Maryland Department of the Environment
Water and Science Administration
Water Supply Program
Gregory Busch, Acting, Manager

EVALUATION OF POTENTIAL HYDROLOGICAL IMPACTS AND DEVELOPMENT OF SINKHOLES CAUSED BY DEWATERING OF QUARRIES IN THE HAGERSTOWN VALLEY, WASHINGTON 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)
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)
Transmissivity		
gallon per day per foot (gal/d-ft)	0.0124	square meter per day (m^2/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

EVALUATION OF POTENTIAL HYDROLOGICAL IMPACTS AND DEVELOPMENT OF SINKHOLES CAUSED BY DEWATERING OF QUARRIES IN THE HAGERSTOWN VALLEY, WASHINGTON COUNTY, MARYLAND

by

Patrick A. Hammond

Key Results

Quarrying of natural limestone in Maryland began in the late 18th century and became a major industry after construction of railroads in the state started in the 1830s. Peak production was reached by the late 19th century. During the same period the processes for the manufacture of portland cement and reinforced concrete were developed, leading to a remarkable growth in the portland cement industry and a rapid decline in natural cement production. The recent production in the state has been primarily crushed stone for road construction, with minor amounts for Portland cement and building stone. The first known dewatering of a limestone quarry in Maryland occurred in the early 20th century. State laws governing water use were first passed in 1933 after the extreme drought of 1930-31; however, the first known permits for dewatering of quarries were not issued until 1969, after the severe 1962-69 drought. At that time quarry withdrawals were by law and regulation reasonable, even if they caused impacts to nearby water supplies. That changed after revised water use regulations were passed in 1989 followed in 1991 by surface mining Zone of Influence (ZOI) regulations in karst terrain.

Limestones and dolomite carbonate rocks are the most important industrial minerals in Washington County. There are six active quarries in the Hagerstown Valley, which are the Security; Beaver Creek East and West; Rockdale, Pinesburg; and Boonsboro quarries. Previous authors noted that there were relatively few active sinkholes in the valley, with the highest concentration along a line between the Rockdale and Pinesburg quarries, just west of Conococheque Creek.

Initial concerns were raised in the early 1970s by several State agencies and private citizens about the impacts to the Albert Powell Fish Hatchery (Houpt) spring due to dewatering of the proposed **Beaver Creek West Quarry**, immediately upgradient of the spring. Over about two decades, various studies were proposed to investigate those impacts. In 1996, a long-term test started in September, with construction of a test pit, that ended in September 1997. During the nine-month drawdown phase, the pumping rate was 8.6% of the spring flow; however, the long-term average during 2003-2005 was 4.5% of the spring flow. The later value was about the same as the area of the quarry groundwater capture zone (4.3%) relative to the drainage area of the spring (8.2 mi^2).

A permit was issued for 400,000 gpd avg with the drawdown limited to an elevation of 510 ft MSL. Most of the water was to be used to provide an emergency supply to the hatchery spring. The maximum reported uses were 397,000 gpd avg in 2003, which was just after the start dewatering of the quarry, suggesting that much of the water was taken from pit and groundwater storage. Since 2004 (284,000 gpd avg), the greatest use (194,000 gpd avg) occurred in 2010, after a period of more than one year without any pumpage, again suggesting that much of the water was taken from storage. To date, no water has been supplied to the hatchery.

The pattern of pumpage from the **Beaver Creek East Quarry** appears to be related to variations in production of crushed stone at the quarry, with periods of low water use reflecting times of slow economic growth and limited production from the quarry, while periods of relatively high pumpage could be due to better economic conditions and increased production from the quarry. A secondary factor causing the rapid increases in pumpage during 2010 and 2014 is that water may have been withdrawn in large amounts to deplete pit and groundwater storage after multiple low water use years.

The east pit groundwater drainage area is 99 acres. If the average base flow (11.8 in/yr) in Antietam Creek at Sharpsburg is applied to that drainage area, the calculated effective recharge would be 86,922 gpd avg. The pumpage for period November 1995 to October 1996 was 121,924 gpd avg. However, that was a period of above average recharge, when Hagerstown rainfall was 1.88 times the average and the Houpt Spring flow was 1.35 times the average. Applying those factors to the average effective recharge, produces estimated values for the east pit drainage area of 163,413 gpd avg and 117,345 gpd avg, respectively. The close agreement between the east pit pumpage and the effective recharge calculated from the Houpt Spring flows would indicate that groundwater was the source to the east pit during the period in question.

At the **Rockdale Quarry** a water level elevation contour map demonstrates that there is a trough of depression in the water levels parallel to the strike direction of the St. Paul Group, which reaches a point about 20 ft below and parallel to Conococheque Creek. This indicates that there is a barrier between the creek and the trough. Previous studies have suggested the sinkhole distribution near the quarry is likely due to the high solubility of the carbonate rocks underlying the trough and that enlargement of bedding plane separations by circulating ground water may have enhanced the development of sinkholes, which may then capture surface drainage and direct it along the strike of the formation. With the limited withdrawals (less than 25,000 gpd avg) from the Rockdale Quarry and the lack of any clear evidence of sinkholes formed due to quarry dewatering, it is likely that the sinkholes in the vicinity of the Rockdale Quarry have a natural origin.

The **Pinesburg Quarry** may have been in operation before the turn of the 19th century. The initial permit was issued for dewatering in 1969; however, that was not necessarily the date of first use since there was not a concerted effort to permit all existing uses until after the extreme drought of 1962-1969. Water use data from 1979, when the MDE computer database was established, to 1987 never exceeded 250,000 gpd avg. There was a relatively steady increase in pumpage until reaching 834,000 gpd avg in 2004, that corresponded with the trends in Hagerstown rainfall and Houpt Spring flows. After declining from 2005 to 2008, pumpage then increases substantially relative to rainfall and spring flow, reaching a maximum of 1,114,000 gpd during 2018. Between 2005 and October 2012 water was discharged intermittently to an inactive quarry pit. After that period water was pumped to the inactive quarry pit continuously, possibly resulting in water recirculating between the inactive and active quarry pits.

Data collected between 1995 and 1999 indicated that there were three collapse sinkholes on the west side of the quarry that did not show up in a 2018 study and were recorded during a period of low reported pumpage for dewatering. In addition, the MDE mining program has been tracking sinkhole formation statewide since 2001 and has no record of any sinkholes caused by operations at the Pinesburg Quarry. It is possible that the three sinkholes were filled prior to the start of the Mining Program tracking system and the 2018 survey. Without knowing the timing of the formation of the sinkholes, it is not possible to determine what caused the sinkholes.

There are various accounts of when dewatering of the **Boonsboro Quarry** started. One report indicated that it was the 1950's. A second indicated that it started in 1969, but that was the date of the first permit, which was for dust control and process water. A final report indicates that mining started in the 1950s and dewatering was not required until the quarry was deepened in 1980. The first permit to include dewatering was issued in 1978 for 114,000 gpd avg, which was consistent with the last report. Reliable water use reports start in 1985 and track with Hagerstown rainfall and Houpt Spring flow records until about 2006, when pumpage effectively doubles relative to rainfall and spring flow.

A 97-d operational was conducted from October 1993 to January 1994 while measuring water levels in monitoring and observation wells, and streamflow at various seepage run stations. No response was noted in 15 of the 16 monitoring wells; however, the pumping rate from the quarry was nearly the same as the average withdrawal during the two years prior to the test. This is the likely reason that there was no effective change in the water levels during the test.

Nearly all the seepage run measurement from the 12 stream stations were either affected by storm surges traveling through the Little Beaver Creek watershed or discharge from the quarry. The one date on which there was no clear evidence of either a storm surge or discharge from the quarry was 10/25/1993, which indicated that there was a significant loss from station G11 to G12, between which a perennial stream on the southwest side of the quarry had discharged in the past. In 1996 it was described as a swale, so the seepage runs provided evidence that the loss of stream flow in the tributary was due to pumping from the quarry pit.

Historical water levels follow the topography of the watershed of the tributary on the southwest side of the quarry. The contours of the low water levels are pulled in two directions relative to the historical levels, one towards the east pit of the quarry and the second upstream in the southwest tributary. A primary flow controlling mechanism could consist of two fractures, the first which is the fault identified are the discharge point in the east pit and the second a fracture zone along the stream bed of the southwest tributary. The flow could be linear in the immediate vicinity of the primary fractures, which act as a conduit for water likely contained in the upper weathered zone or epikarst.

In 2007, there was a sharp increase in withdrawals included in the pumpage reports relative to the Hagerstown rainfall and Houpt Spring flows. A likely possibility is that surface runoff from Little Beaver Creek was being captured. Since quarry operations usually do not result in rapid expansion of quarry pits, the capture of groundwater runoff is less likely unless a prominent conduit is encountered that could greatly expand the capture zone of the quarry.

Mining of the **Security Quarry** started in 1908 with the establishment the first modern portland cement mill in Maryland. Antietam Creek had cut into the flank of an anticline, producing a natural quarry face. The first apparent use of water was for processing of stone starting in 1919. Dewatering of the quarry started at least by 1975. The permitted uses were increased to 7.2 Mgd avg in 2006 due to a major inflow of water discharging at a cave in the quarry, then decreased to 5 Mgd avg due to a major reduction in inflow to the quarry, followed by an increase back to 7.2 Mgd avg in 2013 after there was another major inflow to the quarry. The major inflows of water could not be explained by climatic changes, and the inflow was unlikely from a groundwater source that would have required a drainage area of about 12 mi^2. The proximity to Antietam Creek, and the large amount of and sudden inflow to the quarry cave would indicate that most of the water had come from the creek.

After the first massive increase to 8.2 Mgd in December 2004, creek flow into a sinkhole on the stream bank was dammed, which reduced the total flow to the quarry cave by an estimated 30-50%. The dam was then partially opened, and dye was injected into the sinkhole, with 69% of the dye recovered at the cave. A second dye trace in Antietam Creek was conducted with a recovery at the cave of 0.12%. The low recovery rate from the creek trace may have been due to absorption by streambed sediments or by other chemical reactions. Also, there may be other places upstream of the injection point where water could be leaking from the stream to the quarry. The reported pumpage after the dye trace and probable repair of the sinkhole was reduced by 35%, which was within the estimated range of the reduced flow to the quarry cave when creek flow to the sinkhole was dammed. A second sinkhole opened in the creek causing a sudden average inflow of 33.4 Mgd during March and April 2011 flooding the quarry. After repair of the sinkhole, pumpage declined initially to 4-5 Mgd, then to 2-3 Mgd. The pumpage data is consistent with the Brezinski (2018) observation that extensive grouting has impeded flow into the quarry

A dye trace study was conducted in 2007, from which the quarry ZOI was derived. The dye trace directions of movement were from Antietam Creek and Marsh Run, as well as by groundwater flow from a sinkhole to the east of the quarry and from a monitoring well along a previously unknown fault. Flow may have been captured from an unnamed tributary of Antietam Creek that originally flowed parallel to and about 150-200 ft east of the fault.

Upon dewatering of the quarry, small amounts of groundwater would probably have been captured, but as mining continued and the quarry was deepened, the dewatering withdrawal would have increased due to steeper hydraulic gradients. Upon opening of the cave and possible intersection with the fault/fracture system, the drainage area could have increased substantially. The ZOI appears to reasonably approximate the existing groundwater drainage area (1.64 mi^2) of the quarry pit.

Prior to evidence of stream infiltration, the average use during the period January 2003 to November 2004 was 1.08 Mgd. The average baseflow in Antietam Creek (Sharpsburg) was 20.6 in/yr during that period or about twice the average baseflow of 11.4 in/yr for that basin. If the sole source of inflow to the quarry had been groundwater, then the average yearly groundwater discharge to the quarry would be about 0.60 Mgd. Following the two major inflow events, it was not until 2016-2020 that flows stabilized at lower rates of about 2-3 Mgd. During the same period, the Houpt Spring flows were slightly above average (941 gpd/ac or 12.6 in/yr). Applying that rate to the area of the ZOI produces an effective groundwater inflow to the quarry of 1.0 Mgd, indicating that about ⅓ (37%) of the quarry inflow was from groundwater sources. The remainder was likely from stream infiltration or seepage from Antietam Creek, its tributary, and Marsh Run. If adjusted to average use, the equivalent groundwater inflow for 2016-2020 of 0.96 Mgd is about 60% greater than that for 2003-2004, which is consistent with an expansion of the quarry pit capture area after opening of the cave and a possible intersection with the fault/fracture system.

The operator reported that two wells were replaced and water was supplied to three houses owned by the quarry. The MDE Water Supply Program required that the permittee monitor six wells. The MDE Mining Program also investigated potential impacts to wells within the the area of the ZOI and determined that four wells were impacted by dewatering of the quarry. Three of the wells were replaced, while there is no disposition given for the fourth well. The wells replaced did not inlude any that were being monitored but they were in the same relative location as the monitoring wells.

All of the wells that were monitored due to reported problems or replaced within the ZOI were northeast of the quarry pit, while there were none at equal distances to the west of the quarry. All of the monitored or replaced wells are in the Conococheque Limestion, with the exception of one well, which had a turbidity problem that could not be related to the increased withdrawals by the quarry. The fault and quarry cave are also located in the Conococheque Limestone, while the quarry pit and the wells to the west of the quarry are located in the Stonehenge Limestone. The fault appears to have some control on the groundwater flow, but drawdown contours are oblique to the direction of the fault; the northern extent of the fault is unknown and could change to conform more closely with the contours. The broadening of the contours to the east may be due to differences in permeability and porosity between the Conococheque Limestone and the Stonehenge Limestone. While there is no well control to the west of the quarry, the absence of any complaints would support the relatively steep contours in that direction.

Considering the water use and water level data, initial withdrawals for dewatering came from the relatively low permeability formation (Stonehenge Limestone), that would produce a narrow steep cone of depression near the quarry at the low pumping rates. Upon opening of the quarry cave and connection to the fault, there was a direct inflow from Antietam Creek to the quarry pit through the sinkhole on the gun and rod club property. A broad trough of depression also developed within the Conococheque Limestone that was produced by increased ground water inflows, that were likely due to the potentially high permeability and storage of that formatiom.

There have been relatively few sinkholes caused by dewatering of quarries in the Hagerstown Valley. Seven were near the Security Quarry; however, five occurred near where a previous sinkhole had been repaired in or near Antietam Creek. Three occurred near the Pinesburg Quarry, but there was no data collected that could relate them to quarry dewatering. Two occurred in the Little Beaver Creek valley and were likely related to dewatering of the Boonsboro Quarry. None occurred near the Rockdale, Beaver Creek East or Beaver Creek West quarries.

Seven wells needed to be replaced near the Security Quarry, likely due to the impacts of dewatering of the quarry. Two wells within the Pinesburg Quarry ZOI were replaced and were likely impacted by quarry dewatering. Included within the ZOI water supply disruption database were two wells at the Beaver Creek Quarry. One well was not in the west pit ZOI and, while the second was in the east pit ZOI, the disruption occurred during the 2001-2002 drought, when there was a limited withdrawal for dewateing. The database also includes one well near Boonsboro, but contains no information on the location, cause or diposition of the well impact.

Other than depleting flow in a tributary of the southwest side of Boonsboro quarry, there is little evidence of depletion of streamflow by dewatering of the Hagerstown Valley quarries, since the waters are immediately returned to the watersheds from which they were withdrawn.

Introduction

Limestone/Cement History

The World Cement Association (2021) provides the following account of the history of cement. As early as 12,000 years ago in Turkey a form of cement was in use, when a whitewashed floor was made from burned limestone and clay. About 800 BC, the Phoenicians made a mixture of burnt lime and volcanic ash ('pozzolana'), which was stronger and could also harden under water. The Romans developed a type of concrete made of lime with aggregates of sand and crushed rock, with which they erected massive buildings such as the Colosseum and Pantheon in Rome, and the Hagia Sophia in Istanbul. There are no written records from the Middle Ages, but mortars from that time were probably made of lime and sand.

The late 18th century Industrial Revolution in Europe saw many new developments in cement and concrete. John Smeaton discovered that the hydraulicity of lime was directly related to limestone clay content. In 1824 Joseph Aspdin developed portland cement by heating limestone and clay until the mixture calcined, grinding it, and then mixing it with water. In 1845, Isaac Johnson fired chalk and clay to much higher temperatures of about 1400-1500° C and produced what is essentially modern-day cement. The advent of reinforced concretes in 1840s France allowed construction of larger bridges, taller and larger buildings, and other innovations. Cement production and applications then surged globally at the turn of the century, which the introduction of rotary kilns that replaced the original vertical shaft kilns.

Limestone Quarries of Maryland

The first known mention of limestone as a resource in central Maryland was in a 1744 Daniel Dulaney report to Lord Baltimore indicating the Frederick Valley abounded with limestone, and stone fit for building, good slate, and some marble, which formed the basis for local industrial development that included limestone quarrying through the late 18th century, Porter (1975). Iron furnaces operated in Frederick County primarily from the 18th to the early 19th centuries which needed limestone from quarries for a flux. Industry in Frederick expanded during the 19th century that included the manufacture of lime and bone fertilizer. Merrill and Mathews (1898) notes that the earliest scientific reference to quarrying of Maryland stone was in 1811 about the production of stone on both sides of Jones Falls. There follows in 1834 the first accounts of quarrying of the " Potomac Marble " a few miles east of Hagerstown and the first mention of the marbles of Point of Rocks, Carroll County and Boonsborough. The blue and gray limestones of Paleozoic age have never been quarried in Maryland as building stones except for local use. Nearly all the stone taken out was burned to produce lime.

Early on, inefficient transportation networks limited the production of limestone; however, with the construction of railroads starting in the 1830s, that changed. The amount of natural cement produced in 1818-1830 was 300,000 barrels, but the rate rapidly increased to 11,000,000 barrels by 1850-60 and then to 45,000,000 barrels in 1880-1890, Clark (1909). This was also the period when the processes for the manufacture of portland cement and reinforced concrete were developed. By the mid-19th century, the nation had shifted from an agriculture-based economy toward manufacturing and factory-produced goods, with a subsequent increase in the population and wealth in Maryland and the United States. At the same time there was a remarkable growth of the portland cement industry and the accompanying decline in the production of natural cement. In 1870-1880, the production of natural cement was 22 million barrels, while that of portland cement was 82 thousand barrels; however, natural cement production declined to 1.7 million barrels by 1908, with portland cement increasing to 51 million barrels.

Mathews and Grasty (1910) made the first report of dewatering by a quarry. To get a suitable working face, the M.J. Grove Quarry (now Frederick Quarry) had to be deepened and upon encountering water, it had to be pumped out to prevent flooding of the quarry. The MDE Water Supply Program has electronic records of water use from 1979. There are a limited number of known paper records of water use in the state from the early 1960's, which may have been archived or destroyed. In addition, The Maryland Geological Survey (MGS) may have some other water use records.

Mathews and Grasty (1910) listed 38 active limestone quarries in Washington, Frederick, and Carroll Counties in 1909. Today, there are 13 operating quarries in those counties, 7 of which were in business in 1909. The decline of the smaller enterprises was because profitable quarrying required considerable capital investment in efficient machinery to handle large volumes of stone. In 1969, limestone production in Maryland was 9.8 million tons, most of which was crushed stone used in road construction, with minor amounts for building stone, cement production, metallurgical flux, and agricultural uses. In recent years (2000-2019), production was 19.7 – 35.3 million metric tons of crushed stone, 0.9 – 3.2 million metric tons of portland cement, and 0 – 17.3 thousand tons of building stone.

Laws and Regulations Governing Dewatering of Quarries

Outside of quarries, most of the water withdrawn in the carbonate areas of the Maryland is from surface water for public water supplies in the Hagerstown, Frederick, and Wakefield (Westminster) valleys. Prior to about 1989, quarry withdrawals were determined by law (in a 1969 court decision) and regulation to be reasonable, even if they caused nearby water supplies to go dry, had diminished yields or experienced water quality problems. The legislation requiring permits for surface mines was passed in 1975. Changes of state regulations were made for water use in 1989 and surface mines ("Zone of Influence" or ZOI in karst terrain) in 1991, so that quarries could be held liable for mitigation of impacts caused by dewatering activities. By that time, most quarries had been operating for decades, so any impacts that could have occurred may have already happened and there were probably few, if any, records available concerning such problems. Under the 1991 Amendment to Maryland's Surface Mining Law, the MDE Mining Program is required to develop ZOIs around all limestone quarries in Baltimore, Carroll, Frederick, and Washington counties. The zones are based upon local topography, watersheds, and geologic and hydrologic factors. When establishing ZOIs, MDE conducts field investigations and evaluates any available information, such as groundwater studies and well monitoring data. Upon completion in the 1990s of the ZOIs for existing quarries, The MDE Mining Program started tracking impacts to water supplies and the formation of sinkholes. This also corresponds with the approximate period when the MDE Water Supply Program upgraded its aquifer test and monitoring program in the fractured rock aquifers of Maryland.

References

Clark, W. B. and Mathews, E. B., 1909, Maryland mineral industries, 1896-1907. Maryland Geological Survey, vol. 8, p.99-223.

Code of Maryland Regulations, COMAR 21.02, Department of the Environment, Mining, Zone of Dewatering Influence. http://www.dsd.state.md.us/COMAR/SubtitleSearch.aspx?search=26.21.02.*

Code of Maryland Regulations, COMAR 26.17.06, Department of the Environment, Water Management, Water Appropriation or Use. Criteria for Approval of a Water Appropriation or Use Permit. http://www.dsd.state.md.us/comar/comarhtml/26/26.17.06.06.htm

Mathews, E. B., and Grasty, J.S., 1910, The limestones of Maryland. Maryland Geological. Survey, v. 8, pt. 3, p. 225-484.

Merrill, G.P. and Mathews, E.B., 1898, The building and decorative stones of Maryland: Maryland Geological. Survey, Vol. 2, Pt. 2, p. 47-241.

Porter, F.W. III, 1975, From backcountry to county: The delayed settlement of western Maryland, Maryland Historical Magazine_70, no. 4 (Winter 1975), 342.

World Cement Association, 2021, History of Cement. https://www.worldcementassociation.org/about-cement/our-history

Example: Millville Quarry, Jefferson County, West Virginia

Catoctin Power, LLC filed an application to obtain a Certificate of Public Convenience and Necessity (CPCN) on February 25, 2004, to construct and operate a natural gas fired, nominal 600-megawatt (MW) electric generating station in Frederick County, Maryland. To comply with the Potomac River consumptive use regulations, the applicant identified two low flow augmentation (LFA) facilities, both quarries along the Shenandoah River in Jefferson County, West Virginia. The Millville Quarry was an active aggregate quarry and is the subject of the present investigation. The second was the Old Standard Quarry, an abandoned and flooded quarry. During a site visit to the Millville Quarry, the operator indicated that about 20 million gpd were being pumped out of the quarry and suggested that the water was coming from a groundwater source. In contrast, the MDE project geologist indicated that the recharge area for such a withdrawal amount might be as much as 20 to 30 mi^2 and a more likely source would be infiltration from the Shenandoah River.

The Maryland Power Plant Research Program (PPRP) completed a draft environmental review (ERD) of the proposed project on November 24, 2004 (Catoctin Power ERD-Case No. 8997-11/23/04), which modified an interim draft ERD from October 2004. The active workings of the quarry had been allowed to partially or fully flood, including the main pit, which was proposed for LFA storage. The main pit covered a surface area of approximately 53 ac and was up to 280 ft deep at its lowermost working level. The maintained pool elevation in the main pit was 255 ft above mean sea level (msl), compared to the mean river stage elevation at the USGS Millville gauging station of 295 ft msl. At a pool elevation of 255 ft msl, and a corresponding pool area of 48.7 ac, an estimated 936 million gallons of water was contained in the quarry. The operators of the Millville Quarry discharged water from the quarry daily to maintain the level in the main pit. The reported monthly pumping rate since 2002 averaged 11,000 to 12,000 gpm. Prior to 1997, the dewatering rates were reported to be less than 4,000 gpm but increased dramatically after high flow karst features were intercepted in 1997. The ERD indicated that most of the inflow into the quarry was groundwater likely derived from the areas north and south of the quarry because solution features in limestone and dolomite are well developed along geologic strike, while some of the ground water inflow into the quarry was likely derived from the Shenandoah River. Catoctin Power assumed that the quarry would refill naturally with ground water inflow after water is discharged to meet LFA requirements.

There was little evidence included in the ERD that groundwater was the main source of flow into the quarry. If most of the water was from the Shenandoah River, then much of the water pumped could have been simply water recirculated from and back to the river. As such, it could have been an ineffective source for low flow augmentation to the Potomac River. Subsequently several investigations were found that addressed this potential problem.

Bruce et al. (2001) described the karstic conditions that formed a massive flooding flow conduit at Millville Quarry in April 1997, Figure 1, after production blasting activities and several abnormally severe precipitation events that caused flooding of the river and nearby sinkhole formation. An inflow of river water of over 35,000 gpm was halted through construction of a cement and bitumen grout curtain adjacent to the leakage area in the river.

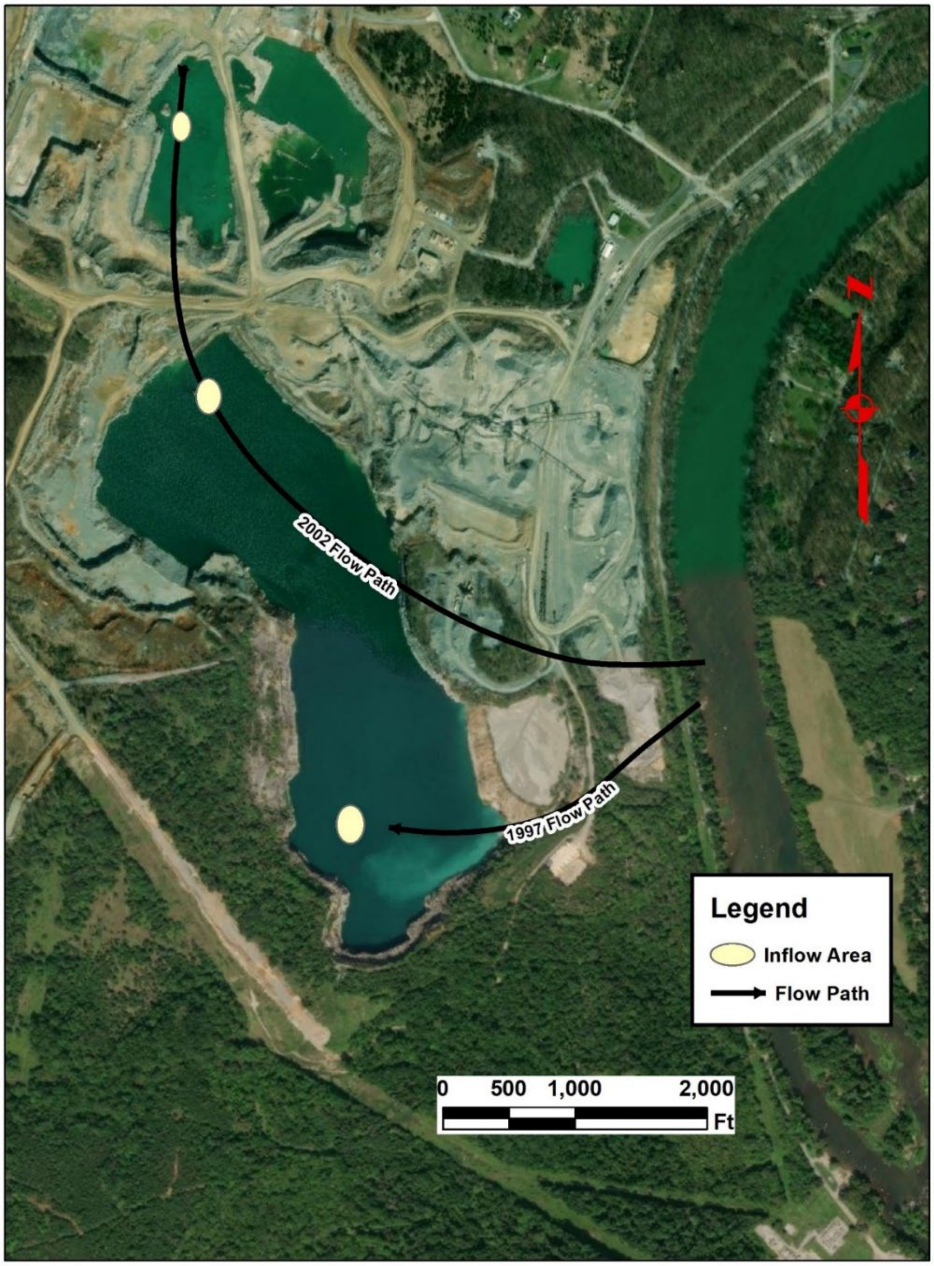


Figure 1. Aerial map of the Millville Quarry with the 1997 and 2002 flow paths from the Shenandoah River to the inflow (discharge) areas within the quarry.

A vortex observed previously in the river appeared to be the point source of the flow. Initially, several attempts were made to construct a cofferdam near the vortex. Such actions resulted in immediate, but temporary, reductions of the new inflow to as little as 6,000 gpm. In each case, the flow conditions were re-established within 8 to 12 hours as a new vortex re-formed, up strike in the riverbed. All the new vortex locations were all along an approximately straight line, corresponding to the regional northeast to southwest strike of the dolomite formation.

There was considerable debate about whether the source of the inflow was regional groundwater, Cattail Run (a small tributary of the Shenandoah River running to the south of the pit), or the Shenandoah

River itself. Geochemical analyses of the quarry inflow, Cattail Run, the Shenandoah River and regional groundwater produced a fingerprint of ions that was present in both the Shenandoah River and the quarry inflow. A hydrogeological model indicated that 60 to 70% of total flow in the quarry was from the Shenandoah River with much of the remainder from the regional aquifer (5 to 15%) and storage losses (5 to 25%), while minor contributions came from precipitation (0 to 10%), quarry catchment (2 to 10%) and Cattail Run (3 to 5%).

A grout curtain was constructed as a cut off, designed to both treat cold karstic features with low mobility grout to permeate fissured rock in a preemptive fashion, and to create a permanent "plug" to the water inflow in the "Hot Karst" zone with hot bitumen. The curtain was to extend laterally for at least 1100 feet and vertically as much as 220 feet. Since hot bitumen grout remains slightly visco-plastic in a hardened state and is susceptible to creep, shrinkage, and extrusion, possibly permitting residual flow paths around the edges of the plugs, it had to be injected simultaneously with cement-based slurries, to jointly create a permanent plug.

A follow-on case study was presented by Lolcama (2005) indicating that following the successful grouting of the inflow, three monitoring wells were installed in the flow conduit to watch for signs of leakage of river water, due to potential deterioration of the grout seal. From 1999 to early2001, there was only a small quantity of seepage through the curtain. In May 2001, a single artesian inflow of 500 gpm with a surface water signature was observed, increasing rapidly in rate to over 5,000 gpm during the following months.

The Shenandoah River was determined to be the source of the inflow water, although the downstream monitoring wells indicated there was no significant leakage through the grout curtain. A deeply penetrating fault zone was identified as a massive flow conduit more than 3000 feet to the north of the previous flooding flow conduit. After six months, the downstream monitoring wells began to respond to a substantial river flow of 5,000 gpm through the grout curtain and a river vortex appeared adjacent to the curtain. A new set of sinkholes occurred on the opposite side of the river from the grout curtain. It was interpreted that a new flooding flow conduit had likely developed adjacent to the grouted feature; however, the two flow conduits appeared to be hydraulically separate from each other.

In 2004, the quarry operator provided quarry pumpage data to the MDE Water Supply Program for the period January 2002 to May 2004, Figure 2. Those data were compared to the average monthly flows in the Shenandoah River at the Millville gage (01636500). While the overall patterns mimic each other, there was a significant decrease in the pumpage relative to river flow in 2002, whereas the ratio remains relatively constant after that point. It appears that some additional remediation of the conduit inflow from the river was completed during 2002. This reduced the inflow somewhat from more than 20,000 gpm to between about 8,000 to 16,000 gpm. This, however, was still substantially more than the maximum reported dewatering rate of 4,000 gpm reported prior to 1997. This would indicate that most of the water pumped by the quarry is recycled back to the Shenandoah River and then to the Potomac River. Lowering the water level in quarry to deplete storage for LFA would also increase inflow from the river due to an increased hydraulic head. Simply measuring the change in the quarry pit water level would not give a precise amount of water taken from storage for augmentation. Water balance methods would have to be employed to account for changes of inflow and outflow, and to a likely lesser extent, additions due to rainfall and losses by evaporation.

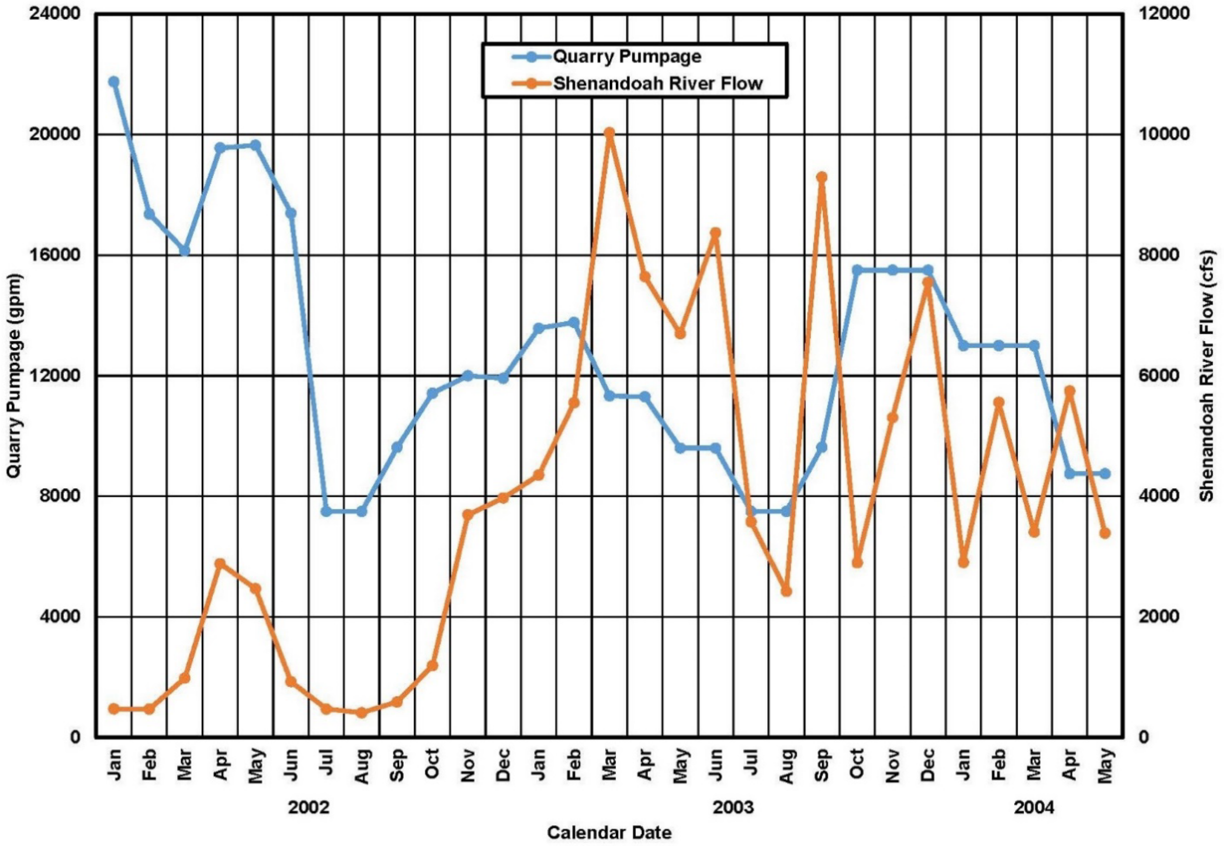


Figure 2. Chart of monthly Millville Quarry pumpage and streamflow measured in the Shenandoah River at the Millville gage (01636500) from January 2002 to May 2004.

References

Bruce, D.A., Traylor, R.P. and Lolcama, J.L., 2001, The sealing of a massive water flow conduit through karstic limestone. Geo-Inst. Conf. Proc. Virginia

Lolcama, J.L., 2005, Case Studies of Massive Flow Conduits in Karst Limestone**.** Sinkholes and the Engineering and Environmental Impacts of Karst, ASCE Geotechnical Special Publication No. 144, pp. 57-65

Maryland Department of Natural Resources, 2004, Draft environmental review of the proposed Catoctin Power project. Power Plant Research Program Annapolis MD.

U.S. Geological Survey, 2022, USGS 01636500 Shenandoah River at Millville, WV, *in* USGS water data for the Nation: U.S. Geological Survey National Water Information System database, accessed January 30, 2022, at http://dx.doi.org/10.5066/F7P55KJN. [Query parameters: Format = sites selection links&search; Site number = 01636500; Date range = 2002-01 to 2004-05]. Data directly accessible at **https://waterdata.usgs.gov/wv/nwis/monthly/?referred_module=sw&site_no=01636500&por_01636500_293252=1119417,00060,293252,1895-04,2021-12&start_dt=2002-01&end_dt=2004-05&format=html_table&date_format=YYYY-MM-DD&rdb_compression=file&submitted_form=parameter_selection_list**

Acknowledgements

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

Geology of Hagerstown Valley

The Hagerstown Valley, part of the Ridge and Valley physiographic province, is in a broad synclinal structure known as the Massanutten synclinorium. It includes part of the west flank of the South Mountain anticlinorium on the east and extends to the base of the Fairview and Powell Mountains on the west. It is marked by two major reverse faults that have thrown upper Cambrian limestones against Ordovician, Silurian, and Permian formations. About 90% of the valley is underlain by Cambrian and Ordovician carbonate rocks.

