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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

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Sponsored by the Marcellus Shale Coalition

RAND

Environment, Energy, and Economic Development

A RAND INFRASTRUCTURE, SAFETY, AND ENVIRONMENT PROGRAM

These proceedings were sponsored by the Marcellus Shale Coalition and were developed in collaboration with the RAND Environment, Energy, and Economic Development Program within RAND Infrastructure, Safety, and Environment, a division of the RAND Corporation.

Library of Congress Control Number: 2012936638

ISBN: 978-0-8330-6972-6

On the cover: Gladden Discharge, Allegheny County, PA. Image courtesy of Elise Noelle Barbot.

Published 2012 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
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Preface

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 formation. Speakers and audience members addressed concerns related to the technical, economic, and regulatory feasibility of using this coal mine water for drilling and hydraulic stimulation of shale gas wells. In summarizing these discussions, these conference proceedings describe many of the challenges and opportunities associated with this approach to extracting natural gas from shale. This document also highlights a number of research gaps, the resolutions for which may assist stakeholders with both short- and long-term decisionmaking.

The event, "Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction," was held in RAND's Pittsburgh office. RAND selected and invited the participants who were not officially affiliated with the Marcellus Shale Coalition, hosted and moderated the roundtable, and retained full editorial control of the writing and production of this proceedings document.

The speakers' prepared white papers and presentation slides are available as a series of online appendixes accompanying these proceedings at http://www.rand.org/pubs/conf_proceedings/CF300.html.

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 selected and invited the non-MSC member participants and retained full editorial control of the content of this document.

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.

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Summary

In recent years, natural gas production in the United States has increased as a result of extraction from shale gas formations, such as the Marcellus Shale. The process of hydraulic fracturing used to tap this resource requires the injection of substantial amounts of water, on the order of 3–5 million gallons, along with chemicals and sand, into a typical horizontal well.[1]

Pennsylvania and the surrounding region have substantial amounts of coal mine water (CMW) in abandoned, closed but actively managed, and active coal mines. Some mines release this polluted, often acidic water into nearby rivers and streams, resulting in coal mine drainage (CMD).[2] In light of the ongoing environmental problems posed by CMD, some have suggested that it could be used as a water source for hydraulic fracturing operations.

These proceedings provide an overview of the topics and discussions at a roundtable conference exploring the use of CMD for hydraulic fracturing in the Marcellus Shale formation. The objective of the roundtable was to assess the technical, economic, legal, and regulatory feasibility of using CMD, and CMW more broadly, in hydraulic fracturing operations. An additional objective was to identify research priorities and to facilitate efforts to address remaining implementation issues.

The event, "Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction," was held in RAND's Pittsburgh office on December 14, 2011. With funding from the Marcellus Shale Coalition (MSC), RAND hosted and moderated the roundtable and retained full editorial control of the writing and production of these proceedings. The roundtable brought together leading researchers, hydraulic fracturing operators, legal experts, representatives from the Pennsylvania Department of Environmental Protection and corresponding agencies in neighboring states (Maryland, Ohio, and West Virginia), and other stakeholders. This document summarizes the presentations of the panelists and the audience's responses and highlights the primary takeaway messages from the day, including a number of research gaps. Resolving these gaps may help policymakers and other stakeholders make better-informed decisions regarding the opportunities and challenges of using CMD for hydraulic fracturing.

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1 Estimates start at 2–3 million gallons of water per horizontal well and go as high as 10 million gallons, i.e., between 7.6 million and 38 million liters per well (Kargbo, Wilhelm, and Campbell, 2010; Mooney, 2011; MSC, undated).

2 Also known as coal mine *discharge*.

Overview of the Roundtable

The roundtable conference opened with introductory remarks by RAND's Pittsburgh office director Susan Everingham and MSC president Kathryn Klaber. The event included four sessions that were moderated by RAND staff.

The first session featured an overview of the availability of CMW in Pennsylvania's Marcellus Shale gas region. Professor Anthony Iannacchione of the University of Pittsburgh shared estimates of the quantity of CMW available for use by operators. He also described the large variation in the chemical composition of CMW, which may affect its suitability for hydraulic fracturing. The remainder of the session focused primarily on the use of CMD, the CMW that is actively draining from mine pools. Charles Cravotta of the U.S. Geological Survey underscored the importance of assessing the suitability of CMD for fracturing operations on a case-by-case basis, referencing his work characterizing CMD in the region.

The second session delved deeper into the technical challenges and uncertainties of using CMD. Professor Radisav Vidic of the University of Pittsburgh discussed the ranges of chemical composition, such as acidity and solute concentrations, that might be acceptable for hydraulic fracturing, stressing that current guidelines are not based on rigorous research. He suggested that a wide range of concentrations of many chemicals may be acceptable for use in hydraulic fracturing operations. This is because chemical treatments and a combination of CMD and fresh or flowback water can be used to adjust the chemical properties of the water used for hydraulic fracturing. Doug Kepler of Seneca Resources Corporation gave an overview of technical challenges from the perspective of industry.

The third session addressed the potential costs of using CMD. David Yoxtheimer of Penn State University discussed his cost estimate for CMD acquisition, transport, treatment, and storage. He and his Penn State colleagues found that transporting water to a well site can account for a significant fraction of the total expense of obtaining water, especially if trucks must travel long distances because of a lack of appropriate local CMD. Furthermore, the approach to treatment will be driven by both the chemistry of a specific CMD source and final operator specifications, with a potential significant impact on cost. Eric Cavazza of the Pennsylvania Department of Environmental Protection presented estimates of the cost of using CMD based on the operating and maintenance costs of existing CMD treatment facilities, which were significantly lower than the cost of building and operating new treatment facilities.

The final roundtable session examined the impact of existing legislation on the use of CMD in hydraulic fracturing operations, especially in the case of *abandoned* mine drainage (i.e., CMD from mines that are no longer owned by private entities). Pam Milavec of the Pennsylvania Department of Environmental Protection opened the session by introducing a draft white paper that is intended to simplify the process of reviewing and approving proposals to use CMD (see Pennsylvania Department of Environmental Protection, 2011b). She explained that the Commonwealth of Pennsylvania intends to establish a multi-program workgroup that will evaluate and make recommendations concerning proposals for the use of CMD. Joseph K. Reinhart and Kevin J. Garber of the law firm Babst Calland lauded the department's recognition of the regulatory and legal barriers facing operators that want to use CMD. They discussed how Pennsylvania's Clean Streams Law often serves to discourage the use of abandoned mine drainage by placing open-ended liability on the user of CMD water. Peter J. Fontaine of the law firm Cozen O'Connor recommended a number of changes in the liability rules, including amending the 1995 Environmental Remediation Standards Act to include covenants not to sue for natural gas operators and others that implement approved, comprehensive, long-term CMD abatement projects in conjunction with natural gas extraction.

Opportunities, Challenges, Potential Research, and Policy Questions

The presentations and discussions covered a range of opportunities and challenges associated with using CMD to support hydraulic fracturing operations throughout the Marcellus Shale region. Several presentations highlighted current research needs and noted some policy questions that decisionmakers will need to address. Chapter Six includes a more in-depth discussion of the following key points.

The use of CMD for hydraulic fracturing activities is technically viable. The panelists and participants were in agreement that the Commonwealth of Pennsylvania has very large amounts of CMW—much more than could be used in the coming decade for hydraulic fracturing. Even considering only CMD, there is a large quantity of water in the region. Operators would most likely not encounter economically significant problems in hydraulic fracturing with much of the CMD available: Many sources would require modest or, in some cases, no pretreatment. Attendees did stress that chemical properties may vary greatly between sites and even sometimes at the same site over time. CMD water from some mines is acidic; from others, it is alkaline. These differences may affect the suitability of the CMD for hydraulic fracturing. However, many CMD sites are close to drilling areas, and piping CMD to fracturing operations is a technically viable option.

Further research could clarify the viability of using CMD for hydraulic fracturing operations at specific sites. The technical and economic viability of hydraulic fracturing with CMD will depend on site-specific characteristics, such as the properties of the particular mine water and CMD-source proximity to natural gas extraction sites. Along these lines, several data and information gaps were identified in the first two sessions of the roundtable and are summarized in Table S.1. There is an additional need to identify the benefits and costs of the near- and midterm use of CMD for hydraulic fracturing relative to long-term CMD remediation and, if appropriate, to craft appropriate mechanisms to obtain a more permanent remediation benefit.

The economics of using CMD could be attractive in some instances but will be highly dependent on site-specific conditions. Estimates of the economic viability of using CMD vary depending on (1) assumptions regarding transport distance and method, (2) the extent of pretreatment required, (3) the cost of the treatment required, and (4) storage requirements, both in terms of total volumes and regulatory containment specifications. None of the analyses presented during the roundtable were completely comprehensive in terms of costs; for example, many parameters were estimated with limited data and assumptions that could not be made a priori. It is clear, however, that the costs of using CMD will be very site-specific. In some cases, using CMD may be less expensive than using fresh water; in other cases, it will be more costly. This is due to transport and storage costs and (often more importantly) to the fact that the extent of treatment required will depend both on the starting quality of the CMD source and the specifications of the final type of water desired by the operator at the extraction site.

The current legal and regulatory framework may discourage the use of CMD for hydraulic fracturing but could be reinterpreted or modified. The Pennsylvania Department of Environmental Protection hopes to clarify and streamline the process of applying to use CMD in

Table S.1
Potential Research Areas Identified During the Roundtable

Research Need	Research Priorities	Responsible Stakeholders
Synthesis, organization, and compilation of existing data on sources of CMW in a publicly available database	Distinctions between CMW pools should be clearly made in terms of quantities, quality, and location, including Chemical composition, pH, and variability Coal mine water (CMW) generally or coal mine discharge (CMD) specifically Among sources of CMD—abandoned or actively managed Among abandoned mines—treated or untreated	Pennsylvania Department of Environmental Protection U.S. Department of the Interior/U.S. Geological Survey Regional research universities Watershed authorities Nongovernmental organizations Industry
More complete, updated characterization of CMD sources to augment existing data in database	Three specific data needs: Quantity (volumes or flow rate) Quality (chemical composition and variability) Location of CMD sites, including relative to natural gas extraction activities	Pennsylvania Department of Environmental Protection U.S. Department of the Interior/U.S. Geological Survey Regional research universities Industry
Development of experience-based guidelines for CMD quantity and quality needs	The guidelines should address the following questions: Which dissolved constituents are truly of concern, and what (ranges of) levels are acceptable? How much variability is tolerable within and between natural gas extraction sites?	Marcellus Shale Coalition Individual operator companies Research universities
Development and analysis of appropriate technical concepts and implementation mechanisms to encourage the long-term remediation of CMD in conjunction with its near- and midterm use for hydraulic fracturing	The policy research might include Cost-benefit analysis of the different technical concepts for long-term CMD remediation Identification of appropriate funding sources and financial incentives for both near- and midterm goals Development of policy mechanisms and identification of appropriate entities for coordinating stakeholders, developing infrastructure, and operating permanent facilities for CMD water remediation	Pennsylvania Department of Environmental Protection Watershed authorities and nongovernmental organizations Industry and Marcellus Shale Coalition

hydraulic fracturing.[3] However, current laws and regulations appear to make operators that make use of CMD liable for environmental damage caused by legacy mine drainage. Both the Environmental Good Samaritan Act and the Environmental Remediation Standards Act (also known as Act 2) set precedents for the possible reinterpretation of the law and can be further explored as CMD use is considered as a part of legacy mine cleanup initiatives. However, legal and regulatory changes must be approached carefully to maximize the specific long-term environmental benefits of using CMD and to simultaneously avoid modifying existing regulations in a manner that is not broadly beneficial or that is even harmful to the environment in some other way.

[3] The Pennsylvania Department of Environmental Protection released a draft white paper on this topic in November 2011. As of late March 2012, the department was in the process of reviewing the feedback provided during the open comment period.

The broader context of watershed quality and sustainability in the region needs to be addressed. Several participants noted that the use of CMD for hydraulic fracturing will not be a panacea for the abandoned mine drainage problem. Regulations allowing operators to use CMD without assuming past liability will not necessarily provide incentives for its use, and long-term remediation requires not a temporary diversion of the CMD water but the establishment of a permanent water remediation infrastructure. These realities should inform realistic goals for the use of CMD for hydraulic fracturing. The policy goals should, in turn, drive the regulatory framework. Nevertheless, a concept that reduces freshwater use in hydraulic fracturing and simultaneously removes contaminated CMD from the watershed represents a potential area of common ground for a diverse group of stakeholders.

Acknowledgments

We would like to thank the Marcellus Shale Coalition (MSC) for providing funding for the roundtable conference and assisting us in reaching MSC members. In particular, Rob Boulware (now with Seneca Resources Corporation) was instrumental in the conception of the roundtable and helped us identify participants with relevant expertise at regional universities. RAND was ultimately responsible for identifying and extending invitations to participants from outside the MSC membership.

We were fortunate to host a very knowledgeable and diverse set of speakers and participants. Professor Anthony Iannacchione and Professor Radisav Vidic of the University of Pittsburgh, David Yoxtheimer of Penn State University, and Peter J. Fontaine of the law firm Cozen O'Connor, along with several co-authors, wrote papers in advance of the meeting. These documents, along with their corresponding presentation slides, can be found in the accompanying online appendixes at http://www.rand.org/pubs/conf_proceedings/CF300.html. Charles Cravotta of the U.S. Geological Survey, Doug Kepler of Seneca Resources Corporation, Eric Cavazza and Pam Milavec of the Pennsylvania Department of Environmental Protection, and Joseph K. Reinhart and Kevin J. Garber of the law firm Babst Calland provided additional remarks and corresponding presentations, which can also be found in the online appendixes.

Our fellow RAND staff provided invaluable support for the event. Debra Knopman, Keith Crane, and Susan Everingham served as session moderators. Jordan Fischbach provided supplemental note-taking for the discussions, especially concerning technical topics. Michelle McMullen, Paula Dworek, and the Pittsburgh office facilities team provided administrative and logistical support in preparation for, during, and after the meeting. Lauren Skrabala provided editorial and document design assistance.

Finally, we thank those who reviewed this proceedings document, including the authors of the four white papers and staff from the Pennsylvania Department of Environmental Protection. We are also grateful to RAND colleague James Bartis for his formal review and valuable feedback. Additional fact-checking was performed by Aviva Litovitz of the Pardee RAND Graduate School. Any remaining errors or omissions remain our own.

Abbreviations

$BaSO_4$	barium sulfate
CMD	coal mine drainage
CMW	coal mine water
CSL	Clean Streams Law
EEED	RAND Environment, Energy, and Economic Development Program
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
ISE	Infrastructure, Safety, and Environment
MSAC	Marcellus Shale Advisory Commission
MSC	Marcellus Shale Coalition
NGO	nongovernmental organization
NORM	naturally occurring radioactive material
NPDES	National Pollutant Discharge Elimination System
SWMA	Solid Waste Management Act
Tcf	trillion cubic feet

CHAPTER ONE

Background on Water Use for Hydraulic Fracturing in the Marcellus Shale

Introduction

Over the past few decades, technological innovations have made it possible to extract natural gas from previously uneconomic "unconventional" deposits in the United States and elsewhere in the world.[1] Expanded access to natural gas resources has largely been the result of the advent of hydraulic fracturing in several natural gas shale basins across the lower 48 states, including the Marcellus Shale formation that underlies much of Pennsylvania and West Virginia, as well as smaller areas of New York, Ohio, and Maryland (Kargbo, Wilhelm, and Campbell, 2010; Mooney, 2011). Figure 1.1 illustrates the size of the area. Less than a decade ago, the U.S. Department of Energy estimated technically recoverable shale gas reserves in the United States to be less than 60 trillion cubic feet (Tcf) (EIA, 2003). By early 2012, the revised estimate was 482 Tcf, with 141 Tcf in the Marcellus Shale alone (EIA, 2012).[2]

Compared with conventional natural gas extraction techniques, hydraulic fracturing requires large quantities of water, mixed with chemicals and a proppant (to keep the fracture open), such as sand, to release the natural gas that is trapped in the shale. The necessary volume of water varies from site to site with shale formation depth and permeability. For the Marcellus formation specifically, recent estimates of average water use range from 3.9 million gallons per well (Ground Water Protection Council and ALL Consulting, 2009) to 5.6 million gallons per well (Chesapeake Energy, 2011).[3] Individual wells in the Marcellus Shale formation have been noted to require up to 8 million gallons of water (Cavazza and Cavazza, 2011).

Depending on the industry's level of expansion in the coming years, hydraulic fracturing using only fresh water would be equivalent to less than 1 percent of Pennsylvania's freshwater use overall.[4] At a local level, however, these required volumes could constitute much larger per-

[1] *Unconventional gas* refers to natural gas extracted from coal beds or low-permeability sandstone and shale formations, as opposed to conventional natural gas that is extracted from natural gas and oil fields.

[2] The U.S. Department of Energy's Energy Information Administration (EIA) estimated in 2011 that shale deposits in the United States contained 862 Tcf of technically recoverable natural gas, so the 2012 number represents a downward revision relative to 2011 but an increase relative to the 2010 estimate of 368 Tcf (Urbina, 2012). Resource estimates change in response to the price of natural gas, advances in extraction technologies, and improved geologic understanding of the resource base; additional experience with extraction in the Marcellus Shale will likely necessitate additional revisions to estimates.

[3] This is equivalent to about 14.8 million and 21.2 million liters, respectively.

[4] In 2005, the volume of fresh water used in Pennsylvania was 3.5 trillion gallons (Kenny et al., 2009). Assuming average water use of 3.9–5.6 million gallons per well, the hydraulic fracturing of 1,741 natural gas wells in 2011 (Pennsylvania Department of Environmental Protection, 2011a) would have required 6.8–9.7 billion gallons—equivalent to 0.2–0.3 percent of annual total freshwater consumption in Pennsylvania. This is a small fraction, especially when contrasted with other

Figure 1.1
Location of the Marcellus Shale Formation

SOURCE: Adapted from U.S. Geological Survey.
RAND *CF300-1.1*

centages of flow, especially if drawn from smaller surface sources. While recycling the flowback and produced water has become common for the shale gas extraction industry in the Marcellus region, reducing the amount of fresh water required by the industry is nevertheless desirable.

Pennsylvania has a large amount of water that has been contaminated by coal mining activities. This water is collectively referred to as *coal mine water* (CMW). When draining from a coal mine pool, the water is specifically referred to as *coal mine drainage* (CMD, also known as *coal mine discharge*). Because much of this water is acidic, it is frequently called *acid mine drainage*.[5] However, because of the actual chemical variability from site to site, a more accurate label for the contaminated water is CMW or CMD.

All told, the amount of CMW in the region is likely to exceed the quantity of water required by the Marcellus Shale extraction industry in the next decade by a large margin.[6] Because of the site-to-site variability in chemical composition and pH, and the differing proximities of CMW sites to shale extraction sites, the economics of using this source of water for hydraulic fracturing will vary. In addition, the locations of the CMW with respect to the hydraulic fracturing operations may impose technical and logistical complications. The sheer volume of CMW in general and CMD in particular—along with current constraints on efforts to clean up contaminated CMD in the absence of sufficient financial resources—have

uses, such as power generation (72 percent of freshwater consumption) and public water supply (12 percent). If the number of new wells increased to 2,500 annually, as in one projection for the year 2020 (Considine, Watson, and Blumsack, 2011), and if water use per well is constant, then demand would increase to 9.8–14.0 billion gallons annually.

5 Acid mine drainage is sometimes abbreviated AMD; to avoid confusion with *abandoned* mine drainage, we do not use this abbreviation in these proceedings.

6 See Chapter Two for a derivation of this estimate.

made this legacy environmental problem a potentially attractive source of water for the gas extraction industry in the Marcellus Shale region.

Recent Legislation and Regulations in the Commonwealth of Pennsylvania

The potential to use CMD to replace fresh water for hydraulic fracturing has not gone unnoticed by policymakers and other stakeholders. On July 22, 2011, Pennsylvania Governor Tom Corbett's Marcellus Shale Advisory Commission (MSAC) presented its final recommendations for "the responsible and environmentally sound development of Marcellus Shale." Among these recommendations, the committee urged the commonwealth to "encourage the use of non-freshwater sources where technically feasible and environmentally beneficial," specifically mentioning CMD from abandoned mines with the dual objectives of reducing freshwater use and limiting the amount of CMW draining into local streams (MSAC, 2011).

On November 15, 2011, the Pennsylvania legislature adopted Senate Resolution 202, A Resolution Urging the Oil and Gas Industry to Utilize Acid Mine Water in Fracturing Marcellus Shale for Natural Gas Extraction, Whenever Economically Feasible and Environmentally Safe (Pennsylvania General Assembly, 2011). Following the legislation's passage, the Pennsylvania Department of Environmental Protection released the draft white paper "Utilization of Abandoned Mine Drainage in Well Development for Natural Gas Extraction."[7] The document addresses technical and legal issues regarding the use of water from abandoned mines, industry concerns, and the Pennsylvania Department of Environmental Protection regulatory process, coordination procedures, and integration issues. The Pennsylvania Department of Environmental Protection intends to finalize the white paper after reviewing and addressing all comments received from industry and other interested groups during the open review and comment period, which included stakeholder meetings.

The Roundtable Conference

On December 14, 2011, the RAND Corporation hosted and moderated a roundtable conference, "Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction," in its Pittsburgh office, with funding from the Marcellus Shale Coalition (MSC). The event brought together representatives from industry, academia, and nonprofit organizations to focus specifically on the use of CMD to support the drilling and hydraulic stimulation of unconventional shale gas wells. The goal of the one-day roundtable was to assess the feasibility of using CMD for hydraulic fracturing activities by answering four key questions:

1. Are there sufficient CMD sources?
2. Is it technically feasible to use CMD for hydraulic fracturing activities?
3. Are there economic or environmental benefits to pursuing the idea?
4. If so, what factors must be in place to enable such initiatives?

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[7] As noted earlier, "AMD" is an abbreviation for both "acid mine drainage" and "abandoned mine drainage"; although it uses the abbreviation "AMD," the white paper specifically refers to *abandoned mine drainage*.

In addressing these questions, the group sought to identify research needs and address the legal and regulatory barriers to applying the concept on a large scale.

Independent of the feasibility of using CMD for hydraulic fracturing, the activities of the region's unconventional natural gas industry will have a substantial impact, potentially both positive and negative, in multiple sectors. For example, economic development and job creation are likely benefits; produced water spills and increased criteria pollutant emissions from industry activities are risks. The magnitude and likelihood of these other impacts were *not* within the scope of this roundtable.

After a welcome from RAND's Pittsburgh office director Susan Everingham, MSC president Kathryn Klaber opened the event with an overview of the progress to date in examining the utility of CMD for hydraulic fracturing, adding that it is an important issue that merits strong consideration. Not only was it among the 96 recommendations from Governor Corbett's 2011 MSAC, she said, but advancing the concept presents an opportunity for improvement that the industry should embrace. She hoped that the day's discussion would help scientists, operators, policymakers, and other stakeholders better understand which barriers are real and which are anecdotal; in this way, real challenges might be immediately addressed.

Klaber was joined at the roundtable by MSC colleague Andrew Paterson. Invited speakers and participants included leading academic researchers from eight universities across the Marcellus Shale region, MSC members representing 25 companies involved with a range of oil and gas industry activities, and representatives from the Pennsylvania Department of Environmental Protection and neighboring state government agencies in Maryland, Ohio, and West Virginia.

Organization of These Proceedings

These proceedings provide an overview of the topics and discussions at the December 14, 2011, roundtable conference. Chapters Two through Five summarize the substance of the four roundtable sessions, respectively. All four technical sessions were moderated by RAND Corporation staff. Chapter Six offers highlights and key takeaways from the day. The meeting agenda, a complete list of participants, and presenter bios are included as an appendix to this document.

The speakers' prepared white papers and presentation slides, which include detailed graphics and tables supporting the summaries presented here, are available as a series of online appendixes at http://www.rand.org/pubs/conf_proceedings/CF300.html.

CHAPTER TWO

Session 1: Volumes and Characteristics of Coal Mine Water

RAND moderator Aimee Curtright introduced the invited speakers and gave a brief overview of the subject matter of the first session. Professor Anthony Iannacchione of the University of Pittsburgh then opened the session by discussing the amount of CMW available for use by operators working in the Marcellus Shale region, with a focus on Southwestern Pennsylvania. He reviewed the locations of CMW in relation to operating sites, with particular attention to the coal beds in Washington, Greene, Fayette, and Armstrong counties. Iannacchione described how water composition and ownership vary by location and suggested that different types of treatment are needed for active and abandoned mines. Charles Cravotta of the U.S. Geological Survey augmented Iannacchione's presentation with an in-depth review of his agency's 1999 study of the chemical variability of selected discharging mine pools (i.e., the CMD subset of the broader regional CMW). The balance of the session was allotted for an open discussion among participants. This chapter summarizes the two presentations and the participant discussions.

Summary of "Assessing the Coal Mine Water Resources: A Marcellus Shale Perspective"

Based on the contribution by Anthony Iannacchione, Associate Professor and Director of the Mining Engineering Program, Swanson School of Engineering, University of Pittsburgh

Iannacchione opened the first session with an overview of CMW in the Commonwealth of Pennsylvania, focusing on the 16 counties in Southwestern Pennsylvania where there is considerable overlap between sources of CMW and Marcellus Shale extraction activities.[1] Drawing on data from several sources, he estimated that there are about 1,600 underground bituminous mines beneath about 1.1 million acres of land in the region. All told, the volume of the region's CMW exceeds the amount that will likely be required by the Marcellus Shale extraction industry in the coming decade or more.[2] Specifically, there is substantial geographic

1 The speaker also noted the likely applicability of his remarks to both northern West Virginia and eastern Ohio.

2 A single 1,300-acre mine in the region was recently estimated to contain 1.4 billion gallons of water (see the white paper by Iannacchione in the accompanying online appendixes at http://www.rand.org/pubs/conf_proceedings/CF300.html). Assuming that the per-acre volume is only half of this estimated volume figure across all 1.1 million acres would imply a total volume of nearly 600 billion gallons of CMD. This is nearly 12 times the estimated annual water requirement for hydraulic fracturing under a *high-end* assumption (5,000 natural gas wells per year requiring 10 million gallons of water each, or 50 billion gallons of water annually).

overlap between the regions with abundant CMW and those with significant Marcellus Shale natural gas extraction activities.

Despite this abundance, however, not all CMW will be useable as industrial water. The quantity of CMW depends on specific conditions in the mine, and the quality of this water (i.e., the specific chemical composition) often depends on local geology. To distinguish and categorize CMW pools, Iannacchione identified and described in detail four types of underground bituminous coal mines: above-drainage abandoned mines, below-drainage abandoned mines, shallow active mines, and deep active mines. These categories offer a way to generalize the amount and chemical composition (e.g., pH) of the water in various types of mines, but the composition will vary from site to site and, in some cases, over time at a single site. Some mines are presently discharging into surface water supplies; such water is technically coal mine *discharge*. At other sites, the water is largely retained in the mine. Iannacchione provided specific examples of mines and their characteristics, as well as current remediation approaches at those sites (e.g., passive versus active), which may vary based on water characteristics and ownership.

