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CONFERENCE PROCEEDINGS

Coal Mine Drainage for Marcellus Shale Natural Gas Extraction

Proceedings and Recommendations from a Roundtable on Feasibility and Challenges

Appendixes A, B, C, and D: White Papers and Presentation Slides

Anthony Iannacchione • Elise Barbot • Radisav Vidic • Seth Blumsack
Thomas Murphy • David Yoxtheimer • Peter Fontaine

With Charles Cravotta • Doug Kepler • Eric Cavazza • Pam Milavec
Joseph K. Reinhart • Kevin J. Garber

Sponsored by the Marcellus Shale Coalition
This research was sponsored by the Marcellus Shale Coalition and was developed in collaboration with the RAND Environment, Energy, and Economic Development Program within RAND Infrastructure, Safety, and Environment, a division of the RAND Corporation.
Preface

Recent technological innovations have enabled access to “unconventional” natural gas resources from shale gas formations, including Pennsylvania’s Marcellus Shale, via hydraulic fracturing. However, this technique uses substantial amounts of water. The Marcellus Shale region also has large quantities of polluted, often acidic, coal mine water. Some mines release this water, resulting in coal mine drainage into nearby rivers and streams. In light of the ongoing environmental problems posed by coal mine drainage, some have suggested that it could be used as a water source in hydraulic fracturing operations.

On December 14, 2011, with funding from the Marcellus Shale Coalition, the RAND Corporation hosted a roundtable conference exploring the use of coal mine water for hydraulic fracturing in the Marcellus Shale. The proceedings of the event, which was held in RAND’s Pittsburgh office, can be found at http://www.rand.org/pubs/conf_proceedings/CF300.html.

These appendixes accompany the conference proceedings and consist of white papers and conference presentations. The white papers were intended to focus the issues for the speakers prior to the meeting, form the basis of the speakers’ presentations, and serve as a reference for researchers and decisionmakers who are interested in delving deeper into the various topics discussed at the roundtable. These materials were written by invited speakers and are included here with their permission. This material was not formally peer-reviewed, and the opinions expressed are those of the invited speakers and do not necessarily reflect the opinions of RAND or the roundtable sponsor, the Marcellus Shale Coalition.

Marcellus Shale Coalition

The Marcellus Shale Coalition provided funding to RAND to plan, host, and moderate this roundtable, as well as to compile and publish these proceedings. As an independent policy research organization, RAND generated the list of non-MSC member participants and retained full editorial control of the content of the main proceedings document. The content of these online appendixes was fully provided by the invited speakers for the roundtable.

The Marcellus Shale Coalition is the industry association “committed to the responsible development of natural gas from the Marcellus Shale geological formation.” For additional information see http://marcelluscoalition.org.

The RAND Environment, Energy, and Economic Development Program

The December 14, 2011, roundtable conference was hosted by RAND under the auspices of the Environment, Energy, and Economic Development Program (EEED) within RAND Infrastructure, Safety, and Environment (ISE). The mission of RAND Infrastructure, Safety, and Environment is to improve the development, operation, use, and protection of society’s essential physical assets and natural resources and to enhance the related social assets of safety and security of individuals in transit and in their workplaces and communities. The EEED research portfolio addresses environmental quality and regulation, energy resources and systems, water
resources and systems, climate, natural hazards and disasters, and economic development—both domestically and internationally. EEED research is conducted for government, foundations, and the private sector.

Questions or comments about the proceedings and these online appendixes should be sent to Aimee Curtright (Aimee_Curtright@rand.org). Information about the Environment, Energy, and Economic Development Program is available online (http://www.rand.org/ise/environ.html). Inquiries about EEED projects should be sent to the following address:

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Online Appendix A: The Coal Mine Drainage Problem and Role as a Potential Water Source

Session 1 of the roundtable conference focused on the issue of coal mine drainage and its potential utility as a water source for hydraulic fracturing operations. The session provided an overview of the unique and variable characteristics of coal mine water in the Marcellus Shale region, including the types of mines that can be found in the region, approaches for treating coal mine discharge, and the quantities and quality of water that might be available.

A white paper prepared by Anthony Iannacchione, associate professor and director of the Mining Engineering Program at the University of Pittsburgh’s Swanson School of Engineering, provides background on these topics. The paper is followed by the slides that were presented during the session by Professor Iannocchione and Charles A. Cravotta of the U.S. Geological Survey’s Pennsylvania Water Science Center.
Session 1 White Paper: Assessing the Coal Mine Water Resources: A Marcellus Shale Perspective

By Anthony Iannacchione, Associate Professor and Director of the Mining Engineering Program, Swanson School of Engineering, University of Pittsburgh

Introduction

This analysis assesses coal mine water resources and discusses the advantages and disadvantages of using this resource for drilling and hydraulic stimulations of deep natural gas wells in the Marcellus Shale play. The Marcellus Formation extends over seven states and encompasses some 95,000 square miles. Southwestern Pennsylvania is the center of Marcellus Shale gas permitting and drilling activity and is the region of focus of this analysis.¹ Coal extraction has occurred in this area since before the revolutionary war. Figure 1 shows the 16 southwestern Pennsylvania counties where both bituminous coal mining and Marcellus Shale gas drilling activity occur.

¹ These findings should also apply to eastern Ohio and most of West Virginia, where bituminous coal mining and unconventional gas drilling are also occurring.
Where Is Underground Bituminous Coal Mining Located in Southwestern Pennsylvania?

There are nearly 1,600 abandoned underground bituminous coal mines in Southwestern Pennsylvania, undermining approximately 1.1 million acres of land. Many of the very smallest, occupying less than a few acres, were mined before 1900. Since that time, the size and mechanization of mines has steadily increased. Today, there are less than 50 underground bituminous coal mines, but some of these are among the most productive in the world. Modern mining layouts and extraction techniques are diverse and have produced a variety of extraction ratios and stability conditions. This variability could impact the size of the water resources contained within these mines and the ability to safely and efficiently extract this resource.

In Southwestern Pennsylvania, several coal seams have been developed. Figure 2 shows the location of the underground bituminous coal mines in this region. The majority of these mines have been developed in the Pittsburgh coal bed, but other prominent seams mined are the Sewickley, Lower Kittanning, Upper Kittanning, Lower Freeport, and Upper Freeport. In some limited areas, multiple seam mining has occurred.

Figure 2. Location of underground bituminous coal mines in Southwestern Pennsylvania (PA DEP, 2011a)

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2 Map data was obtained primarily from the Pennsylvania Department of Environmental Protection (PA DEP), updated with a few additional sources obtained from the Office of Surface Mining, and entered into ArcGIS.
Coal Mine Water Discharge Characteristics Have Been Established, but Further Information Is Emerging

Coal mine water discharge is typically acidic with varying compositions of total dissolved solids (TDS), total suspended solids (TSS), iron (Fe), aluminum (Al), manganese (Mn), barium (Ba$^{2+}$), and sulfates (SO$_4^{2-}$). Waters coming from underground mines have been extensively studied and characterized. The quantity and quality of the water is highly dependent on local mining and geologic conditions (Leavitt et al., 2003; McCoy et al., 2006; and McDonough et al., 2005). Ziemkiewicz et al. (2004) report on the quantity and quality of water in the Pittsburgh coal bed mine pool. Lambert et al. (2004) discuss the long-term changes in the quality of discharge water from abandoned underground coal mines.

While it is beyond the scope of this analysis to discuss these findings at length, it is important to note that significant variability in water properties has been observed. For example, Cravotta (2008a and 2008b) sampled water from 140 abandoned bituminous and anthracite mines in Pennsylvania and found pH values ranging from 2.7 to 7.3 (pH increased with flow rate). Many of these studies have focused on the characteristics of the dissolved metals. More recently, total dissolved solid (TDS) are being measured in conjunction with Pennsylvania’s new standard of 500 mg/L.

Where Are the Marcellus Shale Gas Resources Located?

Marcellus Shale gas wells have been drilled in many of the same areas that possess coal mines. Figure 3 shows the location of the Marcellus Shale gas resources in Southwestern Pennsylvania. As of January 2011, there were 2,735 Marcellus Shale gas wells that had been permitted, spud, drilled, or abandoned in Southwestern Pennsylvania. Many of these wells are located near or above underground mines, especially in Greene, Washington, and Fayette counties.

There Are a Wide Variety of Treatment Methods for Coal Mine Discharge

While there are many ways to treat coal mine discharges, methods can be divided into “passive” and “active” categories. The water coming from abandoned mines—especially those abandoned before important federal and state laws passed in the late 1970s—are generally associated with discharges for which there are no responsible entities to provide treatment. Such discharges do not have a funding mechanism (e.g., trust fund) in place to cover perpetual treatment. Passive treatment processes are often used under these conditions because of their lower capital cost. Passive treatment processes typically allow impaired coal mine discharge to enter settling ponds, where biological processes and water dilution produce a more acceptable discharge.

For example, the Max B. Nobel mine drainage remediation site near Indian Creek, Fayette County, collects and treats two underground mine discharges (Figure 4). This facility successfully removes 87% of the iron load, 70% of the aluminum load, 61% of the acid load, lowering flow rates (Mountain Watershed Association, undated).
Figure 3. Location of Marcellus Shale gas wells that have been permitted, spud, drilled, or abandoned in Southwestern Pennsylvania underlain by abandoned bituminous coal mines (PA DEP, 2011b).

Figure 4. Photographs from the Max B. Nobel mine drainage remediation site, showing (a) coal mine drainage from an abandoned mine in Westmoreland County, (b) an aerial view of the passive treatment facility, and (c) windmills used to oxygenate the water in the settling ponds.

Active treatment systems require higher capital expenditures and much higher operating costs to continuously process significant quantities of water coming from large mine pools. These systems use concentrated soda ash, which is injected into the mine discharge water in an aeration pit to accelerate the deposition of metals (Figure 5). After mixing, these waters enter a series of ponds where the metals settle out of the solution and are periodically dredged from the ponds and disposed according to state regulation.
Each Coal Mine Has Distinctive Water Resource Features That Should Be Considered

There are four categories of underground bituminous coal mines, each with distinctive water resource features.

Above Drainage Abandoned Mines (legacy mines)

The Southwestern Pennsylvania region contains hundreds of abandoned mines, or “legacy mines,” and each has the potential to discharge to surface water systems (above drainage). Legacy mines are often very shallow (< 400 ft) because they were mainly driven with cut, drill, and shot room-and-pillar mining techniques. The mine entries have wide rooms (> 18 ft) with high extraction ratios (> 60%). While the overall extraction ratio is high for these mines, the use of full-extraction mining techniques to achieve these values has produced caved strata with water void ratios estimated to be approximately 25%.

Drilling into areas where the strata have caved presents challenges for maintaining borehole stability. The treatment systems for these mines will be diverse. For example, the PA DEP (2011a) provides data on orphan mine discharges. The data were collected from 2002 to 2006. The sum of all flow data coming from the 126 locations is slightly over 100,000 gal/min, producing pH values averaging 5.1 (SD = 1.6), and TDS values averaging 1,087 mg/L (SD = 725). These data suggest that treatment processes will need to be tailored for site conditions.

Shallow Active Mines

Currently, there are approximately 40 active room-and-pillar mines in Pennsylvania. Almost all of these mines are shallow (overburden < 400 ft) and are located above drainage. The mine entries are narrow (< 18 ft) with extraction ratios of less than 60%. In many of these mines, water is allowed to collect in small pools, often in sealed areas of the mines, where oxygen content is greatly reduced. The water treatment practices for shallow active mines are diverse but are primarily focused on reducing metal concentrations in settling ponds. Active mines are required by
Pennsylvania law (25 PA Code § 87.1–87.122; 25 PA Code § 89.1–89.96) to have a pH value from 6.0 to 9.0, with strict limits on the concentration of Fe, Mn and Al, and TDS (< 500 mg/l).

