Water Production from Coalbed Methane Development in Wyoming: A Summary of Quantity, Quality and Management Options

FINAL REPORT

Prepared for

The Office of the Governor
State of Wyoming

Prepared by

The Ruckelshaus Institute of Environment
and Natural Resources

With contributions from

Faculty, Staff, and Students at
The University of Wyoming

December, 2005

UNIVERSITY OF WYOMING

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INITIALISMS, ABBREVIATIONS, AND UNIT CONVERSIONS
(also see boxed explanations in text for additional terms and units)

Initialisms

BLM	U.S. Department of the Interior, Bureau of Land Management
CBM	Coalbed methane, also known as coalbed natural gas
CBNG	Coalbed natural gas
DEQ	Wyoming Department of Environmental Quality
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
PRB	Powder River Basin of Wyoming
SEO	Wyoming State Engineer's Office
USGS	U. S. Geological Survey
WOGCC	Wyoming Oil and Gas Conservation Commission
WSGS	Wyoming State Geological Survey
WYPDES	Wyoming Pollutant Discharge Elimination System

Water volume measurement abbreviations and unit conversions

AF = acre-foot (1 acre, 1 ft deep)
= 326,000 gallons
= 7,759 barrels (bbl)
bbl = barrel
= 42 gallons

Natural gas volume measurement abbreviations and definitions

cf = cubic foot (a standard cubic foot of natural gas is measured at a standard temperature of 60°F and a standard pressure of 1 atmosphere)
mcf = thousand cubic feet = the standard sales unit for natural gas including CBM
mmcf = million cubic feet
bcf = billion cubic feet
tcf = trillion cubic feet

EXECUTIVE SUMMARY

Introduction

Coalbed methane (CBM) is natural gas associated with coal deposits. While the presence of this gas has been known for centuries, methods for economically collecting it have only recently been developed. Beginning with a few producing wells in Wyoming's Powder River Basin (PRB) in 1987, CBM well numbers in this area have increased to over 13,600 in 2004, with projected growth to 20,900 producing wells in the PRB alone by 2010. In 2003 alone the total value of Wyoming CBM production was about $1.5 billion, with tax and royalty income of about $90 million to counties, $140 million to the state, and $27 million to the federal government. CBM is now being produced and/or evaluated in four other Wyoming coal basins.

Increasing CBM production and higher natural gas prices have clearly helped Wyoming to prosper financially. The speed and extent of development, however, have led to some potential and real socioeconomic, cultural, environmental and other consequences. One of the most serious concerns is management and disposal of the large volumes of water that are co-produced with the CBM gas (this co-produced water is hereinafter referred to as CBM water).

Strongly held disagreements and difficulties about CBM development generally, and water management specifically, have grown to the point that continued growth in CBM production may be under some threat. These concerns are related to:

- an inadequate regulatory framework for CBM development, including water management and disposal;
- decreased CBM production in 2004 possibly due in part to water management issues; and
- recent and pending court decisions.

To gain more information on options to address water management issues, staff members in the Wyoming Governor's Office asked the University of Wyoming in late 2004 to address a series of questions on options for dealing with water produced through CBM development. The main purpose of this report is to provide answers to these questions along with enough additional information to place the answers in context.

Extent and Value of Wyoming's CBM Resource

The full extent of Wyoming's CBM resource, expressed as total recoverable reserves by the Wyoming State Geological Survey, is 31.7 trillion cubic feet (tcf) of gas. This is a sufficient quantity of natural gas to meet U.S. consumption for 1.44 years at 2003 consumption rates.

The approximate total value of 31.7 tcf of CBM is $140 billion, based on $4.40 per mcf, the average 2003 wellhead price. Total tax and royalty income would be $23.5 billion, with $12.8 billion to state, $8.2 billion to county and $2.5 billion to federal governments, assuming $4.40 per mcf and distribution of tax and royalty income to state, county and federal governments roughly equivalent to distribution percentages in 2003.

Water Quantity

Cumulative CBM water production from 1987 through December 2004 has been just over 380,000 acre-feet (2.9 billion barrels), while producing almost 1.5 tcf of CBM gas statewide. Annual CBM water production in 2003 was 74,457 acre-feet (577 million barrels). Almost all of the CBM water, thus far, has come from the PRB. The water quantity co-produced since 1987 would be enough to fill Lake DeSmet 1.5 times, fill Glendo Reservoir over two-thirds full, or fill Buffalo Bill Reservoir just over half full.

Total production of CBM water across all Wyoming coal fields could total roughly 7 million acre-feet (55.5 billion barrels) if all of the recoverable CBM gas in the projected reserves of 31.7 tcf were produced over the coming decades. Of these statewide amounts, about 380 thousand acre-feet (2.75 billion barrels) of water and roughly 1.5 tcf of gas have already been produced through December 2004, leaving approximately 95% of the CBM gas reserves and associated water for potential future production.

Water Quality

In the PRB, CBM water quality generally declines when moving from the Cheyenne River drainage northwestward to the Belle Fourche, Little Powder, and Powder River drainages. Concerns center on the salinity of the water, usually measured as total dissolved solids (TDS), or electrical conductivity (EC) and sodium adsorption ratio (SAR).

CBM water from the Cheyenne and Belle Fourche drainages is of relatively high quality and is within or close to the TDS water quality limits for human drinking water, and within the EC and SAR limits for irrigation water. CBM waters from the Little Powder, Powder and Tongue River drainages have tested above one or more water quality standards or threshold criteria for TDS (human drinking water or stock water standards), EC (irrigation of sensitive plants), and SAR (irrigation water suitability). Water from CBM wells in the Tongue River drainage has better TDS and EC levels relative to CBM wells in the Powder River drainage, but the SAR levels from CBM wells sampled in the Tongue River drainage are higher than all the wells from the other PRB watersheds.

CBM water may be of good quality at the wellhead but this quality can degrade when water picks up additional solids or salts after discharge to a streambed or storage in a reservoir designed to allow water to infiltrate through the soils. A key water quality issue, not yet fully assessed, is the cumulative effect of numerous CBM water discharges on the overall water quality of basin streams. This leads to one of the most contentious issues in CBM development in Wyoming's PRB: Montana's concern about the potential downstream effects of water quality degradation on rivers flowing north into Montana. Prior to CBM development, samples of Powder River water at the Montana border sometimes exceeded the current EC standard of 2500 microsiemens per centimeter (µs/cm) (Clark et al., 2001). Water quality degradation could potentially affect downstream water uses for agriculture and might also affect Montana's ability to develop its own CBM resources in the northern arm of the PRB. CBM waters sampled from the Powder, Little Powder, and Tongue River drainages exceed Montana's numerical standards for TDS and EC.

The main problem with CBM waters in PRB soil-plant systems is the damaging effects of salts on soil physical condition, particularly on infiltration rates. The TDS, EC and SAR of the water, and soil type, are inter-related in how irrigation water can affect soil permeability and plant growth.

Very little water quality information exists for new CBM development areas outside the PRB, e.g., in southern and southwestern Wyoming. The small amount of information available so far suggests that the quality of CBM water in at least some of these fields will be substantially lower than CBM water in the PRB.

Water Management, Disposal, Treatment and Use

In the eastern part of the PRB where CBM water is generally of good quality, most of it is discharged to surface drainages or to soil (irrigation). In the western part of the PRB, most CBM water goes to evaporation/infiltration ponds or reservoirs. Other management options currently in use include injection, managed irrigation (with additives to mitigate the effects of certain salts in the water), atomization, and treatment by reverse osmosis or ion exchange.

Numerous uses for CBM water have included agriculture, domestic and municipal supplies, and could include commercial and industrial uses as well. The economic feasibility of different options depends on CBM water quality, availability of cost-effective treatments, and location of the CBM gas wells.

Several new technologies that are not yet implemented in CBM development on a large scale may hold significant promise for improving process efficiency and reducing cost for the removal of CBM gas while reducing the volume of CBM water. These include alternative wellbore completion methods and downhole raman spectroscopy.

Economic Impacts

Little information has been compiled on how CBM development and regulations affect socioeconomic conditions in communities and throughout the state. The economic impact of CBM water management is influenced by natural gas prices, the amount of water produced per unit of gas, costs for drilling and operating wells, and the water management option chosen by the operator.

Regulatory and Legal Issues

Three state regulatory agencies share the main responsibility for regulating CBM development in Wyoming: the State Engineers' Office (SEO), the Department of Environmental Quality (DEQ), and the Oil and Gas Conservation Commission (WOGCC). In addition, the Game and Fish Department recommends measures to mitigate the impact of oil and gas development on wildlife, and the U.S. Department of the Interior, Bureau of Land Management (BLM) oversees the development of federally owned minerals.

CBM development has been regulated in more or less the same way as conventional oil and gas (gas extracted from formations other than coal seams) even though there are major differences in the issues associated with CBM and conventional oil and gas. Agencies are doing their best to make their governing statutes and regulations "fit" CBM, but this strategy has resulted in some regulatory gaps as well as overlapping regulatory responsibility. The CBM industry may need to be regulated as a unique kind of development.

Several lawsuits filed in federal courts have challenged various aspects of CBM development and its associated impacts. There also has been civil litigation by private landowners against both state agencies and individual CBM operators.

Alternative Strategies Related to CBM Water Management

Concerns over the consequences and lost opportunities associated with current water management methods suggest the need for reconsidering and expanding the available options, especially at a time when the vast majority (about 95% as of December, 2004) of Wyoming's recoverable CBM resources remain to be produced. No single method will address all of the concerns and opportunities associated with CBM water production. Rather, managing CBM water likely will continue to require a suite of management approaches, to be tailored on a regional and even site-specific basis. Some options to consider include:

- minimizing water production;
- injection of CBM water for storage or disposal;
- additional beneficial uses for CBM water;
- developing technology-based limits;
- watershed-based water management;
- watershed-based CBM discharge permitting; and
- coordinated management and regulation of CBM.