In closing, Iannacchione reviewed the benefits and challenges of using CMW for hydraulic fracturing. Benefits include the generally close proximity and abundant supply of CMW relative to shale gas extraction needs. In the case of active mines, existing infrastructure and clear ownership should make the use of CMW relatively straightforward. In the case of CMD, the environmental benefits to streams and wetlands could be significant, especially in the case of abandoned mines.[3] Challenges include site-to-site variability and lingering questions about which CMW sources might be most appropriate for hydraulic fracturing, as well as the fact that not all mines are close to natural gas extraction activities.[4] In some cases, withdrawing the water could, itself, be problematic from technical or legal perspectives (e.g., destabilization of the mine, flow requirements for a stream).

Summary of Additional Remarks: "Use of Acidic Mine Drainage for Marcellus Shale Gas Extractions—Hydrochemical Implications"

Based on the contribution by Charles A. Cravotta III, U.S. Geological Survey Pennsylvania Water Science Center

Charles Cravotta presented additional remarks on the properties of CMD in the region.[5] His comments underscored the importance of understanding the quality and characteristics of CMD on a mine-by-mine basis. Findings from his work with the U.S. Geological Survey sampling CMD across Pennsylvania in 1999 provided a sense of this variability. He found that the pH of freshly sampled CMD ranged from less than 3 to greater than 7 across all surveyed sites. Additionally, the pH of collected CMD changes over time; the pH of a given sample was

[3] One of the reviewers of this document noted that the *temporary* removal of CMD for near-term use in hydraulic fracturing without the introduction of long-term infrastructure for CMD remediation may not have appreciable long-term environmental benefits.

[4] Access to *CMW* that is presently retained in mine pools would likely require drilling. *CMD*, on the other hand, is already available on the surface and is, in many cases, causing environmental problems as it drains into surface water supplies.

[5] Note that Cravotta sampled coal mine discharge specifically, not CMW more generally.

often found to shift dramatically after aging to either a higher or lower value, depending on the dominant chemical processes (e.g., degassing of CO_2, metal oxidation). Similarly, the concentration of dominant ions in the CMD varied over many orders of magnitude, though it did tend to correlate with pH and the concentrations of other ions. For example, CMD with a pH higher than 6 also tends to have a higher sulfate concentration.[6]

In short, the chemical properties of CMD vary spatially and temporally, and much of this water is not acidic (i.e., it is not "acid mine drainage"). However, generalizations can be made, and the variability can often be understood. These findings have implications for determining the appropriate use of CMD in industrial applications or even as makeup water fed into streams from which water has been drawn for industrial uses. Not all CMD will be appropriate for all applications, and varying degrees of pretreatment will likely be required. The timing of the use of CMD for hydraulic fracturing operations also needs to be considered and figured into approaches to storage and use. Moreover, the U.S. Geological Survey's study of CMD properties was not intended to inform its use for industrial applications.[7] The survey was conducted well in advance of the development of the region's shale gas extraction industry and should be viewed with this in mind.

Discussion: Abundant Coal Mine Water May Offer Unique Opportunities but Needs to Be Better Characterized to Be Used on a Large-Scale

During the discussion portion of the session, participants focused primarily on the site-to-site differences in the water composition of various types of coal mines. As noted, composition varies based on geographic location, mining technology, time, and other factors, with important technical and legal distinctions between abandoned and currently operating mines. However, CMW is abundant and often well located relative to shale gas extraction activities. Participants also discussed the potential problems in using CMD for hydraulic fracturing, along with some of the benefits from its use. Some potentially valuable research objectives for characterizing CMD were identified.

Solutes of Concern and Chemical Variability

The participants reiterated concerns about the presence of sulfates in mine water. Precipitation of sulfates can cause scaling and thus obstruct the passage of natural gas through the formation. Sulfates are always a concern for hydraulic fracturing operators because of the presence of barium and other cations (i.e., positively charged elements or molecules such as calcium, Ca^{2+}, or magnesium, Mg^{2+}) in the shale formation itself. It is not clear whether this precipitation will cause a problem in practice or how bad the problem might be. Some mine waters are not high in sulfates.[8] For those that are, treatment is an option.

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6 This is because when sulfate concentrations are high, barium sulfate ($BaSO_4$) forms and thus reduces barium concentrations.

7 The original study was intended to measure the types and levels of solutes in CMD for possible extraction of the dissolved constituents themselves (e.g., gold).

8 According to roundtable participant Joseph Swearman of CONSOL Energy, concentrations are as low as approximately 150 mg per liter.

One participant noted that more cost-effective, non-thermal active treatment options are under development. Cravotta suggested that this issue needs to be explored further, as does the problem of overtreatment and its potential effect on meeting discharge water requirements. Another participant suggested that solving several solute problems at the same time would be a key to cost-effectiveness; in other words, a more "holistic" approach could reduce costs if it considered all solutes and multiple end uses and if an economic and regulatory framework were developed to address the issue.

Robert Hedin of Hedin Environmental commented specifically on the sulfate content of older abandoned mines, which have been flowing for a long time and are "weathered out." For example, he estimated that while a recently abandoned long-wall mine might have sulfate levels of 10,000 milligrams per liter, 40 years later, the level may have dropped to around 1,000 milligrams per liter. He also stressed that variability is generally observed *between* discharges and not *within* an individual discharge; sulfate concentrations in a typical discharge site might vary from 600 to 1,000 milligrams per liter in a year, but two discharges 20 miles apart might differ by several thousand milligrams per liter.

Participant Tammy Tobin of Susquehanna University noted that many microbial organisms live in CMD—even in acidic discharges—and are able to consume contaminants (including sulfates) through their metabolic activities. Another participant raised the concern that additional costs might be associated with preparing water that contains microorganisms for hydraulic fracturing. Tobin responded that these microbes could be used to the advantage of the treatment process and should be considered as a potentially cost-effective part of pretreatment.

Estimating Volumes and Characterizing CMW

The estimates provided by Iannacchione were supplemented by the commentary of participant Robert Hedin, who noted that there are many abandoned mine discharges throughout Pennsylvania's broader western and central regions. He estimated that each produces around 700–2,000 gallons per minute.[9] Paul Ziemkiewicz, director of the West Virginia Water Research Institute, estimated that active mine drainage treatment systems in the Pittsburgh basin release a total of about 44,000 gallons (170,000 liters) per minute, and abandoned mines in the basin release an additional 130,000 gallons (500,000 liters) per minute. For comparison, Doug Kepler of Seneca Resources Corporation estimated that running a horizontal drilling rig requires about 200 gallons (760 liters) of water per minute.[10] Professor Ziemkiewicz's own preliminary water balance estimate indicates that about 19,000 gallons per minute of makeup water, or 10 billion gallons per year, will be needed by the Marcellus Shale extraction industry.[11] This means that if all of the Pittsburgh basin coal water were suitable for hydraulic frac-

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9 The original value quoted was 1–3 million gallons per day (about 3.8–11 million liters per day, or 2,600–7,900 liters per minute).

10 The actual process of hydraulic fracturing of a single horizontal well occurs over the course of days in several distinct stages; pumping is not continuous during that window. Since some preparation time is required between stages, real-time pumping rates are 1,000–3,000 gallons per minute, and demand fluctuates so that, *on average*, about 200 gallons per minute are required. At one well pad, two to eight individual horizontal wells may be fractured over the course of months or years (Hayes, 2009).

11 This calculation assumes the development of 2,000 wells in the region, requiring 6 million gallons each. It further assumes that 10 percent of the water returns to the surface and is recycled for use in hydraulic fracturing.

turing, active treatment plants and abandoned mine water could provide two and seven times the annual water requirements for the hydraulic fracturing industry, respectively.[12] Professor Ziemkiewicz cautioned, however, that this estimate does not take into account the portion of the water that would be suitable for hydraulic fracturing without further treatment or dilution.

One participant asked the practical question of how to go about characterizing a specific CMD pool to determine whether it is appropriate for use in hydraulic fracturing. The group discussed basic approaches and suggested resources to consult. The first step would likely be to determine how much CMD is available near the site. There are substantial amounts of existing data, including mine maps, the orphan mine discharge database maintained by the Pennsylvania Department of Environmental Protection (undated[b]), and findings from a project that characterized the Pittsburgh coal bed mine pool basin in the early 2000s and made calculations of the volume of water in that area (West Virginia Water Research Institute, undated). Professor Ziemkiewicz based his estimates on this latter source.

When assessing CMD, a distinction must be made between the volume of CMW in a mine and the water flowing from the mine (i.e., *discharging* CMW, or CMD). CMD is likely to be easier to tap, and more information is generally available about the quantity and quality of discharging water. Drilling may be required to obtain basic information about water that is stored in mine pools and not being discharged. There are additional complications with some stored underground mine pools:

- Many mine pools are interconnected.
- Due to the absence of regulations and accurate records in early mining days, there is uncertainty regarding the connectivity of mines, as well as water quantity, quality, and the effects of water removal.
- Water quality may be stratified vertically (i.e., concentrations of solutes may differ with depth, and recharge at the top of the pool may dilute the CMW there). This uncertainty might necessitate pump tests and the development of pumping scenarios to determine when stabilization will occur and what the water quality will be prior to use.

Because CMD often contributes to surface water flow, especially in drier months, removing CMD for other uses can, in some cases, pose a problem for minimum flow requirements of streams. This water source is a substantial contributor to some watersheds, on the order of what a surface stream draining an area of 30 square miles might supply.[13]

Distinctions in CMW

While sulfate and other solute levels may differ greatly among abandoned mine pools and cannot be known prior to testing, working mine operators are well aware of the properties

[12] Another estimate presented by Hugh Barnes of Pennsylvania State University was based on U.S. Geological Survey studies: The 98 flowing abandoned bituminous mines sampled in 1999 by that agency (see Cravotta, 2008a, 2008b) had a median flow of about 190 gallons per minute, or 260,000 gallons per day (1 million liters per day), and a total flow of 54,000 gallons per minute, or 78 million gallons per day (294 million liters per day). It is noteworthy that the annual requirement of 19,000 gallons per minute of makeup water could be met with the combined flows of only the six largest of these 98 abandoned CMW sources.

[13] In Session 2, Cravotta noted the importance of considering the *thermal* impacts of mine drainage on water quality. Because of their underground source, this water can have a cooling effect in summer and a warming effect in winter, and aquatic life potentially depends on these thermal effects.

of water discharged at their sites because they need to control the quality of the water as it is released. As Joseph Swearman from CONSOL Energy pointed out, there are many reasons why water from currently operating mines with active treatment processes—or even closed mines with active treatment in place—should be distinguished from abandoned mines.[14] In fact, it may be easier from a technical and legal perspective to use this water in hydraulic fracturing applications:

- Mine water from active operations is under active care.
- Mine owners are liable for the quality of the water coming from their mines.
- Much is already known about the composition of water from these mines, which can (and must) be held consistent within a mine pool.
- Mine operators have significant existing expertise in CMD management.

Despite the advantages of using actively managed mine water, there are a number of additional factors that make the use of abandoned mine waters potentially attractive. For example, cleaning up a legacy environmental problem is likely to be of greater interest to watershed authorities and regulatory agencies than using mine water that is already under active management and is therefore less of an environmental problem. Several participants stressed the desirability of focusing on *abandoned* mine discharge; one referred to it as “the sweet spot” that they want to hit, rather than using water that is already being actively remediated.

Based on the discussions during this session, distinctions between CMW sources should be based a number of defining characteristics:

- chemical composition, which often correlates with geographic location, mining technology, or mine type
- whether the source is CMW, which is stored in mines, or CMD, which flows out of mine pools[15]
- abandoned versus actively managed mine discharge
- in the case of abandoned mines, whether the discharge is currently being treated or not.

Iannacchione summed up the session by saying, “There is plenty of water out there in these pools. . . . That’s not the question.” The issue, rather, is that there are many *different* sources of CMW, all with distinct advantages and disadvantages. Taking water from actively managed mines offers advantages because there is knowledge about the source and clear assignment of liability. On the other hand, cleaning up CMD from legacy abandoned mines could be more beneficial to the environment, despite the added complexity.

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[14] Note that during Session 2, Professor Radisav Vidic of the University of Pittsburgh provided a map of CONSOL’s active mines in the region as a reference for industry. (See Vidic’s paper in the accompanying online appendixes at http://www.rand.org/pubs/conf_proceedings/CF300.html.)

[15] Drilling into pools of mine water below gas fields is technically, economically, and logistically very different from using polluted *drainage*.

CHAPTER THREE

Session 2: Technical Uncertainties and Challenges in Using Coal Mine Drainage for Hydraulic Fracturing

The RAND moderator, Debra Knopman, introduced the invited speakers and reminded participants of the session's objective to explore the technical challenges and uncertainties related to the utilization of CMW (and especially CMD) in shale gas extraction. The speakers focused on hydraulic fracturing water requirements and ways to acquire, manage, treat, and dispose of water associated with hydraulic fracturing processes.

Over the course of the session, Professor Radisav Vidic of the University of Pittsburgh presented co-authored research on technical issues pertaining to CMD use, especially abandoned mine drainage.[1] He reviewed the required composition of hydraulic fracturing water, stressing that these numbers should not be treated as "gospel" because they are not necessarily based on systematic research or the most current information. He suggested that differences in water properties are ultimately "no big deal" because chemical treatment and mixing CMD with flowback water can adjust the water's properties. Vidic suggested that using CMD or a combination of CMD and flowback water may benefit both operators and local watershed associations. Doug Kepler responded to the presentation by providing an overview of the technical challenges from the perspective of industry. He also spoke about the research needed to move forward with the use of CMD in drilling operations in the Marcellus Shale. The balance of the session was allotted to open discussion. This chapter summarizes the two invited presentations and the subsequent participant reactions and discussion.[2]

Summary of "Use of Abandoned Mine Drainage in the Development of Marcellus Shale: Technical Uncertainties and Challenges"

Based on the contribution by Elise Barbot and Radisav Vidic, Department of Civil and Environmental Engineering, University of Pittsburgh

Vidic opened the second session with an overview of "fluid quality requirements" for hydraulic fracturing developed several years ago in a workshop that included industry experts and staff from the Gas Technology Institute.[3] While perhaps a good set of conservative guidelines based on the information at the time, the values have since been taken as hard numbers, which Pro-

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[1] His co-author, Elise Barbot, was also in attendance.

[2] Note that Kepler did not provide written comments or a presentation. The summary herein is based on his oral remarks only.

[3] See Barnett Shale Water Conservation and Management Committee (2007) for the minutes from this meeting.

fessor Vidic notes is inappropriate given their informal derivation and that they were originally developed in the context of the Barnett Shale. In practice, every well is different, and solute tolerance may be much higher with the right expertise. Today it is common to perform hydraulic fracturing with, for example, chloride levels that greatly exceed those specified in this early workshop. Higher tolerances have been demonstrated in the now-common practice of recycling produced water in the Marcellus region, including tolerance for relatively high levels of sulfates. The industry is finding that, by testing the limits of solute tolerance, they have been able to obtain sufficient permeability to generate productive wells with as much as 1,000 milligrams per liter of sulfate.[4]

Considerations for CMD selection include (1) sufficient flow rate (approximately 200 gallons, or 760 liters, per minute); (2) proximity;[5] and (3) appropriate chemical composition. Vidic noted that the discussion in Session One indicated that more than enough mine water is available to meet the hydraulic fracturing need in the region. In terms of proximity, he also agreed that many sources of CMD are located close to current or likely future drilling activities. Furthermore, in terms of chemical composition, hydraulic fracturing fluid can "accommodate a variety of characteristics" as long as they are accounted for in formulating the fluid. Important chemical properties to consider are sulfate concentration, acidity or alkalinity (due to corrosion issues), and iron concentration. Vidic reiterated the importance of the distinction between CMD sources in actively managed mines and abandoned mines, which also differ by whether or not they are presently being treated. He provided maps of the locations of active and abandoned mines where CMD is being treated in the region from which water might be obtained.

Vidic discussed several potential pretreatment schemes in his presentation, including passive treatments.[6] Most of these processes can successfully remove iron (via oxidation) and reduce the acidity of the water. He presented additional details for two possible approaches for using CMD in hydraulic fracturing applications:

- *Blending CMD with recycled hydraulic fracturing fluid as a part, or all, of the additional makeup water needed.* In this approach, the operator would take the 10–20 percent of flowback water from the hydraulic fracturing activities, blend it with CMD, and allow the precipitation of $BaSO_4$ to occur in ponds or holding tanks before the water is used for hydraulic fracturing.[7] Vidic and colleagues are currently looking at the chemistry of this blending approach, including the potential to remove naturally occurring radioactive material (NORM) as part of a solid waste sludge.[8] The researchers are also considering

[4] In his presentation, Vidic provided data from Range Resources showing some of the high-solute water that has been used for hydraulic fracturing.

[5] Vidic pointed out the potential value that CMD sources close to hydraulic fracturing might have in terms of reducing water truck traffic and the associated externalities of this activity. CMD may be closer than freshwater sources or may be piped.

[6] He noted that, in Pennsylvania, there has historically been a shortage of funding for operations and maintenance of passive treatment facilities.

[7] Because barite is used in drilling mud, this precipitate could also be used as a source of barium in lieu of the current supply of largely imported barium.

[8] NORM can be brought to the surface from the surrounding soils and rocks during oil and gas extraction activities. Once exposed or concentrated on the surface by human activities, such as fossil fuel extraction, this material is often called tech-

the specific microbiological activity in the blends. Vidic presented site-specific sample results for the kinetics of different blending ratios and the resulting final chemistry of the blended water and corresponding precipitates. Based on this chemical understanding, it is possible to adjust the blend ratios according to the sulfate (and other solute) concentrations to suit the needs of an individual hydraulic fracturing operation.

- *Direct use of CMD, either as received or diluted with fresh water.* In this second approach, CMD, either untreated or "minimally" treated, serves as the primary constituent of the hydraulic fracturing solution. Vidic asserted that, in many cases, this may be acceptable, and sulfate levels may not be as important as had been thought in the past. In other words, the formation of some $BaSO_4$ "downhole" may not be problematic. This is because even at concentrations of 800 milligrams per liter of sulfate, the volume of $BaSO_4$ solid that is formed is less than 1 percent of the volume of the solid proppant that is *intentionally* added to hydraulic fracturing fluid as a standard part of operations. Whether this $BaSO_4$ forms a surface scale or instead forms "plugs" in the pore network, it is unclear how it will affect well permeability and performance. To his knowledge, this had not been systematically studied and scientifically established, and a few microns of scale on casings and pipes might not significantly affect yields.[9]

At the end of the session, Vidic suggested that further information was needed to make technically sound decisions. He noted several specific needs:

1. research that identifies the level of sulfates and suspended solids that can, in practice, be tolerated by successful fracturing (e.g., understanding how sulfates precipitate "downhole" and affect permeability)
2. development of systematic, scientifically based fracturing fluid quality guidelines
3. research (and development of appropriate regulations) regarding the level of NORM in solid waste, as well as corresponding disposal issues.

Summary of Additional Remarks: Challenges Related to the Use of Coal Mine Drainage from the Industry's Perspective

Based on the contribution by Doug Kepler, Vice President of Environmental Engineering, Seneca Resources Corporation

Kepler began by noting that, from an industry perspective, the decision to use CMD for hydraulic fracturing will be based on how CMD affects well productivity and the bottom line. A small reduction in reservoir productivity could theoretically lead to a major revenue reduction, creating a potentially strong incentive not to put *any* sulfate into the well. What happens "downhole," after the rock is fractured and once the natural gas begins to flow, is what really matters. Though the amount of $BaSO_4$ solid precipitate would be much lower than the total

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nologically enhanced NORM, or TENORM (see U.S. Environmental Protection Agency, 2010). Regulatory and technical issues associated with the disposal of radioactive material in its solid precipitate form are important considerations.

[9] He also noted that there is no naturally occurring sulfate in Marcellus Shale deposits, so there will be no expectation of hydrogen sulfide formation and souring, as has been observed in the Barnett Shale.

amount of proppants (e.g., sand), proppants create pathways, while the $BaSO_4$ could hypothetically make plugs.

On the other hand, the solute levels in CMD should be compared with other sources of water for hydraulic fracturing. Public water supplies, for example, may contain up to 250 milligrams of sulfate per liter and still meet drinking water standards. Industry has successfully used fresh water with hundreds of milligrams of sulfate per liter. Mine drainage sources may have much lower levels than this. As industry moves almost entirely to recycling produced water, the chemistry of CMD is "almost immaterial" when compared with the levels of solutes introduced in recycled produced water.[10] By using a blend of fresh water and flowback or produced water,[11] operators might, in fact, face the same or even greater sulfate issues than those presented by CMD alone. In some cases, if produced water is net alkaline,[12] blending it with acid mine drainage could be technically beneficial. In these cases, the pH reduction caused by adding CMD to produced water could help avoid calcium precipitate if the blend achieved a pH below 7.

In practice, it would be valuable to develop a technical approach to physically removing $BaSO_4$ at the site, or "on the fly," after blending produced water with CMD. Operators do not generally have sufficient on-site storage capacities for the requisite quantities of pretreated water—5 million gallons of storage tank capacity would be prohibitively expensive—and thus the blend would need to be pretreated on an as-needed basis. Kepler noted that he did not believe that NORM disposal would be a problem at "most" solid waste disposal facilities in Pennsylvania because regulations govern the average levels of this material across all accepted waste. In closing, Kepler referred to mine drainage as "just another source of water"—in fact, a "great" source of water relative to fresh water, especially if its use cleans up legacy environmental problems. Physically dealing with solid sludge, he suggested, would be the biggest technical barrier to using CMD.

Kepler recommended a gradual approach to using CMD. While, ideally, 100 percent of CMD would be used either for hydraulic fracturing or to maintain flows of rivers and streams and thus would be returned to the ecosystem fully remediated, this may not be likely to initially happen. A first step would be for industry to utilize a small amount of CMD for hydraulic fracturing—enough to improve the average water quality of rivers and streams with minimal impact on flow.[13] A better next step would be to have the natural gas industry pay to passively fully treat a single CMD site, using some percentage (perhaps 20 percent) of the drainage for hydraulic fracturing needs and allowing the majority of the water (the remaining 80 percent or so) to return to the watershed. This would lead to long-term environmental remediation of CMD. However, in his assessment, neither of these scenarios is likely to happen under the current perceived distribution of liability in Pennsylvania.

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[10] Produced water may have as much as 300,000 milligrams per liter of total dissolved solids.

[11] Kepler's example was a blend ratio of about 80 percent fresh water and 20 percent produced water.

[12] Much of the produced water in Pennsylvania has a pH in the high 6s to low 7s; most of the hydraulic fracturing additives (e.g., friction reducers) need a pH between 6 and 9 to be effective.

[13] One of the reviewers of these proceedings noted that this first scenario provides minimal environmental benefit by only temporarily withdrawing the CMD for the length of active hydraulic fracturing activities. If fracturing of an individual well occurs over days to weeks, and if two to eight wells are completed at a single pad over months or years, the use of CMD water for these activities alone would not provide a permanent benefit. This scenario should be carefully considered in any proposed changes in regulation or liability in the commonwealth.

Discussion: The Concept Is Promising and Technical Challenges Are Surmountable, but More Research and Collaboration May Be Needed

After the presentations, participants posed a number of questions about the technical aspects of hydraulic fracturing with CMD. Many cited logistical and legal concerns as being equally or more important than the technical concerns of hydraulic fracturing itself. Participants also identified several key research questions and areas for potential collaboration among the industry, government, and nonprofit sectors.

Clarifying Technical Questions

Participants asked for further clarification of technical factors raised during the presentation, such as NORM sources and levels. It was explained that most of the radium-226 comes from the shale deposit itself, not from CMD. One participant estimated that radiation generally ranges from 1,000 to 10,000 picocuries per liter in flowback water.[14] The sulfates in the CMD, however, will generally cause precipitation of radium sulfate and other sulfate solids, significantly lowering the radiation levels in the water itself but increasing the level of radium in the solid waste.

One participant, Paul Hart of Hart Resource Technologies, noted that while landfills need to meet specific NORM levels, it is "relatively easy" to treat and dispose of these wastes from a technical standpoint. He added that the levels are "very low" and are not problematic from a general environmental or human health perspective. Radiation does, of course, trigger regulations. In Hart's experience, the management of sulfate is not a major challenge in terms of chemistry; his company has already had some successful experience with co-treatment using mine water. In fact, as Doug Kepler noted, because radium is a water-soluble constituent in the shale formation, it will be a problem in produced water regardless of the source; precipitation with sulfate to form a solid waste may actually be preferable to dealing with radium as a solute. Participants discussed other CMD contaminants, such as aluminum, as potentially problematic for aquatic life but generally not a problem for hydraulic fracturing.

Because of the high levels of bromide in produced water from hydraulic fracturing in Marcellus Shale deposits, participants also discussed the potential to lower bromide concentrations using CMD. Vidic suggested that while bromide levels in rivers and drinking water are a concern, it is unclear why they have risen periodically in recent years in some rivers. Andrew Paterson of the Marcellus Shale Coalition noted that as of May 2011, all MSC members agreed to stop delivering produced water to municipal treatment plants.[15] Cravotta suggested that, regardless of the source, CMD could potentially augment flow and dilute bromide levels during low-flow periods in the summer.

Several participants noted that logistical issues, and not chemical ones, might end up being the largest technical hurdle for CMD. They discussed the implications of integrating CMD sources into a more permanent, piped water supply for the industry. One participant stated that since the CMD problem is relatively well known and characterized, logistical considerations remain the most important problem. Some participants found the legal and regu-

[14] Radium is a regulated drinking-water contaminant and must not exceed 5 picocuries per liter (see U.S. Environmental Protection Agency, 2012a). Long-term exposure to radium above this level has been linked to an increased risk of cancer.

[15] Prior to May 2011, produced water could not be legally accepted at most municipal facilities in Pennsylvania; only a limited number of municipal water treatment facilities were technically allowed to accept produced water.

latory issues to be the greater barrier to using CMD. The technical, logistical, and regulatory challenges will depend, in part, on the specific approach to the use of CMD that is being considered. Table 3.1 summarizes the technical approaches discussed during the session and compares some of their advantages and drawbacks.