Below Drainage Abandoned Mines

These mines generally have overburdens of more than 400 ft but less than 1,100 ft and have used a combination of room-and-pillar and longwall mining methods. In general, they are large (i.e., several thousand acres) with a high concentration occurring within the Pittsburgh coal bed. Figure 6 shows a number of very large mines along the Monongahela River close to the Greene, Washington, and Fayette county boundaries. Many of these mines are either partially and fully flooded with water, and some are discharging water near, or into, the Monongahela River. The volume of water available within these mines is potentially very large; however, full-extraction mining could reduce the quantity and quality of the water.

![Figure 6. Large below drainage abandoned mines near the boundaries of Greene, Washington, and Fayette counties](image)

NOTE: Water treatment facilities are shown as green pentagons. Blue arrows denote the direction of water flow within the mines where water flows from anticlinal highs into synclinal basins (contour intervals represent the elevation of the Pittsburgh coal bed).

Deep Active (Modern Longwall Mines in Washington and Greene Counties)

The deep, active modern longwall mines are located exclusively in Greene and Washington counties (Figure 7). Overburdens range from 600 ft to 1,100 ft (Iannacchione et al., 2011). Longwall mines outline huge blocks of coal with room-
and-pillar mining methods and then extract these blocks or panels with the longwall mining method. Longwall mining fully extracts the coal and allows the overburden to collapse into the void left by mining.

Figure 7. Location of seven active longwall mines (pink) and abandoned mines (blue) in Greene and Washington counties

NOTE: The Bailey mine is actually considered to be three separate mines (Bailey, Bailey Extension, and BMX). All of these mines are below drainage and have overburdens ranging from 600 to 1,100 ft (Iannacchione et al., 2011).

Figure 8 illustrates how longwall mines collect water in a series of pools and transport the water to the surface, where it is piped to the coal refuse embankment. The coal mine discharge is added to a pool on the surface of the embankment. It then flows down through the embankment, exiting at its base.
Discussion

Much of the water that enters a mine has the potential to make its way to groundwater reservoirs or to surface water systems. Capturing this impaired water before it enters these systems would be beneficial for this region. However, it is clear that many challenges exist and much work is needed to understand where and when this capture will be most effective.

The amount of water needed by the gas industry to support drilling and hydraulic stimulation of Marcellus Shale wells can be estimated as follows: Assume 2,000 wells drilled per year with each well using approximately 4 million gallons of water. At this rate, 8 billion gallons of water are needed per year.

Last year, a senior design project team at the University of Pittsburgh estimated that the Gates Mine contained an estimated 1.4 billion gallons of water. This mine is of medium size, encompassing some 1,300 acres. Clearly, the total amount of water present in all of the underground bituminous coal mines is orders of magnitude more than the estimated demand to support Marcellus Shale drilling and hydraulic stimulations.

The volume of coal mine water is not the issue. Finding a mine pool that has the right water composition for drilling and hydraulic stimulation could be a problem, as would withdrawing that water without adversely impacting existing water resources or conditions within the mine pool. In addition, this mine pool will need to be located near a site where long-term water demand will support the development of systems to pipe the water from the mine and to the drill site.

There are benefits and challenges associated with exploiting coal mine water resources in this region.
Benefits

- Many mine pools of varying size are located near Marcellus Shale gas drilling sites.
- Some pools, especially those associated with abandoned mines, represent a potential long-term source of industrial water.
- Active mines have existing infrastructure to handle and treat water.
- Active mines also have clear ownership of the water.
- Reducing the quantity of coal mine discharges entering streams, wetlands, and other water resources could help to
  - Improve the overall quality of the region’s water resources, and
  - Sustain the development of the region’s coal mining and gas drilling industries.

Challenges

- Some mine water will not be appropriate for drilling or hydraulic stimulations.
- Water properties are highly variable and are controlled by mining and geological conditions.
- Reservoir conditions are partially controlled by the mining method used.
- Many Marcellus Shale gas plays are not close to mining.
- Some streams need existing mine drainage to maintain minimum flow requirements.
- Mine water treatment processes produce solid waste and potential disposal issues.
- Water withdrawal from underground mines could damage the mine structure and destabilize the strata.
- Abandoned mines have complicated legal issues (i.e., ownership).

References


PA DEP—See Pennsylvania Department of Environmental Protection.


Session 1 Presentations

The remainder of this appendix is devoted to the two presentations delivered in Session 1 of the conference: “Assessing the Coal Mine Water Resources: A Marcellus Shale Perspective,” by Anthony Iannacchione, and “Use of Acidic Mine Drainage for Marcellus Shale Gas Extraction: Hydrochemical Implications,” by Charles A. Cravotta III.¹

¹ Dr. Cravotta provided additional supplemental slides, which are not included in this appendix. Please contact Aimee Curtright at Aimee_Curtright@rand.org to obtain a copy of those slides.
Assessing the Coal Mine Water Resources: A Marcellus Shale Perspective

Anthony Iannacchione
Associate Professor
Director of the Mining Engineering Program
Civil and Environmental Engineering
Swanson School of Engineering
University of Pittsburgh

PA Counties where Marcellus Shale gas drilling and bituminous underground coal mines co-exist
Sources of data

- PA DEP, Bureau of Mining & Reclamation and Bureau of Oil and Gas Management
- ACT 54 3rd Assessment
- Office of Surface Mining, Mine Map Repository
- WV Water Research Institute, “Monongahela Basin Mine Pool Project”
- USGS, Charles Cravotta III (1999 samples)

PH from mine field samples

Significant variability in the composition of mine waters

Could mine water supply a portion of the region’s demand for industrial water?

- ~ 1,600 underground bituminous coal mines in PA
- ~ 1.1 million acres undermined
- Many partially or completely filled with water
- Quantity is highly dependent on mining conditions
- Quality or composition of water is highly dependent on local geologic conditions
- Can this water be used as a source of industrial water?
Marcellus Shale gas and underground coal mines (active and abandoned)

- > 2,700 Marcellus Shale gas well permits, spud reports, abandoned wells (from PA DEP) in study area
- Many are located over or near underground mines (especially in Washington, Fayette and Greene counties)

Four categories of underground bituminous coal mines with distinctive water resource features

- Above drainage abandoned (hundreds of mines)
- Shallow active (~40 mines in PA, < 400-ft overburden)
- Below drainage abandoned (> 400 but < 1,100-ft overburden)
- Deep active (modern longwall mines in Washington and Greene counties)
**Above Drainage Abandoned Mines** *(legacy mines)*

- Drill, kerf cut, and shot room-and-pillar mining
- Wide rooms, high extraction mining

**Above drainage abandoned mines**

- In general, high in metals, low in pH
- Legacy mines
- Ownership is complicated (DEP has a say)

*Example – Indian Creek Coalfield*

Most abandoned mines are either partially or totally filled with water

Void ratios vary widely depending on the mining type
Indian Creek Coalfield (Fayette Co., PA)

- Underground mining from 1906 to 1976
- Max B Nobel Mine Drainage Remediation Site (Passive Treatment)
- Collects and treats 2 underground mine discharges
- Removes 87% of the iron load, 70% of the aluminum load, 61% of the acid load, lowers flow rates

- Windmills aerate water helping contaminants to settle faster
- Acid mine drainage treatment facility
- Was a big source of sediment and acid runoff

Shallow Active Mines (~40 modern room-and-pillar mines)

- Diverse company ownership
- Considerable expertise handling and treating water
- Water treatment practices vary

- Modern room-and-pillar layouts have extraction ratios between 50 and 70 percent
Below Drainage Abandoned Mines

- Combination of room-and-pillar and longwall operations
- Water properties can change with time – often improve

Rice’s Landing treatment plant (Active process)

- Mine water compositions (often highly acidic, wide range of TDS, TSS, iron, aluminum, manganese, sulfates, barium)

Hydrated lime

Aeration and precipitation
Deep Active Mines (7 longwall mines)

Huge blocks of coal are completely mined...

Deep Active Mines (modern mines)

Marcellus Gas Well
Mine Drainage
Enlow Fork
Treatment Plant
Bailey
Emerald
Blacksville 2
Cumberland
Benefits of using mine water as a source for industrial water

- Many mine pools of varying size are located near Marcellus Shale gas drilling sites
- Some pools, especially those associated with abandoned mines, represent a potential long term source of industrial water
- Active mines have existing infrastructure to handle and treat water
- Active mines also have clear ownership of the water
- Reducing the quantity of coal mine discharges entering streams, wetlands, and other water resources could help to
  - Improve the overall quality of the region’s water resources, and
  - Sustain the development of the region’s coal mining and gas drilling industries
**Challenges of using mine water as a source for industrial water**

- Some mine water will not be appropriate for drilling or hydraulic stimulations
- Water properties are highly variable and are controlled by mining and geological conditions
- Reservoir conditions are partially controlled by the mining method used
- Many Marcellus Shale gas plays are not close to mining
- Some streams need existing mine drainage to maintain minimum flow requirements
- Mine water treatment processes produce solid waste and potential disposal issues
- Water withdraw from underground mines *could* damage mine structure and de-stabilize strata
- Abandoned mines have complicated legal issues (i.e., ownership)
Use of Acidic Mine Drainage for Marcellus Shale Gas Extraction—Hydrochemical Implications

Charles A. Cravotta III, Ph.D., P.G.
USGS Pennsylvania Water Science Center, New Cumberland, PA

Presented at “Summit on the Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction Activities,” December 14, 2011, Pittsburgh, PA

“CLEAN SAMPLING” OF 140 AMD SOURCES IN 1999

Bituminous Field
99 AMD samples

Anthracite Field
41 AMD samples
BIMODAL pH FREQUENCY DISTRIBUTION

A. Anthracite Mine Discharges

B. Bituminous Mine Discharges

DOMINANT SOLUTES IN “AMD”

Nonmetals:
\[ \text{SO}_4 > \text{HCO}_3 > \text{PO}_4 = \text{NO}_3 = \text{NO}_2 = \text{Se} \]

Halogens:
\[ \text{Cl} > \text{Br} > \text{I} > \text{F} \]
DOMINANT SOLUTES IN “AMD”

**Alkali Earths:**
Na > K > Li > Rb > Cs

**Alkaline Earths:**
Ca > Mg > Sr > Ba > Be

DOMINANT SOLUTES IN “AMD”

**Metals:**
Fe > Mn > Al > Zn > Ni > Co > Y > Sc > Ti > Cu > Cr > V > Mo > Cd > W > Zr > Nb > Au
ENVIRONMENTAL SIGNIFICANCE OF “AMD”

- Net Acidity, mg L\(^{-1}\) CaCO\(_3\)
- S\(_2\)O\(_3\), mg L\(^{-1}\)
- Pyrite, µg L\(^{-1}\)
- pH

**As**, µg L\(^{-1}\)

**Fe**, µg L\(^{-1}\)

**Al**, µg L\(^{-1}\)

**SO\(_4\)**, mg L\(^{-1}\)

**Zn**, µg L\(^{-1}\)

**Ni**, µg L\(^{-1}\)

**Cd**, µg L\(^{-1}\)

**Cr**, µg L\(^{-1}\)

**Pb**, µg L\(^{-1}\)

**Cu**, µg L\(^{-1}\)

**Mn**, µg L\(^{-1}\)

- pH

**Bituminous**
- Bituminous BDL
- Anthracite
- Anthracite BDL
- MCL
- CMC
- CCC
- -CrVI
- -CrIII

**PME**
- SCL

**CCC**
- PME
"Appreciable barium" found in reservoirs of Pennsylvanian, Mississippian, Devonian, and Silurian age in WV (Heck, 1940).

