An Analysis of the Use of Mine Water from Abandoned Mines for the Development of Marcellus Shale Gas Wells in Pennsylvania[1]

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Introduction

Pennsylvania has thousands of abandoned mine drainage (AMD) discharges that impair water quality in over 5,500 miles of streams (2010 Pennsylvania Integrated). AMD is responsible for more impaired stream miles in Pennsylvania than any other pollution source. The flow rate and quality of these AMD discharges can vary significantly, and the Commonwealth does not currently have adequate resources to treat all of these discharges. The Marcellus shale gas industry has greatly expanded in Pennsylvania in the last few years, and the long-term outlook predicts tens of thousands of new wells to be drilled in the state over the next several decades. A process used during drilling known as hydraulic fracturing requires five to eight (5-8) million gallons of water per well (Marcellus Shale). Companies are addressing this need primarily with surface water sources or by purchasing water from public water suppliers. The consumption of high volumes of surface water has raised concerns about stream impacts. Although AMD discharges contain pollutants, with treatment the water can serve as a resource for industrial uses, including hydraulic fracturing. Treatment of these discharges can potentially restore thousands of miles of streams, with resulting economic and quality of life benefits. Gas companies could partner with federal, state, or local governments or with watershed groups to target AMD discharges for treatment and use in the development of new gas wells. This type of cooperation could lower the costs for both parties and provide significant environmental benefits. This paper will focus on the background, water requirements, water sources, costs, and benefits for use of mine water from abandoned mines for the development and hydraulic fracturing of Marcellus Shale gas wells in Pennsylvania. Since shale gas formations similar to the Marcellus Shale exist in numerous places across the country, the analysis and issues are applicable in many other states.

Background of the Development of the Marcellus Shale on Pennsylvania

The first gas well drilled in the Marcellus shale formation in Pennsylvania was completed by Range Resources in 2004 in Washington County (Harper and Kostelnik). Since that time, the number of wells drilled has dramatically increased. According to the Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management, 195 gas wells were drilled into the Marcellus shale formation in Pennsylvania in 2008. The number of wells drilled increased to 763 in 2009, and 1,454 during 2010. The Pennsylvania Department of

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Environmental Protection (PA DEP) is projecting that the number of wells drilled per year will continue to increase to approximately 3,500 per year by 2020. Figure 1 shows a Marcellus shale gas well being drilled in Fairfield Township, Westmoreland County. According to the Susquehanna River Basin Commission (SRBC), the average Marcellus gas well requires 4.2 million gallons of water and can require up to 8.3 million gallons of water to hydraulically fracture. Chesapeake Energy estimates a water requirement of 100,000 gallons per well to drill the well, and 5.6 million gallons per well for the hydraulical fracturing process. Most gas companies are either buying this water from municipal water suppliers or withdrawing from surface or groundwater sources near the well site. Purchasing this water or paying fees to river basin commissions for withdrawing it from streams and aquifers can be extremely expensive. The cost to permit and obtain all approvals for these supplies can also be time consuming and expensive.

Pennsylvania has thousands of abandoned mine discharges with flow rates from a few gallons per minute to several thousand gallons per minute. These discharges are located throughout Pennsylvania in the same general areas that are underlain by the Marcellus Shale formation. These mine discharges may offer a lower cost alternative to using clean sources of water. Use of mine water by gas companies could also help solve one of Pennsylvania's biggest environmental problems.

Figure 1. Marcellus shale Gas Well Drilling Site, Fairfield Township, Westmoreland County

Water Requirements for Marcellus Gas Well Development

Water is an essential component of Marcellus deep shale gas well development. A fluid consisting of water, sand, and other additives, is used in both drilling the well and in a process called hydraulic fracturing, which pumps this fluid under high pressure into underground formations creating fractures and allowing natural gas to escape. The fluid is more than 99% water and proppant. The proppant is composed of naturally occurring sand grains, but

specifically engineered materials such as high strength ceramic materials can also be used. The proppant is used to keep the fractures open and still allow natural gas to flow into the well. According to Chesapeake Energy, it takes approximately 100,000 gallons of water to drill a Marcellus gas well and approximately 5.6 million gallons to hydraulically fracture the well. Figure 2 shows an explanation of the hydraulic fracturing process. The water used during the drilling process is used to carry rock cuttings to the surface, as well as to cool and lubricate the drill bit. The amount of water required to hydraulically fracture a typical well (5.6 million gallons) is equivalent to the amount New York City uses in eight minutes; the amount a 1,000 megawatt coal-fired power plant uses in 13 hours; the amount a golf course uses in 28 days; or the amount a nine-acre field of corn requires in a single growing season (Water Use). The SRBC estimates that the consumptive water demand for Marcellus shale gas wells will grow to 28 million gallons per day (MGD) in the Susquehanna River Basin when the drilling reaches its peak in 5-10 years.