The Tomstown Dolomite of Early Cambrian age is exposed along the east margin of the valley and is composed of alternating massive and thin beds of dolomite and limestone and some shale beds. The Waynesboro Formation of Early Cambrian age is exposed in a narrow belt that forms in the eastern part of the valley and is composed of a lower unit of interbedded shale and dolomite, and an upper unit of siltstone, shale, and cross bedded sandstone. The Elbrook Limestone of Cambrian age is exposed in a belt in the eastern part of the valley and in a narrow belt on the west edge of the valley, and consists of limestone, calcareous shale, and some dolomite. The Conococheague Limestone of Cambrian age is exposed on both sides of Conococheague Creek and composed of slate, laminated limestone, and a basal sandy dolomite. The Stonehenge Limestone, the basal unit of the Ordovician Beekmantown Group, is exposed in narrow outcrop belts over a wide area of the valley. It is composed of a lower massive nearly pure algal limestone member and an upper thin-bedded silty limestone member. The Rockdale Run Formation is the most extensively exposed formation of the Beekmantown Group. The lower two thirds part of the formation consists of silty limestone and algal limestone, and subordinate dolomitic limestone and dolomite. The upper one-third of the formation consists of dolomite and dolomitic limestone. The Pinesburg Station Dolomite, the upper formation of the Ordovician Beekmantown Group, is exposed in narrow bands on both sides of Conococheague Creek. The formation consists of cherty, mostly laminated dolomite and some mottled dolomite. The St. Paul Group of Middle Ordovician age is composed of granular limestone, fine-textured limestone, and dolomitic limestone. The Chambersburg Limestone of Middle Ordovician age is exposed in narrow bands on both sides of the Martinsburg Shale outcrop belt in the Conococheague Creek valley. The Chambersburg is composed of thin bedded argillaceous limestone.

There are six active quarries in the valley. The rocks mined at the quarries are as follows, name (Water Appropriation or Use Permit number), formation: Security Quarry (WA1986G016), Conococheque Limestone; Beaver Creek West Quarry (WA1996G005), Elbrook Limestone; Beaver Creek East Quarry (WA1977G120), Tomstown Dolomite; Rockdale Quarry (WA1987G002), St. Paul Group, Pinesburg Station Dolomite and Chambersburg Limestone; Pinesburg Quarry (WA1969G024), Chambersburg Limestone, St. Paul Group, Pinesburg Station Dolomite, and Rockdale Run Formation; and Boonsboro Quarry (WA1980G008), Elbrook Limestone and Tomstown Dolomite.

Sinkhole Distribution in the Hagerstown Valley

Slaughter (1962) observed that there were relatively few sinkholes in the Hagerstown Valley, with the greatest concentration along a narrow belt from Fairview Mill (near the Rockdale Quarry) to Pinesburg Station (near Pinesburg Quarry) immediately west of the Martinsburg Shale and straddling the St. Paul Group, Chambersburg Limestone, and the Pinesburg Station Dolomite. He indicated that their formation was likely due to the high solubility of the pure, thin-bedded fossiliferous carbonate rocks underlying the belt. Nutter (1973) in the early part of his report indicated that the sinkholes along the belt were in the Chambersburg Formation, but subsequently added the St. Paul Group to that statement.

Duigon (2001) observed that many of those sinkholes are aligned along strike with steeply dipping strata. Enlargement of bedding plane separations by dissolution due to circulating ground water may have provided the flow pathways for the development of the solution fissures that enhanced the development of sinkholes. The sinkholes lie 80 to 100 ft or more above the level of Conococheque Creek; consequently, the sinkholes may capture surface drainage and direct it along strike rather than toward the creek.

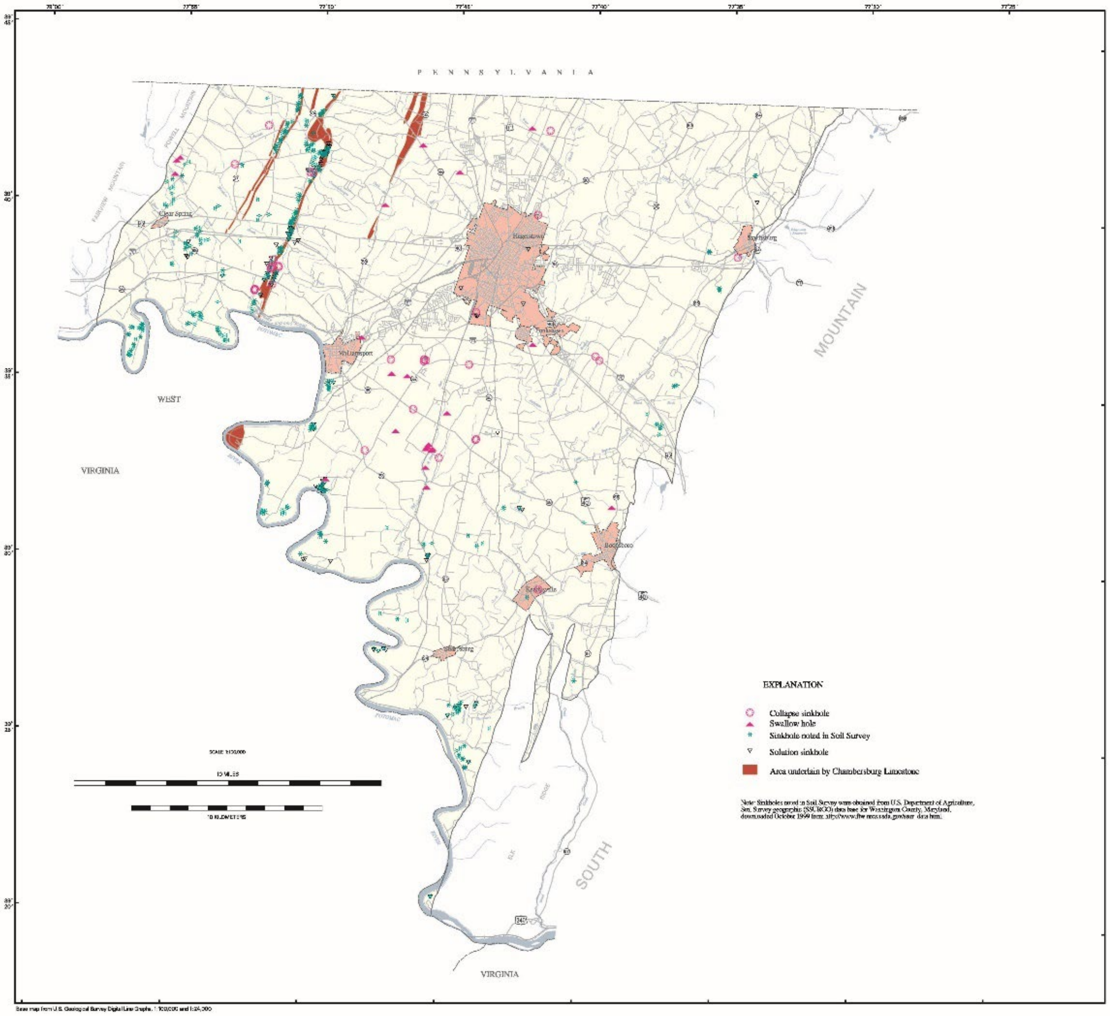


Figure 3. Sinkholes and swallow holes in the Hagerstown Valley. Reproduced from Duigon (2001).

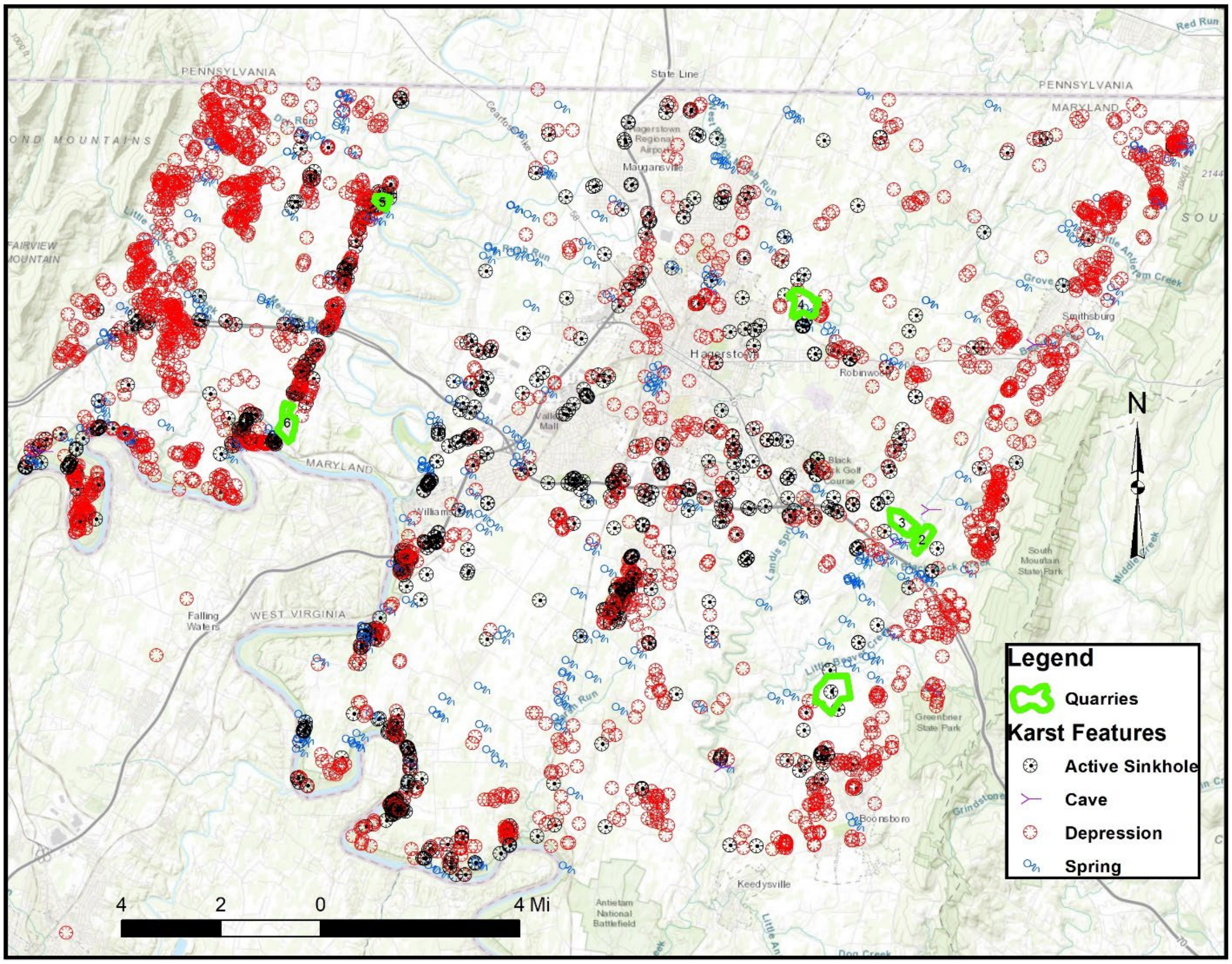


Figure 4. Karst features and active quarries in the Hagerstown Valley. Quarries: 1- Boonsboro; 2 - Beaver Creek-East; 3 - Beaver Creek-West; 4 – Security; 5 – Rockdale; and 6 – Pinesburg.

Brezinski (2018) indicated that Duigon (2001) suggested that the Chambersburg Formation had the highest incidence of sinkhole formation based on the large number observed along Cedar Ridge Road from Pinesburg to Wilson. Brezinski (2018), however, indicated that they were exposed in the St. Paul Group and that this was evidence of a strong proclivity toward dissolution of that rock type.

It is noted that there are many fewer karst features on the Duigon (2001) map, Figure 3, than on Figure 4, derived from Brezinksi GIS data. One reason is that Brezinski included many depressions, whereas Duigon only included sinkholes. Figure 5 eliminates the depressions from Figure 4, but still indicates that there are many more sinkholes than on the Duigon map. It is not clear why there are such significant differences between the two studies. One possibility is that Duigon relied heavily on sinkholes derived from soil conservation maps and identified relatively few collapse sinkholes by field mapping. The Brezinski karst features were derived from multiple MGS studies where they were observed during geologic field mapping in Washington County and located using a GPS receiver. Nonetheless, both studies identified a similar number of sinkholes in the belt between the Rockdale and Pinesburg quarries, Tables 1 and 2

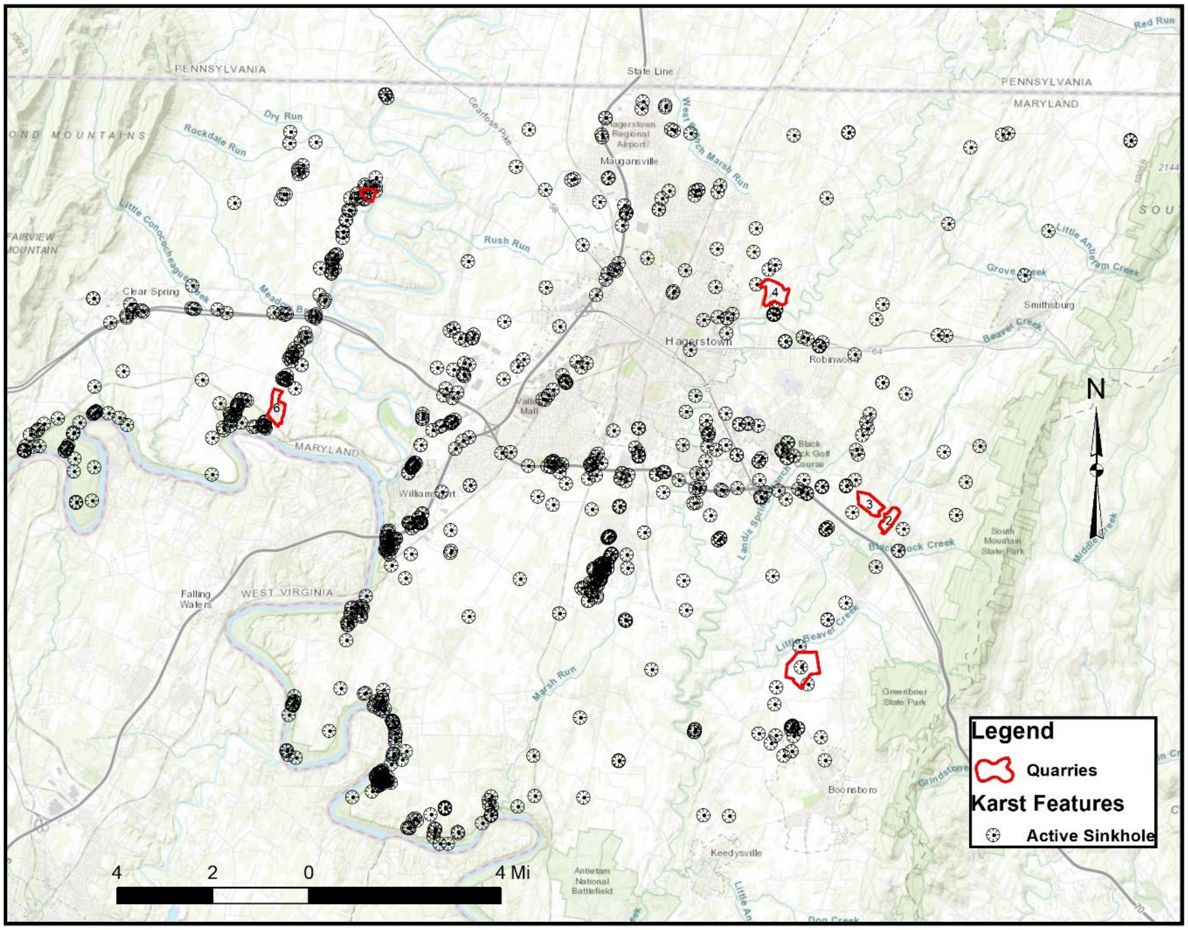
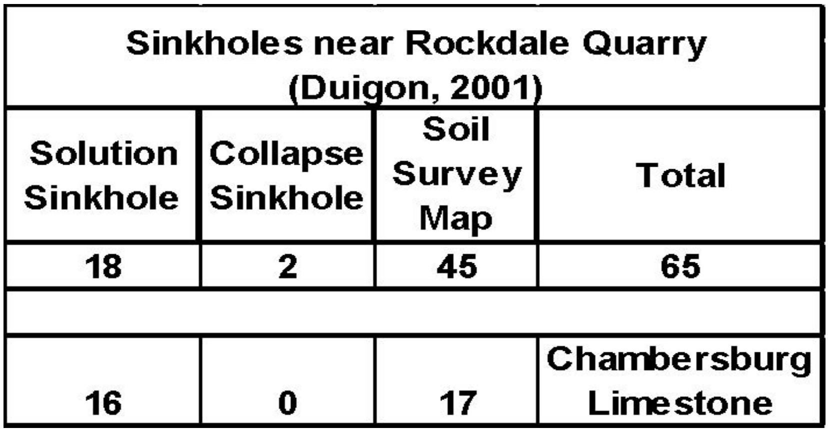


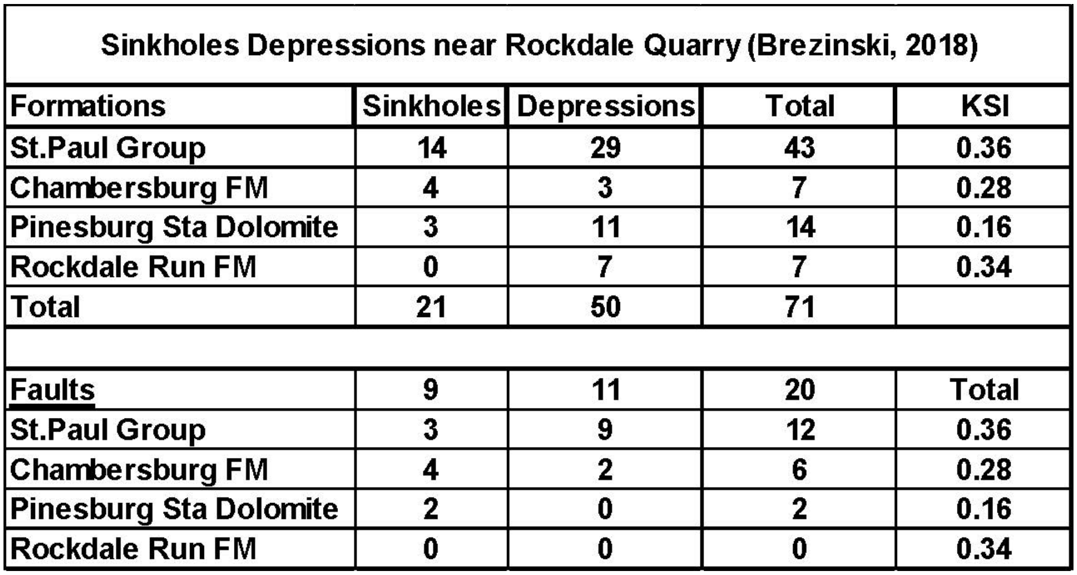
Figure 5. Map of active sinkholes in the Hagerstown Valley.

Table 1. Sinkholes near Rockdale Quarry, Duigon (2001).



Sinkholes near Rockdale Quarry (Duigon, 2001)			
Solution Sinkhole	Collapse Sinkhole	Soil Survey Map	Total
18	2	45	65
16	0	17	Chambersburg Limestone

Table 2. Sinkholes and deprssions near Rockdale Quarry, Brezinski (2018).



Sinkholes Depressions near Rockdale Quarry (Brezinski, 2018)

Formations	Sinkholes	Depressions	Total	KSI
St.Paul Group	14	29	43	0.36
Chambersburg FM	4	3	7	0.28
Pinesburg Sta Dolomite	3	11	14	0.16
Rockdale Run FM	0	7	7	0.34
Total	21	50	71	
Faults	9	11	20	Total
St.Paul Group	3	9	12	0.36
Chambersburg FM	4	2	6	0.28
Pinesburg Sta Dolomite	2	0	2	0.16
Rockdale Run FM	0	0	0	0.34

References

Brezinski, D.K., 2018, Geology and karst development of the Hagerstown Valley (Great Valley) of Maryland. Maryland Geological Survey Report of Investigation 86, 101p.

Duigon, M.T., 2001**,** Karst hydrogeology of the Hagerstown Valley, Maryland: Maryland Geological Survey Report of Investigations 73, 128 p.

Nutter, L.J., 1973, Hydrogeology of the carbonate rocks, Frederick and Hagerstown Valleys, Maryland: Maryland Geological Survey Report of Investigations 19, 70 p.

Slaughter, T.H., 1962, The ground-water resources, in: The Water Resources of Allegany and Washington Counties: Maryland Geological Survey, Bulletin 24, p. 1-243.

Case Studies: Hagerstown Valley Quarries

Beaver Creek West Quarry

Introduction

The MDE permit file (WA1996G005) for dewatering of the Beaver Creek West Quarry contains a chronology prepared by a private citizen (Laura Wright) that, as far as a description of events, appears to be factual. Also included is a summary of discussions of proposed studies at the Beaver Creek Quarry/Albert Powell Fish Hatchery. Since many events occurred before a 1986 application for a water appropriation permit (WA1986G001), original copies of any proposed studies are not contained within the permit file. Since none of these studies were completed, any discussion is offered only to place in context how the quarry development proceeded.

H.B. Mellott Inc. purchased the quarry property in 1971. Initial concerns were raised at that time by the Department of Natural Resources Fish and Wildlife Service (DNR F&W) and MGS about the impacts on the hatchery spring of blasting at and dewatering of the quarry. In 1992, DNR F&W started monitoring the water quality and quantity of the spring to develop baseline data prior to quarry operations. In 1973, the U.S. Geological Survey (USGS) submitted a proposal to MGS for a two-year study consisting primarily of geologic mapping of the presumed drainage area (10-12 mi^2) upgradient from the spring, mapping of the water table in the vicinity of the drainage area, and geochemical tracing studies to determine the source of water supplying the spring.

In 1976, Mellott applied for a surface mining permit (77-SP-0042) that was issued on 6/2/1977 for 16.41 acres, which then increased to 59.34 acres by 1986. On 4/10/1986, Mellott applied for water use permit WA1986G001 in the amounts of 1.3 Mgd average and a maximum of 1.7 Mgd. The DNR Water Supply Program contracted with Dr. James Quinlan to investigate the probable effects that dewatering of the proposed Beaver Creek West Quarry would have on the Houpt Spring supplying the Albert Powell State Fish Hatchery. On 11/5/1987 Dr. Quinlan made three observations/recommendations: 1) Lowering the water table to the requested 400 ft MSL would adversely affect continued operation of the fish hatchery; 2) the proposed dewatering across the regional strike would intercept about 95% of the probable width of the groundwater basin that discharges water to the spring; and 3) additional diagnostic investigations (mapping of the water table, followed by dye-tracing) should be conducted.

On October 22, 1987, in preparation for a 96-h aquifer test, the DNR Water Supply Program notified Mellott of 10 monitoring wells to be completed, wells 1-8 on the State property and wells 9-10 on the quarry property. This was in addition to four observation wells and one pumping well already drilled on the quarry property. Application WA1986G001/1 was then withdrawn on 11/8/1993. There was no record in the permit file that the proposed aquifer test was conducted. On 4/24/1996 application WA1996G005 was submitted by Mellott in the amounts of 750,000 gpd avg and 1.0 Mgd max for dewatering of the Beaver Creek West Quarry pit. The follow-on long-term test was proposed, approved, and conducted starting in 1996. Although the original well locations were well positioned, it is noted that only one monitoring well (FH-1) was completed on the hatchery property. The remaining wells (P-1 to P-6 and W-1 to W-10) were all drilled on the quarry property. The final well locations may have been related to a dispute between the State and Mellott on a release and indemnity agreement that would have "held harmless" any damage caused by Mellott when drilling wells on the State property.

The aquifer test was designed and approved by the MDE Water Management Administration (WMA) and started on about September 1996. A test pit was completed by September 1997, at which time pumping of the pit ceased to allow recovery of the water table prior to the start of the aquifer test procedure. That date was essentially the end of the test procedure. In early 1998, the applicant indicated that there was too much water in the test pit to continue the test and wanted to delay start of the test until the summer of 1998. In late 1998 and early 1999, the WMA project geologist suggested that, if the applicant was not going to finish the test, there was probably enough test data available to support a lesser appropriation to remove surface water from the existing pit during high water table periods**.** In April 1999, the applicant submitted a report requesting an appropriation of 400,000 gpd avg to lower the water table at the quarry to continue mining operations.

Between April 1999 and June 2000, various changes to the application were proposed. First, an appropriation to remove surface water from the west pit was requested. This was followed by a request to remove surface water and provide an emergency supply to the Albert Powell Fish Hatchery. Next, it was suggested that a permit was needed to remove surface water and provide both an emergency supply and a supplemental supply, for normal operations, to the fish hatchery. The applicant's notice to contiguous property owners and public officials indicated that 400,000 gpd avg was being requested to remove surface water from the west pit and provide an emergency supply to the fish hatchery. After the WMA project geologist indicated that the applicant was mining below the high-water table, the applicant then requested an appropriation for quarry dewatering to an elevation of 510 ft to mine the pit to an elevation of 515 ft. The following evaluation is based on the last requested use for a withdrawal to remove surface water, to dewater to work below the water table, and to provide an emergency supply for the hatchery.

Results of West Pit Testing

A large amount of water level data was collected during the one-year period (September 1996 to September 1997) that the test pit was pumped while being developed, and the following recovery period. The test procedure effectively started in September 1996, with the initial development of the test pit. The applicant prepared a contour map showing the water levels measured on September 13, 1996. It indicated that the water table elevation in the pit was at 530 feet (MSL) and that there was a slight depression (about one foot) in the water table. The depression might have been due to development of the existing pit. Initial pumping from 8/01/1996 to 9/7/1996 was only 8520 gpd; however, the rate increased to 577,600 gpd during the five days prior to the water level measurements. Due to the limited drawdown in the monitoring wells, this indicates that most of the initial withdrawal was for dewatering of the surface water that had collected in the main pit prior to starting development of the test pit. Figures 6, 7 and 8 are representative examples of water levels in monitoring wells significantly affected by pumping, P-1, moderately affected by pumping, P-6, and largely unaffected by pumping, P-5. Between September and December 1996, water levels in the P-1 fluctuated over a range of about 10 ft, while declining about 7 ft. Water levels in P-6 also fluctuated about 10 ft and declined about 5 ft. Water levels in P-5 fluctuated less than 10ft and there was no obvious decline in the water levels during the period.

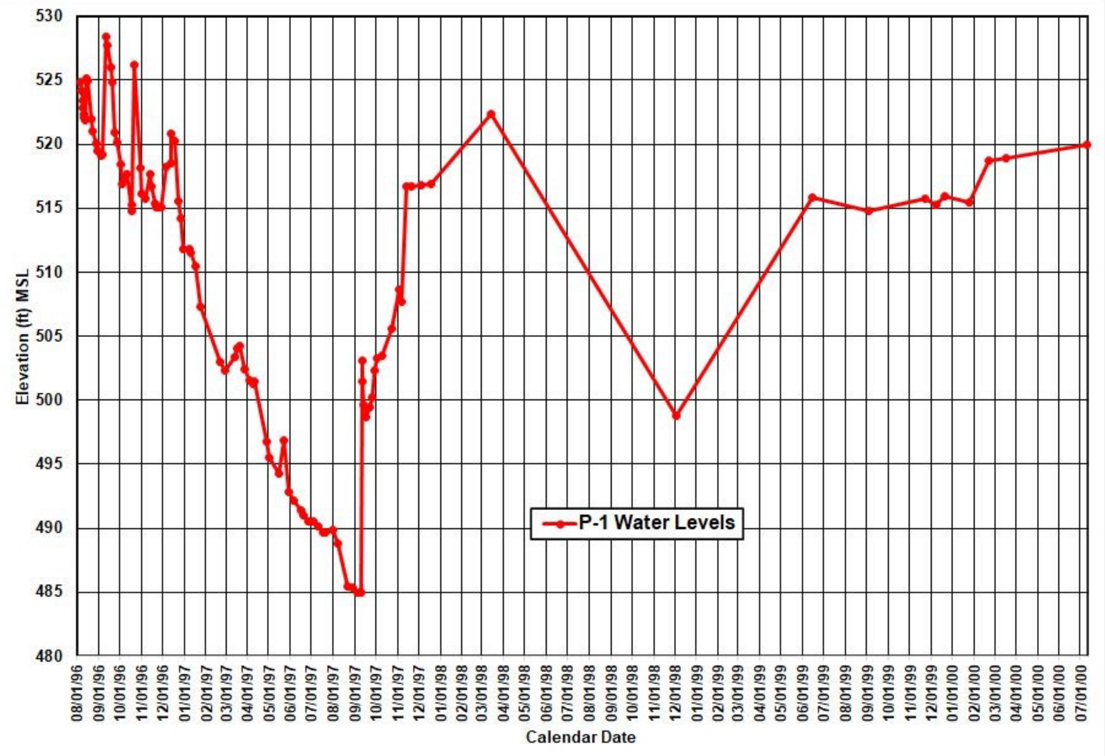


Figure 6. Beaver Creek West Quarry. P-1 monitoring well. Groundwater elevations: 08/06/1996 to 7/11/2000.

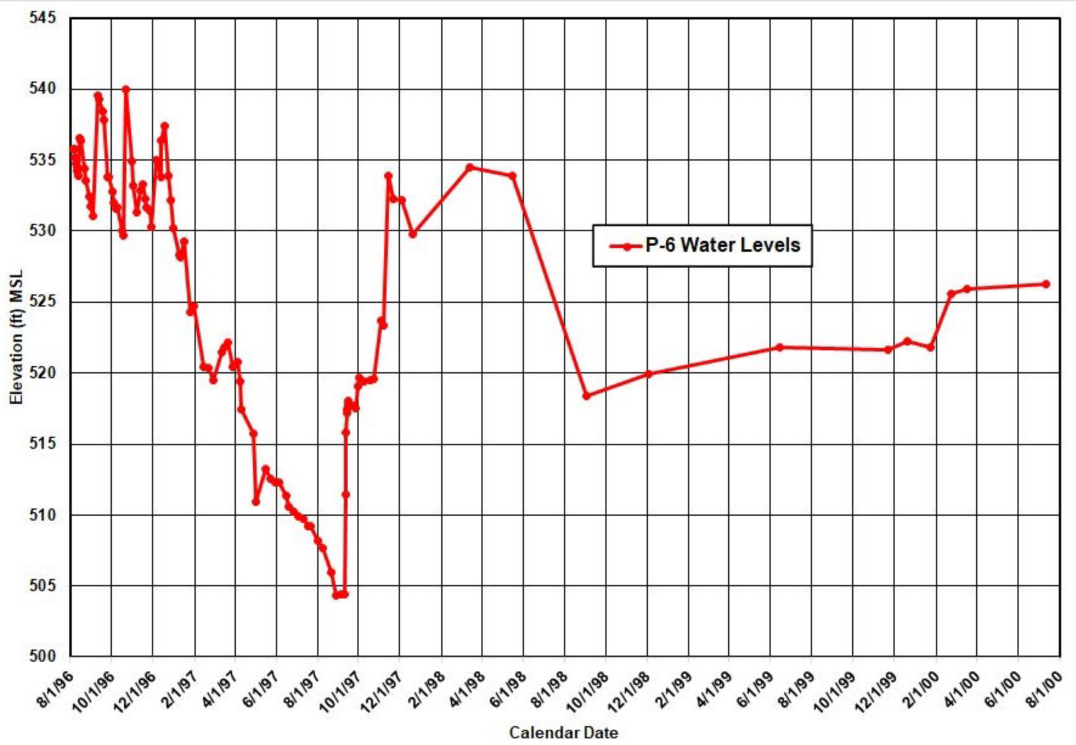


Figure 7. Beaver Creek West Quarry. P-6 monitoring well. Groundwater elevations: 08/06/1996 to 7/11/2000.

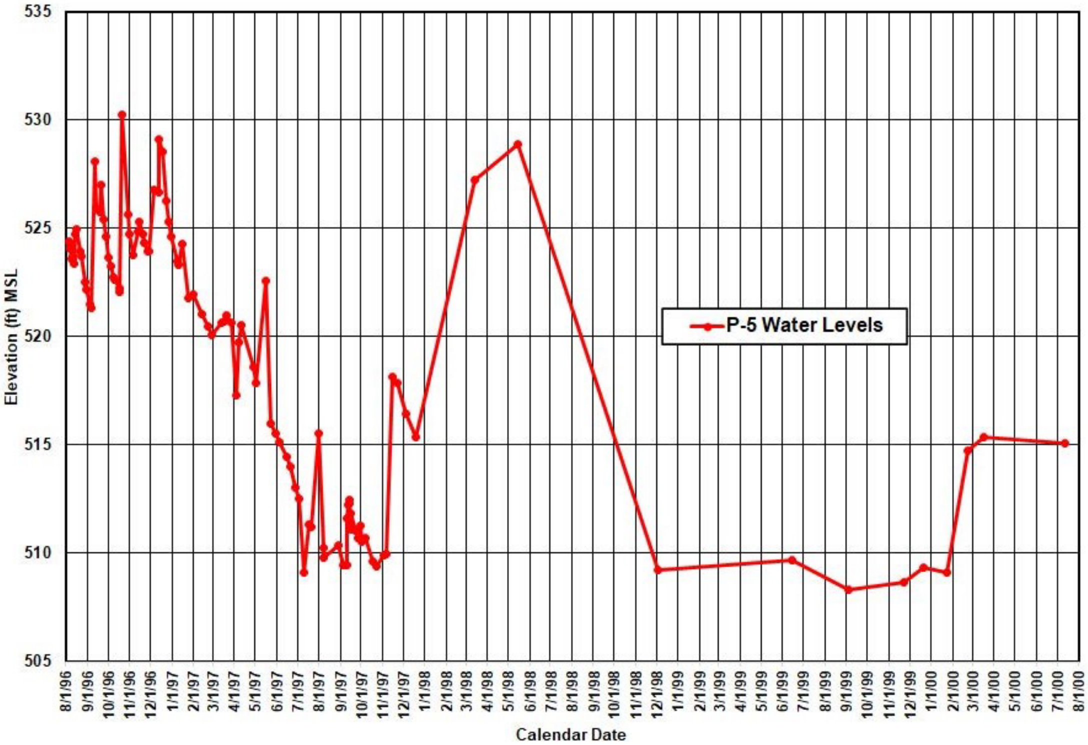


Figure 8. Beaver Creek West Quarry. P-5 monitoring well. Groundwater elevations: 08/06/1996 to 7/11/2000.

Based on the measured water levels and geometry of the pit, it is estimated that there were 20 million gallons in the existing pit at the start of the development phase of the test procedure. That amount was nearly the same as the amount of water pumped during September and October 1996 (20.2 Mgal or 331,000 gpd), Figure 9. This supports the previous observation that nearly all the water pumped during that period came from pit storage and little came from the aquifer.

During November 1996, the pumping rate was increased to 504,000 gpd avg, although there was no change in the pit geometry. Depending on the depth of the pit (maps provided by Mellott indicate that it could be about 510-518 feet deep), this indicates that water was then being removed from the ground water system and aquifer storage. Significant drawdowns started to occur in December 1996 at the effective start of a long-term test. Figure 10 is a water level elevation map indicating that there was a depression of about 10 ft in the pit, which might have been due to development of the existing pit. Fractures also have been shown to cause depressions or drains in the water table due to their high hydraulic conductivities. Development of a quarry pit might produce the same effect since it is an open void in the rock with an infinitely high conductivity. At that point there was a groundwater divide between the quarry and the hatchery spring.

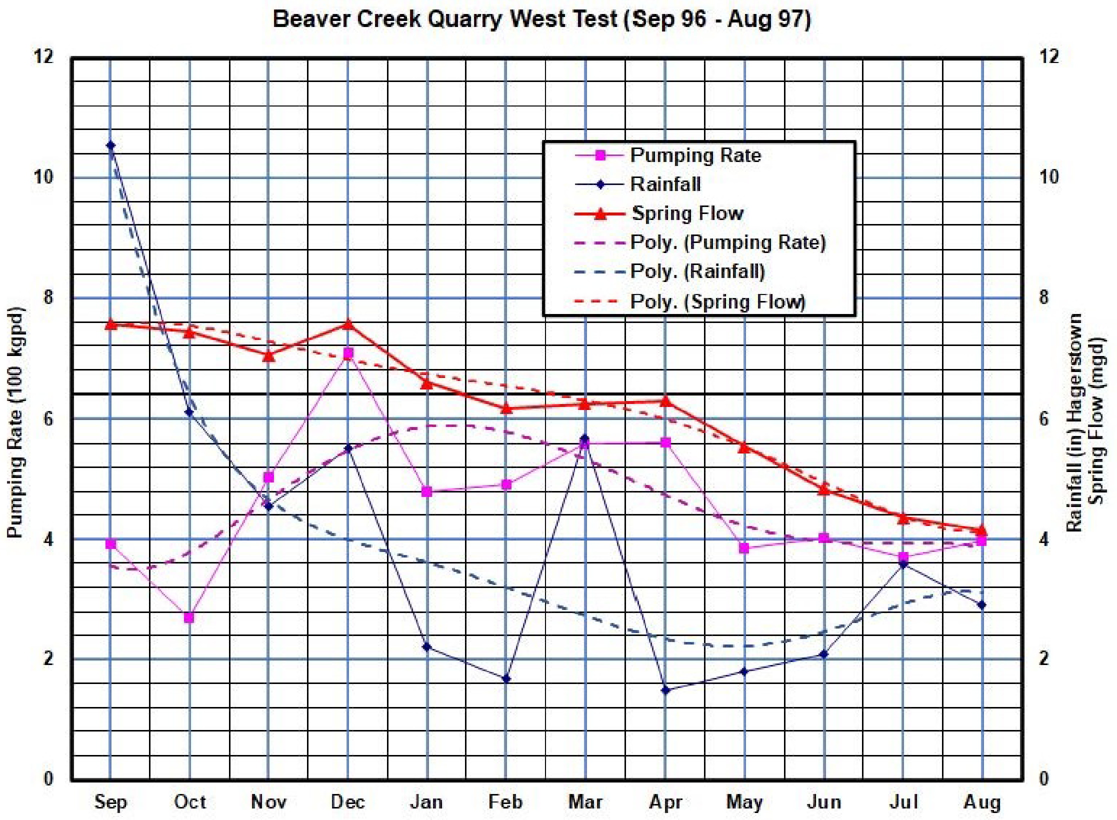


Figure 9. Monthly averages for the Beaver Creek West Quarry pit pumping rate, Albert Powell Fish Hatchery (Houpt Spring) spring flow and Hagerstown 1E rainfall: September 1996 to August 1997.

The test pit was completed by February 1997 with a bottom elevation of 470 ft. Pumping of the test pit continued until September 1997. A water level elevation contour map at that point, Figure 11, indicated that a trough of depression was well developed along strike (NE-SW), while a second trough was starting to develop to the south of the test pit and in the direction of the hatchery spring. The groundwater flow between the quarry pit and the hatchery spring was then reversed such that the flow was from the direction of the spring to the pit. This indicates that there is a possible zone of fast flow (conduit) between the test pit and the hatchery. Other evidence to support these observations is a high concentration of fracture traces and several springs along a tributary to Beaver Creek, the presence of a cross-fault between two major regional faults, and several sinkholes at the northwest end of the tributary. This basically indicates that dewatering of the water table at the west pit likely intercepted groundwater flowing toward the hatchery spring.