**High barium, low sulfate brines**

"In West Virginia, almost without exception, every brine that was free of sulphate contained barium. ... it is probable that most of the sulphate-free brines of Ohio and Pennsylvania also contain barium" (Heck, 1940).

CONCLUSIONS

• Not all “AMD” is acidic—regionally, pH ranged from 2.7 to 7.3 and had a bimodal distribution.

• “Net alkaline” AMD had near-neutral pH ($\geq 6$); persistent $SO_4$, Fe, Mn; decreased Al and trace metals.

• Concentrations of trace metals (As, Cd, Cr, Cu, Pb, Ni, Se, V, and Zn) in near-neutral AMD were less than freshwater CCC levels.

IMPLICATIONS

• Treatment of AMD to pH $> 6$ with removal of dissolved Fe to $< 7$ mg/L may provide a reasonable measure of protection for aquatic life.

• Groundwater pumped from flooded coal mines may be useful to augment stream flow downstream of a stream-water intake for Marcellus Shale gas extraction.
IMPLICATIONS

• Elevated SO$_4$ in untreated or treated AMD is incompatible with Ba in formation or flow-back waters from Marcellus Formation.

• Mixing AMD containing SO$_4$ with flow-back water containing Ba will precipitate barite and decrease constituent concentrations relative to end members.

• Advanced treatment may be needed to remove SO$_4$ and other solutes in AMD or flow-back water.
Online Appendix B: Technical Uncertainties and Challenges in Using Coal Mine Water for Hydraulic Fracturing

Session 2 of the roundtable conference focused on the complexities of using coal mine water for hydraulic fracturing, with particular attention to the technical challenges and uncertainties and whether coal mine drainage can meet current water quality requirements.

A white paper prepared by Elise Barbot and Radisav Vidic of the Department of Civil and Environmental Engineering (which Professor Vidic chairs) at the University of Pittsburgh’s Peterson Institute of Nanoscience and Engineering outlines these technological barriers and points out gaps in the research on this topic. The paper is followed by the slides that were presented at the conference by Professor Vidic. Doug Kepler, vice president of environmental engineering at Seneca Resources Corporation, provided additional remarks, which are summarized in the conference proceedings; he did not provide corresponding slides.
Introduction

Extraction of natural gas from the Marcellus Shale gas play requires large amounts of water for hydraulic fracturing and generates significant quantities of wastewater. There is a lack of options for disposal or treatment of this wastewater for discharge into natural streams. The number of Class II injection wells in Pennsylvania is very limited and cannot accommodate the volume of flowback water generated. Moreover, the high salinity of the wastewater requires energy-demanding thermal processes to reach the total dissolved solids (TDS) limit imposed by the Pennsylvania Department of Environmental Protection for discharge. As a consequence, shale gas development companies have focused on the reuse of hydraulic fracturing flowback and produced waters and are experimenting with alternative sources of water, such as acid mine drainage (AMD). In this paper, we discuss the minimum water quality requirements for hydraulic fracturing in the Marcellus Shale and how well AMD may meet these requirements.

What Are the Minimum Water Quality Requirements for Hydraulic Fracturing in Marcellus Shale?

Regulations and a lack of well-defined water quality requirements for hydraulic fracturing limit the use of water from sources other than surface or municipal water. In September 2007, an expert panel determined the minimum water quality requirements for reliable and effective hydraulic fracturing of Barnett Shale in northern Texas (Hayes, 2008). These requirements are presented in Table 1.
Table 1. Requirements for hydraulic fracturing fluid in Barnett Shale

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and grease</td>
<td>&lt; 200 ppm</td>
<td>Affect friction reducers</td>
</tr>
<tr>
<td>Soluble organics</td>
<td>—</td>
<td>No problem identified</td>
</tr>
<tr>
<td>Chloride</td>
<td>&lt; 10,000 mg/L</td>
<td>Increase demand for friction reducers and scale inhibitors</td>
</tr>
<tr>
<td>Calcium, magnesium, carbonate</td>
<td>Use scale control models (Oddo-Thompson)</td>
<td>Scaling</td>
</tr>
<tr>
<td>Ba²⁺, SO₄²⁻</td>
<td>Simple solubility calculation Scale formation computer models also useful</td>
<td>Scaling</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 20 ppm</td>
<td>Risk of well-plugging (iron hydroxide)</td>
</tr>
<tr>
<td>Soluble calcium</td>
<td>&lt; 350 mg/L</td>
<td>Above 350 mg/L, increase the demand for friction reducer</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>&lt; 100 mg/L</td>
<td>Higher concentration would probably have no effect on the frack job quality</td>
</tr>
<tr>
<td>pH</td>
<td>&lt; 8 (&lt; 7 if possible)</td>
<td>Biocides work best below pH 7</td>
</tr>
<tr>
<td>TDS</td>
<td>Covered through the guidelines on chloride</td>
<td></td>
</tr>
<tr>
<td>Bacteria (APB, SRB)*</td>
<td>&lt; 100/100 mL, indirectly handled according to guidelines on biocides</td>
<td>Gas souring, corrosion</td>
</tr>
</tbody>
</table>

* APB = acid-producing bacteria. SRB = sulfate-reducing bacteria.

The Barnett Shale is different geologically from the Marcellus Shale, and thus the water quality requirements outlined in the table above cannot be directly applied. Moreover, there has been no systematic scientific study to validate these requirements. However, the conclusions of the panel can be used for preliminary decision-making about what water characteristics need to be considered:

- **Potential decrease in efficiency of the hydraulic fracturing chemicals:** Several studies have shown that high TDS content of the fracturing fluid can reduce the efficacy of polyacrylamide-based friction reducers (Tam and Tiu, 1990; Kamel and Shah, 2009).
- **Potential for well-plugging:** Plugging occurs when suspended solids are injected into the wellbore and when precipitation occurs inside the well or in the fractured formation. Both occasions can hinder
productivity. Sulfate and carbonate precipitates, and especially sulfate precipitates, are of concern, as several constituents of the flowback waters (e.g., Ba, Sr, Ca) exhibit low solubilities in the presence of these anions. In the presence of sufficient amounts of sulfate, barium, strontium, and calcium can precipitate and such deposits may cause a reduction in the well permeability. The presence of iron in the fracturing solution may be of significant concern due to the potential for precipitation as iron hydroxide.

- **Bacteriological contamination of the well:** Sulfate-reducing bacteria (SRB) and acid-producing bacteria (APB) can lead to the formation of sour gas and corrosion of the well casing (Bader, 2006). These occurrences can hinder productivity. Sulfate thus presents a double threat, since it can induce rapid formation of sulfate precipitates and growth of SRB.

**Can AMD Meet Local Minimum Water Quality Requirements?**

Plentiful within the Marcellus Shale region, AMD contains high levels of dissolved solids and has a low to mid-range pH. Most of the constituents of the dissolved solids in AMD will not pose a problem with respect to the use of AMD in hydraulic fracturing operations. In fact, recent developments in the synthesis of friction reducers exhibiting effective drag reduction properties in concentrated brines partially eliminated the concerns of using high-TDS waters in hydraulic fracturing (Papso and Grottenthaler, 2010).

However, some ions (Fe, SO$_4^{2-}$) as well as low pH, might limit the application of AMD as a water source for well stimulation. Highly acidic AMD is not suitable for well stimulation, as it will accelerate corrosion of the well casing. High levels of sulfate (SO$_4^{2-}$) are of concern because of the potential to form precipitates, such as CaSO$_4(s)$, BaSO$_4(s)$, and SrSO$_4(s)$ when in contact with the shale.

- **Potential decrease in efficiency of the hydraulic fracturing chemicals:** While AMD is ubiquitous in the Marcellus Shale play, its chemical characteristics vary greatly with the location. Some low-pH discharges are equipped with active treatment systems to neutralize acidity, but a significant number of discharges release water of circumneutral pH, which is not incompatible with the general characteristic of the fluid suitable for hydraulic fracturing. Iron is also removed from some sources by passive treatment in aeration/settling ponds.

- **Potential for well-plugging:** Sulfate is the key contaminant of concern due to its scaling potential. If sulfate is injected in the formation during hydraulic fracturing, well-plugging may occur because of barium sulfate precipitation. Strontium and calcium sulfate are less likely to form, since barium sulfate is less soluble than strontium sulfate and calcium sulfate. The volume of solids that would form in a well if high-sulfate water were used for well stimulation can be roughly estimated under the assumption that there is sufficient barium in the shale to facilitate complete sulfate precipitation as barium sulfate. For example, if an AMD containing 800 mg/L SO$_4^{2-}$ is used as the only frac fluid, the volume of BaSO$_4$ that can potentially precipitate downhole is 4.9 m$^3$. 
which is less than 0.5% of the total volume of sand injected as a proppant. If the calculation is done with the highest sulfate concentration encountered in AMD in the area of the Marcellus Shale, i.e., 2,000 mg/L, the volume of precipitated barium sulfate reaches 1.3% of the volume of sand. Even in the case of injection of AMD highly concentrated in sulfate, the volume of solids formed by precipitation is negligible in comparison to the volume of proppant remaining downhole. This first calculation suggests that the well-plugging may be very limited, but more work needs to be done to quantify the well permeability loss induced by precipitation/scaling.

• Bacteriological contamination of the well: Sulfate is indeed a source of substrate for SRB. There could be a competition between barium-strontium-calcium sulfate precipitation and sulfate reduction by the SRB. It has been shown that SRB could use the barium from solid barium sulfate to grow, thus dissolving the precipitate (Baldi et al., 1996). Using AMD as a water supply for hydraulic fracturing operations requires understanding both its geochemical and microbiological interactions with the formation.

Benefits in the Co-Treatment of Flowback Water and AMD

Many exploration and production companies are practicing flowback water reuse for subsequent hydraulic fracturing operations. The flowback water is generally pretreated to remove suspended solids and, occasionally, metals (calcium, barium, strontium) that tend to generate scale formation. Pretreated flowback water is then mixed with fresh water, which makes up for the fraction that is not recovered during the flowback period and controls the salinity of this mixture for subsequent operations.

AMD, if used as makeup water, can offer a promising alternative for treating both flowback water and AMD at the same time. High sulfate levels in AMD will react with major divalent cations in the flowback water and be precipitated as their insoluble sulfate forms. In addition, some AMD sources are net alkaline, which would lead to additional precipitation of CaCO$_3$. The removal rate and extent depends on the ion concentrations, which change with the initial quality of both streams and the mixing ratio that can be adjusted, depending on the desired final hydraulic fracturing fluid quality.

AMD Regulatory Framework

The relevant legal and regulatory frameworks for AMD are discussed in detail in another, later section in this paper. The most salient points for technical consideration, however, are covered here.

Since the passage of the Clean Water Act in 1972, discharges of water from active mining operations have come under the National Pollutant Discharge Elimination System (NPDES) permitting process established under the law. The establishment of NPDES limits on mine water discharges has resulted in required treatment of water from active mining operations and for some period of time after closure of active mining operations. Several mining companies have already built treatment facilities
that produce finished water of known quantity and quality, which can certainly be considered as a source water for hydraulic fracturing in the vicinity of such facilities.

Abandoned mine discharges are currently not under the NPDES program, and from experience with projects in Pennsylvania and West Virginia, it appears that most of the AMD passive treatment projects which have been undertaken are also not part of the NPDES permitting program. Other uses of AMD in Pennsylvania, such as in low-head hydroelectric projects, also do not fall under water quality regulations at this time. The regulatory environment for use of AMD may be evolving and, indeed, is likely to continue to evolve as AMD is sought as an alternative to fresh water for use in power plant cooling and other applications.