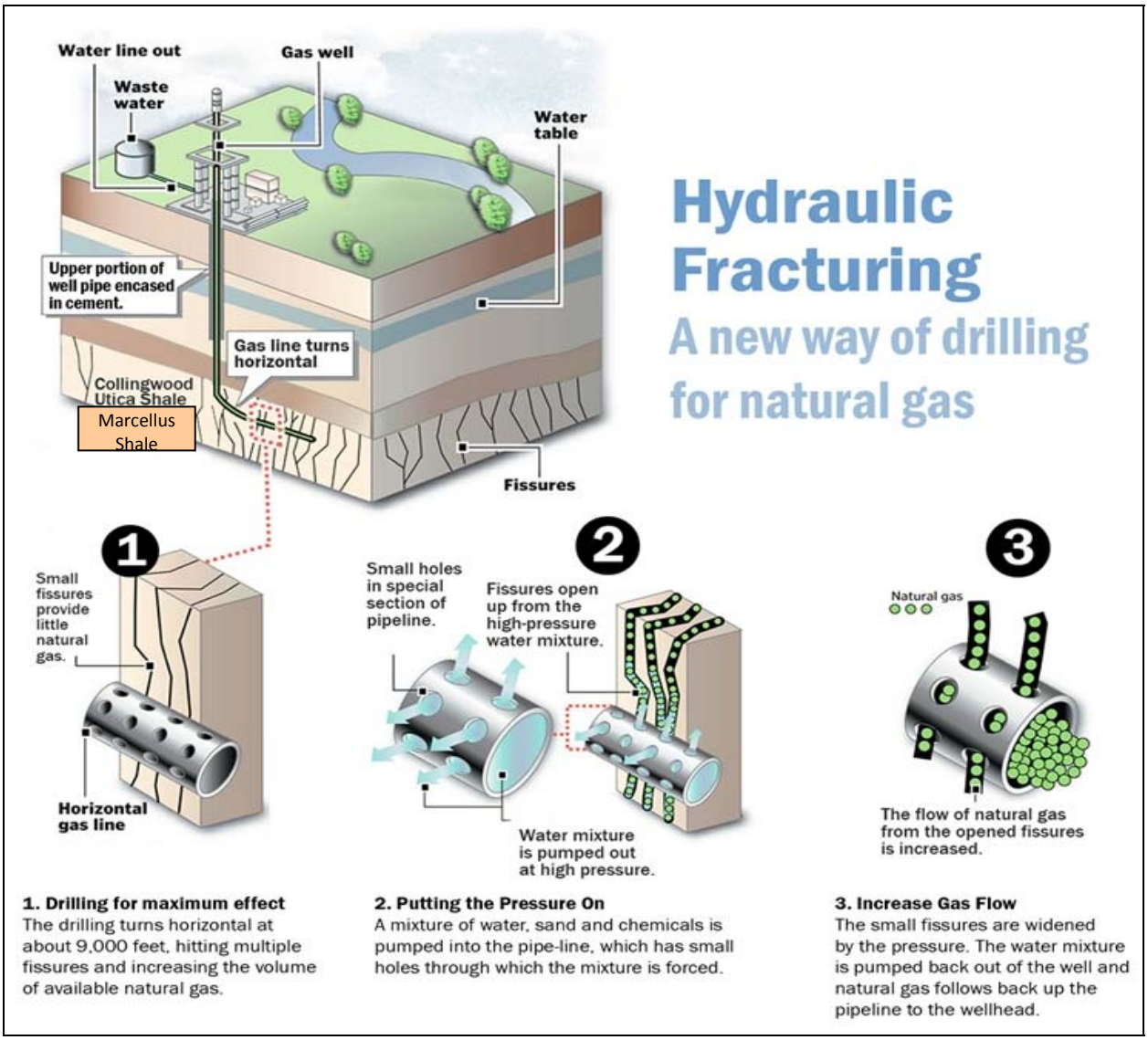

Figure 2. Hydraulic Fracturing Diagram (Hydraulic Fracturing)