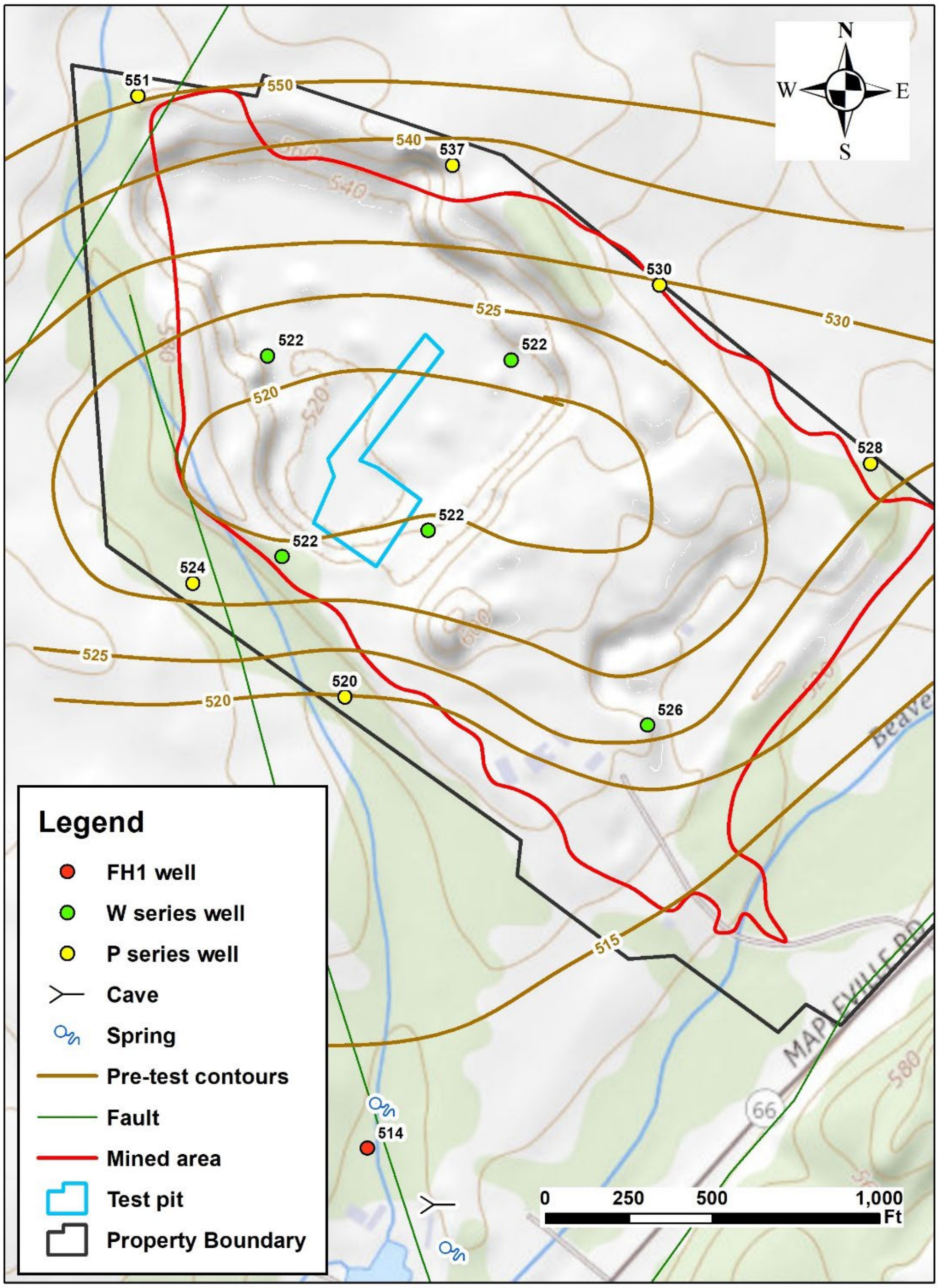


Figure 10. Beaver Creek West Quarry pit. Pre-test groundwater elevations (ft) MSL 12/13/1996. Contour interval-5 ft.

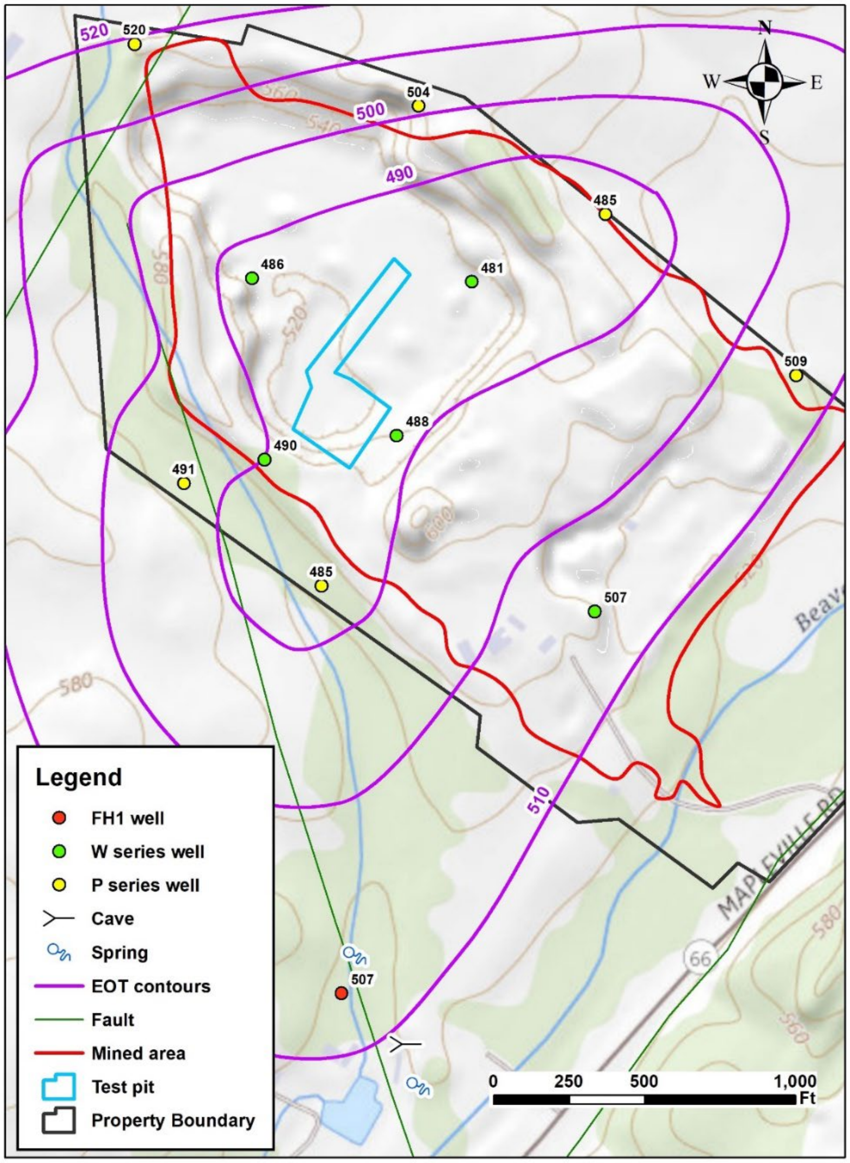


Figure 11. Beaver Creek West Quarry pit. End of test (EOT) groundwater elevations (ft) MSL 9/10/1997. Contour interval-10 ft.

September 1997 was effectively the end of the test phase for the permit application. The pit discharge (480,123 gpd) was 8.6% of the spring flow (5.6 Mgd) during the drawdown phase (12/14/1996 to 9/9/1997). Pumping ceased at that point and water levels started a long, relatively slow, but nearly complete, recovery in the aquifer and test pit, until a high recharge period (Jan-May 1998) occurred. By May 1998, the water levels had recovered about 90 to 95%. Regional water levels (using USGS well WA Bk 25, near Smithsburg, Figure 12, however, recovered about 120% during the same period, indicating that recovery in the vicinity of the test pit was effectively 75-80%. The most likely reason that the water levels did not fully recover is that about 50,000,000 gallons of water (about 330,000 gpd during the high recharge period) was needed to refill storage in the test pit. The drought of 1998-99 started in about June 1998. After the end of the drought, water levels in the wells most affected by pumping (e.g., P-1 and W-8) had nearly completely recovered while those less affected (e.g., P-6) had not fully recovered. This was likely due to differences in permeability and porosity of the different rock units. The fact that the aquifer in the vicinity of the quarry test pit did not fully recover after periods of high recharge indicates that the effects of the pumping test continued for a long period after pumping ceased.

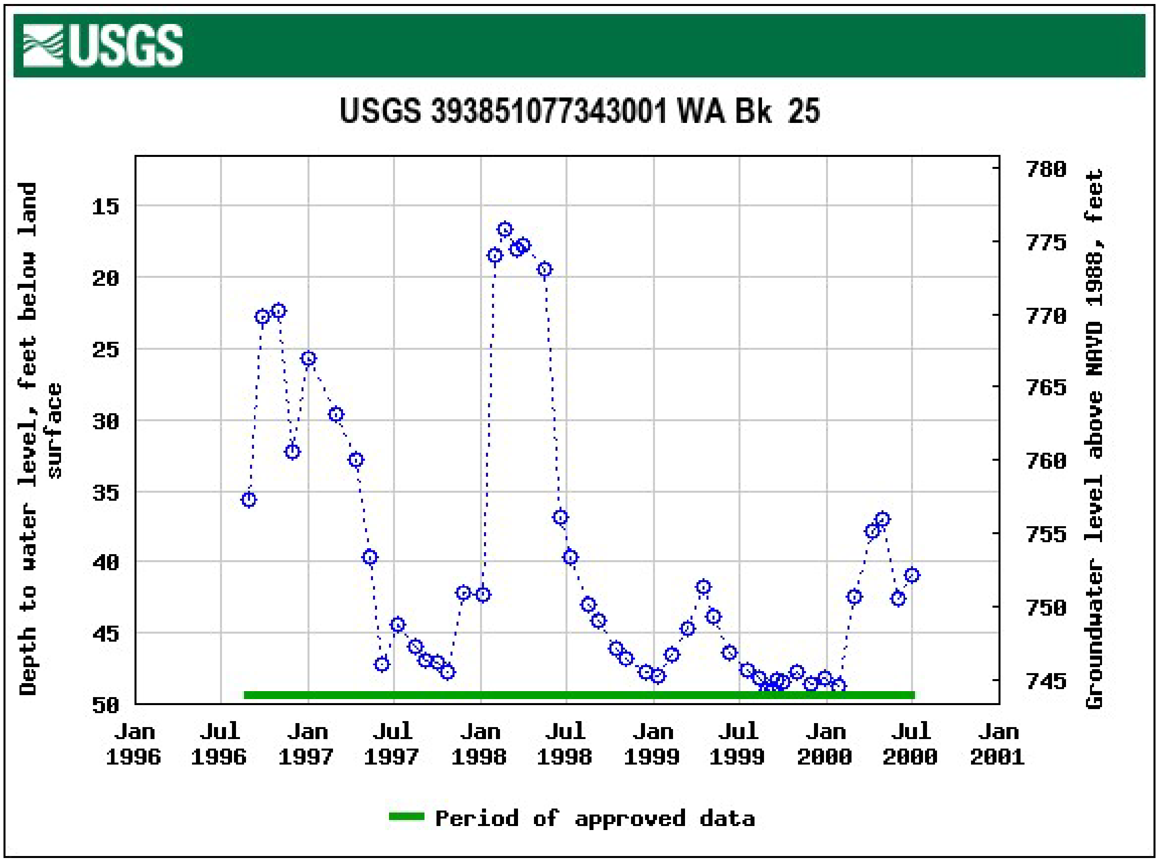


Figure 12. USGS monitoring well WA Bk 25, 0.5 mi. south of Smithsburg. Groundwater levels (depth to water and elevation in ft). Period August 1996 to July 2000.

Figure 13 is a contour map showing the water levels measured on March 17, 2000, and those collected at the effective end of the test (EOT) in September 1997. The 2000 contours indicate that there was a uniform strike and dip reflecting natural ground water flow from the higher elevations near the northwest end of the quarry to the fish hatchery spring, while the September 1997 contours indicate that the groundwater flow had been reversed such that flow was from the spring to the quarry pit. Also, the elevations of the water levels were about 9 ft lower in 2000 than at the start of the drawdown phase in December 1996, reflecting the difference between a post-drought recovery and a very wet period. The same relative differences are shown in the water level data collected in the USGS WA Bk 25 monitoring well, Figure 12.

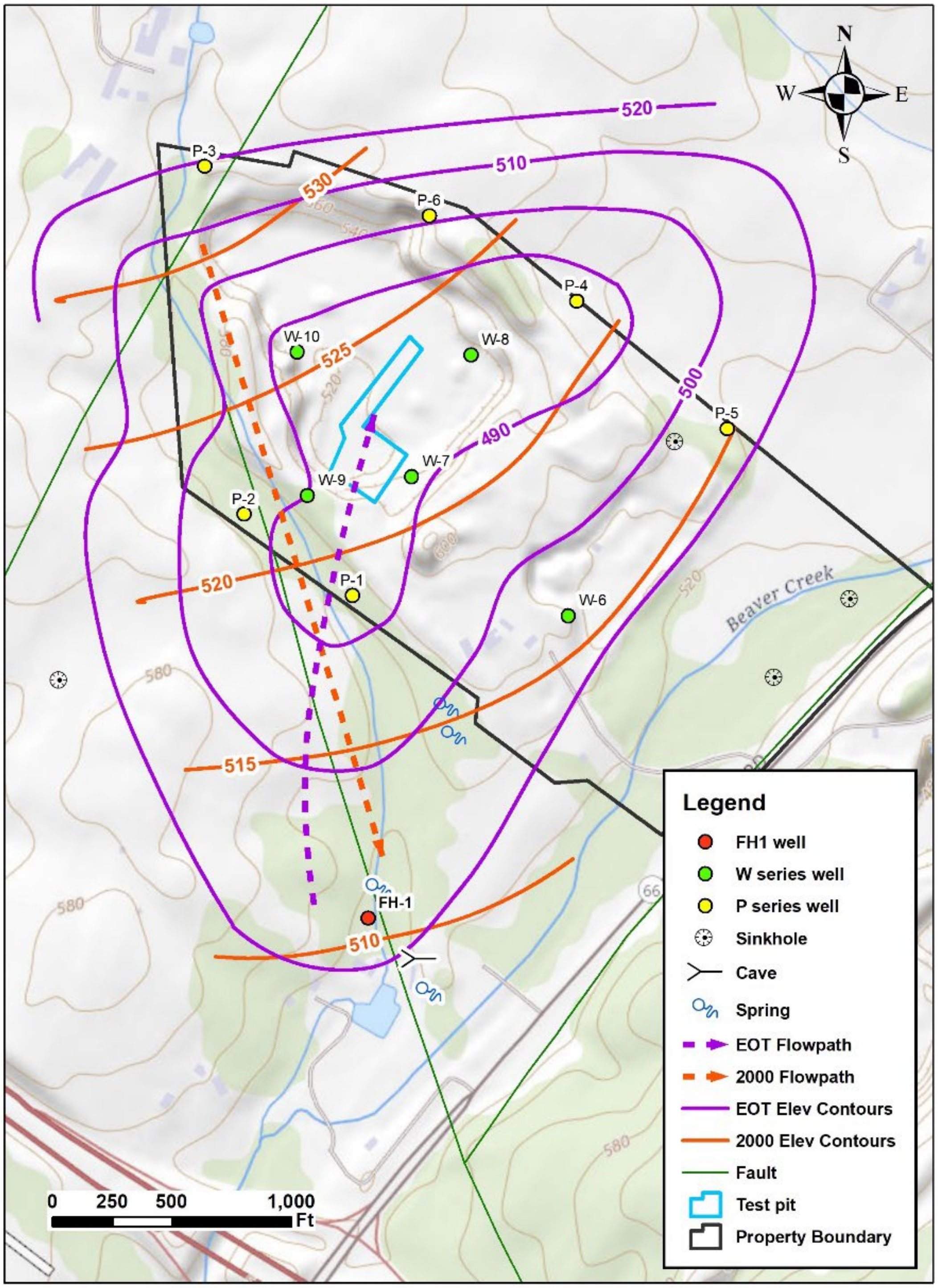


Figure 13. Beaver Creek West Quarry pit. Groundwater elevations (ft) MSL for end of test on 9/10/1997 and recovery on 3/17/2000. Contour intervals 5 and 10 ft. The flow paths demonstrate that the natural flow toward the spring was reversed to flow toward the quarry pit during the 1996-1997 pumping test.

The dye trace study proposed as part of the permit application process was never completed; however, the MGS, assisted by the U.S. Environmental Protection Agency (USEPA), conducted a groundwater tracing program in 2007-08 to help determine the area contributing groundwater to the hatchery spring, Duigon (2009). In 1992, MDE had released dye in Little Antietam Creek that was detected in the hatchery spring discharge. Contemporaneous measurements indicated that the creek lost about 3.71 ft^3/s along a 1.3-mi reach upstream from the spring, nearly equal to the discharge of the spring (3.48 ft^3/s). The suggests that subterranean groundwater flow in Beaver Creek is the main source of water supplying the spring. The MGS study determined that the size of the drainage area contributing groundwater to the hatchery spring was 8.2 mi^2, Figure 14. The flow starts about 6 mi north of the spring from a broad area about 2 mi by 3 mi, mostly within the Little Antietam Creek watershed. It then crosses into the Beaver Creek basin and narrows to an area of about ¾ mi by 2 mi, including the entire property of the Beaver Creek West Quarry.

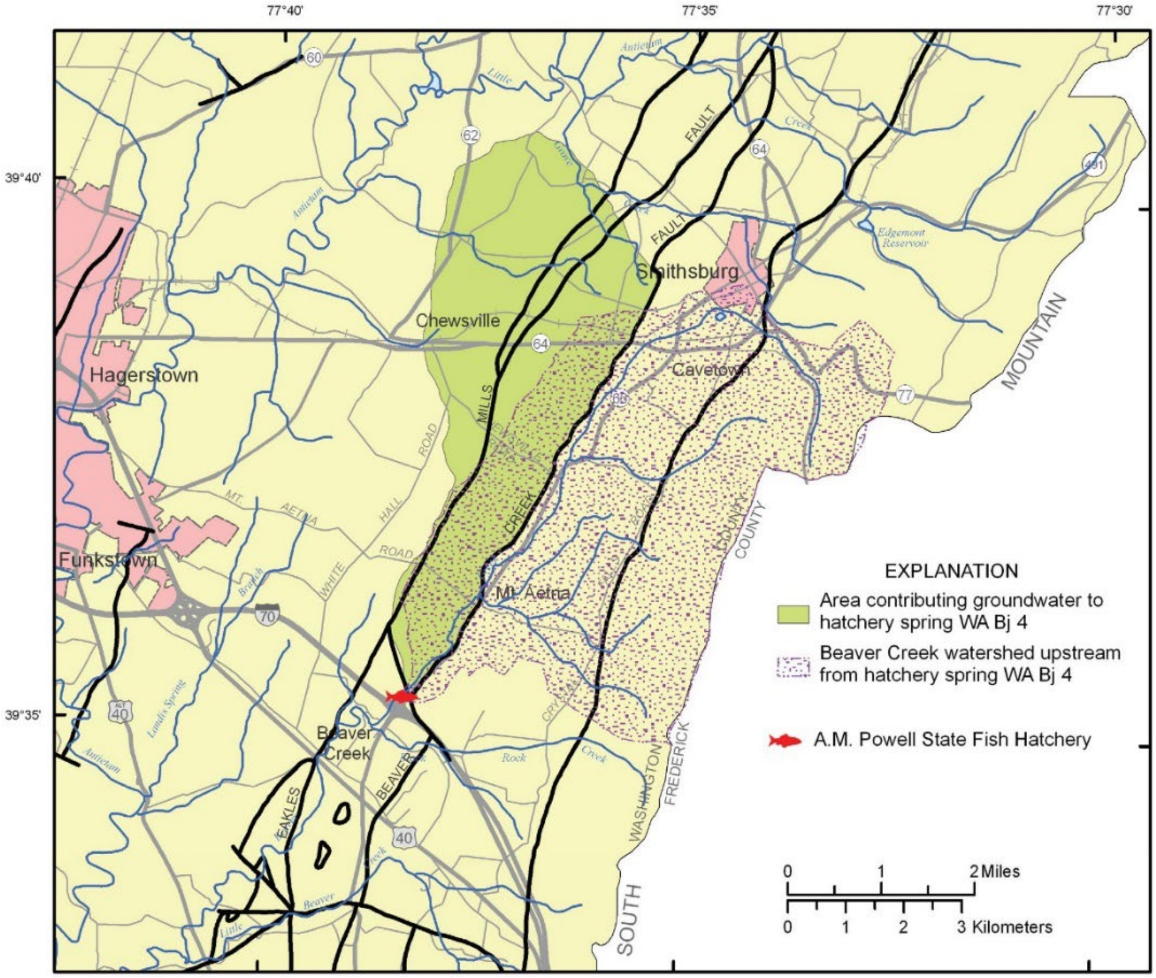


Figure 14. Area contributing groundwater flow to the Albert Powell Fish Hatchery (Houpt Spring) spring as hypothesized by Duigon (2009). Figure reproduced from that study.

The topographic area drained by of the test pit, as determined by the topographic drainage area above the spring (0.45 mi^2) is 5.5% of the contributing area determined by the MGS study, Figure 15. However, this includes a down gradient area outside the potential capture zone of the quarry pit during the pumping test. When the downstream zero drawdown contour and the upstream drainage were used, the estimated capture zone is 224 acres (0.35 mi^2) or 4.3 % of the estimated drainage area (8.2 mi^2) contributing groundwater to the hatchery spring. This would suggest either much of the water withdrawn during the test came from outside the topographic drainage area of the pit or a substantial portion came from groundwater storage. After a permit was issued in April 2002, the quarry started operating in 2003. Figure 16 is a chart of the pumpage reported under permit WA1996G005, the hatchery spring discharge, and rainfall recorded at Hagerstown for the period 2003-2005. The quarry water use reported during the period from March to September 2003 was 7.1 % of the spring flow, but this included a month (September) of extremely high rainfall (11.5 in) where the withdrawal was 18% of the spring flow. Between January 2004 and June 2005, when storage had been depleted, the withdrawal was 4.5% of the spring flow or approximately the same as that of the ratio (4.3%) of the estimated capture zone of the pit during the test relative to the estimated drainage area of the hatchery spring. These data suggest limiting the water level in the pit to 510 ft (MSL) significantly reduced the potential impacts to the spring. After 2005 water withdrawals drop off substantially and were intermittent for long periods of time.

Willey and Achmad (1986), completed a ground water flow model for the Upper Cattail Creek watershed in Howard County. Although a non-carbonate aquifer, the hydraulic characteristics used in the Upper Cattail Creek study are like those contained in the Trainer and Watkins (1975) study for carbonate aquifers of the Upper Potomac River basin. Some observations are offered here to demonstrate the potential impacts that could be associated with the effects of long-term ground water withdrawals on stream base flow in fractured rock aquifers.

Willey and Achmad (1986) indicated that when pumping of a well (or in this case a test pit) commences, water initially comes from ground water storage as the water table is lowered in the vicinity of the well. Over time, increasing amounts of water come from captured ground water runoff that would have gone to a stream or, in this case, the hatchery spring. This eventually reduces base flow by an amount equal or nearly equal to the amount of water pumped from the well. In their ground water flow model, about 65 to 90% of the reduction in base flow occurred by the end of one year of pumping, depending on the aquifer storage constant that was used in a specific simulation. They also indicated that using average annual base flow produced a poor estimate of the impacts of ground water withdrawals on a stream-aquifer system’s base flow during dry periods. In one simulation, under a specific development scheme, annual average base flow declined by 7% after 20 years of pumping. Using the same scheme, the same withdrawals reduced base flow by 17% during a moderately severe drought year, and by 48% during the seasonal low flow period (7Q10) of a drought. That assumes that pumping is constant, while withdrawals from the quarry will likely vary in the same amounts relative to the spring flows. This means that needed withdrawals during a drought would be much less than the permitted amount of 400,000 gpd avg. Under normal operations the permit requires that the water level in the pit shall not be lower than 510 ft MSL. Limiting the water level in that manner will produce variable withdrawals in response to changes in climatic conditions. Any attempts to increase the permitted amounts or lower the operating level would require further evaluation to determine if there would be greater impacts to the hatchery spring flow.

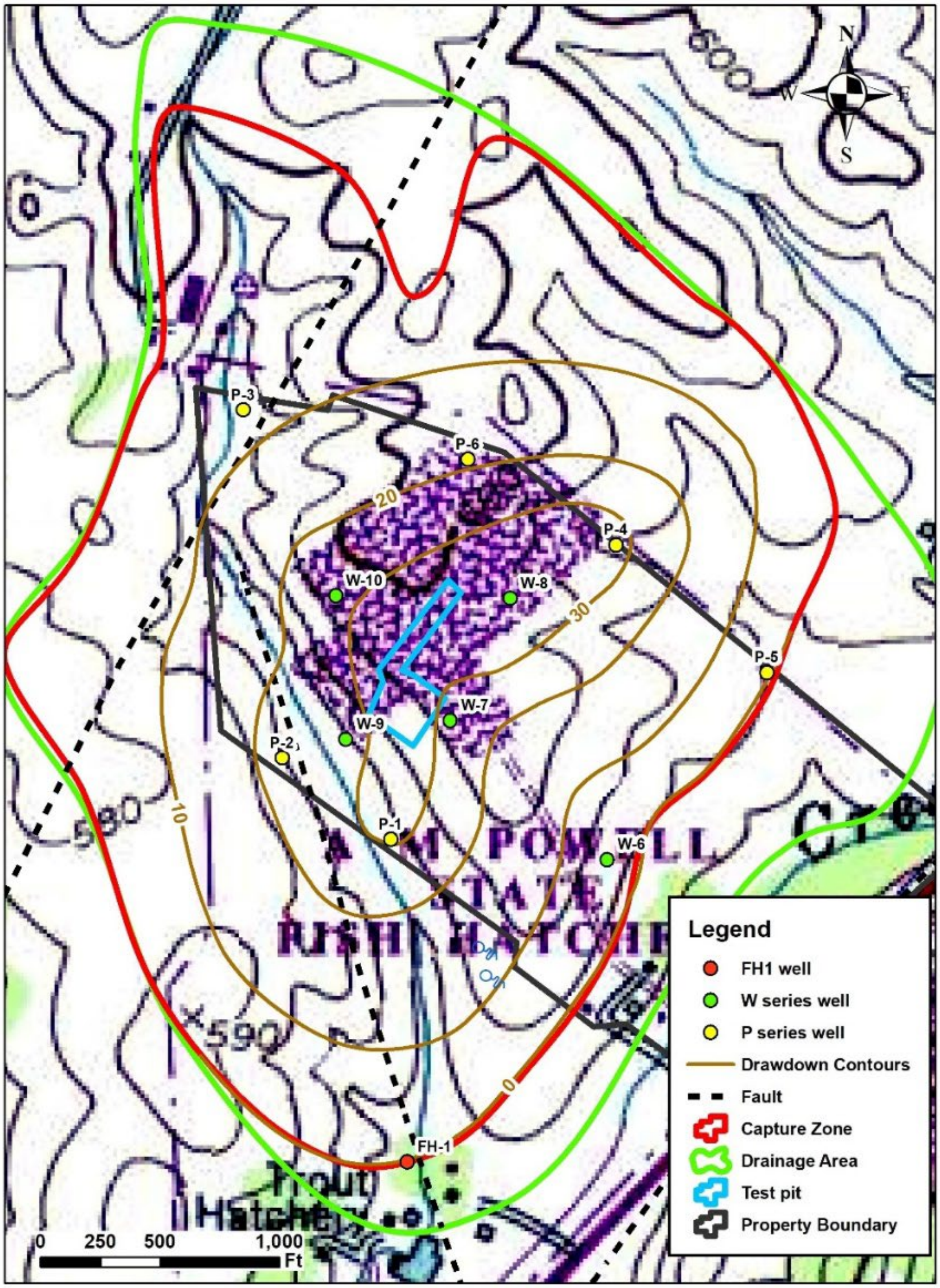


Figure 15. Topographic map. Drawdown contours are at the EOT at the Beaver Creek West Quarry. Capture zone from pumping of the test pit is estimated based on downstream zero drawdown from the test and up gradient topographic limits.

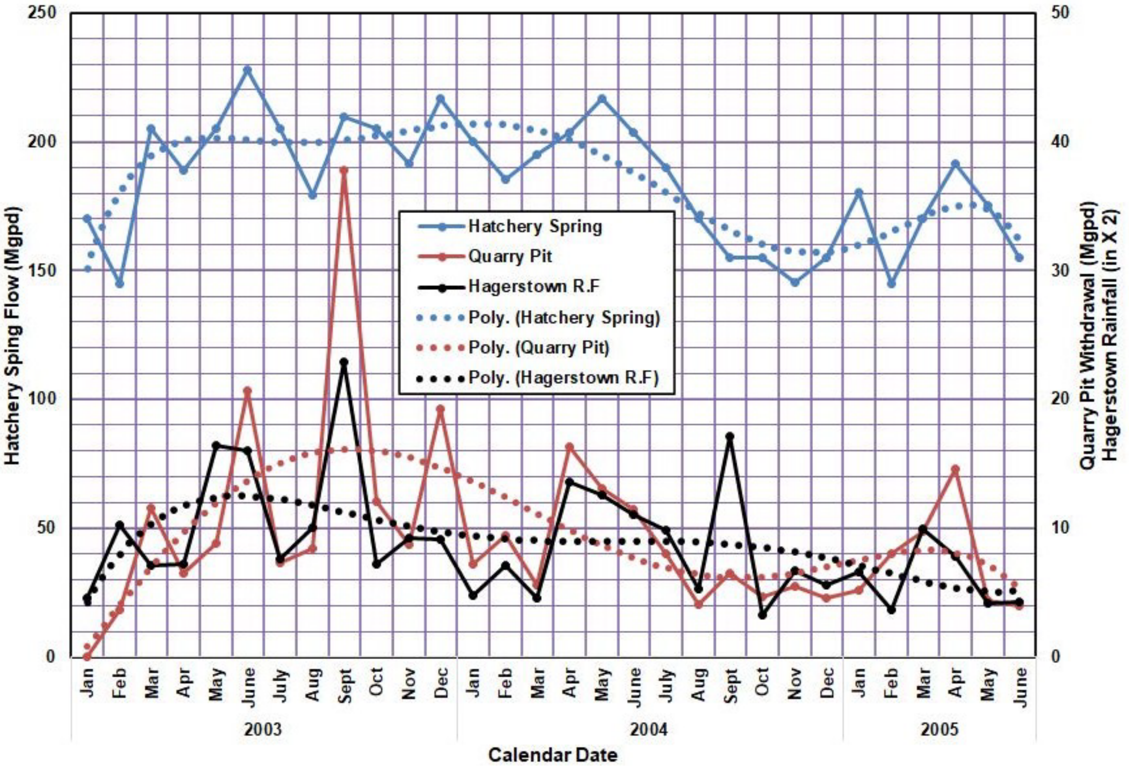


Figure 16. Monthly averages for the Beaver Creek West Quarry pit pumping rate, Albert Powell Fish Hatchery (Houpt Spring) spring flow and Hagerstown 1E rainfall: January 2003 to June 2005.

The quarry was operated continuously from 2003 to mid-2007 and then shutdown in 2009. Upon restart in 2010, the pumping rate was extremely high relative to the hatchery spring flow and Hagerstown rainfall, Figure 17. This may include some accumulated surface water in the pit and groundwater removed from aquifer storage after the long-term recovery of water levels.

The quarry was then operated infrequently until 2018. While the overall trends for the hatchery flow, quarry pumpage, and rainfall are similar, Figure 18, the seasonal fluctuations in spring flow were much less than those of the quarry withdrawals and rainfall. This largely reflects the groundwater source for the spring and natural variations in rainfall. The quarry was operated intermittently during that period (2018-2019), with the high withdrawal rate likely due to removal of surface water collected during previous periods of inactivity and water being taken from groundwater storage.

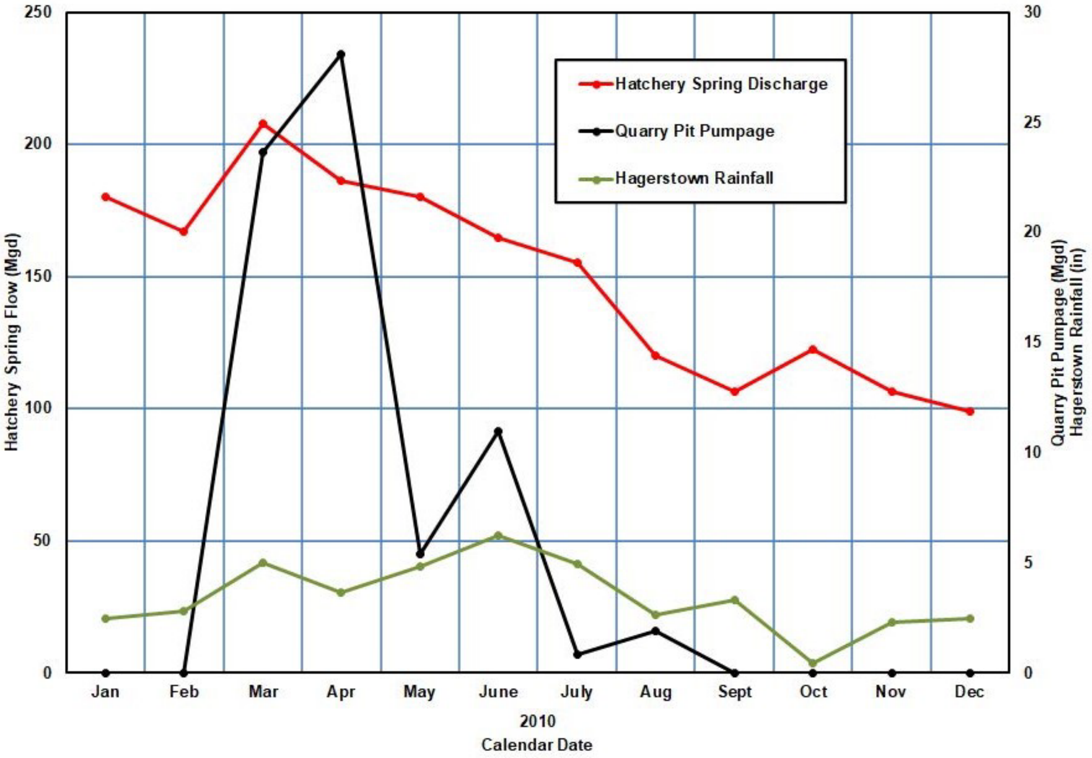


Figure 17. Monthly averages for the Beaver Creek West Quarry pit pumping rate, Albert Powell Fish Hatchery (Houpt Spring) spring flow and Hagerstown 1E rainfall: January to December 2010.

Figure 19 is a chart of the annual average pumpage reported under WA1974G110 for the Albert Powell State Hatchery spring for the period 1986 to 2020. It indicated the peak flow was 7.0 Mgd in 1996, the wettest year on record (76.7 in) and the minimum flow was 2.8 Mgd in 2002, following the drought of October 2000 to September 2002. The long-term pumping test and operational pumpage records indicate that the pit withdrawal was 4.5% of the spring flow after groundwater storage had been depleted. If the quarry is operated continuously at the pit water level elevation of a constant 510 ft MSL, so that groundwater storage is not a significant factor, then the estimated quarry withdrawal demand would be a maximum of 315,000 gpd avg under wet conditions and a minimum of 126,000 gpd avg under drought conditions.

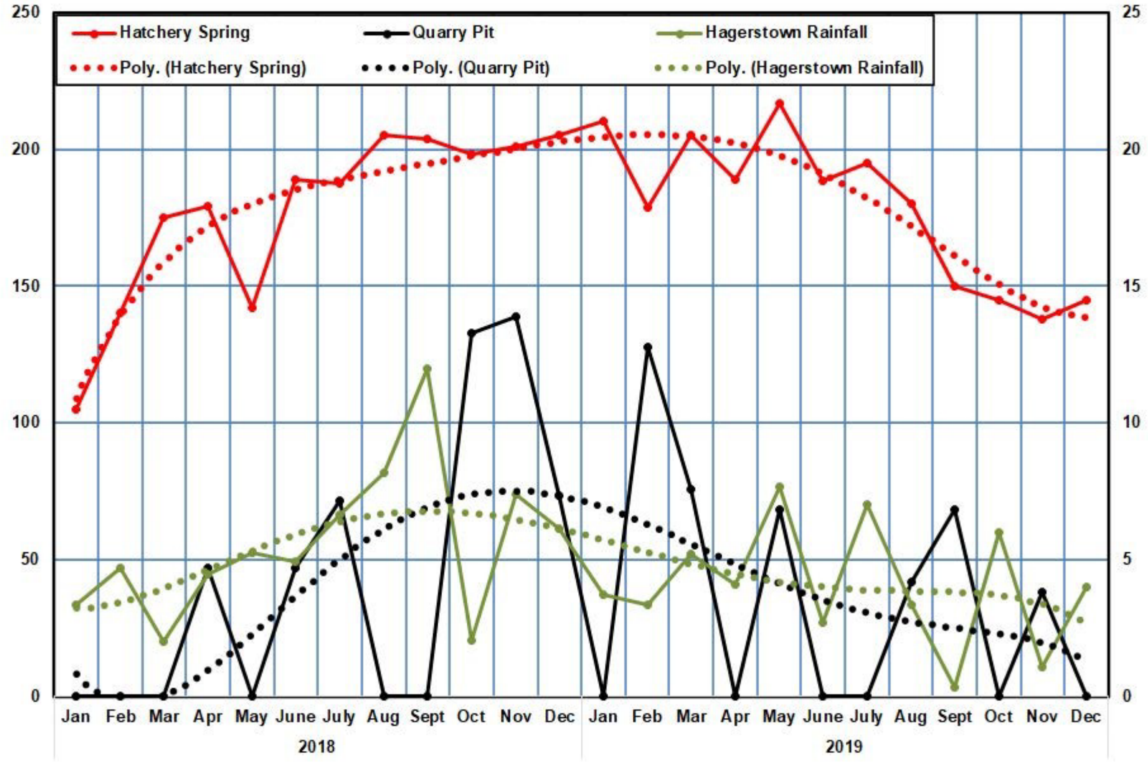


Figure 18. Monthly averages for the Beaver Creek West pit pumping rate, Albert Powell Fish Hatchery (Houpt Spring) spring flow and Hagerstown 1E rainfall: January 2018 to December 2019.