Research and Policy Needs

Data gaps could make it difficult to use CMD on a large scale. Several participants noted the need for a more comprehensive, systematic characterization of CMD locations, flow rates, and chemistry if CMD is to find widespread use in hydraulic fracturing. At a minimum, operators would benefit from the synthesis and organization of existing information. Because these data are largely anecdotal or years-to-decades old, an updated study of the location, characteristics, and volumes of CMD may be needed. If the natural gas extraction industry is to see CMD as a viable, substantial source of water, it will need more—and more reliable—information. Cravotta noted that flow volumes, which may vary by orders of magnitude, are particularly poorly characterized compared to chemical concentrations, which tend to vary by, at most, a factor of two to three. Along these same lines, Professor Ken Klemow of Wilkes Uni-

Table 3.1
Technical Concepts for Using Coal Mine Drainage in Conjunction with Hydraulic Fracturing Activities

Approach	Benefits	Drawbacks
Treatment of hydraulic fracturing–produced water in CMD facilities	Could take advantage of reduced capital costs, including infrastructure for piping water	Not technically viable in existing facilities Chemical complexity increases
Mixing CMD and produced water *prior to* use for hydraulic fracturing or prior to further treatment for discharge	Could allow cleanup of *both* types of contaminated water simultaneously (e.g., precipitation of barium sulfate) and at a lower combined cost	Chemical complexity increases relative to treating separately
Use of CMD for makeup water in surface streams downstream of hydraulic fracturing water withdrawal site[a]	Sulfate levels that are problematic for hydraulic fracturing *may*, in some cases, be appropriate for discharge into streams and allow water withdrawal without flow compromise	CMD may still require treatment prior to discharge into the river
Direct use of CMD for hydraulic fracturing	Least expensive approach to hydraulic fracturing utilization	Requires co-location and appropriate water chemistry
Pretreated use of CMD	More flexible in terms of source chemistry	Increased expense relative to direct use
Pretreated CMD from *active treatment mines*	Liability is clear, treatment is in place, and chemistry is well understood	Does not solve legacy abandoned mine problem
Pretreated use of CMD *with transport or storage*	Most flexible in terms of obtaining desirable chemistry when and where it is needed	Likely to be expensive, especially if transport distances are far and water is transported by truck or if large storage capacity is required
Pretreated use of CMD with mobile treatment facilities	Potential to reduce capital costs for individual operators through cost-sharing	Logistical complications, added cost to treatment unit relative to fixed facility

[a] One of the reviewers of this document questioned the feasibility of this concept as part of a long-term, sustainable infrastructure for the natural gas extraction industry and doubted that this would be a broadly applicable solution to remediate significant amounts of CMD.

versity noted that a regionally specific approach will be required because of differing quantities and locations of CMD and hydraulic fracturing activities. In some regions, substantial quantities of CMD and large-scale unconventional gas extraction may not be in close proximity.[16] There could be value in identifying a few larger, higher-value areas where hydraulic fracturing is taking place and substantial quantities of CMD are available.

Clear alignment of stakeholder interests could advance the concept. Kathryn Klaber of the Marcellus Shale Coalition noted the potential for public-private partnerships to enhance the ability of companies engaged in hydraulic fracturing to use CMD. One example would be a regional infrastructure plan for using and, if necessary, piping CMD (rather than a company-by-company approach). She and other participants stressed the importance of involving many stakeholders—nonprofit organizations, watershed authorities, the Pennsylvania Department of Environmental Protection, and the industry—to meet goals of mutual interest. One participant noted that most of the work to date on abandoned mine drainage remediation had been advanced by community-level, grassroots efforts. He emphasized the importance of moving this concept forward in the same way.

Participants cited the a reduction in truck traffic—with attendant reductions in noise, congestion, air pollution, and life-cycle greenhouse gas emissions—as a potential regional benefit of using a local or piped water resource rather one that must be trucked to sites. Such positive community effects could magnify the perceived benefits of CMD use. Peter Fontaine of the law firm Cozen O'Connor noted that a centralized, strategic plan from the regional or watershed-level perspective, in conjunction with a database, would provide the proper framework for industry to move forward. The Pennsylvania Department of Environmental Protection and watershed groups are likely best positioned to identify these opportunities. One participant noted the potential for MSC to play an organizing role as well.

At the closing of the session, the discussion turned to several research gaps whose resolution might facilitate the broader use of CMD in hydraulic fracturing:

- a comprehensive mapping of the relative location of CMD and hydraulic fracturing operation sites
- an updated and expanded characterization of regional CMD water composition and flow rates
- partnership and collaboration between public and private entities interested in broader and more regionally specific planning, including sharing of information
- development of appropriate policy or financial mechanisms to encourage the long-term remediation of CMD in conjunction with near-term use for hydraulic fracturing.

As one participant put it, all these resources would help "link the problem with the opportunity" and provide needed information to industry.

One local operator closed the session with an appropriate segue into the next sessions. Regarding the economic and legal implications of CMD use, he said that his company would be willing to fund a permanent passive treatment system for a CMD site, with the intention of

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[16] For example, Klemow and his colleagues estimated that about 85 million gallons (320 million liters) of mine water flow daily into the Susquehanna River in the northeast region of Pennsylvania from the major discharges in the Lackawanna and Wyoming valleys to the south (not accounting for CMD discharges in the middle and southern anthracite fields to the south of the valley). Most of this CMD flows into the river untreated. However, discharges may be separated from potential hydraulic fracturing activities by 20–50 miles or more.

temporarily meeting hydraulic fracturing water needs, if a mechanism could be put into place to resolve the current regulatory and liability challenges.

CHAPTER FOUR

Session 3: Economic Feasibility

The third session addressed how the use of local CMD might benefit or challenge operators with costs related to CMD acquisition, transport, treatment, and storage. As RAND moderator Keith Crane explained, the key question of the session was to ask, "Does this make commercial sense?" Both speakers used their expertise in the field to answer this question from a cost perspective. David Yoxtheimer opened the session by discussing the full range of costs associated with CMD transport, treatment, and storage.[1] He then suggested that the cost of using treated CMD may be four to five times greater than that of fresh water, but operators stand to save on transport if the CMD is relatively close to the site. Eric Cavazza augmented Yoxtheimer's presentation by comparing the costs of treating CMD with the use of municipal water from specific sites across Pennsylvania, which were significantly lower.

Summary of "Economics of Utilizing Acid Mine Drainage for Hydraulic Fracturing"

Based on the contribution by Seth Blumsack, Tom Murphy, and David Yoxtheimer, Penn State University

Yoxtheimer discussed a number of factors affecting the estimated costs of using CMD at hydraulic fracturing sites, which are summarized in Table 4.1. There may be significant expense associated with such use, particularly in transporting water to and from a well site. The cost of shipping water by truck is considerable. Operators expect to pay around $0.024 per gallon, assuming a one-hour truck trip to move the water from its source to the operation site.[2] Piping CMD instead may reduce transport costs significantly. Many operators currently pipe in local fresh water and recycle the flowback water to save on transport costs and to reduce the environmental impact of trucking. To reap any financial gain that may be associated with piping CMD to sites, however, operators will need to consider (1) the proximity of the CMD to the drilling operation, (2) access rights to the source, (3) access to rights of way, (4) whether quantities are sufficient, and (5) the cost of treating CMD.

Costs associated with industry's water treatment specifications tend to vary greatly across companies. Flowback water, under the assumed specifications in this analysis, has treatment

1 His co-authors, Seth Blumsack and Tom Murphy, also participated in the roundtable.

2 The assumptions and results were originally presented on a per-barrel-of-water basis; this value, for example, was estimated at $1.00 per barrel. Conversion to gallons assumes 42 gallons of water per barrel and 3.785 liters per gallon.

Table 4.1
Estimated Economic Costs of Coal Mine Drainage for Hydraulic Fracturing

Economic Parameters	Cost Drivers	Range of Cost Estimates (per gallon)[a]
Cost of CMD treatment	Final water specifications[b]	$0.095–$0.19
Cost of CMD transport	Distance and method (i.e., pipe vs. truck)	Truck, 1-hour trip: $0.024
Cost of CMD storage	Double-lined impoundment requirements[c]	$0.012–$0.024
Total cost to treat, transport, and store CMD		$0.13–$0.24
Cost to transport fresh water	Distance and method (i.e., pipe vs. truck)	Truck, 1-hour trip: $0.024
Cost to store fresh water	Minimal containment required	$0.0024
Total cost to transport and store fresh water		$0.026
Cost to treat flowback water	Final water specifications	$0.095–$0.19
Cost to store flowback water	Double-lined impoundment requirements	$0.012–$0.024
Total cost to treat and store flowback water		$0.11–$0.21

SOURCE: Analysis performed by Penn State University.

[a] All figures were originally quoted in units "per barrel" of water, as shown in the Blumsack, Murphy, and Yoxtheimer's white paper in the accompanying online appendixes.

[b] Specifications are assumed to be the same as those for flowback in Penn State's analysis with respect to sulfate levels and other solutes.

[c] Regulatory requirements for CMD storage are assumed to be the same as for storing flowback water.

costs ranging from about $0.095 to $0.19 per gallon, depending on the specific types and concentrations of solutes present and the treatment technology.[3] CMD may need similar levels of treatment to reduce concentrations of potential scaling agents, such as metals and sulfates, to acceptable levels and may thus generate similar costs. The cost estimates included all capital, labor, operating, and disposal costs, which are reflected in the fees being charged to operators.

Under current regulations,[4] CMD will need to be stored in double-lined, engineered impoundments, rather than single-lined freshwater impoundments, which the Penn State analysis assumes will increase CMD use costs by around $0.012–$0.024 per gallon.[5] Freshwater impoundments currently cost operators about $0.0024 per gallon.[6]

Yoxtheimer closed his talk by presenting estimates suggesting that using treated CMD may be more expensive than using fresh water. The costs for using treated CMD are estimated at $0.13–$0.24 per gallon—significantly more than the approximately $0.026 per gallon cost of fresh water. Reductions in CMD-associated costs can be made, however, if CMD is situated close to wells and if alternatives to current treatment and storage methods are found.

3 The original estimate was $4–$8 per barrel of flowback water.

4 The regulations were current at the time of the meeting.

5 Centralized tank farms would also cost around $0.01–$0.02 per gallon, assuming that costs are spread over ten wells.

6 One of the reviewers of this document noted that the significant storage costs imply the need for common infrastructure to reduce this cost driver.

Summary of Additional Remarks: "Economic Analysis of the Use of Mine Water from Abandoned Mines for the Development of Marcellus Shale Gas Wells in Pennsylvania"

Based on the contribution by Eric E. Cavazza, Pennsylvania Department of Environmental Protection

Cavazza suggested that the cost of using existing treated CMD in the Commonwealth of Pennsylvania may be competitive when compared with the cost of using treated municipal water. The costs of treating CMD in various existing Pennsylvania sites ranged from $0.000070 to $0.00076 per gallon.[7] As he clarified in the discussion session that followed, the estimates in his presentation were based on operations and maintenance costs at representative treatment facilities in the commonwealth and did not reflect the cost of building new treatment facilities or infrastructure. The higher costs in the range from these existing facilities were associated with more acidic CMD, which needs extra treatment to raise its pH level. One example of an entity selling treated mine water for use in hydraulic fracturing is the Blue Valley treatment plant in Elk County, which uses the revenue generated from the sale of the CMD to the natural gas extraction industry to continue operating the treatment plant and, potentially, other nearby treatment plants in the future.

Many Pennsylvania natural gas extraction companies, in lieu of using CMD, choose to buy treated municipal water because of liabilities (as discussed in Chapter Five). However, this may not be the most cost-effective option. According to Cavazza, the cost of purchasing water from municipalities can range from $0.007 to $0.015 per gallon.[8]

Discussion: Are There Economic Benefits to Using CMD?

The discussion portion of the session prompted a more detailed exploration of the costs of using CMD, and particularly the differences in the assumptions in the Penn State analysis and the costs presented by the Pennsylvania Department of Environmental Protection. As noted, Cavazza explained that the CMD treatment costs in his presentation reflected operating and maintenance costs of the CMD treatment facility only (i.e., no capital costs were included in the estimates); with capital and storage costs, prices can range from around $0.048 to $0.071 per gallon.[9] These figures are much closer to the treatment costs in the Penn State analysis of $0.095 to $0.19 per gallon. Furthermore, the Pennsylvania Department of Environmental Protection figures did not necessarily include the cost of reducing sulfate concentrations to the current standards demanded by many operators for hydraulic fracturing in the Marcellus region, nor did the figures include the transport and storage costs in the final Penn State numbers. Although, as noted, there is some uncertainty as to the level of sulfate treatment required, such treatment would require an active treatment system whose associated life-cycle costs are generally higher than passive CMD treatment. Cavazza noted that storage costs are increasing. He also suggested that, because there is great variety among companies' water quality standards,

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7 The original estimate was $0.07–$0.76 per *1,000* gallons.

8 The original estimate was $7.00–$14.50 per *1,000* gallons.

9 The original estimate provided by the speaker was $2–$3 per barrel.

it is difficult to assess the applicability of the numbers presented in the session. In general, it is important to remember that decreases in sulfate concentration limits will lead to increases in treated water prices. Several participants thought that regulatory requirements for storage, and not necessarily technical requirements, could drive the costs of storage to uneconomic levels.

Some participants wanted more details about transport and storage options. Rail had not been considered by either of the two speakers but could offer significant savings relative to truck transport, provided that railroad lines were suitably located. Because roads are much more densely distributed throughout the Marcellus Shale region, rail transport may not be an option in all cases. Participants also requested more information on the costs for pretreatment to avoid transport pipeline disruption (e.g., scaling). Putting water in a nearby stream and then withdrawing it downstream was one "transport" option suggested; Cavazza replied that this option had already been considered by various stakeholders who had visited the Pennsylvania Department of Environmental Protection to discuss the use of CMD for hydraulic fracturing, and such arrangements are hypothetically possible. However, one federal court ruling in West Virginia demonstrated that if operators treat and discharge CMD that falls short of Clean Water Act standards, operators can be held responsible for obtaining a National Pollutant Discharge Elimination System (NPDES) permit. This kind of liability can act as a disincentive.

There was also a discussion of the potential for more centralized or coordinated planning in terms of infrastructure. For example, a common pipeline system used by many operators would greatly reduce the average costs of CMD transport. With only pilot-scale systems in use at the present time, these economies of scale cannot be realized. Coordinating the construction of common infrastructure, such as water pipelines or permanent CMD remediation facilities—among industry, watershed groups, and the Pennsylvania Department of Environmental Protection—would help reduce costs.

CHAPTER FIVE

Session 4: Regulatory and Legal Barriers

The increasing interest in hydraulic fracturing with CMD has led to calls from operators and citizen groups for clearer state and federal environmental regulation and oversight. The fourth session of the roundtable conference addressed how existing legislation affects the use of CMD in hydraulic fracturing operations. The session was forward-looking in that the speakers focused on new initiatives being undertaken by the Pennsylvania Department of Environmental Protection and the ways in which current environmental laws might be interpreted to include CMD use.

After introductions by RAND moderator Susan Everingham, Pam Milavec of the Pennsylvania Department of Environmental Protection opened the session by sharing a new white paper from her agency.[1] The final draft of the white paper will be released after stakeholder feedback has been incorporated. In her presentation, Milavec focused on technical and legal issues, which she suggested were the primary obstacles blocking industry's use of CMD in hydraulic fracturing. Joseph K. Reinhart of the law firm Babst Calland then presented work specific to the regulatory and legal barriers facing CMD use.[2] He suggested that there may be ways to work within existing laws, especially the Environmental Good Samaritan Act. Peter Fontaine of the law firm Cozen O'Connor offered further legal insights, suggesting that the Environmental Good Samaritan Act may, in fact, be inappropriate for operators because related actions are voluntary. The law does not, therefore, provide operators with broader liability protections. Fontaine suggested that the Environmental Remediation Standards Act, or Act 2, may set better precedents for change in this case. This chapter summarizes the three invited presentations and participant responses.

Summary of "Utilization of Abandoned Mine Drainage in Well Development for Natural Gas Extraction: Overview of the Pennsylvania Department of Environmental Protection's Draft White Paper"

Based on the contribution by Pam Milavec, Environmental Services Section Chief, Bureau of Abandoned Mine Reclamation, Cambria District Office, Pennsylvania Department of Environmental Protection

1 See Pennsylvania Department of Environmental Protection, 2011(b).

2 The presentation was co-authored by Kevin J. Garber, also of Babst Calland.

Milavec opened her talk by describing the primary purposes of the Pennsylvania Department of Environmental Protection's white paper, "Utilization of Abandoned Mine Drainage in Well Development for Natural Gas Extraction."
The paper was designed to

- define the roles of the department's various abandoned mine drainage–related programs
- establish a process for the oil and gas industry to utilize abandoned mine drainage
- establish a process for the Pennsylvania Department of Environmental Protection to facilitate review and evaluate proposals for the use of abandoned mine drainage.

Milavec focused her talk on how the draft addresses the technical and legal challenges facing the use of abandoned mine drainage for hydraulic fracturing. Solutions to technical issues include the following:

- *Nonjurisdictional impoundments.* Abandoned mine drainage may be stored in nonjurisdictional impoundments if it does not pose potential pollution problems and if it is not a danger to persons or property; there are stringent water quality criteria regarding this option.[3]
- *Centralized wastewater impoundment facilities.* Abandoned mine drainage may also be stored in centralized wastewater facilities.
- *On-site pits and tanks.* This option allows for the storage of CMD in pits or tanks at drilling sites.

Milavec also presented storage standards for nonjurisdictional impoundments being considered by the Pennsylvania Department of Environmental Protection. Because mine drainage must not affect fresh water, there is a "tight limit on what can be stored." Table 5.1 shows

Table 5.1
Possible Storage Standards for Nonjurisdictional Impoundments

Parameter	Abandoned Mine Drainage Storage Standards
Alkalinity	> 20 milligrams per liter
Aluminum	< 0.2 milligrams per liter
Iron	< 1.5 milligrams per liter
Manganese	< 0.2 milligrams per liter
pH	6.5–8.5
Conductivity	1,000 micro-ohms per centimeter
Sulfate	< 250 milligrams per liter

[3] A "nonjurisdictional impoundment" is an impoundment used for the storage of fresh water (or fluids or semifluids other than water), the escape of which does not pose a potential for pollution or danger to persons or property. Such an impoundment is not located on a watercourse and does not have a contributory drainage; it must be less than 15 feet deep, and the impounding capacity at maximum storage must be less than 50 acre feet (approximately 16.3 million gallons). A nonjurisdictional dam is not regulated under the Dam Safety and Encroachments Act (32 P.S. §§ 693.1–693.27) and 25 PA Code Chapter 105. Accordingly, there are no requirements regarding the construction or monitoring of these facilities.

some of the standards that can be problematic with regard to mine discharges. The full list of parameters can be found in the corresponding slides from Milavec's presentation in the accompanying online appendixes.

Milavec noted that site-specific CMD chemistry information is incomplete and outdated and that the Pennsylvania Department of Environmental Protection and other interested stakeholders need an updated database.

Another move toward alleviating technical issues is a clear process for operators to submit proposals to utilize abandoned mine drainage. Milavec reviewed the process of writing the draft white paper, which is summarized in the corresponding slides in the accompanying online appendixes.

Finally, Milavec presented two potential solutions to liability issues facing CMD usage. Under Pennsylvania's Clean Streams Law (CSL), operators face long-term liability for treating mine drainage collected and treated for hydraulic fracturing. Milavec noted that Pennsylvania's Environmental Good Samaritan Act can help provide some operator immunity and that a consent order and agreement with the Pennsylvania Department of Environmental Protection may help lessen the liability for long-term treatment of CMD sources as long as specific conditions, as provided in the consent order and agreement, are met.

Summary of Additional Remarks: "Regulatory and Legal Barriers"

Based on the contribution by Joseph K. Reinhart and Kevin J. Garber, Babst Calland

Reinhart began by commending the Pennsylvania Department of Environmental Protection for issuing a draft white paper that will facilitate the use of CMD for hydraulic fracturing in the Marcellus Shale region. He praised the white paper for its acknowledgment of the potential liability risks for operators. Operators need to be made better aware of potential liabilities, he said, because the language used in environmental laws could pose barriers to the use of CMD.

Operators ought to be especially aware of activities associated with CMD reuse, including (1) the construction of CMD treatment plants, (2) the storage of CMD in nonjurisdictional or centralized wastewater impoundments, (3) CMD collection and transport activities, and (4) the pumping of CMD into mine pools. The CSL (especially §391.315) and Pennsylvania's Solid Waste Management Act (SWMA) contain terms with significant implications that, if misunderstood, could have consequences for operators.[4] Section 315 of the CSL states, "No person shall allow a discharge from a mine into waters of the Commonwealth without a permit." Reinhart noted that most problems occur in cases where operators fail to obtain appropriate permits. However, if operators do not recognize these obligations, they could find themselves liable, even if in practice they made an environmental improvement.

The term *waste* can be especially problematic when applied to mine drainage intended for use in lieu of fresh water for natural gas extraction. According to the SWMA, operators are prohibited from discharging residual waste to the surface or underground without a permit (§610). If mine drainage were to be considered a waste, a gas well operator could not discharge it into the ground without an SWMA permit, it could not be transported to the well site by a

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[4] Reinhart briefly touched on the Clean Streams Law, §391.316 but noted that the next speaker would focus on that section.

trucking company without complying with waste transportation requirements, and the person who originally collected the mine drainage could be responsible for any spills at the well site. Generators of waste have been held to be responsible for waste that is disposed of without a permit, even when the disposal occurs without their consent by third parties who violate the terms of their contracts with the generator. The Hazardous Sites Cleanup Act poses similar problems. Under the law, the definition of *hazardous substance* is very broad, and the owner or operator of a site may find itself in court, responsible for the costs associated with the release of hazardous substances of which it was unaware.

Just as liability has been imposed without fault under the SWMA on persons who generate waste, liability has been imposed without fault under the CSL on persons who own land where historic discharges of mine drainage occur. Under Section 316 of the CSL, authorities have required individuals and mining companies to treat existing discharges and to secure permits to authorize the discharges simply because they own the land. Under Section 315 of the CSL, authorities can also require such persons to treat mine drainage that may discharge onto neighboring property if they can establish a hydrogeologic connection between the discharge and their mining activities.

The session ended with a short discussion of the ways in which existing laws can potentially protect operators. In the Hazardous Sites Cleanup Act, the term *hazardous substance* does not include an element, substance, compound, or mixture from a coal mining operation that falls under the Pennsylvania Department of Environmental Protection's jurisdiction or that is from a site eligible for Abandoned Mine Land funds (§103). Pennsylvania's Environmental Good Samaritan Act may also provide protection against liability, as the use of CMD can be interpreted as a reclamation or water pollution abatement project, which addresses the negative effects of past coal mining operations.

Summary of Additional Remarks: "Liability Reforms to Encourage Comprehensive Watershed-Based Approach to Acid Mine Drainage Abatement and Marcellus Shale Hydraulic Fracturing"

Based on the contribution by Peter J. Fontaine, Co-Chair, Energy, Environmental, Public Utility Practice Group, Cozen O'Connor

Fontaine echoed the first two speakers by stating that the most significant problem facing operators interested in using local CMD for hydraulic fracturing is the open-ended liability clause in the CSL. He noted that this law is the most far-reaching of its kind in the United States. Cases interpreting Section 391.316, "Responsibilities of Landowners and Land Occupiers," have demonstrated that the Pennsylvania Department of Environmental Protection "can compel anyone leasing or holding an easement to abate preexisting ground water contamination." Fontaine also suggested that the potential liability relief offered from the Environmental Good Samaritan Act may be too limited for the oil and gas industry to benefit.

Fontaine argued that the industry needs a different kind of template to move forward, such as the Environmental Remediation Standards Act, or Act 2 (1995). As shown in Fontaine's presentation, cleanup liability protection under Section 501 is extended to persons "who participated in the remediation of the site"—a protection that might be offered to operators who meaningfully take part in "elimination of public health and environmental hazards on existing commercial and industrial land across Pennsylvania." At the end of his presentation, Fontaine presented a number of suggested liability reforms, including amending the Environmental Good Samaritan Act to include "Act 2–like covenant-not-to-sue for natural gas operators and other persons or organizations implementing Department of Environmental Protection–approved comprehensive long-term CMD abatement projects in conjunction with natural gas extraction."

Discussion: Policymakers Should Address the CMD Liability Issue as Soon as Possible

The discussion following the session focused on how quickly policymakers can address the issues at hand. One participant suggested that, in moving forward, "the missing party here is the EPA: We need to have federal regulators in this dialogue." Fontaine replied that the U.S. Environmental Protection Agency (EPA) is carefully examining issues pertaining to the Marcellus Shale and that "there may be pushback in the coming year." This should not be viewed negatively by operators, however, as the situation creates a real opportunity for innovative water quality trading of pollutants.[5] Vidic suggested that, to move ahead, lawmakers and other stakeholders need to "break the problem into pieces; it's too much to try and solve everything at once." After this remark, other attendees expressed concern about the timeline: How long will it take to resolve liability issues compared to the timeline of shale gas development?

There was also some talk about potential ways to amend Pennsylvania's liability laws regarding the use of CMD. When asked about the coal re-mining program, one participant stated that it differed too much in terms of the EPA NPDES permit standards to have any applicability to the issue at hand. The re-mining program was an amendment to the Clean Water Act, and a similar kind of amendment would need to be passed. There was also a query regarding third-party liability for water that was already treated according to NPDES permit standards. Fontaine suggested there would be no liability for operators in such a case, adding that this may be "a good starting point" for writing an amendment.

Other suggestions were offered, including that the commonwealth build and operate a CMD treatment plant on state property. Milavec suggested that Pennsylvania "is willing to do this and in fact encourages companies to come in and partner with the state to this end. In these cases, liability could stay with state if the state builds and operates" the facility. Another participant added, "However, this doesn't mitigate the possibility that a third party could sue." Another suggestion was for another entity to treat the water, such as a new nongovernmental organization (NGO) or nonprofit organization, and sell it to the operators. One participant reminded the rest of the audience that this has happened before. He suggested that there is no reason why an entity could not be formed with operator funding to provide this service.Several participants noted that the whole problem does not need to be solved overnight and that incremental initiatives can be productive.[6]

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[5] Water quality trading allows one source to meet its regulatory obligations by using pollutant reductions at another source with lower pollution-control costs. This approach may be more efficient in achieving water quality goals on a watershed basis. For more information on water quality trading, see U.S. Department of Environmental Protection (2012b).

[6] For example, using water from abandoned mines without planning to discharge what is left after drilling might be more interesting to drillers and an easier way to get started; after that, opportunities can open up.

CHAPTER SIX

Opportunities, Challenges, and Future Research Directions

The objective of the roundtable conference was to assess the technical, economic, legal, and regulatory feasibility of using CMD, and CMW more broadly, for hydraulic fracturing activities in the Marcellus Shale. An additional objective was to identify research priorities to address remaining implementation issues. Independent of the feasibility of using CMD for hydraulic fracturing, the activities of the unconventional natural gas industry in the region will have substantial effects, potentially both positive and negative. Assessing the magnitude and likelihood of these effects, however, was beyond the scope of the roundtable.