Current Sources and Cost of Water for Marcellus Shale Gas Wells

There are a variety of water sources that can supply Marcellus gas well drilling companies with the water they need. Currently sources such as rivers, lakes, streams, and municipal water supplies are used depending on the geographic location of the drilling site. The water is typically transported by truck to drilling locations for storage and use. An alternative is using temporary pipelines to transport the water (Marcellus Shale). There are however, concerns about water resources related to Marcellus drilling. Supplying the water could impact local water resources, and the use of trucks will create large amounts of truck traffic on rural roads, which could lead to degradation of small watersheds and streams (Soeder and Kappel). In Pennsylvania, energy companies involved in gas well drilling and hydraulic fracturing must submit a water management plan to the PA DEP for approval prior to receiving approval of their gas well permit. For streams, a withdrawal impact analysis and a low flow analysis is required. For groundwater sources, only a withdrawal impact analysis is required (Guidelines). For mine drainage or other wastewater sources, a withdrawal impact analysis is required, but is much less stringent (Water Management). The cost to supply water to a Marcellus well site can run in the hundreds of thousands of dollars, particularly if a municipal water supply is used. Table 1 shows some typical costs for municipal water supplies being used for hydraulic fracturing of Marcellus shale gas wells in Pennsylvania.

Table 1. Costs of Municipal Water for Various Geographic Areas of Pennsylvania

Gas Company	County	Supplier	Cost ($/1,000 gal)	Source
East Resources	Tioga	Erwin NY Municipal Authority	$ 14.50	1
Range Resources	Washington	PA American Water	$ 10.50	2
Burnett Oil Co.	Fayette	PA American Water	$ 7.89	3
Burnett Oil Co.	Westmoreland	Highridge Water Authority	$ 8.00	3
EOG Resources	Elk	Ridgway Water Authority	$ 7.00	4
Average			$ 9.57	

1 - Star Gazette Newspaper, Elmira New York, News Article, September 22, 2010
2 - Tom Gray, Tetratech Consultants, Personal Communication, Oct. 19, 2010
3 - Rob Hilliard, Burnett Oil Regulatory Manager, Personal Communication, Dec. 2, 2010
4 - Dubois Courier Express Newspaper, News Article, April 19, 2011

In addition to the PA DEP, water withdrawal approvals are obtained from three institutions that govern interstate waters in Pennsylvania. These three institutions include the Delaware River Basin Commission (DRBC), the Susquehanna River Basin Commission (SRBC), and the Ohio River Sanitary Commission (ORSANCO). The DRBC is responsible for managing the water in the Delaware River. The east and west branches of the Delaware River join near Hancock, New York, and from there, the river flows 330 miles to the Delaware Bay.

The Marcellus Shale underlies about one-third of the Delaware River Basin. The DRBC charges a fee for surface and groundwater withdrawals within the basin. For Marcellus shale gas wells, the water withdrawals are considered a consumptive use, and the DRBC charges $0.06 per thousand gallons. The SRBC is responsible for managing the Susquehanna River, which starts in Cooperstown, New York and runs 444 miles to the Chesapeake Bay. Almost three-quarters of the Susquehanna River watershed is underlain by the Marcellus shale. Like the DRBC, the SRBC charges a fee for surface and groundwater withdrawals within the basin. For Marcellus shale gas wells, the water withdrawals are considered a consumptive use, and the SRBC charges $0.28 per thousand gallons.

The Ohio River basin is not set up the same as the DRBC and SRBC. Instead ORSANCO regulates water quality in the basin but not water withdrawals. Overall these river basin commissions regulate the gas industry's individual and cumulative impacts on water resources. They can determine whether water-use activities could have an "adverse, cumulative adverse or interstate effect on the water resources of the basin (Water Withdrawals)." Table 2 summarizes the consumptive use fees charged within the three major river basins in Pennsylvania. Figure 3 shows the extent of the Marcellus shale and the boundaries of the major river basins in Pennsylvania.