Possible Next Steps

Wyoming's management and regulation of CBM development could be continued under current regulatory policy and procedure, but some adjustment is needed. Based on a request from the Governor's Office, we have outlined possible next steps toward future changes in CBM water management and regulation. Many of these ideas were suggested in discussions stimulated by earlier drafts of this report by various parties with interests or concerns about CBM development, and the ideas are offered here to stimulate thinking and foster broad discussion among CBM stakeholders.

- **Expert technical workshops or studies on key CBM water management issues**

  Several water management issues could benefit from information sharing among knowledgeable experts from the CBM industry, technical consultants, agencies, academics, landowners, environmental groups and others.
  - Water gathering, transport, treatment, storage, use and disposal.
  - Plant and soil reclamation.
  - Suitability of potential receiving formations for water flood enhanced oil recovery or groundwater disposal in the PRB and other Wyoming CBM development areas.
  - "Reservoir engineering" analyses to maximize CBM gas production and minimize water production.
  - Trans-basin diversions.
  - Socioeconomic analysis of positive and negative impacts from CBM development on communities and on landowners with and without mineral rights.
  - Economic analysis of revenue and costs associated with CBM development including regulatory scenarios and other options for dealing with CBM water.
  - Review and analysis of statutory authority and agency regulations for key agencies to determine areas of potential overlap or gaps in statutory authority and/or regulation.
  - Legal/administrative studies to determine the possibility of establishing stronger coordination between federal and state agencies for any of the current federal responsibilities for permitting and managing CBM development and production.
  - Multi-stakeholder or industry-led formulation of Best Management Practices (BMPs) for CBM water (as well as other issues), starting with BMPs developed for CBM by the Western Governors' Association.
  - Review of watershed-based management approaches with representatives from all the existing watershed groups.
  - Evaluate adaptive management approaches in managing CBM water.
  - Review wildlife issues and monitoring needs related to water quality and quantity.

- **Incremental Adjustment in CBM Water Management and Regulation**

Important incremental changes in CBM water management and regulation are already underway, including the Governor's Strengthening and Streamlining Environmental Working Group and Industry Working Group on oil and gas, the Governor's Strengthening and Streamlining Working Group on interagency data sharing and electronic permitting for oil and gas, the CBM Working Group comprised of state agency heads, DEQ's new watershed-based approach for permitting CBM water discharges, and development of voluntary BMPs for CBM development. Some of the additional incremental adjustments listed below could be achieved through voluntary actions by industry, increased or re-directed funding within agencies, regulatory change by agencies, and/or cooperative efforts among agencies. But some of the incremental adjustments listed below may require statutory changes followed by promulgation of new regulations by agencies.

  - Strengthen monitoring and enforcement of existing rules and regulations with additional funding for personnel in DEQ, SEO, and WOGCC.
  - Speed up and strengthen DEQ's watershed-based planning and permitting program with increased staff and funding and with statutory/regulatory revision, as necessary, to formally integrate CBM-related permitting and management by SEO, WOGCC, and others.
  - Implement comprehensive data sharing and management by building on the arrangements being discussed as part of the Governor's Strengthening and Streamlining Working Group on interagency data sharing, with a comprehensive data management clearinghouse system compatible with permitting, monitoring reports, compliance review, etc., that is accessible to agencies, industry and the public. This effort should also take advantage of the existing CBM Clearinghouse maintained by the University of Wyoming (www.cbmclearinghouse.info). Better statewide coordination of geospatial data development and dissemination will be needed.
  - Identify and fix regulatory gaps or overlaps, agency by agency, as necessary.
  - Consider adopting multi-stakeholder and/or industry-formulated BMPs for CBM (see above) as regulations under the authority of WOGCC or multiple agencies.

- **Comprehensive Review and Revision of CBM Management and Regulation**

In addition to workshops, studies, and incremental steps, such as those listed above, another option could be to address these and other issues systematically and comprehensively. We suggest considering two approaches for comprehensive review, management and regulation of CBM.

  - "CBM Coordinator" – Although some coordination already occurs among state agencies and among state and federal agencies, no one agency or one person currently has official responsibility to coordinate CBM management and regulation. Comprehensive management might be difficult to achieve unless the coordinator has decision-making authority, which would require modification of agency-specific authorizing statutes or adoption of some overarching new statute.
  - "CBM Management Act" – Rather than adjusting the authorizing statutes or regulations for each agency, adoption of an overarching new "umbrella" statute for management and regulation of CBM development should be considered. This would certainly require thorough analysis, evaluation and crafting through something like a Legislative interim study and/or some sort of Governor-Legislative blue ribbon committee.

INTRODUCTION

Coalbed methane (CBM) is natural gas. CBM, though, is associated with coal deposits, while most conventional natural gas is found in deep sandstone or other rock formations, such as those in the Jonah and Pinedale Anticline Fields in southwest Wyoming. To avoid confusion about what CBM is, the gas industry often uses the term "coalbed natural gas" to refer to CBM.

Methane gas associated with coal deposits has been known for centuries. This coal-associated methane, known as "fire damp" by early coal miners, was the source of many catastrophic mine explosions in underground coal mining regions of Britain during the 1600s and 1700s (Freese, 2003). And these kinds of methane explosions in underground mines continue to this day in developing nations such as China, where modern mine ventilation and safety measures have not yet been effectively implemented.

Coal mine explosions and detection of gas in early Wyoming underground coal mines are among the sources of evidence used by De Bruin et al. (2004) to characterize presence of methane in various Wyoming coal fields. Even though coal geologists and miners have long known of the presence of methane gas in coal deposits, methods for economically collecting the methane gas from coal have only been developed recently. For those interested in learning more about CBM, De Bruin et al. (2004) have written an excellent overview of the geology, distribution, recovery methods and other issues related to CBM in Wyoming.

Beginning with a few producing wells in the Powder River Basin (PRB) in 1987, CBM well numbers in the PRB increased to over 13,600 in 2004 and are projected to continue increasing (De Bruin, 2005). In 2003 alone, the total value of Wyoming CBM production was about $1.5 billion, with tax and royalty income of about $140 million to the state, $90 million to counties and $27 million to the federal government (De Bruin, 2004).

Increasing CBM production and higher natural gas prices have clearly helped Wyoming to prosper financially. The speed and extent of development, however, have led to potential and real socioeconomic, cultural, environmental and other consequences. One of the most serious of these consequences concerns water. To produce gas from CBM wells, it is first necessary to pump out some of the water from the gas-bearing coal seams, which also may be groundwater aquifers, to reduce the pressure on the coal seam and allow the CBM gas to be released from the coal and flow to the well for recovery. Management of this co-produced CBM water (hereinafter referred to as CBM water) has become an important issue.

Pumping water from coals to produce CBM has been designated as a beneficial water use by the Wyoming State Engineer's Office. Much of this CBM water also has been put to many good additional uses, including stock and wildlife watering, irrigation, and adding to the groundwater aquifer used for the City of Gillette's drinking water supply. But often CBM water has been of poor quality or has not been in locations that made additional post-production uses feasible. Common CBM water management practices have included direct discharge to a surface drainage or to on- or off-channel ponds for evaporation and/or infiltration.

Although the benefits and costs associated with CBM in the PRB and elsewhere have been controversial, dealing with CBM water management and disposal arguably has been the most difficult of all the various issues surrounding CBM development. Some argue that there is really "no problem" and that industry and the agencies are working hard to minimize and mitigate water management and disposal issues within the technical, regulatory and statutory framework that exists. Others argue that the CBM play and all its related consequences, including CBM water, are huge problems that threaten to "destroy" ranching operations and rural landscapes of the PRB and elsewhere that CBM is being developed. As is often the case in these kinds of disagreements, each position ("no problem" or "huge problem") probably is correct in some places and at some times, and more probably the real truth lies somewhere between the positions being taken by proponents and opponents of the CBM play. There is little disagreement, though, that CBM production is providing a much needed supply of natural gas and that the CBM play is providing impressive economic returns to the industry, some landowners, and to state and county governments.

Nonetheless, strongly held disagreements and difficulties about CBM development generally, and water management specifically, have gotten to the point that, at the very least, continued growth in CBM production may be under some threat. Several pertinent lines of evidence or perspectives related to these perceived threats to CBM development are directly or indirectly addressed in later sections of this report and can be summarized as follows:

- **<u>An inadequate and sometimes confusing regulatory framework for CBM, including CBM water management and disposal</u>** – Wyoming's regulatory framework related to oil and gas development and to water management was never really structured to handle the particular challenges posed by CBM development. Various aspects of CBM development are administered by the Wyoming Oil and Gas Conservation Commission (WOGCC), the State Engineer's Office (SEO) and the Department of Environmental Quality (DEQ), as well as several federal agencies, particularly the Bureau of Land Management (BLM). This has led to several real or potential difficulties with respect to management of CBM water, including gaps and overlaps in regulatory coverage, difficulties in achieving agency coordination and cooperation, and lack of regulatory certainty.

    - <u>Gaps and overlaps</u> – Since its beginning in the late 1980s in the Powder River Basin, CBM has been regulated more or less the same as conventional oil and gas (e.g., deep gas from sandstone or other non-coal formations) even though there are major differences in the issues associated with CBM and conventional oil and gas. One notable difference is the much higher number of outfalls per water discharge permit in CBM production. DEQ has about 473 discharge permits for 473 outfalls for conventional oil and gas, versus about 834 discharge permits for 6,000 outfalls for CBM (Parfitt, 2005). Through the recent years of CBM development, agencies have done their best to make their governing statutes and regulations "fit" CBM, but almost all agree now that this strategy has resulted in regulatory gaps as well as overlapping regulatory responsibility. The CBM industry may need to be regulated as a unique kind of development. This would most likely require statutory and regulatory revision.