A recent hydraulic fracturing review in Pennsylvania, which was published in September 2010, states that the Bureau of Oil and Gas Management encourages the use of AMD for hydraulic fracturing purposes and promotes the sale of treated AMD-impacted water to gas developers. A treatment facility that was recently completed in Tioga County to process flowback water is also utilizing local AMD as a make up water through combined blending and treatment strategies. However, this stationary facility requires trucking the flowback water to the site and the treated water back to the well field.

The Marcellus Shale Advisory Commission, whose report was published in July 2011, recommends developing new legislation to encourage operators to decrease their freshwater use and minimize truck traffic in the region. It can be a win-win situation, where operators are provided with some protection against long-term environmental liability for the use of water from abandoned mine pools while watershed groups generate revenues to restore other AMD-impacted streams.

The Use of AMD in Marcellus Shale Needs Technical Analysis and Regulatory Change

The future of the use of AMD for well stimulation depends upon technical and legal progress. One project that may facilitate forward movement is aimed at understanding the chemistry of co-treating AMD and flowback water (Vidic and Gregory, 2011). Supported by the U.S. Department of Energy, this work entails determining the kinetics and equilibrium for chemical reactions occurring when the two waters are mixed, as well as the resulting water chemistry and the characteristics of solid by-products. The need for further treatment to meet specified finished water quality is also being evaluated in this study.

A second key project, also funded by the Department of Energy, evaluates the fate of naturally occurring radioactive materials that are commonly present in the flowback water under different surface impoundment management strategies, including the addition of AMD water as makeup (Gregory and Vidic, 2011).

Currently, there exists a need to evaluate the potential impact of using AMD for Marcellus Shale development on well productivity and gas quality. As suggested, natural resources from the Marcellus Shale cannot be exploited based on Barnett Shale–specific criteria. As sulfate appears to be the main source of concern for using AMD in well stimulation, the first research goal should be to determine the sulfate
concentration limit that would ensure the quality and quantity of natural gas production from Marcellus Shale wells. This study should also develop and validate models of potential permeability loss due to the downhole precipitation of sulfate salts. In parallel, microbiological studies of SRB growth under relevant conditions of temperature, pressure, and water composition must be examined. The ultimate goal is to obtain the limits for the amount of sulfate that can be present under particular hydraulic fracturing solution conditions. In parallel with these efforts, strategies and requirements for treating AMD to remove sulfate prior to use in hydraulic fracturing should be evaluated.

The legal implications of water withdrawal from uncontrolled discharges also need to be examined. Water withdrawals for Marcellus Shale drilling activities are under the jurisdiction of either interstate basin commissions or state agencies. The Code of Federal Regulations states that water withdrawal must be limited in both quantity and rate to avoid any adverse impact on water level, competing supplies, aquifer storage capacity, water quality, fish and wildlife, and low flow of perennial streams. Based on the water demand, a minimum passby flow may be required to maintain adequate health of the stream ecosystem. Withdrawal of AMD falls under the same legislation as surface and ground water, although it is technically a waste and the first source of surface water pollution of the region. There is a need for regulations that are adapted to the specific case of AMD withdrawal for hydraulic fracturing operations.

Direct access to mine pool water may be desirable in some locations. Little attention has been paid to this alternative, but such water sources may be suitable for direct use after some dilution even under the strict rules developed for Barnett Shale. Depending on the exact configuration of the abandoned mine and the position of the water table in the abandoned mine, it is possible to find mine pool waters that have sulfate levels as low as 150 mg/L (Ziemkiewicz et al., 1997). Furthermore, mine pool waters are often located underneath well pads in the Marcellus Shale region and offer a unique opportunity to minimize transportation costs for water supplies in many locations. Moving forward, it is important to understand all possible adverse impacts (e.g., mine subsidence) and develop best management practices that will minimize such outcomes.

**Conclusion**

The use of AMD or combined AMD-flowback water in hydraulic fracturing operations could benefit both gas developers and watershed associations. The benefits of using mine water include a decrease in the use of fresh water, reduced truck traffic, limited cost for flowback water treatment, and limitation of the environmental impact of mine drainage to freshwater streams. Of course, as with any solution, there are challenges that need to be overcome. Rigorous understanding of the chemical and microbiological limitations and the impacts of AMD withdrawals, as well as development of appropriate regulations, would be needed to overcome these challenges.
References


Session 2 Presentation

The remainder of this appendix is devoted to the first presentation delivered in Session 2 of the conference: “Using AMD for Hydraulic Fracturing: Technical Uncertainties and Challenges,” by Radisav Vidic. Professor Vidic’s presentation was followed by remarks by Doug Kepler, vice president of environmental engineering at Seneca Resources Corporation; no corresponding slides were provided.
Using AMD for hydraulic fracturing: Technical uncertainties and challenges

Elise Barbot and Radisav Vidic

University of Pittsburgh

Fracturing fluid quality requirements

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil and grease</td>
<td>&lt; 200 ppm</td>
<td>Affect friction reducers</td>
</tr>
<tr>
<td>Soluble organics</td>
<td>-</td>
<td>no problems identified</td>
</tr>
<tr>
<td>Chloride</td>
<td>&lt; 10,000 mg/L</td>
<td>Increase demand for friction reducers and scale inhibitors</td>
</tr>
<tr>
<td>TDS</td>
<td>covered through the guidelines on chloride</td>
<td></td>
</tr>
<tr>
<td>Suspended solids</td>
<td>&lt; 100 mg/L</td>
<td>Higher concentration would probably have no effect on the frac job quality</td>
</tr>
</tbody>
</table>
### Fracturing fluid quality requirements

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Concentration</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>&lt; 8 (&lt; 7 if possible)</td>
<td>Biocides work best below pH 7</td>
</tr>
<tr>
<td>Calcium, Magnesium, Carbonate</td>
<td>Use scale control models</td>
<td>Scaling</td>
</tr>
<tr>
<td>Ba, SO4</td>
<td>Simple solubility calculation Scale formation computer models also useful</td>
<td>Scaling</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt; 20 ppm</td>
<td>Risk of well plugging (iron hydroxide)</td>
</tr>
<tr>
<td>Bacteria (APB, SRB*)</td>
<td>&lt; 100/100 mL, Indirectly handled through guidelines on biocides</td>
<td>Gas souring, corrosion</td>
</tr>
</tbody>
</table>

### Conventional Unconventional Requirements

- **Simplified Fluid Design**
  - Slickwater with scale inhibitor and bactericide
- **Water Quality**
  - Shale permeability
    - Production mechanism
    - Water mobility

#### Challenge conventional rules of thumb

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional Limits</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>60 to 80 mD</td>
<td>Fluid density, Scaling</td>
</tr>
<tr>
<td>Chloride</td>
<td>&lt;20,000 mg/L</td>
<td>Fluid stability</td>
</tr>
<tr>
<td>Iron</td>
<td>&lt;50 mg/L</td>
<td>Fluid stability</td>
</tr>
<tr>
<td>Ca, Mg, Br, SO₄₂⁻, CO₃⁻</td>
<td>pH(P₂O₅)=&lt; 300 mg/L</td>
<td>Scaling</td>
</tr>
<tr>
<td>Bacteria Count</td>
<td>&lt;10/100 mg/L</td>
<td>Bacteria Growth</td>
</tr>
<tr>
<td>Suspended Solids</td>
<td>&lt;50 mg/L</td>
<td>Silica</td>
</tr>
<tr>
<td>Oil &amp; Soluble Organics</td>
<td>&lt;20 mg/L</td>
<td>Fluid stability</td>
</tr>
</tbody>
</table>
**AMD Selection guide**

- Sufficient flowrate
- Proximity: transportation cost evaluation
- Chemical composition
  - sulfate concentration
  - acidity / alkalinity (corrosion)
  - iron concentration: treatment / no treatment

---

**Drilling sites and AMD locations in PA**

Marcellus well sites (permitted)

AMD sites
Types of Mine Discharges

- Active mining operations
- Abandoned mines
  - Treated
  - Untreated

Active Mining Operations
Availability of Treated Mine Water

Treatment of AMD

Passive treatment systems
- Ponds
- Wetlands
- Anoxic limestone drains
- Vertical flow ponds
- Open limestone channel

- Iron removal by water aeration, iron oxidation, precipitation and settling
- Acidity reduction and Alkalinity increase
**Co-treatment of flowback water and AMD**

Flowback water

Abandoned mine drainage (AMD)

Barium, Strontium, Calcium

Sulfate

Hydraulic fracturing

**Ongoing projects:**
- Determine the chemistry of AMD and flowback water blending
- Understand the fate of radium during blending

---

**AMD and flowback water chemistry**

<table>
<thead>
<tr>
<th></th>
<th>AMD</th>
<th>Flowback</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Site A</td>
<td>Site B</td>
</tr>
<tr>
<td>pH</td>
<td>5.7</td>
<td>7.03</td>
</tr>
<tr>
<td>Alkalinity (mg/L as CaCO3)</td>
<td>62</td>
<td>394</td>
</tr>
<tr>
<td>SO4</td>
<td>696</td>
<td>242.5</td>
</tr>
<tr>
<td>Fe</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>TDS</td>
<td>-</td>
<td>1574</td>
</tr>
</tbody>
</table>

**Mixing ratio based on flowback water recovery**

FB 1 15% + AMD A or B 85%
FB 2 10% + AMD C or D 90%
**Precipitation kinetics**

Initial \( \text{BaSO}_4 \) supersaturation

- 10
- 18
- 35
- 52

Flowback 1 + AMD B Low sulfate
Flowback 2 + AMD D Low sulfate

AMD A High sulfate
AMD C High sulfate

Barium concentration (mg/L)

Time (hr)

Fast and total barium removal for supersaturation above 18

**Crystal growth and composition**

Crystal composition after 30 min:

- \( \text{Ba}_0.75\text{Sr}_0.25\text{SO}_4 \)

Crystal growth and composition

Size (µm)

Volume (%)

30 min
1 hr
3 hr
5 hr
20 hr

\( \text{BaSO}_4 \)
Calcite
Residual sulfate concentration

For 70% AMD
Final SO₄ = 82 mg/L

Possibility to adjust the mixing ratio to limit the sulfate residual concentration

Radium removal during precipitation

70 to 90% radium removal can be achieved during BaSO₄ precipitation by coprecipitation / adsorption
Radium removal during precipitation

Ra removal may be completed within 1 hour

Radioactive solid waste handling

<table>
<thead>
<tr>
<th>Material type</th>
<th>Radium-226 (pCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shale Cutting</td>
<td>2.1 1.2</td>
</tr>
<tr>
<td>Landfill Local Background Soil and Rock</td>
<td>0.9 0.1</td>
</tr>
<tr>
<td>EPA recommended cleanup level (40CFR192)</td>
<td>5 pCi/g</td>
</tr>
<tr>
<td>Typical landfill limits for NORM</td>
<td>5-50</td>
</tr>
</tbody>
</table>

- Naturally Occurring Radioactive Materials such as drill cutting can be disposed in landfills
- Disposal methods:
  - Burial at a licensed NORM landfill or low-level radioactive waste disposal facility
  - Downhole disposal via encapsulation inside the casing of a plugged and abandoned well
  - Underground injection via a permitted well.