A contingency plan was proposed to provide an emergency supply in case there were diminished flows or water quality issues at the hatchery spring. The needed minimum available flow was 2200 gpm (3.2 Mgd), which the hatchery manager (Wade Moore) indicated was a satisfactory level during the drought of 1999. For normal operations he indicated that 2500 gpm (3.6 Mgd) was needed. During the follow-on 2001-2002 drought, the average flow from the spring during the period August 2001 to November 2002 was 3.0 Mgd (2083 gpm), with a minimum of 2.0 Mgd (1389 gpm) in January 2002. While a water use permit was issued for quarry dewatering in April 2002, effective dewatering of the quarry did not start until after the end of the drought in February 2003. The present hatchery manager (Eric Bittner, personal communication, November 9, 2021) indicated that there were no major problems at the hatchery during the 2001-02 drought, with only some minor changes in operations. He indicated that there was a reuse system in place at that time capable of recycling water at 1000 gpm. There are plans in place for an upgrade that will increase the quality of the water supplied by the reuse system.

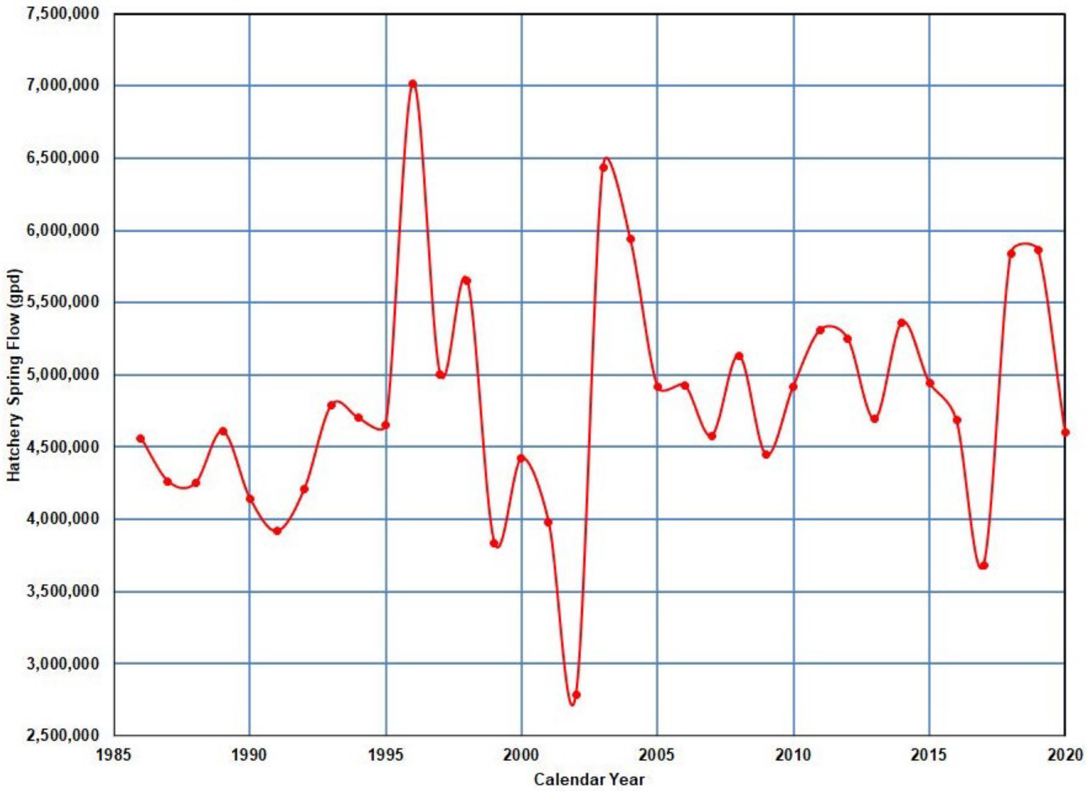


Figure 19. Annual average flows from the Albert Powell Fish Hatchery (Houpt Spring) spring: 1986 to 2020.

In an emergency, Wade Moore indicated that 2000 gpm (2.9 Mgd) for a 45–100-day period would be needed to allow for transportation of the fish. This would require a minimum 45-d volume of 130 Mgal and a maximum 100-d volume of 288 Mgal. To determine how much water would be available from the quarry in an emergency at the hatchery, several scenarios are considered.

The first one is to assume that the quarry pit is as full as at the start of the long-term test. The water levels in the observation wells remained relatively constant from 9/8/1996 to 12/13/1996, at between 520 and 530 ft, during which 44.5 Mgal were pumped from the pit. Since there was no decline in the groundwater levels, this indicates that much, or all the water was taken from surface water that had collected in the pit during a record wet year. The water levels in the monitoring wells started declining on 12/14/1996 and continued declining until the end of the test on 9/9/ 1997, during which a total 130 Mgal were pumped from the pit. The total amount of 174.5 Mgal would have provided a hatchery emergency supply for 61 days at 2000 gpm and 48 days at 2500 gpm.

The pit discharge (480,123 gpd) was 8.6% of the spring flow (5.6 Mgd) during the drawdown phase (12/14/1996 to 9/9/1997) of the test while the long-term average from the 2003-2005 pumpage records was 4.5%, after depletion of groundwater storage. This indicates that nearly ½ of the water withdrawn during the drawdown portion of the test was taken from groundwater storage.

Since the first scenario requires the quarry to be out of operation for a long period of time, including a record wet year, a more likely scenario is that the emergency use is required during a drought while the quarry pit operating level is 510 ft (MSL), to mine at 515 ft (MSL). Using the spring discharge records during the drought of 2001-2002 (October 2001-September 2002) and the ratio of 0.045 for the quarry discharge, it is estimated the pit would have been pumped at 117,400 gpd avg (42.8 Mgal) throughout the drought. Adding an estimated storage volume of 28.9 Mgal between pit elevations 515 ft (MSL) and 440 (MSL) produces a total water availability 71.7 Mgal or 25 days at 2000 gpm and 20 days at 2500 gpm. This assumes that most of the groundwater storage was depleted during the drought while operating at 510 ft (MSL). It appears that much of the water pumped may have come from relatively shallow zones, since a high pumping rate was required during the early portions of the construction and dewatering of the test pit. Regional studies indicate that most of the water in fractured rock aquifers is stored in the weathered zone. The base is usually indicated by the depths of bedrock or casing in a well. Figure 20 is a structural map on the top of bedrock constructed from the driller's well completion reports for the Beaver Creek West Quarry monitoring wells. This pattern is like that of drawdowns observed at the end of the pumping phase of the long-term test, Figure 15, in that the drawdowns extended in two directions, one along strike, likely due to bedding plane parting fractures and the second downdip, probably controlled by a vertical fracture in the tributary between the quarry and the hatchery spring. While this hypothesis needs testing, it is possible that little groundwater is stored below an operating water level of 510 ft (MSL) and deepening of the quarry below that level may not result in significant withdrawals beyond the current permitted use of 400,000 gpd avg.

The previous calculations indicate that only under optimum conditions (wet year and quarry shutdown for an extended period) could the quarry supply the proposed 45-d emergency supply to the hatchery. In no case could a 100-d supply be provided. It is more likely that an emergency would occur during a drought, in which case an emergency supply would be available for only 20-25 days.

2002 was one of the three worst droughts on record. The average calculated base flows for Antietam Creek at Sharpsburg (gage # 01619500) for the droughts of 1931, 1966 and 2002 are 4.3, 5.6 and 5.0 in/yr, respectively. These data indicate that the drought of 2001-2002 was representative of a near worst case scenario.

Since most of the water available for emergency use would come from what is effectively a surface water reservoir, a substantial portion of the water might not be available due to thermal effects, potentially low dissolved oxygen, and possible turbidity problems. Thermal effects may be important, since most of the water would be stored in the upper part of the reservoir; however, in the case of continuous quarry operation and the occurrence of a severe drought, the surface area of the pit would be small relative to the depth of the pit. This should reduce heating at the surface of the water accumulated in the pit. Low oxygen concentrations in water bodies are generally due to excessive growth of algae or phytoplankton, as well as high temperature. Since this is a quarry, elevated turbidity in the pit could occur due to runoff from the stone product. It is beyond the scope of this investigation to evaluate these effects since there are no data available concerning those factors.

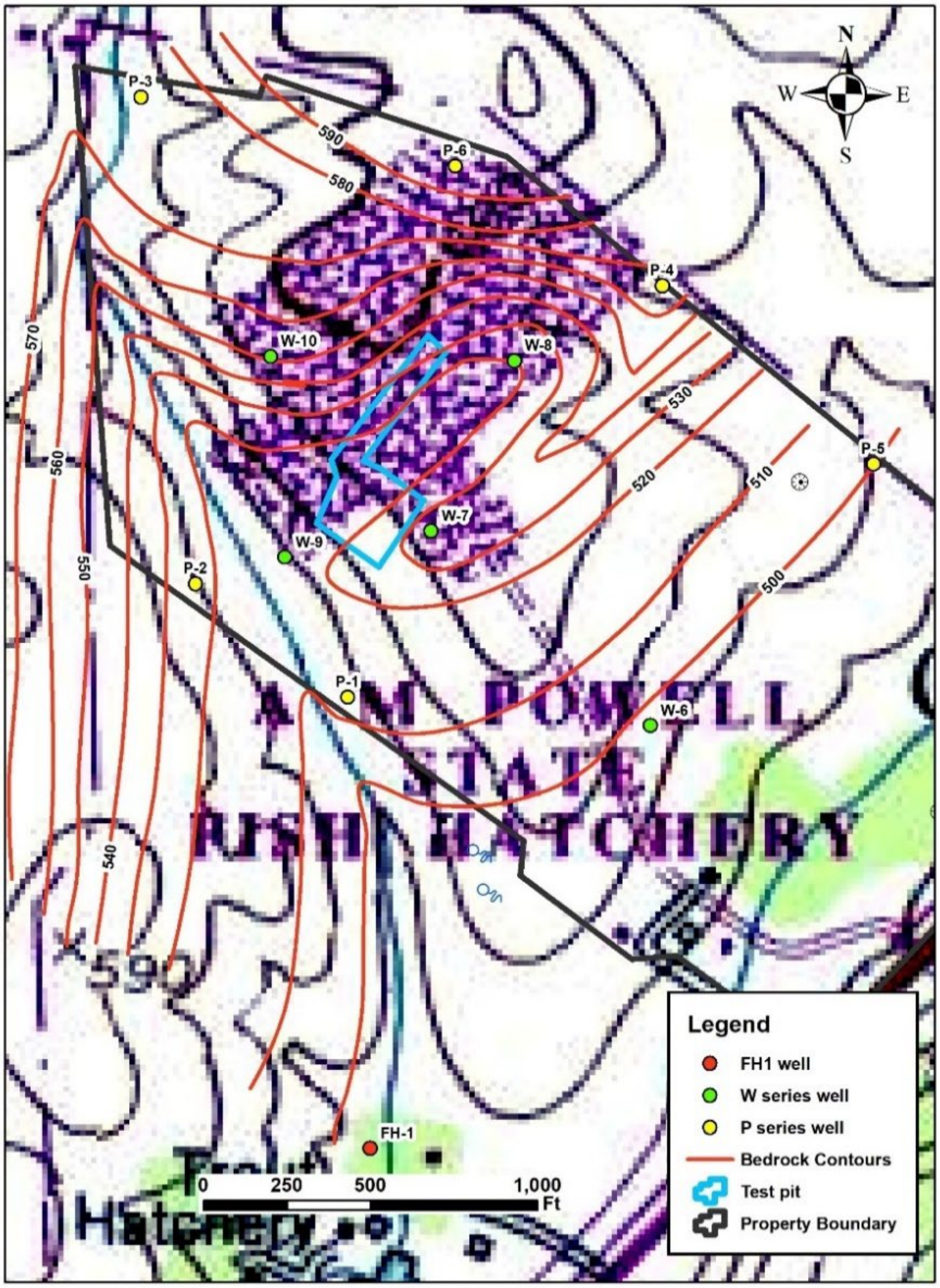


Figure 20. Beaver Creek West Quarry and Albert Powell Fish Hatchery. Elevation of top of bedrock. Contour Interval = 10 ft.

Other factors of quarry operations that may affect spring flow are blasting or sinkholes diverting ground water flow or causing damage to the hatchery water supply facility. Although evaluation of the effects of blasting on spring flow is beyond the scope of this evaluation, the present quarry pits are located at such distances that blasting likely would not cause complete disruption of hatchery spring flow. Depending on the nature of the fracture/aquifer system feeding the spring, blasting at the existing pits may cause changes in spring flow that may be beyond the accuracy of the techniques used by MDE to fully evaluate. The pumping test of the west pit and recovering water level data identified a possible fast flow (conduit) zone supplying water to the spring. Future expansion of the quarry may bring the mine into closer proximity to primary ground water flow zones feeding the spring.

In the Willey and Achmad (1986) study, ground water was pumped at a steady average annual rate and produced significant effective reductions in base flow during the low flow periods of droughts. In the case of a quarry, the pumping rate will not be constant, but will, after depletion of aquifer storage, be effectively equal to the average ground water runoff or base flow intercepted during any year.

Another potential impact concerns the possible development of sinkholes because of dewatering of the aquifer if groundwater is withdrawn to work below the water table. An inventory conducted by the Friends of Beaver Creek indicated that there were several dozen springs and sinkholes within the Beaver Creek watershed, which were verified in the field by DNR in 1987 (Mark Eisner, file memo, revised April 9, 1987). A map of the springs and sinkholes indicated that most of the springs are located at lower elevations and the sinkholes at higher elevations. This seems logical since springs develop where the water table comes to the surface and sinkholes may develop where the water table is relatively deep and provides less buoyant support for the overburden of the rock formations. If this holds true, then lowering of the water table by quarry dewatering could cause one or more sinkholes to develop in the vicinity of the Beaver Creek west pit and hatchery spring. This could cause a disruption or decrease of spring flow by routing flow around or below the natural discharge point of the spring or causing structural damage to the spring collection and distribution system.

A MGS map of the geologic and karst features of the Funkstown Quadrangle, Brezinski and Bell (2009), includes a sinkhole 142 m (466 ft) southwest of the quarry boundary located between 2007 and 2009 that did not appear on the 1987 inventory. However, no date is available as to when it formed, so it could have occurred at any time after 1987, or it was missed on the original survey. No sinkholes were reported to have occurred during the 1996-1997 test. The Zone of Influence (ZOI) for the quarry was established on December 14, 2000, which combined the zones for both the east and west pits. The MDE Mining Program's Minerals, Oil and Gas (Non-coal) Division has been tracking sinkholes since 2001 and has observed none near the Beavercreek Quarry. The three sinkholes found in the quarry during 1987 do not appear on the 2009 MGS map. It is possible that those sinkholes were repaired or destroyed during quarry operations prior to completion of the survey for the 2009 map.

LaMoreaux and Newton (1986) state that sinkholes do not occur in areas where the water table was below the bedrock/soil contact prior to dewatering. This may be the case at the Beaver Creek West Quarry. All the wells listed in Table 3 have pre-test static water levels below the bedrock/weathered zone interface, except P-5, W-6, and W-7. All water levels were likely below the soil/rock interface. In addition, P-5 and W-6 were at the boundary of the capture zone (0-5 ft of drawdown).

In addition, the mining division has a record of two wells that went dry within in the ZOI. Both are about 4000-4500 ft from the quarry boundary. The first one at 10702 Mapleville Road is not within the ZOI. The second one at 1116 Black Rock Road could not be precisely located but Black Rock Road is solely within the ZOI of the east pit. Nonetheless, the disruptions to the water supplies occurred during the 2002 drought, long after the 1996-97 pumping test and before operational dewatering of the quarry started in 2003.

Table 3. Beaver Creek West Quarry. Construction characteristics monitoring wells.

Well No.	Permit	Elev	Bedrock		SWL	Sat. Zone	Csg Depth		wbz	Tdepth	Rate	Elev SOT	Elev EOT	Elev 1999	Drawdown	Δ SOT-1999
No.	**No.**	**ft**	**Depth**	**Elev**	**ft**	**ft**	**ft**	**ft**	**ft**	**ft**	**gpm**	**ft**	**ft**	**ft**	**ft**	**ft**
P-1	WA-94-0469	552	35	517	40	-5	42	510	145	160	100	520	485	515	30	5
P-2	WA-94-0470	552	30	522	30	0	46	506	120	160	30	524	491	517	26	7
P-3	WA-94-0471	583.5	10	573.5	40	-30	23	560.5	N/R	190	30	551	520	528	8	23
P-4	WA-94-0472	573	5	568	40	-35	23	550	40	180	20	530	485	517	32	13
P-5	WA-94-0473	550.5	50	500.5	30	20	57	493.5	120	155	50	528	509	509	0	19
P-6	WA-94-0485	608	10	598	45	-35	23	585	150	210	10	537	504	522	18	15
W-6	WA-94-0474	570	75	495	60	15	87	483	150	180	100	526	507	512	5	14
W-7	WA-94-0475	586.5	55	531.5	40	15	64	522.5	130/170	200	40	522	488	517	29	5
W-8	WA-94-0476	530	10	520	20	-10	23	507	115	130	100	522	481	519	38	3
W-9	WA-94-0477	550	35	515	35	0	45	505	120	150	100	522	490	518	28	4
W-10	WA-94-0486	570	15	555	40	-25	27	543	N/R	160	40	522	486	N/R	29E	
FH-1				536.0				524.1				513.6	506.7	507.3	0.4	6.3

It is also noted that most of the sinkholes are located to the north of the spring and the quarry, in the limestone formations of the eastern part of the Hagerstown Valley. There appears to be a rough correlation between location of sinkholes and major tributaries to Beaver Creek, indicating that the sinkholes may be associated with fast flow (conduit) zones along the stream channels. Near the streams it is expected that the water table is at or near the surface and above the soil/bedrock interface, which are conditions preferable to the formation of sinkholes. At the higher elevations on the west side of South Mountain, where the Tomstown Dolomite and non-carbonate rocks dominate, there are fewer sinkholes, but many depressions. This may be because the rocks on the slopes of South Mountain are more resistant to the formation of sinkholes than the limestone rocks of the Hagerstown Valley.

The Franz and Slifer (1971) study of the caves of Maryland indicates that there are eight caves in the Beaver Creek watershed. Six of those caves are located near Beaver Creek or, its tributary, Mt. Aetna Creek. The fish hatchery (Houpt Spring) spring is at the base of the Elbrook Limestone. Where surveyed, most of the cave passages in the Beaver Creek watershed have steep slopes and are developed along strike, with apparent secondary development along joint systems, nearly perpendicular to strike.

There is a subterranean stream flowing in the Jugtown Cave. In addition to the concentration of caves along Beaver Creek, it has been noted that Beaver Creek above the hatchery spring frequently has little or no flow. This loss of surface water flow may be related to subterranean ground water flow in the vicinity of the creek, which may then be discharged at the hatchery spring.

Of note is that there are two springs up gradient of the hatchery spring. These are in or near the gully trending from the west pit to the hatchery. These appear to be intermittent springs that discharge at the same approximate elevations (510-18 feet) at which it appeared that significant ground water flow first occurred during the test of the west pit test. This is additional evidence of a significant change in permeability at the weathered zone bedrock interface.

The water may move laterally along strike, or down dip, until intersecting a primary joint system. Movement may then continue in a general down dip direction until reaching Beaver Creek. The groundwater may tend to move toward Beaver Creek along prominent topographic drainage features, such as Mt. Aetna Creek or the gully connecting the hatchery with the west pit of the Beaver Creek Quarry. Upon reaching Beaver Creek groundwater may discharge to the creek or become subterranean flow until it discharges at the hatchery spring.

The potential impacts to the hatchery spring will depend on the amount of groundwater withdrawn from the quarry. With the limited operating water level in the pit (510 ft), the available test and operational data indicate that withdrawals would reduce the hatchery spring flow by less than 5%. To date, there has been no evidence of unreasonable impacts due to withdrawals for dewatering of the west pit of the Beaver Creek Quarry.

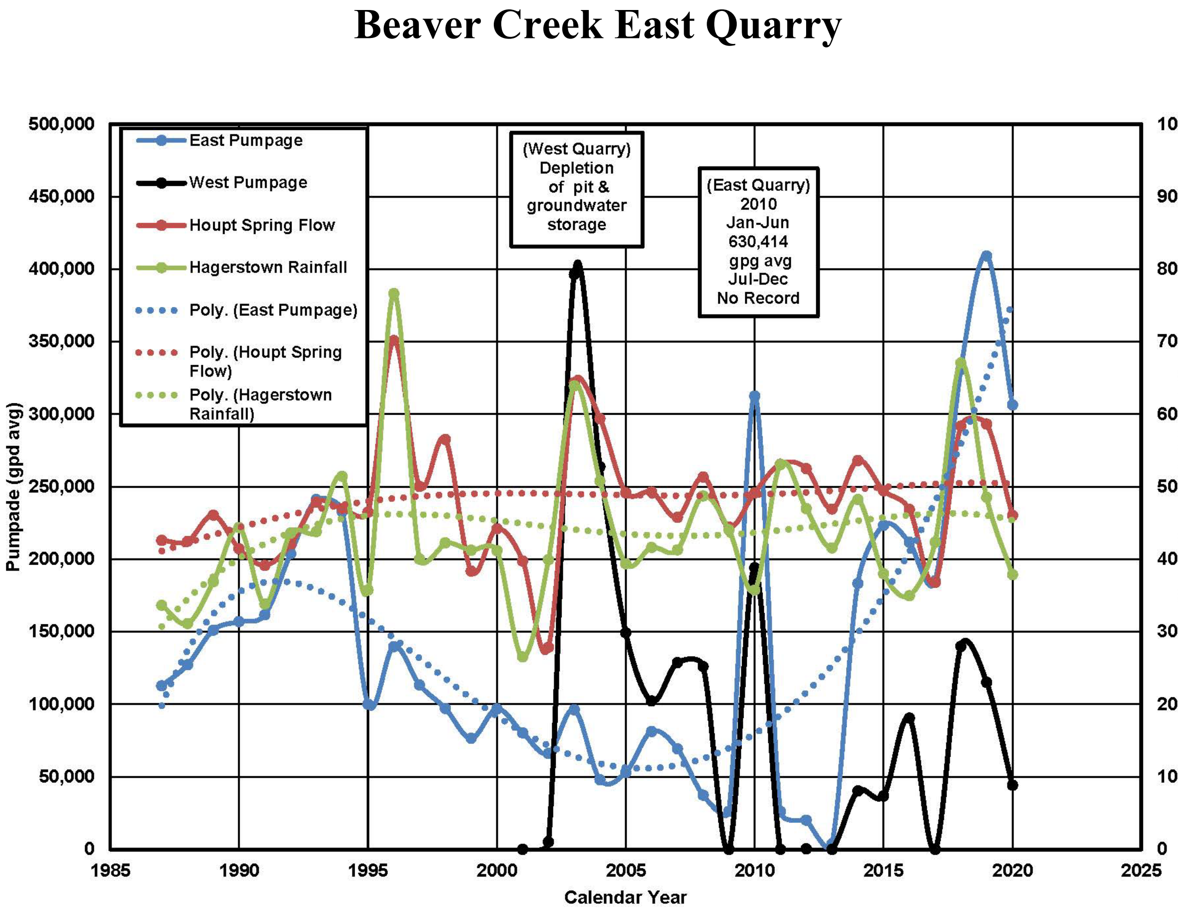


Figure 21. Annual averages for the Beaver Creek East and West Quarries pit pumping rate, Albert Powell Fish Hatchery (Houpt Spring) spring flow and Hagerstown 1E rainfall: 1987 to 2020.

From 1987 to 1995, the pumpage for dewatering of the Beaver Creek East Quarry generally mimics the trend of the Hagerstown rainfall and Houpt Spring flow records, Figure 21. From 1996 to 2009, the pumpage declines relative to rainfall and spring flow, then in 2010, pumpage increases rapidly to a somewhat higher use relative to rainfall and spring flow. Pumpage then declines through the period 2011 to 2013, then increases rapidly again in 2014. The pumpage then tracks with the rainfall and spring flow data from 2014 to 2017, then increases above the rainfall and spring flow tracks from 2018 to 2020. The Beaver Creek West pumpage tracks that of the Beaver Creek East Quarry at lower rates, except for 2003, when a large amount of water was taken for pit and groundwater storage upon startup of operations.

This pattern could be due to variations in production of crushed stone at the quarry. The periods of low water use (1996 to 2009 and 2011 to 2013) could reflect times of slow economic growth and limited production from the quarry. The periods of relatively high pumpage from the quarry could be due to better economic conditions and increased production from the quarry. Figure 22 indicates that this is not the case, since the trendline of the normalized (to protect confidential information) annual production is a mirror image of the annual reported pumpage, such that there is a negative correlation between the two factors.

An August 26, 2010, letter in the permit file indicates that there was a possible error in the 2009 pumpage data, when a water use of 203,934 gpd avg was reported, after the dewatering pump had been replaced in October 2008. The meter from the old pump was read from right to left, using 7 digits for volume calculations, with the three last leading digits on the right were taped over. Eight digits on new pump meter were then read from left to right with a zero digit at the right end. It is possible that there was a decimal before the last digit, since the corrected use for 2009 was about an order of magnitude less (26,298 gpd avg) than the original report. The operator indicated that the lower benches were not worked in 2009, which would accounting for a low water use. Since the question only concerned the 2009 water use report, the anomalous January-June 2010 data (July to December data are missing) may also be in error and was not corrected. As explained previously, the high use from the Beaver Creek West Quarry likely included some accumulated surface water in the pit and groundwater removed from aquifer storage after the long-term recovery of water levels. Then it is possible that the high water use from the east pit was due to changes in production. Since there were no significant changes in the amounts mined, this would have indicated that mining of the lower benches was required.

The pumpage increased rapidly in 2014 to 183,446 gpd avg and remained relatively stable at about 200,000 gpd until 2017. Figure 23 indicates that the area mined in 2015 was 65.4 ac, which then increased by 12.6 ac by 2017. These data suggest that the large increase in the 2014 pumpage was due to mining the lower benches in the old area, while the lack of change in the amount use from 2014 to 2017 indicates that the lower benches were not worked in the new area. There was no change in the mined area by 2022; however, there was a substantial increase in water use during the period 2018-2020 to 349,000 gpd avg. When compared to previous similar periods, the spring flow appeared to have declined by about 5-10%. When compared to the period 2014-2017 (201,000 gpd avg), the water use increased by 78%, while the Houpt Spring flow and Hagerstown rainfall increased by 15% and 24%, respectively, and the normalized production decreased by 20%. These data indicate that some of the increased use (about 20% or 30,000 gpd) was due to mining the lower benches. Unaccounted for is about 120,000 gpd avg, which could be due to interception of groundwater flowing to the Houpt Spring or an increase equivalent to 2.4% of the spring flow. A dye trace did show a connection between the unmined northern portion of the quarry property and the spring. A second dye trace connected an area on the northwest side of the Beaver Creek Fault to the Beaver Creek East sump. A more extensive dye trace study is needed to confirm any connection between the east quarry and the spring.

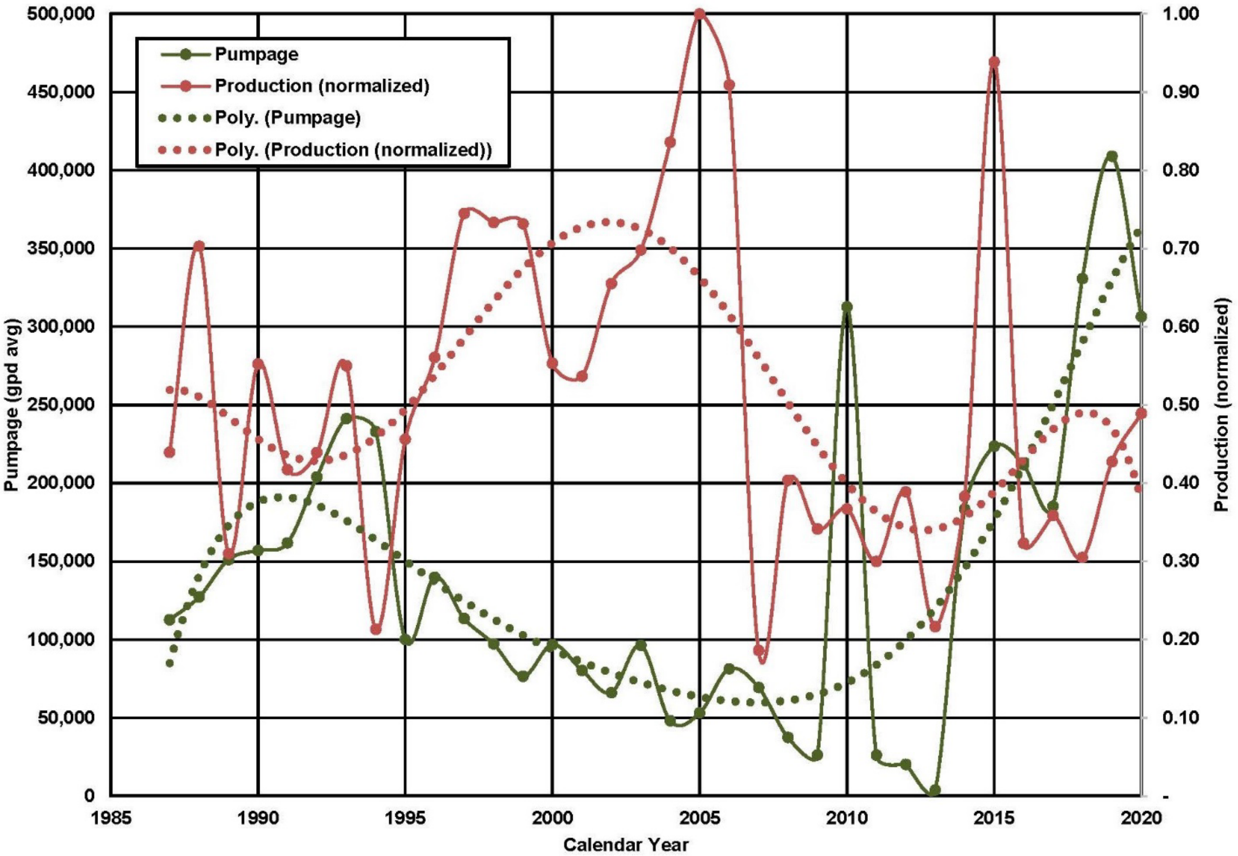
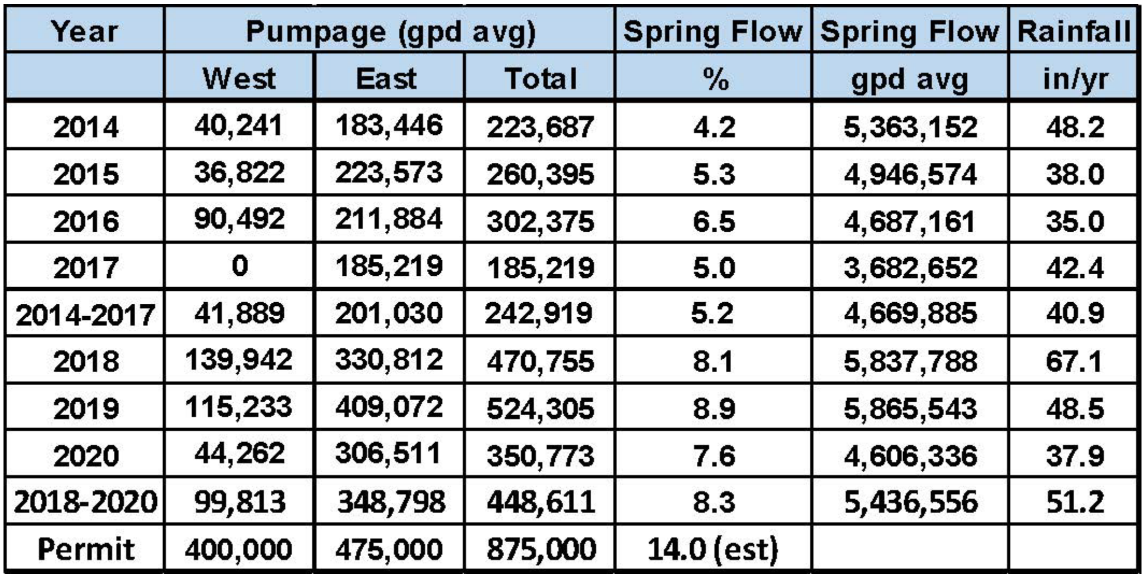


Figure 22. Annual averages for the Beaver Creek East Quarry pumping rate and normalized production: 1987 to 2005.

Table 4 includes the pumpage data, Houpt Spring flows and Hagerstown rainfall for the period 2014 to 2020. ??The average total pumpage for the period 2014 to 2017 of 242,919 gpd avg and per cent of spring flow (5%) is like the pumpage of 260,588 gpd avg from the west pit during the period January 2004 to June 2005, when the withdrawals were 4.5% of the spring flow. In the west pit case, long-term aquifer testing, monitoring, and mapping supported the hypothesis that dewatering the west pit had a proportional impact of the Houpt Spring flow. By analogy, as no such studies have been conducted on the east pit, and since 83% of the water withdrawn from the quarries during 2014 to 2017 was from the east pit, this would indicate that most of the water withdrawn was intercepted spring flow. It follows that during the period 2018 to 2020, water withdrawn for dewatering was 8% of the spring flow. Using the % spring flow ratio (1.69) between the two periods, adjusted for the difference in the ratio of pumpage between the two periods (1.85) and the ratio of the permitted use and the pumpage for the last period, it is estimated that total permitted use could reduce the spring flow by 14%. It would take long-term monitoring and additional analysis to determine if this ratio would apply during the critical period of a severe to extreme drought.

Table 4. Annual average pumpage (Beaver Creek East Quarry), spring flow (Houpt Spring) and rainfall (Hagerstown) during the period 2014 to 20220.



Year	Pumpage (gpd avg)			Spring Flow	Spring Flow	Rainfall
	West	East	Total	%	gpd avg	in/yr
2014	40,241	183,446	223,687	4.2	5,363,152	48.2
2015	36,822	223,573	260,395	5.3	4,946,574	38.0
2016	90,492	211,884	302,375	6.5	4,687,161	35.0
2017	0	185,219	185,219	5.0	3,682,652	42.4
2014-2017	41,889	201,030	242,919	5.2	4,669,885	40.9
2018	139,942	330,812	470,755	8.1	5,837,788	67.1
2019	115,233	409,072	524,305	8.9	5,865,543	48.5
2020	44,262	306,511	350,773	7.6	4,606,336	37.9
2018-2020	99,813	348,798	448,611	8.3	5,436,556	51.2
Permit	400,000	475,000	875,000	14.0 (est)		

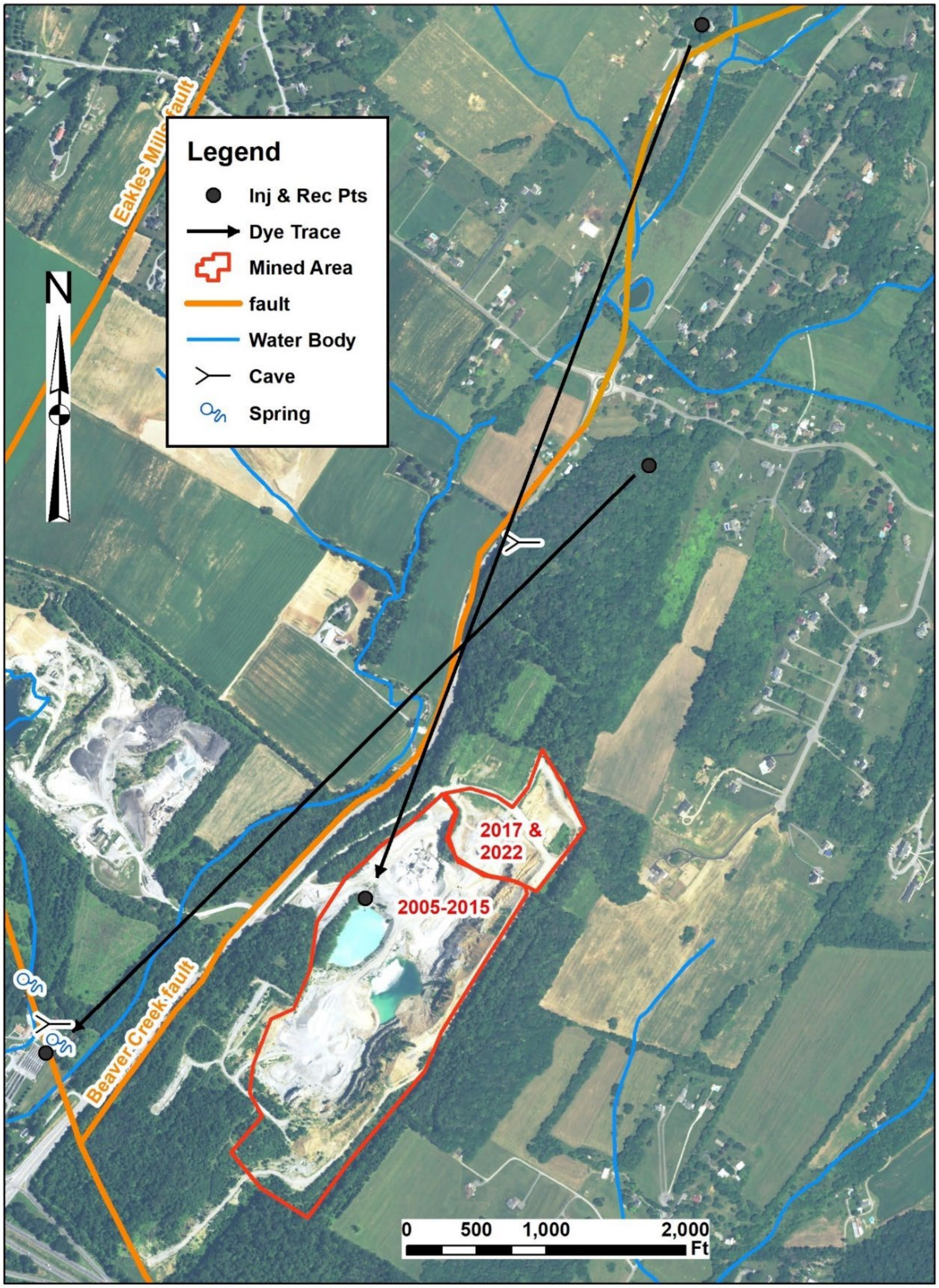


Figure 23. Aerial view of the Beaver Creek East Quarry. The area (65.4 ac) mined up to 2015 was determined from photos taken between 2005 and 2015 and includes some reclaimed areas on the south and southeast sides of the quarry. The area mined after 2015 was determined from photos taken between 2017 and 2022. Nearly all the expansion occurred by 2017.