    - <u>Agency cooperation</u> – In recent years, efforts like the Governor's Strengthening and Streamlining Environmental Working Group and Industry Working Group on oil and gas, the Governor's Strengthening and Streamlining Oil and Gas Working Group on electronic permitting and data sharing, and the CBM Working Group have made strides in bringing agencies together. The permitting Strengthening and Streamlining Working Group has developed a pilot project to share water quality and quantity data among the DEQ, WOGCC, SEO and BLM. This is a significant first step in broader data sharing among agencies that is still to come. Many agree that these efforts are steps in the right direction, but the effort is progressing very slowly and, ultimately, much more than data sharing is needed.

  - Evolving regulatory changes and lack of regulatory certainty – As the CBM play in the Powder River Basin evolved and moved from shallower coals in the eastern basin with relatively good water quality to deeper coals in the western basin with poorer quality water, the industry and agencies have had to find ways other than permitted direct discharge to manage CBM water. Methods such as on- and off-channel infiltration/evaporation ponds and atomization have been used by industry to dispose of the poorer quality water. And more recently, several producers have begun considering or even implementing plans for pipeline collection systems and injection for disposal and/or water flood enhanced oil recovery. Downstream states adopted numeric water quality standards for electrical conductivity (EC) and sodium adsorption ratio (SAR), both related to salinity, which has required negotiation between states on allowable loading of salts in rivers flowing into Montana. All of this has led to some uncertainty in the CBM industry on the future of water quality and quantity regulation, which can directly affect CBM field development and production.

- **Decreased CBM production in 2004** – After a decade of steady growth in the number of CBM wells and CBM gas production in the PRB (including dramatic growth from 1998 to 2003), production dropped about 5% from 2003 to 2004. As discussed later, according to industry representatives, this reduction was apparently due to difficulties in managing and disposing of CBM water. Partly as a consequence of these difficulties, industry is now considering other disposal options including injection and more expensive water treatment methods. But if difficulties in disposing and/or permitting CBM water discharges were, in fact, the root causes of reduced production in 2004, additional acceptable options for managing the water will be needed or production may continue to level off or decline.

- **Recent and pending court decisions** – As discussed in later sections of this report, several federal lawsuits have challenged various aspects of CBM development and its associated impacts. These lawsuits are based on the laws at issue (National Environmental Policy Act [NEPA], Clean Water Act, and Clean Air Act) as well as civil litigation by private landowners against both state agencies and individual CBM operators. In one federal case, originally filed in Montana, the court held that the BLM failed to adequately assess the "phased development alternative," and recently the Ninth Circuit Court of Appeals granted an injunction halting new CBM development in Montana's portion of the PRB pending resolution of an appeal on that decision. Another NEPA case is still pending before the Wyoming Federal District Court related to similar issues in the Wyoming portion of the PRB.

With growing concerns about adverse consequences of CBM water disposal, including environmental impacts and the possible decline or temporary cessation of CBM production, many inside and outside of the CBM industry have been seriously exploring options for acceptable alternatives for disposing of CBM water. To gain more information on options to address these water management issues, in late 2004 staff members in the Wyoming Governor's Office asked the University of Wyoming to answer a series of questions framed around a fundamental question and related issues, as follows (see Appendix A for the complete set of questions):

- What are the options for dealing with water produced through CBM development?
    - How much CBM water has been, is and will be produced in the future?
    - What will be its quality?
    - Provide an analysis of the current options for dealing with this water.
    - What other options are we missing?

The main purpose of this report is to provide answers to these questions along with enough additional information to place the answers in context. To provide the answers and the context, this report summarizes available information on quantity and quality of CBM water in Wyoming and assesses current and possible future alternatives for water management, disposal, treatment and use. After reviewing initial drafts of the report, the Governor's staff also asked the authors to address regulatory and statutory issues surrounding CBM water management and disposal.

Information for this report has been summarized from numerous sources including personal communications with state and federal agency staff, industry representatives, landowners, and landowner and environmental groups; state and federal agency web sites; government, industry, and non-governmental organization reports; conference proceedings; and published peer-reviewed literature. This information was the basis for discussions among members of the Ruckelshaus Institute Board during their spring and fall meetings in 2005, followed by recommendations from board members on revising the report. The authors also received and used numerous helpful comments and suggestions from reviewers of two earlier drafts of the report.

EXTENT AND VALUE OF WYOMING'S CBM RESOURCE

Commercial development of coal bed methane (CBM) began very tentatively in Wyoming's Powder River Basin (PRB) in 1987. But after new techniques for CBM well completion were developed in 1997, followed by a U.S. Supreme Court decision favorable to CBM in 1999 and increased pipeline capacity (De Bruin, 2004), CBM production increased dramatically. Well numbers in the PRB have increased to over 13,600 in 2004, with the Wyoming State Geological Survey projecting growth to 20,900 producing wells in the PRB alone by 2010 (Figure 1).

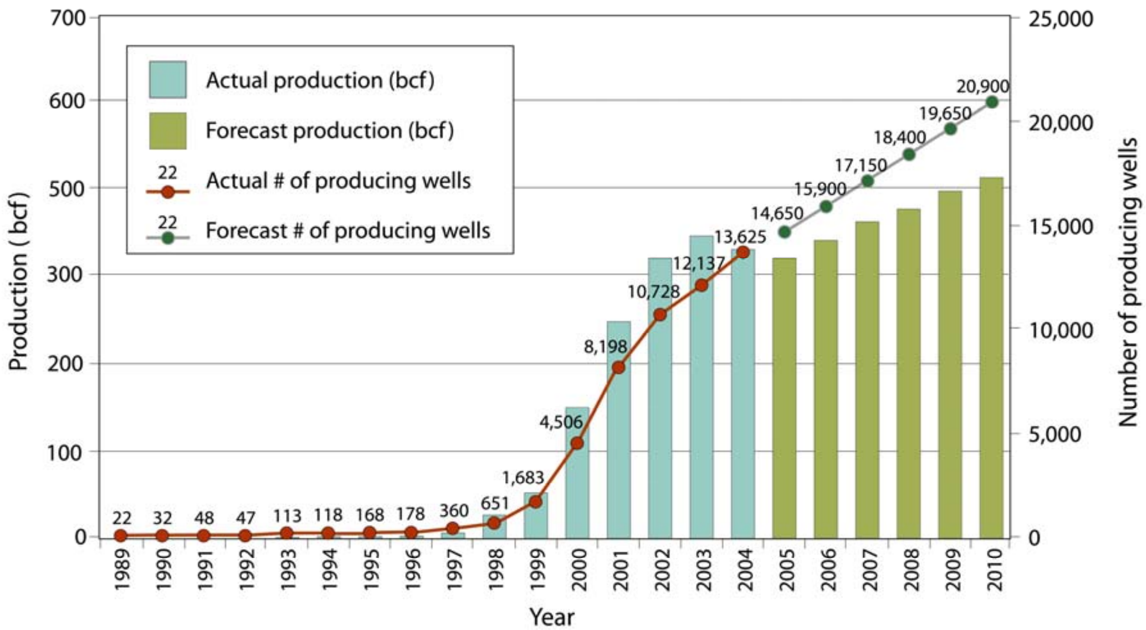

Figure 1. Yearly production and numbers of producing wells for coalbed methane in the Powder River Coal Field, Wyoming, 1989 through 2004, with forecasts to 2010 (modified from De Bruin, 2005). bcf = billion cubic feet.

After steady growth in both well numbers and gas production through 2003, the most recent data for the PRB (Figure 1) show a roughly 5% drop in gas production during 2004, in spite of continued growth in well numbers. Because of this 2004 production decrease, the Wyoming State Geological Survey (De Bruin, 2005) recently reduced previously published (De Bruin et al., 2004) estimates for CBM production through 2010. Possible reasons for the 2004 drop in CBM production include the following.

- Gas production in many of the earliest PRB wells in the shallower coals on the east side of the basin (see Figure 2) has begun to decline.
- Newer wells in deeper coals in the center and west side of the PRB have not yet begun to produce enough gas to replace the fall-off in production from older east basin wells, possibly because the newer wells in this area are expected to produce large volumes of water to reduce pressure at the wellhead prior to the onset of gas production.
- The CBM industry has begun to encounter difficulties with management and disposal of CBM water, in part because of poorer quality water being produced from central and western PRB CBM wells (see discussion of this issue in later sections of this report).

- Some industry representatives suggest that declines are due in part to state and federal regulatory requirements, possibly associated with lower quality of CBM water in the central and western portions of the PRB.

In spite of this 2004 production decrease in the PRB, the Wyoming State Geological Survey still projects continued growth in PRB CBM well numbers and gas production volumes as shown in Figure 1. Moreover, with CBM development now being evaluated for 11 pilot projects underway or planned in the Hanna, Green River, Hams Fork and Wind River coal fields (Likwartz, 2004), added to the continuing expansion of the PRB development (see permitted CBM wells in these coal fields in Figure 2), Wyoming figures to continue as a major producer of CBM. In fact, the BLM has already projected full and pilot CBM development projects in Wyoming for substantially more CBM wells across the state (Table 1) with additional proposals under review.