This chapter summarizes the key takeaway points from the roundtable, as discussed by the invited panelists and the participants at large. In this chapter, we step back from the detailed analysis offered in the individual sessions to highlight some key findings garnered from the roundtable papers, presentations, and the ensuing discussion. We also offer directions for future research that may need to be fulfilled if the use of CMD for hydraulic fracturing operations is to be implemented at scale.

Synopsis of Sessions 1 and 2: CMW Is Plentiful and Its Use Is Technically Feasible, but Water Quality Is Variable

The Use of CMW for Hydraulic Fracturing Activities Is Technically Viable

CMW Quantity. The roundtable panelists and participants were in agreement that there are large quantities of CMW in the Commonwealth of Pennsylvania—all told, much more than could be used in the coming decade for hydraulic fracturing. From the perspective of availability, the use of CMW is feasible. Even if there are technical, environmental, or regulatory reasons to target *one specific CMW type*, such as CMD, there are large quantities of each of the various categories of CMW. For example, environmental benefits would be maximized by using abandoned mine drainage, but the technical and regulatory complexity would be minimized by using only CMD from actively managed discharges; each of these sources alone is sufficiently large to warrant consideration from the perspective of availability.

CMW Quality. Although opinion in the research community varies, and current industry standards for water for hydraulic fracturing span a wide range of specifications, significant amounts of CMW may be usable in fracturing operations with levels of dilution or treatment comparable to what is currently done for municipal water sources or recycled produced water. In some cases, no pretreatment may be required. However, chemical properties vary greatly between sites and even sometimes within a site (e.g., over time, seasonally, based on recent precipitation); some mines are acidic and others are alkaline, with corresponding differences in suitability for hydraulic fracturing and pretreatment needs. Regardless of these variations, the panelists and participants widely acknowledged CMW's potential usability. CMD is likely to be technically viable for hydraulic fracturing in many instances. However, the likelihood that industry will consider it an attractive source of water will depend on details that are specific to each mine water source, each company, and each natural gas extraction site.

Logistics of CMD Use. There appears to be significant overlap in the general location of sources of CMD and Marcellus Shale natural gas extraction activity. Piping CMD is technically feasible. However, co-location and proximity were addressed only at a macroscopic level; site-specific characterization would be required to assess logistical feasibility on a case-by-case basis. It was not clear as a result of the day's discussion exactly how many useful sources of CMD are sufficiently close to drilling sites to be used economically. A difference of tens of miles can lead to important cost implications for the use of CMD.

Research Could Clarify the Viability and Facilitate CMD Use at Specific Sites

A number of research needs were identified in Sessions 1 and 2, as summarized in Tables 6.1 and 6.2. First, several panelists and participants felt that compiling existing data on CMD would be highly useful. This would ideally include developing a comprehensive list of CMD sites, characterized by the quality of the CMD sources and their locations. The existing data on CMD quantity and quality could be aggregated and made publicly available. This assembly of data could facilitate an assessment of what types of additional or updated information are needed. Something akin to the past U.S. Geological Survey CMD characterization effort, specifically considering the needs of the natural gas extraction industry, may be needed. The information could be used by industry to assess how CMD overlays the natural gas resource and whether or not CMD meets the site-specific needs of natural gas extraction operations in terms of quantity, quality, and accessibility. Such information would also be useful for a more comprehensive, region-wide approach to CMD utilization.

Some agreement from industry on the characteristics that CMD must have to be used for hydraulic fracturing operations, especially the ranges of workable concentrations of the most important solutes, would help inform the most relevant data to be collected in any updated studies. To the extent that characteristics differ by geographic region or from site to site, the industry may wish to spatially represent these needs. For example, some sites may be more amenable to higher solute levels or greater variability in chemistry; others may have more stringent requirements. Even without large site variability, by mapping the relative locations of CMD and drilling operations, those sites that are most likely to be drawn upon could be identified more easily. The next step might be to identify sources of CMD and shale gas sites that require greater pretreatment or piping over longer distances. Again, this visualization could facilitate the creation of a longer-term, coordinated effort and a permanent infrastructure for CMD remediation with near-term use by the natural gas industry.

If there is a mismatch between the availability of appropriate CMD and industry needs, further research and development of less expensive pretreatment technologies or new concepts in hydraulic fracturing approaches may be useful. The conversation at the roundtable, however, implied that much CMD could likely be utilized via existing technological approaches with little or no pretreatment. The industry is already successfully using fresh water of variable quality and is recycling the flowback water with high concentrations of total dissolved solids. At the more stringent end of the specifications, it may be the case that less expensive technologies and approaches need to be developed to produce on-site water of consistent quantity and

Table 6.1
Potential Research Areas Identified During the Roundtable

Research Need	Research Priorities	Responsible Stakeholders
Synthesis, organization, and compilation of existing data on sources of CMW in a publicly available database	Distinctions between CMW pools should be clearly made in terms of quantities, quality, and location, including Chemical composition, pH, and variability Coal mine water (CMW) generally or coal mine discharge (CMD) specifically Among sources of CMD—abandoned or actively managed Among abandoned mines—treated or untreated Notes: Initial database should be compiled prior to extensive further characterization studies. Database should be updated regularly.	Pennsylvania Department of Environmental Protection (and perhaps corresponding organizations in neighboring states) U.S. Department of the Interior/U.S. Geological Survey Regional research universities Watershed authorities NGOs Industry
More complete, updated characterization of CMD sources to augment existing data in database	Three specific data needs: Quantity (volumes or flow rate) Quality (chemical composition and variability) Location of CMD sites, including relative to natural gas extraction activities Note: Past study of the CMD source is dated and was not done with hydraulic fracturing applications in mind	Pennsylvania Department of Environmental Protection (and perhaps corresponding organizations in neighboring states) U.S. Department of Interior/ U.S. Geological Survey Regional research universities Industry
Development of experience-based guidelines for CMD quantity and quality needs	The guidelines should address the following questions: Which dissolved constituents are truly of concern, and what (ranges of) levels are acceptable? How much variability is tolerable within and between natural gas extraction sites?	Marcellus Shale Coalition Individual operator companies Research universities
Development and analysis of appropriate technical concepts and implementation mechanisms to encourage the long-term remediation of CMD in conjunction with its near- and midterm use for hydraulic fracturing	The policy research might include Cost-benefit analysis of the different technical concepts for long-term CMD remediation (e.g., area-wide infrastructure vs. a site-by-site approach) Identification of appropriate funding sources and financial incentives for both near- and midterm goals Development of policy mechanisms and identification of appropriate entities (e.g., Pennsylvania-chartered water remediation corporation) for coordinating stakeholders, developing infrastructure, and operating permanent facilities for CMD water remediation	Pennsylvania Department of Environmental Protection Watershed authorities and NGOs Industry and Marcellus Shale Coalition

quality. However, it appears that much CMD can be used in the absence of significant new technological breakthroughs.

Policy research could explore the costs and benefits of alternate technical and logistical approaches to CMD treatment and use. Such research may also identify better policy mechanisms, regulatory structures, and organizational entities for a *long-term* remediation of CMD. As Kepler described it in Session 2, the best CMD-use scenario would fully remediate *all* CMD water at a legacy site, make use of some portion of this water for hydraulic fracturing

Table 6.2
Potential Supplemental Research Directions

Research Need	Research Priorities	Responsible Stakeholders
Development of pilot projects to assess tolerances for CMD specifications	Specific assessments might include The effects of marginal quality CMD on well productivity Note: This effort could target areas where CMD removal has high environmental value but water quality makes its use less desirable.	Industry, Marcellus Shale Coalition Collaboration and potential cost-sharing with universities, Pennsylvania Department of Environmental Protection, watershed authorities, and NGOs
Development of lower-cost, improved pretreatment approaches	Specific examples might include Less expensive techniques for on-site removal of precipitates, such as $BaSO_4$ Technical approaches to disposal of solid precipitate sludges formed in mixing CMD and produced water, especially to deal with NORM Assessment of trade-offs between, e.g., passive and active treatment, mobile and fixed treatment facilities. Note: Other approaches may be identified in pilot efforts, or further research may be deemed largely unnecessary	Industry and universities NGOs, Pennsylvania Department of Environmental Protection, and watershed authorities wishing to provide incentives for greater CMD use

activities in the near term, and leave behind a new legacy of investment in infrastructure for long-term remediation of CMD after hydraulic fracturing for natural gas is complete. Careful consideration of the appropriate policy, regulatory, legal, and organizational frameworks for achieving this long-term benefit could improve environmental outcomes. In this way, the use of CMD for hydraulic fracturing would not only provide a near-term reduction in the use of fresh water and a temporary removal of contaminated water, but it could also lead to a long-term improvement in the health of the watershed.

Synopsis of Session 3: Economics of Using CMD Could Be Attractive in Some Instances

Estimates of the cost of using CMD vary widely, depending on assumptions about transport distance and method, pretreatment requirements and technical approach, and storage requirements, in terms of both total volumes and regulated containment specifications. At the lower end of the cost estimates, using CMD appears, in some instances, to be economically attractive to drillers—that is, the costs are competitive with those of the alternative (namely, fresh water). However, neither of the analyses presented was completely comprehensive in terms of these costs, and many parameters were estimated with limited data and assumptions that could not be made a priori.

For example, because distance is a driver of costs, it would be necessary to have site-specific information on transport distance and method to assess economic feasibility. The need to build an extra mile of pipeline for water, or to truck water an extra mile, could make CMD less attractive than locally available non-mine sources of water. While CMD may be available in abundance and technically acceptable to use, freshwater sources are likely to be less expensive, especially if they are closer. Furthermore, there are more freshwater sources in the commonwealth than sources of CMD. In the absence of information on exact distances, it is impossible to make conclusive statements regarding economic viability. Similar arguments hold for site-specific water quality and the resulting variability in treatment costs. Because of the lack of clear economic benefits in the concept, the group discussion turned to ways to make the use of CMD more economically attractive by providing subsidies, easing access, and reducing liability concerns.

Synopsis of Session 4: The Current Legal and Regulatory Framework Could Discourage the Use of CMD for Hydraulic Fracturing but Could Be Reinterpreted or Modified

There was general consensus from panelists and participants that industry is not likely to pursue this concept on a large scale under the current legal and regulatory framework. A number of possible general scenarios for achieving change were discussed. Some participants argued that if regulatory agencies established a policy with a broader, more inclusive interpretation of existing laws (e.g., the Environmental Good Samaritan Act) specifically in the case of abandoned mine drainage use, the industry would be more willing to consider using CMD. There may or may not be a need to pass entirely new laws, and there may already be working models (e.g., Act 2). Care should be taken, however, to consider the broader, long-term impacts of any regulatory changes.

The representatives from the Pennsylvania Department of Environmental Protection were generally supportive of the concepts discussed, especially in the case of abandoned mine drainage, and were interested in alleviating or removing barriers if it would encourage the natural gas industry to use this water source. Along these lines, in some cases, the Pennsylvania Department of Environmental Protection might be able to set regulatory conditions under which liability is limited within the existing legal framework. However, it is important to note that the relevant laws were established for specific protective purposes, despite any unintended interpretation or application that may result in "barriers" to the use of CMD. There will be a need for the regulatory agencies involved to strike a balance between competing interests and to consider the context of the regulations' original intent before modifying them. Whether rewriting regulations or law is appropriate, participants agreed that the use of abandoned mine drainage is not likely to go forward on any significant scale without clarification of existing laws, at a minimum. However, the requisite changes, such as technical approaches to the use of CMD, may differ depending on the nature of the specific source in question. Use of abundant actively managed mine drainage, for example, would require little or no legal or regulatory change for use; in this case, access to a full characterization of the resource might be sufficient incentive, assuming local economic competitiveness with freshwater sources. The key challenge will be to strike a balance between allowing and even encouraging the industry to tap CMD sources and at the same time maintaining appropriate regulation and oversight of the water resources of Pennsylvania.

The Broader Context of Watershed Quality and Sustainability in the Commonwealth Needs to Be Considered

In a broader context, it is important for the Commonwealth of Pennsylvania to clearly define the objectives behind any revisions to the regulatory framework. If the primary public-interest goal is cleaning up CMD, then the legal, regulatory, and economic incentives should be structured specifically to motivate the use of CMD for hydraulic fracturing to the greatest extent possible. If the goal is to minimize the use of fresh water for hydraulic fracturing, then the incentives should both *discourage* the use of fresh water and *encourage* the use of CMD. With respect to the first goal, several participants noted throughout the four sessions that the use of CMD for hydraulic fracturing will not be a panacea for the abandoned mine drainage problem in the region, largely because the abandoned mine problem is so large. Regulations simply allowing operators to use CMD without assuming past liability will not necessarily provide incentives for its use, and complete mine cleanup requires the establishment of permanent infrastructure for remediation. Even assuming that *all* regional hydraulic fracturing activities in the coming decade were to make use of CMD, it was clear that this use would not be able to solve the CMD legacy problem. This is especially true assuming only a temporary diversion of CMD by the industry rather than establishment of a permanent water remediation facility and infrastructure for its use or return to the watershed. Nevertheless, the convergence of a need for water for ongoing hydraulic fracturing activities and a desire to remove already contaminated CMD from the watershed in lieu of freshwater resources presents an opportunity for mutually beneficial reuse and a potential area for common ground among diverse stakeholders. These realities should inform realistic goals, and the policy goals should, in turn, drive the regulatory framework.

APPENDIX

Roundtable Agenda, Participants, and Speaker Biographies

Roundtable Agenda

Roundtable on the Feasibility and Challenges of Using Acid Mine Drainage for Marcellus Shale Natural Gas Extraction Activities

December 14, 2011

RAND Corporation, 4570 Fifth Avenue, Pittsburgh, Pennsylvania 15213

9:30 a.m.	Registration; coffee and tea
10:00 a.m.	Welcome from Susan Everingham, Director, Pittsburgh office, RAND Corporation
10:05 a.m.	Opening remarks from Kathryn Klaber, President, Marcellus Shale Coalition
10:10 a.m.	Session 1: The AMD Problem and Potential Resource *Moderated by Aimee Curtright, RAND Corporation* • Presentation by Professor Anthony Iannacchione, University of Pittsburgh • Additional remarks by Charles A. Cravotta III, U.S. Geological Survey • Open discussion
11:10 a.m.	Session 2: Technical Uncertainties and Challenges in Using AMD for Hydraulic Fracturing *Moderated by Debra Knopman, RAND Corporation* • Presentation by Professor Radisav Vidic (with Elise Barbot), University of Pittsburgh • Additional remarks by Doug Kepler, Seneca Resources Corporation • Open discussion
12:15 p.m.	Break for lunch
1:00 p.m.	Session 3: Economic Feasibility and Business Issues *Moderated by Keith Crane, RAND Corporation* • Presentation by David Yoxtheimer (with Tom Murphy and Professor Seth Blumsack), Penn State University • Additional remarks by Eric Cavazza, Pennsylvania Department of Environmental Protection • Open discussion

2:15 p.m. Session 4: Regulatory and Legal Barriers
Moderated by Susan Everingham, RAND Corporation

- Presentation by Pam Milavec, Pennsylvania Department of Environmental Protection
- Additional remarks by Joseph Reinhart (with Kevin Garber), Babst Calland
- Additional remarks by Peter Fontaine, Cozen O'Connor
- Open discussion

3:30 p.m. Wrap-up and closing remarks by session moderators

4:00 p.m. Adjournment

Roundtable Attendees

Elise Barbot
University of Pittsburgh

Hu Barnes
Penn State University

Seth Blumsack
Penn State University

Greg Boardman
Virginia Tech

Rob Boulware
Seneca Resources

Richard (Ricc) Brown
Newfield Exploration Company

Nicholas Burger
RAND Corporation

Fred Cannon
Penn State University

Brian Carr
West Virginina Department of Environmental Protection

Eric Cavazza
Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation, Cambria Office

Kevin Coleman
Chevron North American Exploration and Production Company

Emily Collins
University of Pittsburgh

Vince Conrad
CONSOL Energy, Inc.

John W. Cramer
Superior Well Services

Keith Crane
RAND Corporation

Chuck Cravotta
U.S. Geological Survey

Aimee Curtright
RAND Corporation

Evelyn Dale
National Energy Technology Lab

Matthew J. DeMarco
Advanced GeoServices Corp.

Huiqi Deng
University of Pittsburgh

Brian Dillemuth
Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management

Robert (Bob) Dilmore
National Energy Technology Lab

Rick Diz
Gannon University

Marissa Dullinger
Seneca Resources

Susan Everingham
RAND Corporation

Patrick Findle
Gas Technology Institute

Jordan Fischbach
RAND Corporation

James Flavin
Energy Corporation of America

Lauren Fleishman
RAND Corporation

Peter J. Fontaine
Cozen O'Connor

Kevin Garber
PA Coal Association/Babst Calland

Ganesh Ghurye
Exxon Mobil, XTO Appalachia Division

Kate Giglio
RAND Corporation

Tom Gray
Tetra Tech, Inc.

Kelvin Gregory
Carnegie Mellon University

J. Alexandra Hakala
National Energy Technology Lab

Marie Hanley
National Energy Technology Lab

Paul Hart
Hart Resource Technology

Tom Hayes
Gas Technology Institute

Bruce Hebblewhite
University of South Wales

Bob Hedin
Hedin Environmental

Anthony Iannacchione
University of Pittsburgh

Joseph Katruska
Talisman Energy USA Inc.

Doug Kepler
Seneca Resources Corporation

Kathryn Klaber
Marcellus Shale Coalition

Kenneth Klemow
Wilkes University

Debra Knopman
RAND Corporation

Jill Kriesky
University of Pittsburgh

C. Edmon Larrimore
Maryland Department of the Environment

Louis LeBrun
APTwater, Inc.

Matt Lock
Anadarko Petroleum Corporation

Tom Lopus
J-W Energy

Andy McAllister
Western PA Coalition for Abandoned Mine Reclamation

John McArdle
Battelle Memorial Institute

Ben McCament
Ohio Department of Natural Resources

Jim McDonald
Ohio Department of Natural Resources, Division of Geological Survey

Sandy McSurdy
National Energy Technology Lab

John Mendeloff
RAND Corporation

Pam Milavec
Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation, Cambria Office

Pete Miller
Range Resources

Austin Mitchell
Carnegie Mellon University

Jason Monnell
University of Pittsburgh

Richard S. Morrison
Pennsylvania Department of Environmental Protection

Tom Murphy
Penn State University

Tim Murrin
URS Corporation/NETL

Roger Myers
Atlas Energy

Doug Oberdorf
EQT Corporation

David Ortiz
RAND Corporation

Richard Palmer
Pennsylvania Department of Environmental Protection, Bureau of Oil and Gas Management

Andrew Paterson
Marcellus Shale Coalition

Joseph Pinkhouse
Universal Well Services

Jim Prohonic
P. Joseph Lehman, Inc.

Randy Reimold
Williams

Joseph K. Reinhart
Babst Calland Attorneys at Law

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Penn State University

Henry Willis
RAND Corporation

David Yoxtheimer
Penn State University

Mark Zeko
Environmental Engineering and Contracting, Inc.

Paul Ziemkiewicz
West Virginia University

Speaker Biographies

Elise Barbot currently holds a postdoctoral position in the Department of Civil and Environmental Engineering at the University of Pittsburgh, where she is performing research on the sustainable management of flowback water from the Marcellus Shale basin. The chemistry of flowback water mixed with fresh water or acid mine drainage, as well as membrane filtration, are important elements of this work. She has a degree in chemical engineering from the National Higher School of Chemical Synthesis, Processes and Engineering at the University of Aix-Marseille (France) and an M.S. in process engineering and physical chemistry and a Ph.D. in process engineering from the University of Aix-Marseille.

Seth Blumsack is an assistant professor in the John and Willie Leone Family Department of Energy and Mineral Engineering at Pennsylvania State University, co-director of the Penn State Initiative for Energy and Environmental Economics and Policy Research, and the John T. Ryan Faculty Fellow in the College of Earth and Mineral Sciences. He is also an adjunct research professor at the Carnegie Mellon Electricity Industry Center. His research centers on engineering-economic studies of energy and electric power systems, regulation and deregulation in network industries, network science, risk analysis, and managing complex infrastructure systems. He has a B.A. in mathematics and economics from Reed College, an M.S. in economics from Carnegie Mellon University, and a Ph.D. in engineering and public policy from Carnegie Mellon University.

Eric E. Cavazza has more than 27 years of service with the Pennsylvania Department of Environmental Protection's Bureau of Abandoned Mine Reclamation. He spent nine years in the Cambria Office Planning and Development Section, 14 years as design section chief of the Cambria Office, two years as chief of division of acid mine drainage abatement in Harrisburg, and the last two years as the manager of the Cambria District Office. He recently served on the department's internal workgroup to establish an evaluation and approval process for the use of abandoned mine drainage for industrial uses, including natural gas extraction. He has a B.S. in mining engineering and an M.S. in environmental engineering from Penn State University and is a registered professional engineer.

Charles Cravotta III is a research hydrologist with the U.S. Geological Survey in the Pennsylvania Water Science Center. He is a research hydrologist/geochemist with 20 years of experience sampling, analyzing, and interpreting the chemistry of groundwater in abandoned coal mines in Pennsylvania, during which time he has published more than 60 peer-reviewed research articles. He has a B.S. in environmental sciences from the University of Virginia and an M.S. and a Ph.D. in geochemistry and mineralogy from Penn State University.

Peter J. Fontaine is a shareholder and co-chairman of the Energy, Environmental, and Public Utility Practice Group at Cozen O'Connor, an international law firm headquartered in Philadelphia. He is an environmental lawyer representing clients in a variety of environmental and energy matters, including a leading electric vehicle charging company and the Battery Electric Vehicle Coalition, a trade group he helped form to advocate for policy changes to catalyze a market for electric vehicles. He previously served as an attorney with the U.S. Environmental Protection Agency (EPA) in Washington, D.C., where he was special assistant to the director of civil enforcement, enforced EPA's clean air regulations, executed EPA's 1992 pulp and paper industry enforcement initiative, and was a founding member of EPA's first Multimedia Enforcement Team. In 2003, he served on Governor Rendell's transportation transition team. He writes and speaks frequently on environmental and sustainability issues, is chairman of the Open Space Advisory Committee of Camden County, New Jersey, and is a board member of the New Jersey Conservation Foundation.

Kevin J. Garber is a shareholder and chairman of the Environmental, Health, and Safety Services Group of Babst Calland. A substantial part of his practice concentrates on the federal Clean Water Act and Pennsylvania's Clean Streams Law and related issues facing the manufacturing, coal mining, and oil and gas industries. He represents oil and gas companies working in the Marcellus Shale industry, serves as counsel to the Pennsylvania Coal Association, and serves as special environmental counsel to many municipalities, authorities, and developers in western Pennsylvania. He has written and lectured extensively on water and development issues. Garber is a member and past chairman of the Allegheny County Bar Association, Environmental Law Section, and is a member of the Pennsylvania and American Bar Associations. He has a B.S. in biology/chemistry from Penn State University, an M.S. in oceanography and limnology from the University of Wisconsin, a Ph.D. in ecology from the University of Pittsburgh, and a J.D. from Duquesne University. He is an adjunct professor at the Duquesne University School of Law and at the Bayer School of Natural Science at Duquesne University, where he teaches courses in environmental law.

Anthony Iannacchione is director of the Mining Engineering Program at the University of Pittsburgh, where he teaches mining engineering and conducts research. Prior to this appointment in 2008, he worked for the U.S. Bureau of Mines and the National Institute for Occupational Safety and Health for approximately 34 years. His educational background is split between civil engineering (in which he has a Ph.D. and an M.S.) and geology (in which he has an M.S. and a B.S.). He is a registered professional engineer and geologist in the Commonwealth of Pennsylvania.

Doug Kepler is vice president of environmental engineering at Seneca Resources Corporation. From 1990 to 2007, he was general partner of an environmental consulting firm specializing in the environmental restoration of mine drainage–impacted watersheds, with project experience spanning 15 states and six countries. He has been at Seneca Resources Corporation since 2007, where his responsibilities include oversight of the Environmental Engineering Group's Project Engineering, Construction/Compliance, Water Management, and Geomatics Departments. He has a B.S. in environmental resource management from Penn State University and an M.S. in aquatic ecology from Clarion University of Pennsylvania.

Kathryn Klaber serves as the Marcellus Shale Coalition's first president and executive director. In this role, on behalf of the MSC member companies, she works closely with elected leaders, regulators, and the civic community to realize the responsible development of natural gas from the Marcellus and Utica Shale geological formations and the associated benefits for the region's economy. Prior to joining the MSC, she was executive vice president for competitiveness at the Allegheny Conference on Community Development and executive director of the Pennsylvania Economy League. A lifelong Pennsylvanian, she has an undergraduate degree in environmental science from Bucknell University and an M.B.A. from Carnegie Mellon University.

Pam Milavec has been employed by the Pennsylvania Department of Environmental Protection for 28 years as a water pollution biologist, a water quality specialist, and, presently, as Environmental Services Section chief in the Bureau of Abandoned Mine Reclamation, Cambria District Office. This section is responsible for watershed planning and project development of abandoned mine drainage treatment and abatement projects in the bituminous portion of the state. It also provides biological, hydrologic, and environmental services to the bureau and assists in the monitoring and operation of passive treatment facilities. She recently served on a Pennsylvania Department of Environmental Protection internal workgroup to establish an evaluation and approval process for the use of abandoned mine drainage for industrial uses, including natural gas extraction. She has a B.S. in biology from the University of Pittsburgh at Johnstown.

Tom Murphy is co-director of Penn State's recently created Marcellus Center of Outreach and Research (MCOR). He has more than 25 years of experience working with landowners, researchers, industry, government agencies, and public officials during his tenure with the outreach branch of the university. His work has been in the realm of educational consultation in natural resource development, with an emphasis on natural gas exploration and related topics. He has lectured widely on unconventional shale gas development and its impacts, including landowner leasing issues, environmental aspects, the drilling process, infrastructure development, the workforce, and financial considerations. In his role with MCOR, he provides leadership to a range of Penn State's related Marcellus research activities. He is a graduate of Penn State University.

Joseph K. Reinhart is a shareholder and co-chairman of the Natural Resources Group at the law firm Babst Calland. He has more than 25 years of experience with environmental law, focusing on laws and regulations governing oil and gas development, including conventional and unconventional gas (e.g., Marcellus Shale) and environmental law relating to coal mining. His practice also includes the application of state and federal waste management laws to the disposal of wastes generated by the gas, coal, and electric utility industries. Since 2003, Reinhart has been appointed annually by the Secretary of the Pennsylvania Department of Environmental Protection to the Pennsylvania Solid Waste Advisory Committee. In addition, he is a trustee of the Energy and Mineral Law Foundation, where he serves on its Law Student Scholarship Committee. He has a B.A. from the University of Notre Dame and a J.D. from the University of Pittsburgh.

