feet of the panel. At the second panel (K7-K9) two wells, 60 and 105 feet deep, 600 feet above the mine, were located near the panel centerline. As the wells were undermined, the water levels declined by 30 feet in both wells. Two months later both wells went dry. One was abandoned and the second was deepened to 213 feet. The water level measured in the second well then indicated that it had dropped more than 100 feet. There were no significant declines in the water levels due to mining in three wells located 200-1950 feet from the panel.

Duigon and Smigaj (1985) and Hiortdahl (1988) conducted seepage runs in the Mettiki area steams, which required measuring instantaneous flows at both upstream and downstream sites. The USGS rated the measurement errors of the stream gages in the Mettiki area to be 10-15% or potential cumulative errors of 20-30%. Hiortdahl (1988) was the only author to conduct replicate seepage runs. The data that Hiortdahl (1988) produced shows a 12% difference in the flow measured during replicate runs U-V (losing reach) and U-V' (gaining reach). The greatest magnitude change observed by Duigon & Smigaj (1985) noted losses along two reaches that were undermined, however, a significant error was made in computing the seepage losses. Once the error is corrected, the losses observed were 10% and 4% of the total discharge. The greatest fractional loss (-19% of total discharge) noted by Duigon & Smigaj (1985) was observed along Sand Run (section G-I) where no mining operations were conducted. Extremely large unexplained gains occurred along Sand Run, which has a low flow volume, that could lead significant measurement errors. Hiortdahl (1988) observed the greatest fractional loss (-20% of total discharge) in Laurel Run (section V-W) on September 18, 1984, after the upper portion of the reach had been undermined in July 1984.

Hobba (1981) noted losses of 1.1 to 1.8 cfs/mile and a gain of 6.7 cfs/mile along Buffalo Creek and its tributaries near a collapsed mine area at Farmington, West Virginia. The losses were 1.7% & 2.1% and the gain 9.0% of the total discharge. Considering the measurement error in seepage runs, the losses observed in that case were insignificant.

The studies of Cifelli & Rauch (1986) and Tieman & Rauch (1987) employ many of the same methods of investigation. The flow measurements in each study were made one to three years after the undermining of each stream. Each study relied heavily on door-to-door surveys of domestic users, comments from mine personnel and review of published but uncited reports; consequently, much of the data presented cannot be verified for reliability. Only three well hydrographs, over one active mine, were presented; however, pre-mining measurements of streamflow or groundwater levels were not made. Pre-mining conditions were estimated by comparing measured streamflow in mined areas to average streamflow in unmined areas.

Cifelli & Rauch (1986) show a decrease in streamflow from point A to Point B along Stream III (Mine D). The % of mined area in the watershed was calculated according to the total amount of extraction by both conventional retreat and longwall mine workings. In one case, only the longwall workings were considered when calculating the % of mined area. In the second case, no evidence was presented as to why the room & pillar and unmined areas in the watershed were not included in their calculations; however, by excluding unmined and room and pillar areas, a good correlation was produced between % of mining in the watershed and % of normal streamflow. During high flow periods, stream III (points A to B) of mine D showed a slight gain over the same reach that had significant losses under low flow conditions. Stream III (point A) of mine A had 60% of the average streamflow under high flow conditions vs less than 10% during the low flow period, with only the area of longwall workings used in the calculations. Stream II of, mine B had no loss over the entire reach measured (AC - longwall, BC - unmined), but was about 20% of the average value during high streamflow, while no measurements were taken under low flow conditions.

Tieman & Rauch (1987) measured two baseflow periods, producing flows on June 6, 1986, five times those on July 24, 1986. Streamflow was measured at the major stream H and two of its tributaries. Stream H and segment A1-A3 had higher than average flow; segment A3-B1-C1, C1, B3 and G3-11 had average to slightly below average flows; and segments B1-B3 and G1-G4 had well below average flows. All the streams were undermined. Mine subsidence theory was used to predict an upper or surface fractured zone, although no obvious fractures were observed in the soil zone above the mine. The predicted, but unobserved, fracture zone extended only deep enough to lower water to the regional base level, causing water losses along segments B1-B3 and G1-G4 to be regained in segments A1-A3 & A3-B1-C1 and stream H. The streamflow measurements were made during the drought year of 1986. Under normal conditions losing stream reaches can occur naturally; under drought conditions they may develop more readily.

The 1988 MDWRA water use permit evaluation used the responses in 32 wells, located within 2000 feet of longwall panels, in the studies discussed above to estimate the potential impacts to water wells caused by dewatering of Mettiki's D-mine. Six wells located within 50 feet of a panel centerline had declines equal to or greater than 100 feet. Four other wells located near a centerline had declines of 7 to 60 feet. Six of the 10 wells near a centerline had immediate and complete or nearly complete recoveries. Water levels in 21 of the 22 remaining wells did not respond to mining or the declines were short-term and less than 30 feet. At the Mettiki site, drawdowns greater than 200 feet were observed wells as a mine face, using room and pillar methods, approached to within 1000 feet of certain monitoring wells. Based on these data, it was expected that about 25-35% of the 65 wells and 25 springs on the Mettiki water supply inventory might have been significantly affected by dewatering of the D-mine. As a result, the State required that the operator provide an adequate and secure alternate water supply for any user whose existing supply was impacted by mining activity.

The decision to issue the water use permit for dewatering of the Mettiki D-mine was made in 1990. In preparing the present report it was found that, since then, several comprehensive studies on the impacts to water supplies caused by mining activity have or had been published.

Van Voast and Hedges (1975) demonstrated that removal of overlying aquifers by surface excavation methods and dewatering of the Decker Mine in Montana produced a substantial depression in the potentiometric surface of the mined coal seam at distances greater than one mile from the pumping center. Two especially diagnostic wells, WR-15 and WR-17 were 300 to 390 feet deep and located 1.2 miles each from the mine. Water levels in those wells were drawn down by 14 and 5 feet, respectively, after three years of mining (in 1975), at which time they appeared to stabilize. Figures 5 and 6 in Wheaton and Metesh (2002) indicated that water levels in each well then declined at steady rates of 1.5-1.6 feet/year from 1980 to 1999, producing drawdowns of 41-45 feet due to mine dewatering effects. After 1999, water levels in each well dropped precipitously due to initiation of withdrawals for a coalbed methane development project. The lack of any significant seasonal variation in the water levels in either of the wells suggested that the aquifer existed under confined conditions.

Booth and Spande (1992) studied the effects of subsidence at two active longwall panels in Jefferson County, Illinois, where the coal seam was about 725 feet deep. Piezometers were installed in or below the top of the Mount Carmel Sandstone at depths of greater than 100 feet to greater than 300 feet. Local farm and domestic wells in the areas were completed in a shallow drift aquifer or upper bedrock shale above the Mount Carmel Sandstone. Twenty of those wells were monitored, 13 of which were within 1000 feet of a panel. None of the drift wells responded to mining, but some rapid drawdowns occurred in shallow bedrock wells within 500 feet of an active panel. Greater declines were noted in the piezometers, with the most occurring in a well with a screened interval of 298-318 feet. Packer tests were conducted on two wells 100 feet apart, at intervals of 20-650 feet in the first well before mining and at intervals of 20-500 feet in the second well after mining had occurred. The hydraulic conductivity of the Mount Carmel Sandstone generally increased by about an order of magnitude between the first and second set of tests due to fracturing caused by my subsidence.

Zipper at al. (1994) examined the potential impacts to 73 domestic water supplies (54 wells and 19 springs) due to the impacts caused by underground coal mining in southwest Virginia. That study was based on investigations completed by the Virginia Division of Mined Land Reclamation (VDMLR) between 1981 and 1987. They found that 16, 34 and 4 of the complaints of possible impacts were caused by room and pillar, retreat, and longwall mining, respectively. One case was listed that had an unknown cause. Most large coal companies in Virginia had policies that included voluntary replacement of damaged water supplies or compensation for losses to the owners; consequently, most problems were handled by private negotiations. The Virginia regulatory files only included those cases where the VDMLR was required to resolve a dispute; consequently, no data were available for other situations where mining did not cause impacts or water supplies were replaced without State involvement.

For 16 of the 27 VDMLR complaints related to room and pillar mining, it was determined that the water supplies had been impaired by mining. Eleven of those impacts occurred suddenly at one mine as entries were being developed that intersected a major fracture, requiring extensive dewatering of the mine. This affected domestic water supplies as far away as 3300 feet from the mining activity, with five impacts occurring at distances greater than 2000 feet. The coal was being extracted from a seam about 150 feet below a long linear valley, resulting in an average vertical separation of 105 feet between the mine and water supplies. In addition to the impacts to the domestic water supplies, the creek flowing in the valley went dry. The four wells that were impacted by longwall mining had an average vertical separation of 450 feet and were 200 to 2000 feet from a panel. Of the 41 investigations related to retreat mining, 34 of the water supplies were determined to be affected by mining. Those water supplies were located 0-1100 feet from active mining and had an average vertical separation of about 250 feet.

Witowski (2010) assessed the effects on domestic and farming water supplies that were undermined during operations at seven active longwall mines in southwestern Pennsylvania. Water supplies with diminution or total loss of supply were included in the study, while water supplies not meeting this criterion and outside of 200 feet from a panel were not considered. Of the 1214 water supplies considered, 106 (9%), as determined by the Pennsylvania Department of Environmental Protection (PA DEP), were impacted by mining activity. Thirteen per cent of the water supplies located on hilltops were impaired, while 9% located on both hillsides and valley bottoms were impacted. Five of the affected water supplies were located at distances of 0.5 to 1.5 miles from a longwall panel. Five of the mines with average overburdens between 648 and 887 feet had impact rates of less than 8%. One mine with an average overburden of 627 feet had an impact rate of 14%. The final mine had an average overburden of 338 feet and 100% of the six nearby water supplies were impaired. No information on the vertical separation of individual water supplies was given in the Witowski (2010) study.

Acknowledgements

This study fulfills one of the objectives of a cooperative regional study (USGS Publication SIR 2012-5160) of the fractured rock areas of Maryland that involved the Maryland Department of the Environment (MDE), the Maryland Geological Survey (MGS), the U.S. Geological Survey (USGS) and the Monitoring and Non-Tidal Assessment (MANTA) division of the Maryland Department of Natural Resources (MDNR).

General Geology of Garrett County

The study area is in the Appalachian Plateaus Province which includes part of Allegany County, west of Dans Mountain and all of Garrett County, the westernmost county in Maryland. The bedrock of this region consists principally of gently folded shale, siltstone, and sandstone, that has produced elongated arches across the region~~.~~ Most of the natural gas fields in Maryland are associated with these anticlinal folds. Coal bearing strata are preserved in the intervening synclinal basins. The rocks exposed in the study area are all in the Pennsylvanian System, are within the Upper Potomac Syncline, and represent a transition from an alluvial plain to a shallow marine environment. There are no significant faults present in the study area, but the rocks are jointed. Fracture traces indicate tectonic stress fracturing, and some may correspond to zones of weak roof rocks and concentrated zones of water seepage into the mines, Duigon and Dine (1985). The oldest rocks exposed belong to the Pottsville Group, which consists primarily of sandstone and siltstone and includes some thin coal beds that are not economically important. An indurated sandstone forms the Backbone Mountain ridge. Downslope from the Pottsville is the Allegheny Group with some thick coalbeds, but only the Upper Freeport is economically significant in the study area and is the coal seam that was extracted at the Mettiki D-mine. The Conemaugh Group underlies the rest of the study area. It consists of siltstone, sandstone, shale, and coal deposits, and represents the shallow marine stage in the Pennsylvania transgressional sequence. Red shales characteristic of the Conemaugh are absent in the Allegheny and Pottsville Groups. The Lower Bakerstown coal is the only coal in the Conemaugh Group of economic importance in the study area.

Mettiki Coal Mine Case Study

Impacts to Groundwater Supplies

Figure 2 is a map of the water supplies located within 1000 feet of Mettiki's proposed D-mine area, which were included in the 1985 inventory conducted by the mine operator. Fifty-five were drilled wells (including two at one site), five were dug wells, and 25 were spring supplies. The sources of six others in the inventory records are unknown; however, they were shown as wells on the inventory map. The locations of three water supplies could not be found. While the operator was required to notify the State of any water supplies potentially disrupted by mining operations and replace any that were determined to be unreasonably impacted, there were no specific directions on how to track the complaints and impacts. The operator did maintain partially complete records of the receipt and nature of complaints, and the action taken to resolve the problems. In most of 23 complaints on record, the mine replaced the water supply without question. In five cases, the operator asked the MDBOM to determine the cause of the disruption to an individual water supply. A review of mine records and well completion reports indicated that 37 water supplies (30 wells and 7 springs) were replaced, and one spring box was repaired after the commencement of mining operations. In some cases, there was a conflict between the driller's report and the operator's record, so the drilling company was asked to indicate if the mine had paid for the replacement well. The well completion reports often, but not always, included a street address. The 1985 inventory was accompanied by a map showing well and spring locations, and property boundaries, but no street addresses. Using the 1985 inventory map and records, well completion report information and State property records, reasonably accurate locations were found for the replacement water supplies.

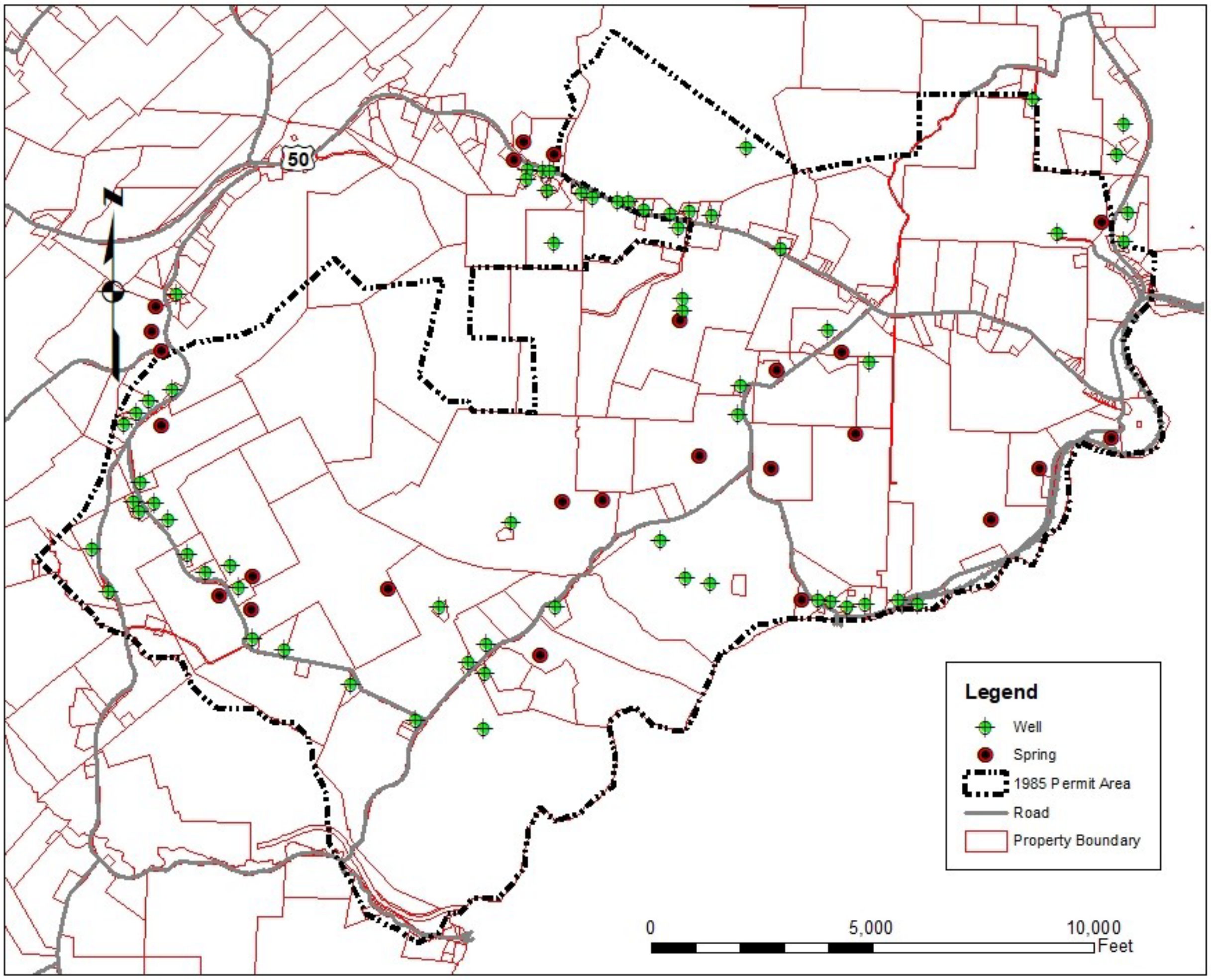


Figure 2. Map of the 1985 water supply inventory of the proposed D-Mine

There were 66 wells, 25 springs and three unknown sources (total 94) on the 1985 inventory. Because the final mined area was different than the planned area, the inventory had to be adjusted. Nine wells and one spring were replaced that were not on the inventory, but within 2000 feet of the final mine boundary. The water supplies of three other properties within 2000 feet of the final mined area were not on the inventory and did not need replacement wells. Ten water supplies were on the inventory (six wells and four springs), but they were more than 2000 feet from the final mine boundary and did not require replacements. After these adjustments were made, there were 97 water supplies that could have potentially been impacted by mining activity. Figure 3 shows the water supplies inventoried in 1985, after the adjustments made after the start of mining.