Table 1. Total numbers (or low to high range estimates, where provided) of CBM wells estimated for full development in four Wyoming CBM project areas as published in EPA and other federal documents. Note that peak numbers of wells producing at any one time likely will be lower than total well numbers by approximately 25 to 40 % (see CBM project locations in Figure 2).

Project Area	Number of Wells	Coal Region	Source
South Piney	100 - 210	Green River Region	U.S. EPA, 2003a
Atlantic Rim	3,880	Green River Region	U.S. EPA, 2001
Seminoe Road	1,240	Hanna Field	U.S. EPA, 2003b
Powder River Basin	51,000 – 139,000	Powder River Region	U.S. BLM, 2003 (Appendix A)

The full extent of Wyoming's CBM resource, expressed as total recoverable reserves by the Wyoming State Geological Survey, is 31.7 trillion cubic feet (tcf) of gas (De Bruin et al., 2004). To place in context this estimate of 31.7 tcf of total recoverable CBM gas and the 348 billion cubic feet (bcf) in total 2003 Wyoming CBM production (PRB plus other Wyoming coal fields; WOGCC, 2004), Box 1 presents a series of comparisons and projections. These comparisons and projections rely on a number of assumptions shown in Box 1 and are intended to provide rough answers to questions such as:

- How much is 31.7 trillion cubic feet (tcf) of natural gas?
- How big a gas supply is Wyoming's 2003 production or Wyoming's total recoverable reserves of CBM relative to U.S. demand for natural gas?
- What is the rough dollar value of 31.7 tcf of CBM gas?
- How much royalty and tax income will the state, counties and federal government expect to receive from production of 31.7 tcf of CBM gas?

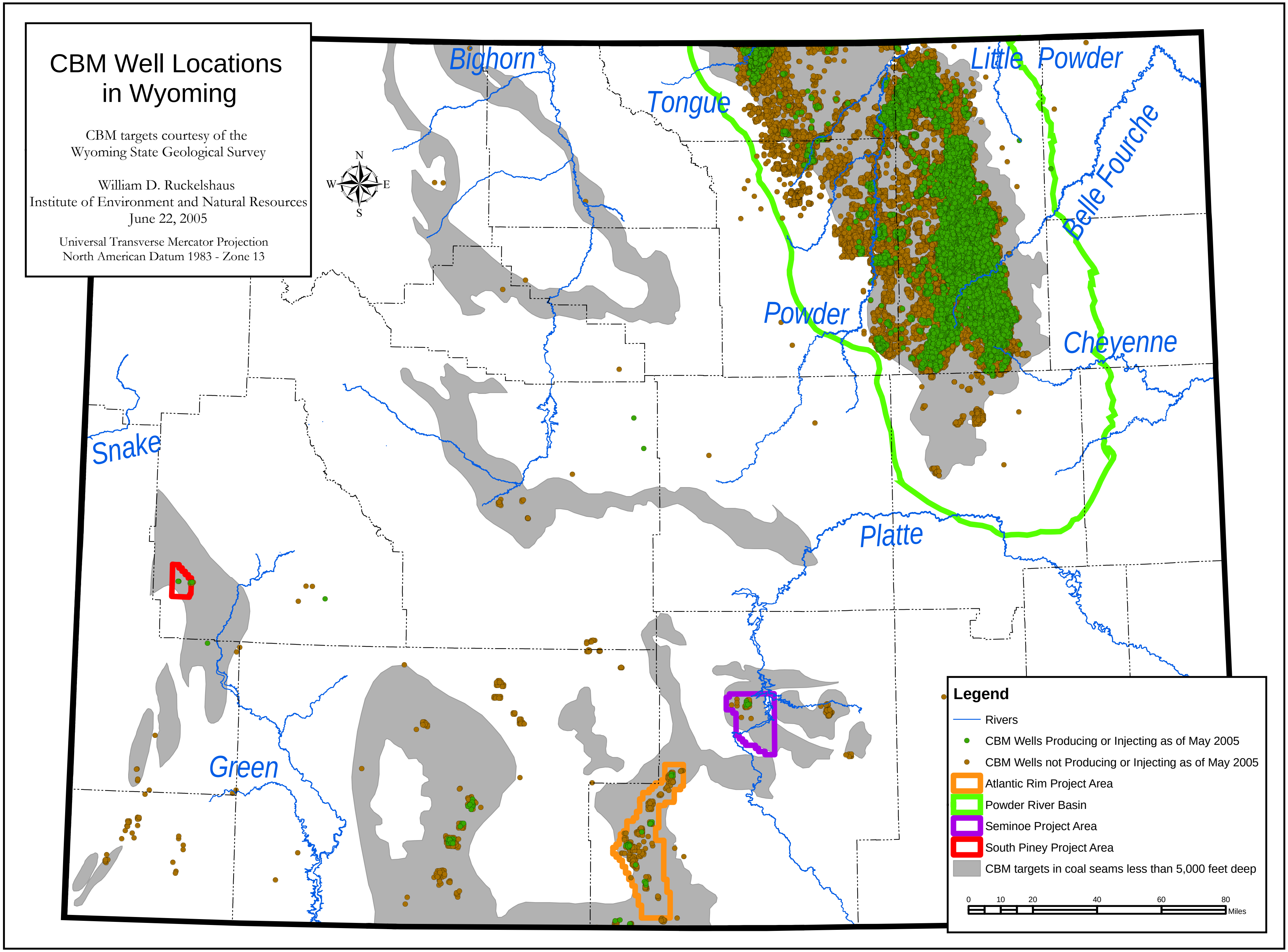

Figure 2. Locations of permitted CBM wells as of December 31, 2004, as associated with various Wyoming coal fields shown as primary CBM targets in coal seams less than 5,000 feet deep (well locations from WOGCC, 2004 and coal fields from De Bruin et al., 2004).

Box 1. Natural gas use, production and value figures.

83 mcf = average annual household use in the U.S. (U.S. DOE, 2004)
22 tcf = total 2003 U.S. natural gas consumption (U.S. DOE, 2004)

348 bcf = total 2003 production of CBM gas in Wyoming (346 bcf from PRB plus 2 bcf from all other CBM producing areas in Wyoming) (WOGCC, 2004)
= 19% of 2003 Wyoming natural gas production
= 1.6% of 2003 U.S. natural gas consumption
= sufficient gas to meet annual needs for 4.2 million U.S. households
= $1.5 billion approximate total value based on $4.40 per mcf, the average 2003 wellhead price (De Bruin, 2004)
= total tax and royalty income of approximately $257 million, with about $140 million to state, $90 million to county, and $27 million to federal governments (De Bruin, 2004)

1.85 tcf = total 2003 natural gas production in Wyoming including both CBM and conventional deep natural gas (WOGCC, 2004)
= 8.4% of 2003 U.S. natural gas consumption

31.7 tcf = estimated total recoverable reserves of CBM natural gas in all Wyoming coal fields (De Bruin et al., 2004)
= 91 years of CBM production at the rate of Wyoming's total 2003 CBM production of 348 bcf
= sufficient natural gas to meet U.S. consumption for 1.44 years at 2003 consumption rates
= $140 billion estimated total value assuming $4.40 per mcf (2003 average price reported by De Bruin, 2004)
= total tax and royalty income of $23.5 billion, with $12.8 billion to state, $8.2 billion to county and $2.5 billion to federal governments, assuming $4.40 per mcf (the 2003 average price) and roughly equivalent distribution of tax and royalty income to state, county and federal governments as occurred with PRB production in 2003

So how much natural gas does this recoverable reserve of 31.7 tcf of CBM gas represent? On the one hand, from the information presented in Box 1, it seems to be a great deal, given that it would take roughly 91 years to produce at Wyoming's 2003 CBM production rate. But on the other hand, because of the high and increasing demand for natural gas in the U.S. for commercial, industrial, electric power production and household use, all of Wyoming's estimated CBM reserves of 31.7 tcf would be enough to supply U.S. needs for less than 1.5 years. And the total Wyoming CBM production of 348 bcf in 2003 was enough to have met the needs of 4.2 million U.S. households on average, but yet was only 1.6% of total U.S. demand in 2003. It is also important to note that 2003 CBM production, which was almost entirely from the PRB, was only about one-fifth of Wyoming's total natural gas production, indicating the prominent importance of conventional, deep gas production from such gas fields as those in southwestern Wyoming.

The economic value of CBM gas depends on the price of natural gas in what has always been a highly volatile natural gas and energy market. Wellhead sale prices depend on many things, including supply and demand, distance to market, pipeline capacity, and "price differentials" between Wyoming's Opal and Cheyenne Pipeline Hubs and that of the Henry Hub in Louisiana (U.S. DOE, 2003; U.S. DOE, 2004). Average wellhead prices in Wyoming have fluctuated from a few dollars per mcf several years ago to a fairly steady range of $4 to $5 and higher per mcf since 2003 (U.S. DOE, 2004). According to De Bruin (2004), the average Wyoming wellhead price in 2003 was about $4.40 per mcf, and this was the basis for his estimated total value of $1.5 billion and $257 million in taxes and royalties for 2003 CBM production from the Powder River Basin, as discussed above. As shown in Box 1, if we assume that the same price and other conditions continue into the future, the total value (in 2003 dollars) of the estimated 31.7 tcf in Wyoming's recoverable CBM reserves would be roughly $140 billion.

WATER QUANTITY

Cumulative Water Production

Since the first CBM wells in the PRB began producing in 1987, through 2004, Wyoming has produced just over 380,000 acre-feet (2.9 billion bbls) of CBM water, while producing roughly 1.5 tcf of CBM gas statewide (Table 2 – also see Box 2 for water volume conversions). Virtually all of this gas and water production (about 99%) from CBM development has been from the PRB coal field, though other coal fields in southern and southwestern Wyoming are still in early stages of development (see Figure 2 for location of permitted CBM wells in association with Wyoming coal fields).