Radisav Vidic is the William Kepler Whiteford Professor of Environmental Engineering and chairman of the Department of Civil and Environmental Engineering at the Swanson School of Engineering, University of Pittsburgh. His research efforts focus on advancing the applications of surface science by providing a fundamental understanding of molecular-level interactions at interfaces, development of novel physical/chemical water treatment technologies, water management for Marcellus Shale development, and reuse of impaired waters for cooling systems in coal-fired power plants. He has published more than 150 journal articles and roundtable proceedings on these topics. He has a B.S. in civil engineering from the University of

Belgrade, an M.S. in civil and environmental engineering from the University of Illinois, and a Ph.D. in civil and environmental engineering from the University of Cincinnati.

David Yoxtheimer is a hydrogeologist and extension associate with Penn State University's Marcellus Center for Outreach and Research. He has a B.S. in earth science from Penn State University, where he is currently completing his Ph.D. in geosciences. His areas of expertise include water supply development, geophysical surveying, environmental permitting, shale gas geology, and integrated water resource management.

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This document has not been peer-reviewed or edited.

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

RAND

Environment, Energy, and Economic Development

A RAND INFRASTRUCTURE, SAFETY, AND ENVIRONMENT PROGRAM

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.

Published 2012 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
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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.

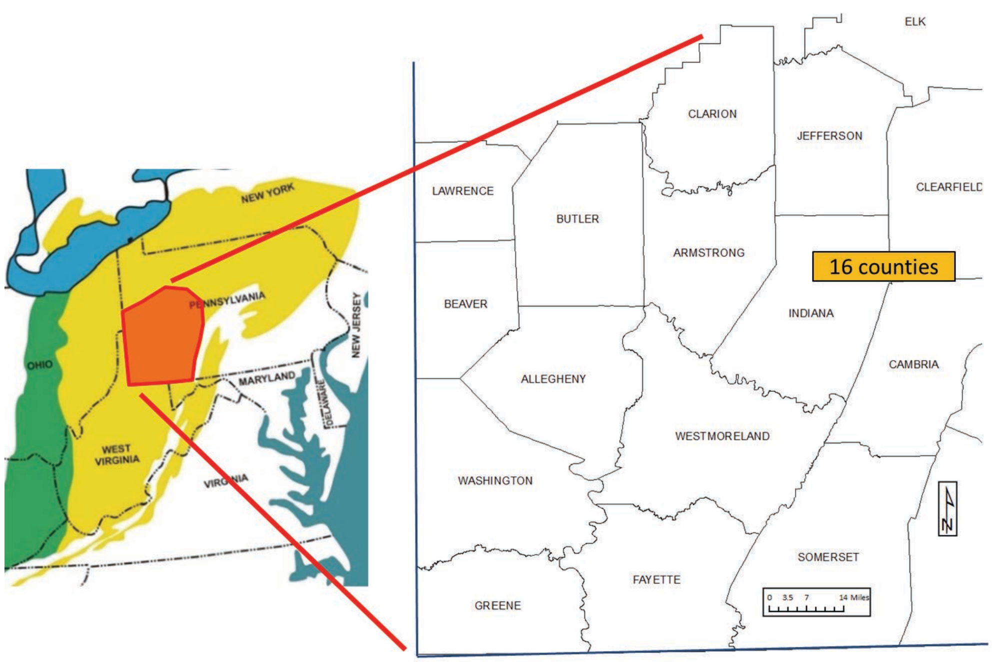

Figure 1. Aerial extent of the Marcellus Shale Formation and the 16 counties in Southwestern Pennsylvania where bituminous coal mining and unconventional shale gas drilling have occurred

[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.[2] 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.

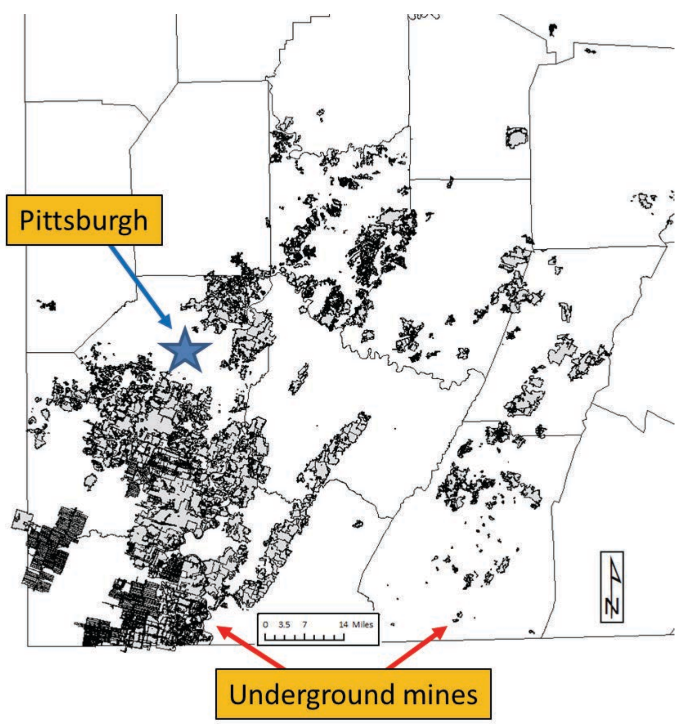

Figure 2. Location of underground bituminous coal mines in Southwestern Pennsylvania (PA DEP, 2011a)

[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).

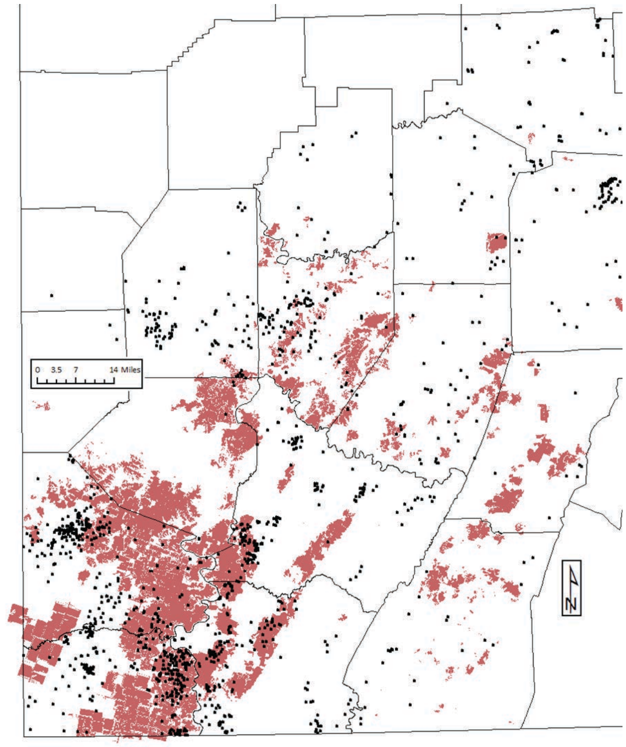

Figure 3. Location of Marcellus Shale gas wells that have been permitted, spud, drilled, or abandoned in Southwestern Pennsylvania underlain by abandoned bituminous coal mines (PA DEP, 2011b).

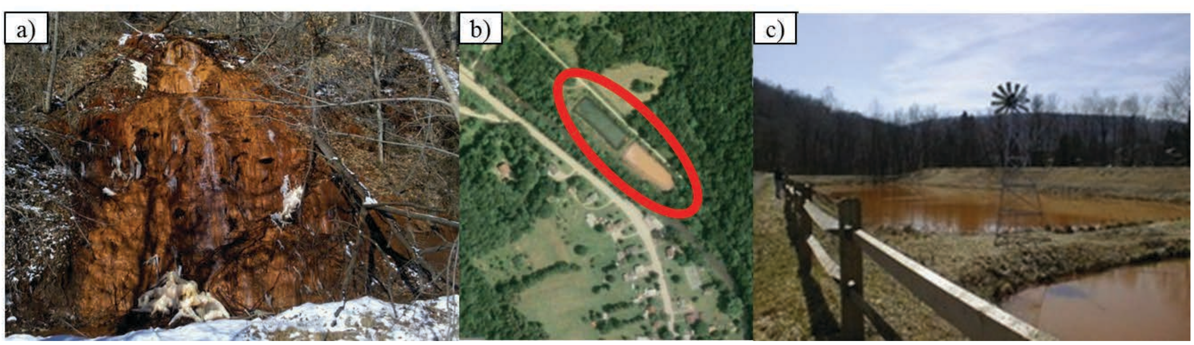

Figure 4. Photographs from the Max B. Nobel mine drainage remediation site, showing (a) coal mine drainage from an abandoned mine in Westmoreland County, (b) an aerial view of the passive treatment facility, and (c) windmills used to oxygenate the water in the settling ponds

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.

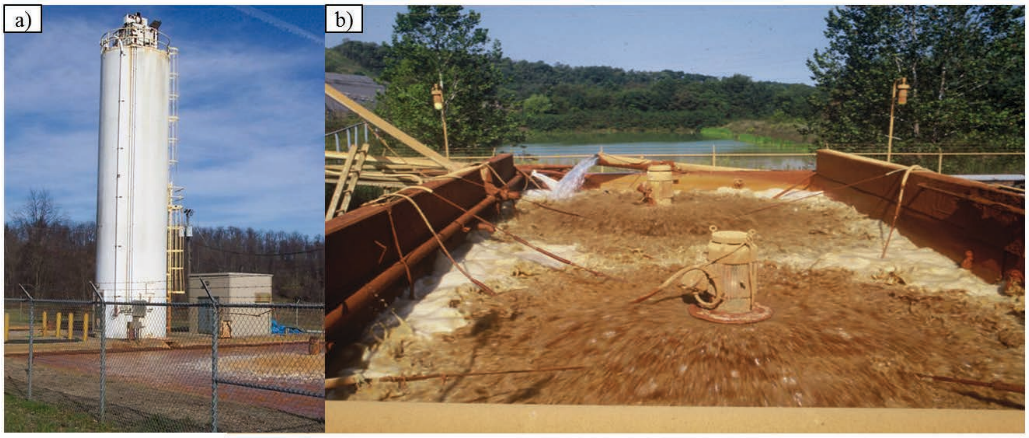

Figure 5. Photographs from Rice's Landing treatment facility, showing (a) hydrated lime (CaO) storage tank and (b) aeration pit with settling pits in the background

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 ether 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.

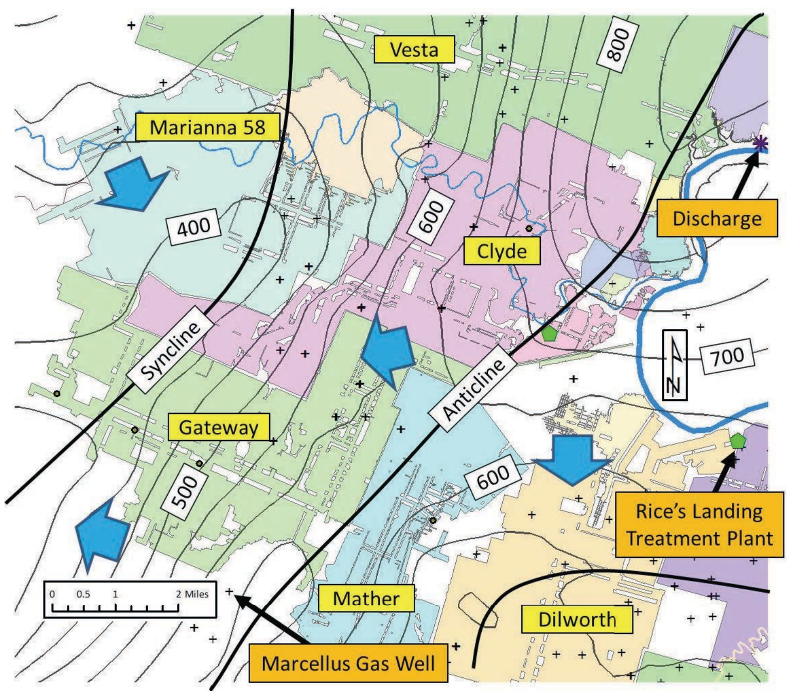

Figure 6. Large below drainage abandoned mines near the boundaries of Greene, Washington, and Fayette counties

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.

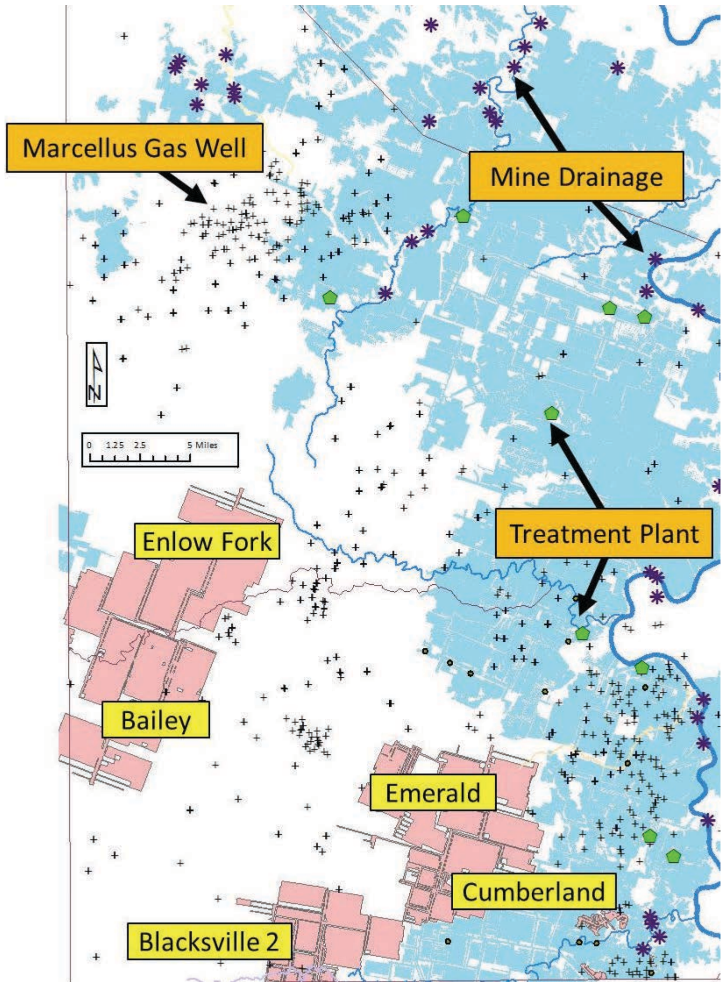

Figure 7. Location of seven active longwall mines (pink) and abandoned mines (blue) in Greene and Washington counties

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.

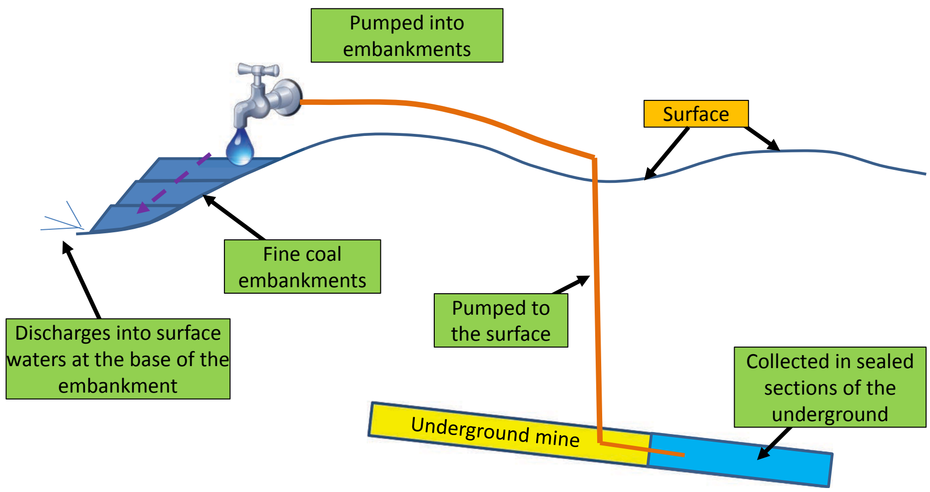

Figure 8. Flow diagram of water discharged from large longwall mines

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).

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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
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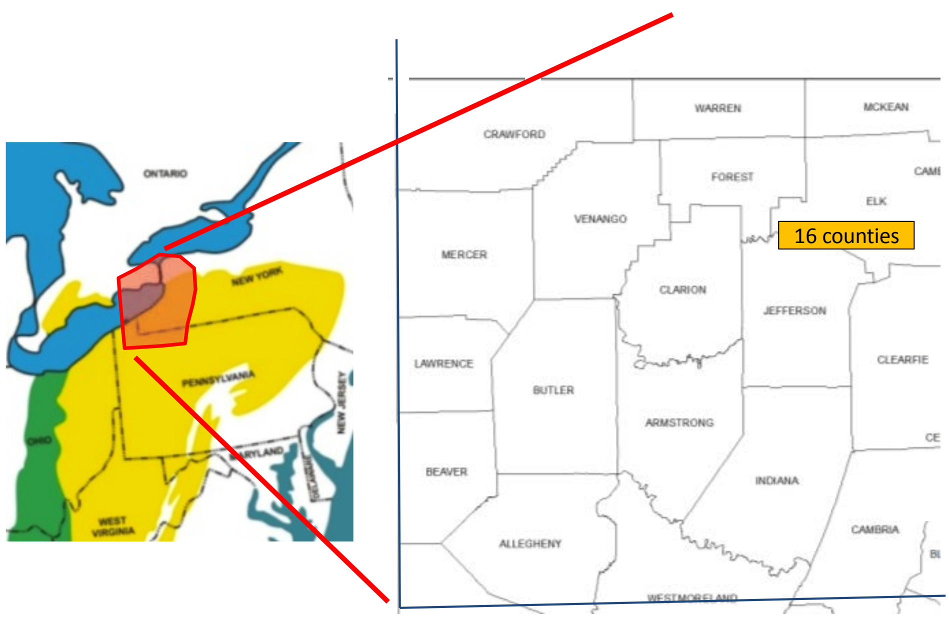
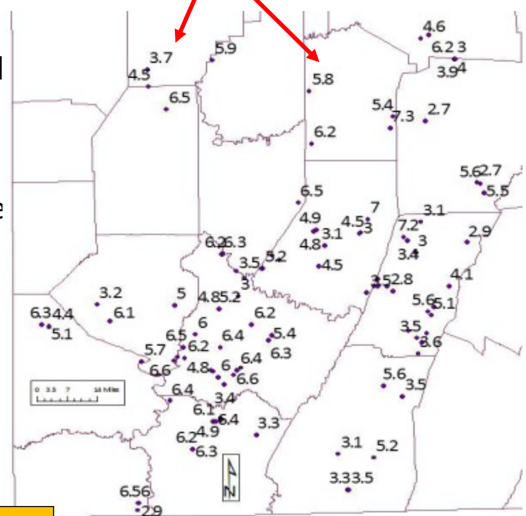
University of Pittsburgh

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



Sources of data

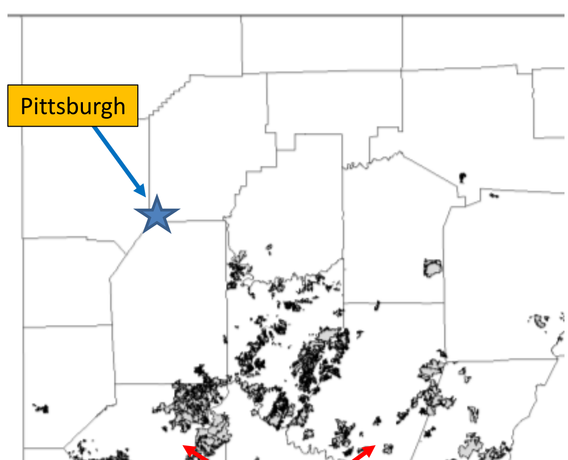
- PA DEP, Bureau of Mining & Reclamation and Bureau of Oil and Gas Management
- ACT 54 3rd Assessment
- Office of Surface Mining, Mine Map Repository
- WV Water Research Institute, "Monongahela Basin Mine Pool Project"
- USGS, Charles Cravotta III (1999 samples)



Significant variability in the composition of mine waters

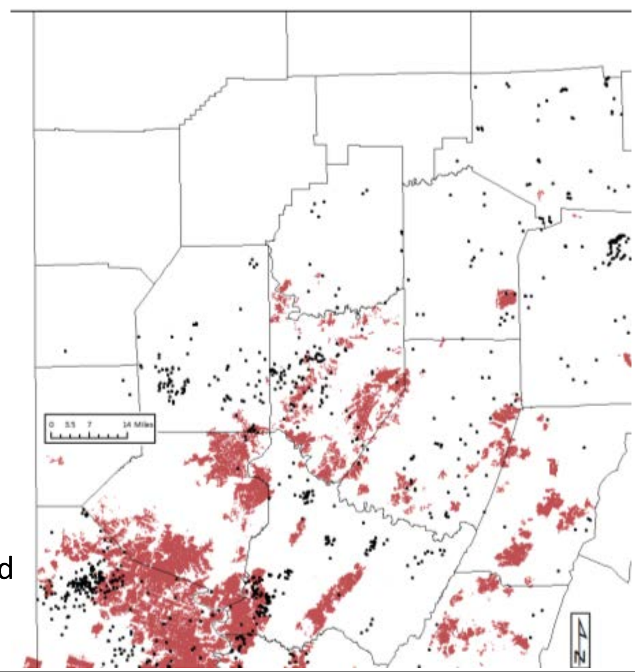
Could mine water supply a portion of the region's demand for industrial water?

- ~ 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?**



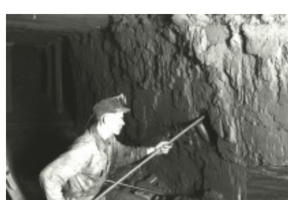
Marcellus Shale gas and underground coal mines (active and abandoned)

- > 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

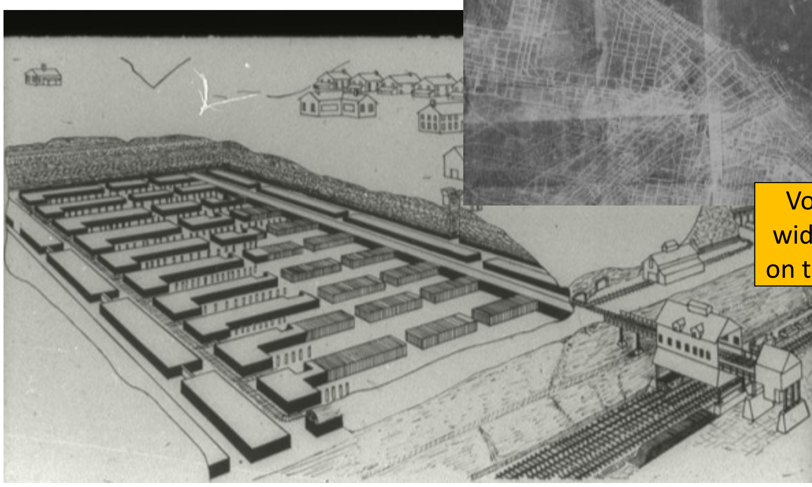
- Above drainage abandoned (hundreds of mines)
- Shallow *active* (~40 mines in PA, < 400-ft overburden)
- Below drainage abandoned (> 400 but < 1,100-ft overburden)
- Deep *active* (modern longwall mines in Washington and Greene counties)

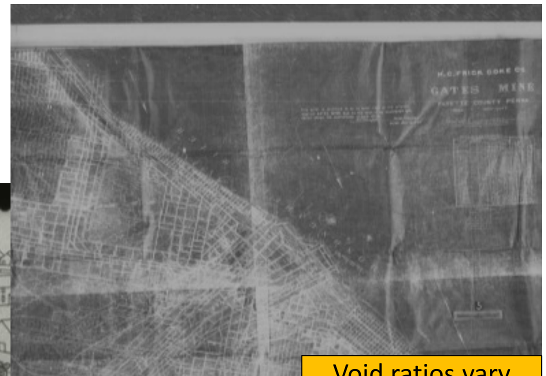


Legacy mines

Above Drainage Abandoned Mines (<u>legacy mines</u>)

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



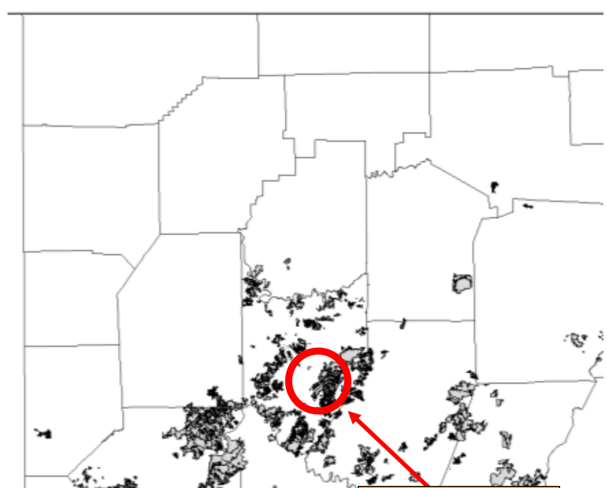


Void ratios vary widely depending on the mining type

Above drainage abandoned mines

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

Most abandoned mines are either partially or totally filled with water



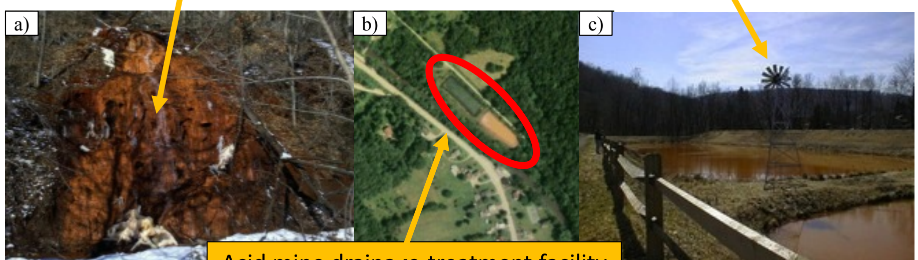
Example – Indian Creek Coalfield

Indian Creek Coalfield (*Fayette Co., PA*)

- Underground mining from 1906 to 1976
- Max B Nobel Mine Drainage Remediation Site (**<u>Passive Treatment</u>**)
- 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

Was a big source of sediment and acid runoff

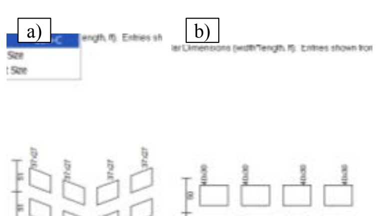
Windmills aerate water helping contaminants to settle faster