Figure 24 is a topographic map showing the water level contours in the east quarry on October 30, 1996, and the topographic drainage areas of the east and west pits. The area of the east pit drainage is 99 acres. If the average base flow (12.1 in/yr) in Antietam Creek at Sharpsburg is applied to that drainage area, the calculated effective recharge would be 89,124 gpd avg. This is substantially less than the pumpage for period November 1995 to October 1996 (121,924 gpd avg). However, that was a period of above average recharge, when Hagerstown rainfall was 1.88 times the average, the Houpt Spring flow was 1.35 times the average and the estimated baseflow in Antietam Creek was 1.91 times the average. When these factors are applies to the average effective recharge, then the estimated values for the east pit drainage area are 170,227 gpd avg 167,553 gpd avg and 120,317 gpd avg relative to the Antietam Creek, Hagerstown rainfall and Houpt Spring flow data, respectively. The patterns in Figures 21 and 22 suggest that some portions of the lower benches may have been worked during November 1995 to October 1996. This would indicate that the calculated effective recharge from the Houpt Spring provides the best estimate for groundwater flow from the drainage area of the Beaver Creek East Quarry.

From the data collected at the Beaver Creek East Quarry, it appears that there are several factors involved in the dewatering volumes taken from a quarry. Mining initially consists of shallow excavation of a pit. This changes the hydraulic characteristics of the site since an open pit has maximum relative permeability and storage constants. This can depress the water table without pumping in a manner like how a major fracture can naturally lower the water table relative to the surrounding bedrock. Mining can continue in the upper parts of the quarry with little or no need to dewater the pit. Deeper mining then requires substantial pumping to remove water below the water table. The rate of withdrawal may reach a constant seasonally variable level at a certain depth due to decreased permeability of the bedrock. In this case, the amount of groundwater withdrawn is not based just on the area mined, but also the depth of the excavation. Other factors to consider are precipitation and evaporation from both the quarry sump and floor. The quarry pit sump and lake have a relatively small surface area (9 ac) and about ¾ of the precipitation is lost due to evaporation. In addition to losses due to evaporation, much of the remaining precipitation will infiltrate the water table from the flat floor of the quarry. A complex numerical model addressing seasonal variations would be needed to estimate the dewatering rate for a quarry.

The mining division has recorded no sinkholes within the ZOI of the eastern quarry. In addition, a well reported to go dry at 1116 Black Rock Road could not be precisely located but Black Rock Road is within the ZOI of the east pit. The disruption to that water supply occurred during the 2002 drought, when withdrawals from the east pit were low (66,118 gpd avg). The lack of any recorded impacts at much higher rates of withdrawals suggests that the impact to the Black Rock Road well was drought related.

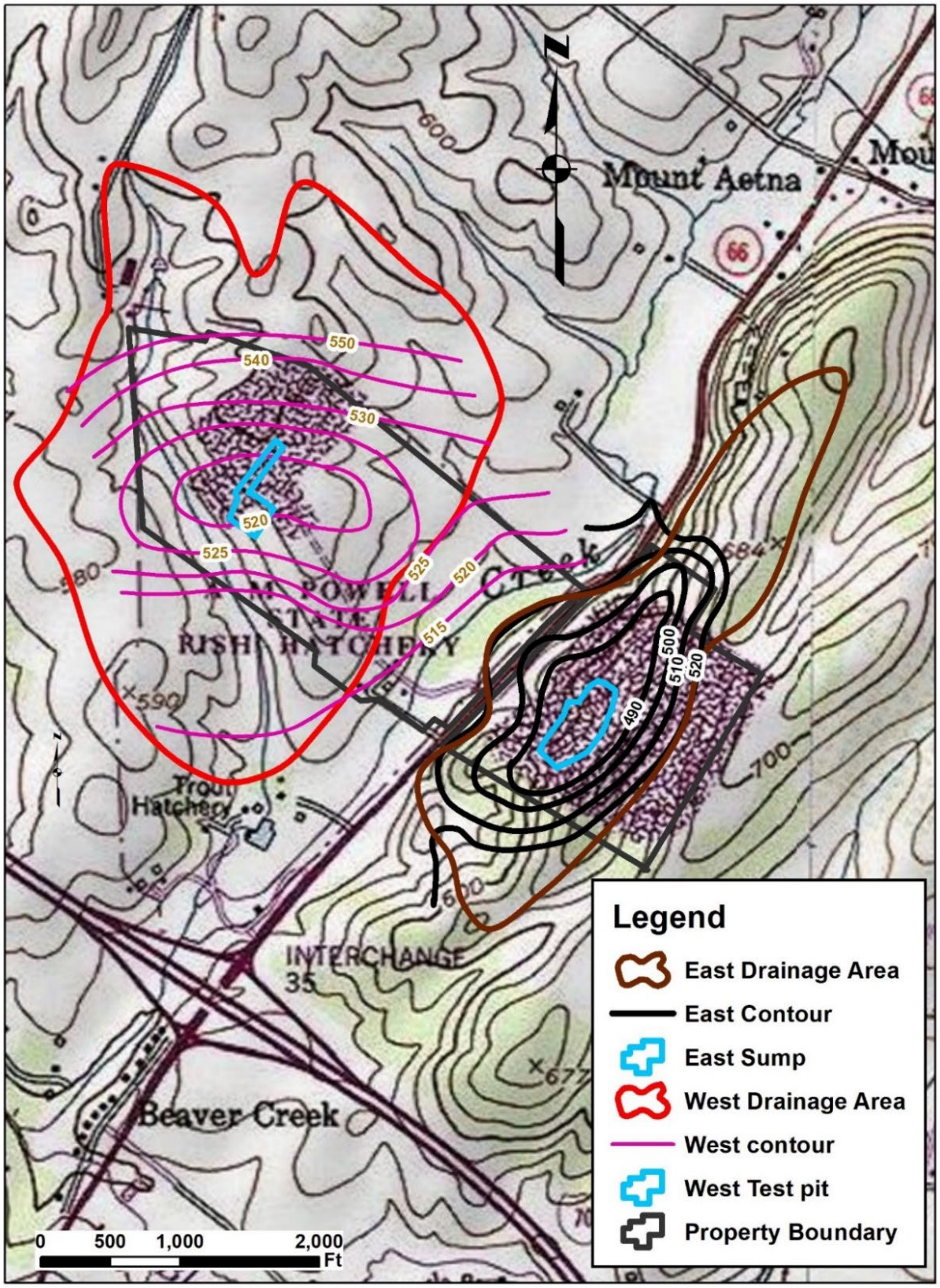


Figure 24. Topographic map. Water level contours for the Beaver Creek Quarry east and west pits are from October 30, 1996. The drainage area (D.A.) for the east pit is 99 ac and for the west pit is 224 ac.

References

Brezinski, D.K. and Bell, S.C., 2009, Funkstown geologic and karst features quadrangle map, Maryland Geological Survey, retrieved 5 August 2021 from http://www.mgs.md.gov/publications/data_pages/quadrangle_geo.html

Duigon, M.T., 2009, Phase 2 study of the area contributing groundwater to the spring supplying the A.M. Powell State Fish Hatchery, Washington County, Maryland. Maryland Geological Survey Open-File Report No. 2008-02-18, 31 p.

Franz, R. and Slifer, D., 1971, Caves of Maryland, Maryland Geological Survey Educational Series No. 3, 120 p.

LaMoreaux, P.E and Newton, J.G., 1986, Catastrophic subsidence: An environmental hazard, Shelby County, Alabama, Environmental Geology Water Science 8(1/2):25-40.

Maryland Department of the Environment, Water Appropriation and Use Permit Application WA1986G001 and Permit WA1996G005, Baltimore, Maryland.

Trainer, F.W. and Watkins, Jr., F.A., 1975, Geohydrologic Reconnaissance of the Upper Potomac River Basin, U.S. Geological Survey Water-Supply Paper 2035, 68 p.

U.S. Geological Survey, USGS Groundwater Data for the Nation, retrieved October 1, 2021, from http://waterdata.usgs.gov/usa/nwis/gw

Willey, R.E. and Achmad, G., 1986, Simulation of Ground-water Flow in Weathered Crystalline Rock, Upper Cattail Creek, Howard County, Maryland, Maryland Geological Survey Report of Investigation 45, 68p.

Rockdale Quarry

The authors of previous studies offered three different explanations for the sinkhole distribution near the Rockville Quarry. Slaughter (1962) suggested that the sinkholes were likely due to the high solubility of the carbonate rocks underlying the belt from Fairview Mill (near the Rockdale Quarry) to Pinesburg Station (near Pinesburg Quarry). Nutter (1973) did not speculate about the mechanism for the formation of the sinkholes. Duigon (2001) indicated that enlargement of bedding plane separations by circulating ground water may have enhanced the development of sinkholes and that the sinkholes may capture surface drainage and direct it along strike. Brezinski (2018) indicated that near the junction of Rockdale Road and Cresspond Road, and Rockdale Quarry, the sinkhole and spring distribution was related to faulting, Figure 25.

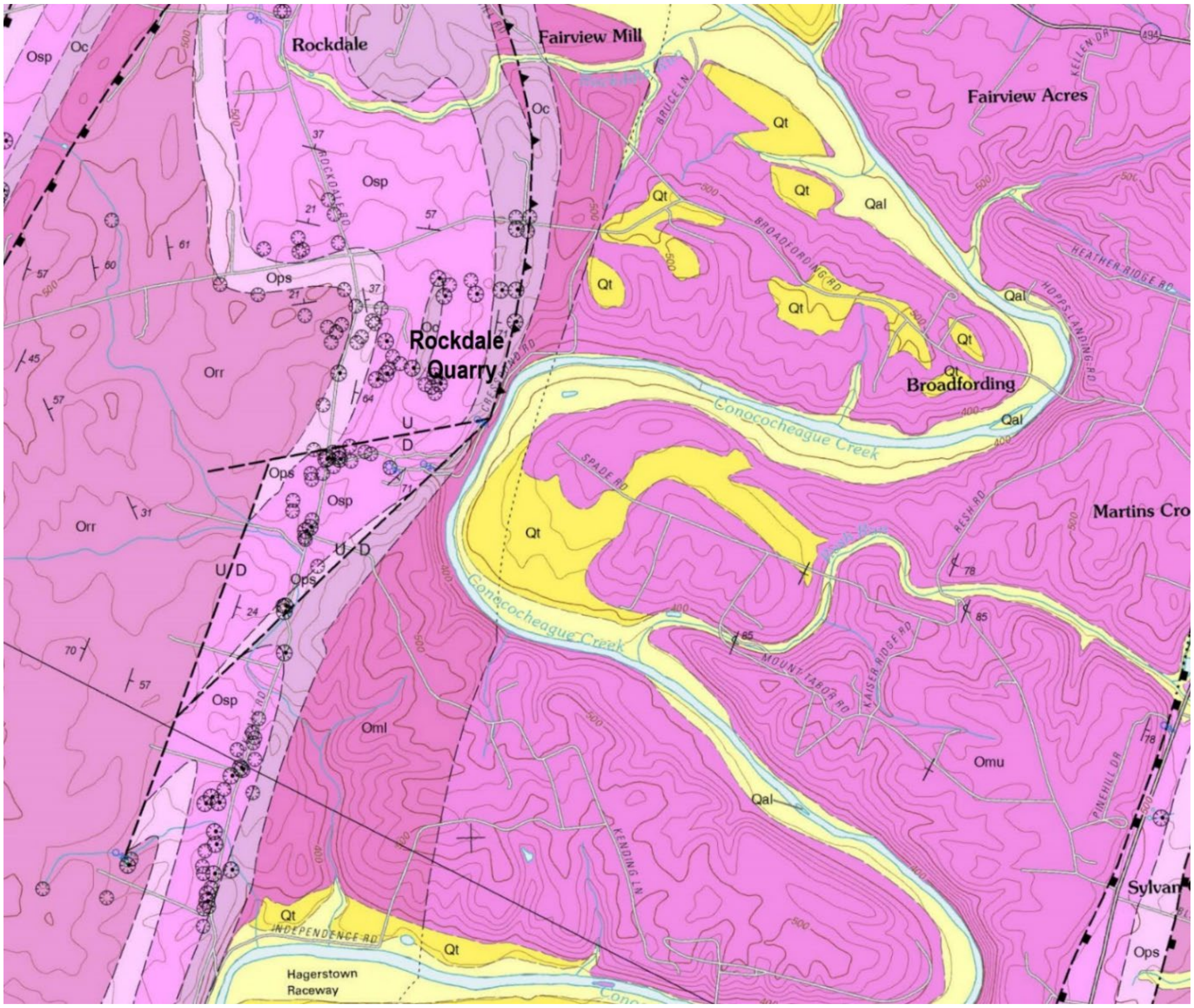


Figure 25. Geologic map of the distribution of swallow holes, sinkholes, depressions, and springs along a number of faults at Cresspond Road near Rockdale Quarry. Om=Martinsburg Formation; Oc=Chambersburg Formation; Osp=St. Paul Group undifferentiated; Ops=Pinesburg Station Dolomite; Orr=Rockdale Run Formation.

Figure 26 provides the locations of 23 domestic wells and 12 monitoring wells from which water level data were collected on multiple dates in 2004, Tables 5 and 6. The most comprehensive set of measurements occurred on 2/17/2004, which were used to prepare a water level elevation contour map, Figure 27. It demonstrates that there is a trough of depression in the water table parallel to the strike direction of the St. Paul Group. The trough reaches a point about 20 ft below the level of Conococheque Creek stream level in the Miller well at the south end of map, indicating that there is a barrier between the creek and the trough.

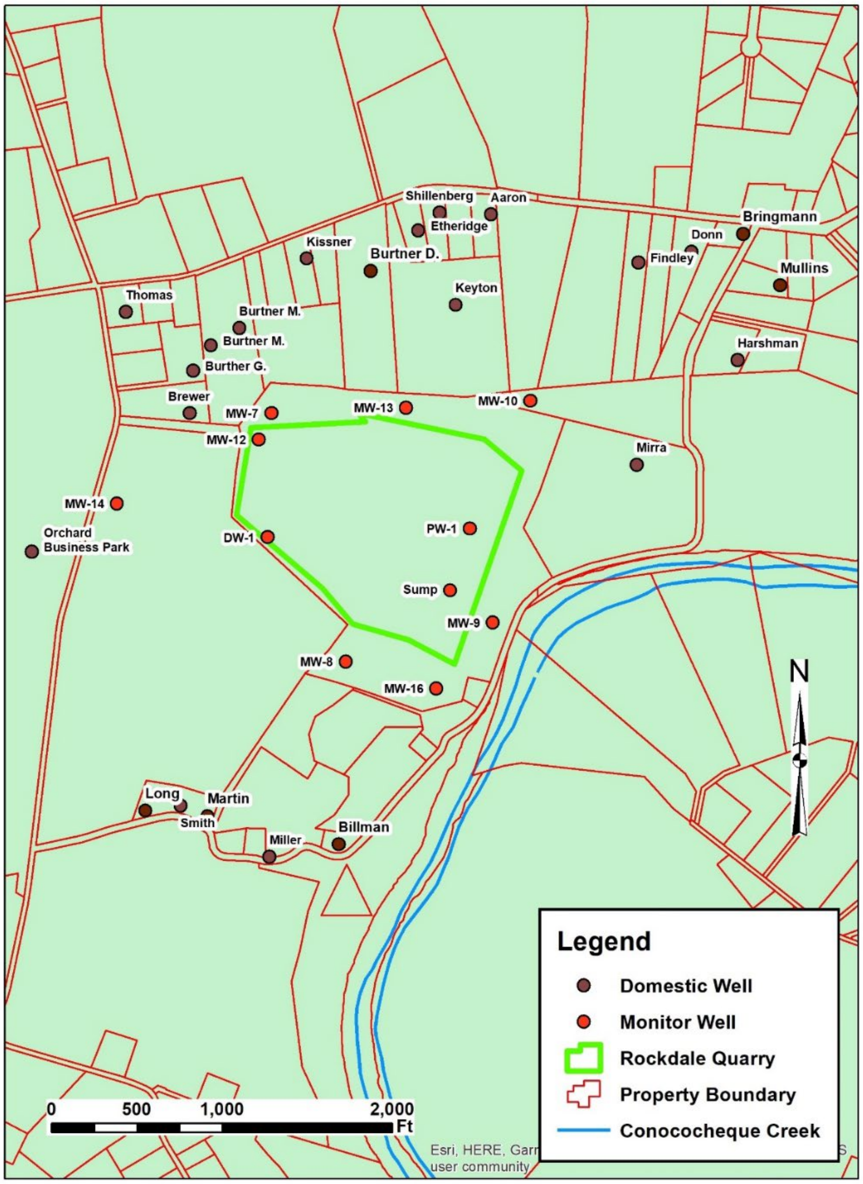


Figure 26. Location map showing domestic (DW-X) and monitoring wells (MW-X) in or near the Rockdale Quarry.

Table 5. Name, location, well reports and water level data for domestic wells near Rockdale Quarry.

Domestic Wells														
Name	**Address**		**Tax Map**	**Parcel**	**Lot**	**Well Rpt**	**Water Level (W/L) (ft)**							
	No.	Road	No.	No.	No.	No.	SWL	Elev TOC	W/L BTOC	Elev W/L	Date	W/L BTOC	Elev W/L	Date
Mirra	13818	Cresspond	23	196		WA-73-0660	15	417.1	13.1	404	2/3/1994	**14.2**	**402.9**	**2/17/1994**
Harshman	13845	Cresspond	23	411	1									
Donn	15627	Broadfording	23	404	3									
Findley	15615	Broadfording	23	404	5			516	34.5	481.5	2/7/1994	**34.1**	**481.9**	**2/17/1994**
Aaron	15527	Broadfording	22	159	1	WA-88-0759	45	504.2				**64**	**440.2**	**2/17/1994**
Shillenberg	15515	Broadfording	22	159	3	WA-88-1042	35	493.8	50.7	443.1	2/3/1994	**57.3**	**436.6**	**2/17/1994**
Etheridge	15509	Broadfording	22	159	4	WA-88-1357	35							
Keyton/Lafferty	15505	Broadfording	22	159	5	WA-72-0223	20	498.5	44	454.5	2/4/1994	**45.1**	**453.4**	**2/17/1994**
Kissner	15421	Broadfording	22	155	11			486.7	41	445.7	2/3/1994	**49.6**	**437.2**	**2/17/1994**
Burtner M.	15407	Broadfording	22	119		WA-73-3234	55	487.2	56.1	431.1	2/4/1994	**55.5**	**431.7**	**2/17/1994**
Burtner M.	15407	Broadfording	22	119				482	37.5	444.5	2/4/1994	**44.2**	**437.8**	**2/17/1994**
Orchard Busi. Park	13602	Rockdale	22	28										
Thomas	13725	Rockdale	22	145	5	WA-88-0324	60	482.5	64.8	417.8	2/3/1994	**60.9**	**421.6**	**2/17/1994**
Burtner G.	13707	Rockdale	22	145	8	WA-88-1035	60	482.3	40	442.3	2/7/1994	**46.5**	**435.8**	**2/17/1994**
Brewer	13703	Rockdale	22	158		WA-88-7040	56							
Smith	13528	Cresspond	22	36		WA-73-3241	25	452.5	60	392.5	2/7/1994	**60.6**	**391.9**	**2/17/1994**
Miller	13548	Cresspond	22	58				391.4	39.3	352.2	2/15/1994	**39.3**	**352.1**	**2/17/1994**
Burtner D.	15435	Broadfording	22	147		WA-81-1316	60	494.3				**74.3**	**420**	**2/17/1994**
Martin?	13544	Cresspond	22	P/O 36				472.6	49.8	422.7	2/3/1994	**49.9**	**422.7**	**2/17/1994**
Billman	13602	Cresspond	22	59				430	40.7	389.3	2/3/1994	**41.3**	**388.7**	**2/17/1994**
Mullins	13589	Cresspond	23	411	5									
Bringman	15637	Broadfording	23	280										
Long	13540	Cresspond	22	P/O 36										

Table 6. Location, well reports and water level data for the Rockdale Quarry monitoring wells.

Monitor Wells										
Name	**Location**	**Well Rpt**		**Water Level (W/L) (ft)**						
		No.	SWL	Elev TOC	W/L BTOC	Elev W/L	Date	W/L BTOC	Elev W/L	Date
PW-1	Quarry-Center Pit	NRF	2.6	403.3	Ice		2/3/1994	2.6	400.7	2/10/1994
					3.1	**400.2**	**2/17/1994**	Flood		2/24/1994
MW-1	Quarry-East Center Pit	NRF	4.9	403.8	Ice		2/3/1994	4	399.8	2/10/1994
					4.5	**399.4**	**2/17/1994**	Flood		2/24/1994
MW-3	Quarry-North Center Pit	NRF	9.8	407.3						
MW-5	Quarry-South Center Pit		NRF	426.5	inaccessible-snow					
MW-7	Quarry-NW Corner Property	NRF	NRF	474.2	23.7	450.5	2/4/1994	23.9	45.2	2/10/1994
					23.9	**450.2**	**2/17/1994**			
MW-8	Quarry-East Bench	NRF	NRF	436.2	49.2	387	2/3/1994	50.7	385.6	2/10/1994
					50.8	**385.4**	**2/17/1994**	46.8	389.5	2/24/1994
MW-9	Quarry-South Perimeter	NRF	NRF	474.1	80.5	393.6	2/3/1994	81.1	393	2/10/1994
					80.8	**393.3**	**2/17/1994**	77.7	396.4	2/24/1994
MW-10	Quarry-NW Corner Property	NRF	NRF	504.5	77.8	426.7	2/3/1994	78.2	426.7	2/10/1994
					78.5	**426**	**2/17/1994**	71.6	432.9	2/24/1994
DW-1	Quarry-East of Scale House	WA-88-1221	44.3	468.4	46.5	421.8	2/3/1994	49.3	419.1	2/10/1994
					Pumping	**420E**	**2/17/1994**	44.5	423.8	2/24/1994

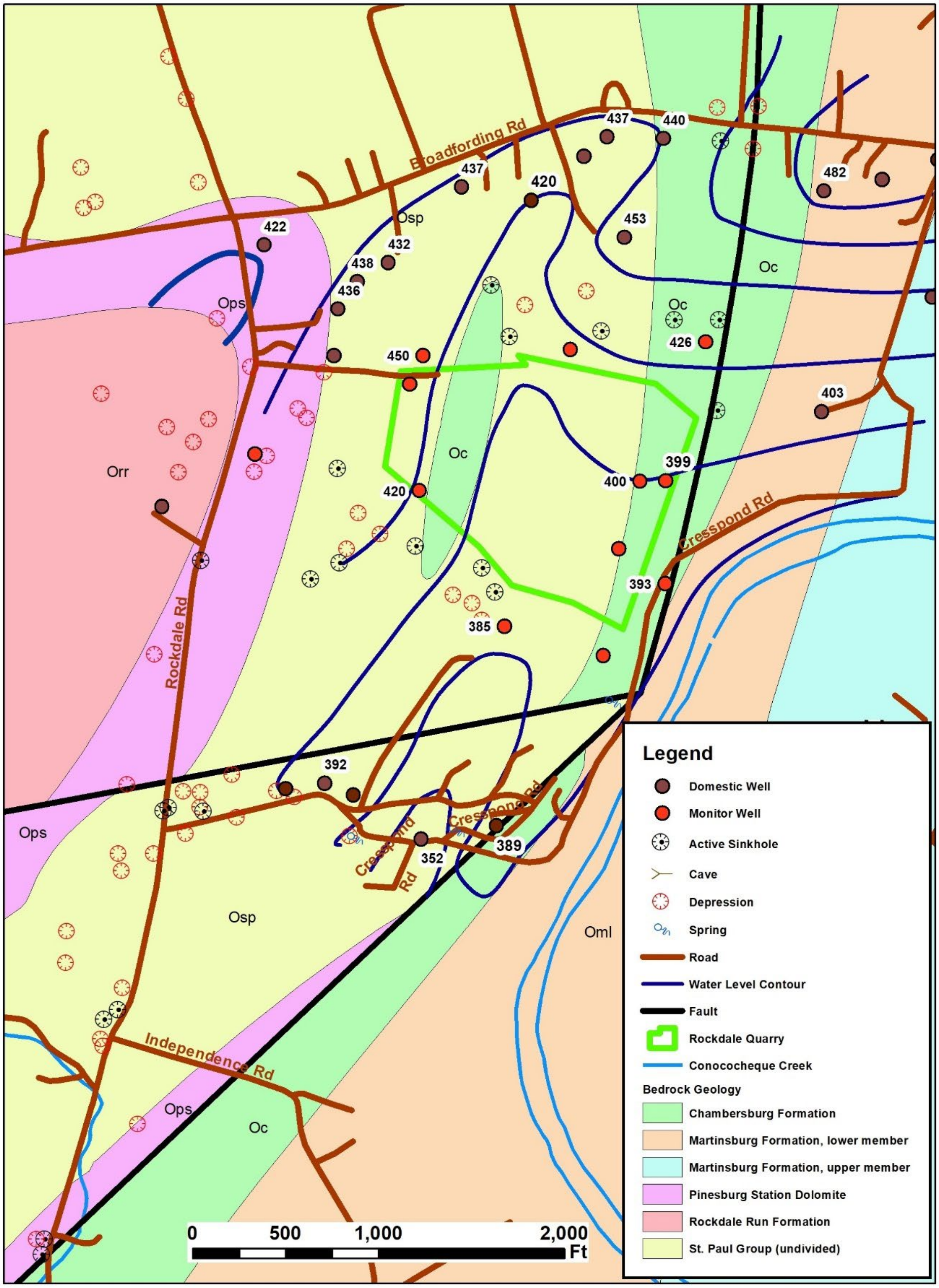


Figure 27. Water level elevation contour map at the Rockdale Quarry. Measurements taken on 2/17/2004.

Water withdrawals from the Rockdale Quarry started in 2004 and ended in 2010, with a maximum withdrawal of less than 25,000 gpd avg in 2005, Figure 28. This would indicate that the Duigon (2001) study was completed prior to the start of withdrawals and the Brezinski (2018) study, which used the Brezinski (2013) geologic and karst features map, was completed after withdrawals ceased. A comparison of the features mapped in both studies might indicate if any sinkholes occurred due to dewatering of the Rockdale Quarry, but there are several problems with such an analysis. Duigon (2001) indicated that only 93 sinkholes were inventoried in the Hagerstown Valley. However, Brezinski (2018) mapped 938 active sinkholes and 2518 depressions in the valley. About 35% of the depressions are near the eastern and western borders of the valley. He indicated the lack of sinkhole development in those areas was due to a thick colluvium that appears to have clogged the karst system. Most of the sinkholes in the Duigon (2001) study were taken from soil conservation service maps and there was no differentiation made between collapse or solution sinkholes. In addition, the MDE mining program has been tracking sinkhole formation and water supply disruption statewide since 2001 and has no record of any sinkholes or water supply impacts caused by operations at the Rockdale Quarry.

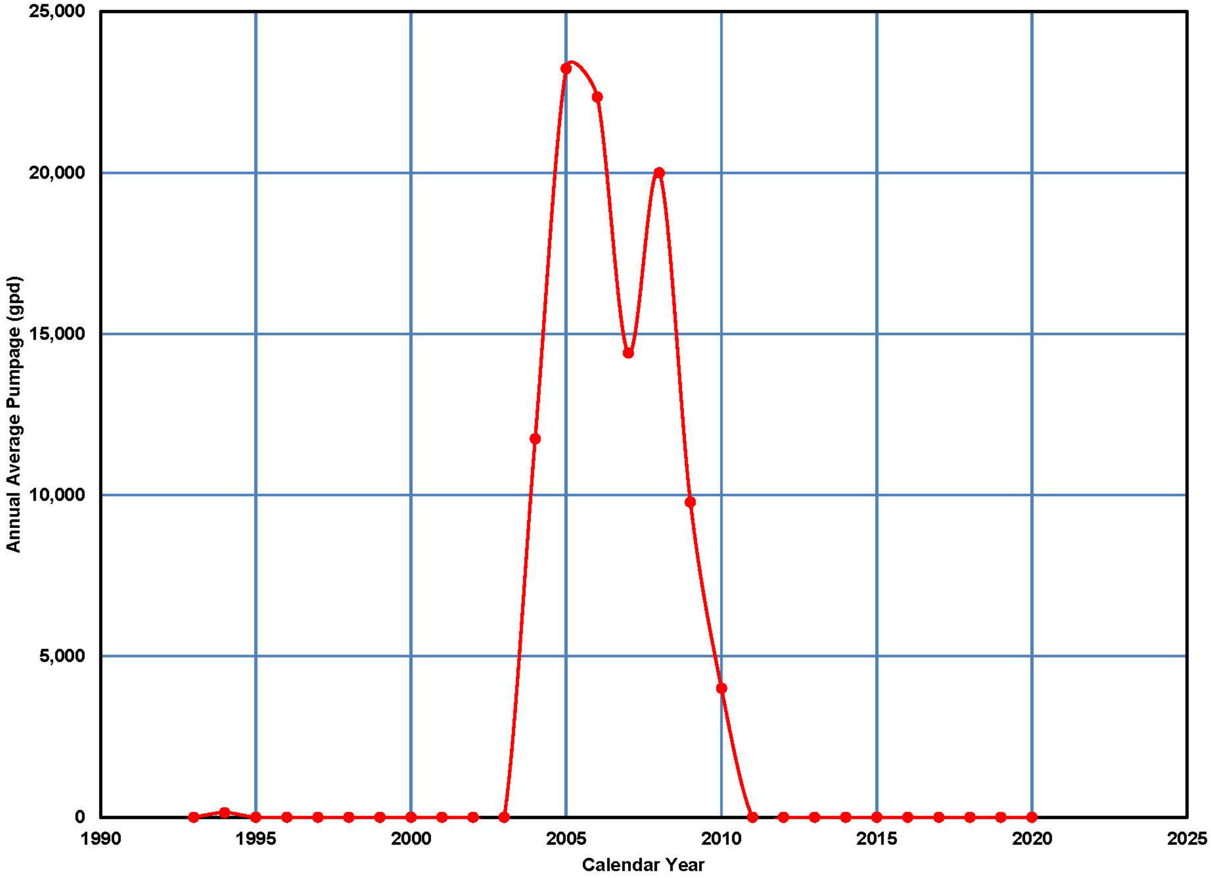


Figure 28. Water withdrawals (pumpage) from the Rockdale Quarry during the period 1993 to 2020.

With the limited withdrawals from the Rockdale Quarry and the lack of any clear evidence of sinkholes formed due to quarry dewatering, it is most likely that the sinkholes in the vicinity of the Rockdale Quarry have a natural origin. Previous studies have offered several mechanisms that might explain their occurrence. Slaughter (1962) indicated that their formation was likely due to the high solubility of the carbonate rocks underlying the belt from the Rockdale Quarry to the Pinesburg Quarry. Duigon (2001) indicated that bedding plane separations enhanced the development of sinkholes, and they may capture surface drainage and direct it along strike. Brezinski (2018) related the sinkhole and spring distribution near the Rockdale Quarry to faulting. The highest number sinkholes and depressions (43 of 71 or 61%) occur in the St. Paul Group. In the area north of the Rockdale Quarry there are no sinkholes and relatively few depressions where the St. Paul Group broadens out with an east-west strike and moderate dips. The highest density of sinkholes occurs in the immediate vicinity of the quarry where the St. Paul Group has a north-south strike and steep dips. There are 20 of 71 (28%) sinkholes or depressions within 300 feet of a fault; however, 12 (60%) are also in the St. Paul Group. In this case, the high solubility of the St. Paul Group carbonate rocks in conjunction with steep dips appear to be the primary factors in the formation of sinkholes and depressions near the Rockdale Quarry. While a significant number occur near faults, many of those are also in the St. Paul Group, which suggests that faulting is a secondary factor in the formation of sinkholes and depressions near the Rockdale Quarry

Pinesburg Quarry

The Pinesburg Quarry is one of the earliest ones established in Washington County, Maryland. The first recorded date that it was in operation is 1906, Williams (1906). Though not directly identified Clark (1898) indicated that the quarry may have been in operation before the turn of the 19th century. It is not known when dewatering of the quarry started, but the first water use permit (WA-69-SAP-14) for dewatering was issued on July 2, 1969, for an annual average of 1.75 Mgd and a maximum daily use of 3.5 Mgd. This is not necessarily the date of first use, since while the water statutes and regulation governing water appropriation were passed in 1933/34, there was not a concerted effort to permit all existing uses until after the extreme drought of 1962-1969.

That it was initially a surface water permit was likely because the water was withdrawn from a pond; however, it was revised to a groundwater permit (WA69G024) on June 11, 1987, likely because it was determined that infiltration into the pond was from a groundwater source. At that time, the use was also reduced to 1.0 Mgd average and 3.5 Mgd during the month of maximum use, although there is no clear explanation for that action in the permit file. Reductions in use at that time were usually made based on pumpage reports. The MDE computer database was established in 1979. Water use from 1979 to 1987 was reported under the surface water permit and never exceeded 250,000 gpd avg, Figure 29.

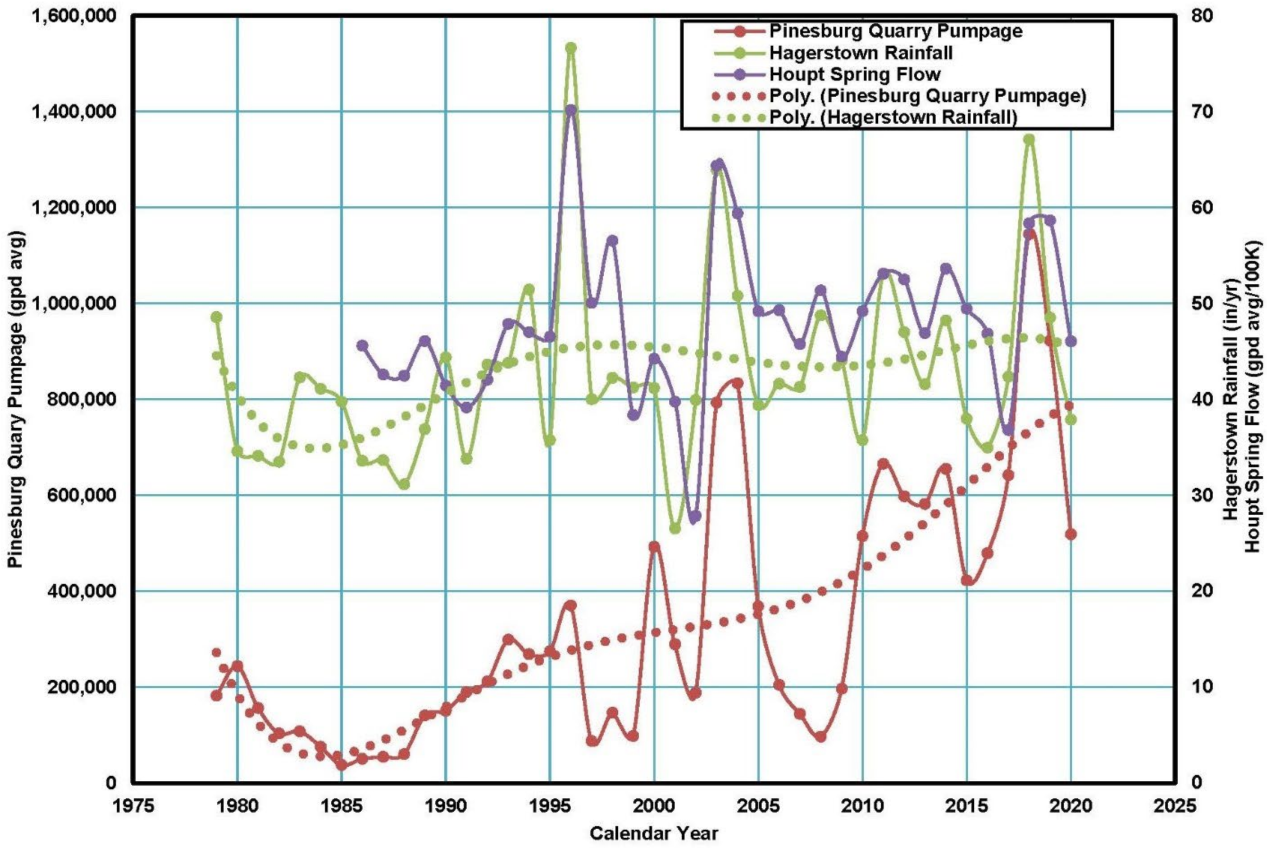


Figure 29. Pumpage reported for the Pinesburg Quarry, rainfall at Hagerstown and Houpt Spring flows during the period 1979 to 2000.

During a permit review in 1999, it was noted that the water use did not exceed 400,000 gpd avg, so MDE required the operator to complete a water demand analysis. As a result, the permit was then adjusted to 0.8 Mgd avg and 1.8 Mgd max. While the frequency of the fluctuations of the pumpage tracked closely the changes in the Hagerstown rainfall record and Houpt Spring flows, the amplitude of the pumpage did not follow the rainfall or spring flow records. To obtain better water use records the applicant was required to install a flow meter in the dewatering system, which was completed in March 2011. Prior to that time water withdrawals were calculated using the rated pump capacity times the number of hours pumped.

Once the flowmeter was installed both the frequency and the amplitude of the pumpage followed that of the Hagerstown rainfall records and the Houpt Spring discharge (hatchery pumpage records). The water withdrawals then appear to have also increased relative to the prior period. This could indicate that the water is coming from another source. Since October 2012, the operator has not discharged water from the active pit but has pumped it to the inactive quarry pit lake to the south, Figure 30, and from 2005 to October 2012 the discharge to the inactive quarry pit was intermittent. This is also the period when the trendline for the reported withdrawal starts to increase. One possible explanation for the increased withdrawals is that water is being recirculated from the inactive quarry lake to the active quarry pit.