Table 2. Cumulative (1987 through December 2004), annual (2003), and projected total recoverable production of coalbed methane (CBM) gas and associated water production in Wyoming. The Powder River Basin includes the Cheyenne, Belle Fourche, Little Powder, Powder, and Tongue Rivers.

Time period Coal field	CBM gas production (billion cubic feet)	CBM water production (acre-feet)
Cumulative production (1987-Dec., 2004)[a]		
Powder River Basin	1,533	373,649
Other coal fields	8	6,743
Wyoming totals	**1,541**	**380,392**
Annual production (2003)[a]		
Powder River Basin	346	72,920
Other coal fields	2	1,537
Wyoming totals	**348**	**74,457**
Projected recoverable production[b]		
Powder River Basin	25,200	5,684,193
Other coal fields	6,500	1,466,161
Wyoming totals	**31,700**	**7,150,354**

[a] Source: WOGCC (2005) compiled from the WOGCC web site through December 31, 2004.

[b] Projected recoverable CBM is based on De Bruin (2004) and De Bruin et al. (2004), and projected CBM water is based on assumed production of 1.75 bbls of water per mcf of gas (U.S. DOE, 2002).

Box 2. Water volume conversions.
1 Acre-foot (AF)
= 1 acre, 1 ft deep
= 325,851 gallons (gal)
= 7,758 barrels (bbl)
1 Barrel = 42 gallons

The cumulative co-production of water from CBM development in different major watersheds[1] across Wyoming is shown in Figure 3, with greater water production indicated by darker colors on the map. The cumulative CBM water production in each watershed mapped in Figure 3 is also shown graphically in Figure 4a along with cumulative CBM gas production for the same watersheds.

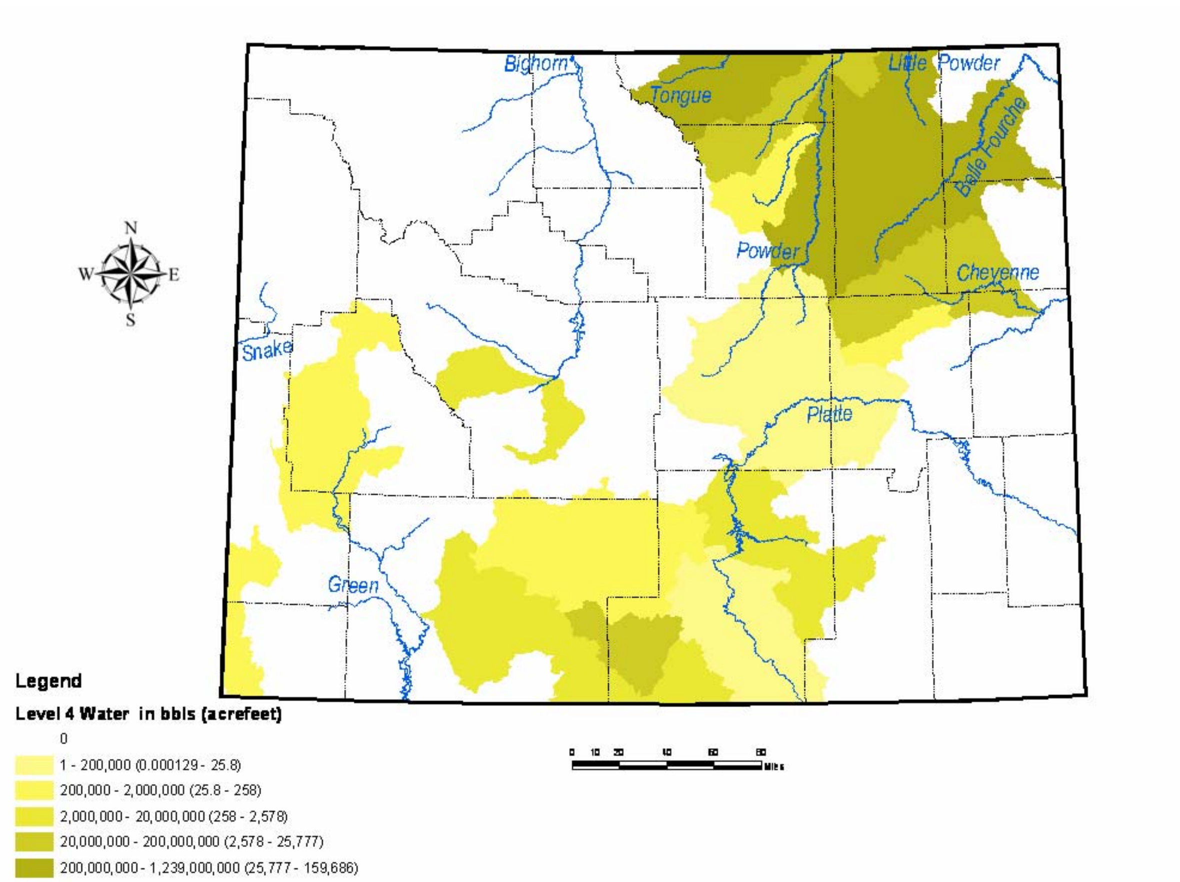

Figure 3. Cumulative co-produced CBM water (bbls and acre-feet) from 1987 through December, 2004 within major Wyoming watersheds (compiled from WOGCC, 2005).

Cumulative CBM water and gas production shown in Figure 4a, studied in conjunction with Table 2 and the watershed map in Figure 3, allow one to draw several key impressions about cumulative gas and water production.

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[1] Well data were compiled within Level 4 watersheds, which are associated with 4th order streams, where the Mississippi River is a 1st order stream and major main-branch tributaries of the Mississippi are 2nd order streams.

- Water and gas production from CBM development in the PRB constitutes about 98 to 99% of total Wyoming production through 2004 (for instance, 374 thousand acre-feet of water for the PRB compared to less than 8 thousand acre-feet for all the other non-PRB coal basins combined; Table 2).
- In the PRB, the biggest producer of both gas and water, by far, has been the Upper Belle Fourche watershed (over 700 bcf of gas and over 156 thousand acre-feet of water), followed in succession by the Upper Powder, the Little Powder, the Upper Tongue, the Upper Cheyenne and then all the other PRB and non-PRB watersheds (note the heights of the water and gas bars shown in Figure 4a and the darker shading on the map in Figure 3).
- In the other coal fields outside of the PRB (Table 2 and Figure 4a), CBM wells are producing proportionally more water than gas so far, as compared to the PRB coal field. In the PRB, 1.9 bbls of water have been produced per mcf of gas (2.9 billion bbls of water [374 thousand acre-feet] divided by 1.5 billion mcf of gas; Table 2). In all of the non-PRB coal fields combined, 6.8 bbls of water have been produced for every mcf of gas (Table 2). These non-PRB wells are associated with projects that are in an earlier stage of development than the PRB field, and as noted by De Bruin et al. (2004) based on experience in the PRB coal field, water production tends to decline in most wells over time. Alternatively, though, the water production per mcf of gas could possibly be higher in the southern and southwestern coal fields than has been the experience in the PRB.

So if Wyoming has produced just under 374 thousand acre-feet of CBM water so far (Table 2), how much water is that? Box 3 provides several examples of water storage volumes in Wyoming reservoirs to help understand how much water CBM development in Wyoming has produced so far. As examples, the CBM water produced since CBM production began in 1987 would be enough to fill Lake DeSmet 1.5 times, fill Glendo Reservoir over two-thirds full, or fill Buffalo Bill Reservoir just over half full.

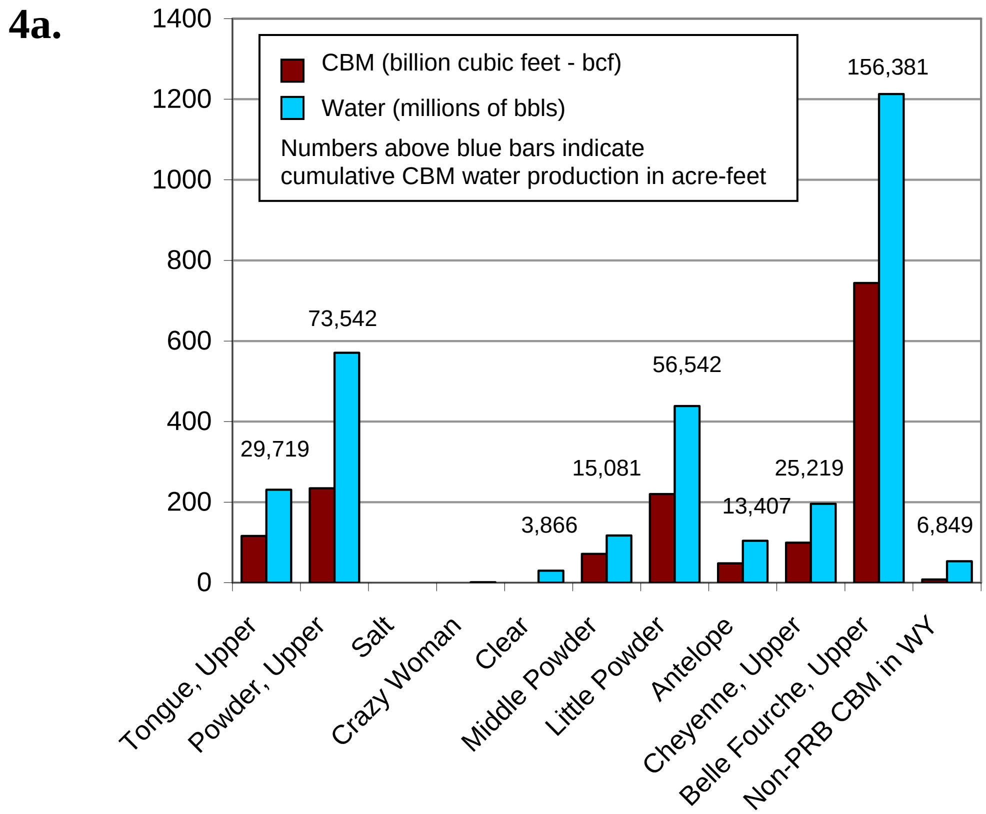
Box 3. Water storage and discharge volumes for selected Wyoming reservoirs.