Citation: CoPhysic Corporation: Radiological Survey Report on Marcellus Shale Drilling Cutting
Sulfate precipitation downhole

Calculations performed with:
- Fracturing fluid volume = 3 million gal
- 9\% proppant
- Proppant density = 1201 kg/m³

<table>
<thead>
<tr>
<th>SO₄ (mg/L)</th>
<th>BaSO₄ volume (m³)</th>
<th>Volume percentage compared with proppant</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>0.44</td>
<td>0.05%</td>
</tr>
<tr>
<td>200</td>
<td>0.98</td>
<td>0.1%</td>
</tr>
<tr>
<td>800</td>
<td>4.9</td>
<td>0.5%</td>
</tr>
</tbody>
</table>

Negligible volume compared with the volume of proppant injected.
Research needs

• Develop fracturing fluid quality requirements for the Marcellus Shale:
  - Suspended solids
  - Sulfate concentration

• Understand how sulfate precipitates downhole and determine the potential for associated permeability decrease

• Waste disposal options
Online Appendix C: Economic Feasibility and Business Issues

Session 3 of the roundtable conference focused on the economic feasibility of using coal mine water for hydraulic fracturing and a comparison of the costs of fresh water versus coal mine water for this purpose.

A white paper prepared by Professor Seth Blumsack, Tom Murphy, and David Yoxtheimer of Penn State University offers an estimate of the relative costs and the factors that must be considered in weighing the advantages and disadvantages of each approach. The paper is followed by the slides that were presented at the conference by David Yoxtheimer and by Eric Cavazza, manager of the Bureau of Abandoned Mine Reclamation in the Pennsylvania Department of Environmental Protection, that present the costs of using water from existing coal mine drainage treatment facilities.
Session 3 White Paper: Economics of Utilizing Acid Mine Drainage for Hydraulic Fracturing

By Seth Blumsack, Tom Murphy, and David Yoxtheimer, Penn State University

Introduction

The Appalachian Basin has experienced significant fossil fuel energy extraction over the course of time, including coal, oil, and natural gas. The extraction of coal has left behind the environmental legacy issue of acid mine drainage (AMD) in many parts of the Appalachian Basin. Although toxic because of its elevated concentrations of sulfates and metals, AMD as a partial substitute for fresh water in hydraulic fracturing may mitigate existing environmental damage to surface waters and relieve some pressures on freshwater withdrawals. There has been some limited use of AMD for hydraulic fracturing by operators, but a combination of practical, economic, and legal constraints have possibly limited its use. Natural gas drillers will choose to substitute significant quantities of AMD for fresh water only when doing so makes economic and operational sense. Here, we examine the feasibility of using AMD in hydraulic fracturing by comparing the cost of AMD use with that of other water sources.

While AMD transport and treatment costs will be explored in full, it should be remembered that the location of the AMD source must be sufficiently close to development activities to allow it to be cost-effectively transported to the well site(s). Additionally, AMD chemistry must be carefully considered, as borehole precipitation of the metals with sulfates could cause fracture plugging and potentially impede gas flow. Therefore, the AMD may require some treatment or at least significant dilution prior to use to minimize fracture-plugging potential. The legal ramifications of using AMD in Pennsylvania may include that the entity treating AMD from a source must continue to treat the discharge in perpetuity, which would likely involve significant long-term cost. For the purpose of this analysis, it is assumed that the operator will treat only that portion of AMD being used for natural gas development. An additional consideration is that AMD water, even if treated, currently cannot be stored in the lined impoundments that are often used to store fresh water but rather would have to be stored in more-expensive steel tanks or specially engineered impoundments.

Three Primary Factors Need to Be Considered When Comparing Costs

Water purchase, transport, and storage generate significant costs in the development of a shale gas well. In this section, we briefly describe these factors and the costs associated with new water and AMD for hydraulic fracturing in the Marcellus Shale.

Purchase. According to Susquehanna River Basin Commission records, the average horizontal Marcellus well requires 4.2 million gallons of water (100,000 barrels). Reasonable water requirements might range from 3 million to 6 million gallons per
well (about 71,400 to 142,800 barrels, respectively). Typically, costs for water range from approximately $5 to $20 per thousand gallons, or approximately $0.21 to $0.84 per barrel. Thus, water procurement costs might run between $15,000 and $120,000 for completion of a horizontal Marcellus well.

**Transportation.** Moving water represents a larger expense, as it costs approximately $100 per hour to transfer it to the well pad by truck. This figure includes the cost of truck fuel. Typical truck sizes are about 100 barrels (4,200 gallons) of water, so a well-located one-hour round trip from a freshwater source would require between 700 and 1,400 truck trips, representing $70,000 to $140,000 in transportation costs, or nearly $1 per barrel. Thus, assuming all water is trucked in from a location that is a one-hour round trip from the well, the range of water costs to develop a single Marcellus well would be between $85,000 and $260,000, or $1.21 to $1.84 per barrel of water, for use of 3 million to 6 million gallons of water, respectively. The transportation cost figure scales linearly with distance, while water cost is fixed; therefore, a well that is a two-hour round trip from a freshwater source would incur estimated costs of $2.21 to $2.84 per barrel of water, dependent on the cost of water. Freshwater impoundment construction costs are approximately $1 per barrel based on industry estimates (Yeager, 2011), which would equate into approximately $119,000 for a 5 million gallon impoundment.

Where possible, water is being directly piped from the source to the well pad impoundment because this ultimately reduces the life-cycle cost and road impacts of water transportation; however, this approach will increase initial capital costs relative to truck transport. According to industry estimates, the costs to permit and construct a surface water intake with 1.5 miles of 6-inch pipe and a 5 million gallon impoundment is approximately $1.5 million (Memory, 2011). The costs of installing permanent intakes, water pipelines, and impoundments can be recaptured if reused to serve multiple wells, where approximately 10 wells would provide a break-even point to cover initial capital expenditures.

**Treatment.** There are several treatment options for AMD with varying levels of sophistication and commensurate cost. These include AMD dilution with fresh water, dilution with flowback water, physical/chemical treatment, and filtration technologies. It is necessary to consider the initial water quality of the AMD and the level of treatment necessary to remove contaminants of concern down to acceptable concentrations for use in hydraulic fracturing. Sulfate concentrations in AMD can vary from several hundred to over 10,000 mg/L. For the purposes of this analysis, an initial sulfate concentration of 1,000 mg/L is assumed, and an acceptable sulfate concentration of 250 mg/L is used, which is consistent with secondary drinking water standards.

Blending AMD water with an initial sulfate concentration of 1,000 mg/L to an acceptable level of less than 250 mg/L would require a nearly 4:1 dilution, with fresh water having a sulfate concentration of 50 mg/L. Assuming that 4 million gallons of fresh water and 1 million gallons of AMD are blended, then a savings of $0.21–$0.84 per barrel would be achieved on the 1 million gallons of AMD ($5,000–$20,000). The blended water would need to be stored in tanks or special
impoundments at costs of $0.75–$1 per barrel (as detailed below), thus eliminating any cost savings.

Blending AMD with flowback water enriched in barium in a 1:1 ratio has been proposed and reportedly tried; this would theoretically cause barite precipitation and reduce sulfate to less than 250 mg/L. The costs to dilute AMD would still involve the transport of both fresh water and AMD, either via truck or pipeline. In addition, operation/maintenance costs to manage fluids would be more involved and would require additional labor and equipment, although some costs savings on chemical use may be achieved. It is difficult to estimate the costs to blend AMD with flowback without operational experience, which is scarce; however, it is expected that it could approximate the low-cost range for other mobile treatment techniques at $4 per barrel or perhaps less, dependent on efficiency and scale.

Physical/chemical treatment to remove sulfates from AMD water involves the addition of chemicals to facilitate the precipitation of potential scaling agents out of solution. The addition of barium to sulfate-laden water would form BaSO₄ (barite), which readily precipitates out of solution. Similar treatment is being conducted on flowback water in the field at well sites at a cost of approximately $4 to $6 per barrel, including disposal of generated sludges. Microfiltration or nanofiltration technologies may also be deployed to remove sulfates, with estimated costs of approximately $6 to $8 per barrel. These figures assume treatment of AMD taken directly from the mine pool, where mineral concentrations are highest. An alternative might be to withdraw downstream from the mine pool, where the AMD has mixed with fresh water and mineral concentrations are lower. While this alternative would likely have lower treatment costs, allowing the AMD to become diluted with unpolluted stream water may reduce the environmental benefits of AMD utilization for natural gas drilling.

Storage. AMD storage costs should also be factored, since AMD currently cannot be stored in freshwater impoundments. Rather, AMD must be stored in tanks or flowback impoundments, consistent with applicable waste management regulations. Costs for a tank farm or centralized impoundment capable of storing 4.2 million gallons (100,000 barrels) of water are estimated to range from $0.75 million to $1 million (Miller, 2011). These costs equate to $7.50 to $10 per barrel if used for a single well. However, for the purposes of this evaluation, it is assumed that the storage costs could be spread across 10 wells; therefore, storage costs would be approximately $0.75–$1 per barrel of AMD.

How Do the Costs of Fresh Water and Treated AMD Compare?

We conclude that the costs of trucking and storing water for a single Marcellus well are approximately $1 per barrel per round-trip hour, plus $0.21 to $0.84 per barrel of water. AMD water, assuming a similar transport distance, would generate a similar transportation-related cost but would not incur the purchase price of fresh water. The costs of piping water will be lower than the costs of trucking in most circumstances, but they would be the same for either fresh or AMD water, assuming no additional regulatory requirements for piping AMD water.
Treatment costs to remove sulfates from AMD are estimated to range from $4 to $8 per barrel. The estimated AMD storage cost ranges from $0.75 to $1 per barrel, assuming costs are spread across 10 wells. Freshwater storage costs spread across 10 wells would be approximately $0.10 per barrel, assuming a lined freshwater impoundment is used. The total estimated costs to transport (assuming a one-hour round trip), treat, and store AMD water for use would range from $5.75 to $10 per barrel. The costs to use fresh water would range from $1.31 to $1.94 per barrel, assuming one-hour round-trip transport and the use of a freshwater impoundment. The costs for treatment of AMD to remove sulfates to acceptable levels would appear to make the use of AMD in hydraulic fracturing cost-prohibitive in most cases, even if the storage and transportation were provided at no cost.

Figure 1 illustrates the trade-off between the treatment cost of AMD and the distance to transport fresh water to the drilling location. The area to the right of the solid line indicates combinations of AMD treatment costs and freshwater transportation distances where the use of fresh water would have lower costs; the area to the left of the solid line represents combinations where AMD would be an economical choice. The figure assumes a freshwater cost of $0.50 per barrel, that AMD is collected directly from the mine pool and transported one hour round trip to the drilling site, and that storage costs for fresh water and AMD are $0.10 and $0.75 per barrel, respectively.

![Figure 3.1 Comparison of AMD Treatment Cost with Transport Costs Associated with Fresh Water](image_url)

As illustrated in the figure, AMD would be a cost-effective choice in hydraulic fracturing applications if the treatment costs are low and the transportation distance from freshwater sources is high. When all factors are considered, we find that the following are necessary for AMD to be cost-competitive with fresh water:
• Low-cost AMD treatment technology,
• Treatment system designed for long-term use,
• Centralized location with respect to well pads to minimize water transfer,
• Adequate storage, and
• Efficient water transfer system (e.g., piping).

Conclusion
We have shown that AMD can be a cost-effective choice for hydraulic fracturing operations only under limited conditions, including when the source is close, when it can be stored in preexisting centralized impoundments, and when low-cost treatment is available. Additional study and analysis are needed to determine where and under what conditions will grant the most benefit to operators and other stakeholders. If AMD is used in sufficient volumes, AMD-impacted streams or rivers may see water quality improvements. Water quality improvements and associated ecosystem (and potentially human health) benefits would need to amount to more than $5 per barrel of affected water in order to make the decision to use AMD in place of fresh water an economically efficient option.