Table 2. River Basin Commission Consumptive Use Charges in Pennsylvania

River Basin Commission	Consumptive Use Fee Charged	Cost ($/1,000 gal)	Source
Delaware	Yes	$ 0.06	1
Susquehanna	Yes	$ 0.28	2
Ohio (Sanitary)	No	$ -	3
Average		$ 0.11	

1 - Delaware River Basin Commission (DRBC) – (Basin Regulations)
2 - Susquehanna River Basin Commission (SRBC) – (Regulatory Program)
3 - Ohio River Sanitary Authority Commission (ORSANCO)

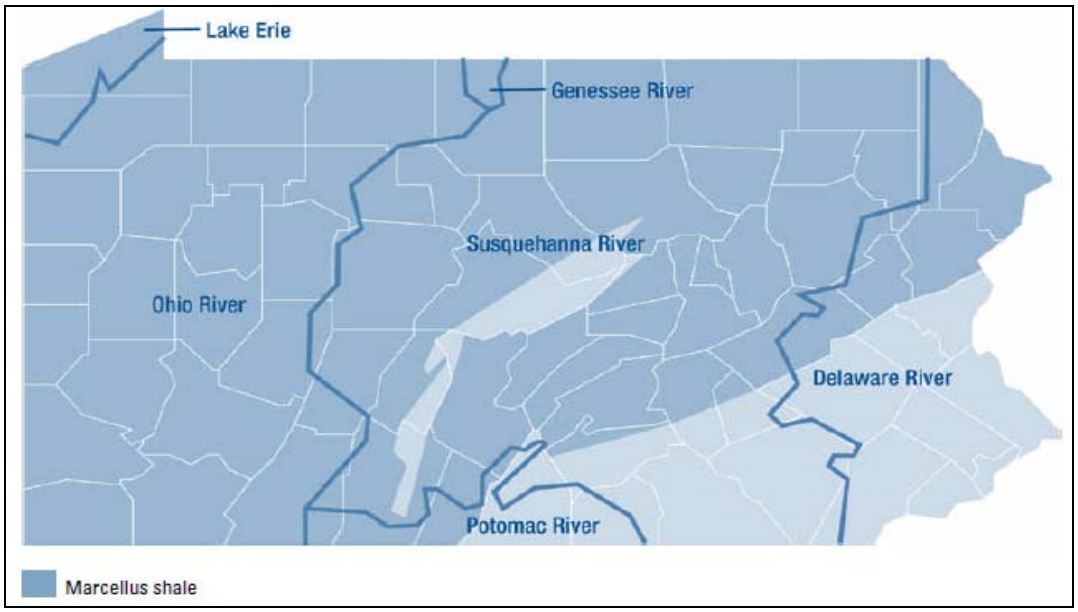

Figure 3. Extent of Marcellus Shale and Major River Basins in PA (Water Withdrawals)

Use of Mine Water for Gas Well Development and Hydraulic Fracturing

Pennsylvania has thousands of AMD discharges that have impaired water quality in over 5,500 miles of streams located within the Commonwealth. AMD is responsible for more impaired stream miles than any other pollution source (2010 Pennsylvania Integrated). Figure 4 shows the location of some of the major AMD discharges in Pennsylvania and relative to the extent of the Marcellus shale formation. The flow rate of these AMD discharges varies from a few gallons to thousands of gallons per minute, and the quality of the discharges, while highly variable, are generally characterized by high levels of iron, manganese, aluminum, sulfates, chloride and total dissolved solids (TDS). Treating AMD from abandoned mines could have significant environmental benefits by restoring water quality in streams. AMD is usually treated by raising the pH with some alkaline reagent such as hydrated lime or sodium hydroxide. Once the pH has been raised high enough, the dissolved metals undergo various chemical reactions (oxidation, hydrolysis, and precipitation) and can then be settled out in large settling ponds. The cost to treat AMD can be vary significantly from discharge to discharge. Table 3 includes the 2009 treatment costs for several AMD treatment facilities in Pennsylvania. Some very severe AMD discharges would not be suitable for use by gas well developers even after treatment due to high TDS, primarily sulfates, which are undesirable for use in hydraulic fracturing. The benefits to Pennsylvania of encouraging the use of mine water for Marcellus shale gas well development are significant. Companies stand to decrease costs by treating or purchasing mine water at a lower cost than purchasing water from public water supplies. Monies provided by the industry could be used to treat more discharges and to provide funding for long-term operation and maintenance (O&M) of treatment systems. More AMD would be treated, long-term O&M costs would be addressed, and more stream miles would be permanently recovered. In addition, the impact to surface waters by the removal of large quantities of water for gas well development would be greatly reduced.