Lake DeSmet Storage = 239,000 acre feet

Glendo Reservoir Storage = 517,000 acre feet

Buffalo Bill Reservoir Storage = 695,000 acre feet

Guernsey Dam Discharge = 1,154,050 acre feet/year



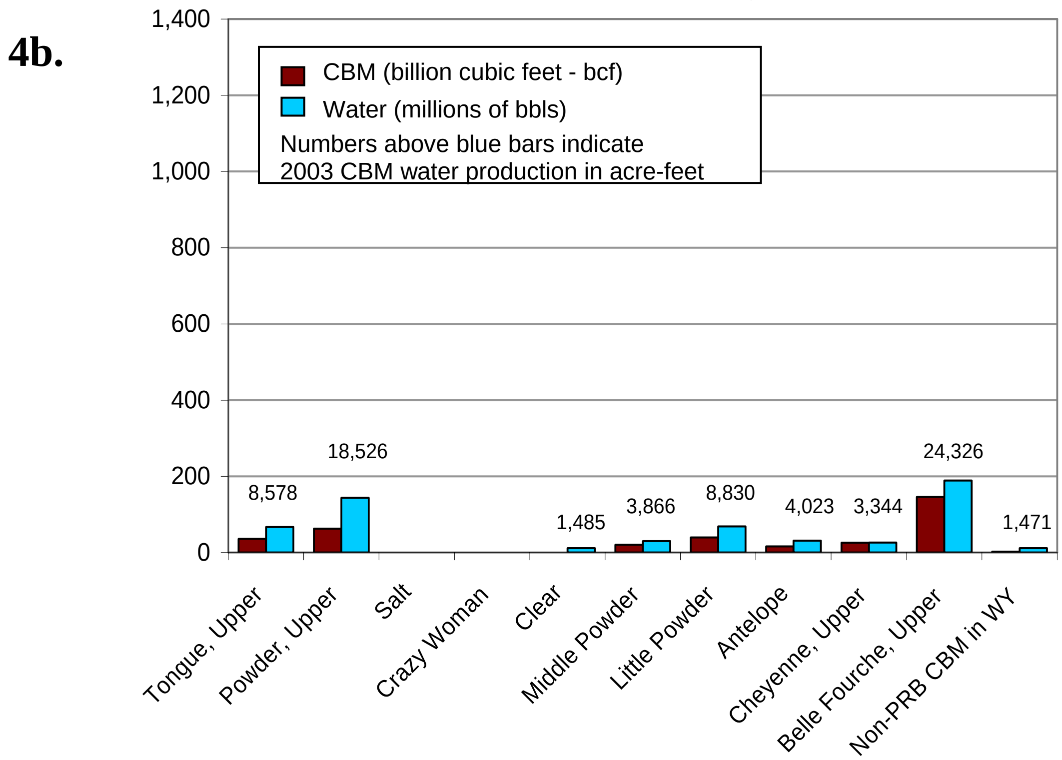


Figure 4. CBM gas and water production from major watersheds in the PRB and from all other non-PRB watersheds combined for the time periods: (a) Cumulative (1987-December, 2004), and (b) 2003 (data compiled from WOGCC, 2005).

Annual Water Production

In 2003, Wyoming's CBM industry produced just over 74 thousand acre-feet (578 million bbls) of water in recovering 348 bcf of CBM gas from coal fields throughout the state (Table 2). The PRB continued in 2003 to dominate in production of CBM water and gas with almost 73 thousand acre-feet of water (566 million bbls) (98% of state totals) and 346 bcf of gas (99% of state totals). The presentation of 2003 gas and water production from PRB and other non-PRB watersheds in Figure 4b shows the continued domination of PRB production, with the Upper Belle Fourche, Upper Powder, Little Powder and Upper Tongue watersheds (in that order) again dominating PRB gas and water production.

The growth of annual CBM production in the PRB from 1989 through 2004 was shown earlier in Figure 1, along with forecasts from the Wyoming State Geological Survey (WSGS) for growth of annual CBM production from the PRB through 2010. As noted earlier, CBM production in the PRB fell off about 5% from 2003 to 2004 (from 346 to 328 bcf), and attendant CBM water production fell off as well from 2003 to 2004 (from 73 thousand to 68 thousand acre-feet) (De Bruin, 2005). De Bruin (2005) also forecasts a further small decline in annual PRB CBM production in 2005, followed by a return of annual production growth to about 510 bcf in 2010.

Given the unexpected decline in annual PRB gas and water production in 2004, and given the likely reasons for this decline discussed earlier (including problems with water management and disposal), forecasts of future CBM gas and water production must be considered uncertain at best. Nonetheless, the recent WSGS forecast presented in Figure 1 (De Bruin, 2005), for increasing annual CBM production in the PRB to just over 500 bcf in 2010, is lower than earlier forecasts published by De Bruin et al. (2004) that estimated annual CBM production growth to about 610 bcf in 2010. These estimates by De Bruin et al. (2004) and De Bruin (2005) assume 1,250 additional producing wells each year. As De Bruin et al. also note, more than 1,250 wells will need to be drilled each year to maintain the growth of producing well numbers and gas production to make up for the production decline anticipated from older wells.

Though the WSGS forecasts do not include projections for water production, we can estimate PRB water production increases from the newer WSGS CBM forecasts (De Bruin (2005) and an assumed ratio of 1.75 bbls of water for every mcf of gas produced (U.S. DOE, 2002). So, based on these and other assumptions, such as continued use of the same well completion and gas production methods as have been used in the past, we can estimate the following for the PRB:

- In 2010 the projected annual CBM water production in the PRB would be roughly 41 thousand acre-feet more than the 68 thousand acre-feet produced in 2004, which would be an estimated annual water production rate of about 109 thousand acre-feet in the PRB alone.

These estimates of 2010 CBM water production in the PRB do not include production from other Wyoming coal fields outside the PRB. Moreover, the PRB estimates could be substantially underestimated or overestimated, for several reasons. They may be underestimated because, as CBM production in the PRB moves into other coal seams and greater coal depths, water production may, in fact, increase beyond that predicted above. The principal issue here is that, as the very thick and deeper "Big George" coals in the Powder River drainage are further developed, there is a possibility that water and gas production per well may increase substantially, or that the ratio of water to gas production may be higher than the assumed 1.75 bbls of water per mcf of gas. In sampling the WOGCC (2004) web site for water and gas production from the relatively new wells in the Big George coals, it appeared at the end of 2004 that many wells were still producing mainly water with little or no gas. In any case, several years of CBM production in the Big George coals may be needed before better water and gas production estimates can be made.

Projections of annual water production for the PRB in 2010 also could be greatly overestimated. For instance, this could be the case if promising new and emerging technologies for CBM well completion or well-field management were to work out and be adopted broadly in the PRB and other coal fields. These new and emerging technologies for well completion and management show some promise for reducing the volume of water per unit of gas production. More about these technologies can be found later in this report's Water Management section.

Projected Total Water Production

Production of CBM water across all Wyoming coal fields could total roughly 7 million acre-feet if all of the recoverable CBM gas in the projected reserves of 31.7 tcf were, in fact, produced over the coming decades (Table 2 and Figure 5). Of these statewide amounts, about 380 thousand acre-feet of water and roughly 1.5 tcf of gas had already been produced through December 2004, leaving approximately 95% of the CBM gas reserves and 95% of the associated water for potential future production.

Of course, the PRB, with the largest share of Wyoming's estimated CBM producible reserves (25.2 tcf or 79% of Wyoming's estimated reserves), would continue to be the area with the greatest gas and water production in the future. (See Figure 5 for distribution of producible CBM gas reserves and possible water production in different Wyoming coal fields.) Since just over 1.5 tcf of CBM gas and just over 374 thousand acre-feet of water had already been produced from the PRB through December 2004, roughly 94% of CBM gas and CBM water remained for potential production at the end of 2004.

As discussed above in the section on Annual Water Production, the above estimates of projected total water production statewide and in the PRB may be underestimated or overestimated. Since there has been so little industry and agency experience so far with production from the Big George coals of the PRB or, for that matter, with all the remaining coal fields outside of the PRB, too little is known to hazard a guess about the level of uncertainty that should be attached to projections of future annual or total water production from the PRB and other Wyoming coal fields. Moreover, changes in future industry practice or agency regulatory policy could markedly reduce the volume of water production per mcf of CBM gas produced. And dramatic increases or decreases in the wellhead sale price of gas could affect the year-to-year economics of continuing CBM development, thereby influencing the rate of gas and water production and possibly, even, the final full extent of CBM development.

In any case, if we assume that the total water production estimates presented in Table 2 and discussed above are at least "in the ballpark," it is worth considering just how much water that is. If we compare the 7 million acre-feet of projected CBM water production statewide (Table 2) to Wyoming water use and water storage figures in Box 3, the statewide CBM water production from complete development of all CBM reserves would be sufficient to:

- fill Lake DeSmet about 30 times or Glendo Reservoir about 14 times; or
- equal over 6 years of average annual discharge from Guernsey Reservoir.