References
Session 3 Presentations

The remainder of this appendix is devoted to the presentations delivered in Session 3 of the conference: “Economics of Utilizing Acid Mine Drainage for Hydraulic Facturing,” by David Yoxtheimer, and “Economic Analysis of the Use of Mine Water from Abandoned Mines for the Development of Marcellus Shale Gas Wells in Pennsylvania,” by Eric E. Cavazza, manager of the Bureau of Abandoned Mine Reclamation in the Pennsylvania Department of Environmental Protection.
Economics of Utilizing Acid Mine Drainage for Hydraulic Fracturing

Presented by David Yoxtheimer, P.G.
Co-authors: Seth Blumsack & Tom Murphy

Economics of AMD Use Topics

• Acquisition
• Transport
• Treatment
• Storage
• Costs
• Feasibility
AMD Availability

Geologic Units Containing Potentially Significant Acid-Producing Sulfide Minerals

- Proximity of source location to drilling operations
- Access rights
- Means of ROW (ingress/egress)
- Sufficient volume of available AMD
- AMD quality—is it economically treatable

AMD Intake Locations

Considerations

- Proximity of source location to drilling operations
- Access rights
- Means of ROW (ingress/egress)
- Sufficient volume of available AMD
- AMD quality—is it economically treatable
AMD Transport

- Trucking costs of ~$1/bbl/hr
- Piping will generally be least expensive over long term

Flowback Treatment Specifications

Example industry flowback treatment levels for recycling purposes:

- Total cations in the <10 to <2,000 ppm range
  - Acceptable levels range from company to company
  - Primary focus on Ba and Sr, but Ca also a concern
  - Ba, Sr, Fe, Mn, Mg < 10 ppm
  - Ca <1,000 ppm
  - Hardness <2,500 ppm

- Processed water sulfates levels <250 ppm

- TSS <30 ppm

- TDS is variable, >50,000 ppm can be acceptable
AMD Treatment Options

Methods considered:
- Dilution with fresh water
- Blending with flowback water
- Physical/chemical treatment
- Filtration

Treatment costs range from $<4-$8/bbl

Chemical precipitation can have >99% removal efficiency for potential scaling agents.
Can generate several tons of sludge per 100,000 gallons treated.

AMD Storage

- Centralized impoundments or tank farms are going to cost approximately $0.75-$1/bbl assuming used to serve 10 wells.
- Freshwater impoundments estimated to cost about $0.10/bbl.
Assumptions:
- Transport cost (one hr) = $1/bbl
- Freshwater storage cost = $0.10/bbl
- AMD storage costs of $0.75/bbl

Conclusions

Cost for use of treated AMD ~4-5 times greater than fresh water:
- AMD = $5.75 to $10 per barrel
- Fresh water = $1.31 to $1.94 per barrel

The following factors appear necessary for AMD to be cost-competitive with fresh water:
- Low-cost AMD treatment technology,
- Treatment system designed for long-term use,
- Centralized source location with respect to well pads to minimize water transfer costs,
- Adequate storage to serve multiple well pads for long term, and
- Efficient water transfer system (e.g. piping).
Thank you!

Questions?
Economic Analysis of the Use of Mine Water from Abandoned Mines for the Development of Marcellus Shale Gas Wells in Pennsylvania

Eric E. Cavazza, P.E.
Environmental Program Manager

<table>
<thead>
<tr>
<th>Treatment Plant</th>
<th>County</th>
<th>Operator</th>
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<th>2009 Treatment Cost ($/1,000 gal)</th>
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Costs of Municipal Water for Various Geographic Areas of Pennsylvania

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<td>Ridgway Water Authority</td>
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<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td><strong>$9.57</strong></td>
</tr>
</tbody>
</table>

River Basins in Pennsylvania

- Ohio River
- Susquehanna River
- Delaware River
- Lake Erie
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.
Economics

- 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.

Questions?
Online Appendix D: Regulatory and Legal Barriers

Session 4 of the roundtable conference focused on the regulatory and legal barriers to using coal mine water for hydraulic fracturing.

A white paper prepared by Peter J. Fontaine of the Energy, Environmental, and Public Utility Practice Group at the law firm Cozen O’Connor. The paper is followed by the three sets of slides that were presented at the conference by: Pam Milavec, chief of the Environmental Services Section of the Bureau of Abandoned Mine Reclamation, Pennsylvania Department of Environmental Protection; Joseph K. Reinhart and Kevin J. Garber of the Pittsburgh law firm Babst Calland; and Peter J. Fontaine.
Thousands of current and future Marcellus Shale natural gas extraction wells are located near Pennsylvania’s 250,000-plus abandoned coal mines. Many of these mines discharge acid mine drainage (AMD) into local streams and rivers (Figure 1). AMD is the biggest single cause of stream impairment in Pennsylvania.
fishable and swimmable use mandated by state and federal clean water laws. The convergence of Pennsylvania’s 19th-century coal industry with its 21st-century natural gas industry could create a new opportunity to turn the vision of watershed-based restoration into reality.

In order to transform the potential advantages of using AMD for hydraulic fracturing into reality, new legislation is necessary to eliminate the open-ended liability associated with using AMD for hydraulic fracturing. With the right mix of legal and economic incentives, the Marcellus Shale could represent not just an opportunity to secure a dependable supply of cleaner-burning fuel but also the promise of lasting improvement to Pennsylvania’s streams and rivers.

**What Reforms Are Needed to Capture the Opportunity?**

In order to capture the opportunity, however, several reforms must be implemented:

- **Clear and certain AMD treatment targets must be established.**

- **The siting of natural gas wells must become more rational and anticipatory.** A watershed-based approach would identify opportunities for deployment of centralized treatment systems to service both multiple wells and AMD areas. It would build upon the existing knowledge base developed through such programs as Operation Scarlift and rely upon public-private partnerships between the Commonwealth, operators, and local watershed organizations. Partnerships would enhance the ability to pool resources to construct centralized wastewater treatment systems to service the needs of both natural gas operators and AMD abatement. Through its various funding sources, such as the Surface Mining Control and Reclamation Act set-aside, Growing-Greener grants, and any future natural gas impact fees, operators and the Commonwealth might be able to design and construct centralized combined wastewater treatment systems to handle both flowback and produced waters and AMD using a watershed-based planning approach.

- **Legislation should establish clear and unambiguous liability protection** for operators to encourage voluntary use of AMD through reforms along the lines of Pennsylvania’s landmark Land Recycling and Environmental Remediation Standards Act, known as “Act 2.”

This white paper focuses upon the third recommendation—liability protection.

**AMD Is Pennsylvania’s Enduring Problem**

The intractable nature of Pennsylvania’s AMD problem—and the public policy imperative to abate it—has long been recognized by the legislature. In 1965, the legislature closed a loophole in the Clean Streams Law (CSL) that had enabled the coal industry to discharge untreated AMD to Pennsylvania’s streams without treatment. In amending the CSL, the legislature declared,

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4 Clean Streams Law, 35 P.S. § 691.1 et seq.
It is hereby determined by the General Assembly of Pennsylvania and declared as a matter of legislative findings that: (1) The Clean Streams Law as presently written has failed to prevent an increase in the miles of polluted water in Pennsylvania. (2) The present Clean Streams Law contains special provisions for mine drainage that discriminate against the public interest. (3) Mine drainage is the major cause of stream pollution in Pennsylvania, and is doing immense damage to the waters of the Commonwealth. (4) Pennsylvania, having more miles of water polluted by mine drainage than any state in the Nation, has an intolerable situation which seriously jeopardizes the economic future of the Commonwealth. (5) Clean, unpolluted streams are absolutely essential if Pennsylvania is to attract new manufacturing industries and to develop Pennsylvania’s full share of the tourist industry, and (6) Clean, unpolluted water is absolutely essential if Pennsylvanians are to have adequate out-of-door recreational facilities in the decades ahead. The General Assembly of Pennsylvania therefore declares it to be the policy of the Commonwealth of Pennsylvania that: (1) It is the objective of the Clean Streams Law not only to prevent further pollution of the waters of the Commonwealth, but also to reclaim and restore to a clean, unpolluted condition every stream in Pennsylvania that is presently polluted, and (2) The prevention and elimination of water pollution is recognized as being directly related to the economic future of the Commonwealth.

With the 1965 amendments to the CSL, for the first time AMD was deemed to be “industrial waste,” thus prohibiting the discharge of AMD into waters of the Commonwealth under Section 307:

No person shall hereafter erect, construct or open, or reopen, or operate any establishment which, in its operation, results in the discharge of industrial wastes which would flow or be discharged into any of the waters of the Commonwealth and thereby cause a pollution of the same, unless such person shall first provide proper and adequate treatment works for the treatment of such industrial wastes, approved by the board. . . .

In 1968, Pennsylvania authorized a $200 million bond issue dedicated to AMD abatement. The program, called “Operation Scarlift,” resulted in the construction of about 500 AMD abatement projects but left most of the difficult AMD-impaired streams untouched.

**How Feasible Is It to Use AMD for Hydraulic Fracturing?**

Given the enduring environmental harm caused by Pennsylvania’s last energy extraction boom, there is concern about the long-term environmental impact of natural gas development in the Marcellus Shale. The development of natural gas reserves trapped within this formation requires copious amounts of water to hydraulically fracture the shale and to liberate the gas trapped within. While recycling wastewater from the drilling process is an increasingly popular strategy,
only about one-third to one-fifth of the water is recovered. Therefore, drillers have to find additional water for each new gas well.\(^5\) In some areas of Pennsylvania, sufficient quantities of fresh water may be seasonally unavailable due to stream flow limitations and other regulatory restrictions. For example, in the summer of 2011, the Susquehanna River Basin Commission (SRBC) prohibited 36 natural gas well drillers from withdrawing water due to low stream-flow levels in Northern Pennsylvania.

The SRBC’s temporary moratorium on withdrawals illustrates the industry’s challenge of finding year-round, readily available fresh water under an increasingly stringent set of controls. These are typically imposed by the Pennsylvania Department of Environmental Protection (PA DEP) and by Pennsylvania’s two interstate river basin commissions, the SRBC and the Delaware River Basin Commission (DRBC). Securing a reliable supply of fresh water and managing the 20% that flows back to the surface as contaminated produced water are both potentially large costs associated with natural gas extraction in the Marcellus Shale.\(^6\)

In many areas of the Marcellus Shale, copious amounts of water exist in abandoned coal mines. AMD water is a potential source of frac water if it can be treated to reduce suspended solids and other compounds that can block the horizontal fractures that are essential to the economic recovery of natural gas.\(^7\) The suitability of AMD as a source of frac water was demonstrated in the field with several Marcellus Shale wells using impaired mine drainage waters for frac water. For example, Range Resources and Anadarko EP Co. have hydraulically fractured wells in Snow Shoe, Centre County, using acidic water diverted from the Beech Creek. Beech Creek is badly impaired by AMD (pH ranging from 3 to 5) generated by abandoned deep and strip mines located within the watershed.\(^8\) All of the AMD in the watershed eventually flows into Beech Creek, which flows easterly through Centre and Clinton Counties and empties into Bald Eagle Creek. Figure 2 shows an aerial photo of the AMD areas in relation to three Marcellus Shale wells within the Beech Creek watershed.