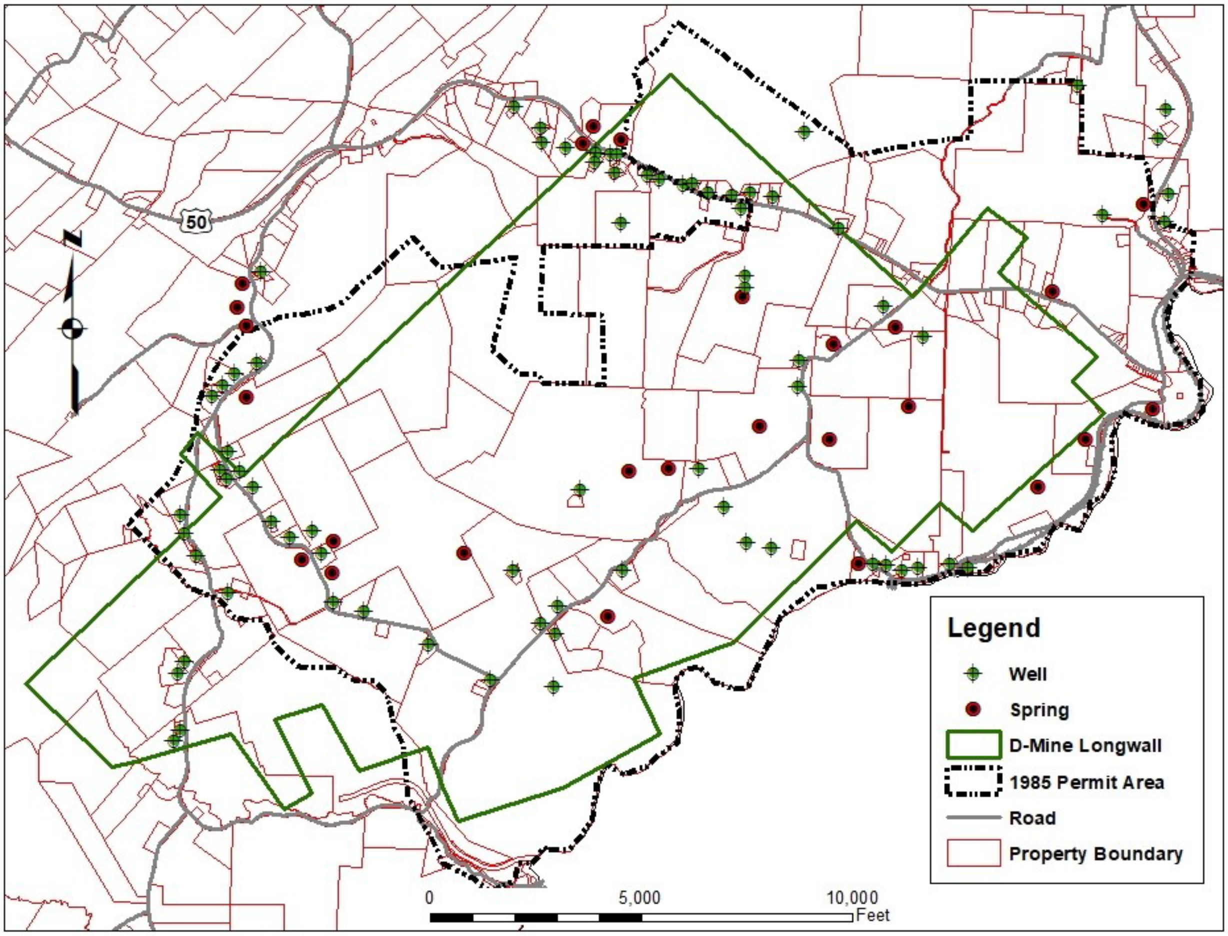


Figure 3. Map of the adjusted water supply inventory for the final area of the D-Mine

Figure 4 is a map showing the location of the replacements for the water supplies impacted by mining activity. Table 1 provides information about the characteristics of the original sources. The mine record and action columns indicate whether the mine had a record of the complaint and what action, if any, was taken to replace the water supply. The Mettiki paid column gives information provided by the driller as to whether Mettiki did or did not pay for the well. Information on potentially impacted supplies are property owners name and address, the Water Supply Inventory ID number, type of source, depth and elevation, the elevation of the Freeport (FC) coal seam, the vertical separation between the coal seam and well bottom, overburden separation (B), distance to mining activity and whether it involved longwall operations, and property tax information (TM, BLK and Par). The replacement column indicates whether the driller checked a box on the completion report that indicates that the new well replaces an existing well. In the case of existing springs, the box would not be checked, but the new well would still be a replacement water supply. In most cases the replacement was a new well and the information provided are the well construction permit number, completion date, coal seam depths, total well depth, test rate, static water level, and pumping water level.

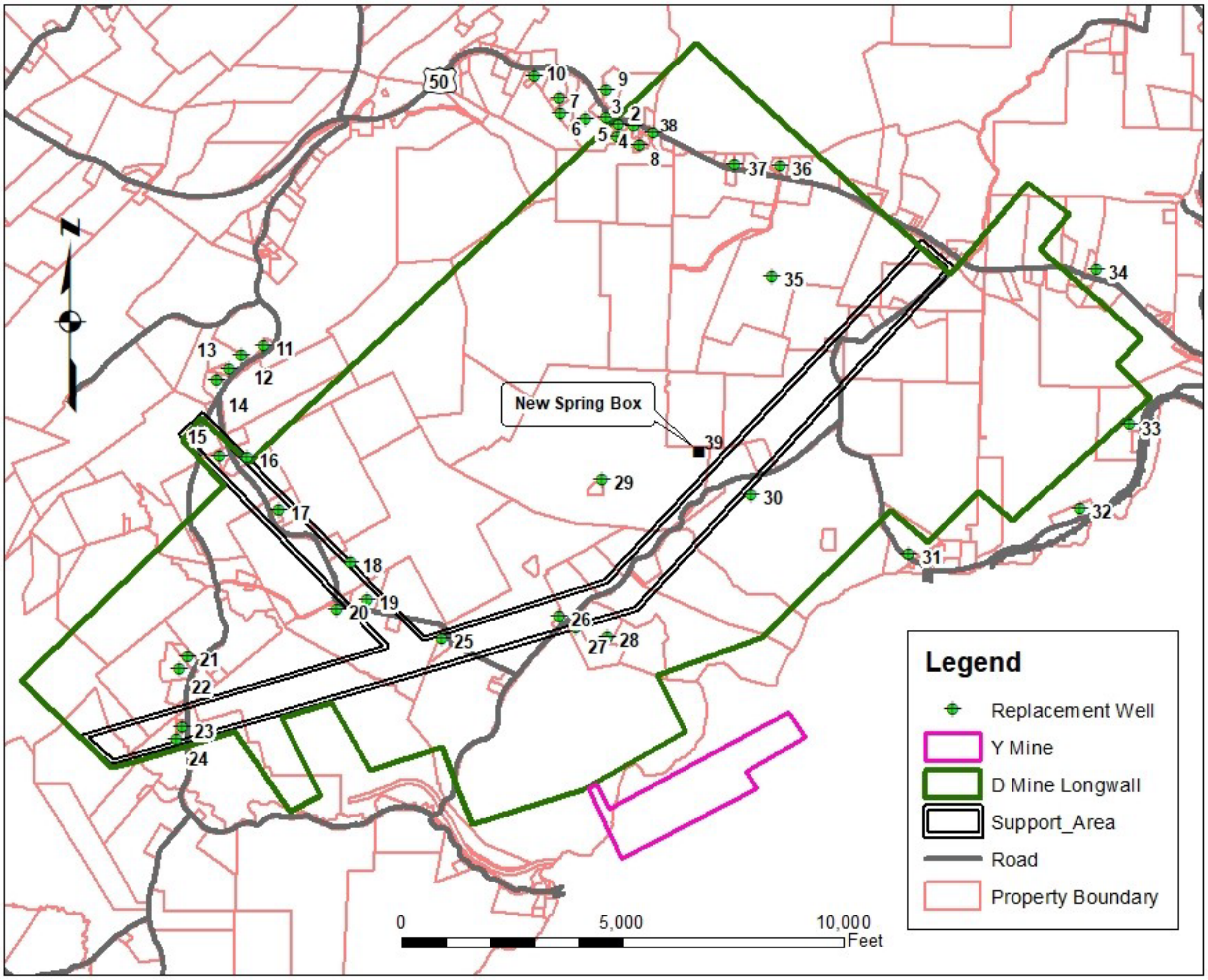


Figure 4. Map of the replacements for the impacted water supplies at the D-Mine

Table 2 contains details of the replacement water supplies, including data from 42 water supplies, 39 which are shown on the map in figure 4. Based on a review of all available records, it was determined that 38 were impacted or effectively impacted by mining activity. Either the mining operator or the drilling contractor indicated that 32 water supplies were replaced or repaired, either by drilling a new well, deepening an existing one or repairing a spring box. In one case, two new wells, map nos. 1 and 2, were drilled for separate houses that had previously been supplied by a single well. Three wells, map nos. 18, 20 and 28, were included for new houses built after mining operations commenced, because they had to be drilled to 340-542 feet, or depths substantially greater than those for pre-mining wells. One well, no. 24, at the mine office had to be replaced. The mine operator paid for one well, map no. 9, that neither the mine nor driller had a record that it was a replacement. One well, map no. 19, seemed to clearly be a replacement, although neither the mine nor driller had a record that it was one. One well, map no. 15, had a bacteria problem. A State well inspection report indicated that the domestic well had not been properly grouted. A water sample was analyzed indicating the presence of coliform bacteria and the absence of fecal bacteria, indicating that the source of the contamination was probably surface or soil water runoff entering the well. The MDBOM then determined that the problem with that well was not due to mining activity. The problem; however, occurred about 9 years after the well was drilled and shortly after the start of mining operations. Later, case studies indicated that lowering of water levels by groundwater withdrawals can cause turbidity or bacteria problems in fractured rock wells. In this case, a primary water-bearing zone may have been dewatered at 140 feet, in part due to lowering of the water table by mine withdrawals. While well construction issues may have been a problem, the timing of the impacts indicate that mining activity may have been primarily responsible for the problem, so the well has been included in the tabulation of impacted water supplies. Finally, two other wells were included in the table, but were not shown on the map. They were not considered to be impacted, because they were 2 to 4 miles from any mining activity.

It is estimated that 30 (including one well replaced twice, in 1987 and 2003) of 66 drilled wells (45%) required replacement due to mining–related impacts, including four new wells that had to be drilled to depths greater than 340 feet, the Mettiki office well, and three unknown water supplies that were probably wells. Six of 22 (27%) springs and two of five (40%) dug wells had to be replaced, and one spring box had to be repaired. A total of 38 of the 97 (40%) water supplies had to be replaced or repaired. A review of the State's wells database indicated that during the period 1969-1987, three replacements of 46 (6.5%) wells were drilled in the area of the D-mine prior to its development. Although not part of this study, a review of mining maps and the wells database indicated that wells possibly replaced seven (28%) of 25 water supplies (A-Mine, 8 springs and 10 wells; B-Mine, 6 springs and 1 well; and C-Mine, none) in the A-C mine areas after the start of mining, while zero of two (0%) wells drilled prior to their development were replacements.

Table 1. Characteristics of the impacted water supplies at the Mettki D-Mine

Map No.	Name	Address	TM	BLK	Par	Impacted	Mine Record	Mine Action	Replacement	Mettiki Paid	INV ID	Source	Depth	Elev	FC Elev	Vert.Sep(B)	B>500ft	Topo. Pos.	Longwall	Dist Mine
1	Moreland R.	5992 GW Hwy - Same as Zimmerman	96	15	106	No	No	N/R	No(dup)	?	9-32/33	Well	160	2665	2580	-75	No	Dup	N/A	N/A
2	Zimmerman	5976 GW Hwy-same as Moreland R.	96	15	83	Yes	No	N/R	Yes	Yes	9-32/33	Well	"	2650	"	-75	No	V	No	1100
3	Moreland A.	6006 George Washington Highway	96	15	75	Yes	Yes	New Well	Yes		9-34	Well	100	2700	2545	55	No	HS	No	1000
4	Thomas D.	5890 George Washington Highway	96	14	79	Yes	Yes(1991)	Fixed Reservoir	Yes		9-31	Spring	0	2690	2615	75	No	V	No	1100
5	Carruthers	5846 George Washington Highway	96	14	91	Yes	Yes	New Well	Yes		N/R	N/R	443	2800	2650	-293	No	V	No	900
6	Uphole E.	210 Callicoat Road	96	14	96	Yes	Yes	New Well	Yes		N/R	N/R	382	2820	2650	-212	No	HS	No	1300
7	Callicoat	180 Callicoat Road	96	14	2	Yes	Yes	New Well	Yes		N/R	N/R					N/R	HT	No	1800
8	Moreland R.	6602 George Washington Highway	96	21	163	Yes	Yes	New Well	Yes		9-35	Dug Well	48	2680	2490	142	No	HS	No	1000
9	Evans R.	5923 GW Hwy-House built 1920	96	14	100	Yes	No	N/R	Yes	Yes	9-71	Spring	0	2730	2680	50	No	V	No	1600
10	Janoske R.	45 Callicott Rd (Old House 2902 GW Hwy)	96	14	114	Yes	Yes (1995)	New Well	Yes		N/R	N/R	140	2830	N/A	Updip of outcrop		HS	No	2800
11	Pike	2189 Table Rock Road	100	6	65	Yes	Yes	New Well	Yes		11-8	Well	120	3050	2830	100	No	HS	No	2600
12	Liller P.	2077 Table Rock Road	100	6	54	Yes	Yes	Deepen Well	Deepen		11-20	Well	172	3065	2845	48	No	HS	No	1800
13	Hebb G.	1979 Table Rock Road	100	6	85	Yes	Yes(2000)	Investigate	Yes	N/R	11-21	Well	190	3040	2845	5	No	HS	No	1800
14	Wolfe	1931 Table Rock Road	100	6	17	Yes	Yes	New Well	Deepen		11-22	Well	170	3030	2845	15	No	HS	No	1700
15	Gray	238 Fairview Church Road	100	12	132	No	Yes	Not at Fault	Yes	?	11-27	Well	270	2960	2675	15	No	HT	N/A	N/A
16	Gordon J.	295 Fairview Church Road	100	12	110	Yes	No	N/R	Yes		11-56	Well	N/R	2920	2610		No	HT	No	500
17	Miller J.	417 Fairview Church Road	100	12	108	Yes	Yes	Hauled Water	Deepen		11-17	Well	100	2915	2440	375	No	HS	No	1900
18	Miller Harold	1019 Fairview Church Road-built 1991	101	7	11	Yes	No	N/R	New		11-13	Spring	0	2740	2176	564	Yes	HS	N/A	N/A
19	Atkins George	1235 Fairview Church Road	101	13	81	Yes	No	N/R	Yes		12-7	Well	400	2710	2110	200	No	HS	Yes	2500
20	Cutter M.	Jct Nurses Home Road-built 1999	100	18	47	Yes	No	N/R	New		N/R	N/R	340	2775	2130	305	No	HT	N/A	N/A
21	Bramble C.	665 Table Rock Road	100	23	48	Yes	No	N/R	Yes	Yes	N/R	N/R	360	2800	2320	120	No	HS	Yes	Under 6/05
22	Bentley M.	595 Table Rock Road	100	17	63	Yes	No(BOM-yes)	N/R	N/R(yes)		N/R	N/R					N/R	HS	N/A	N/A
23	Lambert	379 Table Rock Road	100	23	52	Yes	No	N/R	Yes	Yes	N/R	N/R	302	2715	2200	213	No	HS	Yes	1600
24	Mettiki (Mine Office	293 Table Rock Road	100	23	97	Yes	No	N/R	Yes		N/R	N/R	271	2680	2200	209	No	HS	No	700
25	Beeman M.	1902 Fairview Church Road	101	14	24	Yes	No	N/R	Yes	Yes	12-5/6	Well	342	2660	2000	318	No	HS	No	1100
26	Schrock	1023 Wilson-Corona Road	101	14	86	Yes	Yes	New Well	Yes		12-39	Well	200	2675	2000	475	No	HS	No	4000
26	Bittinger H.	1023 Wilson-Corona Road	101	14	86	Yes	Yes(1987)	New Well	N/R(yes)		12-39	Well	43	2675	2000	632	DUP	DUP	No	4500
27	Cooper	1066 Wilson Corona Road	101	14	50	Yes	Yes	New Well	Yes		10-52	Well	78	2675	2000	597	Yes	HS	No	1600
28	Cooper	1194 Wilson-Corona Road (subd.)	101	15	58A	Yes	No	N/R	New		N/R	N/R	542	2660	2020	98	Yes	HS	N/A	N/A
29	McNeill James	1059 Wilson Corona Rd (Mine Map)	101	14	87	Yes	Yes	New Well	Yes		10-48	Well	46	2625	2015	564	Yes	HS	Yes	500
30	Dixon W.	2324 Wilson-Corona Road	101	10	22	Yes	Yes	Deepen Well	Yes		10-45	Well	59	2620	2020	541	Yes	HT	No	1200
31	Lower	140 Corona-Bayard Road	101	17	65	Yes	No	N/R	Yes	Yes	10-44	Well	162	2380	2150	68	No	V	No	2000
32	Hanlin Beryl	751 Althouse Hill Road (see below)	101	12	20	Yes	No	N/R	Yes	N/R	10-12 N/A	Spring	0	2400	2230	170	No	HS	No	1100
33	Lane	1163 Althouse Hill Road	101	12	82	Yes	Yes	Redrilled Well	Yes		8-89A	Spring	0	2360	2215	145	No	HS	Unk	Unk
34	Uphole Daley	8105 GW Hwy - House built 1965	96	24	67	Yes	Yes	Filled Spring Tote	Yes		N/R	Spring	0	2600	2090	510	Yes	HS	Yes/No	1500
35	Bramble M.	6680 George Washington Highway	101	4	2	Yes	Yes	Deepen Well	Yes		10-14B	Well	50	2620	2055	515	Yes	HT	Yes	2000
36	Fisher R.	6687 George Washington Highway	96	22	76	Yes	No	N/R	Yes	Yes	9-8	Well	200	2650	2170	280	No	HS	No	3400
37	Stoner	6415 George Washington Highway	96	15	112	Yes	Yes	New Well	Yes		9-72	Well	75	2760	2235	450	No	HS	Yes/No	3800
38	Mettiki (house well)	6068 GW Hwy - drillers report	96	15	60	Yes	No	N/R	Yes		9-36	Dug Well	25	2720	2510	185	No	HS	No	1800
39	Rourbaugh	1947 Wilson Corona Rd	101	9	33	Yes	Yes	New Spring Box	N/A(yes)		10-47	Spring	0	2600	2000	600	Yes	HS	No	1500
N/A	Wilt R.	445 Wayne Harvey Road	96	18	121	No	No	N/R	No	NA	8-26	Spring	0	NA	NA	NA	NA	NA	NA	4 mi
N/A	Wilt E.	South side Harvey Road	96	18	123	No	No	N/R	Yes	NA	8-21	Well	53	NA	NA	NA	NA	NA	NA	4 mi
N/A	Hanlin	Replaced by GA942041 (see No. 32)	101	12	18	No	No	N/R	No	NA	10-12	Spring	0	NA	NA	NA	NA	NA	NA	2 mi