A possible confirmation of recirculation of water from the inactive to the active quarry is that there is a saddle in the water level elevation contours between the active and inactive ponds, Figure 31, which could indicate that there is a conduit or fast flow zone between the two ponds. Additional confirmation could be achieved by conducting a dye trace.

Figure 30. Aerial view of the Pinesburg Quarry showing dewatering line from the active quarry sump to the inactive quarry pond.

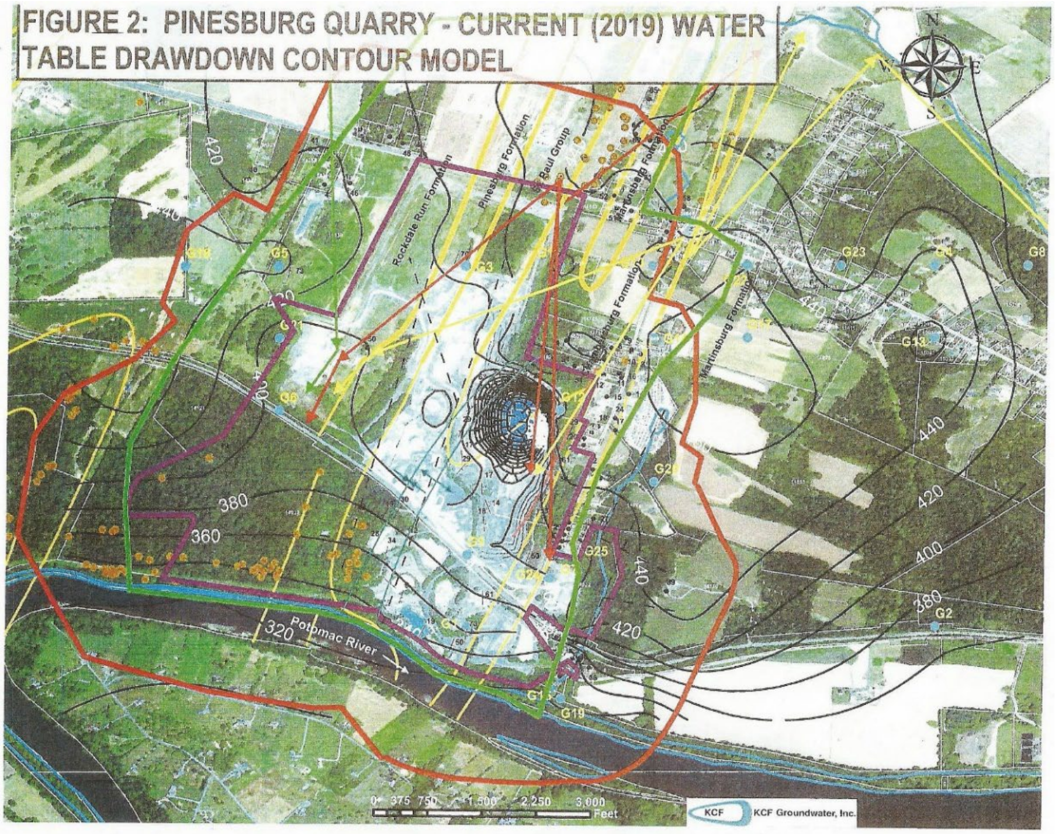


Figure 31. Pinesburg Quarry. 2019 water table contours. Reproduced from the KCF Groundwater, Inc. report dated September 16, 2020.

A comparison indicates that three collapse sinkholes noted by Duigon (2001), Figure 32, on the west side of the quarry did not show up in the Brezinski (2018) study, Figure 33. In addition, the MDE mining program has been tracking sinkhole formation statewide since 2001 and has no record of any sinkholes caused by operations at the Pinesburg Quarry. It appears that data for the Duigon (2001) was collected during the period 1995 to 1999, so it is possible that the three sinkholes were filled prior to the start of the Mining Program tracking system and the Brezinski (2018) survey. Without knowing the timing of the formation of the sinkholes, it is not possible to determine if the sinkholes were due to a natural occurrence or were man induced.

Finally, the mining division records indicate that the water supplies at two homes (14916 and 14920 Bottom Road) were disputed during the 2001-2002 drought. Additional information would be needed to determine whether the disruptions were due to the drought or were related to quarry dewatering activity.

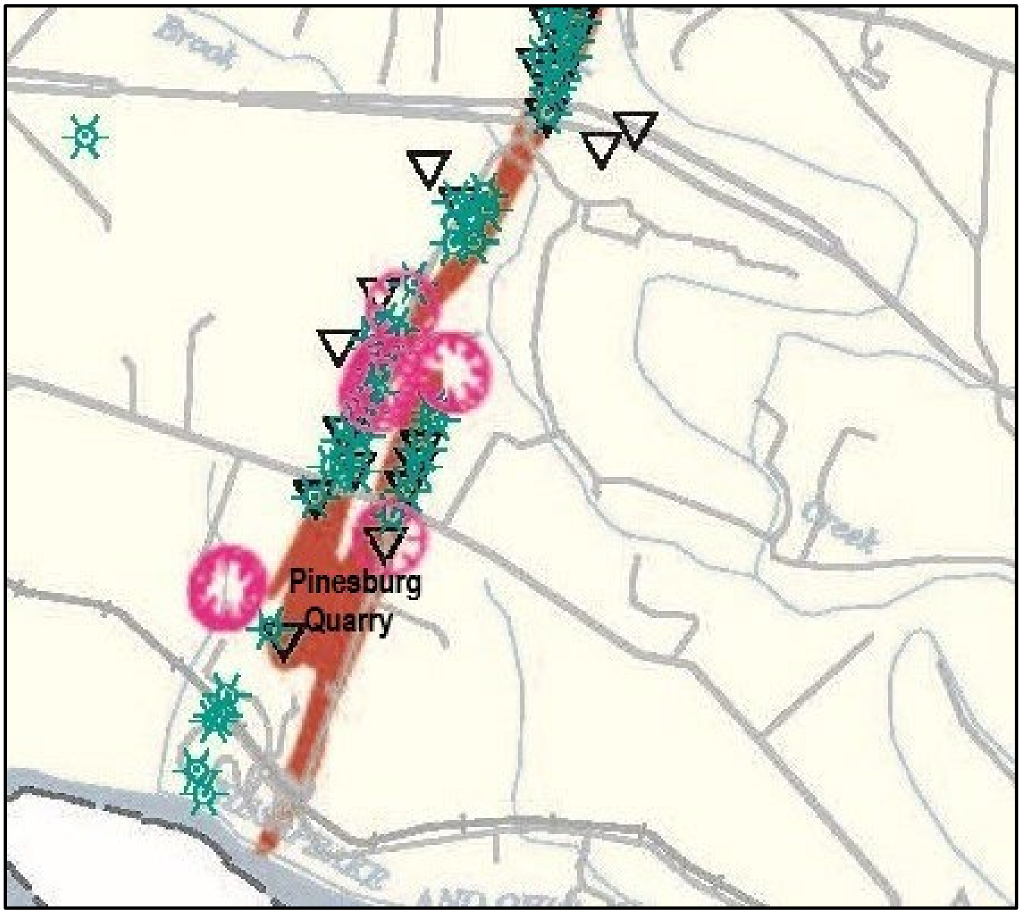


Figure 32. Location map showing karst features near the Pinesburg Quarry, modified from Duigon (2001). Pink features are collapse sinkholes.

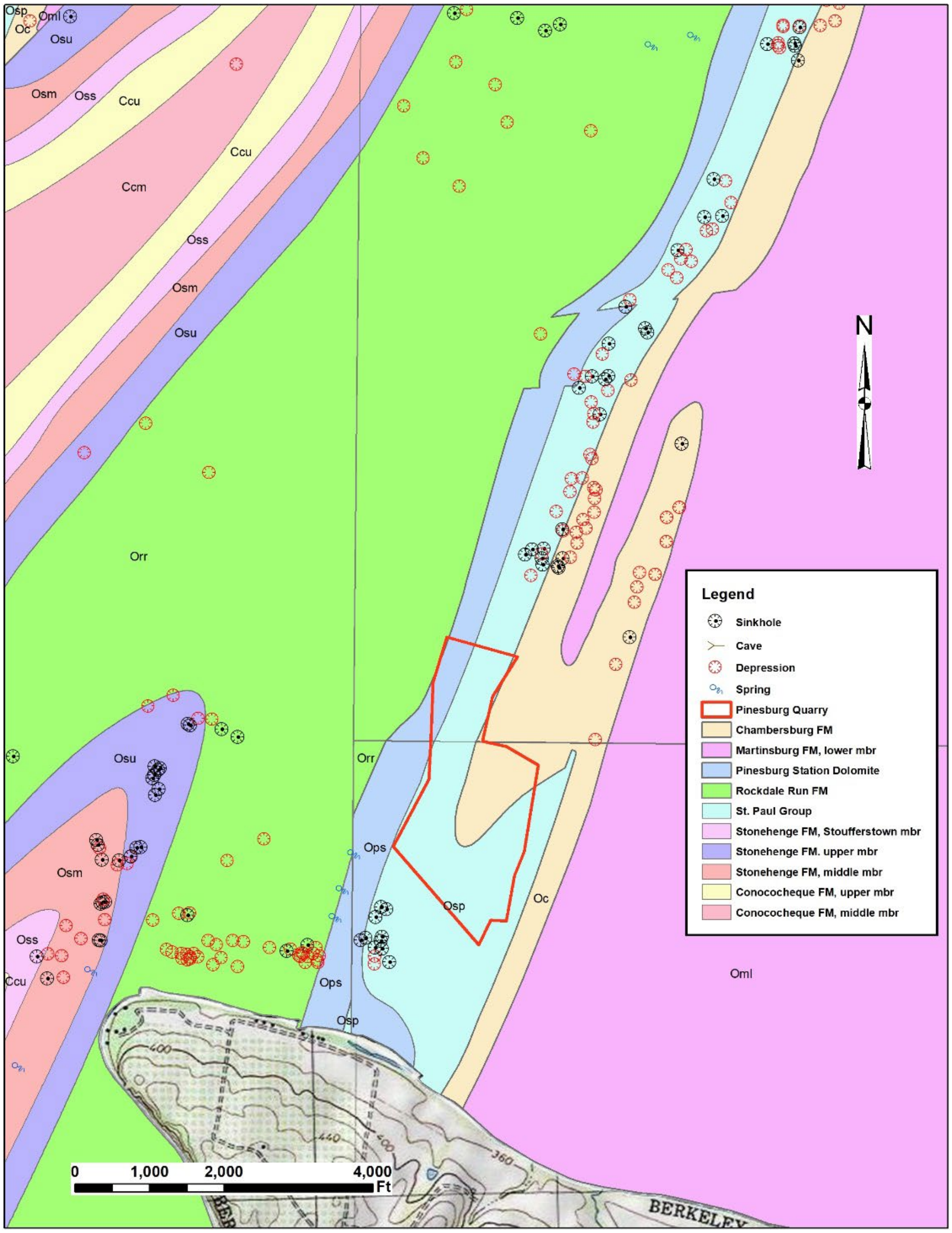


Figure 33. Geologic map showing karst features near the Pinesburg Quarry. Prepared from data contained in Brezinski (2013), Brezinki (2014), and Brezinski and Glaser (2013).

References

Brezinski, D.K., 2013, Geologic and karst features map of the Mason-Dixon quadrangle, Washington County, Maryland: Maryland Geological Survey Digital Geological Map MASON2013.1, scale 1:24,000.

Brezinski, D.K., 2018, Geology and karst development of the Hagerstown Valley (Great Valley) of Maryland. Maryland Geological Survey Report of Investigation 86, 101p.

Duigon, M.T., 2001**,** Karst hydrogeology of the Hagerstown Valley, Maryland: Maryland Geological Survey Report of Investigations 73, 128 p.

KCF Groundwater, Inc., 2020, Hydrogeologic assessment for the Water Appropriation and Use Permit application, Martin Marietta-Pinesburg Quarry: Prepared for Martin Marietta Materials, 16 September 2020. 12 p. and appendices.

Maryland Department of the Environment, Water Appropriation and Use Permit WA1987G016 (Rockdale Quarry). Water Supply Program, Baltimore, Maryland.

Maryland Department of the Environment, Water Appropriation and Use Permit WA1969SG014 and WA1969G024 (Pinesburg Quarry). Water Supply Program, Baltimore, Maryland.

Merrill, G.P. and Mathews, E.B., 1898, The building and decorative stones of Maryland: Maryland Geological. Survey, Vol. 2, Pt. 2, p. 47-241.

Nutter, L.J., 1973, Hydrogeology of the carbonate rocks, Frederick and Hagerstown Valleys, Maryland: Maryland Geological Survey Report of Investigations 19, 70 p.

Slaughter, T.H., 1962, The ground-water resources, in The Water Resources of Allegany and Washington Counties: Maryland Geological Survey, Bulletin 24, p. 1-243.

Williams, T.J.C., 1906, A history of Washington County, Maryland: From the earliest settlements to the present time, including a history of Hagerstown, Vol. 1, Pt 1. Higginson Book Company, Salem Massachusetts.

Boonsboro Quarry Case Study

Boonsboro Quarry is located immediately south of the junction of Benevola Church Road and Toms Road, about two miles north of Boonsboro, Washington County, Maryland. The Water Appropriation and Use Permit (WA1980G008) file has three volumes; however, the second one has not been located. Information from MDE Minerals, Oil and Gas Division files, especially Kampmeyer (1996), indicate that the missing file appears to contain the results of a hydrogeological evaluation by R.E. Wright Associates of an aquifer test conducted during the period from October 13, 1993, to January 17, 1994 (97 days), while pumping water from the east pit sump at variable rates. Seepage runs were conducted between 12 stations along Little Beaver Creek and water levels were measured in 16 monitoring wells.

Multiple sources give different dates for when dewatering of the Boonsboro Quarry started. A R.E. Wright report (1995) suggested that it started in the 1950s; however, Kampmeyer (1996) indicated that, while mining started in the 1950s, it wasn't until deepening of the quarry in 1980 that dewatering was required. The Water Use Permit file indicates that a surface water permit (WA69SAP015) was issued in 1969 for dust control and process water. A follow-on undated note indicated that dewatering of the quarry started in 1969. The surface water permit was reissued in 1978 for 114,000 gpd avg to be taken the quarry pit for dust control and dewatering of the quarry. That permit was superseded in 1983 by changing it to a groundwater permit (WA80G008). A major increase in the water use permit to 1.5 Mgd avg was issued in 1998 and renewed in 2010.

Reliable records of water use for dewatering of the quarry are only available from 1985. Figure 34 includes those water use records compared to Hagerstown rainfall and Houpt Spring flows. There is a long-term trend of increasing water use from less than 100,000 gpd avg to 1.5 Mgd avg relative to the rainfall and spring flow records. A discussion of the geology of the site and the available test and monitoring data is needed to determine why the increase in water use occurred.

The quarry pits have been excavated into the Elbrook (Limestone) and Tomstown (Dolomite) Formations. Several regional faults occur in the general area of the quarry, with the Eakles Mill fault exposed in the east pit of the quarry, separating the Elbrook and Tomstown Formations, Figure 35. Kampmeyer (1996) describes numerous structural features, including four high-angle fault planes exposed on the east highwall that probably form a fault zone related to the Eakles Mill fault. An east-west high-angle cross fault contact is exposed on the west highwall.

During the 1993/94 aquifer test, no response was noted in 15 of the 16 monitoring wells, Figure 36. Only a limited response was noted in one well (1P). There are several possible reasons for this lack of response to pumping in the monitoring wells. They were all completed in limestone/dolomite rocks, which tend to be highly impermeable except were secondary porosity exists; consequently, this can lead to a lack of response during the typical short-term aquifer test. Another factor to consider is the previous pumping for dewatering of the pit prior to the 97-day test. While the pumping rates during the test are not directly available, the reported use during the approximate test period (October 1993 to January 1994) was an average of 744,390 gpd, which is very close to the average of 756,131 gpd during the two-year period (October 1991 to September 1993) prior to commencement of the test. After two years of pumping the water levels in the monitoring wells would be stable and with no effective change in the withdrawal rate, the water levels in the monitoring wells would likely remain unchanged during the test.

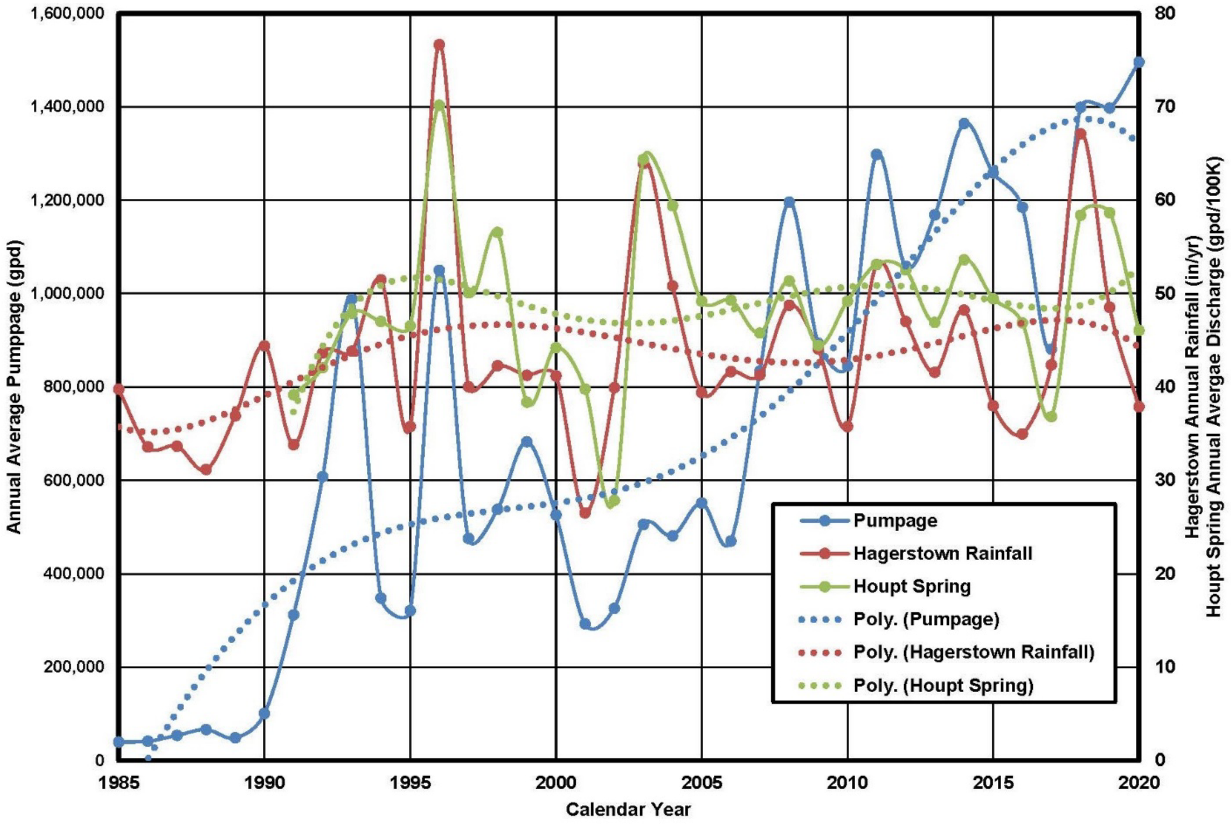


Figure 34. Annual pumpage from the Boonsboro Quarry, rainfall in Hagerstown and flow from Houpt Sprimg for the period 1985 to 2020.

Stream flow was measured at 8 stations on Little Beaver Creek, two tributary sites and two stations along the quarry outfall discharge channel, Table 7. In addition to the stream flows, water levels were measured in 9 existing domestic wells and 5 observation wells drilled as part of the test, Figure 36.

Kampmeyer (1996) reported that 4.0 cfs was lost between G8 and G9 and 1.0 cfs was lost between G11 and G12, indicating that quarry dewatering did not appear to cause the losses. The losses were related to the location of the I-70 cross fault, which was indicated to cross Little Beaver Creek downstream of G10, where the loss of 4.0 cfs was reported, and again downstream of G12, where the loss of 1.0 cfs was reported. It was further suggested that the I-70 cross fault was connected to a cross fault in the east quarry pit from which the largest inflow (300 gpm) is discharged. Figure 35 indicates that the I-70 intersects Little Beaver Creek between G2 and G4, runs along the creek, exits upstream of G8, and then intersects the Beaver Creek fault north of Little Beaver Creek. A branch of the Beaver Creek fault does cross Little Beaver Creek immediately downstream of G12.

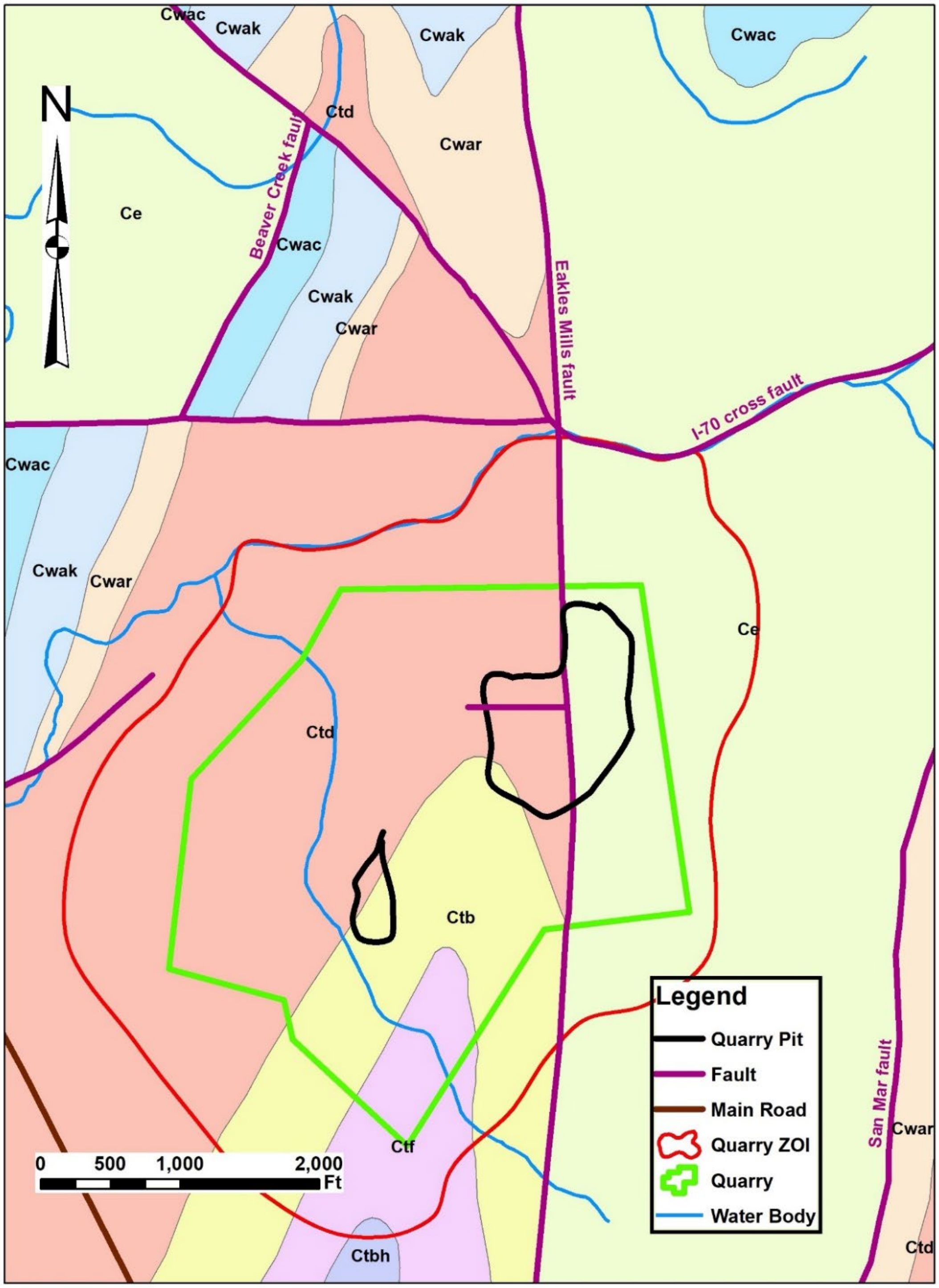


Figure 35. Geologic map in the vicinity of the Boonsboro Quarry. Geologic units are the Elbrook Limestone (Ce), the Tomstown Dolomite (Ctb, Ctbh, Ctd and Ctf), the Waynesburg Formation (Cwac, Cwak, Cwar) and Diabase Dikes (Jd).

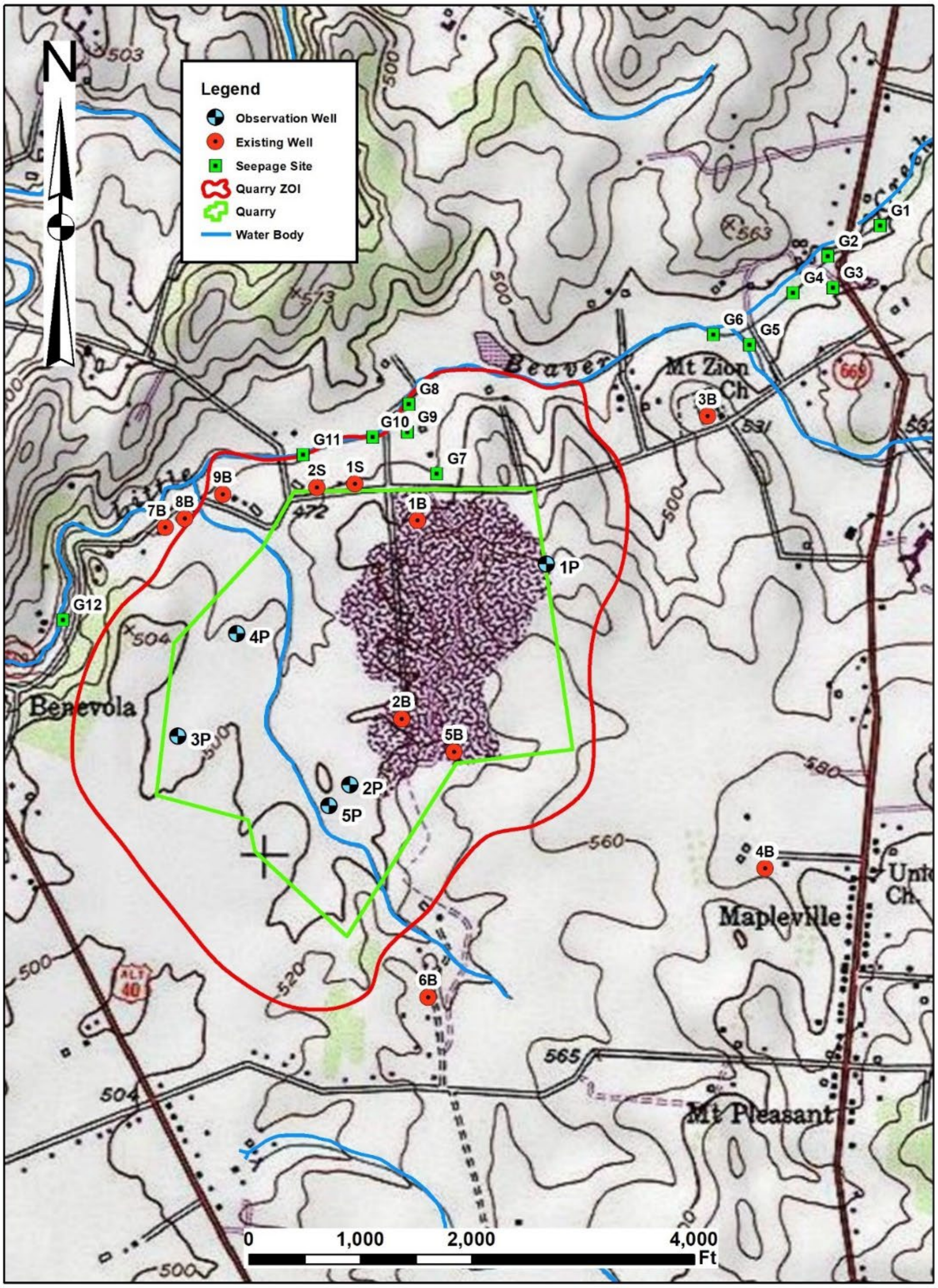


Figure 36. Topographic map showing existing domestic and quarry wells, drilled observation wells, and stream seepage stations within in or near the Boonsboro Quarry Zone of Influence (ZOI).

These were seepage runs, so if there were stream losses, they would have occurred between G8 and G10 and G11 and G12, not downstream of G10 and G12. The calculated losses were based on the average of six sample flow periods between 10/11/1993 and 11/22/1993, Table 7. One factor not considered was how long it takes a storm surge to travel through a watershed. Starting at G1 which contains 79% of the drainage area above G8, Figure 37, there is little difference in the flows during the sample period, except for those measured during the low flow period on 10/25/1993. There were extremely high flows at G8 on 10/11 and 10/18, high flows on 11/22 at G10, and moderately high flows at G6, G11 and G12 on various dates, especially on 11/15. These measurements are evidence of storm surges moving through the watershed that can bias any estimates of seepage losses. Also, on those dates a substantial amount of water was discharged at the quarry outfall between G8 and G10.

Table 7. 1993/1994 flow measurements at the seepage stations along Little Beaver Creek near the Boonsboro Quarry.

Date	10/04/93	10/11/93	10/18/93	10/25/93	11/01/93	11/15/93	11/22/93	10/11-11/22	11/29/93	12/12/93	12/20/93	12/27/93	01/10/94	D.A.
Location	cfs	cfs	cfs	cfs	cfs	cfs	cfs	avg cfs	cfs	cfs	cfs	cfs	cfs	mi^2
G1	6.36	4.63	4.18	2.49	5.44	5.17	5.88	4.63	22.81	15.22	22.78	14.85	9.4	5.6
G2	2.28	4.55	3.7	1.35	1.69	2.74	2.79	2.80	14.79	10.69	13.31	12.75	6.03	
G3(trib)	2.34	2.8	1.63	0.22	0.22	0.44	0.34	0.94	0.6	0.58	0.6	0.66	0.52	
G4	4.39	4.95	4.61	3.62	2.88	4.31	5.18	4.26	19.56	17.39	14.34	12.83	7.6	
G5(Trib)	0.68	0.81	0.39	0.74	0.33	0.62	0.39	0.55	1.95	1.69	1.47	1.15	0.86	
G6	11.46	2.53	5.26	2.6	3.96	8.92	4.81	4.68	34.15	18.52	22.23	20.58	10.28	6.7
G8	11.2	14.4	13.05	5.94	4.43	7.29	6.91	8.67	29.78	21.19	19.97	24.86	9.79	7.1
G7(outfall)	4.22	4.4	3.75	0	0.66	0.46	0	1.55	1.81	2.66	2.89	2.37	0.18	
G9(outfall)	3.19	2.03	4.05	0.16	1.3	3.02	2.91	2.25	3.75	1.98	2.46	2.71	3.71	
G10	16.48	5.04	6.05	5.24	7.06	5.34	10.66	6.57	28.18	22.46	18.16	17.41	15.47	7.2
G11	3.68	4.62	9.75	4.57	8.6	8.7	7.8	7.34	27.14	29.16	29.36	23.95	23.04	7.3
G12	12.46	5.3	7.54	3.01	4.3	8.45	9.41	6.34	28.71	18.88	25.72	16.61	16.19	8.8

The one date on which there was no clear evidence of either a storm surge or discharge from the quarry was 10/25/1993, which indicated that there was a minor loss (0.9 cfs) between G8 and G10 and a significant loss between G11 and G12 (1.5 cfs or 2.5 cfs, when adjusted for the difference in drainage areas). Kampmeyer (1996) described the tributary on the southwest side of the quarry as a swale, instead of the perennial stream shown on the USGS topographic map, Figure 38. He attributed this to either an error on the USGS map or dewatering by the quarry. There is no evidence of a mapping error; but the seepage runs provide evidence that the loss of stream flow in the tributary was due to pumping from the quarry pit. On the most representative seepage run date, 10/25/1993, the flow in the G5 tributary (D.D.= 1.02 mi^2) was 0.74 cfs. If that unit rate is applied to the downstream tributary (D.A. = 1.33 mi) the result would be 1.0 cfs or 64% of the loss (1.56 cfs) between G11 and G12. Considering the potential additive error (20-30%) of the two streamflow measurements, much of the loss between the two stations likely was due to dewatering of the quarry. An additional factor to consider is that the water level contours shown in Figure 39 indicate that a significant portion of the water withdrawn from the quarry comes from outside of drainage area of the tributary. While there was limited discharge (0.16 cfs at G9) from the quarry on 10/25/1993 date, this would not consider the antecedent effects of pumping. Although there are no daily flow records available for review, the average withdrawal rate in October 1993 was 576,000 gpd (0.9 cfs) or nearly the same as the calculated flow in the tributary on the date of the seepage run.

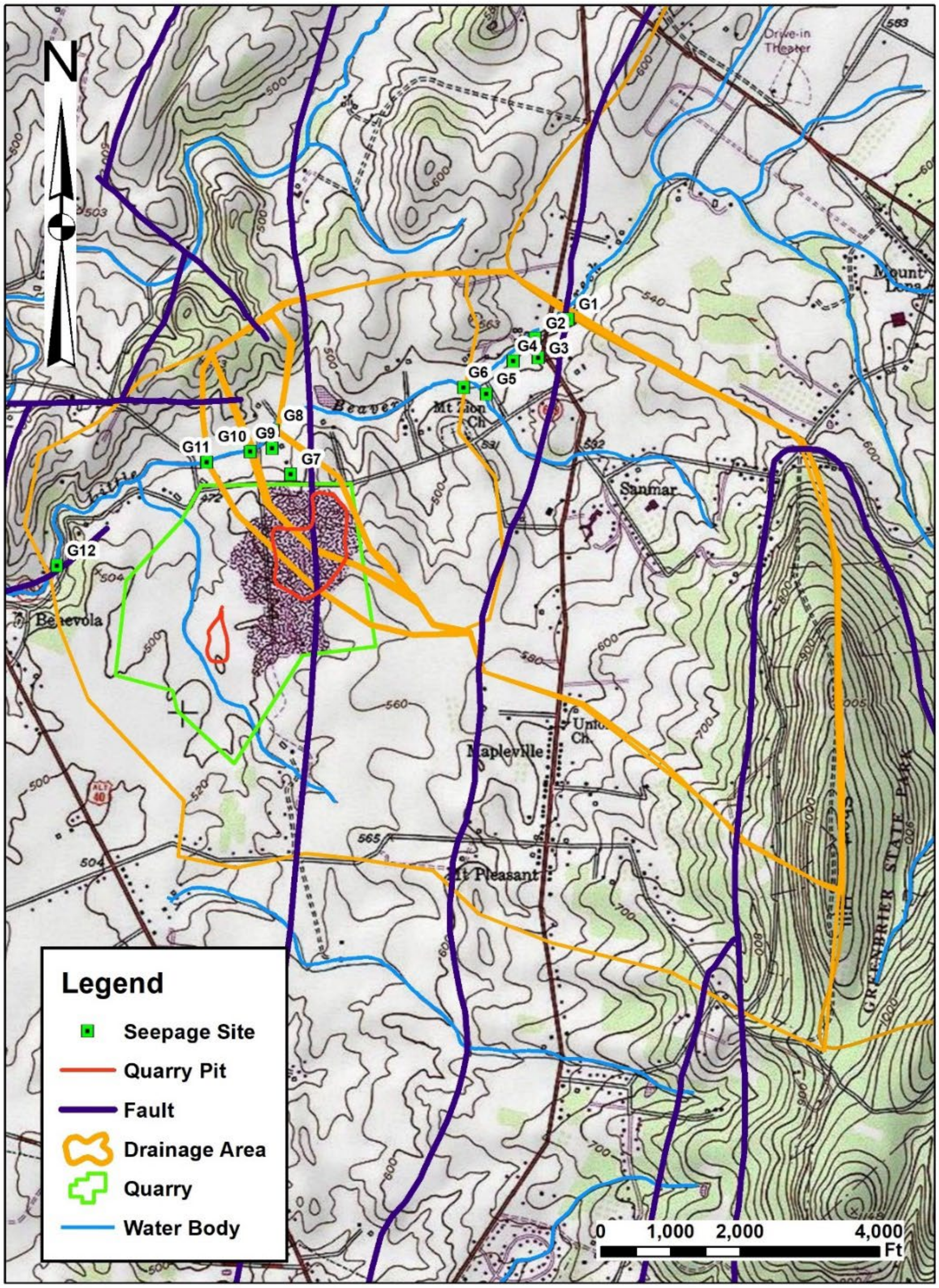


Figure 37. Topographic map with drainage areas for selected seepage run sites near the Boonsboro Quarry.