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\(^8\) See Acid Mine Drainage Restoration Plan for the Beech Creek Watershed, Hedin Environmental, June 19, 2006.
Figure 2. Overlay of Abandoned Mine Pools and Marcellus Shale Wells Outside Clarence and Snow Shoe, Centre County (PA DEP and Google Earth)

Beech Creek illustrates the potential for centralized or regional AMD treatment facilities that could supply frac water for multiple gas wells to achieve economies of scale for effective AMD abatement. According to the Beech Creek Watershed Association, 15 miles of tributary streams contributing significant AMD loadings on Beech Creek could be restored at a cost of $1.8 million.\(^9\) The SRBC also has concluded that strategic treatment plant site selections could enable several “Top-20” AMD sources within the Susquehanna River Basin to be treated by the same plant, thereby reducing capital, operation, and maintenance costs.\(^10\)

To encourage the use of AMD in natural gas extraction, the SRBC exempts from the application fee requirements the beneficial reuse of mine drainage. The SRBC program encourages beneficial use of AMD on a case-by-case basis for projects that use surface water or groundwater degraded by past or present mining activities. The SRBC policy anticipates that many natural gas projects may be able to use waters impacted by mine drainage. To qualify for fee waiver, an operator must show the following:

1. The proposed withdrawal is directly from mine drainage and will have a demonstrable downstream benefit, defined as water that is net acidic or has no alkalinity;


2. Manganese, iron, aluminum, and sulfate concentrations do not meet the respective water quality standards;
3. PH is less than or equal to 6.0; and
4. No aquatic life (except midges/worms) exist.

The SRBC also grants a partial waiver (50% of the applicable fee) if the proposed withdrawal is directly from mine drainage or from a stream impacted by mine drainage, with the withdrawal expected to have a demonstrable downstream benefit, provided the following criteria are met:
1. Meets respective water quality standards;
2. PH does not meet water quality standards; and
3. Limited aquatic life.

_Open-Ended Liability May Deter the Use of AMD in Pennsylvania_

AMD remains a great environmental challenge for the Commonwealth, in part due to liability issues. Under Pennsylvania’s Clean Streams Law ( CSL), anyone encountering preexisting AMD in the course of resource extraction potentially is subject to open-ended liability to treat the AMD. This creates a major disincentive to make use of AMD. Under the CSL, any person whose activities encounter preexisting AMD can be held strictly liable to abate the all of the AMD, even if they had nothing to do with creation of the AMD in the first instance. The CSL authorizes the PA DEP “not only to prevent further pollution of the waters of the Commonwealth, but also to reclaim and restore to a clean, unpolluted condition every stream in Pennsylvania that is presently polluted.” Persons are prohibited from allowing the discharge or flow of any industrial wastes into Pennsylvania’s waterways. Pollution occurs not just when a substance is “first” discharged into a water of the Commonwealth, but also whenever it is discharged. Thus, for example, a natural gas driller could be liable for the discharge of AMD under the CSL even if the AMD was caused by another entity and had migrated from another source. Once the PA DEP is aware that pollution or even if the threat of pollution exists, it can order any landowner or occupier to correct the condition.

11 Clean Streams Law, 35 P.S. § 691.1 et seq.
12 See, e.g., Commonwealth v. Harmar Coal Co., 452 Pa. 77 (1973); Commonwealth v. Barnes & Tucker Co., 472 Pa. 115 (1977) (holding one who mines an area adjacent to a preexisting AMD area and causes commingling of AMD, pumping of AMD, or a new seep is liable to treat all of the AMD, even though they did not create the AMD).
13 Clean Streams Law, 35 P.S. § 691.4.
14 Legislation in 1965 changed the CSL’s definition of “industrial waste” to include AMD. See 35 P.S. § 691.1.
16 “Landowner” is defined as any person holding title or having a proprietary interest in surface or subsurface rights (Clean Streams Law, 35 P.S. § 691.316).
pollution (including AMD) is not a prerequisite for establishing liability. Thus, natural gas operators attempting to utilize AMD for hydraulic fracturing may find themselves responsible for the remediation of large areas of AMD, even though they did not cause the AMD.\textsuperscript{18}

For obvious reasons, the risk of incurring a “perpetual treatment” obligation potentially costing tens of millions of dollars must be completely eliminated if natural gas drillers are to be encouraged to reuse AMD as frac water. Otherwise, given a choice between obtaining frac water from AMD or from an existing freshwater stream, groundwater, or a public water supplier, drillers always will choose non-AMD waters to avoid the risk of perpetual treatment liability.

In 1987, the Congress sought to encourage AMD abatement by amending the federal Clean Water Act to allow coal operators to remine previously mined coal areas without having to treat the discharge to U.S. Environmental Protection Agency (EPA) effluent guideline standards applicable to new coal mines. The Rahall Amendment (named after the prime sponsor, Nick Representative Rahall of West Virginia) sought to provide incentives for remining and reclaiming abandoned mine lands that predated the federal Surface Mining Control Act of 1977 by exempting certain remining operations from effluent limitations, thereby making remining economically feasible. The Rahall Amendment allowed EPA or the states with approved NPDES permitting programs to issue discharge permits based on “best professional judgment” in lieu of otherwise applicable numerical effluent limitations for pH, iron, and manganese.\textsuperscript{19}

Pennsylvania attempted to solve the “perpetual treatment” problem in 1999, when it enacted the Environmental Good Samaritan Act of 1999 (EGSA).\textsuperscript{20} The EGSA was designed to encourage voluntary reclamation of lands adversely affected by mining or oil and gas extraction and, thereby, to protect wildlife, decrease soil erosion, aid in the prevention and abatement of pollution of rivers and streams, and protect and improve the environmental values of the Commonwealth. The EGSA limits a

\textsuperscript{17} Clean Streams Law, 35 P.S. § 691.316.


\textsuperscript{19} The Rahall Amendment ultimately proved to be unsuccessful in encouraging AMD abatement, however, because coal mining companies and most states remained reluctant to pursue remining without formal EPA approval and guidelines. In 2002, EPA promulgated regulations establishing a new Coal Remining Subcategory to the effluent guidelines at 40 C.F.R. Part 434. EPA found that the existing regulations created a disincentive for remining because of their high compliance costs. Moreover, the potential of the statutory exemption contained in the Rahall Amendment to overcome this disincentive and derive the maximum environmental benefits from remining operations has not been fully realized in the absence of implementing regulations. If mining companies face substantial potential liability or economic loss from remining, they will continue to focus on mining virgin areas and ignore abandoned mine lands that may contain significant coal resources. Based on information collected in support of this proposal, EPA believes that remining operations are environmentally preferable to ignoring the coal resources in abandoned mine lands.


\textsuperscript{20} 27 Pa. C.S.A. §§ 8001–8114.
person’s liability arising as a result from the voluntary reclamation of abandoned lands or the reduction and abatement of AMD. A person voluntarily providing equipment, materials, or services at no charge or at cost for a reclamation project or water pollution abatement project has a defense to civil liability if additional pollution occurs. To qualify, the person must submit a detailed plan for the proposed project to the PA DEP, which will approve the plan if it is likely to improve and not worsen water quality. Persons providing equipment, materials, or services at cost for a water pollution abatement project are immune from liability for injury or damage arising out of the water pollution abatement facilities constructed or installed during the water pollution abatement project, and for any pollution emanating from the water pollution abatement facilities. However, immunity will not apply if the person affects an area hydrologically connected to the water pollution abatement project work area and causes increased pollution by activities that are unrelated to the implementation of the water pollution abatement project. Also, the EGSA does not provide immunity for water pollution abatement projects that would otherwise exist; if the projects cause injury or damage resulting from reckless or gross negligence, willful misconduct, or unlawful activities; or written notice was not provided.

The PA DEP’s guidance implementing the EGSA acknowledges the disincentive created by the specter of CSL liability:21

Numerous landowners, citizens, watershed associations, environmental organizations, and governmental entities who do not have a legal responsibility to reclaim abandoned lands or abate water pollution are interested in addressing these problems. These groups have been reluctant to engage in such reclamation and abatement activities because of potential liabilities for personal injury, property damage, water pollution, and the continued operation, maintenance or repair of water pollution abatement facilities.

As applied to beneficial use of AMD for hydraulic fracturing, however, the EGSA suffers from a major weakness: It does not give the PA DEP the authority to determine who does or does not receive the protections from liability. If a lawsuit is brought against a project participant for injury or damage, the participant still has the burden of proof to prove that they qualify for the protections in the EGSA.

For Marcellus Shale drillers, the uncertain scope of protection offered by the EGSA and the prospect of defending CSL citizen suits designed to stop production is a major disincentive to beneficially use AMD. For obvious reasons, the risk of incurring a “perpetual treatment” obligation potentially costing tens of millions of dollars must be eliminated if natural gas drillers are to be encouraged to reuse AMD as frac water. Otherwise, given a choice between obtaining frac water from AMD or from an existing freshwater stream, groundwater, or a public water supplier, drillers usually will choose non-AMD waters to avoid the risk of perpetual treatment liability.

21 See Bureau of Mining and Reclamation, Pennsylvania Department of Environmental Protection, Environmental Good Samaritan Projects, September 4, 2000.
Unless the Clean Streams Law is amended to relieve natural gas drillers from the risk of incurring the “perpetual treatment” obligation that the law currently imposes on those who would attempt to use AMD as frac water, the prospects for the beneficial use of AMD in hydraulic fracturing are limited.

In its report to Governor Corbett, the Marcellus Shale Advisory Commission recognized this problem, recommending that

The Commonwealth should encourage the use of non-freshwater sources where technically feasible and environmentally beneficial. For example, legislation that would provide operators with immunity from environmental liability for the use of acid mine drainage water from abandoned mine pools would encourage operators to reduce their use of freshwater sources for water utilization as well as reduce the amount of acid mine water draining into local streams.22

The Marcellus Shale Citizens Commission rejected this recommendation in its competing assessment of Marcellus Shale activities in Pennsylvania. The group asserted, “Under no circumstances, however, should liability be reduced for spills of Acid Mine Drainage just because of attempted uses in gas well fracking.”23 If the legislature adopts the view of the commission and operators remain subject to full liability, then the opportunity to take advantage of AMD as frac water while abating the Commonwealth’s polluted waterways will be missed.

The PA DEP’s draft white paper, *Utilization of AMD in Well Development for Natural Gas Extraction*, outlines a process to facilitate the use of AMD for hydraulic fracturing of natural gas wells. The white paper offers two solutions for eliminating the risk of incurring long-term AMD treatment liability, neither of which is likely to spur greater use of AMD for natural gas well fracturing. The PA DEP suggests that the Environmental Good Samaritan Act could protect operators from long-term treatment liability or that the PA DEP could enter into consent order and agreements promising not to hold operators liable for long-term treatment for the use of AMD provided certain conditions were met. Neither approach is likely to encourage operators to use AMD because both still give rise to uncertainty and therefore to risk.

**Liability Protection Reforms Are Necessary and Possible**

Notwithstanding the 1965 amendments to the CSL, Operation Scarlift, the Rahall Amendment, and the Environmental Good Samaritan Act, AMD remains a daunting challenge in large part because of the uncertain scope of liability. To create meaningful liability protection, legislation is needed to give the PA DEP the authority to confer broad liability protection to natural gas drillers who receive approval to construct treatment systems to beneficially use AMD and to treat

flowback from hydraulic fracturing, thus encouraging voluntary use of AMD. Legislative reforms along the lines of Pennsylvania’s landmark Land Recycling and Environmental Remediation Standards Act, known as Act 2, would create the necessary certainty to encourage operators voluntarily to use AMD. Liability protection could be structured in the same manner as the “release of liability/covenant not to sue” that the PA DEP provides to persons who voluntarily remediate contaminated land under Act 2. The regulatory certainty and liability protection offered by the Act 2 approach is credited with encouraging the voluntary remediation of tens of thousands of brownfield sites across Pennsylvania.