Table 2. Characteristics of the replacement water supplies at the Mettki D-Mine

Map No.	Name	Address	Well Permit	Comp Date	Coal Depth	Tdepth	Rate	SWL	PWL
1	Moreland R.	5992 GW Hwy - Same as Zimmerman	GA941590	Jul-Aug/2000		No completion report			
2	Zimmerman	5976 GW Hwy-same as Moreland R.	GA940176	10/22/1995	331-39	705	3	0	705
3	Moreland A.	6006 George Washington Highway	GA940217	2/20/1996	None	143	15	36	143
4	Thomas D.	5890 George Washington Highway	GA940152	10/7/1995	192-95	283	30	0	283
5	Carruthers	5846 George Washington Highway	GA940151	10/5/1995	169-71	443	4	72	443
6	Uphole E.	210 Callicoat Road	GA920494	6/8/1995		382	10	138	382
7	Callicoat	180 Callicoat Road	N/R	N/R		Complaint 1/95			
8	Moreland R.	6602 George Washington Highway	GA940216	2/21/1996	79-81	163	25	27	163
9	Evans R.	5923 GW Hwy-House built 1920	GA940150	10/15/1995	238-40	363	30	0	363
10	Janoske R.	45 Callicott Road (Old House 2902 GW Hwy)	GA880617	6/7/1991	None	140	6	51	191
11	Pike	2189 Table Rock Road	GA880045	6/8/1989	179-80	262		29	202
12	Liller P.	2077 Table Rock Road	GA880721	8/19/1991	251-52	398	1	154	398
13	Hebb G.	1979 Table Rock Road	GA881124	9/18/1992	None	215	1	24	215
14	Wolfe	1931 Table Rock Road	GA910097	8/20/1991	221,293 313,377	428	8	188	428
15	Gray	238 Fairview Church Road	GA732486	1990/1995	71-73	Turbidity Contamination			
16	Gordon J.	295 Fairview Church Road	GA811756	3/17/1989	132-34,210-11	250	1	6	250
17	Miller J.	417 Fairview Church Road	GA880722	8/22/1991	180,274	350	1	135	350
18	Miller Harold	1019 Fairview Church Road-built 1991	GA880578	7/29/1991	53,117	402	6	117	402
19	Atkins George	1235 Fairview Church Road	GA881024	7/14/1992	52,56,263	400	6	32	400
20	Cutter M.	Jct Nurses Home Road-built 1999	GA941019	2/26/1999		340	11	208	340
21	Bramble C.	665 Table Rock Road	GA950579	4/25/2006		360	0.5	260	360
22	Bentley M.	595 Table Rock Road	N/R	BOM-loss yield. Subsidence Impacts. 6/15/ 2005					
23	Lambert	379 Table Rock Road	GA950578	10/26/2005		302	6	153	302
24	Mettiki (Mine Offi	293 Table Rock Road	GA950284	11/10/2004	None	271	50	114	271
25	Beeman M.	1902 Fairview Church Road	GA942395	11/4/2002	53,155,334	342	3	112	342
26	Schrock	1023 Wilson-Corona Road	GA942743	11/24/2003	20,50	200	40	32	200
26	Bittinger H.	1023 Wilson-Corona Road	N/R	New well	N/R				
27	Cooper	1066 Wilson Corona Road	GA942397	11/7/2002		362	6	193	362
28	Cooper	1194 Wilson-Corona Road (subd.)	GA942744	11/21/2003		542	1	162	542
29	McNeill James	1059 Wilson Corona Rd (est. Mine Map)	GA881286	8/28/1993		120	40	31	120
30	Dixon W.	2324 Wilson-Corona Road	GA940075	12/10/1995		403	4	225	403
31	Lower	140 Corona-Bayard Road	GA942372	10/22/2002	138-40	162	100	56	162
32	Hanlin Beryl	751 Althouse Hill Road (see below)	GA942041	11/5/2001	137,153,169,193	202	75	63	202
33	Lane	1163 Althouse Hill Road	GA942398	11/12/2002	54,59,121,175	262	8	49	262
34	Uphole Daley	8105 GW Hwy - House built 1965	GA941693	12/11/2000		162	100	32	162
35	Bramble M.	6680 George Washington Highway	GA940201	11/2/1995		202	25	73	202
36	Fisher R.	6687 George Washington Highway	GA940218	2/27/1996	108-09	183	8	38	183
37	Stoner	6415 George Washington Highway	GA940193	11/2/1995	127-28	565	2	110	565
38	Mettiki (house wel	6068 GW Hwy - est. from drillers report	GA940206	11/5/1995	35-37	263	3	67	263
39	Rourbaugh	1947 Wilson Corona Rd-New Spring Box	N/A	11/1/1992					
N/A	Wilt R.	445 Wayne Harvey Road	GA880008	5/12/1989	NA	447	1	190	447
N/A	Wilt E.	South side Harvey Road	GA811538	11/22/1988	NA	70	7	21	70
N/A	Hanlin	Replaced by GA942041 (see Map No. 32)	GA880601	6/10/1991	NA	104	15	22	104

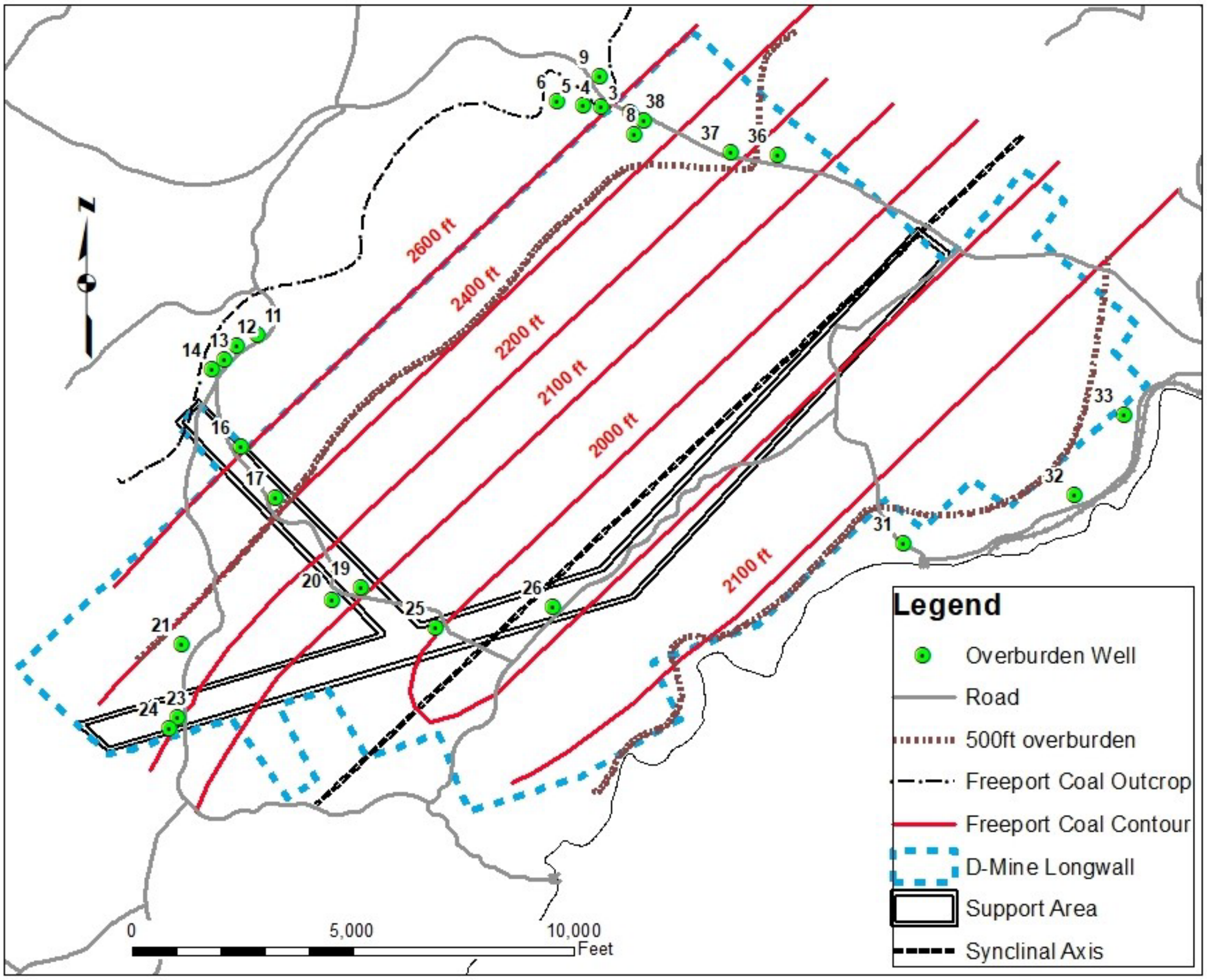


Figure 5. Structural map on the top of the Upper Freeport coal seam

Figure 5 is a structure map on the top of the Upper Freeport coal seam. Shown are the approximate locations of the vertical separation depths of less than 500 feet between the coal and the bottom of 17 water supplies (11 drilled wells, 2 dug wells, and 4 springs) that were impacted. The range of vertical separation depths for all those water supplies was 5-450 feet, with an average of 153 feet. Also included were 10 water supplies (5, 6, and 20-26) for which there were no records of sources or depths, but the replacement wells had vertical separations of less than 500 feet. Not included were two wells (Nos. 1 and 2) completed below the coal seam and one well (No. 10) completed up-dip of the outcrop. Seven impacted water supplies (3 drilled wells and 3 springs) had a vertical separation of greater than 500 ft. To that total was added one water supply with no record of source or depth, but for which the replacement well had a separation of greater than 500 feet. If it is assumed that all the unknown sources were drilled wells, then of the 97 water supplies on the adjusted inventory, 29 of the 61 drilled wells (48%), 8 of 22 springs (36%) and 2 of 5 dug wells (40%) had overburden thicknesses of less than 500 feet. Of those, 21 of 29 drilled wells (69%), 4 of 8 springs (50%) and 2 of 2 dug wells (100 %) were impacted. For those water supplies with a vertical separation of greater than 500 feet, 5 of 32 drilled wells (16%), 3 of 16 springs (19%) and 0 of 3 dug wells (0%) were impacted. These data suggest that overburden thickness was a significant factor in the impacts to the domestic water supplies. The average overburden thickness in the mined area is about 400 feet and 38 of the 97 water supplies (40%) had to be replaced or repaired. These results are like those in the Witkowski (2010) study. In that case, six of the seven mines in the study had overburden thicknesses of 627 to 887 feet and 4 to 14 % of the water supplies were impacted. The seventh mine had an average overburden 338 feet and 100% of six water supplies were impacted by mining.

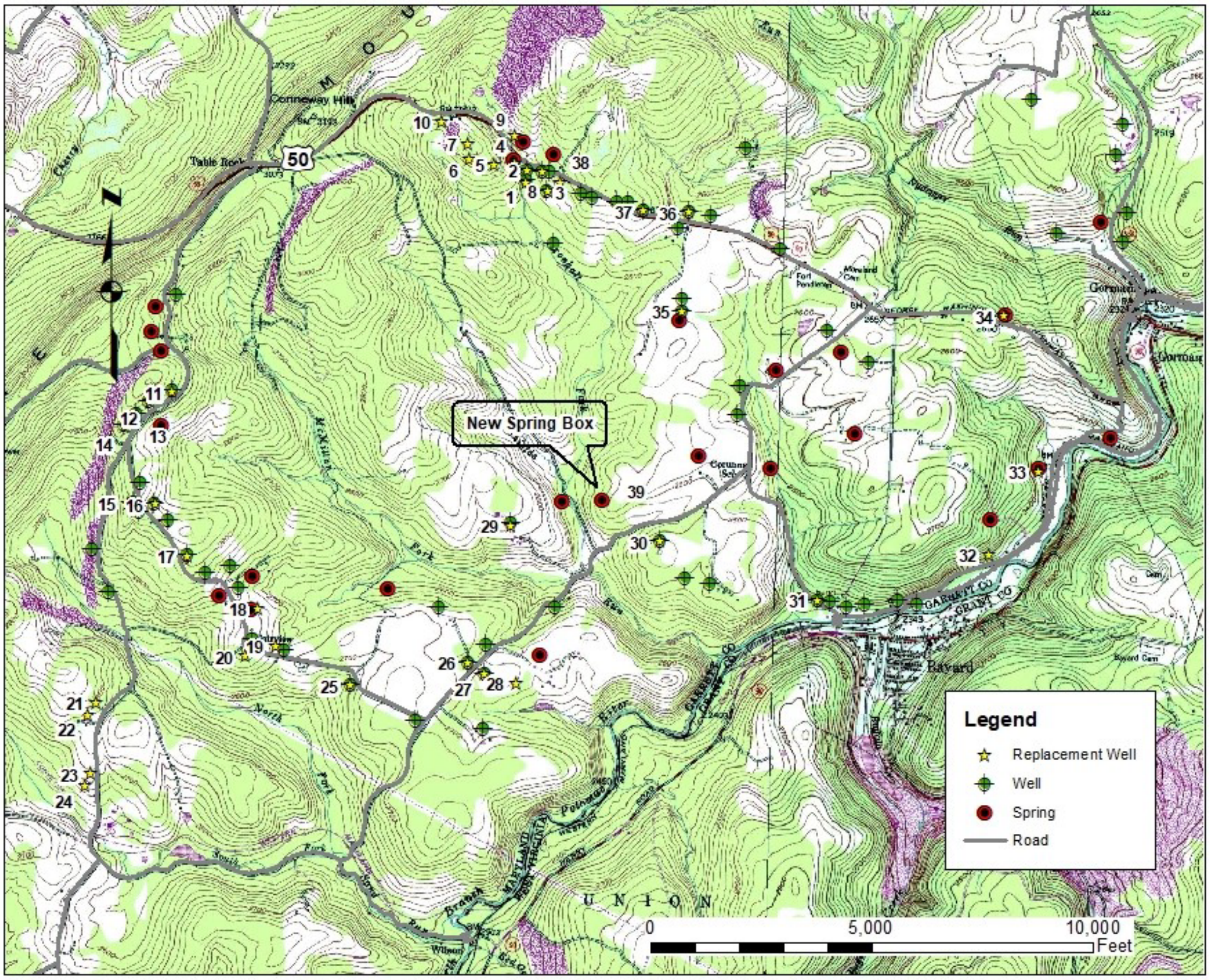


Figure 6. Topographic map in the area of the D-Mine

Figure 6 is topographic map in the area of the D-mine. Five of 17 (29%) impacted valley supplies (two springs and three drilled wells), five of 18 (28%) hilltop supplies (six drilled wells) and 27 of 59 (46%) hillside supplies (four springs, one spring box, two dug wells and 20 drilled wells) were replaced. These results do not include the three unknown water supplies. In the Witkowski investigation, 9, 13, and 9 percent of the water supplies on valley bottoms, hilltops, and hillsides, respectively, were impacted. The higher rates in the present study appear to reflect the relatively shallow depths of the Freeport Coal seam at the Mettiki Mine. There is little evidence that topography is a controlling factor of the impacts caused by dewatering of the

Mettiki mine since valley water supplies were affected by mine dewatering in the same manner as the hilltop water supplies.

Table 1 indicates that, where the type of mining causing an impact could be identified, only seven and two other possible ones of 38 water supplies could be related to longwall mining, while the room and pillar operations were closest to the remaining 29 water supplies. This is misleading; however, since the room and pillar main entries and gate roads were developed in advance of longwall mining, so many of the impacts could have already occurred before a panel was developed.

The distance from mining activity could be reasonably determined for 38 water supplies. There were 13 impacts within 1000 feet of mining, 21 greater than 1000 to 2000 feet of mining and seven greater than 2000 to 4500 feet from mining.

In 1982, a surface water supply from Mount Storm, West Virginia was developed to serve 55 homes and businesses in Gorman, Garrett County Government (2014). An MDE grant and Mettiki Coal Mine funds were used to construct a public groundwater supply, Garrett County Government (2014), in 1996-1997 for the town of Gorman using two wells drilled just across the top of Backbone Mountain, to serve customers in Gorman and along U.S. Route 50 (George Washington Highway). This appeared to have been a replacement supply for poor quality water provided by the Mount Storm system. In 2003, a water line was extended from US Route 50 along Wilson Corona Road to supply 35 additional customers apparently having private well problems, Figure 7. Alan Hooker of the MDBOM (Wheeler and Pelton, 2006) indicated that about a dozen homes were without well water along Table Rock Road. In 2007, a water line was constructed along Table Rock Road and a portion of Fairview Church Road to supply an additional 26 customers whose water supplies were affected by deep mining activity, Garrett County Government (2014). This is consistent with the Mettiki mine actions in that nearly all replacement wells were drilled before 1996, 2003 and 2006 along George Washington Highway, Wilson-Corona Road, and Table Rock-Fairview Church Road, respectively, indicating that later impacted water supplies were mitigated by connecting the homes to the Gorman public water supply.