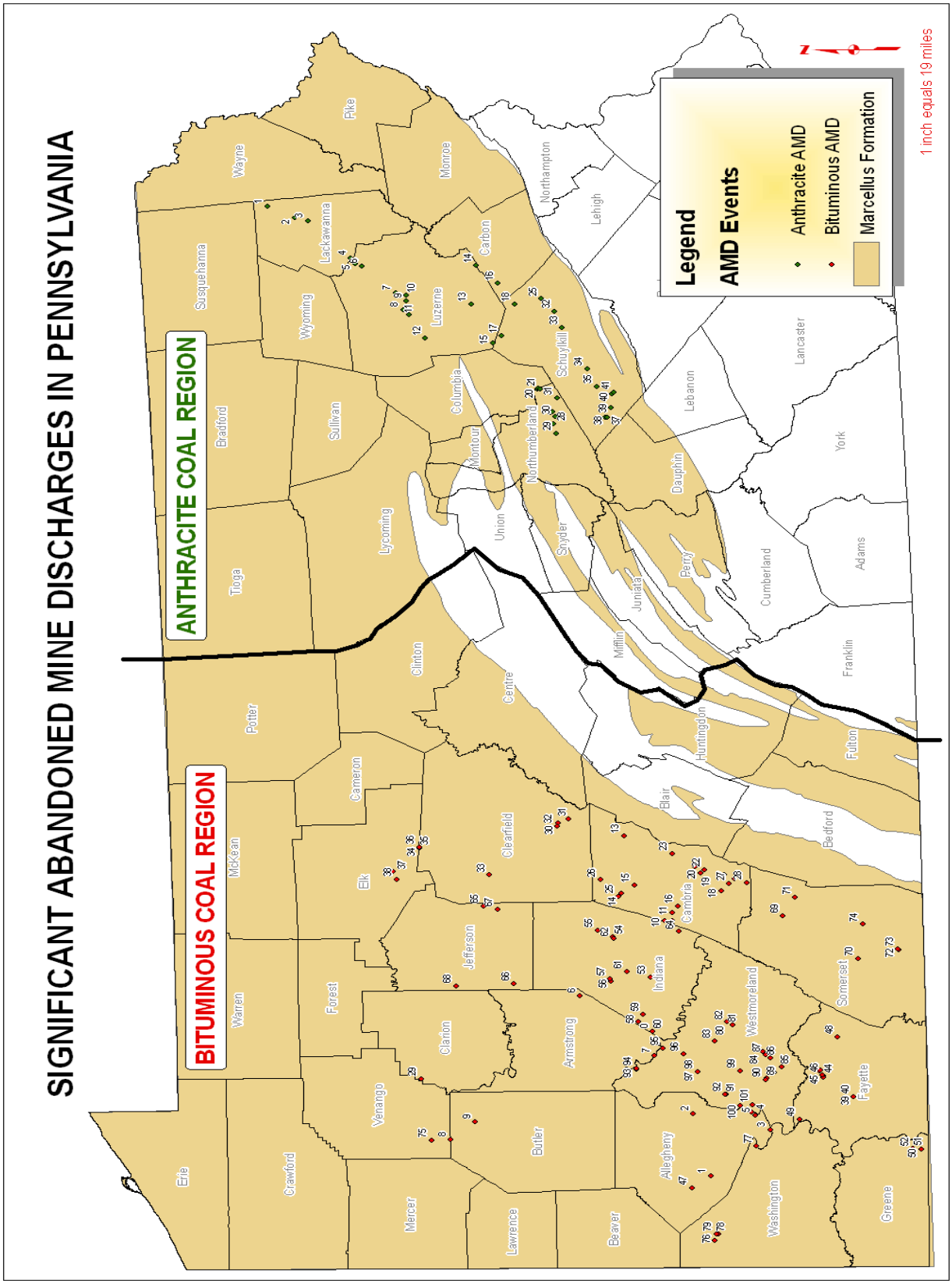

Figure 4. Significant Abandoned Mine Discharges in Pennsylvania (Source: PA DEP)