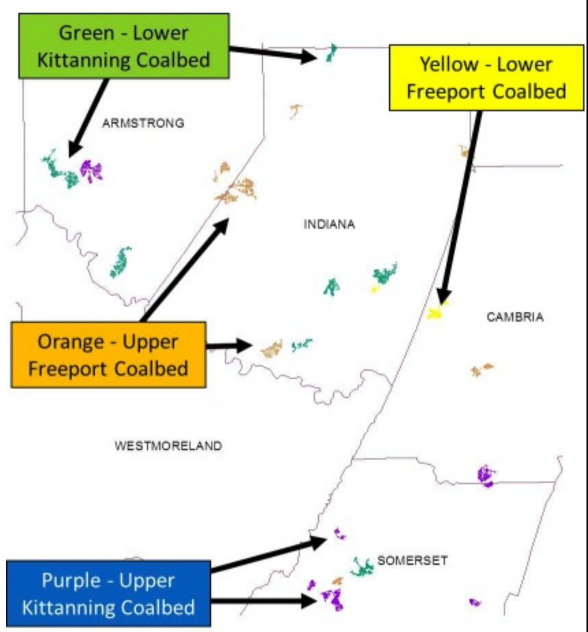
Acid mine drainage treatment facility

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

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

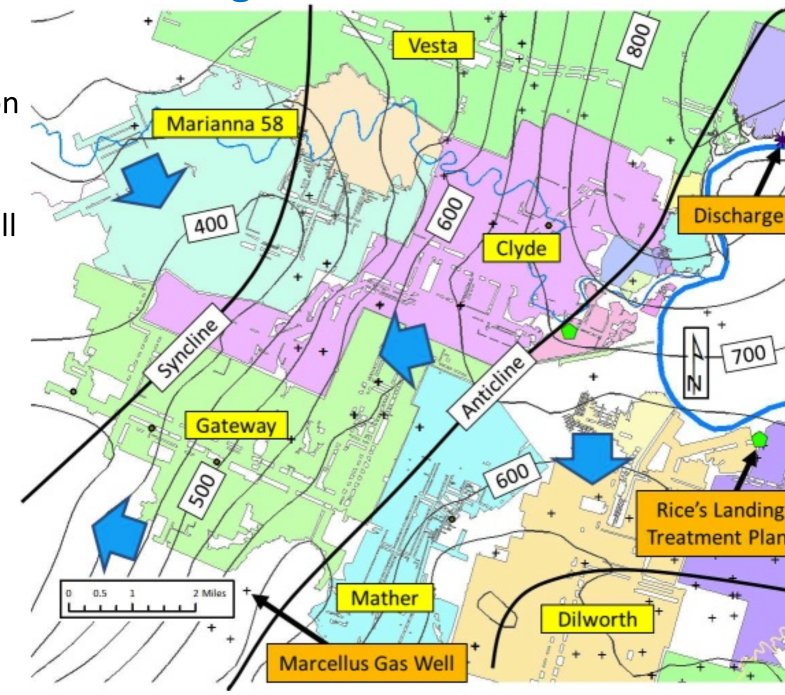


Modern room-and-pillar layouts have extraction ratios between 50 and 70 percent



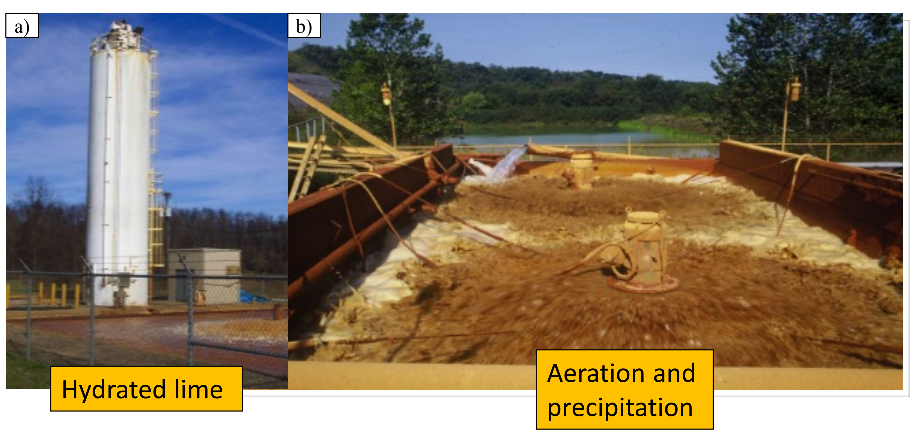
Below Drainage Abandoned Mines

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

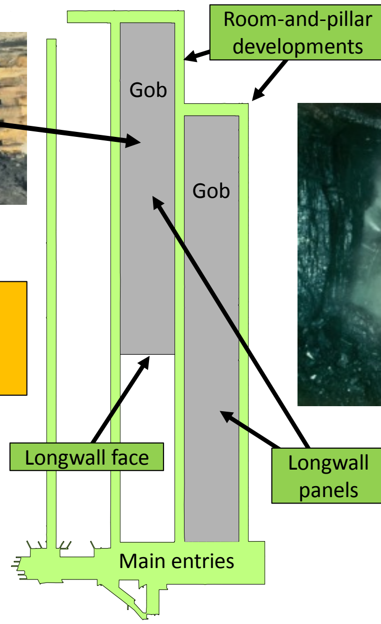


Rice's Landing treatment plant (<u>**Active process**</u>)

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

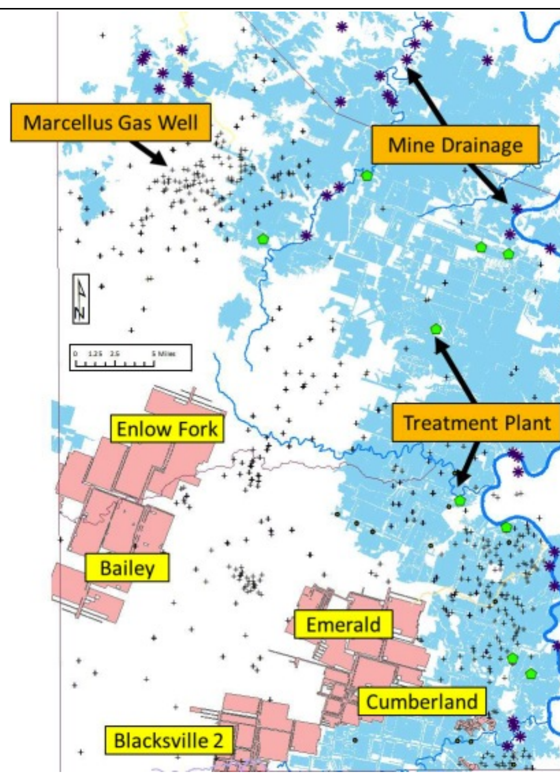


Deep Active Mines (*7 longwall mines*)

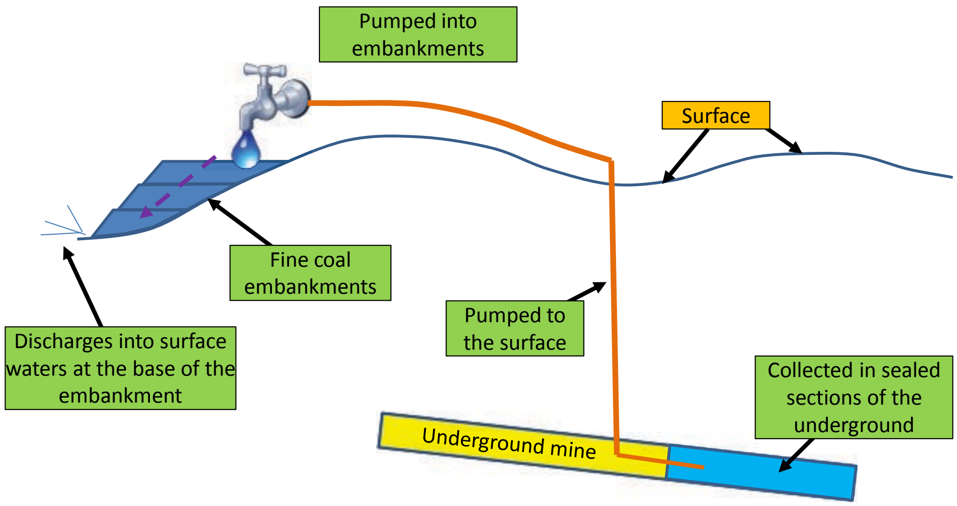


Huge blocks of coal are completely mined…

Deep Active Mines (*modern mines*)



Water treatment practices for deep active mines



Significant expertise handling and treating water

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

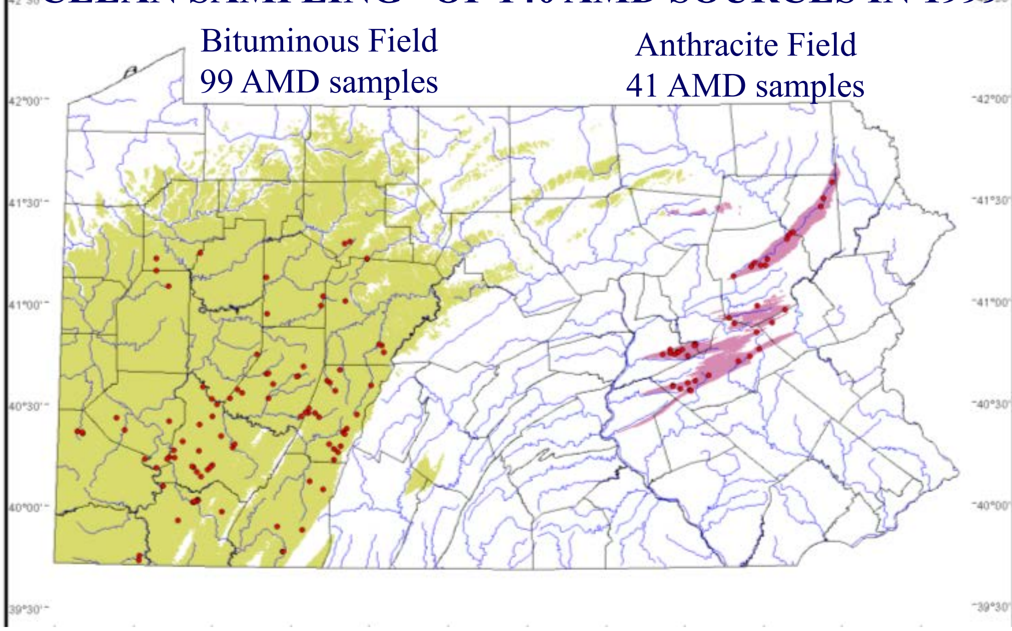
- Some mine water will not be appropriate for drilling or hydraulic stimulations
- Water properties are highly variable and are controlled by mining and geological conditions
- Reservoir conditions are partially controlled by the mining method used
- Many Marcellus Shale gas plays are not close to mining
- 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

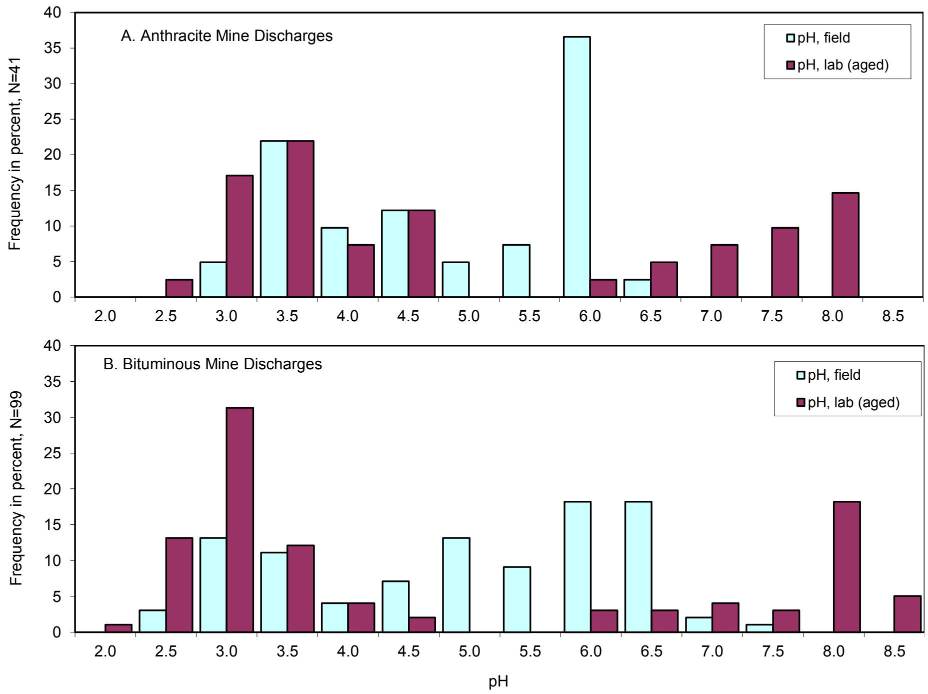
Charles A. Cravotta III, Ph.D., P.G.
USGS Pennsylvania Water Science Center, New Cumberland, PA

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

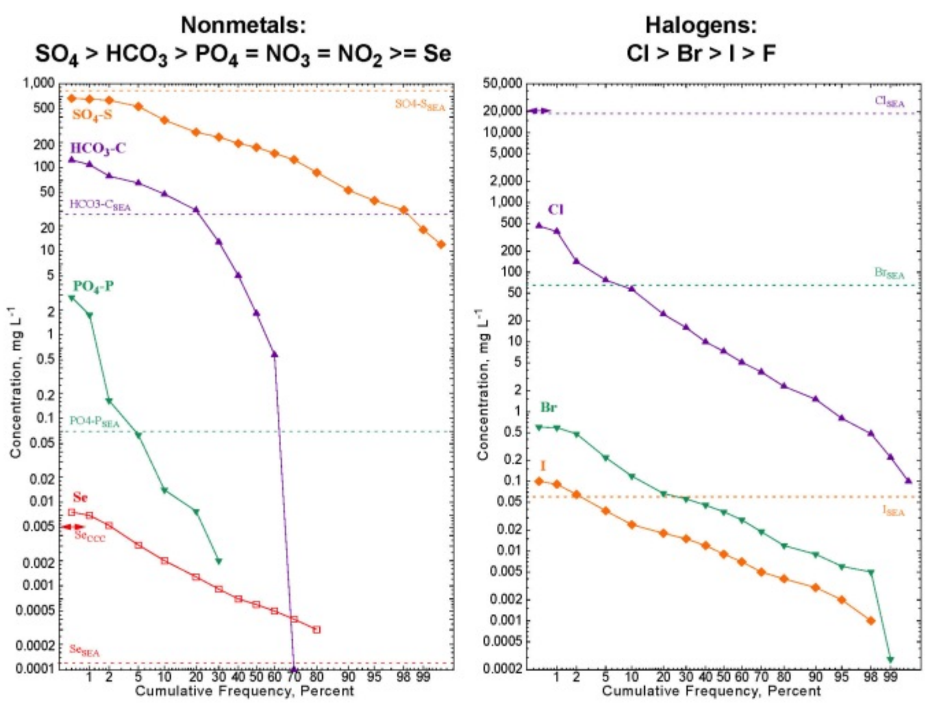
"CLEAN SAMPLING" OF 140 AMD SOURCES IN 1999



BIMODAL pH FREQUENCY DISTRIBUTION



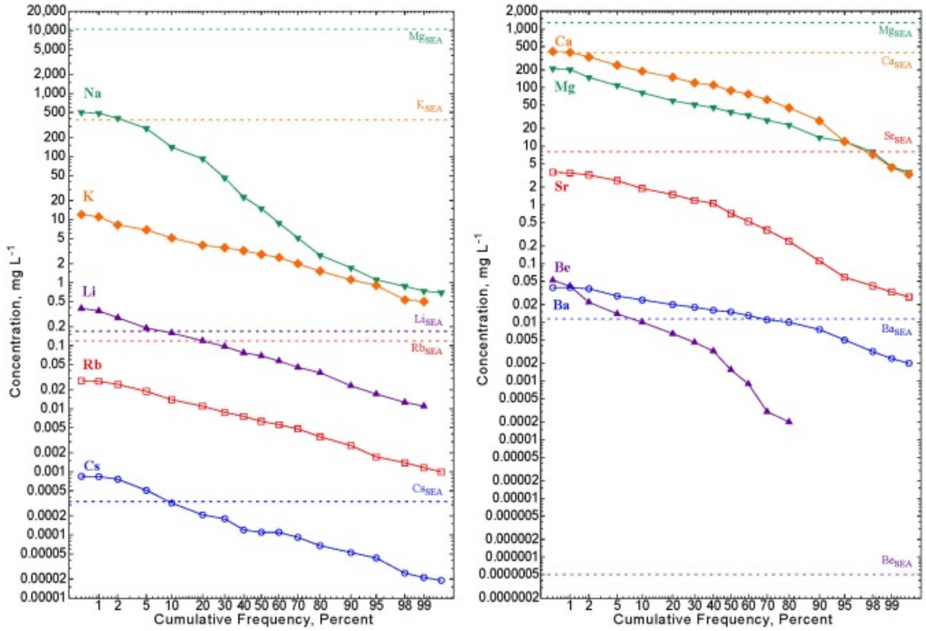
DOMINANT SOLUTES IN "AMD"



DOMINANT SOLUTES IN "AMD"

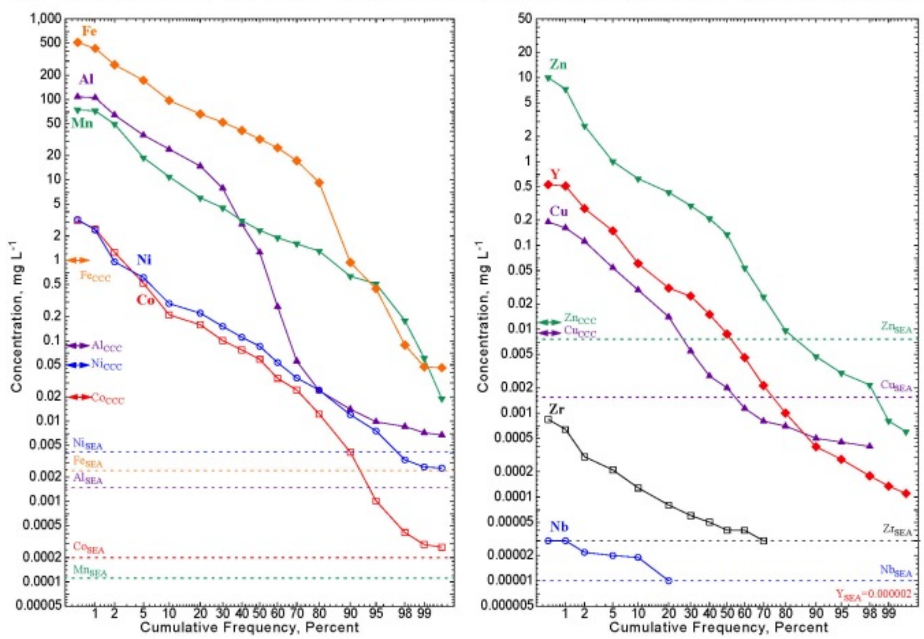
Alkali Earths:
Na > K > Li > Rb > Cs

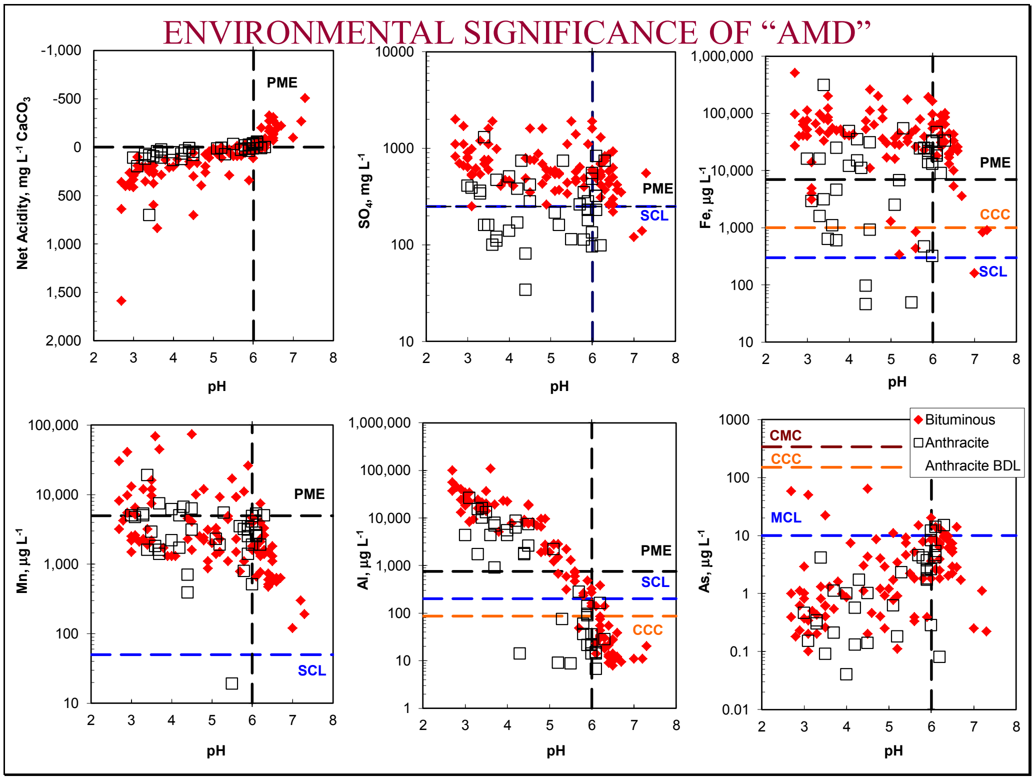
Alkaline Earths:
Ca > Mg > Sr > Ba > Be

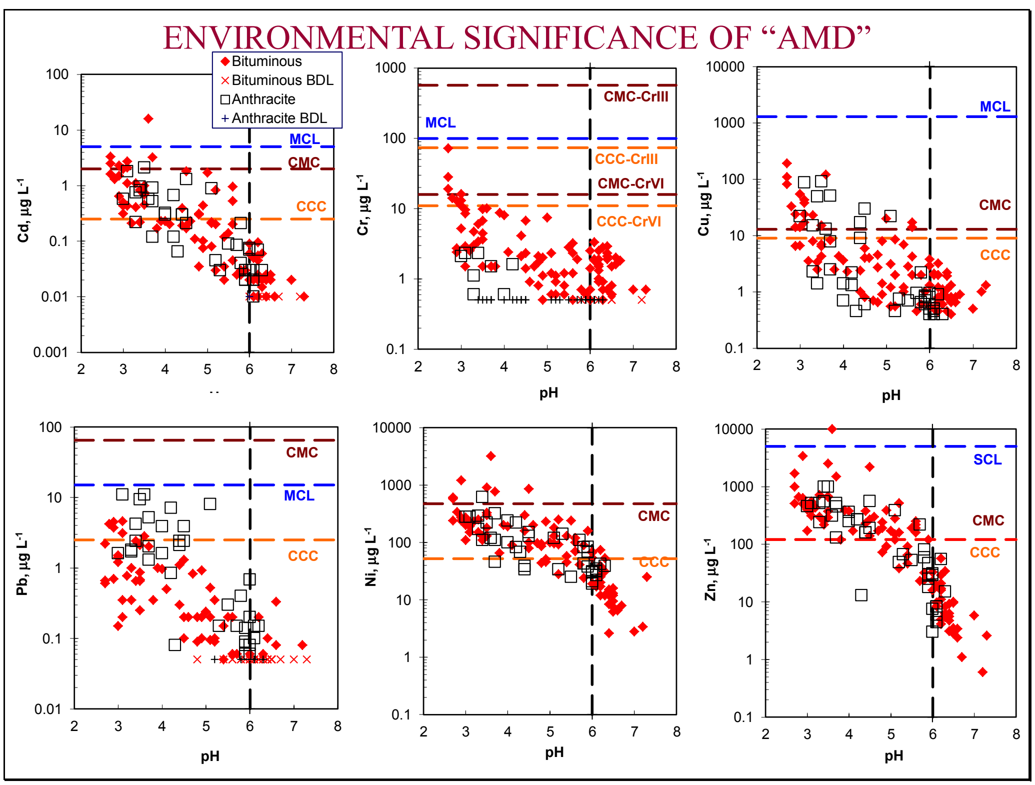


DOMINANT SOLUTES IN "AMD"

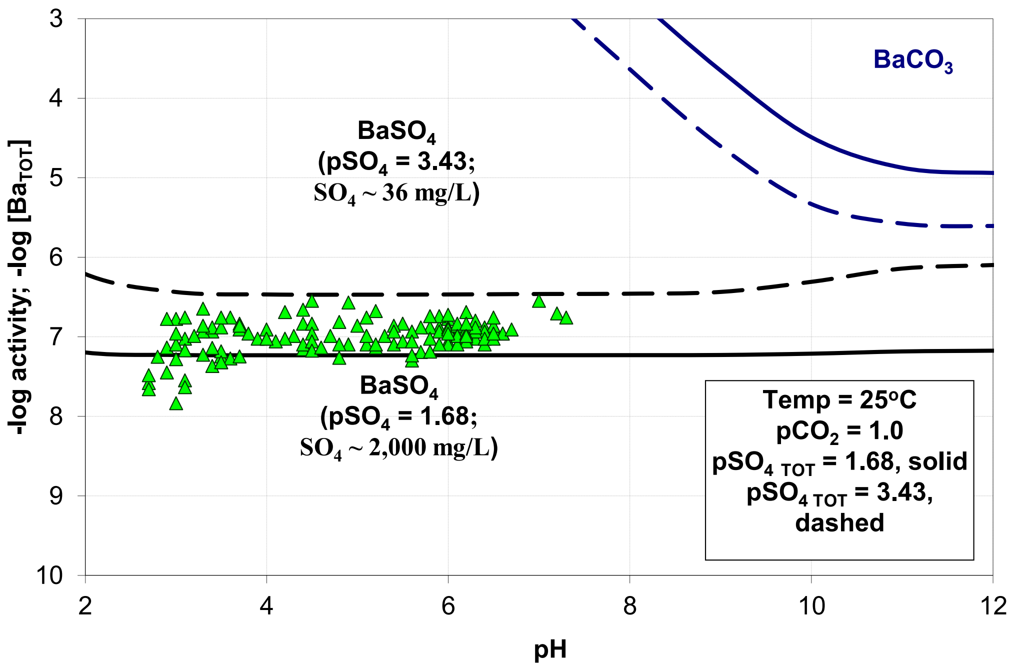
Metals:
Fe > Mn > Al > Zn > Ni > Co > Y > Sc > Ti > Cu > Cr > V > Mo > Cd > W > Zr > Nb > Au




ENVIRONMENTAL SIGNIFICANCE OF “AMD”
Net Acidity, mg L-1 CaCO3
PME
SO4, mg L-1
PME
SCL
Fe, µg L-1
PME
CCC
SCL
Mn, µg L-1
PME
SCL
Al, µg L-1
PME
SCL
CCC
As, µg L-1
CMC
CCC
MCL
Bituminous
Anthracite
Anthracite BDL
pH


ENVIRONMENTAL SIGNIFICANCE OF “AMD”
Bituminous
Bituminous BDL
Anthracite
Anthracite BDL
Cd, µg L-1
MCL
CMC
CCC
Cr, µg L-1
CMC-CrIII
MCL
CCC-CrIII
CMC-CrVI
CCC-CrVI
Cu, µg L-1
MCL
CMC
CCC
Pb, µg L-1
CMC
MCL
CCC
Ni, µg L-1
CMC
CCC
Zn, µg L-1
SCL
CMC
CCC
pH

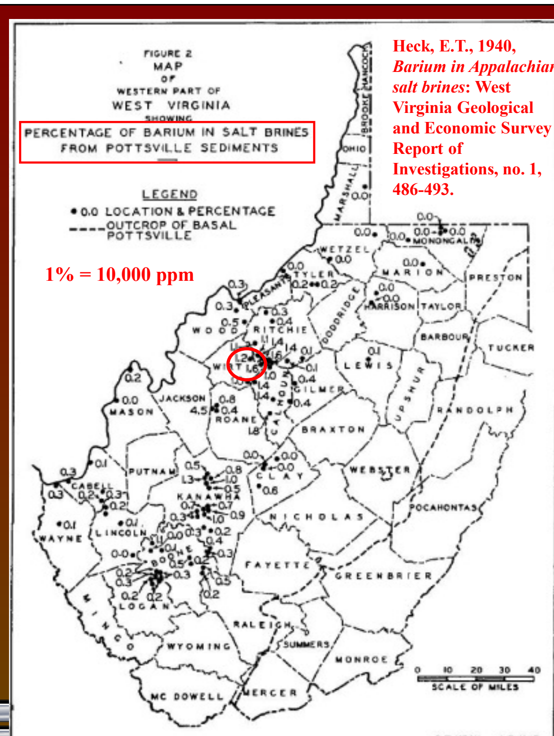
SULFATE LIMITS BARIUM CONCENTRATIONS IN "AMD"



"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).