Garrett County Government (Diane Rohrbaugh, personal communication, 2020) provided the initial records of the customers to be connected to the Table Rock water line extension, Table 3. There were only 14 new customers along Table Rock Road and Fairview Church Road, which is approximately the number of wells Alan Hooker indicated were impacted by mining activity. This included replacement wells for four customers drilled during the period 1989-1991. Two were on the mine inventory that had not previously been replaced. Seven were outside the inventory boundary and one was inside the inventory boundary but not on the inventory. The county government had no initial records of customers along Wilson-Corona Road to be connected to the system

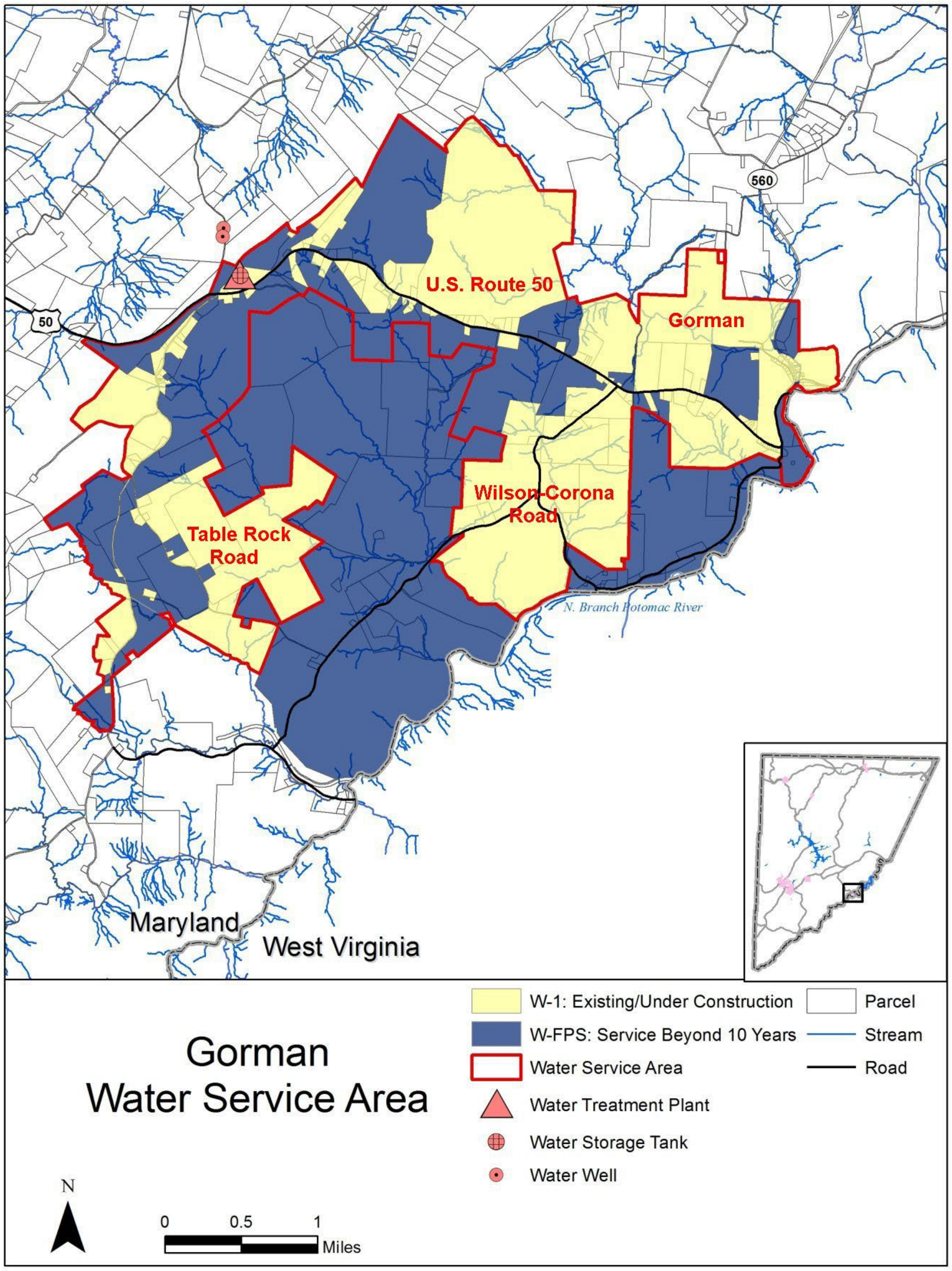


Figure 7. Map of Gorman Water Service Area. Modified from Garrett County Water and Sewerage Plan (2014)

Table 3. Gorman water service area – Proposed Table Rock/Fairview Church customers

Name	Address	Tax Map	Block	Parcel	Yr Built	Replaced	Dist. Mine
Evans, Charles P.	749 Fairview Church Road	100	12	10	1940		1000 est
& Mary K.	Oakland, 21550-5919						
Thomac, Larry E.	3158 Table Rock Road	95	26	66	2002		5875
& Robin L.	Oakland, 21550						
Teter, Catherine L.	2746 Table Rock Road	95	24	90	1984		3970
& Brenda L.	Oakland, 21550-6019						
Hebb, Georg W.	1979 Table Rock Road	100	6	85	2004*	1992	1850
& Rachel K.	Oakland, 21550-6014			Lot bought in 1992			
Waligorski, Dorothy A.	2690 Table Rock Road	95	24	115	1999		3850
	Oakland, 21550						
Knox, Layman Jr.	2686 Table Rock Road	95	24	47	1970		3800
	Oakland, 21550						
Pike, Ronald E.	1931 Table Rock Road	100	6	17	1964	1989	1830
& Shirley S.	Oakland, 6014						
Sisler, Boyd R.	2654 Table Rock Road	95	24	76	1992		3600
&Donna R.	Oakland, 21550-6018						
Green, Ronald	3020 Table Rock Road	95	24	65	1945		5100
& Tina	Oakland, 21550-6022						
Skeweris, Richard A.	2994 Table Rock Road	95	24	64	1930		5000
& Victoria L.	Oakland, 21550-6021						
Wolfe, Ralph V.L.	2189 Table Rock Road	100	6	65	1985	1991	1700
& Agnes C.	Oakland, 21550-9348						
Sisler, Arnold	2668 Table Rock Road	95	24	62	1900		3400
& Boyd & Donna	Oakland, 21550-6018						
Kyle, Richard G.	2077 Table Rock Road	100	6	54	1966	1991	1850
& Linda L.	Oakland, 21550						
Lambert, Ellsworth G.	2793 Table Rock Road	95	24	60	1977		4250
& Mary F.	Oakland, 21550-6019						

Garrett County Government subsequently provided an excel file listing all the Gorman water system customers as of October 2020, Table 4 and Figure 8. Of 94 customers, 32, 10, 33, and 19 are in the Gorman, Wilson-Corona, U.S. Route 50, and Table Rock-Fairview Church service areas, respectively. Of note is that only 10 of the 14 homes listed in Table 3 were connected to the system. In addition, only 10 of 35 homes along Wilson-Corona Road, and 19 of 26 homes along Table Rock and Fairview Church Roads were connected to the system, contrary to the previous estimates of water supply impacts in the county water and sewer plan.

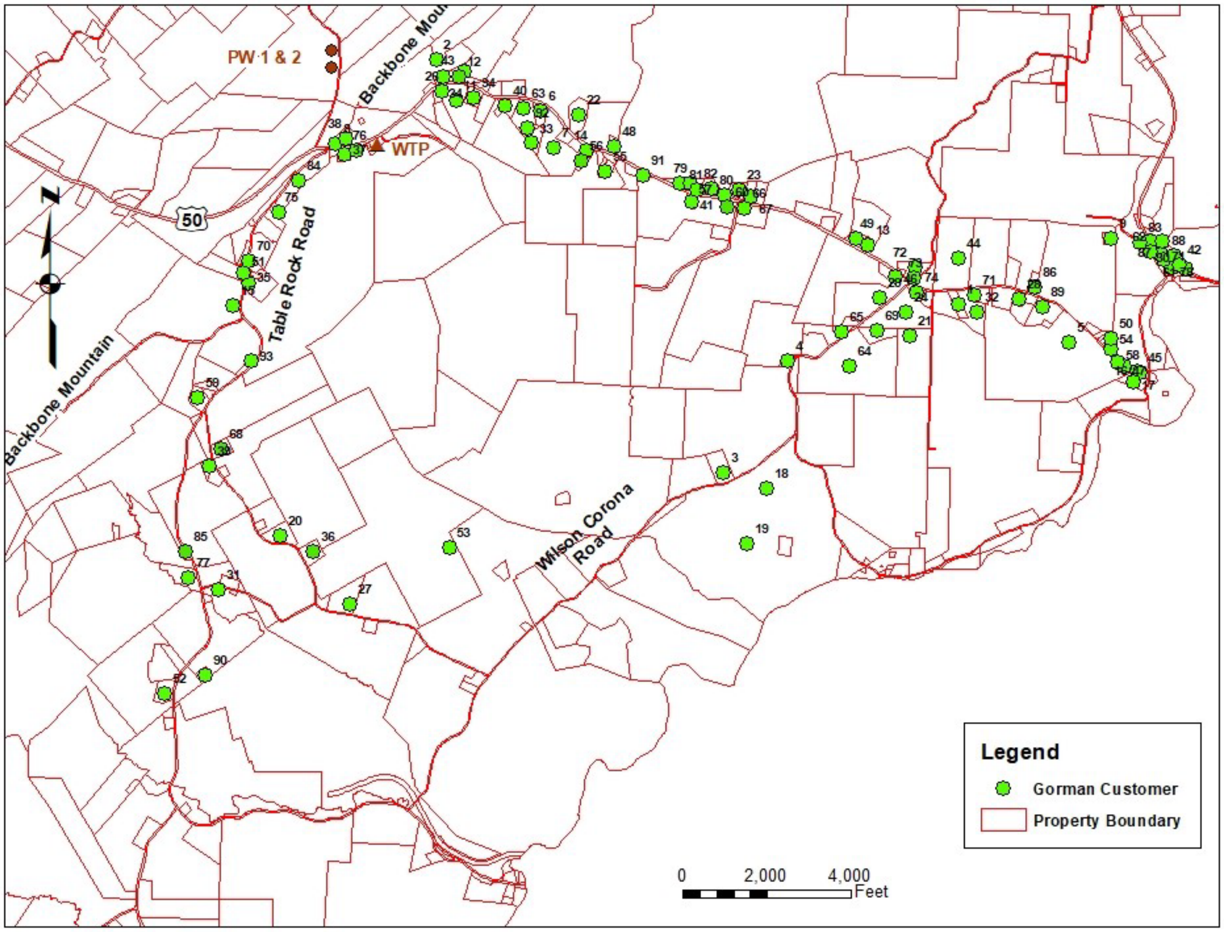


Figure 8. Map of the customers served by the Gorman public water supply system

Table 4. List of customers served by the Gorman public water supply system.

Map ID	Area	Name	Address 1	Tax Map	Block	Parcel	Yr Built	INV ID	REPL No	Date	Impacts	Dist. Boundary	Dist. Outcrop
1	E	ALEXANDER SARAH	7740 GEORGE WASHNGTN HWY	96	5	160	2006				Gorman	N/A	
2	E	BIRD RODNEY H & JENNIFER N	4987 GEORGE WASHINGTON H	96	8	7	1974	Outside Inventory Boundary			No Mining	4,000	2,500
3	E	BLAMBLE CANDACE J	2173 WILSON CORONA ROAD	101	10	95	1988	Mettiki 1985-No W/S			**Impacted**	<2,000	Downdip
4	E	BLAMBLE KEITH E & SANDRA	2883 WILSON CORONA RD	101	4	55	1983	W10-59	N/A		**Impacted**	<2,000	Downdip
5	E	BLAND CHARLES JR & REUNE	7984 GEORGE WASHINGTON HWY	101	6	9	2009				Gorman	N/A	
6	E	BOLYARD JEREMY S	5676 GEORGE WASH HWY	96	14	90	1976	Not on Inventory			**Impacted**	1,300	200
7	E	BOLYARD JEREMY S & KATHRYN M	5846 GEORGE WASH HWY	96	14	91	1980	N/A	5	10/5/1995	**Impacted**	400	Downdip
8	W	BOSLEY JEREMY R & HEATHER	4627 GEORGE WASHINGTON	96	13	80	1999	Outside Inventory Boundary			No Mining	4,000	1,500
9	G	BROWN BRUCE E	261 GORMAN ST	97	19	141	2004				Gorman	N/A	
10	G	BUTTS GLENN E	179 GORMAN ST	97	19	69	1920				Gorman	N/A	
11	E	CHAPMAN, JR DONALD	5288 GEORGE WASH HWY	96	14	18	1976	Outside Inventory Boundary			No mining	3,000	1,000
12	E	CORBIN WILLIAM & SANDRA	5267 GEORGE WASHINGTON H	96	13	88	1974	Outside Inventory Boundary			No mining	3,000	1,600
13	E	COSNER TIMOTHY	7301 GEORGE WASH HWY	96	23	54	1960				Gorman	N/A	
14	E	CRITES, JAMES	5976 GEORGE WASH. HWY	96	15	83	1975	W9-32	2	10/22/1995	**Impacted**	0	Downdip
15	W	CULP ARTHUR W JR & NORMA L	2485 TABLE ROCK	100	5	14	<1985	S11-6	N/A		**Impacted**	3,000	500
16	G	DENNIS & MARGARET KUHN	8722 GEORGE WASHINGTON HIGHWAY	102	1	11	1920				Gorman	N/A	
17	G	DICKS JAMES	1655 ALTHOUSE HILL ROAD	102	1	26	1995				Gorman	N/A	
18	E	DIXON JAMES	2310 WILSON CORONA ROAD	101	10	97	2003	W10-45B	N/A		New House	N/A	
19	E	DIXON WILLIS S	2324 WILSON CORONA RD	101	10	22	1883	W10-45C	30	12/10/1995	**Impacted**	<2,000	Downdip
20	W	EVANS CHARLES P & MARY K	749 FAIRVIEW CHURCH RD	100	12	10	1940	W11-53	N/A		**Impacted**	<2,000	Downdip
21	E	EVANS RICHARD & DELORAS	3258 WILSON CORONA RD	101	5	7	1990	W10-20	N/A		**Impacted**	<2,000	Downdip
22	E	EVANS, ET AL CAROLINE	5923 GEORGE WASHINGTON H	96	14	100	1920	S9-71	9	10/15/1995	**None**	500	100
23	E	FISHEL BARBARA	6687 GEORGE WASHINGTON H	96	22	76	2000	W9-8	36	2/27/1996	New House	0	Downdip
24	E	FLANAGAN NAOMI J	3416 WILSON CORONA RD	101	5	4	1973	1985 Mettiki-No Water Supply			Gorman	N/A	
25	G	GEARE DIANA R	82 GORMAN ST	97	19	71	1910				Gorman	N/A	
26	G	GEARHART THOMAS A	5182 GEORGE WASHINGTON H	96	13	105	1991	Outside Inventory Boundary			No Mining	N/A	
27	E	GEROSKI ERIK J & ELAINE D	1235 FAIRVIEW CHURCH RD	101	13	81	2010	W12-7	19	7/14/1992	New House	N/A	
28	E	GNEGY JESSIE	8048 GEORGE WASH HWY	96	24	104	2004				Gorman	N/A	
29	E	GOODWIN GLEN & CATHERINE	3353 WILSON CORONA RD	101	5	3	1955	W10-16	N/A		**Impacted**	0	Downdip
30	G	GORMAN VOLUNTEER FIRE STATION	270 GORMAN RD	97	19	87	N/R				Gorman	N/A	
31	W	GREGORY LAWRENCE W JR	1062 TABLE ROCK ROAD	100	18	119	1992	On Adjusted Inventory			**Impacted**	<2,000	Downdip
32	E	GRUBB ET AL JAMES	7876 GEORGE WASHINGTON H	101	5	8	1930				Gorman	N/A	
33	E	HARVEY JAMES	210 CALLICOAT ROAD	96	14	96	1976	N/R	6	6/8/1995	**None**	1,000	Downdip
34	E	HEBB LEE	5209 GEORGE WASH HWY	96	13	61	2003	Outside Inventory Boundary			No mining	3,400	1,600
35	W	HEBB PERRY P & JUDY A	2608 TABLE ROCK RD	95	24	69	1976	W11-4	N/A		No mining	3,000	800
36	W	HENLINE DONALD W & FRANCES R	889 FAIRVIEW CHURCH	100	18	58	1970	W11-15	N/A		**Impacted**	<2,000	Downdip
37	W	HIGHPOINT HOLDINGS, LLC	4676 GEORGE WASHINGTON HIGHWAY	96	13	97	1999	Outside Inventory Boundary			No Mining	4,000	1,100
38	W	INGLESE PHYLLIS	4651 GEORGE WASH HWY	96	13	11	1930	Outside Inventory Boundary			No Mining	4,000	1,300
39	W	JAMES JESSE L	238 FAIRVIEW CHURCH RD	100	12	132	1965	W11-27	15	N/A	**Impacted**	<2,000	Downdip
40	E	JANOSKE WILLIAM & LISA	45 CALLICOAT RD (was 2902 GW HWY)	96	14	114	1992	N/R	10	6/7/1991	**None**	2,000	400
41	E	KELLY JUSTIN	6436 GEORGE WASH HIGHW	96	21	132	2012	Not on Inventory			New House	0	Downdip
42	G	KISSELOVICH JOSEPH R	57 STEYER GORMAN RD	97	19	144	1987				Gorman	N/A	
43	E	KITZMILLER LISA	5277 GEORGE WASH HWY	96	13	129	1992	Outside Inventory Boundary			No Mining	3,000	1,700
44	E	KNOTTS DANIEL E & KATHERN	9335 GARRETT HWY (Mailing address)	96	5	46	N/R		Cattle Trough		Gorman	N/A	
45	G	KUHN DENNIS	8712 GEORGE WASHINGTON H	102	1	10	1920				Gorman	N/A	
46	E	LANSBERRY MIA	7466 GEORGE WASHINGTON H	96	23	78	1971	1985 Mettiki-no water supply			Gorman	N/A	
47	G	LEE, DESTINY	8642 GEORGE WASHINGTON HIGHWAY	102	1	14	1920				Gorman	N/A	
48	E	LIVENGOOD JAMES & ANNETTE	6083 GEORGE WASHINGTON H	96	15	24	1990	S9-4	N/A		New House	0	Downdip
49	E	LOPEZ ANTHONY & JAMIE	7215 GEORGE WASHINGTON H	96	23	33	1950				Gorman	N/A	
50	G	LOPEZ CELSO & GUADALUPE	8519 GEORGE WASHINGTON H	102	1	18	1930				Gorman	N/A	
51	W	LUDWIG DEREK	2690 TABLE ROCK ROAD	95	24	115	1999	Outside Inventory Boundary			No Mining	3,000	1,100
52	W	METTIKI COAL CORP	545 TABLE ROCK ROAD	100	23	134	1994	Outside Inventory Boundary			**Impacted**	<2,000	Downdip
53	W	MILLER HAROLD E & RUBY M	1019 FAIRVIEW CHURCH ROAD	101	7	11	1991	S11-13B	N/A		**Impacted**	<2,000	Downdip
54	G	MOON JOEL	8541 GEORGE WASH HWY	102	1	19	1920				Gorman	N/A	
55	E	MORELAND ROYCE B & LAURA L	6002 GEORGE WASHINGTON H	96	21	163	2010	W9-35	8	2/21/1996	New House	0	Downdip
56	E	MORELAND ROYCE G & VONDA	5992 GEORGE WASHINGTON H	96	15	106	1976	W9-33	1	N/R	**Impacted**	0	Downdip
57	E	PAUGH DAVID & JESSICA	6445 GEORGE WASHINGTON	96	21	149	1983	1985-Mettiki no water supply			**None**	0	Downdip
58	G	PENNINGTON CHARLES A	8612 GEO WASH HWY	102	1	7	1977				Gorman	N/A	
59	W	PIKE RONALD E & SHIRLEY S	1931 TABLE ROCK ROAD	100	6	17	1964	W11-22	14	8/20/1991	**None**	<2,000	Downdip
60	E	RATLIFF SHANE DOUGLAS	6610 GEORGE WASH HWY	96	22	169	1998	W9-40	N/A		New House	0	Downdip
61	G	RIDDER NITA M	77 STEYER GORMAN ROAD	97	19	164	1900				Gorman	N/A	
62	G	ROBINETTE DEBORA	137 GORMAN STREET	97	19	68	1920				Gorman	N/A	
63	E	ROBINETTE JR GREGORY B	126 CALLICOAT RD	96	14	26	1984	Not on Inventory			**Impacted**	2,000	100
64	E	ROHRBAUGH GALEN & DOTTIE	3033 WILSON CORONA RD	101	5	6	1920	1985-No W/S Airplane Hanger			**None**	<2,000	Downdip
65	E	ROHRBAUGH GALEN JR & CHRIS	3197 WILSON CORONA RD	101	5	77	1991	S10-21			**Impacted**	<2,000	Downdip
66	E	ROHRBAUGH JEREMIAH & RENA	6690 GEORGE WASH HWY	101	4	155	N/R	1985-Mettiki No W/S (trailer)			**None**	<2,000	Downdip
67	E	RUSH JOEL	6737 GEORGE WASH HWY	96	22	164	2008	1985-Mettiki no water supply			New House	0	Downdip
68	W	SHANE & STACEY WHITEHAIR	195 FAIRVIEW CHURCH ROAD	100	12	25	1940	W11-24	N/A		**Impacted**	<2,000	Downdip
69	E	SINES, JR DAVID	3244 WILSON CORONA RD	101	5	5	1985	S10-22	N/A		**Impacted**	<2,000	Downdip
70	W	SISLER DANIEL	2746 TABLE ROCK RD	95	24	90	1984	Outside Inventory Boundary			No Mining	3,000	1,400
71	E	SISLER EDWARD	7902 GEORGE WASHINGTON H	96	24	130	1976	Mettiki no water supply			Gorman	N/A	
72	E	SKEWERIS ANGELA	7499 GEORGE WASH. HWY	96	23	39	1920				Gorman	N/A	
73	E	SKEWERIS DENNY	7545 GEORGE WASHINGTON HIGHWAY	96	23	93	1920				Gorman	N/A	
74	E	SKEWERIS GARY A	3542 WILSON CORONA RD	96	23	77	1977				Gorman	N/A	
75	W	SKEWERIS RICHARD A & VICTORIA L	2994 TABLE ROCK ROAD	95	24	64	1930	Outside Inventory Boundary			No Mining	4,000	1,800
76	W	SKEWERIS ROBERT G	4704 GEORGE WASH HWY	96	13	131	N/R	Outside Inventory Boundary			No Mining	4,000	1,000
77	W	SNYDER ANDREW C	1099 TABLE ROCK ROAD	100	17	74	1940	1985-Mettiki no water supply			**None**	<2,000	Downdip
78	G	STEMPLE WILLARD J	26 GORMAN STREET	97	19	75	1957				Gorman	N/A	
79	E	STONER CHARLES W & LORETTA	6415 GEORGE WASHINGTON H	96	21	112	1999	W9-72	37	11/2/1995	**Impacted**	0	Downdip
80	E	STONER DAVE	6655 GEORGE WASHINGTON H	96	22	152	1997	W9-8	N/A		New House	0	Downdip
81	E	STONER FRED R & ESTHER N	6577 GEORGE WASHINGTON H	96	22	62	1973	W9-6B	N/A		**Impacted**	0	Downdip
82	E	STONER KEVEN T & KIMBERLY A	6483 GEORGE WASHINGTON H	96	21	120	1988	1985-Mettiki no water supply			**Impacted**	0	Downdip
83	G	STRAIT MICHAEL	205 GORMAN	97	19	69	N/R				Gorman	N/A	
84	W	THOMAS LARRY E & ROBIN L	3158 TABLE ROCK ROAD	95	24	66	2002	Outside Inventory Boundary			No Mining	4,000	1,700
85	W	THOMAS WILLIS W & SHEILA M	1257 TABLE ROCK ROAD	100	17	60	1930	W11-29	N/A		**Impacted**	<2,000	Downdip
86	E	UPHOLD DALEY	8105 GEORGE WASHINGTON H	96	24	67	1965				Gorman	N/A	
87	G	UPHOLD EDGAR, SR	197 GORMAN RD	97	19	43	1930				Gorman	N/A	
88	G	UPHOLD NANCY	60 GORMAN STREET	97	19	60	1920				Gorman	N/A	
89	E	UPOLE HAROLD & KAREN	8190 GEORGE WASHINGTON HWY	101	6	72	1920				Gorman	N/A	
90	W	WARSAW BRUCE A	688 TABLE ROCK ROAD	100	18	127	2013	Outside Inventory Boundary			New House	N/A	
91	E	WARSAW, II BRUCE & MARCELLA	6128 GEORGE WASHINGTON H	96	15	103	2005	W9-38	?		New House	0	Downdip
92	E	WHITACRE BRANDON C	180 CALLICOAT ROAD	96	14	2	1998	N/A	7	N/R	New House	1,000	Downdip
93	W	WOLFE RALPH & AGNES	2189 TABLE ROCK ROAD	100	6	65	1985	W11-8	11	6/8/1989	**Impacted**	1,000	Downdip
94	E	WOTRING GARY & MARY	5388 GEORGE WASHINGTON H	96	14	5	1978	Outside Inventory Boundary			No Mining	3,000	1,200