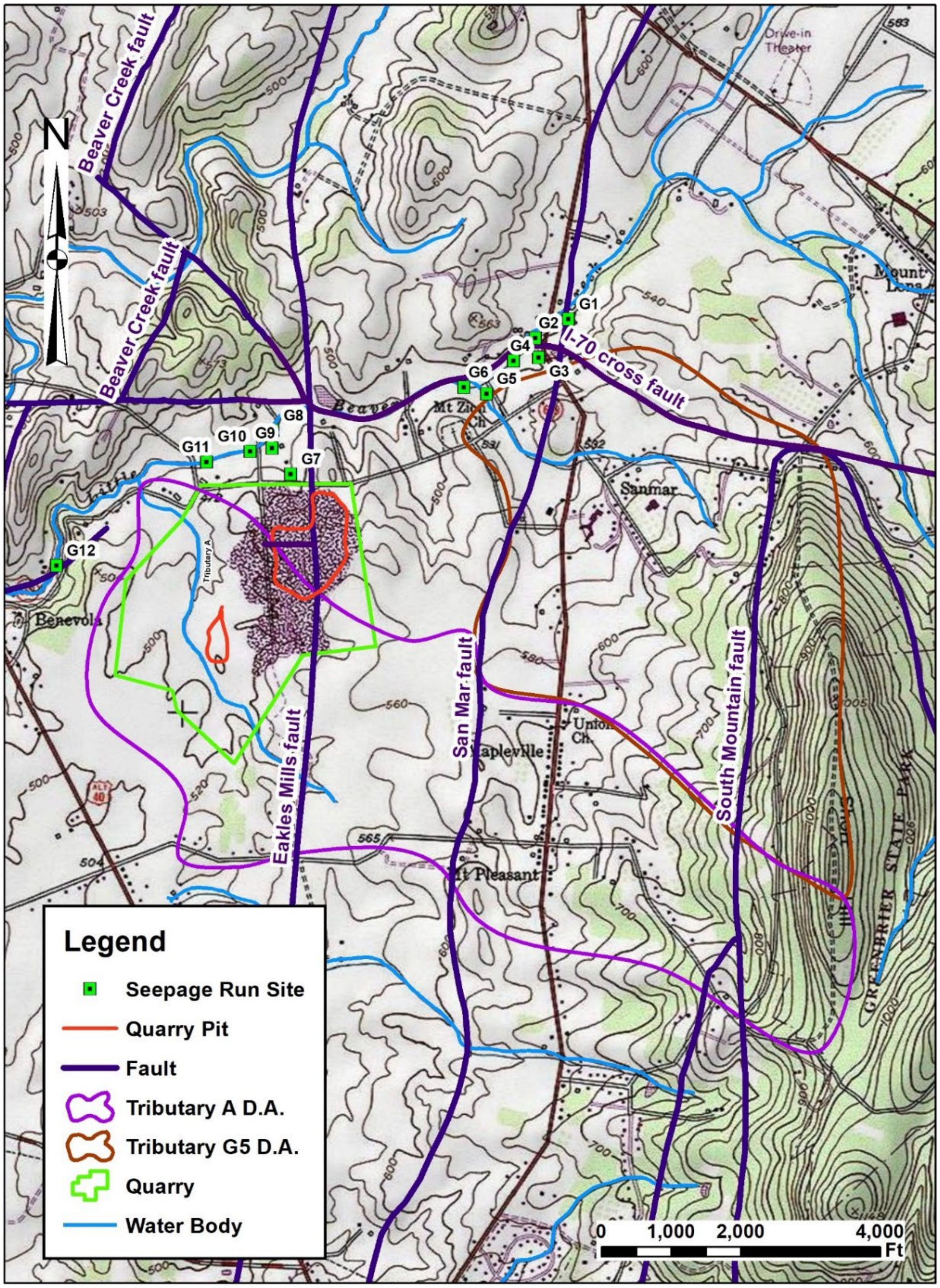


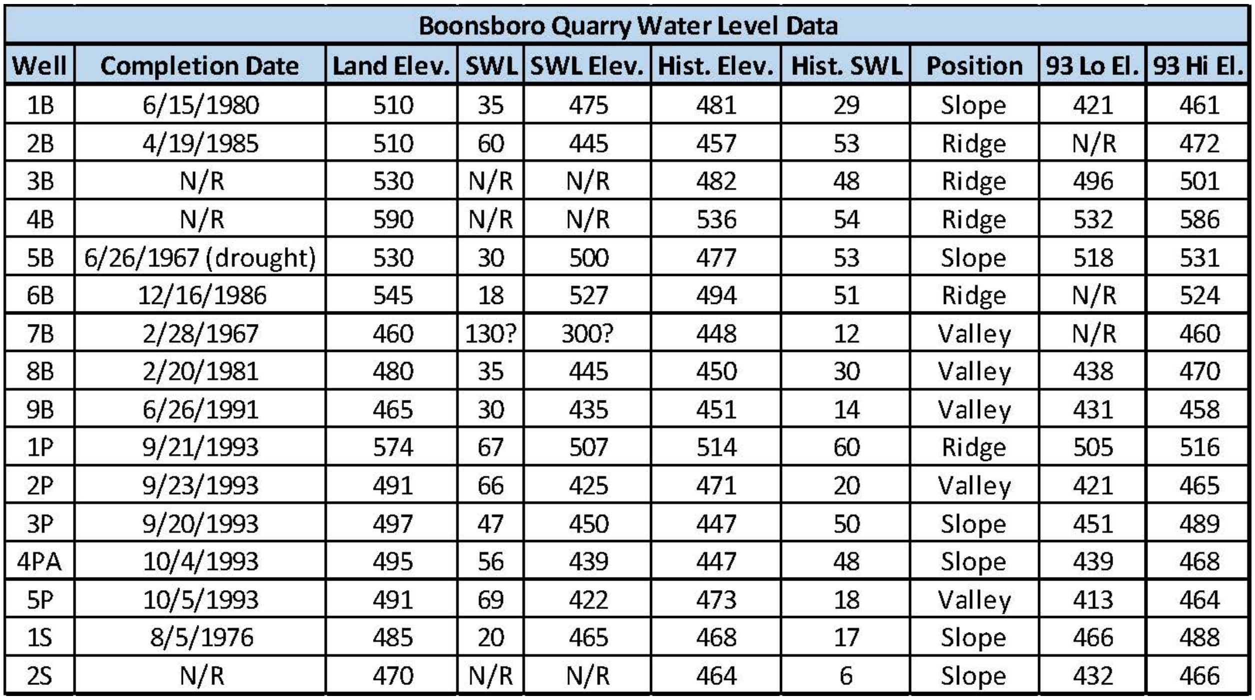
Figure 38. Topographic map with drainage areas for tributaries A and G5 near the Boonsboro Quarry.

Historical water levels near the quarry were estimated by R.E. Wright (1995) assuming they were 50 ft below land surface under slopes and valleys and 60 ft below land surface under ridges. Kampmeyer (1996) indicated that these assumptions were in error, since a review of a larger wells database indicates that historic water levels were about 30-40 ft below land surface at the quarry. Table 8 provides the historical water levels from the R.E. Wright (1995) report. Twelve of the monitoring wells are classified as being in a valley or on a slope with an average water level that is 27 ft below land surface, while four are classified as on a ridge, with and average water level of 53 ft below land surface. The overall average water level was 35 ft below land surface. Since the R.E. Wright (1995) water levels are within the average range of 30-40 ft cited by Kampmeyer (1996), which provided no data, the R.E. Wright (1995) data appears to be reasonable.

The historical water levels follow the topography of the watershed of the tributary on the southwest side of the quarry, Figure 39. The contours of the low water levels measured during the test period are pulled in two directions relative to the historical levels, one towards the east pit of the quarry and the second upstream in tributary A. A primary flow controlling mechanism could consist of two fractures, the first which is the fault identified at the discharge point in the east pit and the second a fracture zone along the stream bed of tributary A. The flow could be linear in the immediate vicinity of the primary fractures, which act as conduit for water likely contained in the upper weathered zone or epikarst. While there may be some capture of surface runoff, the model suggests that much of the water captured is groundwater runoff to tributary A.

In 2007, there was a sharp increase in withdrawals included in the pumpage reports relative to the Hagerstown rainfall and Houpt Spring flows, Figure 34. The data in Table 9 show withdrawals increase by 106% between 1991-2006 and 2007-2017, while there was no effective increase in the Hagerstown rainfall (-4%) or the Houpt Spring flows (0%) during the same period. An even more substantial change in the withdrawals occurred between 1991-2006 and 2018-2020 when they increased by 170%, when only slight increases in rainfall (13%) and spring flow (13%) occurred. A likely possibility is that surface runoff from Little Beaver Creek was being captured. Since quarry operations usually do not result in rapid expansion of quarry pits, the capture of groundwater runoff is less likely unless a prominent conduit is encountered that could greatly expand the capture zone of the quarry. Additional monitoring of stream flow and groundwater levels would be required to determine what flow mechanism caused the rapid increases in water withdrawals.

Table 8. Historical water level data from the R.E. Wright (1995) report.



Boonsboro Quarry Water Level Data									
Well	**Completion Date**	**Land Elev.**	**SWL**	**SWL Elev.**	**Hist. Elev.**	**Hist. SWL**	**Position**	**93 Lo El.**	**93 Hi El.**
1B	6/15/1980	510	35	475	481	29	Slope	421	461
2B	4/19/1985	510	60	445	457	53	Ridge	N/R	472
3B	N/R	530	N/R	N/R	482	48	Ridge	496	501
4B	N/R	590	N/R	N/R	536	54	Ridge	532	586
5B	6/26/1967 (drought)	530	30	500	477	53	Slope	518	531
6B	12/16/1986	545	18	527	494	51	Ridge	N/R	524
7B	2/28/1967	460	130?	300?	448	12	Valley	N/R	460
8B	2/20/1981	480	35	445	450	30	Valley	438	470
9B	6/26/1991	465	30	435	451	14	Valley	431	458
1P	9/21/1993	574	67	507	514	60	Ridge	505	516
2P	9/23/1993	491	66	425	471	20	Valley	421	465
3P	9/20/1993	497	47	450	447	50	Slope	451	489
4PA	10/4/1993	495	56	439	447	48	Slope	439	468
5P	10/5/1993	491	69	422	473	18	Valley	413	464
1S	8/5/1976	485	20	465	468	17	Slope	466	488
2S	N/R	470	N/R	N/R	464	6	Slope	432	466

Figure 40 is a map of the karst features around the Boonsboro Quarry, prepared from data in Brezinski (2009). There are few in its the immediate vicinity, with most occurring well south or east of the quarry. A large majority are depressions along the flanks of South Mountain. Brezinski (2018) indicated that the thick Quaternary deposits appear to have clogged the karst system, inhibiting active sinkhole development. The remainder seem to be limited to the limestones and dolomites of the Elbrook and Tomstown formations. The MDE mining program has reported that three active sinkholes formed within the ZOI of the quarry during the periods 2019-2021. Two are shown on Figure 40, while the location of the third appears to be in error, since it is 9.3 miles south of the quarry. The two within or near the ZOI are in the valley of Little Beaver Creek. The timing of their formation coincides with the later large increase in withdrawals from the quarry. Whether or not they were caused by dewatering of the quarry would be subject to additional investigation, with a primary focus on dye trace methods.

The Mining Program indicates that one water supply was disrupted within the Boonsboro Quarry ZOI; however, no information was provided about the location, cause, or disposition of that case.

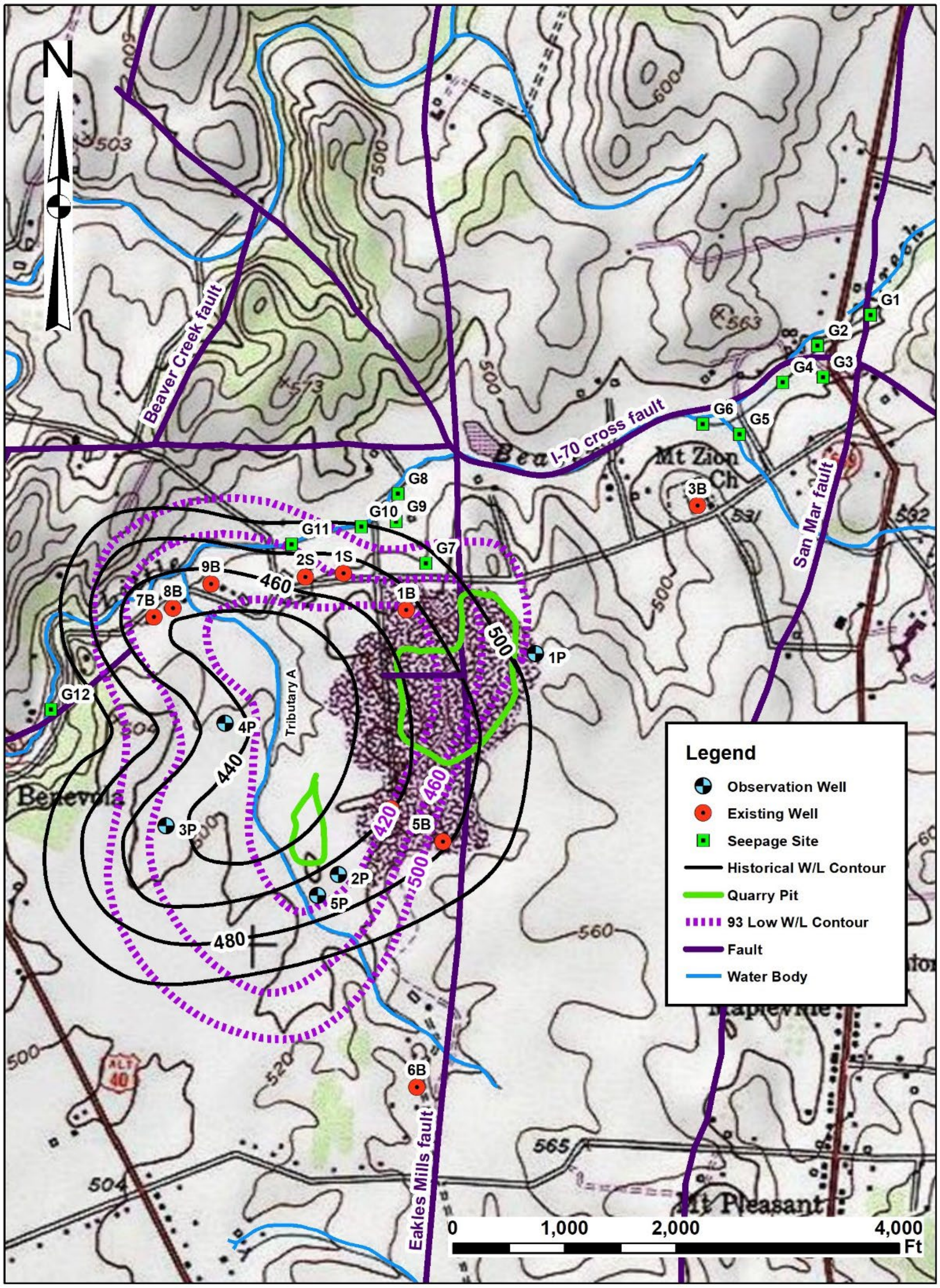
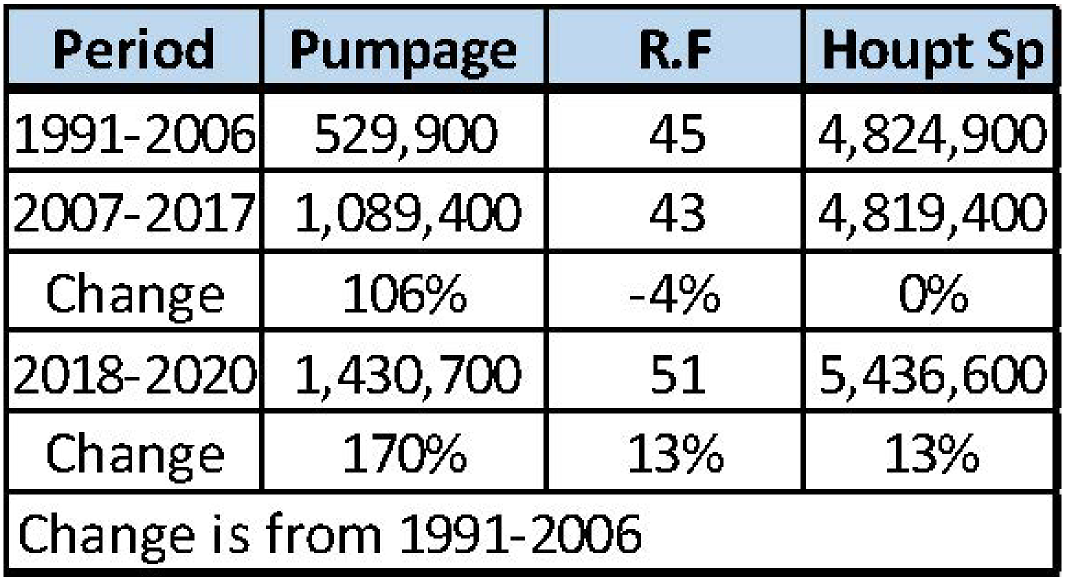


Figure 39. Topographic map showing existing domestic and quarry wells, drilled observation wells, and stream seepage stations in or near the Boonsboro Quarry, with estimated historical (pre-pumping) water levels and low water levels measured during the 1993 pumping test.

Table 9. Average pumpage from the Boonsboro Quarry, rainfall at Hagerstown, and flows at Houpt Spring for the periods 1991-2006, 2007-2017 and 2018-2020.



Period	Pumpage	R.F	Houpt Sp
1991-2006	529,900	45	4,824,900
2007-2017	1,089,400	43	4,819,400
Change	106%	-4%	0%
2018-2020	1,430,700	51	5,436,600
Change	170%	13%	13%
Change is from 1991-2006			

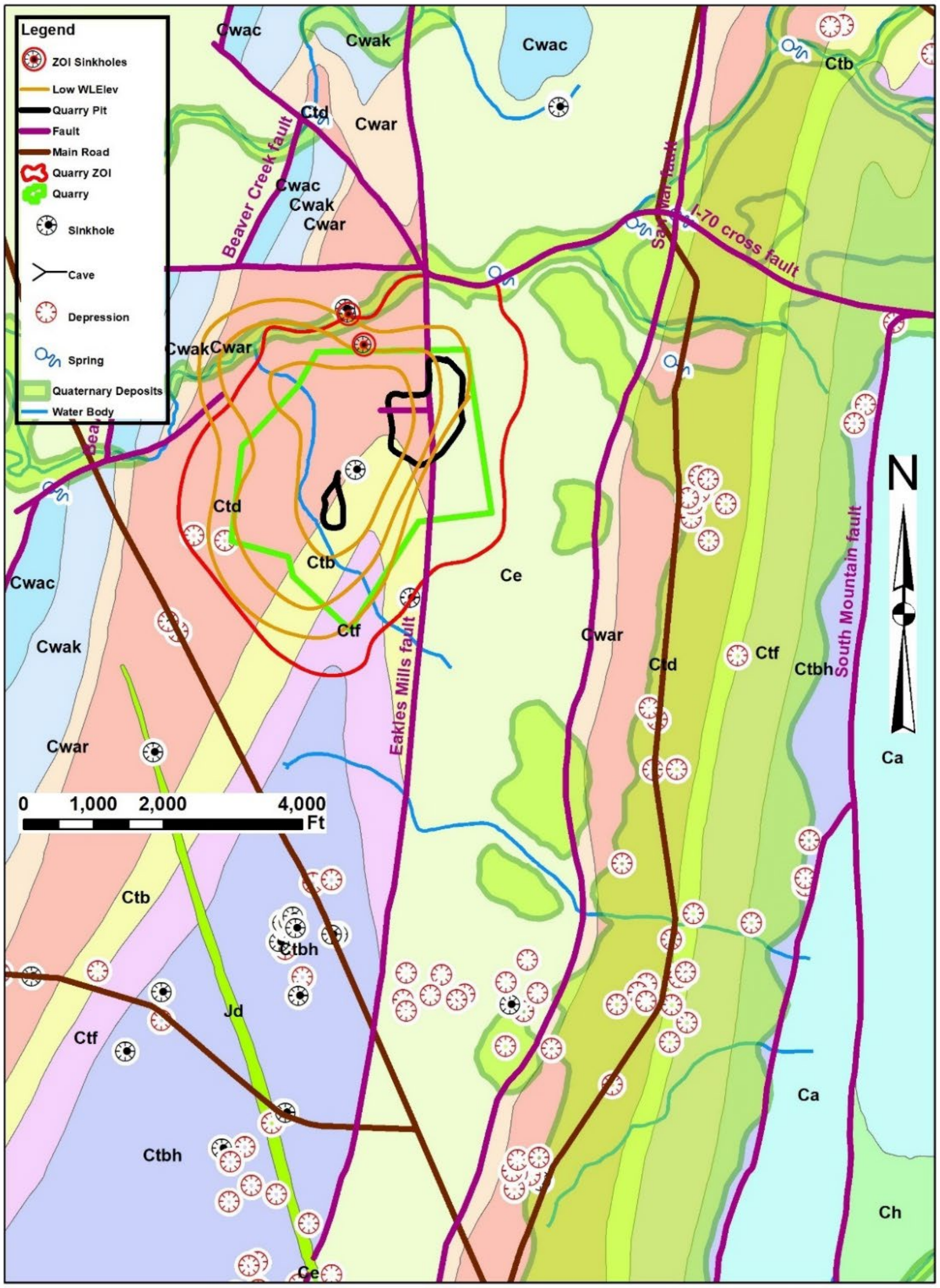


Figure 40. Geologic map in the vicinity of the Boonsboro Quarry. Geologic units are the Elbrook Limestone (Ce), the Tomstown Dolomite (Ctb, Ctbh, Ctd and Ctf), the Waynesburg Formation (Cwac, Cwak, Cwar) and Diabase Dikes (Jd). Lithologic units and karst features are taken from Brezinski (2009).

References

Brezinski, D.K., and Bell, S.C., 2009, Geologic Map of the Funkstown quadrangle, Washington County, Maryland: Maryland Geological Survey Digital Geological Map FUNKSGEO2009.1, scale 1:24,000.

Brezinski, D.K., 2018, Geology and karst development of the Hagerstown Valley (Great Valley) of Maryland. Maryland Geological Survey Report of Investigation 86, 101p.

Kampmeyer, A.R., 1996, Zone of dewatering influence, Martin Marietta Aggregates, Inc. Boonsboro Quarry. Maryland Department of the Environment, Water Management Administration, Minerals, Oil & Gas Division.32 p.

Maryland Department of the Environment, Water Appropriation and Use Permit WA1980G008 (Boonsboro Quarry). Water Supply Program, Baltimore, Maryland.

R.E. Wright Associates, 1995, Boonsboro Quarry dewatering investigation, Washington County, Maryland, Volumes I and II: Report submitted to Maryland Department of Natural Resources, Water Right Division. 107 p.

Security Quarry (Hagerstown) Case Study

Mining of the Security Quarry started in 1908 with the establishment of a large cement plant, the first modern portland cement mill to be erected in Maryland. It was located at the Security Western Maryland station, near a bridge over Antietam Creek about 2 miles east of Hagerstown. The Conococheague limestone on this property varies in composition within different beds but is uniformly low in the content of magnesia, an important property in the manufacture of portland cement. Antietam Creek had cut into the flank of an anticline, producing a natural quarry face.

The first water use permit (WA1919S050) was issued with an effective date of 12/1/1969 to the Marquette Company for 1.25 Mgd avg / 4.32 Mgd max from Antietam Creek. The use apparently was for process water starting in 1919. A revised permit was issued to St. Lawrence Cement, Inc. with an effective date of 8/1/1987 in the amounts of 2.16 Mgd avg / 4.32 Mgd for cooling and process water. On the same date, the first groundwater permit (WA1986G016) was issued in the amounts of 0.82 Mgd avg / 1.0 Mgd max for mine construction and dewatering (mining only), which the operator indicated started at least by 1975. The permitted uses were increased to 7.2 Mgd avg / 13.4 Mgd max on 8/1/ 2006 due to a major inflow of water to the quarry. The use was then decreased to 5 Mgd avg / 10 Mgd max due to a substantial reduction in inflow to the quarry and a new permit issued to Holcim (US) Inc. On the same date, WA1919S050 was reduced to 1 Mgd avg / 2.2 Mgd max and the use changed to a backup supply to WA1986G016. The most recent use under WA1986G016 was increased back to 7.2 Mgd avg / 13.4 Mgd max on 2/1/2013 after there was another major inflow to the quarry.

Upon renewal of WA1986G016 in 2001, a review of the pumpage reports indicated that they were likely unreliable, Table 10. The best example was that nearly all of months (97%) had amounts identical to other months year to year and within the same year, in addition to the identical consecutive yearly totals for 1988-89, 1990-91, 1992-93 and 1998-99, when there should have been seasonal and annual variations in use. The quarry environmental coordinator agreed to install elapsed time meters on the pumping system, then read and record monthly the water withdrawals. After 1993 and prior to 2003, the pattern of annual use from the Security Quarry is like of four other quarries, Figure 41. The operator then reported that the pumps were operated continuously, while the sump level was allowed to fluctuate; consequently, the changes in sump storage affected the withdrawal rate. This may be why the annual amounts looked reliable, while the monthly reported uses were repetitive, but that data cannot be verified. Water use increased steadily from 109,00 gpd avg in 2002 to 928,000 gpd avg in 2003, then to 1,841,000 gpd avg in 2004, with a sudden increase in December of that year to 8.2 Mgd, after blasting opened a cave from which a massive inflow was discharged, Figure 42. Finally, the average withdrawal in 2005 was 6,646,000 gpd avg. These data indicate that there was a major inflow of water that could not be explained by changes in climatic conditions. The inflow also was unlikely from a groundwater source, as it would require a drainage area of about 11.7 mi^2 to account for water withdrawn in 2005. While some portion the inflow may have been from groundwater, the proximity to Antietam Creek, and the large amount of and sudden inflow to the quarry cave would indicate that most of the water had come from the creek. After 2005, the reported water use data appears to be reliable, with only a few repetitive monthly measurements, and decreases to about 3-4,000,000 gpd avg until 2011, when it increases to about 9.8 Mgd avg, after the second massive inflow event. It then declines to about 2.2-2.8 Mgd avg during the period 2016-2020.

Table 10. Security Quarry Pumpage (WA1986G016)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Total Usage	Annual Average
1987							5,649,750	5,649,750	5,647,500	5,649,750	5,649,750	5,649,750	33,896,250	92,866
1988	5,649,750	5,103,000	5,649,750	5,647,500	5,649,750	5,647,500	5,649,750	5,649,750	5,647,500	5,649,750	5,649,750	5,649,750	67,243,500	183,725
1989	5,649,750	5,103,000	5,649,750	5,647,500	5,649,750	5,647,500	5,649,750	5,649,750	5,647,500	5,649,750	5,649,750	5,649,750	67,243,500	184,229
1990	5,649,750	5,103,000	5,649,750	5,647,500	5,649,750	5,647,500	5,649,750	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	66,881,250	183,236
1991	5,649,750	5,103,000	5,649,750	5,647,500	5,649,750	5,647,500	5,649,750	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	66,881,250	183,236
1992	5,649,750	5,285,250	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	66,703,500	182,250
1993	5,649,750	5,285,250	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	66,703,500	182,749
1994	5,649,750	5,103,000	5,649,750	5,467,500	5,649,750	5,467,500	30,132,000	30,132,000	29,160,000	30,132,000	29,160,000	30,132,000	211,835,250	580,371
1995	5,649,750	5,103,000	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	5,649,750	5,467,500	5,649,750	5,467,500	5,649,750	66,521,250	182,250
1996	15,000,000	11,500,000	17,800,000	17,000,000	17,800,000	17,000,000	30,132,000	30,132,000	29,160,000	30,132,000	29,160,000	30,132,000	274,948,000	751,224
1997	17,856,000	16,128,000	17,856,000	17,280,000	17,856,000	17,280,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	145,080,000	397,479
1998	6,561,000	4,374,000	6,318,000	6,318,000	6,318,000	6,318,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	77,031,000	211,044
1999	6,561,000	4,374,000	6,318,000	6,318,000	6,318,000	6,318,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	6,804,000	77,031,000	211,044
2000	6,561,000	4,374,000	6,318,000	6,318,000	6,318,000	6,318,000							36,207,000	98,926
2001							5,649,750	5,103,000	5,649,750	5,647,500	5,649,750	5,647,500	33,347,250	91,362
2002	2,824,875	2,551,500	3,766,500	5,647,500	2,824,875	2,823,750	3,100,000	3,100,000	3,255,000	3,410,000	3,150,000	3,317,000	39,771,000	108,962
2003	24,800,000	22,400,000	30,132,000	29,160,000	31,000,000	15,000,000	34,596,000	34,596,000	33,480,000	31,248,000	30,240,000	22,176,000	338,828,000	928,296
2004	33,480,000	31,320,000	33,480,000	32,400,000	33,480,000	33,480,000	44,640,000	44,640,000	43,200,000	44,640,000	43,200,000	255,744,000	673,704,000	1,840,721
2005	272,304,000	245,952,000	272,304,000	263,520,000	200,880,000	177,120,000	167,400,000	167,400,000	162,000,000	167,400,000	162,000,000	167,400,000	2,425,680,000	6,645,699
2006	51,840,000	129,600,000	115,920,000	94,920,000	108,780,000	85,680,000	44,000,000	130,000,000	130,000,000	125,000,000	121,000,000	86,000,000	1,222,740,000	3,349,973
2007	87,000,000	139,000,000	92,000,000	105,000,000	85,000,000	94,000,000	86,000,000	78,000,000	73,000,000	63,000,000	80,000,000	87,000,000	1,069,000,000	2,928,767
2008	101,000,000	160,000,000	126,000,000	150,000,000	75,200,000	75,200,000	75,210,000	122,830,000	107,190,000	85,210,000	68,130,000	120,663,000	1,266,633,000	3,460,746
2009	124,620,000	82,040,000	88,040,000	53,400,000	57,040,000	79,200,000	143,000,000	111,000,000	108,000,000	100,000,000	107,200,000	100,000,000	1,153,540,000	3,160,384
2010	148,000,000	137,000,000	163,000,000	156,000,000	178,000,000	117,000,000	120,900,000	111,300,000	96,000,000	96,100,000	93,000,000	94,300,000	1,510,600,000	4,138,630
2011	76,260,000	43,120,000	942,960,000	1,096,800,000	283,536,000	285,600,000	139,572,000	139,250,250	157,177,500	147,492,000	145,800,000	128,880,000	3,586,447,750	9,825,884
2012	143,121,960	130,563,000	122,449,680	148,211,100	134,563,140	130,454,640	143,050,000	142,918,000	138,292,000	143,072,000	138,628,000	143,185,200	1,658,508,720	4,531,445
2013	103,536,000	93,696,400	103,286,400	99,632,000	102,944,000	99,640,000	145,248,000	145,728,000	143,040,000	144,288,000	141,840,000	144,048,000	1,466,926,800	4,018,978
2014	143,764,000	131,730,400	144,984,000	141,287,600	146,748,000	139,364,000	186,949,200	186,949,200	183,112,200	163,665,000	143,020,200	157,723,200	1,869,297,000	5,121,362
2015	156,571,800	140,743,200	213,317,400	72,313,132	107,852,251	114,913,412	126,287,901	112,047,874	95,540,330	92,150,157	77,330,748	77,299,840	1,386,368,045	3,798,269
2016	66,119,195	102,009,672	105,296,879	72,381,791	91,818,352	90,061,842	104,782,442	104,489,703	74,321,324	78,498,116	66,443,246	71,653,735	1,027,876,297	2,808,405
2017	74,848,343	60,088,637	76,462,950	91,374,025	67,857,919	82,757,533	91,869,080	105,262,706	96,208,280	90,369,903	101,668,404	95,782,196	1,034,549,976	2,834,383
2018	76,772,562	65,236,876	87,634,466	88,562,635	90,806,943	80,960,665	84,306,631	112,964,418	112,800,846	112,695,932	120,817,462	125,335,463	1,158,894,899	3,175,055
2019	58,290,526	45,629,930	62,443,014	75,330,509	80,816,482	79,453,911	81,548,206	76,369,737	65,152,377	64,423,407	62,097,846	75,620,780	827,176,725	2,266,238
2020	84,194,120	78,023,827	85,282,460	85,045,409	85,888,152	81,580,301	86,146,872	79,534,961	68,204,445	55,157,617	78,683,805	96,638,911	964,380,880	2,634,920
2021	58,130,485	57,513,648	64,339,801	59,337,631	70,335,139	76,825,267							386,481,971	1,058,855

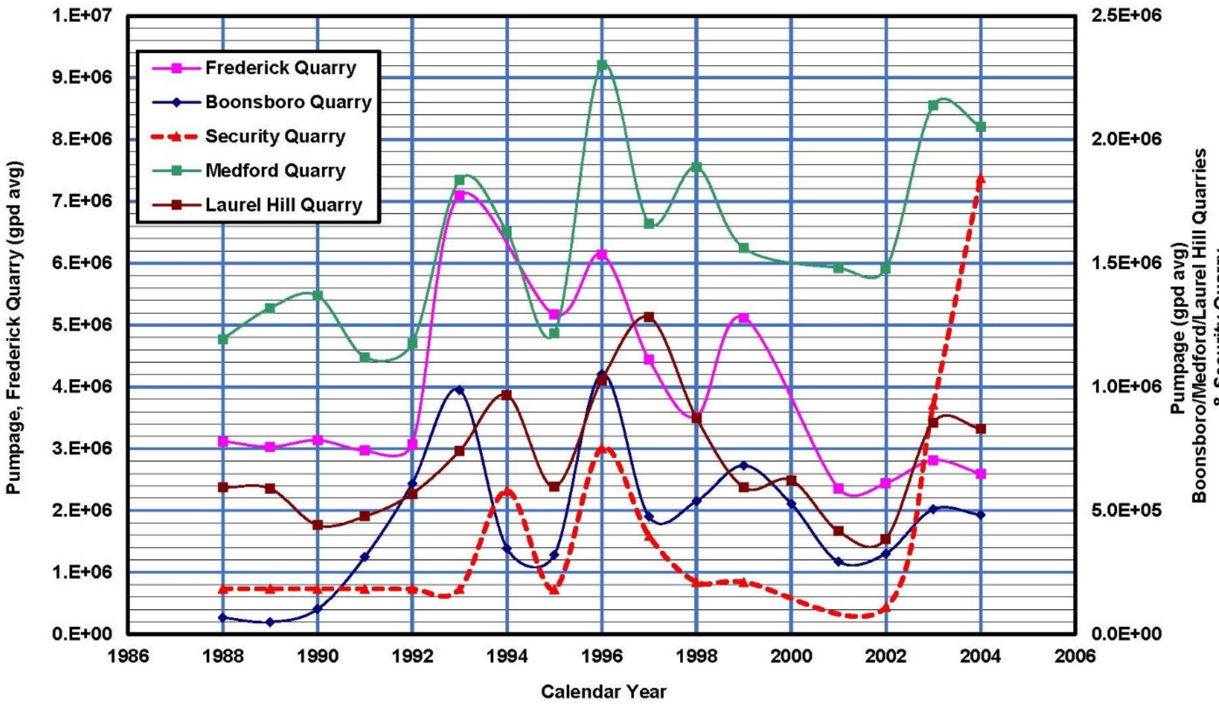


Figure 41. Annual pumpage (gpd avg) during the period 1988 to 2004 for the Security, Boonsboro, Frederick, Larurel Hill and Medford quarries.

After the massive increase to 8.2 Mgd in December 2004, MDE proposed that a dye trace study be conducted to determine the degree of connection between the cave or main quarry inflow point and Antietam Creek. Gartner Lee Limited (2005) designed the study and completed a report in July 2005. Just prior to commencement of a proposed stream dye trace, a new sinkhole was discovered, about 523 m (1716 ft) south of the quarry cave, on the North American Rod & Gun Club property and immediately on the opposite bank of Antietam Creek from the quarry, Figure 43. Creek flow into the sinkhole was dammed, which reduced the total flow to the cave by an estimated 30-50%. The next day the dam was partially opened to allow flow (about 475 gpm) for the tracer test. On June 14, 2005, dye was then injected into the sinkhole and the tracer concentration was measured at the quarry cave discharge point. The dye arrived after 1.67 h, reached a peak concentration at 2.45 h, and 69% of the dye was recovered at the cave. Later, on June 14, 2005, a second dye trace was performed by injecting dye in Antietam Creek about 1240 ft upstream of monitor #2, which was located near the sinkhole. The first tracer arrived 2.65 h after injection, with a peak concentration at 3.48 h, and a recovery at the cave of 0.12%. There are several possible reasons for the low recovery rate from the creek trace. There may be other places upstream of the injection point where water could be leaking from the stream to the quarry. Also, most of the dye could have been lost due to absorption by streambed sediments or by other chemical reactions. If dye loss was an issue, then additional traces with conservative tracers (such as bromide, chloride, or fluoride) or chemical fingerprinting of water samples may have solved the problem; however, there is no evidence in the MDE files that such studies were completed.

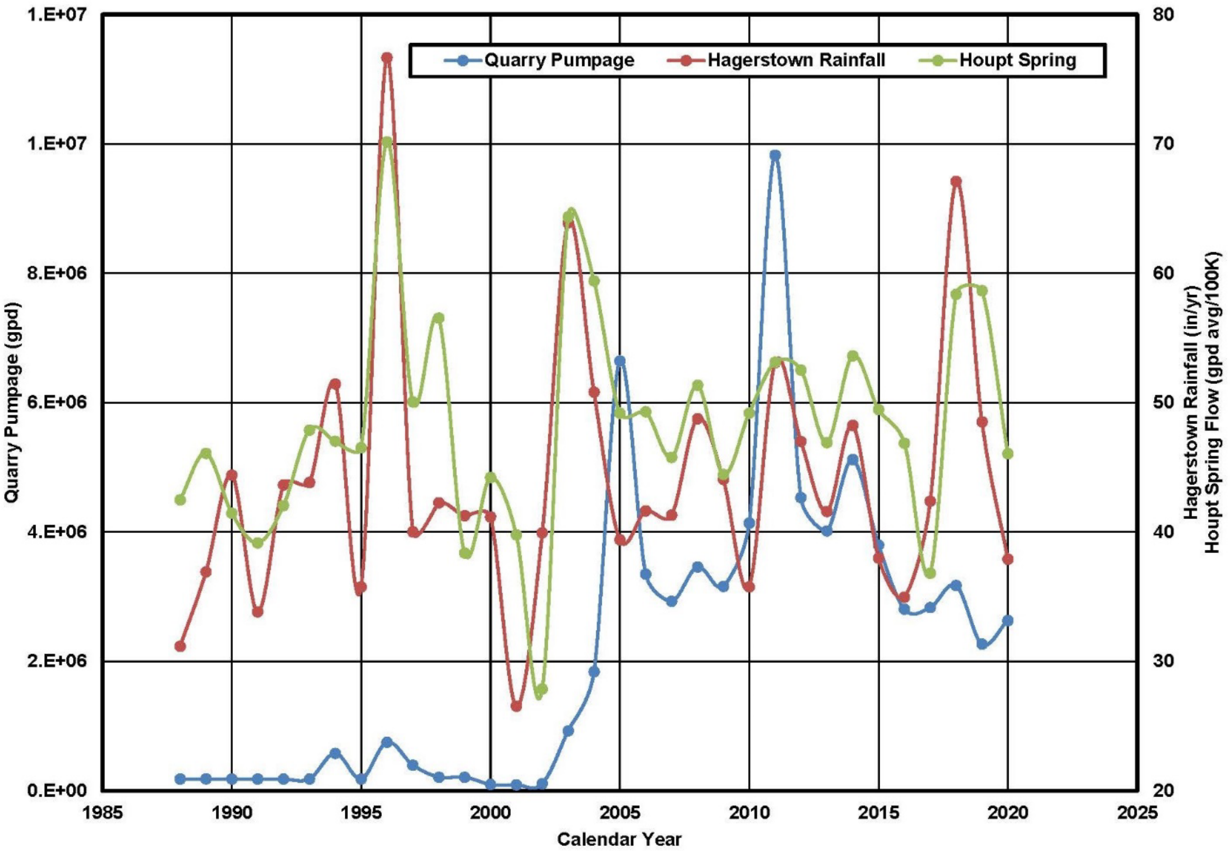


Figure 42. Annual pumpage from the Security Quarry, rainfall in Hagerstown and flow from Houpt Sprimg for the period 1988 to 2020.