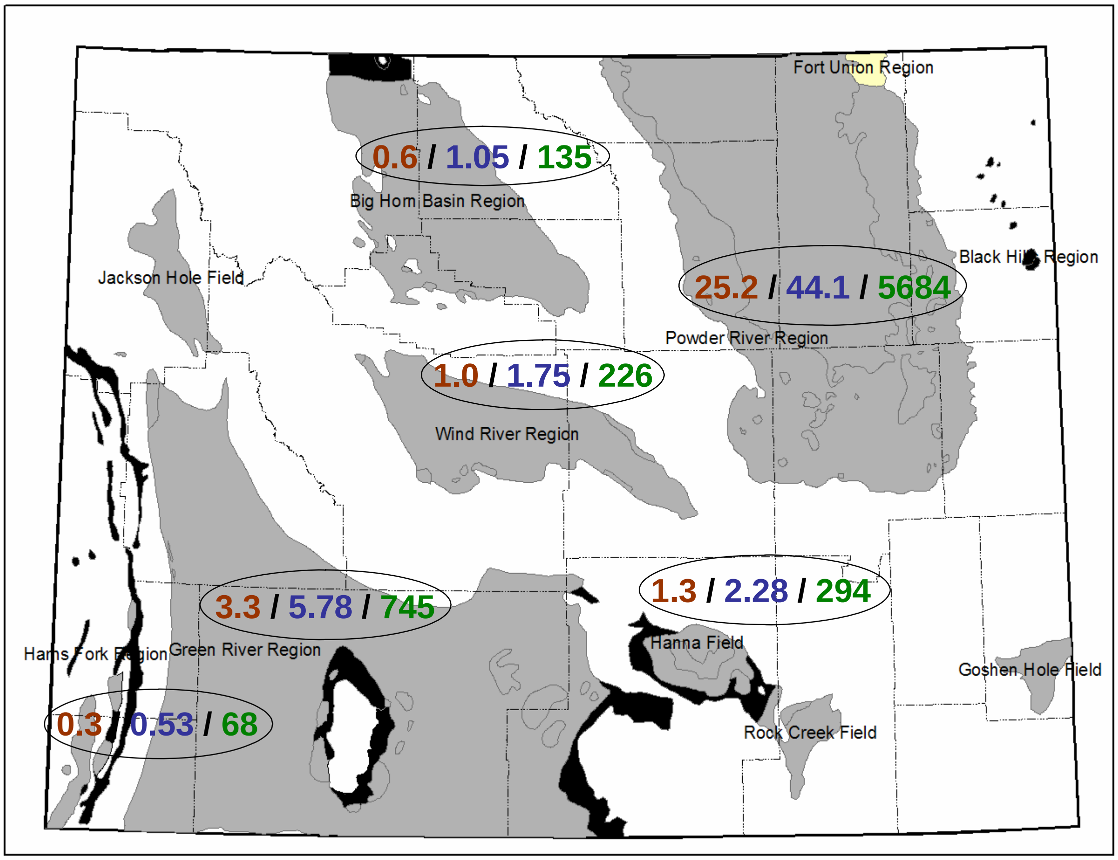


Figure 5. Projected recoverable CBM gas production in various Wyoming coal fields (red numerals in tcf) and expected CBM water production associated with the same coal fields (blue numerals in billion bbls, green numerals in thousands of acre-feet). Recoverable CBM gas production estimates are from WSGS (De Bruin, 2004 and De Bruin et al., 2004) and projected co-produced CBM water volumes are based on assumed production of 1.75 bbls of water per mcf of gas. Black areas indicate bituminous coal, grey areas indicate subbituminous coal, and the yellow area is lignite coal (map modified from De Bruin, 2004).

Given that more than 7 million acre-feet of CBM water could be produced to recover Wyoming's remaining producible CBM gas, given that water is a precious resource in arid Wyoming, and given that roughly 95% of Wyoming's producible CBM reserves remained to be produced at the end of 2004, some have argued that perhaps it is worth considering alternatives to discharging CBM water, to seek ways to manage CBM water differently (at least in some drainage basins), and possibly use and/or save this CBM water resource for the future. On the other hand, others argue that only 5 % or less of the water in coal aquifers is normally produced to stimulate CBM gas production, leaving about 95 % of the original aquifer water volume in place.

WATER QUALITY

The quality of CBM water in Wyoming varies from coal seam to coal seam, watershed to watershed, and within watersheds. In general, though, CBM water quality is better in the Powder River Basin than the CBM water from other coal fields in Wyoming and elsewhere in the west. And in the PRB, water quality is best where CBM development began in the southern and eastern edges of the basin where the coal seams are shallower. As the CBM play moved into deeper coals toward the north and the west in the PRB, the quality of CBM water decreased, resulting in difficulties for discharge or use of the water without treatment or special handling.

The water quality parameters of greatest concern related to this CBM water include total dissolved solids (TDS), or electrical conductivity (EC) and sodium adsorption ratio (SAR). These parameters are all related primarily to the inorganic salt content of the water and the particular chemicals that make up that salt content.

In one series of studies on the quality of CBM water, K. J. Reddy and his students at the University of Wyoming have analyzed CBM well water and CBM disposal pond water in all the major river drainages developed so far in the PRB (Reddy, 2004; Patz et al., 2004; McBeth et al., 2003). A graphical summary of their data for TDS, EC and SAR of CBM well water in the PRB is included in Figures 6, 7 and 8. By inspecting their results in Figures 6, 7 and 8 (along with Figures 2 and 3 for locations of river basins) and by noting the water quality standards for TDS and tolerance levels for EC and SAR included in the figures, several conclusions can be drawn:

- Water quality generally declines in CBM well water when moving from the Cheyenne River drainage northwestward to the Belle Fourche, Little Powder, and Powder River drainages.
- CBM well water from the Tongue River drainage represents a break in this trend in that TDS and EC levels improve relative to the Powder River drainage, but the SAR levels in the Tongue River CBM well samples are higher than the SAR levels in wells from the other watersheds.
- CBM well waters from the Cheyenne and Belle Fourche River drainages are of relatively high quality, with TDS, EC and SAR levels all within or close to the limits for human drinking water (500 mg/L TDS) and for any water uses for irrigation (EC 1200 µs/cm for sensitive plants, and SAR 8 to 20 depending on soil type).
- CBM well waters from the Little Powder, Powder and Tongue River drainages have tested above one or more water quality standards or threshold criteria for TDS (human drinking water [500 mg/L] or stock water [2000 mg/L] standards), EC (irrigation of sensitive plants), and SAR (irrigation water suitability).
- Water quality tends to decrease somewhat in retention ponds associated with and receiving the CBM well water represented in Figures 6, 7 and 8 in all but the Cheyenne River drainage. Moreover, in a related study by Reddy and colleagues (Reddy, 2004), they reported increased trace elements (arsenic and selenium) in retention/disposal ponds and stream channels, apparently concentrating these elements above that measured in the original CBM well water.

These findings are in general agreement with others, including Rice et al. (2000) who examined water samples from 47 CBM wells in the PRB and found EC values ranging from 470 to 3020 µs/cm and SAR values from 5.7 to 32. Also, Bartos and Ogle (2002) tested water from

13 monitoring wells in coalbed aquifers or CBM wells in the PRB and found EC values ranging from 665 to 4180 µs/cm, TDS values from 382 to 2720 mg/L, and SAR values from 6 to 26.

One possible emerging issue about PRB CBM water quality relates to ongoing efforts to tap the potentially huge CBM gas resource in the very thick "Big George" coals in the Powder River drainage. Mean values for 5 Big George wells sampled between August, 2002 and November, 2004 were as follows: sodium adsorption ratio (SAR) = 35; electrical conductivity (EC) = 3,420 µs/cm; total dissolved solids (TDS) = 2,210 mg/L (George, 2005a). These samples from CBM wells in the Big George coals suggest that CBM water is generally of lower quality than other PRB CBM water studied by Reddy (2004) (see Box 4 for comparisons).

Very little data are available on water quality for new CBM development areas outside the PRB in southern and southwestern Wyoming. But the small amount of information available so far suggests that the quality of CBM water in at least some of these fields will be substantially lower than has been the case in the PRB. The draft Resource Management Plan (RMP) (U.S. BLM, 2004) for the Rawlins Field Office notes that CBM water from several proposed projects may have TDS concentrations more than 10,000 mg/L, two to six times higher than the TDS levels in the PRB.

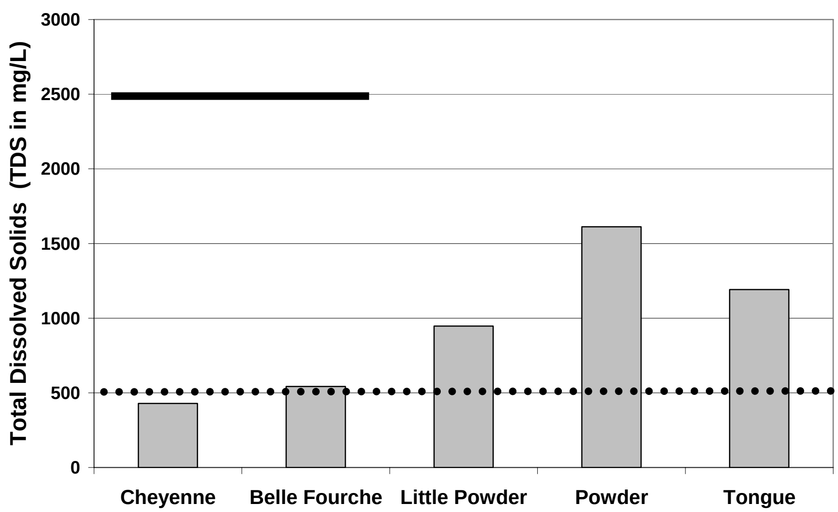


Figure 6. Total dissolved solids (TDS) concentrations (mg/L = parts per million) for Power River Basin CBM well water within major watersheds (modified from Reddy, 2004). EPA secondary standard for drinking water shown as a dotted line at 500 mg/L. South Dakota monthly average limit for the Cheyenne and Belle Fourche Rivers shown as heavy solid line at 2500 mg/L (South Dakota, 2005). South Dakota limits are applied at the state line but the water samples reported by Reddy (2004) were collected from CBM wells at upstream locations and do not account for downstream dilution or concentration effects.