Figure 9 is a mine timing map which indicates that mining activity occurred along US Route 50, between Wilson Corona Road and Backbone Mountain during the period 1995-1998. This was the same period during which wells were drilled to replace impacted water supplies 1-10 and 36-38 in Tables 1 and 2. This was also the same period during which the Gorman groundwater supply system was constructed. Mining between Wilson-Corona Road and the Potomac River occurred between 1999 and 2003 causing water supply problems that led to the construction of the Wilson-Corona Road water line extension in 2003. Early impacts occurred along Table Rock and Fairview Church Road between 1989 and 1992 due to mining in that area. Subsequent impacts occurred in 2006 when mining returned to the same area, after which the Table Rock-Fairview Road water line extension was constructed.

Since some of the water supplies may have been impacted, then mitigated by connecting to the Gorman water system, this requires some interpretation of the existing data. The main task is to determine which water supplies were either connected due to impacts or the decisions to connect were simply based on economic decisions made by the individual homeowner. One factor is that some new homes were built on properties without private water supplies, after the Gorman water supply was available for connection, so there were no water supplies at those sites to be impacted. In other cases, new homes were built on properties that had existing private water supplies but were connected to the public system. If these homes had low well yields, it is assumed that they were impacted, but if they had high well yields, then it is assumed that the homeowner connected to the public supply for economic reasons. Finally, there were properties connected to the public water supply that were more than 500 feet up-dip of the Upper Freeport Coal outcrop. It is unlikely that these homes would have been impacted since the drawdown due to pumping from the mine would not cause the water level in the aquifer to decline below the Upper Freeport Coal and the immediately underlying Freeport Sandstone.

Table 5 provides a summary of the final analysis performed to determine the percentage of the private water supplies that were impacted by dewatering of the D-mine. To calculate the number of water supplies on the adjusted inventory, those Gorman water system customers not on the Mettiki water supply inventory were added, then the ones up-dip of the coal outcrop were subtracted from the number on the Mettiki inventory, producing a total of 106 water supplies on the final adjusted water supply inventory. To calculate the number of water supplies impacted, the number of replicants, or those 16 properties connected to the public water that had previously had replacement wells drilled, had to be adjusted for wells replaced by public water due to either low yields or for economic reasons. The adjusted replicant number is then subtracted from the sum of the number of customers and previous replacements as were the number of new homes, customers up-dip of the coal outcrop and those customers without a previous water supply. The result is that an estimated 58 (55%) of 106 water supplies were impacted by mine dewatering. The impacts in the Wilson-Corona, U.S. Route 50 and Table Rock-Fairview Church areas were 52%, 52% and 69%, respectively.

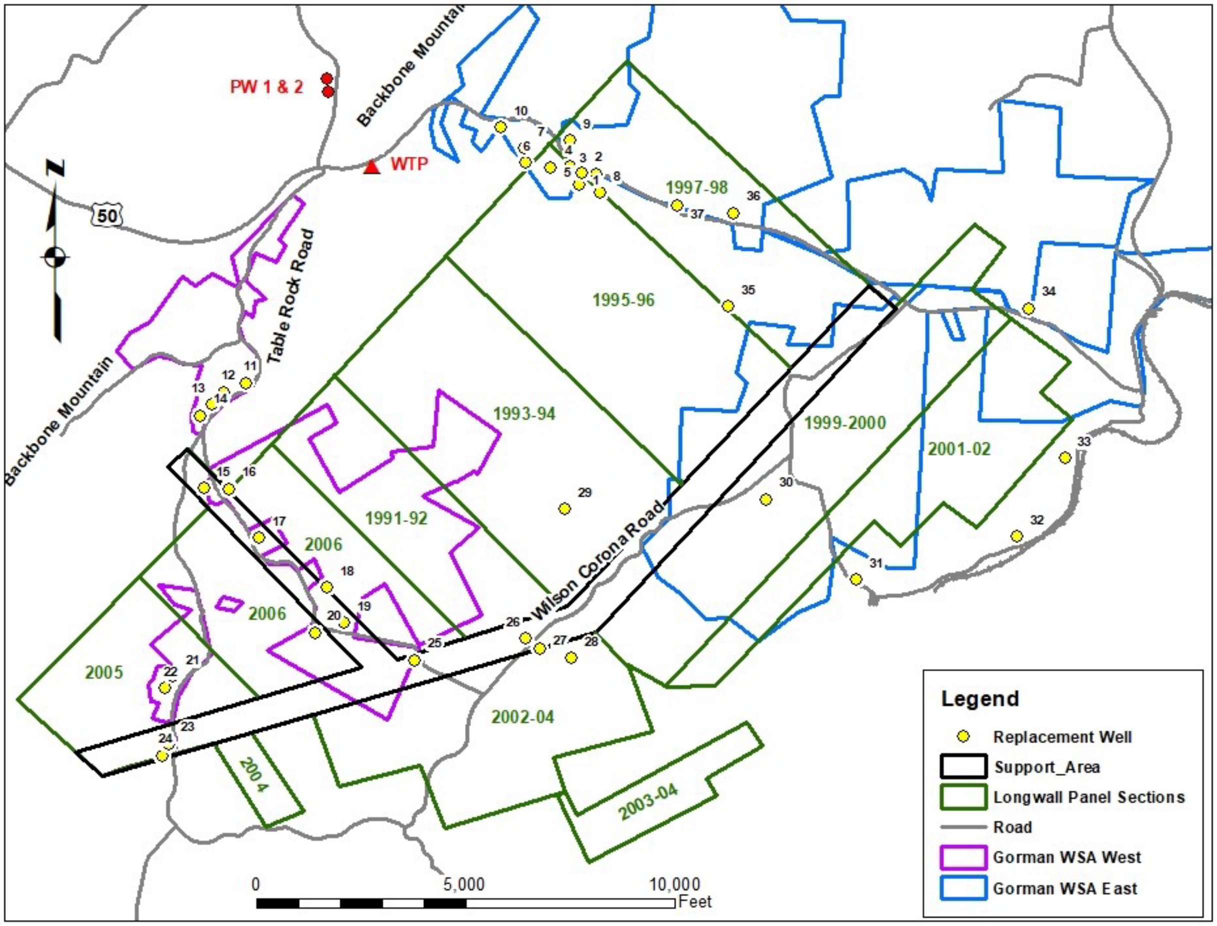


Figure 9. Timing advancement map for the D-Mine

Table 5. Summary of data used to estimate water supplies impacted by dewatering at the D-mine

Area	Customers	Not on Inventory	Updip Outcrop	W/S Inventory	Adj. Inventory	Replacements	Replicants	Note	Repl. Adj	New Houses	Updip Outcrop	No Water Supply	Adj. Impacts	Adj. Inventory	% Impacted
Wilson-Corona	10	2	0	31	33	8+1 repair	1	1-Low Yield	0	1	0	1	16+1 repair	33	52
Table Rock-Fairview Church	19	7	4	33	36	15	4	2-Low yield 1-New House	2	2	4	1	25	36	69
U.S. Route 50	33	17	11	27	33	13	10	4-Low yield 4-New House	6	10	11	2	16	33	52
Unknown	0	0	0	3	3	0	0	None	0	0	0	0	0	3	0
Subtotal	62	26	15	94	105	36+1 repair	15	7-Low yield 5-New House	8	13	15	4	58	105	55
Gorman	32	N/A	N/A	8	1	1	1	100 gpm	0	N/A	N/A	N/A	0	1	0
Total	94		15	102	106	37+1 repair	16	None	8	13	15	4	58	106	55

Where impacts to water supplies have occurred in fractured rock aquifers, it has frequently been proposed that they are drought related and not due to groundwater withdrawals. Mettiki mine reported that a drought occurred during the period of June 1991 to October 1991, when five water supplies were replaced. Table 6 shows the number of water supplies replaced by Mettiki and the calculated annual baseflow (in/yr) from data collected at the USGS gage at Steyer (01959500) on the North Branch of the

Potomac River during each year that the D-mine was in operation. The long-term mean baseflow for the gage is 17.9 in/yr, while for a severe drought (1-in-10-year return) it is 13.7 in/yr and for a record drought (1946) it is 11.2 in/yr. As can be seen, the average baseflow during the five years (1991-92, 1995-96 and 2002) when more than two water supplies were replaced (total of 24) was 16 in/yr, 20.6 and 17 .2 in/yr, respectively. The Palmer Drought Index for Garrett County indicates there was severe drought during July 1991 to May 1992, an average to wet period during 1995-1996, and a moderate drought from October 2001to February 2002, while only three water supplies were replaced during the four years (1988, 1999, 2000 and 2001) with the lowest average baseflow. The Palmer Drought Index for Garrett County, Dai et al. (2019), indicates there was a severe drought during July 1991 to May 1992, an average to wet period during 1995-1996, and a moderate drought from October 2001to February 2002, while only three water supplies were replaced during the four years (1988, 1999, 2000 and 2001) with the lowest average baseflow. The Palmer Drought Index indicates that there were severe to extreme drought conditions during the period December 1998 to May 2000, when only 1 water supply was replaced. However, the lower number of impacted water supplies replaced by wells after 1996 likely relates to the construction of the Gorman public groundwater supply, with extensions in 2003 and 2007, to which homes with impacted water supplies could have then been connected. Overall, however, there does not appear to be a connection between the impacted water supplies and droughts.

Table 6. Annual baseflow of the North Branch of Potomac River at Steyer and the number of replacement wells for the period 1987-2006

Year	No. Replaced	Baseflow	Year	No. Replaced	Baseflow
1987	1	16.4	1997	0	17.6
1988	***0***	***14.0***	1998	0	18.3
1989	1	24.1	***1999***	***1***	***14.6***
1990	0	21.1	***2000***	***1***	***13.2***
1991	***5***	***15.3***	***2001***	***1***	***14.2***
1992	***3***	***16.7***	***2002***	***4***	***17.2***
1993	1	20.5	2003	2	28.5
1994	0	21.1	2004	1	19.5
1995	***9***	***15.1***	2005	1	18.2
1996	***3***	***26.1***	2006	2	15.2

USGS Monitoring Data

The USGS installed a monitoring system that consisted of five nested well sites, one single well and four stream gages in the areas of the A and D mines. Their locations are shown in Figure 10.