The reported pumpage for the six months from December 2004 to May 2005 was an average of 8.3 Mgd, while the use reported for the six months (July to December 2005) after the dye trace and probable repair of the sinkhole was 5.4 Mgd. The reduction in use of 35% was within the estimated range of the reduced flow to the quarry cave when creek flow to the sinkhole was dammed. The use subsequently declined to 3-4 Mgd until a sinkhole opened in the creek causing a sudden average inflow of 33.4 Mgd during March and April 2011that flooded the quarry. After repair of the sinkhole, pumpage declined initially to 4-5 Mgd (2012-2015) then to 2-3 Mgd (2016-June 2021). The pumpage data is consistent with the Brezinski (2018) observation that extensive grouting had impeded flow into the quarry.

A follow-on dye trace study was conducted in 2007, Aley (2007), from which the quarry Zone of Influence (ZOI) was derived, Figures 44 and 45. The dye trace directions of movement were from Antietam Creek and Marsh Run, as well as by groundwater flow from a sinkhole to the east of the quarry and from a monitoring well along a previously unknown fault. Flow may have been captured from an unnamed tributary of Antietam Creek that originally flowed parallel to and about 150-200 ft east of the fault.

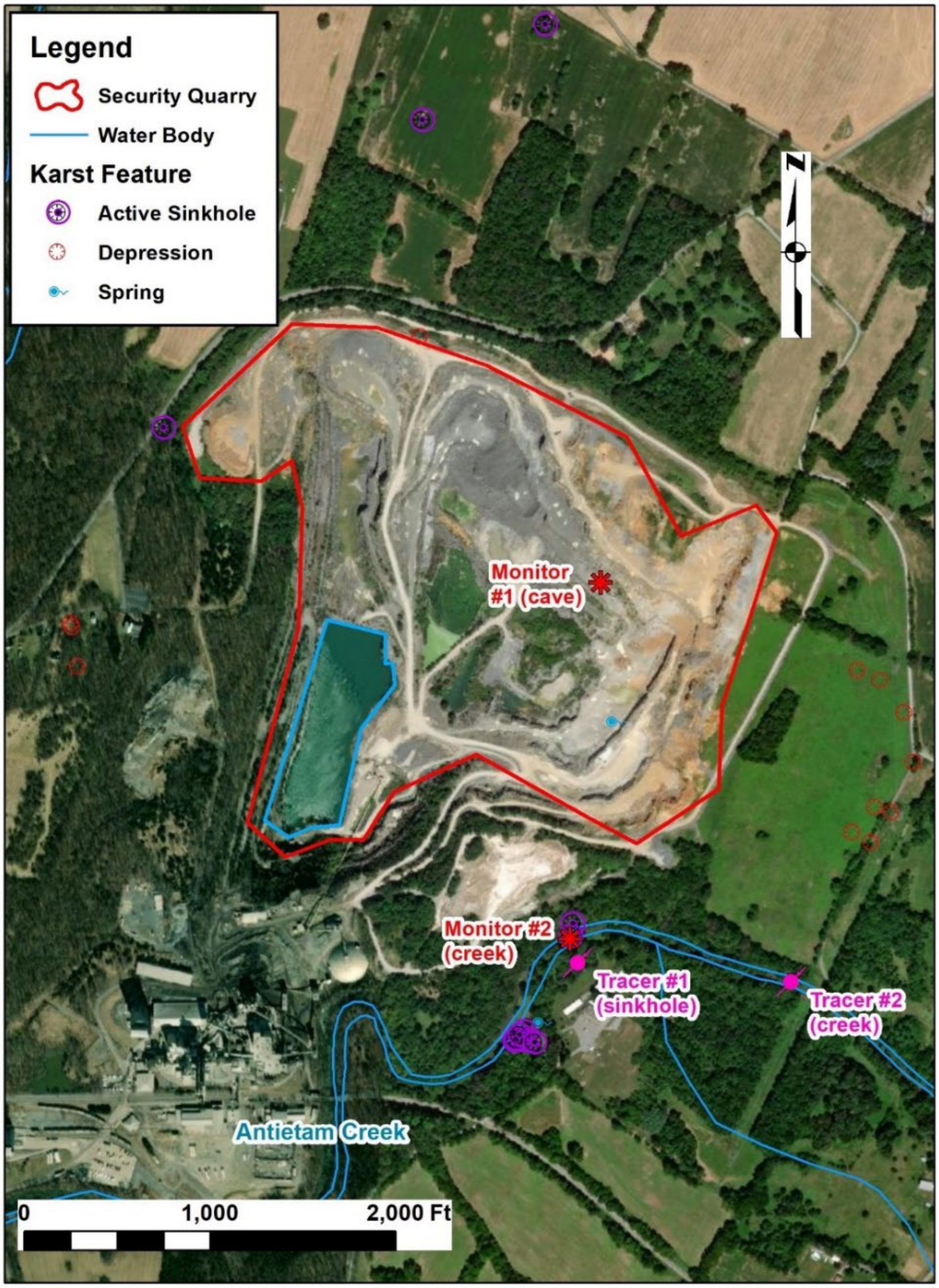


Figure 43. Aerial view of the Scecurity Quarry (Hagerstown) showing karst features and the locations of the injection and recovery points for the 2005 sinkhole and Antietam Creek tracer tests.

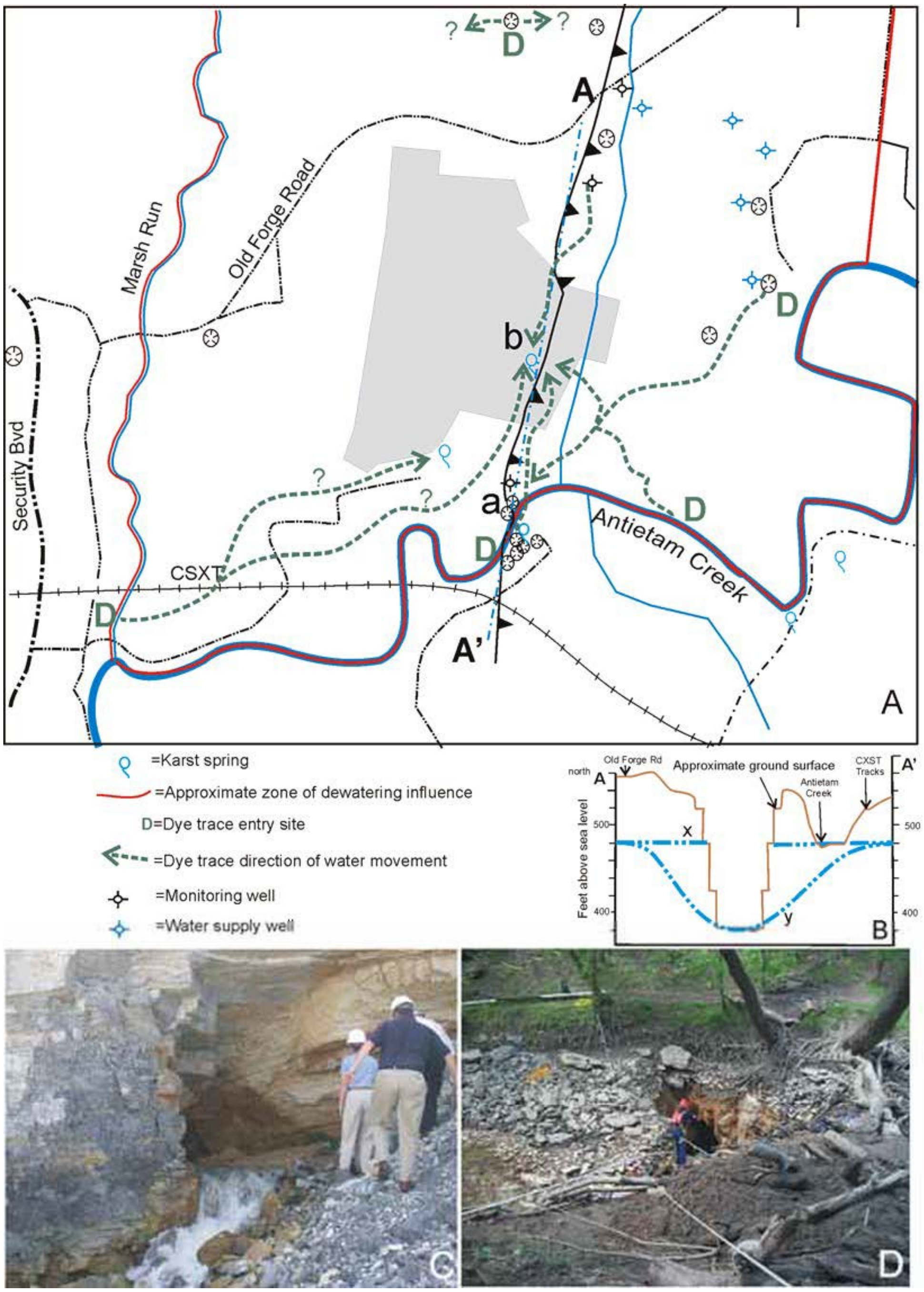


Figure 44. Quarry dewatering and karst activation. A, Map of the area surrounding Security quarry (gray shaded area) and locations of interpreted fault, sinkholes, and springs. Groundwater flow patterns based upon dye trace analysis of Aley (2007). B, Topographic profile along strike from A to A' illustrating interpreted pre-quarrying (x) and current (y) water table and resulting cone of depression. C, Catastrophic collapse sinkhole along the stream channel of Antietam Creek in April 2011. The sinkhole exposed in the stream channel is within a coffer dam during repair attempts (image courtesy of Greg Day, Maryland Department of Environment). D, Spring emerging from the cave opened in eastern face of the Security quarry in 2005. Reproduced from Brezinski (2018).

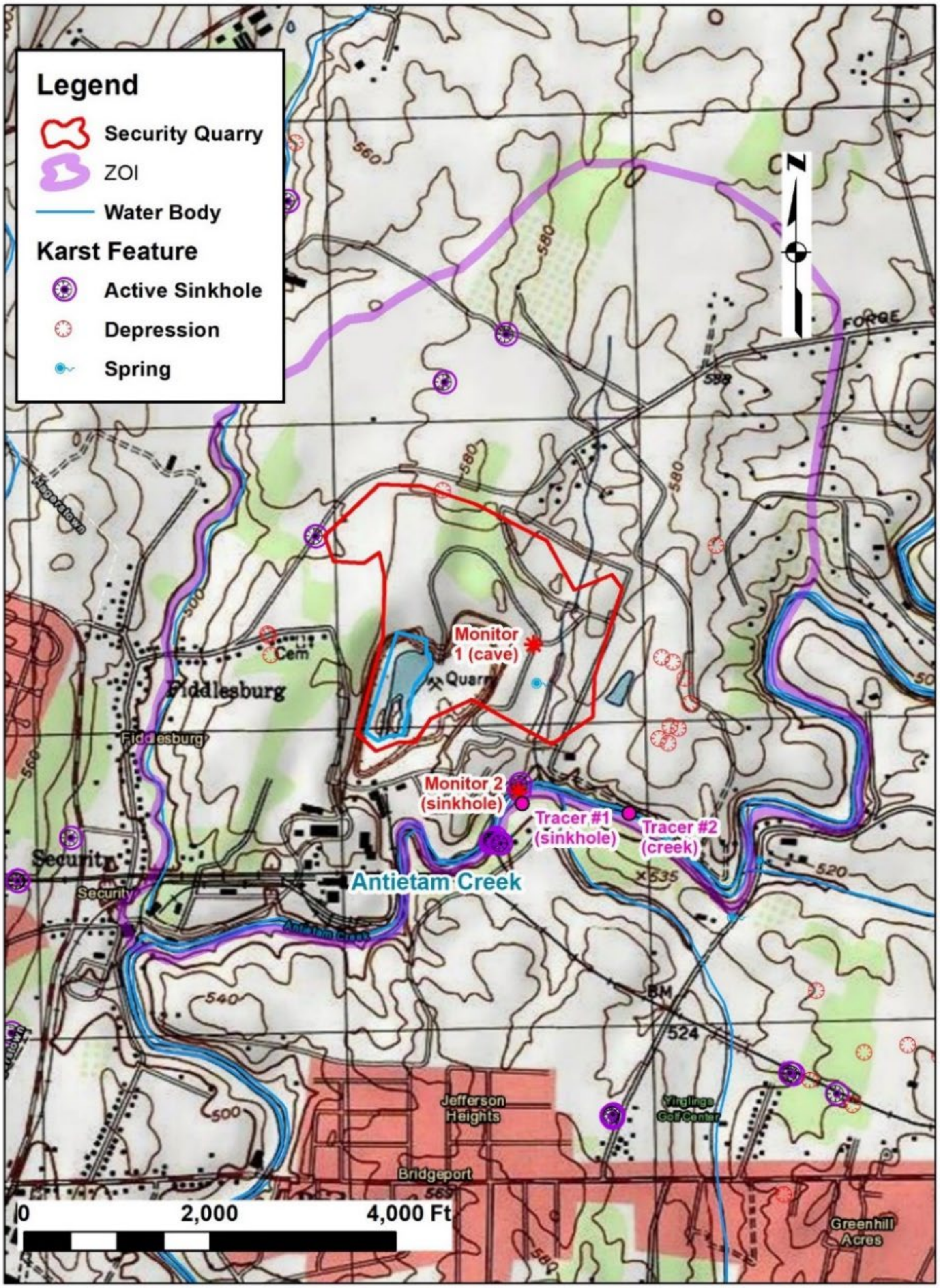


Figure 45. Topographic map showing the Security Quarry, its Zone of Influence (ZOI), karst features, and the injection and recovery points for the 2005 sinkhole and Antietam Creek tracer tests.

The 2007 dye trace cannot be used to determine the quantities of water from the different sources. The contribution of groundwater may be estimated by multiplying the potential drainage area of the quarry pit by an effective recharge rate. Initially, small amounts of groundwater would probably have been captured, but as mining continued and the quarry was deepened, the dewatering withdrawal would have increased due to steeper hydraulic gradients. Upon opening of the cave and possible intersection with the fault/fracture system, the drainage area could have increased substantially. The ZOI appears to reasonably approximate the existing groundwater drainage area (1.64 mi^2) of the quarry pit. There are various potential effective recharge rates that might be applied to the drainage area. In an unpublished report, Hammond (2005) estimated that the average effective rate was 15 in/yr for a carbonate watershed. The discharge from the Houpt Spring (A. Powell Hatchery) might also be used, as a baseflow separation analysis indicates that the spring flows are 99% groundwater discharge. The average baseflow for the period of record (1986-2020) from the spring is 917 gpd/ac (12.3 in/yr).

For the Security Quarry, the reliability of the early withdrawals (1988-2002) cannot be verified. Prior to evidence of stream infiltration, the average use during the period January 2003 to November 2004 was 1.08 Mgd. It is noted that the average baseflow in Antietam Creek (Sharpsburg) was 20.6 in/yr during that period or about twice the average baseflow of 12.1 in/yr for that basin. If the sole source of inflow to the quarry had been groundwater, then the average yearly groundwater discharge to the quarry would have been about 0.63 Mgd. For the period from 2005 to 2015, there were the two major inflow events (2005 and 2011) after which flows remained elevated for several years while sinkhole repairs and the construction of a grout curtain were completed, Figure 46. It was not until 2016-2020 that flows stabilized at lower rates of about 2-3 Mgd (2.7 Mgd avg). During the same period, the Houpt Spring flows were slightly above average (941 gpd/ac or 12.6 in/yr). Applying that rate to the area of the ZOI produces an effective groundwater inflow to the quarry of 1.0 Mgd, indicating that less than ½ (37%) of the quarry inflow was from groundwater sources. The remainder could have been stream infiltration or seepage from Antietam Creek, its tributary, and Marsh Run. If adjusted to average use, the equivalent groundwater inflow for 2016-2020 of 0.96 Mgd is about 52% greater than that for 2003-2004, which is consistent with an expansion of the quarry pit capture area after opening of the cave and a possible intersection with the fault/fracture system.

After the high inflow starting in December 2004, the operator reported that two wells (Snyder and Herbst) were replaced and water was supplied to three houses owned by the quarry. During 2006, MDE investigated complaints received from homeowners concerning potential impacts to their wells by dewatering of the Security Quarry (Patrick A. Hammond file memo dated May 25, 2006), Figure 47 and Table 11. The investigation involved 7 properties, all supplied by wells. At three (Hunt, Davis, and Hammer) there were no impacts and probably no impact to a fourth well (Stockslager). The quarry replaced two wells (Snyder and Herbst) and one on its own property. The MDE Mining program also investigated potential impacts to wells within the the area of the ZOI and determined that four wells were impacted by dewatering of the quarry. Three of the wells were replaced, while there is no disposition given for the fourth well. The MDE Water Supply Program required that the permittee monitor six wells.The wells replaced did not include any that were being monitored but the monitor wells were in the same relative location as those wells that were replaced.

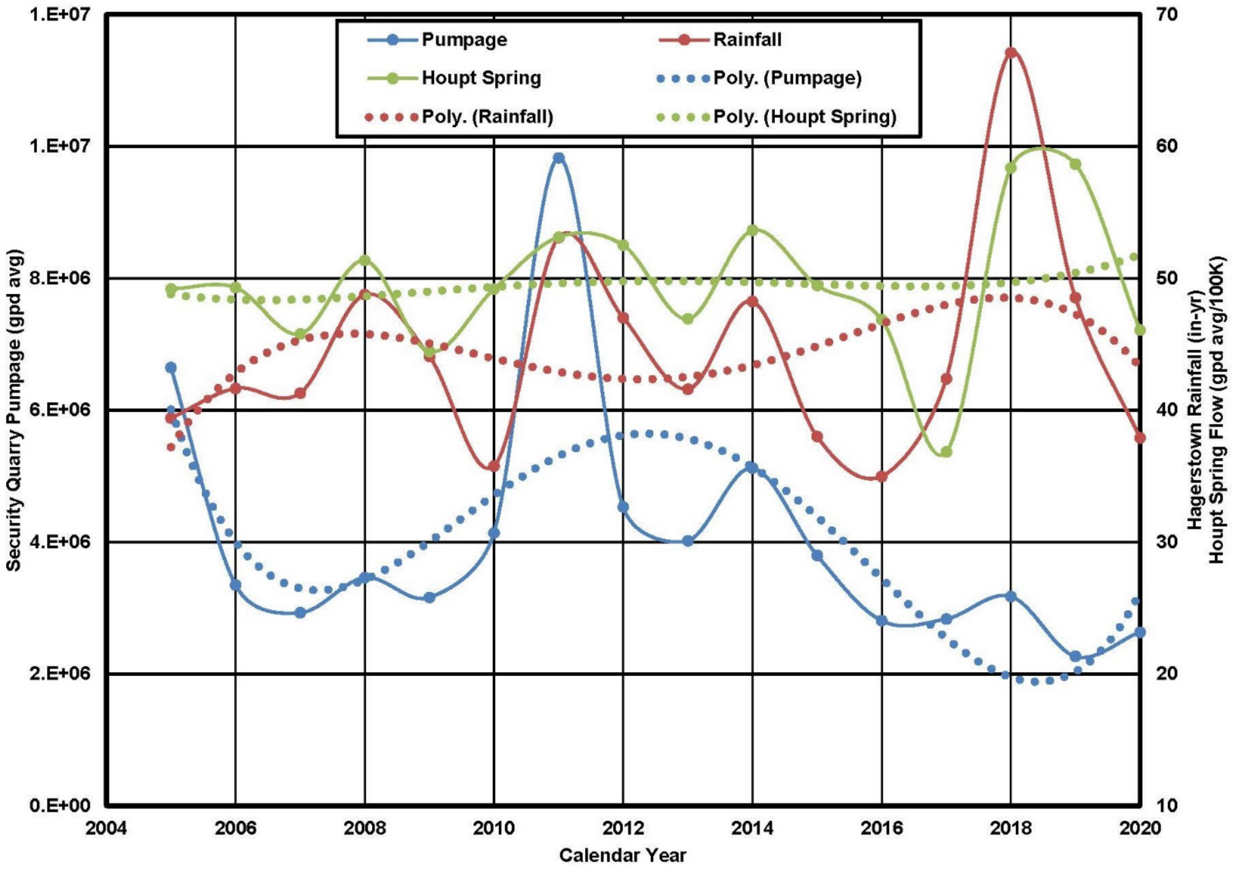


Figure 46. Annual pumpage from the Security Quarry, rainfall in Hagerstown and flow from Houpt Spring for the period 2005 to 2020.

All of the wells that were monitored due to reported problems or replaced within the ZOI were northeast of the quarry pit, while there were none at equal distances to the west of the quarry, near the junction of Old Forge Road and Shiloh Church Road. The geologic map of the area provides a possible explanation for the directional nature of the potential or actual impacts. All of the monitored or replaced wells are in the Conococheque Limestion, with the exception of the Stockslager well. In that case, the owner reported having a turbidity problem only when the well was drilled in 1995, which could not be related to the increased withdrawals by the quarry. The fault and quarry cave are also located in the Conococheque Limestone, while the quarry pit and the wells to the west of the quarry are located in the Stonehenge Limestone. The operator submitted water levels from five wells in 2017 and 2018. The average for those two years and the elevation of the quarry cave (about 400 ft MSL) were used to determine the drawdowns in the vicinity of the quarry, Figure 48. The fault appears to have some control on the groundwater flow, but the contours are oblique to the direction of the fault. However, the northern extent of the fault was not given in the the Brezinski (2018) report, so the direction of the fault could change and conform more closely with the contours. Another factor to consider are potential geologic controls. The broadening of the contours to the east may be due to differences in permeability and porosity between the Conococheque Limestone and the Stonehenge Limestone, Figure 49. While there is no well control to the west of the quarry, the absence of any complaints in the area of the junction of Shiloh Church Road and Old Forge Road would support the relatively steep contours in that direction.

Considering the water use and water level data, initial withdrawals for dewatering came from a relatively low permeability formation, that would produce a narrow, steep cone of depression near the quarry at the low pumping rates. Upon opening of the quarry cave and connection to the fault, there was a direct inflow from Antietam Creek to the quarry pit through the sinkhole on the gun and rod club property. A broad trough of depression also developed within the Conococheque Limestone that produced increased ground water inflows, due to the potentially high permeability and storage of that formatiom.

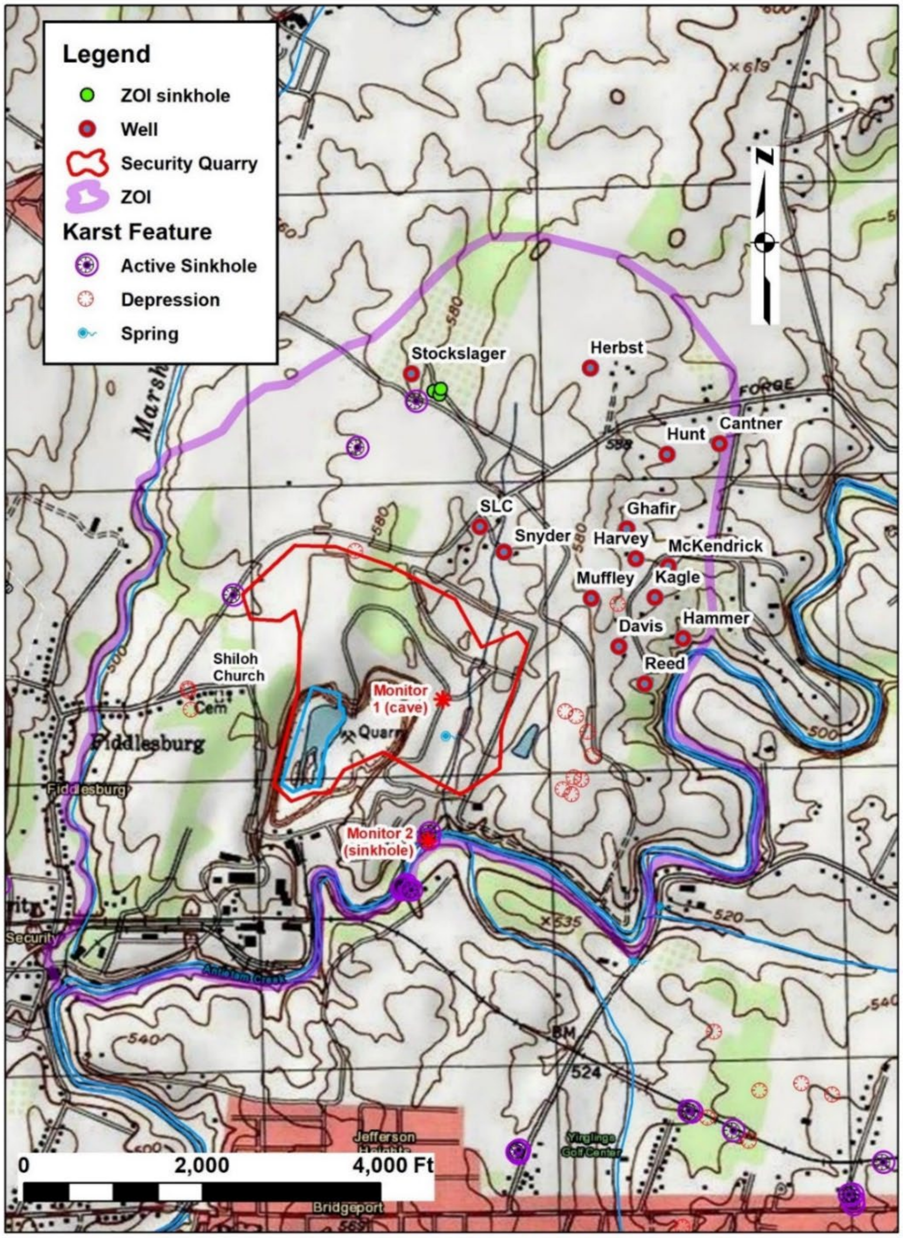


Figure 47. Topographic map showing wells within the Security Quarry ZOI monitored (Snyder, Herbst, Davis, Hammer, Reed and Hunt), inventoried (SLC, Stockslager and Muffley), replaced (Snyder, Herbst, Ghafir, McKendrick, and Kagle) and either were unimpaired or had no disposition (Harvey and Cantner).

Table 11. Domestic water wells within the Security Quarry ZOI that were inventoried, monitored, replaced, and were either unimpaired or for which there was no disposition.

Domestic Wells																
Name	Address		Tax Map	Grid	Parcel	Lot	Well Rpt	Well Rpt		Water Level (W/L) (ft)						Comment
	No.	Road	No.	No.	No.	No.	No.	Comp. Date	Depth(ft)	SWL		W/L 2006	Drawdown	W/L 2017	W/L 2018	
Inventory/Monitor																
St. Lawrence Cement	20023	Old Forge Road	38	9	779		No record	-	140+	-		92				House built 1968-pump lowered to 140ft
Harne (MGS Bi 108)	near 20023 Old Forge Road						WA-69-0059	2/14/1969	105	83						MGS BDR 18
Snyder (Holcim)	20029	Old Forge Road	38	9	773		WA-94-4322	11/3/2005	275	60 (E)		107	47+	141	117	Pump lowered, dirty, new well drilled
Snyder (Holcim)	20029	Old Forge Road	38	9	773		No record									Barn well - dry, mud @ 60-63 ft
Stockslager	20122	Old Forge Road	38	3	871	2	WA-94-0244	8/18/1995	325	120?		N/A				well in use
Herbst	20204	Old Forge Road	38	4	8		WA-94-4139	4/23/2005	400	60		N/R	NR	139	117	
Muffley	20228	American Way	38	10	827	C3	WA-94-2135	11/14/2000	275	61		77	16			
Davis	20212	American Way	38	10	827	C1	WA-73-0814	8/29/1974	125	50		73	23	82	74	
Hammer	20205	American Way	38	16	829	E3	WA-73-1613	12/13/1976	250	56		54	-2	56	53	
Reed	20202	American Way	38	16	829	E1	WA-73-2741	4/14/1979	205	45		N/A	N/A	65	59	
Hunt	12809	Navy Way	38	10	824	A5	WA-73-2558	10/20/1978	120	50		66	16	78	66	Pumped air, check valve replaced
ZOI Investigations											Problem	Replace No.	Comp. Date	Depth	SWL	
Harvey	20254	American Way	38	10	827	C5	WA-73-1621	10/2/1976	150	60	Sediment	N/A				Installed sand separator
McKendrick	20255	American Way	38	10	827	C6	Unknown				No water	WA-95-1171	2/4/2016	300	30	New well drilled
Kagle	20241	American Way	38	10	827	C7	WA-73-2748	4/17/1979	125	65	No water	WA-95-1167	1/7/2016	150	80	New well drilled
Ghafir	20256	American Way	38	10	824	A1	WA-73-2949	11/16/1979	100	30	No water	N/R				New well drilled
Cantner	12816	Cedar Hills Drive	38	10	824	A12	WA-73-1655	11/2/1976	85	45	No water	N/R				No disposition found

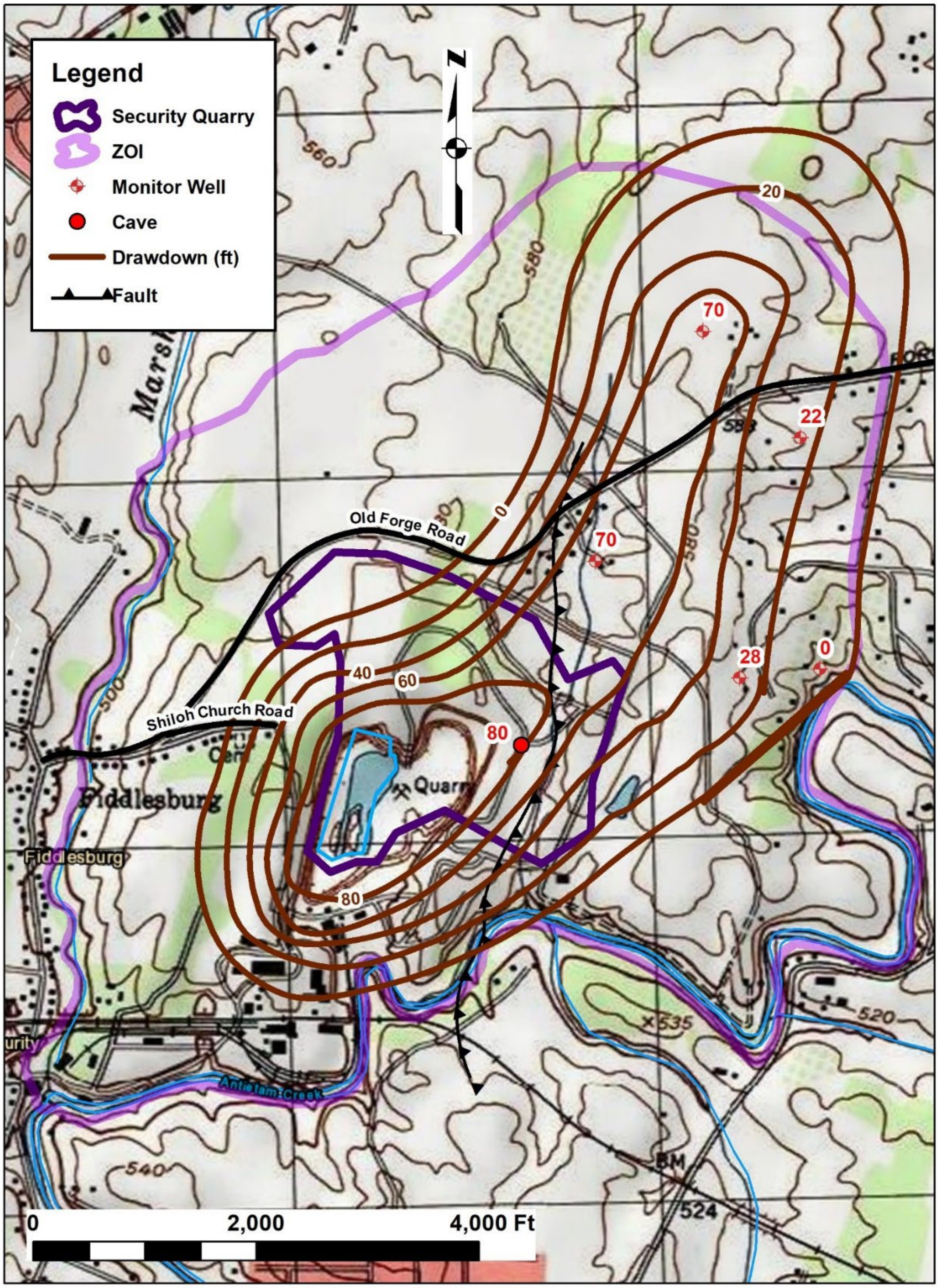


Figure 48. Topographic map within the Security Quarry ZOI showing the drawdown contours constructed from water levels in the monitoring wells and estimated for the cave discharge point due to dewatering of the quarry as of 2017/18.

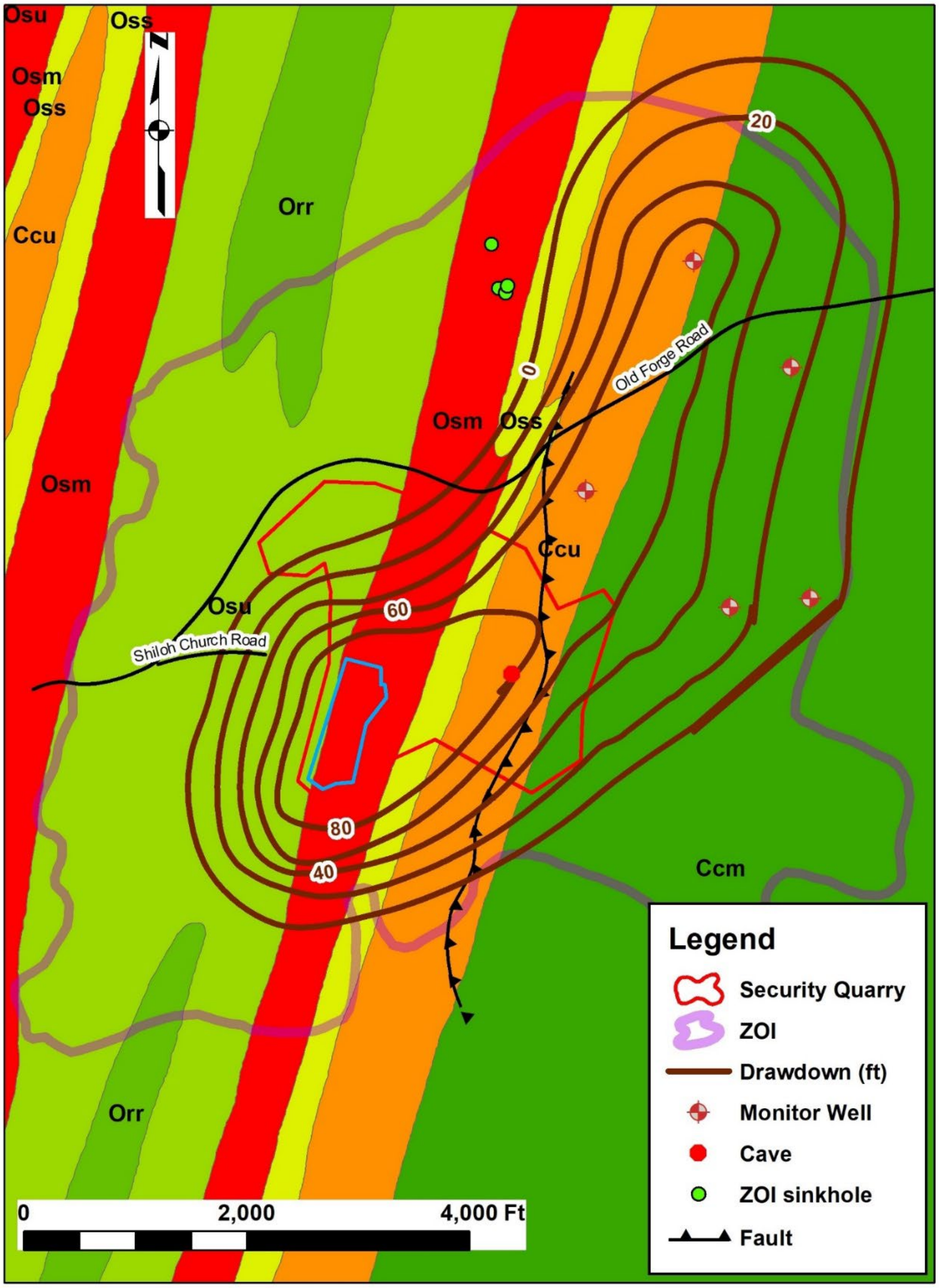


Figure 49. Geologic map within the Security Quarry ZOI showing the drawdown contours constructed from water levels in the monitoring wells and estimated for the cave discharge point due to dewatering of the quarry as of 2017/18. Units are the Conococheque Limestone (Ccm-middle member, Ccu-upper member), Stonehenge Limestone (Osm-middle member, Oss-Stoufferstown member, Osu-upper member) and Rockdale (Orr) Formation.

References

Aley, T., 2007, Delineation of the zone of influence for the St. Lawrence Cement Quarry, Hagerstown, Maryland. Ozark Underground Laboratory Water and Land Use Investigations, 33 p.

Brezinski, D.K., 2018, Geology and karst development of the Hagerstown Valley (Great Valley) of Maryland. Maryland Geological Survey Report of Investigation 86, 101p.

German, D.L. and Worthington, R.H., 2005, Hagerstown Quarry tracer test. Gartner Lee Limited, Ontario, Canada. Prepared for St. Lawrence Cement USA in July 2005. 17p.

Hammond, P.A., 2006, File memo for Water Appropriation and Use Permit WA1986G016/5, titled "St. Lawrence Cement Hagerstown Quarry, evaluation of water level monitoring data". May 25, 2006. Maryland Department of the Environment, Water Supply Program, Baltimore, Maryland.

Hammond, P.A., 2005, Carbonate Recharge Rates – Maryland/Pennsylvania/Virginia, February 3, 2005. Maryland Department of the Environment, Water Supply Program, Baltimore, Maryland.

Maryland Department of the Environment, Water Appropriation and Use Permits WA1919S050 (Antietam Creek) and WA1986G016 (Security Quarry). Maryland Department of the Environment, Water Supply Program, Baltimore, Maryland.