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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 (≥ 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.

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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.

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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.

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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.

Session 2 White Paper: Use of AMD in the Development of Marcellus Shale: Technical Uncertainties and Challenges

By Elise Barbot and Radisav Vidic, Department of Civil and Environmental Engineering, Peterson Institute of Nanoscience and Engineering, University of Pittsburgh

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

Constituent	Concentration	Effect
Oil and grease	< 200 ppm	Affect friction reducers
Soluble organics	—	No problem identified
Chloride	< 10,000 mg/L	Increase demand for friction reducers and scale inhibitors
Calcium, magnesium, carbonate	Use scale control models (Oddo-Thompson)	Scaling
Ba^{2+}, SO_4^{2-}	Simple solubility calculation Scale formation computer models also useful	Scaling
Iron	< 20 ppm	Risk of well-plugging (iron hydroxide)
Soluble calcium	< 350 mg/L	Above 350 mg/L, increase the demand for friction reducer
Suspended solids	< 100 mg/L	Higher concentration would probably have no effect on the frack job quality
pH	< 8 (< 7 if possible)	Biocides work best below pH 7
TDS	Covered through the guidelines on chloride	
Bacteria (APB, SRB)*	< 100/100 mL, indirectly handled according to guidelines on biocides	Gas souring, corrosion

* 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 frack 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.

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Gregory, K., and Vidic, R. D. (2011) *Fate of Naturally Occurring Radioactive Material (NORM) in Flowback and Produced Waters from Natural Gas Development*. Quarterly progress report for the U.S. Department of Energy, Activity 4000.4.640.920.003.

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Papso, J., Blauch, M., and Grottenthaler, D. (2010) "Gas well treated with 100% reused frac fluid," *E&P Magazine*, August 1.

Tam, K. C., and Tiu, C. (1990) "Role of ionic species and valency on the steady shear behavior of partially hydrolyzed polyacrylamide solutions," *Colloid and Polymer Science*, 268(10), 911–920.

Vidic, R. D., and Gregory, K. (2011) *Sustainable Management of Flowback Water During Hydraulic Fracturing of Marcellus Shale for Natural Gas Production*. Quarterly progress reports for the U.S. Department of Energy, Project No. DE-FE0000975.

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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

Constituent	Concentration	Effect
Oil and grease	< 200 ppm	Affect friction reducers
Soluble organics	-	no problems identified
Chloride	< 10,000 mg/L	Increase demand for friction reducers and scale inhibitors
TDS	covered through the guidelines on chloride	
Suspended solids	**< 100 mg/L**	Higher concentration would probably have no effect on the frac job quality

Fracturing fluid quality requirements

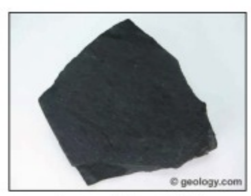
Constituent	Concentration	Effect
pH	< 8 (< 7 if possible)	Biocides work best below pH 7
Calcium, Magnesium, Carbonate	Use scale control models	Scaling
Ba, SO4	Simple solubility calculation Scale formation computer models also useful	Scaling
Iron	< 20 ppm	Risk of well plugging (iron hydroxide)
Bacteria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

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

Parameter	Conventional Limits	Considerations
pH	6.0 to 8.0	Fluid Stability, Scaling
Chlorides	<20,000 mg/L	Fluid Stability
Iron	<20 mg/L	Fluid Stability
Ca, Mg, Ba, SO_4, CO_3, ...	*f*(P,T,pH) (+/- 350 mg/L)	Scaling
Bacteria Count	<100/100 mg/L	Bacteria Growth
Suspended Solids	<50 mg/L	Skin
Oil & Soluble Organics	<25 mg/L	Fluid Stability



nanodarcy, nD, 1 x 10^{-9} D

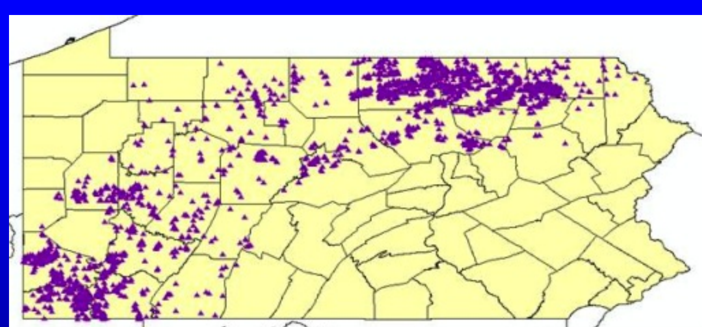
millidarcy, mD, 1 x 10^{-3} D

AMD Selection guide

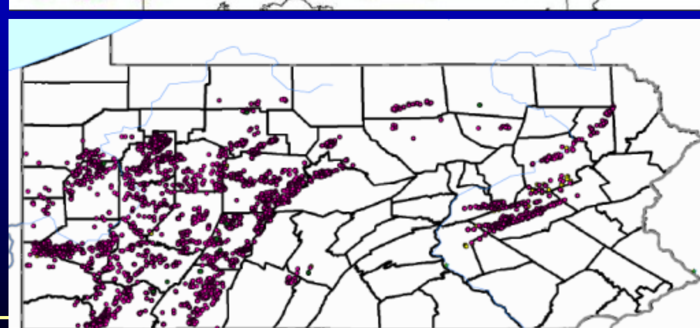
- Sufficient flowrate
- Proximity: transportation cost evaluation
- Chemical composition
  - sulfate concentration
  - acidity / alkalinity (corrosion)
  - iron concentration: treatment / no treatment

Drilling sites and AMD locations in PA

Marcellus well sites (permitted)



AMD sites



Types of Mine Discharges

- Active mining operations
- Abandoned mines
  - Treated
  - Untreated

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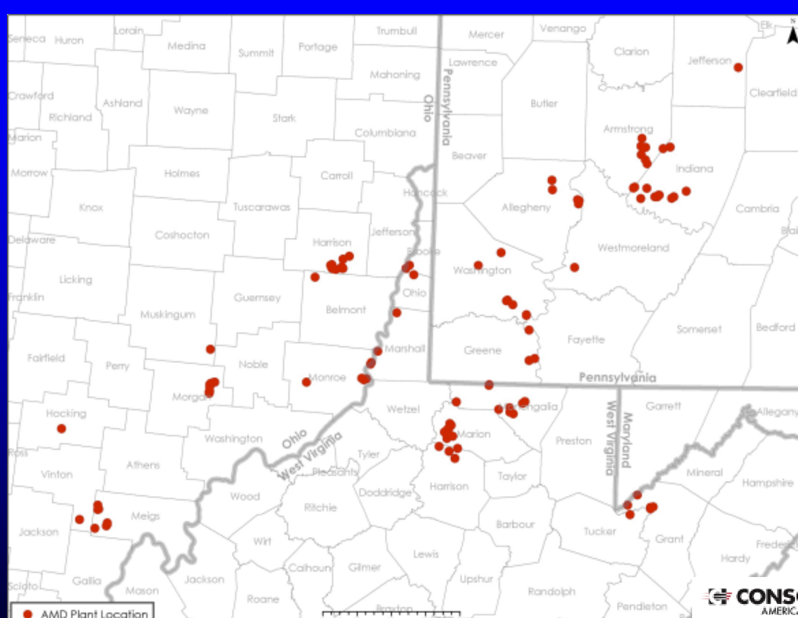
Active Mining Operations



CONSOL ENERGY
AMERICA'S ENERGY STARTS HERE

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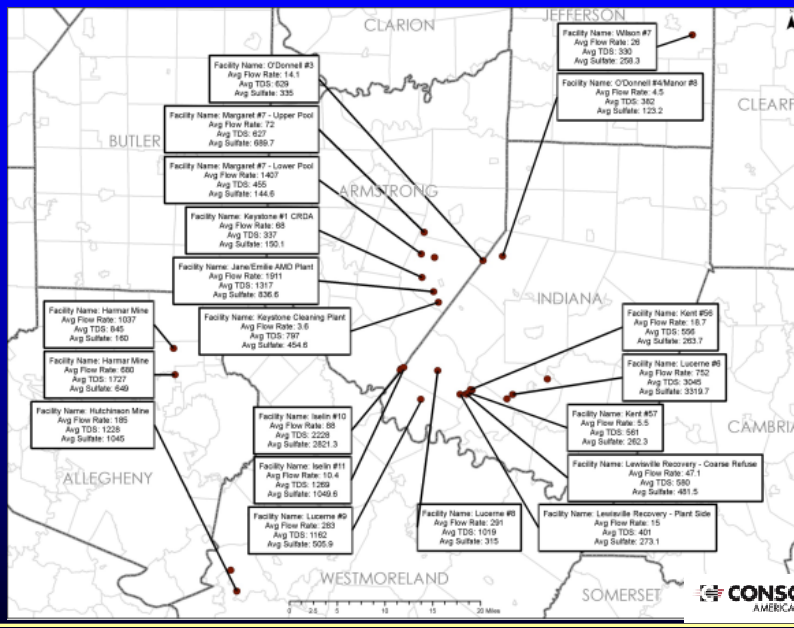
Availability of Treated Mine Water



Treatment of AMD

Wingfield Pines
Allegheny Land Trust

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

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

AMD

	Site A	Site B	Site C	Site D
pH	5.7	7.03	6.14	7.56
Alkalinity (mg/L as CaCO3)	62	394	40.5	47.5
SO4	696	242.5	709	328
Fe	27	0	32.1	0
TDS	-	1574	1328	1127

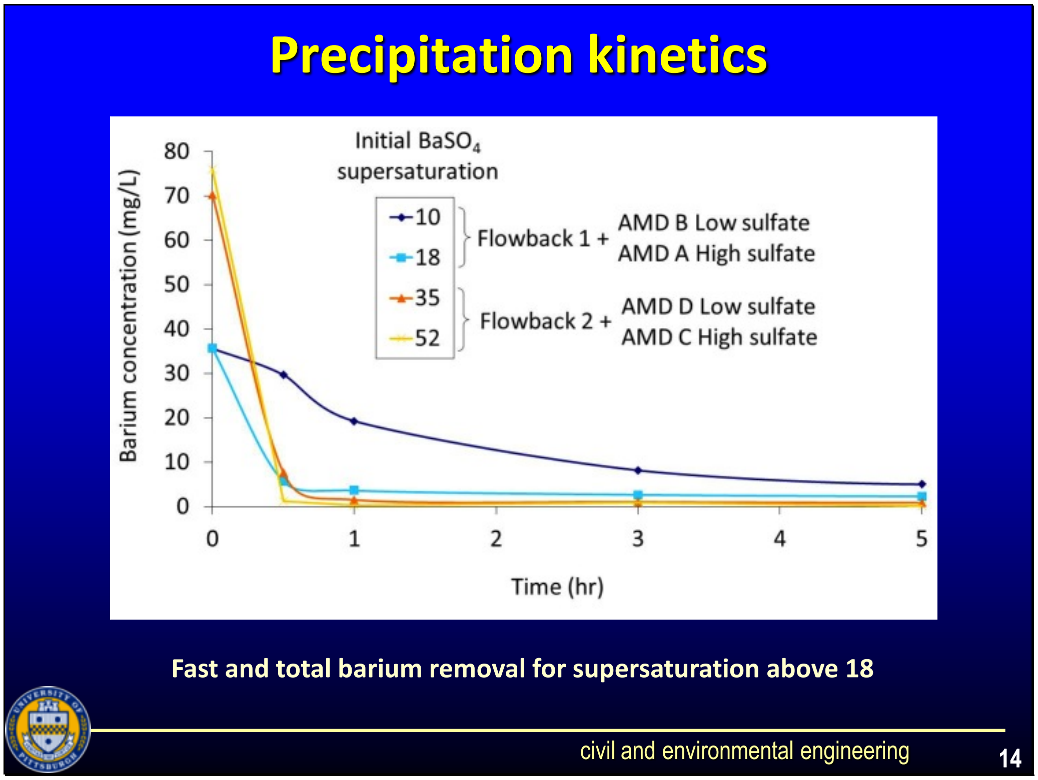
Flowback

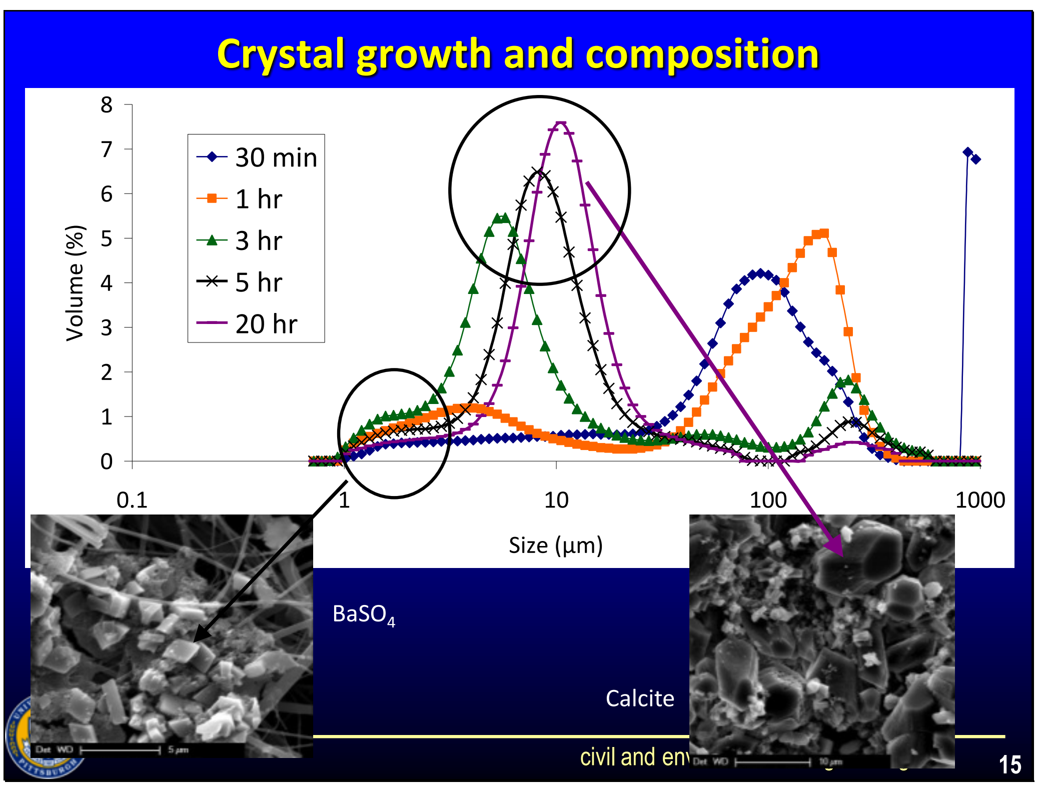
	FB 1	FB 2
Cl	104,300	29,000
Na	38,370	11,860
Ca	15,021	2,224
Mg	1,720	249
Sr	1,800	367
Ba	236	781

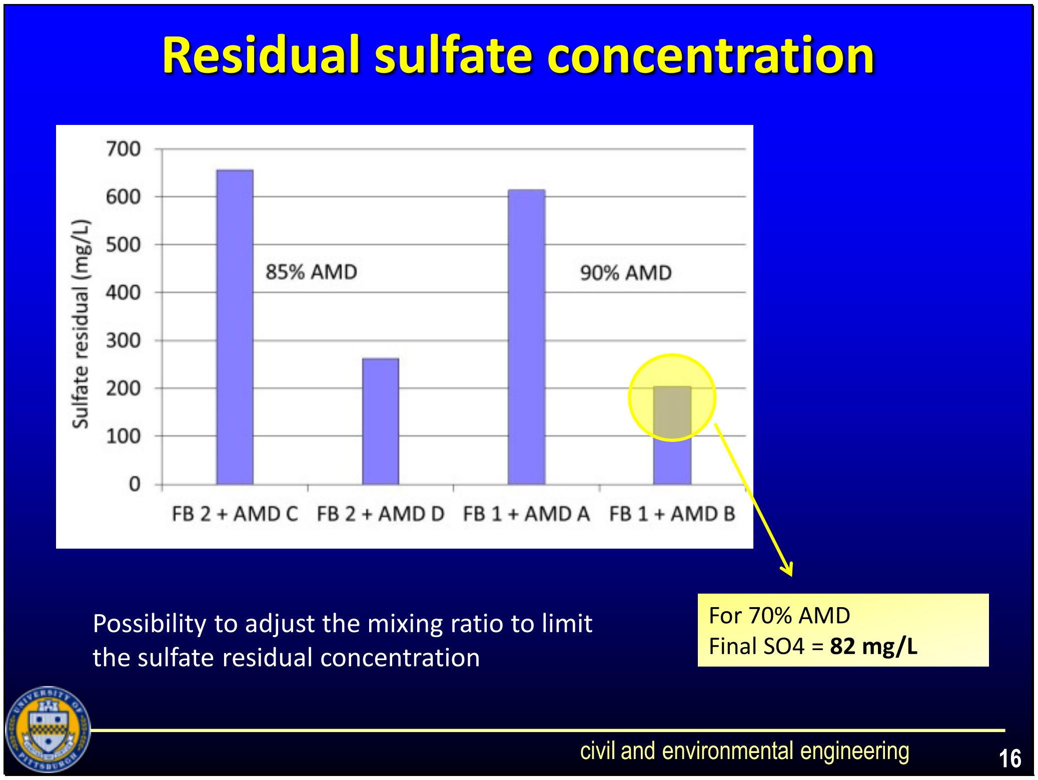
Mixing ratio based on flowback water recovery

FB 1 15% + AMD A or B 85%

FB 2 10% + AMD C or D 90%


Precipitation kinetics
Initial BaSO4 supersaturation
10
18
35
52
Flowback 1 +
AMD B Low sulfate
AMD A High sulfate
Flowback 2 +
AMD D Low sulfate
AMD C High sulfate
Barium concentration (mg/L)
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
Time (hr)
Fast and total barium removal for supersaturation above 18
civil and environmental engineering
14


Crystal growth and composition
30 min
1 hr
3 hr
5 hr
20 hr
Volume (%)
0
1
2
3
4
5
6
7
8
0.1
1
10
100
1000
Size (µm)
BaSO4
Calcite
civil and env
15


Residual sulfate concentration
700
600
500
400
300
200
100
0
Sulfate residual (mg/L)
85% AMD
90% AMD
FB 2 + AMD C
FB 2 + AMD D
FB 1 + AMD A
FB 1 + AMD B
Possibility to adjust the mixing ratio to limit the sulfate residual concentration
For 70% AMD
Final SO4 = 82 mg/L
civil and environmental engineering
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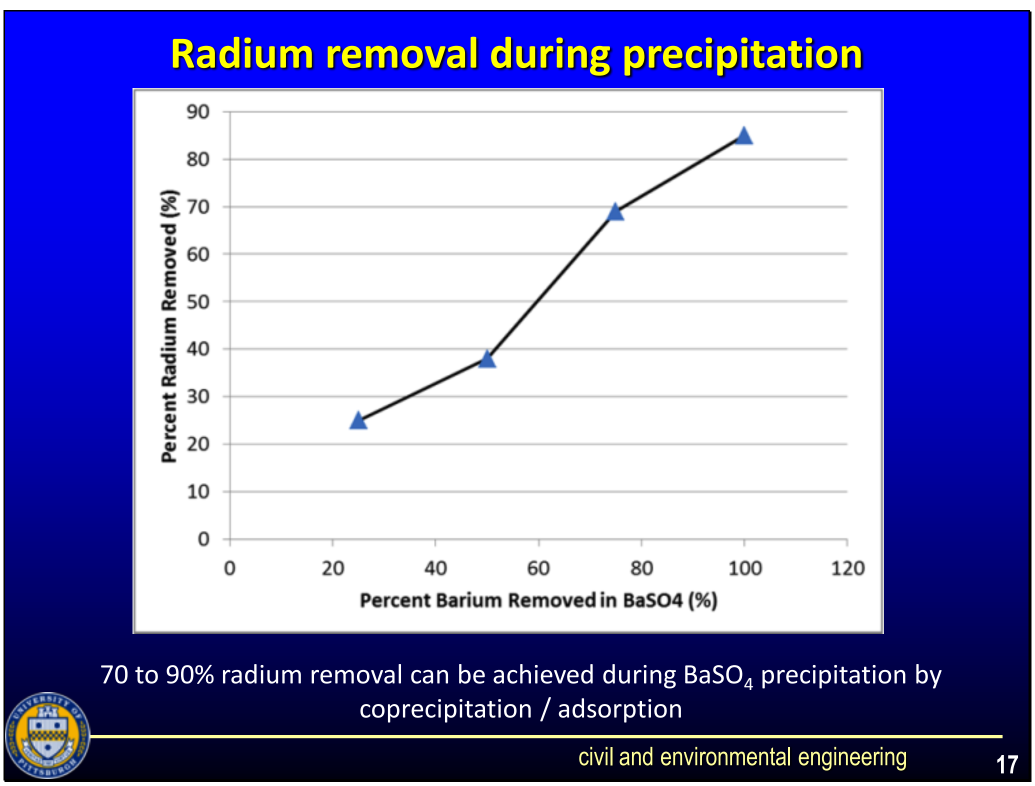
Radium removal during precipitation
90
80
70
60
50
40
30
20
10
0
Percent Radium Removed (%)
0
20
40
60
80
100
120
Percent Barium Removed in BaSO4 (%)
70 to 90% radium removal can be achieved during BaSO4 precipitation by coprecipitation / adsorption
civil and environmental engineering
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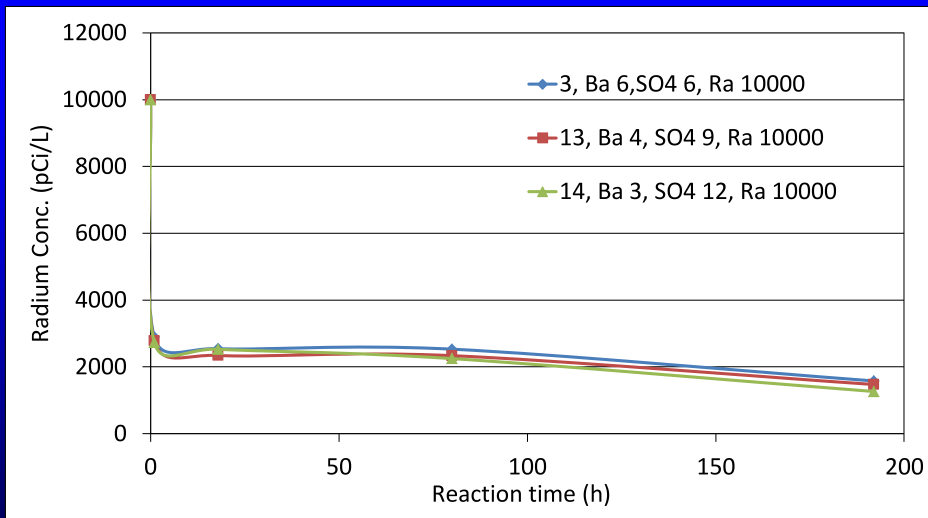
Radium removal during precipitation



Ra removal may be completed within 1 hour

Radioactive solid waste handling

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

Citation: CoPhysic Corporation- Radiological Survey Report on Marcellus Shale Drilling Cutting

- 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.