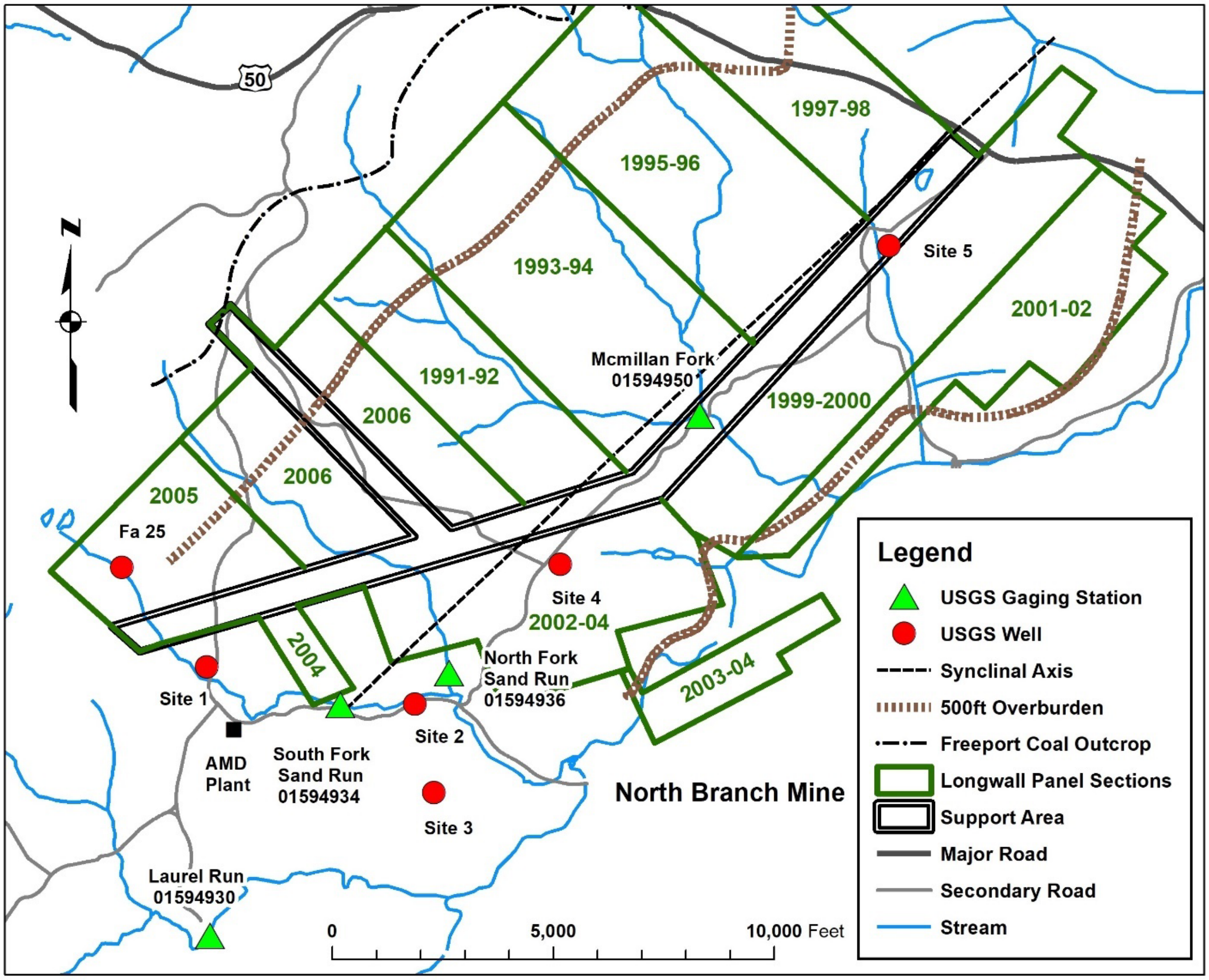


Figure 10. USGS groundwater monitoring well clusters and streamflow gaging stations.

Monitoring Well Data

Figure 11 includes a general map of the Mettiki Coal Mine, showing the locations of the USGS monitoring wells clusters (1-5). Cross-section A-A’ (Sites 1-3) is in the vicinity of A-mine, while sites 4 and 5 are in the area of the D-mine. Water use reporting from the A-C mines commenced in July 1979. Water level measurements were first taken in early 1980 from clusters 1-3, before any significant amount of water were withdrawn. In 1987, Mettiki applied to increase its withdrawal from 3 Mgd to 10 Mgd avg and to double its mined area to about 10,000 acres, by adding the D mine to its water use permit. Water use then was reported for the A-D mines under a single permit. Well clusters 4 and 5 were constructed at that time and water level measurements, USGS (2020) commenced prior to any mining in the vicinity of those wells.

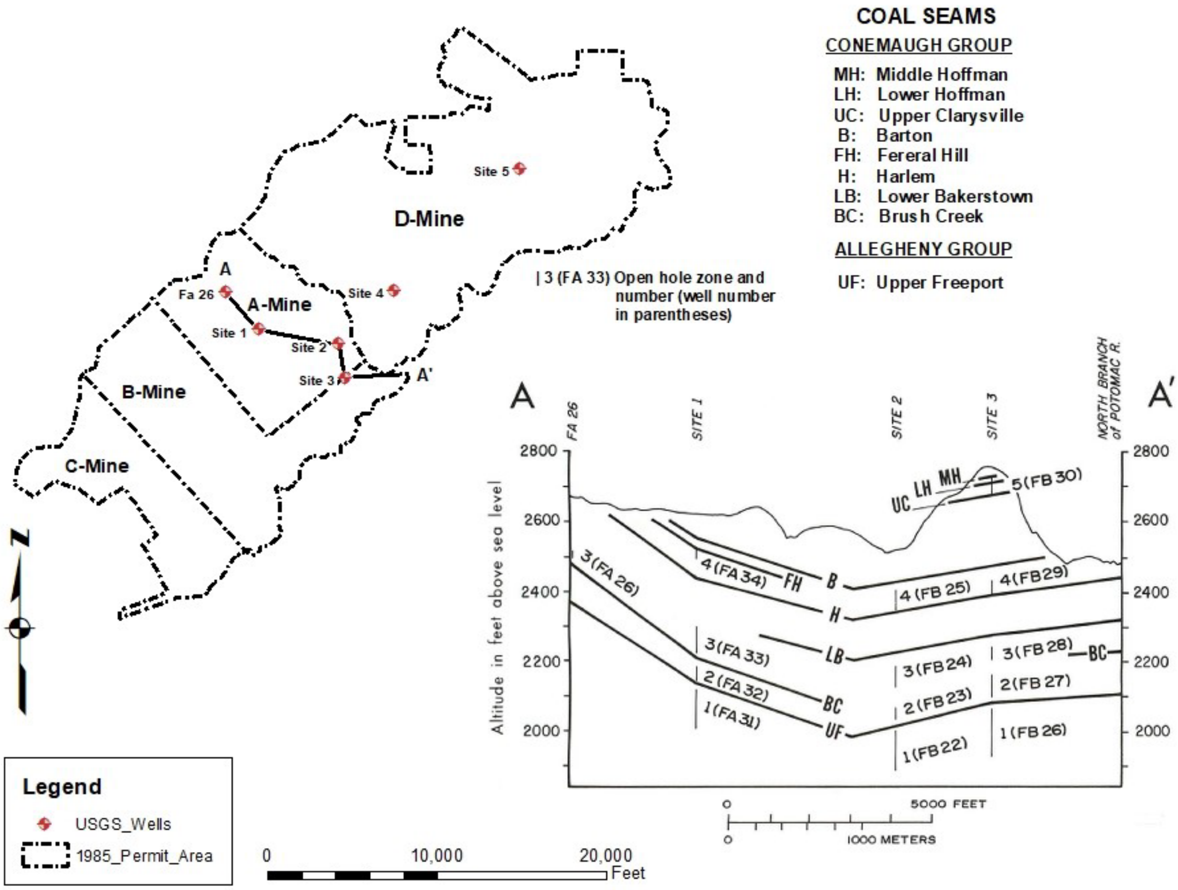


Figure 11. Open-hole zones of monitoring wells at sites 1-3, locations of sites 4 & 5 (D-Mine) and structural cross-section with coal seams (modified from Duigon and Smigaj, 1985)

The nested wells were drilled in the following order: Interval 1 – below the Upper Freeport Coal (UF) (mined seam), Interval 2 –just above the seam, Interval 3 – intermediate level, Interval 4 – shallow level, Interval 5 – very shallow near surface level. MGS indicated that all wells were cased and completed in consolidated sandstone units and that Interval 1 was isolated from the other units by a regionally extensive underclay. MGS also indicated that there was an underclay below the Lower Bakerstown coal seam, just above zone 3. These and other relatively impermeable overlying confining units initially led the mine and state geologists to believe that it was unlikely that there would be any unreasonable impacts to nearby wells due to mine dewatering.

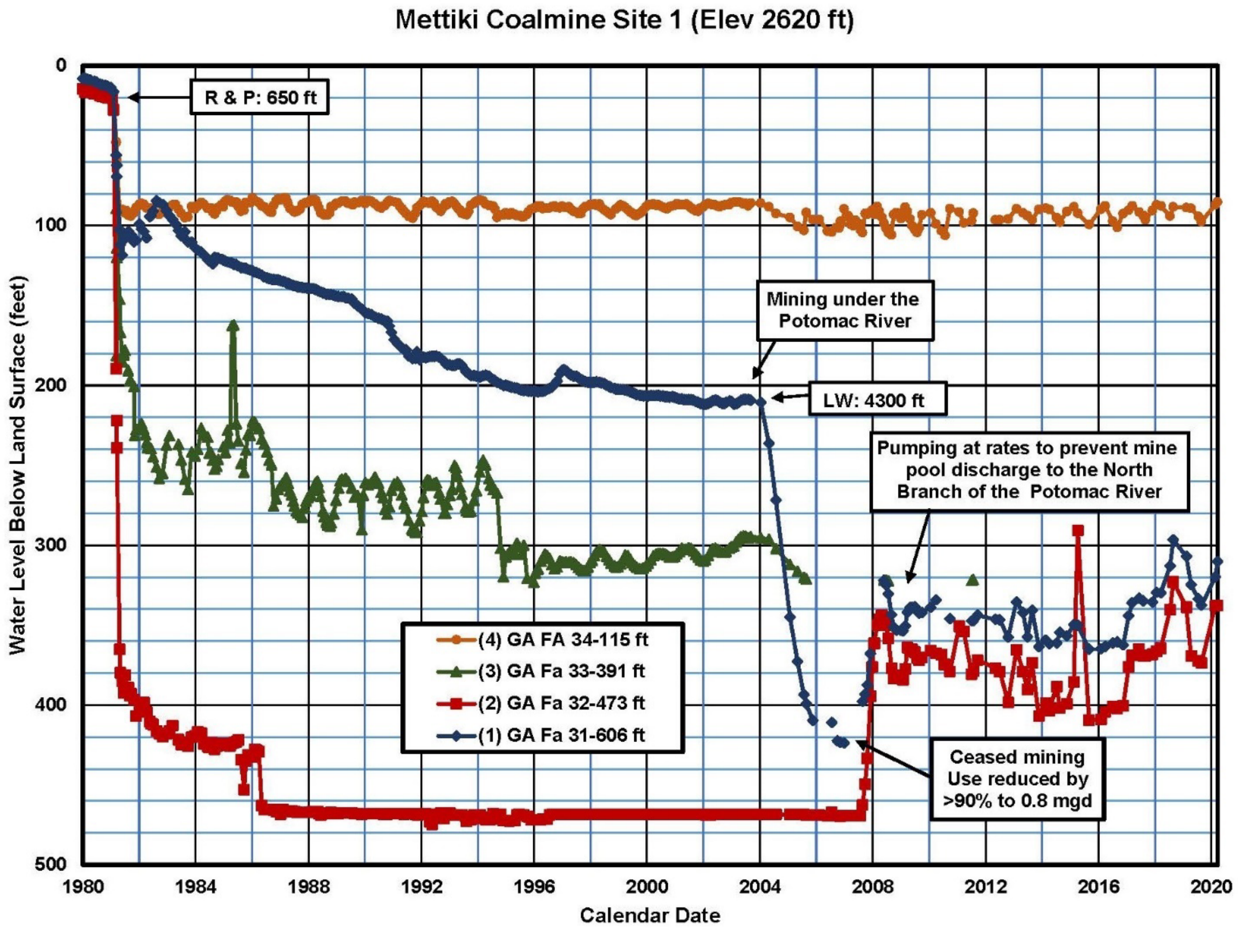


Figure 12. Groundwater levels at site 1 for the period 1980-2020

Figure 12 shows the water levels collected over time at Site 1. As the mine shaft (by room and pillar method) approached to within about 650 feet of the nested wells in 1981, there were water level declines in all wells of about 80 to 400+ feet, indicating the overlying clay/silt units were not effective confining units. The greatest decline was in well FA 32, located just above the Upper Freeport Coal Seam (zone 2), which went dry in 1986. There was a lesser, but still substantial longer-term decline in Fb 31, located just below the coal seam (zone 1), which appears to have taken about 20 years to stabilize, after which an additional sharp decline occurred 2004. At that time the closest activity was longwall mining at 4300 feet from the well cluster. This was followed by recovery of water levels after water use was reduced to an annual average 0.8 Mgd, when mining ceased in 2007. In the spring of 2008 Mettiki started pumping the mine pool at a rate to maintain the mine pool at a level to prevent discharges through breakouts into the North Branch Potomac River, Pointon and Felbinger (2013). Somewhat similar responses were noted in the wells at site 2.

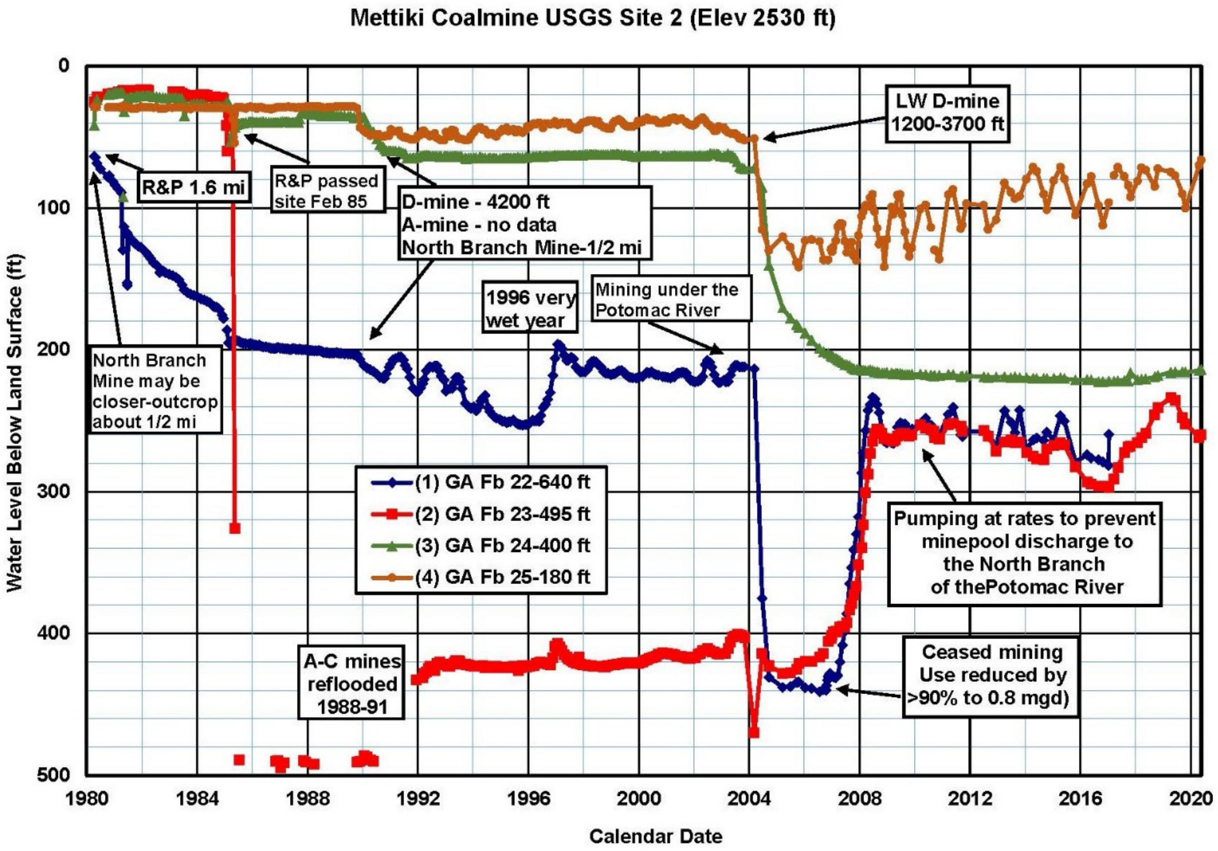


Figure 13. Groundwater levels at site 2 for the period 1980-2020

Figure 13 is a plot of water levels at site 2. It was noted that there was an immediate decline in the water level in Fb 22 (zone 1). This response did not appear to be related to activity at the Mettiki Mine, since room and pillar mining started at the A-mine about 1.6 miles from site 2 at that time and there were no significant withdrawals for dewatering of the mine. The outcrop of the Island Creek North Branch mine in West Virginia is located about ½ mile from the well cluster, but no information could be found concerning that mine, except that was operating until 1992. The pattern of the changes in water levels in zone 1 at sites 1 and 2 are very similar, except that the rates of drawdown and recovery are greater at site 2 than at site 1 (i.e., the water level at site 1 drew down more slowly and never stabilized for any significant length of time). Such a common pattern would indicate that each well was affected by pumping from the same location, while the faster rate of change at site 2 would indicate that it was closer to the withdrawal point. This could suggest that dewatering of the North Branch mine mainly caused the long-term drawdowns observed in zone 1 at sites 1 and 2; however, there were some later changes that could be related to Mettiki Mine operations.

In 1985, there was a water level decline of about 500 feet in FB 23 (zone 2), just above the coal seam, with modest water level drops (10-15 feet) in FB 22 and 24, and a small decline with immediate recovery in the shallow well (Fb 25). These responses occurred while room and pillar operations at the A-mine passed immediately by the site. There was a second moderate decline starting in October 1990 (about 20-50 feet) in all wells except Fb 23, which was already dry. After that event, the seasonal variation increased in the shallow well (Fb 25) and the deepest well (Fb 22), and the water levels recover after several years. For the shallow well, this may be due to increased fracturing caused by subsidence related to longwall mining. The fractures then seal themselves over time producing the recovery noted in the water levels. Although somewhat more problematical, until a better explanation can be found, this is probably what happened in the deeper well (FB 22). Mining of a longwall panel started in November 1990 at 1500 feet from site 2. While there are no available times on the map for preparatory room and pillar operation, it seems reasonable to assume that they started shortly before the longwall mining and may have advanced in the immediate vicinity of site 2. Activity at the D-mine occurred at 4200 feet during the same period. While extraction and dewatering at the North Branch Mine cannot be ruled out, the responses in the shallow wells (zones 3 and 4) and their timing suggest that they were due to Mettiki operations. During the same period, water levels recovered more than 100 feet in FB 23, located just above the UF seam. This may be related to partial reflooding of mines A-C, which occurred between 1989 and 1991. In 2003, there was a major decline in the water levels in all wells, except FB 23, which is probably related mining in the area between the original proposed D-mine and the A-mine. At the time of the declines, there were two longwall panels being mined at distances of 1200 and 3700 feet from the site. Finally, there was a sharp recovery in all water levels in 2007, as total pumpage from the mine declined to 0.8 Mgd avg, due to the effective cessation of mining operations. Water levels then stabilized because of the follow-on pumping at rates of 8-9 Mgd to prevent discharges from the mine pool to the North Branch of the Potomac River.