Table 3. Treatment Costs for AMD Treatment Facilities in Pennsylvania

Treatment Plant	County	Operator	Flow Treated (MGD)	2009 Treatment Cost ($/1,000 gal)	Source
Wildwood	Allegheny	PA DEP	0.9	$ 0.11	1
Brandy Camp	Elk	PA DEP	1.4	$ 0.66	1
Blue Valley	Elk	Toby Creek Watershed Assoc.	0.4	$ 0.76	2
Toby Creek	Elk	PA DEP	0.7	$ 0.57	1
Rausch Creek	Schuylkill	PA DEP	10.8	$ 0.07	1
Bethlehem Mine 31	Cambria	Pristine Resources	3.0	$ 0.45	3
Bethlehem Mine 38	Cambria	Pristine Resources	4.0	$ 0.41	3
Monview-Mathies Mine	Washington	PA DEP	1.5	$ 0.09	1
Average			2.8	$ 0.20	

1 – Dan Sammarco, PA DEP, Chief of AMD Operations, Personal Communication, Sept. 17, 2010
2 - Bill Sabatose, President, Toby Creek Watershed Assoc., Personal Communication, Oct. 29, 2010
3 - Larry Neff, Operations Manager, Pristine Resources, Personal Communication, Sept. 2, 2010

Economic Analysis of Using Mine Water versus Other Sources

Based on the cost of purchasing water from a municipal water supplier, the use of AMD could dramatically reduce costs for gas well developers in Pennsylvania. At an average cost of $9.57 per 1,000 gallons for municipal water, and an average of 5.6 million gallons of water required per well, the cost to purchase water for each well would be approaching $60,000 without taking into consideration the trucking or piping costs. Assuming treated AMD can be used for hydraulic fracturing without additional treatment, and at a cost of only $0.10 – $0.75 per 1,000 gallons treated, using the treated AMD could reduce the cost to only a few thousand dollars per well. The cost of using treated AMD is also competitive when comparing it to the consumptive use fees charged by the SRBC and the DRBC. Also, the DRBC has put a moratorium on approving any new water sources for Marcellus shale gas wells and public opposition is making it more expensive and difficult to get approvals for any new water sources in the Susquehanna and Ohio River Basins.

There are many potential partners for gas companies to work with to treat mine water for use in developing Marcellus shale gas wells. There are many watershed groups in Pennsylvania

that have constructed passive mine drainage treatment systems. Additionally, many federal, state, and local government entities have also built AMD treatment facilities that are actively being operated throughout Pennsylvania (Pam Milavec, PA DEP, Personal Communication, 7 Dec 2010). All of these groups and agencies have ongoing costs to operate and maintain these treatment systems. Gas companies could partner with these treatment system operators and purchase water for lower costs than that of municipal water supplies or watershed basin consumptive use charges. This money could be used to pay for or offset the annual operating costs for these treatment systems or generate additional funds to be used to treat additional AMD discharges.

Summary

The Marcellus shale gas industry has expanded significantly in Pennsylvania in the last few years. The long-term outlook is for thousands of Marcellus gas wells to be drilled and completed in Pennsylvania over the next several years. This activity often requires in excess of five (5) million gallons of water per well. Companies are addressing this need primarily with surface water (stream) sources and by the purchase of water from public water supplies, at costs as high as $15 per thousand gallons. The consumption of high volumes of surface water has raised concerns about stream impacts. The PA DEP's Bureau of Oil and Gas Management staff evaluates the sources of water and potential impacts to surface and groundwater resources during the well permitting process. Although AMD discharges carry some pollutants, with treatment the water could serve as a resource for industrial uses, including as a source of water for development and hydraulic fracturing of Marcellus shale gas wells. Use of AMD water by the Marcellus gas industry could enable the treatment of significantly more AMD discharges. Gas companies could partner with federal, state, or local governments or with watershed groups to target AMD discharges for treatment and use in the development of new gas wells. This type of cooperation could lower the costs for all parties and provide significant environmental benefits.

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