Sulfate precipitation downhole

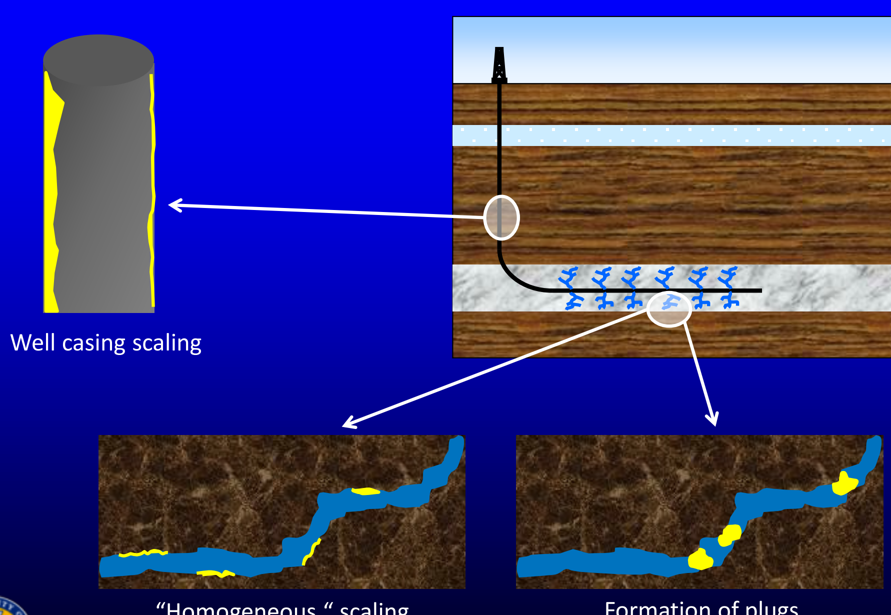
Calculations performed with:

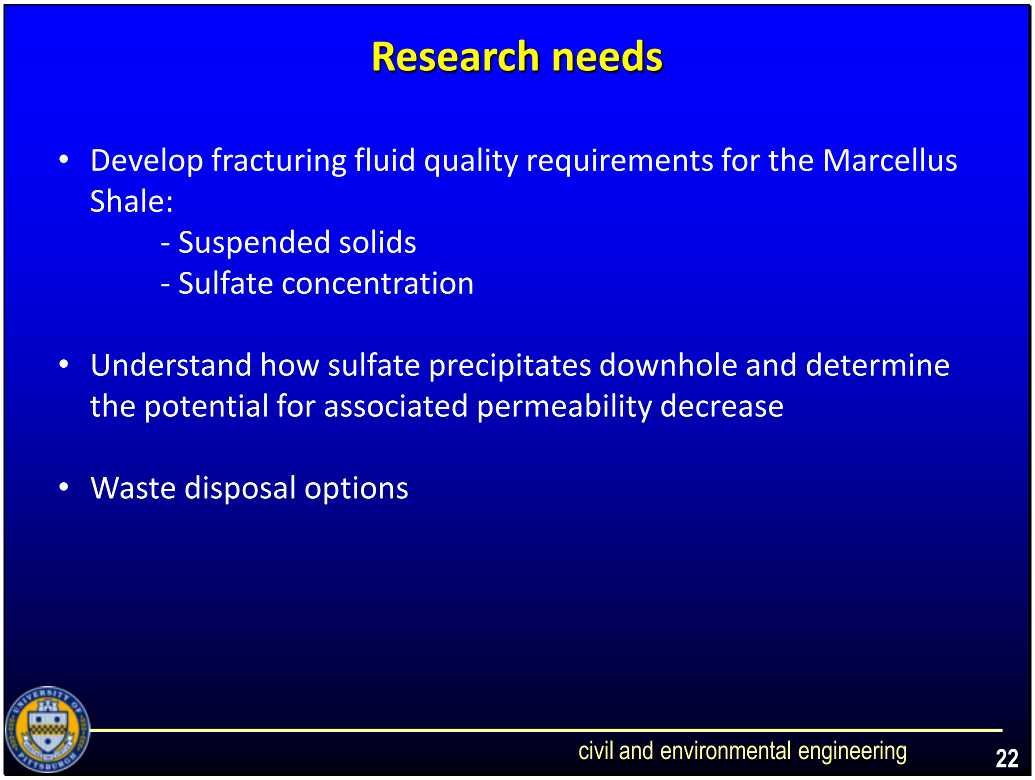
- Fracturing fluid volume = 3 million gal
- 9%$_w$ proppant
- Proppant density = 1201 kg/m^3

SO_4 (mg/L)	$BaSO_4$ volume (m^3)	Volume percentage compared with proppant
100	0.44	0.05%
200	0.98	0.1%
800	4.9	0.5%

Negligible volume compared with the volume of proppant injected

Sulfate precipitation downhole




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
civil and environmental engineering
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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 $BaSO_4$ (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.

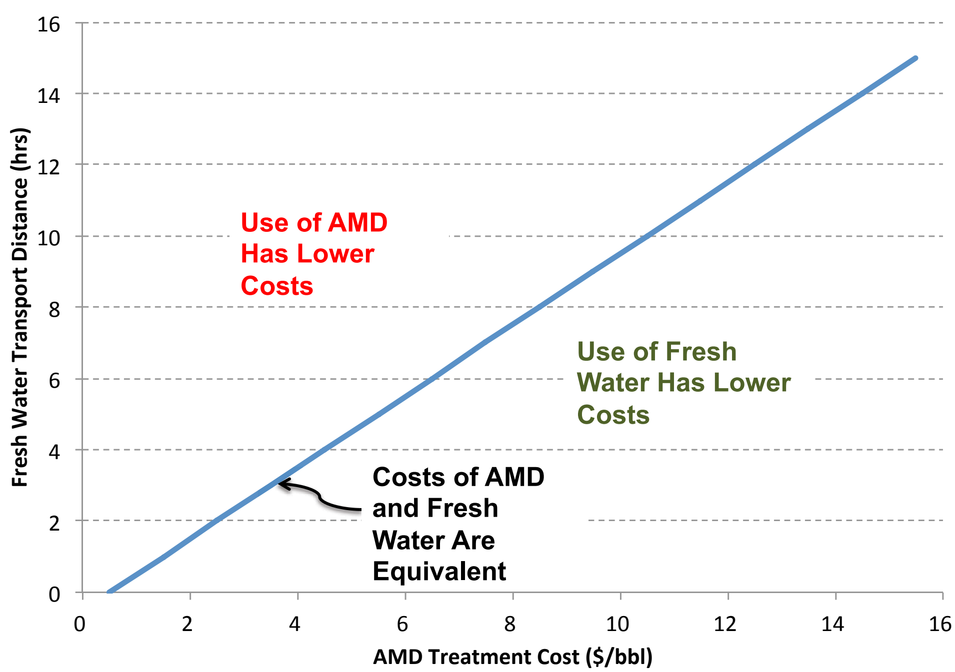

Figure 3.1 Comparison of AMD Treatment Cost with Transport Costs Associated with Fresh Water

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

Memory, M. (2011), "Marcellus Source Water Optimization," presentation given at the Shale Gas Water Management Initiative, Canonsburg, PA, April.

Miller, P. (2011), "Evaluating Flowback and Fresh Water Storage Options," presentation given at the Shale Gas Water Management Initiative, Canonsburg, PA, April.

Yeager, B. (2011), "Energy Corporation of America-Waterline Project," presentation given at the Shale Gas Water Management Initiative, Canonsburg, PA, April.

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

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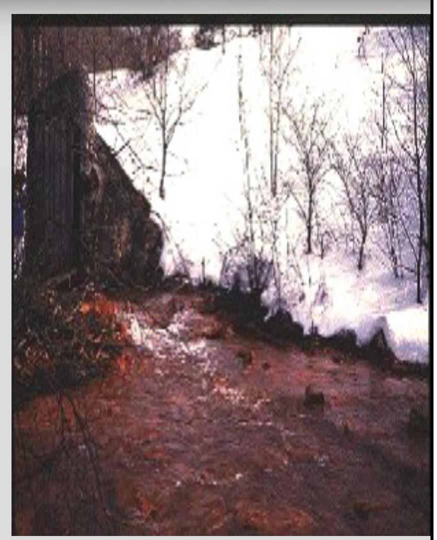
Economics of AMD Use Topics

- Acquisition
- Transport
- Treatment
- Storage
- Costs
- Feasibility



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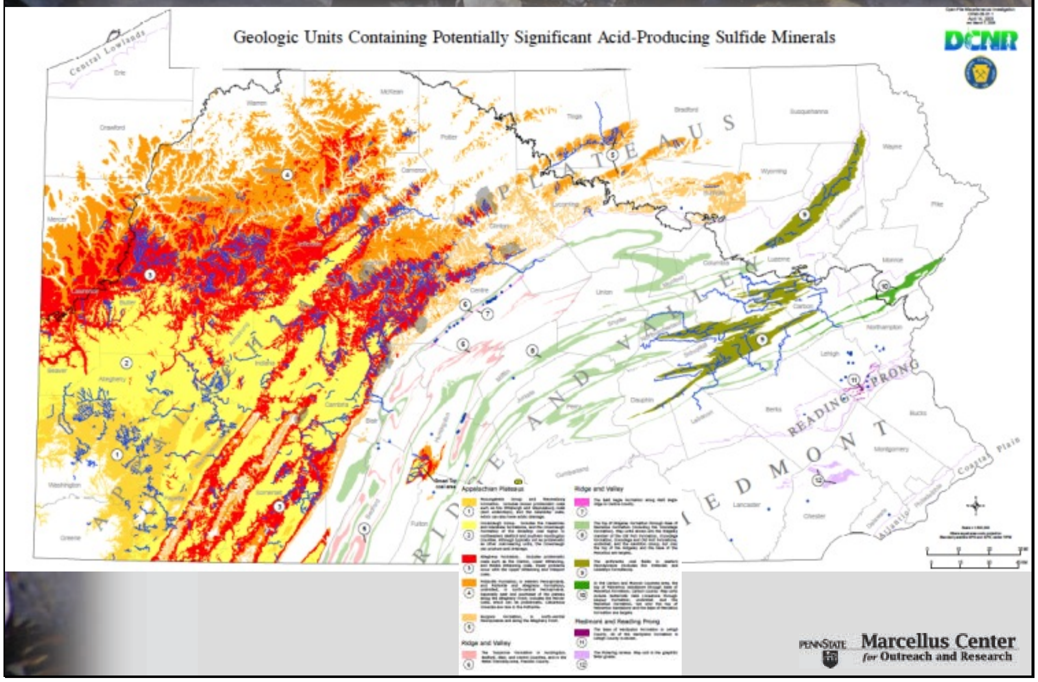
AMD Availability



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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

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AMD Transport

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

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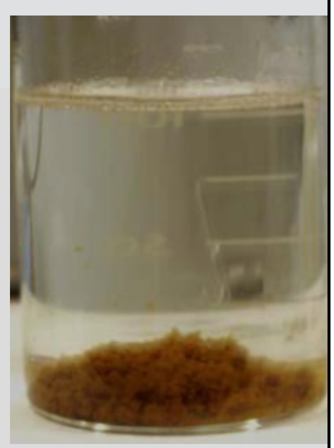
Flowback Treatment Specifications

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



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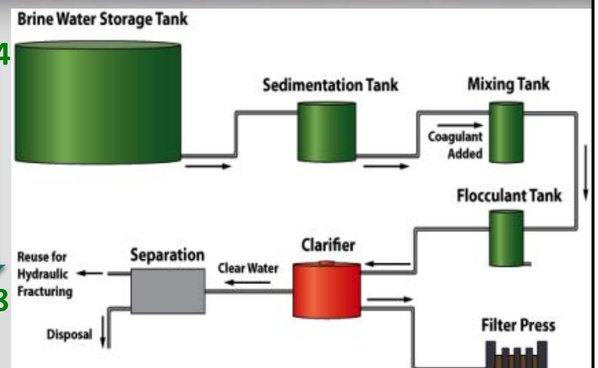
AMD Treatment Options

Methods considered:

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

$<4 → $8



Chemical precipitation can have >99% removal efficiency for potential scaling agents

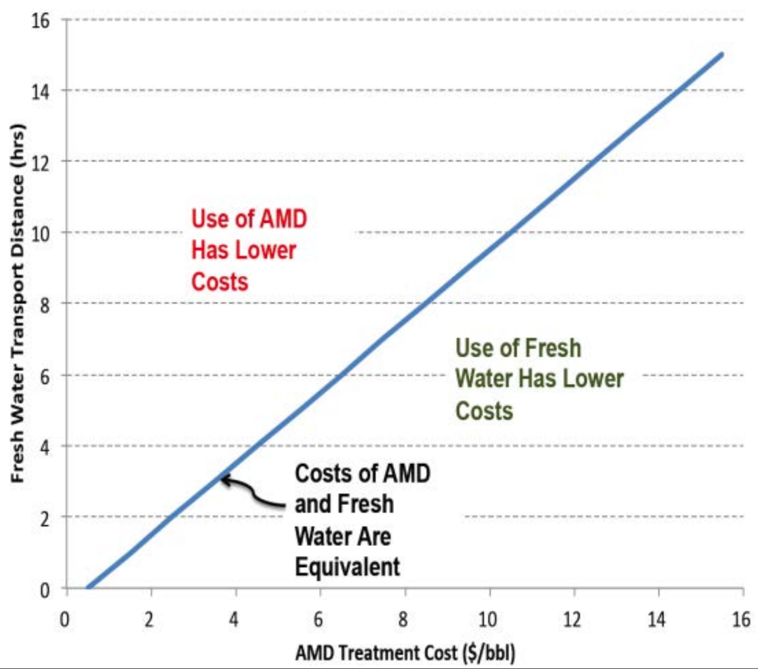
Can generate several tons of sludge per 100,000 gallons treated

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

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.

Cost of AMD versus fresh water



Assumptions:

Transport cost (one hr) = $1/bbl

Freshwater storage cost = $0.10/bbl

AMD storage costs of $0.75/bbl

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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).

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Thank you!
Questions?
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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
pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF ABANDONED MINE RECLAMATION
CAMBRIA DISTRICT OFFICE

Treatment Costs for Selected AMD Treatment Facilities in Pennsylvania

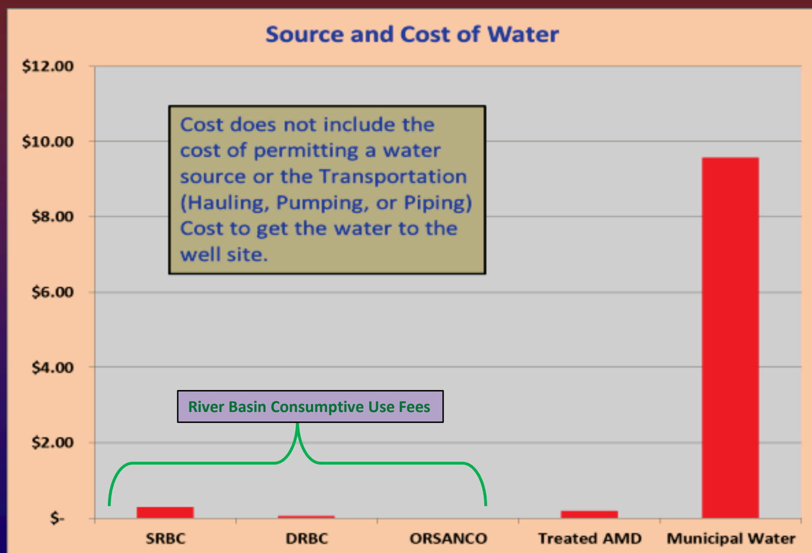
Treatment Plant	County	Operator	Flow Treated (MGD)	2009 Treatment Cost ($/1,000 gal)
Wildwood	Allegheny	PA DEP	0.9	$ 0.11
Brandy Camp	Elk	PA DEP	1.4	$ 0.66
Blue Valley	Elk	Toby Creek Watershed Assoc.	0.4	$ 0.76
Toby Creek	Elk	PA DEP	0.7	$ 0.57
Rausch Creek	Schuylkill	PA DEP	10.8	$ 0.07
Bethlehem Mine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

Costs of Municipal Water for Various Geographic Areas of Pennsylvania

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

River Basins in Pennsylvania

Cost Summary



Economics

- 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?

pennsylvania
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BUREAU OF ABANDONED MINE RECLAMATION
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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.

Session 4 White Paper: Healing Wounds of the Past: How Marcellus Shale Gas Extraction—with Some Legislative Reforms—Could Help Clean-Up Pennsylvania's Acid Mine Drainage Legacy

By Peter J. Fontaine, Co-Chair, Energy, Environmental, and Public Utility Practice Group, Cozen O'Connor

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.

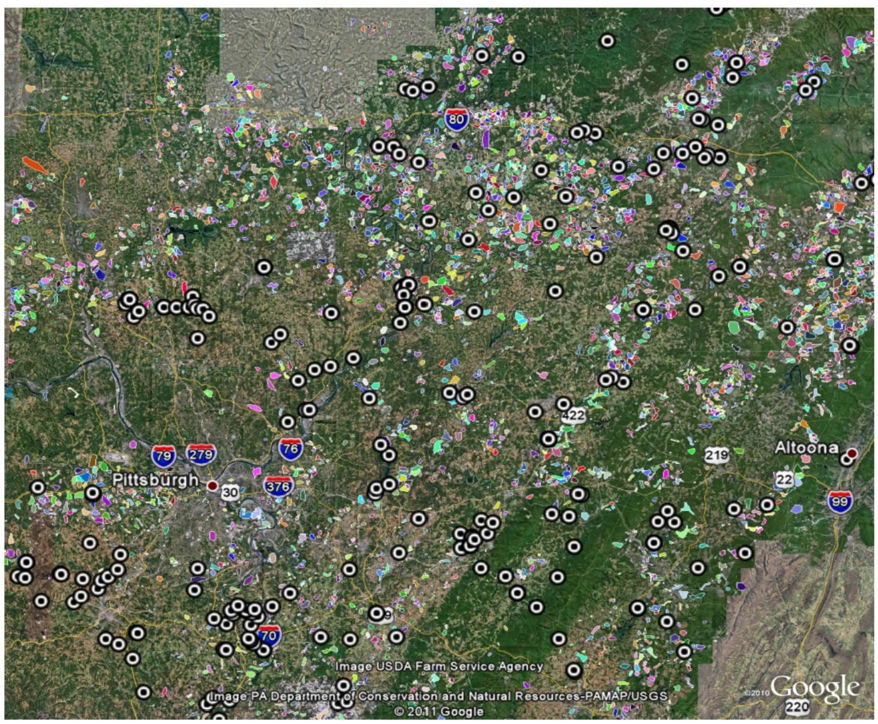

Figure 1. Overlap of Marcellus Shale Wells and Abandoned Mines in Western Pennsylvania (PA DEP)

NOTE: Abandoned coal mines are depicted in color.

Historically, Pennsylvania has spent about $19 million annually on abandoned mine reclamation. However, this amount has been inadequate to fully address the problem, and relatively few AMD areas have been remediated. The cost of constructing and operating treatment systems in remote areas, the lack of sufficient funding, and the potential to incur perpetual treatment liability all have impeded progress toward returning Pennsylvania's streams to water quality standards of 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.[4] In amending the CSL, the legislature declared,

[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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5 *Treatment of Abandoned Mine Drainage for Use as Marcellus Gas Well Hydrofracture Makeup Water*, ProChem Tech International, Inc., p. 1, http://www.prochemtech.com/Literature/TAB/PDF_TAB_Marcellus_Hydrofracture_Water_Suppl y_%20From_AMD_1009.pdf.

6 "Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities." David M. Kargbo, Ron. G. Wilhelm, and David J. Campbell. *Environmental Science & Technology*, Vol. 44, No. 15, 2010,p. 5679, http://pubs.acs.org/doi/abs/10.1021/es903811p.

7 "Natural Gas Plays in the Marcellus Shale: Challenges and Potential Opportunities." David M. Kargbo, Ron. G. Wilhelm, and David J. Campbell. *Environmental Science & Technology*, Vol. 44, No. 15, 2010, p. 5682, http://pubs.acs.org/doi/abs/10.1021/es903811p.

8 See *Acid Mine Drainage Restoration Plan for the Beech Creek Watershed*, Hedin Environmental, June 19, 2006.

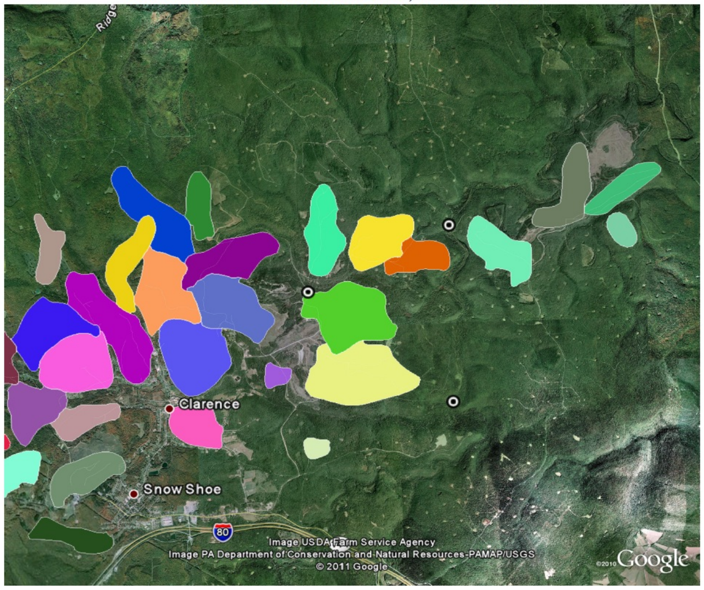

Figure 2. Overlay of Abandoned Mine Pools and Marcellus Shale Wells Outside Clarence and Snow Shoe, Centre County (PA DEP and Google Earth)

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;

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[9] *Acid Mine Drainage Restoration Plan for the Beech Creek Watershed*, Hedin Environmental, June 19, 2006.

[10] See Susquehanna River Basin Commission, "Anthracite Region Mine Drainage Remediation Strategy Preliminary Findings," press release, March 31, 2011, http://www.srbc.net/newsroom/NewsReleasePrintFriendly.aspx?NewsReleaseID=57.

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.[11] 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.[12] 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."[13] Persons are prohibited from allowing the discharge or flow of any industrial wastes into Pennsylvania's waterways.[14] 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.[15] Once the PA DEP is aware that pollution or even if the threat of pollution exists, it can order any landowner[16] or occupier to correct the condition.[17] Fault for creating

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[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.

[15] *See Commonwealth v. Harmar Coal Co.*, 452 Pa. 77 (1973).

[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.[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. [19]

Pennsylvania attempted to solve the "perpetual treatment" problem in 1999, when it enacted the Environmental Good Samaritan Act of 1999 (EGSA).[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

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[17] Clean Streams Law, 35 P.S. § 691.316.

[18] See *Commonwealth v. Barnes & Tucker Co.*, 455 Pa. 392 (1974); *Western Pennsylvania Water Co. v. Dep't. of Environmental Resources*, 526 Pa. 443 (1990); and *Thompson & Phillips Clay Co. v. Dep't of Environmental Resources*, 136 Pa.Cmwlth. 300 (1990).

[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.

See 65 Fed.Reg. 19,440 (April 11, 2000).

[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

[22] Governor's Marcellus Shale Advisory Commission, *Report*, July 22, 2011, p. 109.

[23] Citizens Marcellus Shale Drilling Commission, *Marcellus Shale: A Citizen's View*, October 2011, p. 45.

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,[24] 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

[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

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF ABANDONED MINE RECLAMATION
CAMBRIA DISTRICT OFFICE

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

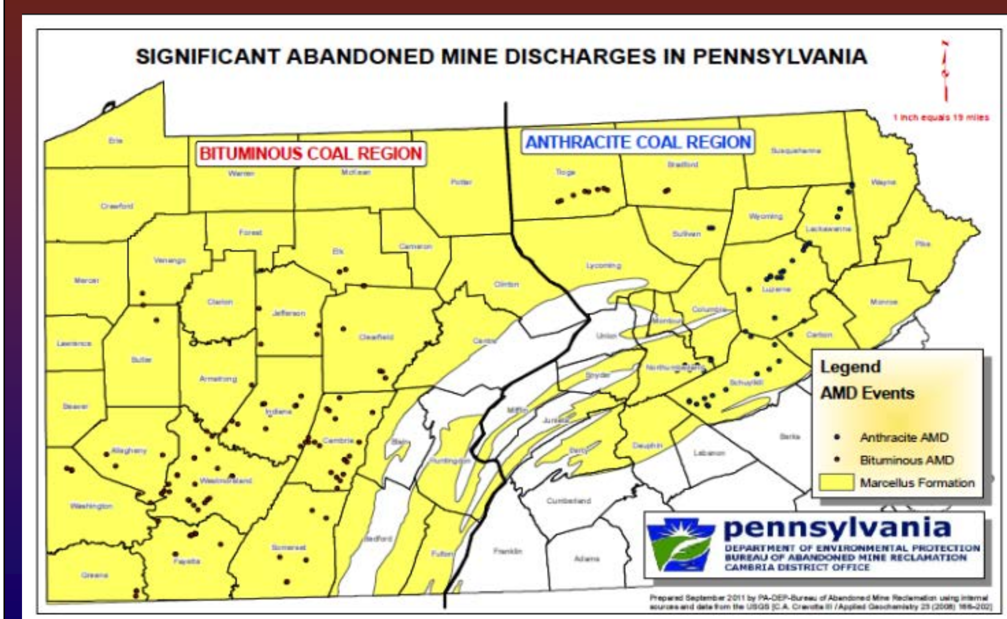
- 1. Define the roles of the various department programs
- 2. Establish a process for the oil and gas industry to utilize AMD
- 3. Establish a process for the Department to facilitate review and evaluate proposals for use of AMD

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, 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?

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DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF ABANDONED MINE RECLAMATION
CAMBRIA DISTRICT OFFICE

Regulatory and Legal Barriers

Joseph K. Reinhart, Esq.
Kevin J. Garber, Esq.
December 14, 2011

Babst Calland
Attorneys at Law

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

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Attorneys at Law

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

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Environmental Laws Creating Potential Barriers

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

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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

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Attorneys at Law

§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

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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

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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

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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

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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

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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

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Liability Reforms to Encourage Comprehensive Watershed-Based Approach to Acid Mine Drainage Abatement and Marcellus Shale Hydraulic Fracturing

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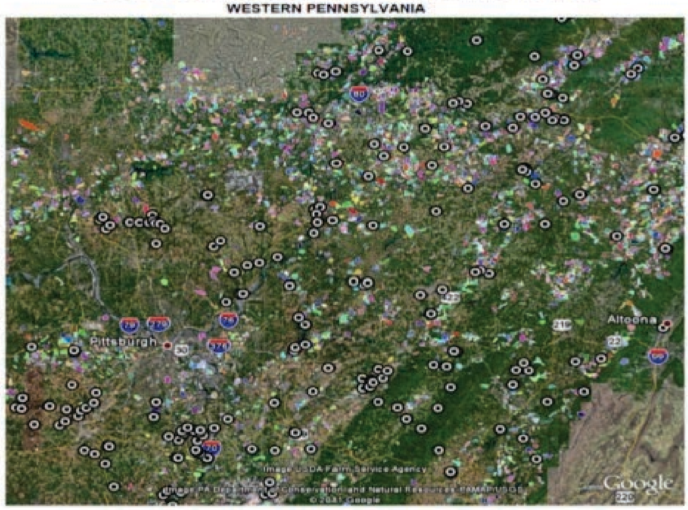
Presented by:

Peter J. Fontaine, Esquire
Energy, Environmental & Public Utility Practice Group
Cozen O'Connor

Opportunity

OVERLAP OF MARCELLUS SHALE WELLS AND ABANDONED MINES

WESTERN PENNSYLVANIA



SOURCE: PENNSYLVANIA DEPARTMENT OF ENVIRONMENTAL PROTECTION

KEY: ABANDONED COAL MINES (COLOR)

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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.***

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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.

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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

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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

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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.

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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

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Thank You!

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