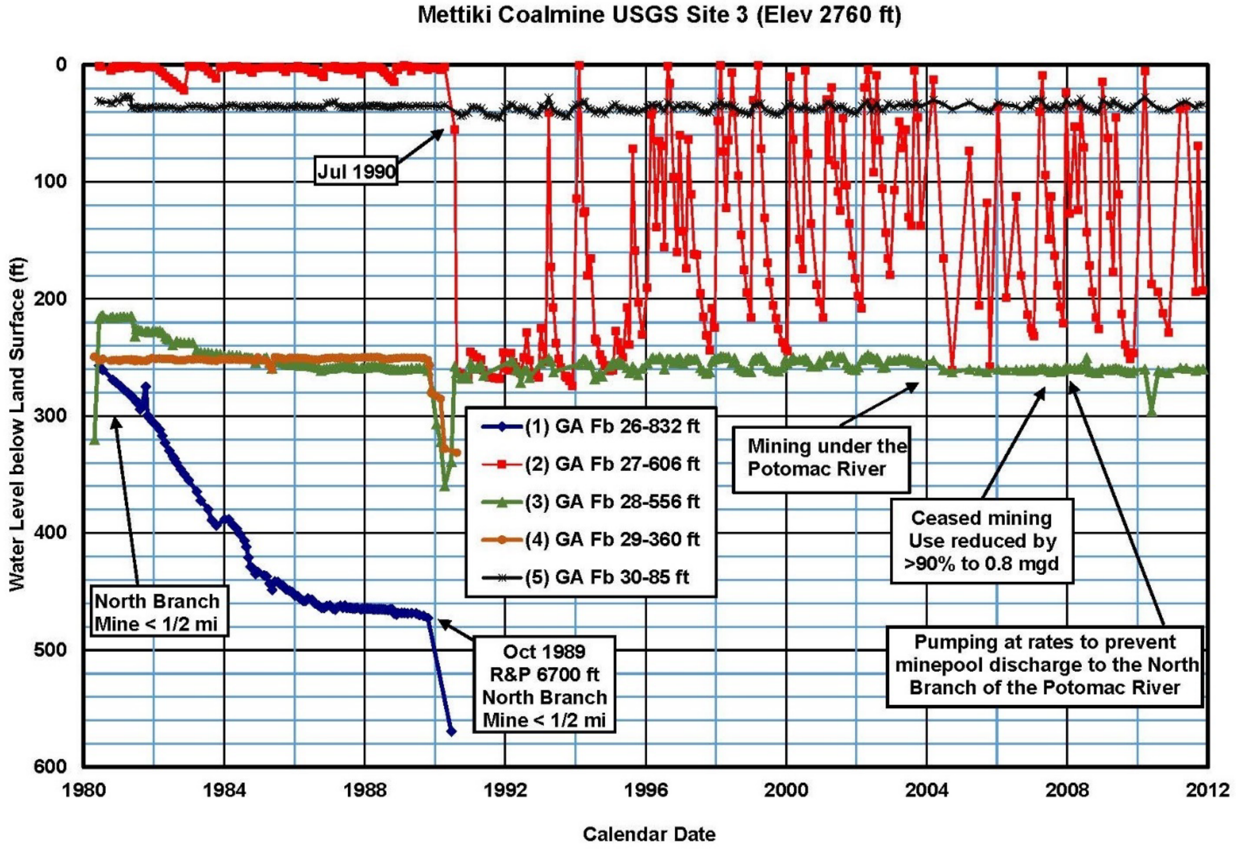


Figure 14. Groundwater levels at site 3 for the period 1980-2012

At site 3 in 1981, Figure 14, the water levels in three wells were about 250 feet below land surface, while the water level in the fourth well (Fb 27) was near its surface elevation of 2755 feet. The elevations of the three lower water levels were about 2500 feet, which were about the same as the nearby Potomac River, suggesting that those water levels represented drainage to a regional base level. The higher level in the fourth well was probably that of a perched water table, separated by a low permeability layer from and not hydraulically connected to the regional system. The initial drawdown in zone 1 was like that at site 2; again, suggesting that it was due to pumping at the North Branch Mine. The drawdowns in late 1989 occurred at the same time as those at site 2, indicating that they were caused by the same activity. The main difference is that the drawdowns were greater at site 3, while site 2 was closer to the activity (room and pillar) at the D-mine. This would indicate that the water level declines were due to dewatering of the A-mine. The immediate recovery of water levels and seasonal fluctuations after that point are evidence of the effects of longwall mining. In the case of Fb27, the water level in that well dropped immediately by about 250 feet; then seasonally fluctuated by 250 feet for the remainder of the record. This suggests that the sandstone was virtually impermeable prior to mining, the mining formed some fractures that did not seal, but the formation remained nearly impermeable, both factors leading to the large seasonal water level fluctuations in that well. Other than those changes, there were no further changes in water levels in response to mine dewatering activities until the end of the record in 2012.

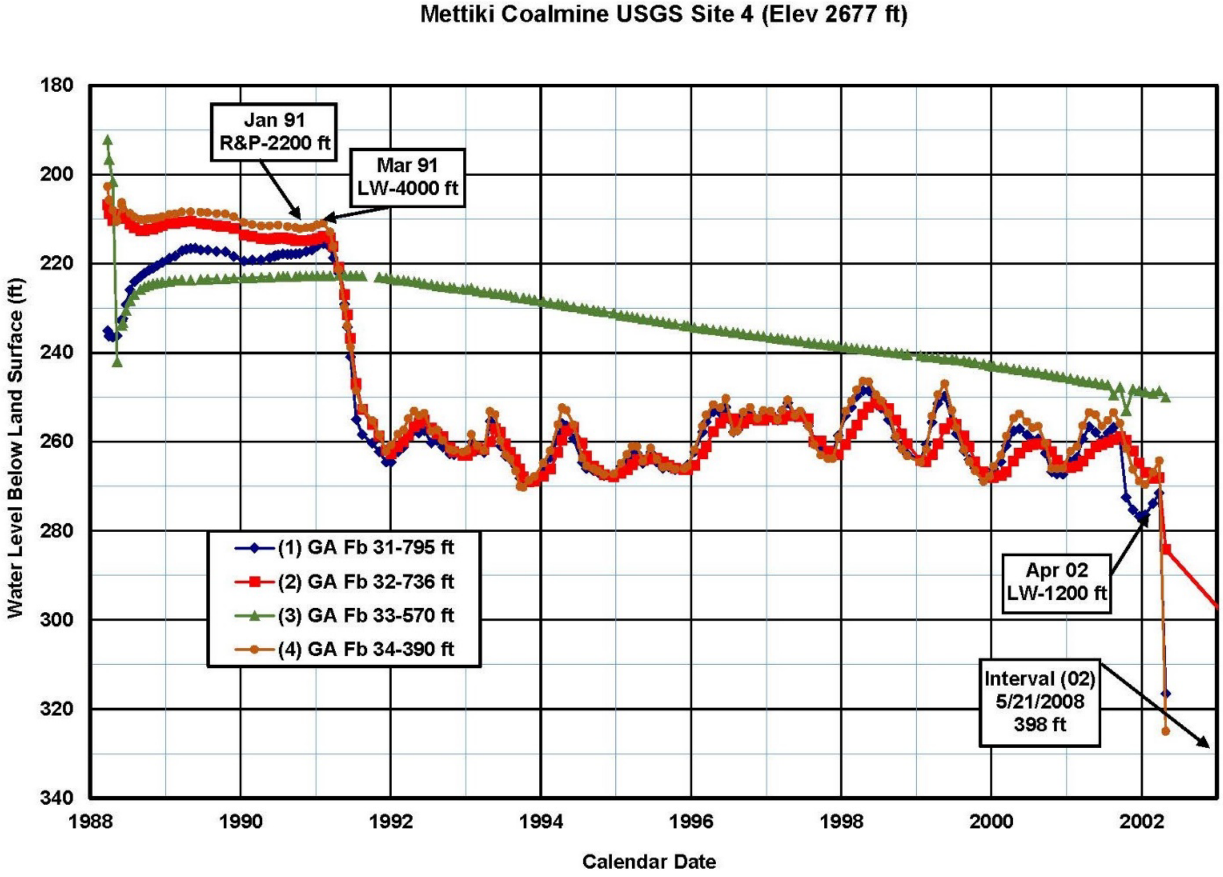


Figure 15. Groundwater levels at site 4 for the period 1980-2008

At site 4, Figure 15, the early (1988) fluctuations of water levels in all wells, especially Fb33, suggest a response to pumping and slug tests, and the relatively slow recovery after testing indicates that the formation has a very low permeability and limited recharge potential. At Site 4 in 1991, there were immediate water level declines of about 50 feet in three wells (Fb 31, 32 & 34) followed by an increased seasonal fluctuation in those water levels. The water level in the fourth well (Fb33) also started to decline (after a lag of one year) about 50 feet, but at a much slower rate (10 years vs one year), and there was no change in the seasonal water level fluctuations. For Fb33, this suggests that the well has a much poorer hydraulic connection to the mined/dewatered zone than the other wells, no new fractures were formed in that well, and the response was typical of a leaky aquifer. Finally, there were sharp declines in water levels noted in April 2002, which were likely due to the approach of a longwall panel to within 1200 feet of the well cluster. The record ends shortly thereafter, except for a single water level measurement of 398 feet in GA Fb 32 on 5/21/2008.

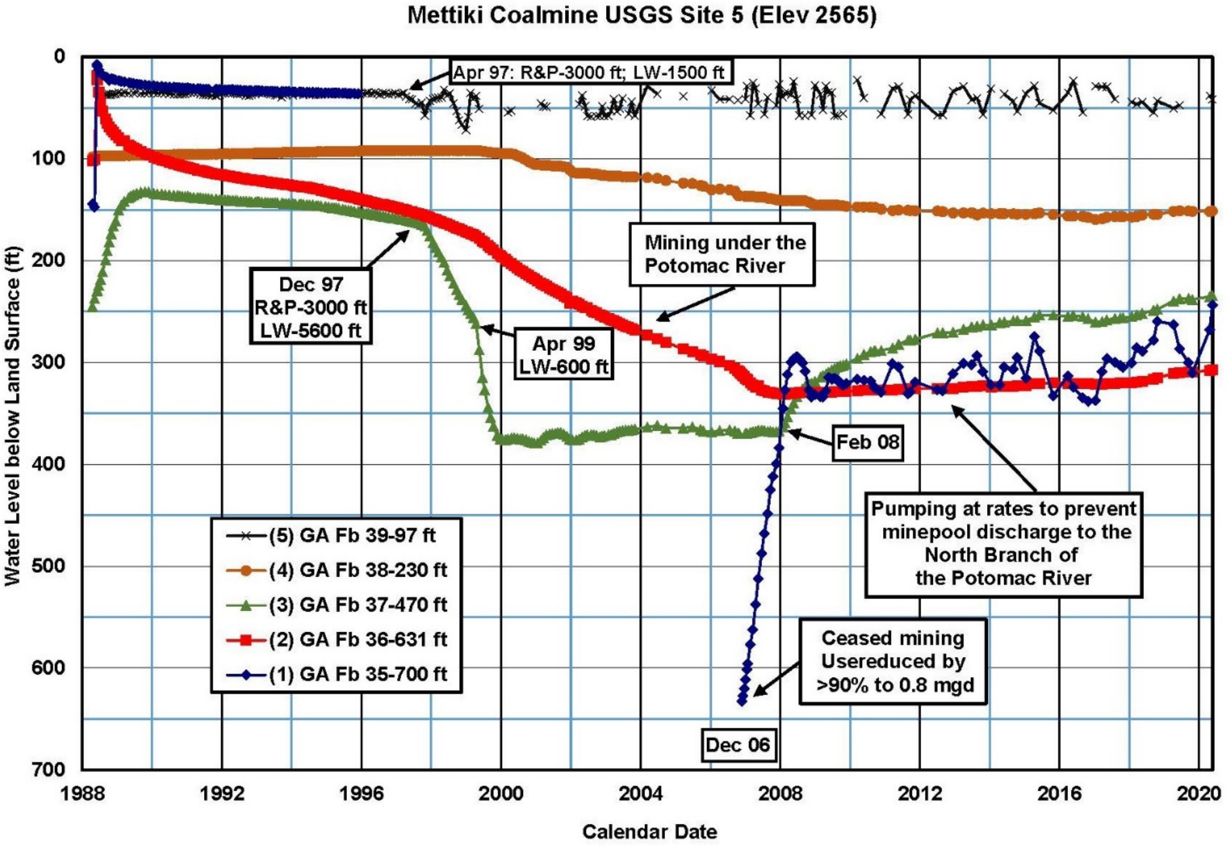


Figure 16. Groundwater levels at site 5 for the period 1980-2020

Prior to mining activity in 1998, there was no consistent pattern in the water levels in the four wells at site 5, Figure 16. One water level remained unchanged (Fb35), one recovered (Fb38) and the remaining two declined (Fb 36 &37). As with site 4, early changes (1988) in water levels may have been affected by pumping tests, with an especially slow recovery in Fb37. In response to mining activity in 1998, all wells showed water level declines of between 45 (shallow well) to 600+/-(deep well) feet, although the changes in Fb 36 and Fb 38 were very gradual (10 years) with initial lags of 1-2 years. The last two responses (Fb 36 and Fb 38) were probably due to leaky aquifer effects. The specific declines in 1997 and 1999 occurred when mining activity was within 600 to 5600 feet of the well site. In 2007, water levels started to recovery in Fb35 and Fb 37, as water levels were responding to the cessation of mining and re-flooding of mine D. There, however, was no recovery in Fb 38, but the water level did stabilize. These responses were probably related the earlier noted lag in changes in of the water levels relative to mining activity.

Impacts to Stream Flow

The baseflows of McMillan Fork, the North and South Fork of Sand Run, and Laurel Run have been tracked over time to determine the impacts of mining on streamflow, USGS (2020), MDE (2000) and Rutledge (1993). The ratios of the annual average baseflows of each stream relative to those of the North Branch of the Potomac River at Steyer were determined. The reason that the North Branch data were chosen for comparison was that all mine withdrawals are returned to the Potomac River upstream of the Steyer gage; consequently, any decrease in the ratios would provide evidence of mining impacts. The results are presented in Figure 17.

In the first few years, there was evidence of high flows in all streams, except McMillan Fork, for which there were no stream flow data. These high flows were due to various mine discharges. Although the Kempton Coal Mine was abandoned, there was a large amount of water flowing into Laurel Run from an open borehole. There was also a discharge into the North Fork of Sand Run from the abandoned Buffalo Coal Mine. Finally, the active Mettiki Coal Mine discharged water to the South Fork of Sand Run from its acid mine drainage (AMD) treatment plant. The flows at all three gages peaked in 1984 and declined substantially after that point. In the case of the South Fork, there was large increase in the AMD discharge from 0.5 Mgd in 1983 to 2.0 Mgd in 1984 that could account for the increased flows. This was followed by declines in flow and discharge, after which the record ends. The decline of flows in the North Fork and Laurel may be due to a combination of efforts to reduce or eliminate the mine discharges and the depletion of flows due to dewatering of the Mettiki Mine. In addition, re-flooding of the A-C mines during the period 1988-91 may have affected the flows in Laurel Run and Sand Run, causing them to stabilize.

Mine timing (advancement) maps indicate that McMillan Fork was undermined in 1990 by the D-mine, producing a decline in baseflow of about 25-35% until 2002. The effects on seasonal flows were much greater as the stream dried up for extended periods under low flow conditions. The North Fork was not undermined, but there might have been a slight reduction in flows of about 10% since the North Fork could have been at the edge of the mine dewatering capture zone. Both streams returned to normal flows in 2003, most likely due to re-flooding of the D-mine. In addition, 2003 was very wet year, but this should have not been a cause, since the data presented represent ratios of flows, not absolute values. When compared to data from the other wet year (1996) in the record, the only ratio that changes appreciably is that for McMillan Fork, confirming that dewatering of D-mine was the cause, since MacMillan Fork is the only stream with a gage in the area of the D-mine.

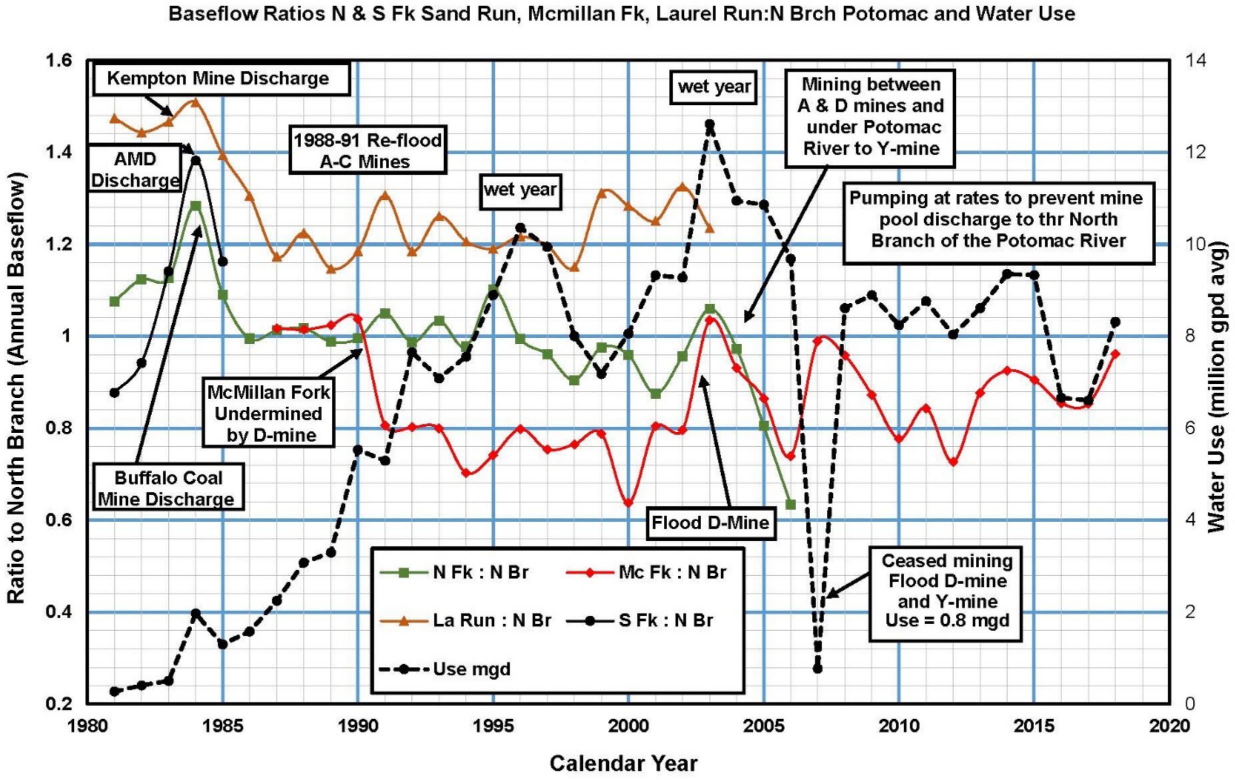


Figure 17. Ratios of the annual flows in the North and South Forks of Sand Run, the McMillan Fork of Shields Run and Laurel Run to the annual flows in the North Branch of the Potomac River, and the annual average water use (pumpage) from the Mettiki Mine

There were substantial declines in baseflow after 2003 in McMillan Fork and the North Fork of Sand Run, which mostly likely were related to advancement of a mine shaft between the A and D mines and under the Potomac River, to facilitate mining of the Y mine in West Virginia. There was full recovery of baseflow in McMillan Fork in 2007, which reflected the effective cessation of mining as water withdrawals dropped to 0.8 Mgd, from 9.7 Mgd in 2006. The flows in the North Fork of Sand Run may have recovered, but the streamflow record for that gage ended in 2006. After 2007, the flows in McMillan Fork declined again, as withdrawals by Mettiki increased to 8-9 Mgd, to maintain the mine pool level to prevent breakouts and discharges to the North Branch of the Potomac River.