Enacted in 1995, Act 2 changed existing law to make it easier and less costly to clean up thousands of contaminated Pennsylvania sites impacted with actual or potential contamination. The essential feature of Act 2 is the certainty and finality offered to those who voluntarily clean up. The program gives a remediating party certainty and finality once they complete the Act 2 process under the oversight of the PA DEP, which reviews and approves or disapproves the clean-up reports. A party completing the process, current and future owners, any person who develops or otherwise occupies the site, and their successors and assigns receive a “release of liability” and “covenant not to sue” from the PA DEP, essentially promising not to require additional clean-up on the property and to protect the remediating party against third-party suits by others for clean-up expenses.

As part of any comprehensive natural gas legislation, the legislature should provide the PA DEP with the authority to furnish a release of liability/covenant not to sue to operators who receive PA DEP approval to treat AMD for purposes of hydraulic fracturing. The approach outlined in the PA DEP’s AMD white paper is an excellent start toward a more comprehensive watershed-based program that identifies opportunities for the deployment of centralized treatment systems to service both multiple wells and AMD areas. This approach would build upon Pennsylvania’s existing knowledge base developed through Operation Scarlift and subsequent watershed efforts and would implement a public-private partnership approach among the PA DEP, operators, and local watershed organizations to pool resources for the construction of centralized wastewater treatment systems servicing the needs of both natural gas operators and watershed groups working to abate AMD. Under this approach, operators and the Commonwealth (through its various funding sources, such as the SMCRA set-aside, Growing-Greener grants, and any natural gas impact fees) would design and construct centralized combined wastewater treatment systems to handle both flowback and produced waters and AMD using a watershed-based planning approach.

Conclusion

New legislation is necessary to eliminate the open-ended liability under the CSL associated with using AMD for hydraulic fracturing. With the right mix of legal and economic incentives, the Marcellus Shale could represent not just an opportunity to secure a dependable supply of cleaner-burning fuel but also the promise of lasting

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24 Clean Streams Law, 35 P.S. § 6026/101, et seq.
improvement to Pennsylvania’s AMD-impaired streams and rivers. While the
broad-brush recommendations of the Marcellus Shale Advisory Commission and
the Pennsylvania Senate Environmental Resources and Energy Committee are steps
in the right direction, bold and substantive changes to existing law will be required
if the Marcellus Shale boom is to be leveraged toward long-term environmental
improvement in AMD areas. Regulatory barriers must come down if the beneficial
use of AMD for frac water is to occur at a sufficient scale to improve water quality.

In order to leverage this unique opportunity, Pennsylvania must enact meaningful
Marcellus Shale legislation that (1) strengthens liability protection under the CSL for
drillers who reuse AMD, similar to the “release of liability/covenant not to sue”
given to redevelopers of brownfield sites under Pennsylvania’s Act 2 program, and
(2) creates economic incentives for drillers to beneficially reuse AMD as frac water,
such as a meaningful reduction in impact fees.
Session 4 Presentations

The remainder of this appendix is devoted to the three presentations delivered in Session 4 of the conference: “Utilization of AMD in Well Development for Natural Gas Extraction,” by Pam Milavec; “Regulatory and Legal Barriers,” by Joseph K. Reinhart and Kevin J. Garber; and “Liability Reforms to Encourage a Comprehensive Watershed-Based Approach to Acid Mine Drainage Abatement and Marcellus Shale Hydraulic Facturing,” by Peter J. Fontaine.
Utilization of AMD in Well Development for Natural Gas Extraction

Overview of the PADEP’s Draft White Paper

Pam Milavec, Environmental Services Section Chief

Establishment of an Evaluation and Approval Process for the Use of Abandoned Mine Drainage (AMD) for Industrial Uses Including Natural Gas Extraction

- DEP team included a sub-group of legal and technical staff who reported to executive staff
- Developed a draft White Paper
- Providing a review and comment period that will include stakeholder meetings
- White Paper to be finalized in February
Goals

- 1. Define the roles of the various department programs
- 2. Establish a process for the oil and gas industry to utilize AMD
- 3. Establish a process for the Department to facilitate review and evaluate proposals for use of AMD

Obstacles to Overcome for Use of AMD

- Solutions to Technical Issues
- Solutions to Industry Concerns
- Solutions to Legal Issues
- Department Coordination
- Program Integration
Solutions to Technical Issues

- Target AMD sources for use by oil and gas industry
- Draft storage options for AMD
- Draft proposal review process
Storage Options

- Option #1: Nonjurisdictional Impoundments – can be used for AMD that meets certain criteria
- Option #2: Centralized Wastewater Impoundment Dam for Oil and gas activities
- Option #3: On-site Pits and Tanks

Possible Storage Standards for Nonjurisdictional Impoundments

- See Appendix B for full list
- Problematic common AMD parameters include:
  - Alkalinity > 20 mg/l
  - Aluminum < 0.2 mg/l
  - Iron < 1.5 mg/l
  - Manganese < 0.2 mg/l
  - pH 6.5 – 8.5
  - Conductivity 1,000 umho/cm
  - Sulfate < 250 mg/l
  - TDS < 500 mg/l
Review & Approval Process Summary

- Industry initiates process by reviewing DEP AMD discharge databases and meeting with DEP staff
- Treatment requirements determined in order to meet industry needs and watershed concerns
- Industry completes data collection and submits written proposal to DEP (checklist in White Paper)
- DEP team reviews proposal with feedback provided within 15 days
- Approvals and COAs developed as appropriate

Solutions to Liability Issues

- Option #1 – Environmental Good Samaritan
  Provides immunity from civil liability for operating and maintaining water pollution abatement facilities on AML sites
- Option #2 – Consent Order and Agreement
  DEP agrees not to hold entity liable for long-term treatment of AMD source as long as specific conditions are met
Comment Process

- Review White Paper: [www.dep.state.pa.us](http://www.dep.state.pa.us), Water, Bureau of Watershed Management
- 2 Workshops:
  - January 24th in Harrisburg
  - January 25th by web conferencing
- Contact John Stefanko, Deputy Secretary for Active and Abandoned Mine Operations, at 717-783-9958

Questions?
Regulatory and Legal Barriers

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PADEP Draft AMD Reuse White Paper

• Recommends incentivizing AMD reuse for gas extraction (citing SRBC/DRBC policies)

• Proposes to use AMD databases and teams to assist with AMD reuse proposals

• Highlights storage impoundment issues

• Acknowledges potential liability concerns
Potential Activities Associated with AMD Reuse

• Construction of AMD treatment plant located at the discharge point
• Storage of AMD in “nonjurisdictional” impoundments / “centralized wastewater” impoundments
• Collection/transportation of AMD from existing treatment facilities to the well pad
• Pumping water well development in mine pools

Environmental Laws Creating Potential Barriers

• Clean Streams Law
• Solid Waste Management Act
• Hazardous Sites Cleanup Act
Clean Streams Law

- No person shall allow a discharge from a mine into waters of the Commonwealth without a permit - §315
- The DEP may order a landowner or occupier of land to correct conditions resulting in pollution or a danger of pollution - §316
- The DEP may recover expenses associated with correcting a pollutional condition - §316

§315 Caselaw

- On – Permit Mine Discharge
  - Strict liability to operator regardless of source
- Off – Permit Mine Discharge
  - Liability based upon hydrogeologic connection
- The discharge of acid mine drainage from a point source into surface water constitutes the discharge of “industrial waste” for NPDES permitting purposes
Solid Waste Management Act

- Prohibits any person from discharging residual waste into the surface or underground of the earth without a permit - §610
- The treatment, storage or disposal of a residual waste is unlawful without first securing a permit - §302
- Residual waste does not include treatment sludges from coal mine drainage treatment plants operated under a valid CSL permit

Hazardous Sites Cleanup Act

- The owner or operator of a site may be responsible for response costs associated with the release of a hazardous substance - §701
- The term “hazardous substances” is broadly defined and includes CERCLA hazardous substances - §103
- The term does not include an element, substance, compound, or mixture from a coal mining operation under DEP jurisdiction or from a site eligible for AML funds - §103
PA Environmental Good Samaritan Act

• Encourages “Reclamation Projects” and “Water Pollution Abatement Projects” to address historic impacts from coal mining
• A “Water Pollution Abatement Project” includes a plan for the treatment or abatement of water pollution on eligible land and water
• The law grants protection to landowners and persons who voluntarily provide equipment, material or services for reclamation projects and water pollution abatement projects

PA Environmental Good Samaritan Act (cont.)

• Eligible parties may be immune from civil liability in any legal proceeding brought to enforce environmental laws or otherwise impose liability - §8105
• Eligible parties will not be subject to a citizen suit under the CSL for pollution emanating from water pollution abatement facilities installed during the abatement project - §8107
Agency Guidance

- The DEP’s White Paper references a Consent Order and Agreement (COA) as a means to address potential liabilities for AMD reuse
- A COA may provide a covenant not to sue for defined conditions and otherwise acknowledge DEP enforcement discretion
- A COA is usually not subject to notice and comment, and may not preclude third party actions
Liability Reforms to Encourage Comprehensive Watershed-Based Approach to Acid Mine Drainage Abatement and Marcellus Shale Hydraulic Fracturing

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Opportunity
Clean Streams Law

§ 691.316--Responsibilities of landowners and land occupiers

Whenever the department finds that pollution or a danger of pollution is resulting from a condition which exists on land in the Commonwealth the department may order the landowner or occupier to correct the condition in a manner satisfactory to the department or it may order such owner or occupier to allow a mine operator or other person or agency of the Commonwealth access to the land to take such action. For the purposes of this section, “landowner” includes any person holding title to or having a proprietary interest in either surface or subsurface rights.

Pennsylvania Constitution

Article I, Section 27

The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. Pennsylvania’s public natural resources are the common property of all the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people.
Cases interpreting CSL

- DEP can compel anyone even leasing land for the operation of a business, or holding an easement for the installation of utilities, to abate pre-existing ground water contamination pursuant to CSL Section 316 without having to demonstrate that the party was responsible for or knew of the contamination.

- Hydrological connection between AMD and other water usage can be sufficient to impose liability

Environmental Good Samaritan Act (EGSA)

- Liability relief is too limited:
  - No protection for impacts on an area hydrologically connected to the water pollution abatement project work area that causes increased pollution by activities that are unrelated to the implementation of a water pollution abatement project (i.e. unforeseen impacts on hydrologically connected areas)
  - No protection for damage resulting from acts or omissions that are reckless, grossly negligent or result from willful misconduct
  - No protection against citizen suits for pollution emanating from an area hydrologically connected to the good samaritan project/facilities
  - No protection for any person receiving a payment, consideration or other benefit through a contract for the abatement project
Act 2 Release of Liability As a Template

- Section 501. Cleanup liability protection.
  - Any person demonstrating compliance with the environmental remediation standards established in Chapter 3 shall be relieved of further liability for the remediation of the site under the statutes outlined in section 106 for any contamination identified in reports submitted to and approved by the department to demonstrate compliance with these standards and shall not be subject to citizen suits or other contribution actions brought by responsible persons. The cleanup liability protection provided by this chapter applies to the following persons:
  - (1) The current or future owner of the identified property or any other person who participated in the remediation of the site.
  - (2) A person who develops or otherwise occupies the identified site.
  - (3) A successor or assign of any person to whom the liability protection applies.
  - (4) A public utility to the extent the public utility performs activities on the identified site.

Liability Reforms

1. Eliminate EGSA requirement that equipment, materials or services be provided at cost.
2. Amend EGSA to include Act 2-like Covenant-Not-To-Sue for natural gas operators and other persons or organizations implementing DEP-approved comprehensive long-term AMD abatement projects in conjunction with natural gas extraction
3. In conjunction with these reforms, may need to create meaningful financial incentives for comprehensive long-term AMD abatement in conjunction with natural gas extraction
Thank You!

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