Impacts to Aquatic Resources

MDNR considers McMillan Fork a natural high-quality trout stream; however, anecdotal reports indicate that the trout population in the watershed has declined significantly, since the early 1990s. Table 7 shows the results of biological sampling conducted at various sites in streams potentially impacted by mine dewatering. McMillan Fork and the North Fork of Sand Run were randomly sampled in 2001. The BIBI and FIBI were 4.25 and 1.50, respectively, in McMillan Fork on 8/20/2001, indicating that the fish habitat was impaired. The estimated unit flow at the sample on that date was 0.15 cfsm. When compared to the flows at the McMillan Fork gage (0.32 cfsm), this may reflect measurement error, since the drainage areas of the two sites are similar, or the difference may be caused by comparing an instantaneous measurement to a daily average one. However, when the McMillan Fork streamflow was compared to that at the North Branch of the Potomac River gage, the ratio was 0.17, indicating that low FIBI was probably due to a lack of adequate stream flow. Based on a 2000 survey, Heft (2006) indicated that low flows due to mining activity were a limiting factor in the number of Brook trout in McMillan Fork. There was a 16% percent decline in annual baseflows at the McMillan Fork gage in 2000, followed by a full recovery in 2001. This followed declines of 20% in 1992, with no recovery and 10% decline with recovery, for a total decline of 36% in 2000. Each time there was a decline in flows, there was mining nearby or directly within the watershed; but, with the exception 1992, there were complete recoveries, possibly reflecting the effects of fractures formed by subsidence that eventually close.

For the North Fork of Sand Run, the BIBI and FIBI were 2.25 and 2.00, respectively, which would indicate that the stream was impaired. The flow measured in the North Fork on the sample date, 8/6/2001, indicated that flow was minimally impacted by mine activity. Various State biologists have stated that basins with small drainage areas may have low indices but not be impaired. To rule out this possibility, the stream was re-sampled in March-April 2012, downstream of the original location. The BIBI was again 2.25, but no fish sample was taken. The effects of the smaller drainage of the first survey cannot be discounted, because evidence of impacts due to mine dewatering did not occur until after the date of the biological assessment. Heft (2006) indicated Brook trout were not present in Sand Run in 1989 or prior to mining in the area. He suggested that high embeddedness in the stream substrate might be a limiting factor in the Brook trout population. The effects of mine dewatering cannot be determined for the 2012 sample, since there is no record of streamflow measured at the sample site and the stream gage record ended in 2006 The South Fork of Sand Run receives treated AMD, which allowed the stream to be stocked with 1,000 adult rainbow trout annually, Heft (2006).

Table 7. MBSS and streamflow data from streams overlying the Mettiki Mine and streamflow data from the North Branch of the Potomac River

Mettiki Coalmine - mine dewatering (≈ 9 mgd)																
Stream	ID No	D (ac)	D (mi^2)	Flow (cfs)	Flow (cfsm)	Date	BIBI	FIBI	PHI 98	PHI 05	%Urban	%Pasture	%Crops	%Forest	%Total	pH
Shields Run	PRUN-207-B	3352.5	5.24	3.11	0.594	6/23/2010	4.5	3.5	N/R	N/R	4.6	18.3	0.5	73.8	97.2	7.8
	2010															
McMillan Fork Gage	594950		2.3	1.1	0.478	6/23/2010										
(Shields Run Flow) - (McMillan Fork Flow)			2.94	2.01	0.684	6/23/2010										
N. Brch. Potomac Gage	5875		73.1	68	0.930	6/23/2010										
Mettiki Pumpage - 8.2 mgd in 2010																
McMillan Fork	PRUN-190-B	1537	2.4			Mar-Apr 2012	3.75									
	2012															
North Fork	PRUN-191-B	1058	1.65			Mar-Apr 2012	2.25									
	2012															
Mettiki Pumpage - 8.0 mgd in 2012																
McMillan Fork MBSS site	PRUN-102-R	1227	1.92	0.29	0.15	8/20/2001	4.25	1.50	75.0	78.5	0.2	9.8		89.2	99.2	7.2
	2001															
McMillan Fork Gage			2.3	0.73	0.32											
N Branch Potomac Gage			73.1	64	0.88											
Mettiki Pumpage - 9.3 mgd in 2001																
North Fork	PRUN-109-R	431	0.67	1.42	2.12	8/6/2001	2.25	2.00	98.7	37.6	0.0	9.3		86.7	96.0	7.1
	2001															
North Fork Gage			1.91	2.4	1.26											
N Branch Potomac Gage			73.1	114	1.56											
Mettiki Pumpage - 9.3 mgd in 2001																
Laurel Run	PRUN-203-R	2350	3.67	6.96	1.90	6/7/2007	1.75	2.00	N/R	N/R	2.0	5.9		85.6	93.5	4.6
	2007															
N Branch Potomac Gage			73.1	44.7	0.61											
Mettiki Pumpage - 0.8 mgd in 2007																

Shields Run, just downstream of the confluence with McMillan Fork was sampled in 2010. The BIBI was 4.5 and the FIBI was 3.5. In this case, the unit flows that were measured in Shields Run were 36.1% less than the unit flows in the North Branch of the Potomac River, while the unit flows in McMillan Fork on the same day were 48.6% less than those in the Potomac River. Finally, duplicate samples were taken in McMillan Fork in 2012, which produced a BIBI of 3.75, which was like the value of 4.25 calculated in 2001. Heft (2006) indicated that Brook trout were present during a survey in 2000. When both samples were taken, there were reductions in flows of about 20% in McMillan Fork due to mine dewatering. Although limited, the data from Shields Run and McMillan Fork provide some measure of how much flow might be reduced in a stream without causing unreasonable impacts to aquatic habitat.

The calculated BIBI and FIBI for the 2007 sampling in Laurel Run were 1.75 and 2.00, respectively. The flows in Laurel Run at that time were above average and still appeared to be affected by discharges from the Kempton mine. The low pH (4.6) suggested that the mine discharge was the cause of the biological impairment in the stream. Heft (2006) indicated that anecdotal information indicated that Brook trout were present in the watershed, but they were then absent due to severe AMD

Summary

This study describes the hydrologic impacts due to dewatering of the Mettiki Coal Corporation D-Mine in southwestern Garret County, Maryland, while coal was extracted by longwall mining techniques. It is a follow-on study to two Maryland Geological Survey reports on changes in mining activity and hydrologic conditions in the three adjacent permit areas (Mines A-B-C) covering the period 1978-1984 that were mined using room-and-pillar methods. Dewatering of the four mines reached a maximum of an annual average of 12 million gallons per day during the wet year of 2003. The maximum number of acres undermined increased from 1650 acres in 1984 to 7267 acres in 2006, when mining in Maryland and the Y-mine in West Virginia ceased and withdrawals were reduced to 0.8 Mgd. Withdrawals were then increased to 8-9 Mgd after 2006 to maintain the elevation of the mine pool to prevent breakouts and discharges to the North Branch of the Potomac River.

The 1990 decision to issue a revised Water Appropriation or Use permit for dewatering of the Mettiki D-Mine based potential impacts to water resources largely on a review of scientific literature, the early results of USGS monitoring of nested wells, and MGS/USGS seepage runs in overlying streams. From these reports and data, it was estimated that about 25-35% of about 100 water supplies within 2000 feet of a mine face might be impacted by dewatering of the D-Mine, but that the impacts could be mitigated by drilling replacement wells or developing a public water supply. It was also indicated that streamflow impacts would be minimal, as the changes noted during the seepage runs were within the measurement error of the instruments used to measure the streamflow.

The MDE Water Supply Program continued to monitor the progress of mining and the impacts due to dewatering of the D-Mine until the present. Another review of the literature indicated that water supplies at distances from ½ to greater than one mile could be impacted by mine dewatering activities. The Mettiki Coal Mine maintained an active program of replacing impacted water supplies. A review of available records indicated that 38 water supplies were replaced, and one spring box repaired, which was 39% of the water supplies on inventory, while there were only three replacements of 46 (6.5%) wells drilled in the D-Mine area prior to its development. No correlation could be found between impacted water supplies and topographic position; however, water supplies with overburdens greater than 500 feet were less impacted that those where the overburden was less than 500 feet. Where distances could be determined, of 32 water supplies, 10 were between 0 and 1100 feet of mining, 15 were between 1200 and 200 feet of mining and 7 were between 2100 and 4500 feet of mining when impacts occurred.

In 1996-1997, a public groundwater supply was constructed for the town of Gorman as a replacement for poor quality water provided by the Mount Storm system in West Virginia. In 2003, water lines were extended along US Route 50 and Wilson Corona Road to supply 35 customers apparently having private well problems. In 2007, a water line was constructed along Table Rock Road and a portion of Fairview Church Road to supply an additional 26 customers whose water supplies were affected by deep mining activity. Garrett County Government indicates that 14 homes were ultimately added to the Table Rock water line, including 4 that previously had replacement wells drilled. No known record exists for the homes added to the US Route 50 and Wilson Corona water lines; but. based on overburden thicknesses, it is estimated that three water supplies may have been replaced. Adding the new homes to the previous inventory indicates that 55% of the water supplies in the vicinity of the D-mine were impacted by mining activity and were replaced or repaired.

The USGS installed five well clusters, with wells in 4 or 5 intervals from a minimum of 85 feet deep to a maximum of 832 feet deep. There were relatively gradual long-term declines in the interval below the upper Freeport coal seam at sites 1-3 that started prior to mining in the A-mine area and appears to have been related to dewatering of the North Branch Mine in West Virginia. In the A-Mine area, the greatest drawdowns occur in the intermediate intervals at sites 1 & 2 (200-400 feet), while the least drawdowns occur in the shallow interval (less than 100 feet). At site 3, the drawdowns were less than those at site 1 and 2. At site 4, there were sharp declines in water levels of about 50 feet in all zones, except the interval just above the coal, which had a long-term gradual decline of less than 30 feet. At site 5, the water level decline in the deep interval was greater than 600 feet. In the intermediate intervals, the declines were about 200 feet and less than 60 feet in the shallow intervals. While drawdowns occurred when distance to mined intervals were less than 4500 feet, there was some evidence than mining activity at distances of greater than one mile may have affected water levels in the USGS wells. After 2006, partial recoveries in groundwater levels occurred first after mining ceased, and withdrawals were reduced to 0.8 Mgd avg and then increased to maintain the mine pool elevation at a level to prevent breakouts and discharges to the North Branch of the Potomac River.

Early stream flows (prior to 1986) were augmented by mine discharges to all streams. In 1991, the annual average flows in McMillan Fork declined by about 20%, after being undermined by the D-Mine. Flows were also reduced in 1994 and 2000, but rapidly recovered, possibly due to sealing of fractures caused by collapse mining. Flows recovered rapidly in 2006, upon the end of mining and when pumpage declined by >90%. Flows in the North Fork of Sand Run were stable until 2004, when mining between the A and D mines commenced, at which point the flows declined about 40% and the record then ends. There were no apparent declines in flows in Laurel Run, until that record ended in 2003.

Biological sampling in 2001 indicated that the fish habitat in McMillan Fork was impaired, probably due to the lack of adequate streamflow. Both the benthic and fish habitats were impaired in the North Fork of Sand Run during the same period, but that was a period when flows in the creek were minimally impacted by mining activity. That impairment was probably related to the small drainage area at the sampling point or stream embeddedness. Treated AMD in the South Fork of Sand Run allowed it to be stocked with rainbow trout. Shields Run, just downstream of the confluence with McMillan Fork, was sampled in 2010 and there was no evidence that the stream was impaired. The drainage area was 2+ times and the flow 3 times that of McMillan Fork. It is then possible that the higher flows in Shields Run were the reason that the stream was not impaired. While flows were not an issue with Laurel Run, the stream was impaired in 2007. The most likely reason was the low pH in the stream due to acid mine drainage from the Kempton Mine.

References

Booth, C.J., 1986, Strata-movement concepts and the hydrological impact of underground coal mining. Groundwater 24(4):507-515. https://doi.org/10.1111/j.1745-6584.1986.tb01030.x

Booth, C.J. and Spande, E.D., 1992, Potentiometric and aquifer property changes above subsiding longwall panels, Illinois Basin Coalfield, Groundwater, 30(3):362-368. https://doi.org/10.1111/j.1745-6584.1992.tb02004.x

Dai, A., National Center for Atmospheric Research staff (Eds.). Last modified December 12, 2019. The Climate Data Guide: Palmer Drought Severity Index (PDSI). Retrieved on xx/xx/2020. https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi

Duigon, M.T. and Smigaj M.J., 1985, First report on the hydrologic effects of underground mining in Garrett County, Maryland: Maryland Geological Survey Report of Investigations No. 41, 99p.

Fleming, B.J., Hammond, P.A., Stranko, S.A., Duigon, M.T., and Kasraei, S., 2012, A science plan for a comprehensive assessment of water supply in the region underlain by fractured rock in Maryland: U.S. Geological Survey Scientific Investigations Report 2012–5160, 29 p. https://doi.org/10.3133/sir20125160

Garret County Government, 2014, Garrett County Water and Sewerage Master Plan 2014 revision, December 9, 2011. 188p.

Heft, A.A. (ed.), 2006, 2006 Brook trout fisheries management plan. Maryland Department of Natural Resources, Fisheries Service, Inland Fisheries Management Division, 130 p.

Green, J.B., Trevitts, M.A., and Walker, J.S., 1986. A case study of the effects of subsidence on a local ground water system. 1986 National Symposium on Mining, Hydrology, Sedimentology and Reclamation, University of Kentucky, Lexington, Kentucky, December 8-11, 1986.

Hill, J.G. and Price, D.R., 1983, The impact of deep mining on an overlying aquifer in western Pennsylvania. Groundwater Monitoring Review, Winter 1983:138-143. https://doi.org/10.1111/j.1745-6592.1983.tb00875.x

Hiortdahl, S.N., 1988, Hydrologic and mining data from an area of underground coal mining in Garrett County, Maryland: Maryland Geological Survey Report of Investigations No. 41-A, 81p.

Lyons, R.C. and Jacobsen, E.F., 1985, Sources of data, procedures, and bibliography for coal resource investigation of western Maryland. U.S. Geological Survey Open-File Report 81-739, 33p. https://doi.org/10.3133/ofr81739

Maryland Department of the Environment (MDE), 2000, BASEFLOW, A Program for Base Flow Separation, unpublished MDE implementation of the methodology of USGS program PART, Rutledge (1993).

Pointon, N.R. and Felbinger, J., 2013, North Branch Potomac River mine pool assessment study. U.S. Department of the Interior, Office of Surface Mining, Appalachian Regional Office, Pittsburgh, PA, 117p.

Rutledge, A.T., 1993, Computer Programs for Describing the Recession of Ground-Water Discharge and for Estimating Mean Ground-Water Recharge and Discharge from Streamflow Records, U.S. Geological Survey Water Resources Investigations Report 93-4121, 45 pp. https://doi.org/10.3133/wri934121

Stoner, J.D., 1983, Probable hydrologic effects of subsurface mining. Groundwater Monitoring Review, Winter 1983:128-137. https://doi.org/10.1111/j.1745-6592.1983.tb00874.x

U.S. Geological Survey (USGS), 2020, National Water Information System data available on the World Wide Web (USGS Water Data for Maryland), accessed November 6, 2019 (surface water) and June 19, 2020 (groundwater), http://waterdata.usgs.gov/md/nwis/nwis

Van Voast, W.A. and Hedges, R.B., 1975, Hydrogeologic aspects of existing and proposed strip coal mines near Decker, southeastern Montana: Montana Bureau of Mines and Geology Bulletin No. 97, 31 p.

Water Appropriation and Use Permit (GA1977G005) file for Mettiki Coal Corporation. Maryland Department of the Environment, Water and Science Administration, Water Supply Program, Source Protection and Appropriation Division.

Wheeler, T.B. and Pelton, T., 2006, “After 29 years, coal runs out at a Western Maryland mine”, *Baltimore Sun*, September 23, 2006. Accessed 11/6/2020, https://www.baltimoresun.com/news/bs-xpm-2006-09-23-0609230142-story.html

Wheaton, J. and Metesh, J., 2002, Potential ground-water drawdown and recovery from coalbed methane development in the Powder River Basin, Montana. Butte: Montana Bureau of Mines and Geology, Open-File report MBMG 458, 53 p.

Witowski, M.N., 2010, The effects of longwall coal mining on the hydrogeology of southwestern Pennsylvania. MS thesis, University of Pittsburgh, Pittsburgh, PA, 71p.

Wolman, M.G., 2008, Water for Maryland's future: What we must do today. Final report of the advisory committee on the management and protection of the State's water resources, 52p.

Zipper, C., Balfour, W., Randolph, J., and Roth, R., 1994, An analysis of household water supply impacts by underground coal mining in Virginia. Virginia Center for Coal and Energy Research Report No. 94-2, 34p.