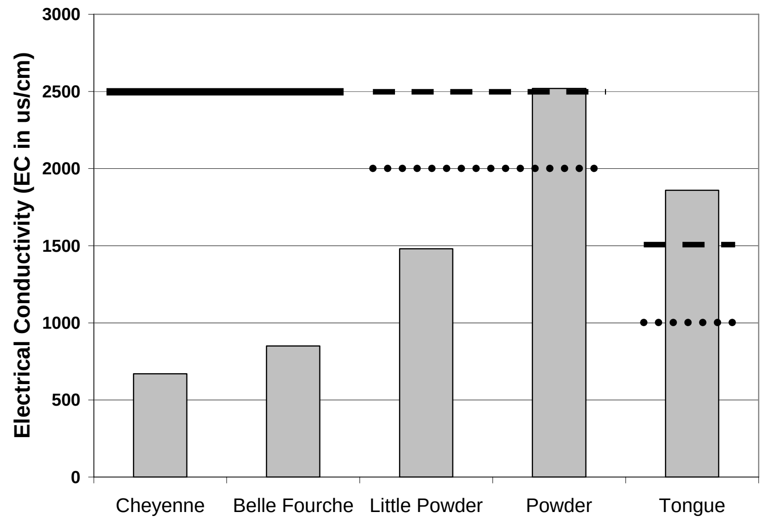


Figure 7. Electrical conductivity (EC in microSiemens/centimeter [µs/cm = µmhos/cm] for PRB CBM well water within major watersheds (modified from Reddy, 2004). Dashed lines (November 1 through March 1) and dotted lines (March 2 through October 31) indicate Montana monthly average limits for the Little Powder, Powder, and Tongue Rivers (Montana, 2003). Heavy solid line indicates South Dakota monthly average limits for the Cheyenne and Belle Fourche Rivers (South Dakota, 2005). These limits are applied at state lines but the water samples reported by Reddy (2004) were collected from CBM wells at upstream locations and do not account for downstream dilution or concentration effects.

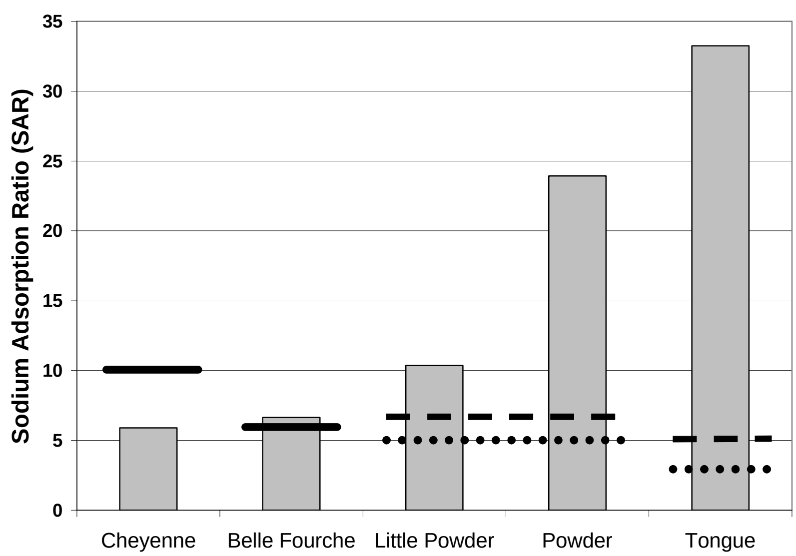


Figure 8. Sodium adsorption ratios for Powder River Basin CBM well waters within major watersheds (modified from Reddy, 2004). Dashed lines (November 1 through March 1) and dotted lines (March 2 through October 31) indicate Montana monthly average limits for the Little Powder, Powder, and Tongue Rivers (Montana, 2003). Heavy solid line indicates South Dakota monthly average limits for the Cheyenne and Belle Fourche Rivers (South Dakota, 2005). These limits are applied at state lines but the water samples reported by Reddy (2004) were collected from CBM wells at upstream locations and do not account for downstream dilution or concentration effects.

To gain some perspective about how these water quality measurements for TDS and EC in CBM waters can affect possible disposal or use options, we have included water quality standards or threshold criteria for these parameters in Box 4. High TDS levels can adversely affect the use of water for drinking, with standards set at 500 mg/L for humans and 2000 mg/L for livestock. But possibly the most talked about water quality issue with CBM discharge and use in Wyoming as well as downstream in Montana has been about SAR and potential effects of high SAR water on irrigated croplands, though SAR, salinity (EC or TDS) and soil type are really inter-related in how irrigation water can affect soil permeability and plant growth (Hanson et al., 1993). The recommended limits for SAR levels for sensitive as well as tolerant plant-soil combinations range from 2 for high clay soils, to 8 for any soil type.

CBM water may be of good quality at the wellhead but this quality can degrade when water picks up additional solids or salts after discharge to a streambed or storage in a reservoir designed to allow water to seep out through the soils. A key water quality issue, not yet fully assessed, is the cumulative effect of numerous CBM water discharges on the overall water quality of basin streams. Another issue is that grass in ephemeral draws is important forage for livestock and wildlife and where CBM water is of poor quality, overflow or seepage from ponds or reservoirs can damage plants and soils in these grazing areas.

Components that will determine success or failure of irrigation in agriculture include water quality, water quantity and timing, the water delivery system, management skills of the irrigator, climate, soil type, and plant type. Relative to CBM development, the state can only exercise control of the water components through the permitting process. Quality of water allowed to be released at the surface therefore needs to be carefully controlled to minimize or prevent negative impacts to agriculture. Alfalfa is the most salt sensitive crop commonly grown in the Powder River Basin and water with EC above 1200 µs/cm could damage alfalfa. This limit (water EC of 1200 µs/cm) is the threshold limit for yield decline in alfalfa (Keren, 2000; Hanson et al., 1993). Applying water to soil will, over several years, typically result in the soil root zone acquiring an EC value that is 1.2 to 2 times higher than the water (Keren, 2000; Hanson et al., 1993).

In recognition that the main problem with sodium (i.e., SAR) in Powder River Basin soil-plant systems is its damaging effect on soil physical condition and particularly on infiltration rate, water released to channels or stored in on-channel reservoirs should be restricted to SAR of 10 or less according to Levy (2000). There may still be problems with meeting these water quality criteria if CBM water is allowed to flow continuously in formerly ephemeral channels and sub-irrigation occurs into areas of fields along the channel. Also, flooding from normal spring snowmelt and storm runoff will be greater in channel systems where CBM water additions have converted intermittent drainages to year-around or long-term continuous flow. On-channel reservoirs may be expected to overflow during spring snowmelt-rainfall events and this will mix salt in CBM water into the normal runoff flows.

Where CBM water is stored in off-channel reservoirs and applied to upland surfaces to support plant growth as a disposal strategy, higher limits of water EC and SAR may be tolerated, but reclamation of dry saline and high sodium soils is difficult even when good quality irrigation water is available and sub-surface drainage is adequate. Land application water disposal sites will require long-term reclamation efforts, so these lands may need to be bonded to guarantee that resources will be available for long-term site stabilization. Re-vegetation of the original plant community with more salt tolerant plants that provide surface protection may be the best rehabilitation possible for many sites where only natural precipitation will be available after CBM water production stops. This may imply a long-term reduction in productivity.

In large part because of these kinds of concerns in the use of high SAR waters for downstream irrigation, one of the most contentious issues early in the development of CBM in Wyoming's PRB was a concern from Montana about the potential effects of water quality degradation on rivers flowing north into Montana. Water quality degradation could potentially affect downstream water uses for agriculture but might also affect Montana's ability to develop its own CBM resources in the northern arm of the PRB. Monthly average limits for TDS, EC and SAR for Montana and South Dakota are shown in Figures 6, 7 and 8.

Further understanding about the relative quality of Wyoming's CBM water compared to various standards as well as other water bodies can be gained by inspecting the water quality comparisons shown in Box 4. Note, again, that the quality of Wyoming's CBM water is sometimes good (Cheyenne River Basin wells) and sometimes not-so-good (CBM wells in the Powder River Basin and particularly the Big George coal seam in the Powder River drainage), depending on the coal seam, coal depth, and the watershed.

Box 4. Water quality comparison values for total dissolved solids (TDS) and electrical conductivity (EC) in Powder River Basin and other comparator waters and limits (CBM-related PRB values in bold and standards or threshold limits in italic type).

Water Body or Limit	TDS (mg/L)	EC (µS/cm)
Lake Superior	63	97
Lake Tahoe	64	92
Cheyenne R. basin CBM well water	**429**	**670**
EPA standard for human drinking water	*500*	---
Belle Fourche R. basin CBM well water	**542**	**850**
Lake Mead	640	850
Montana Tongue R. std (summer monthly ave.)	**---**	*1,000*
Maximum for irrigation of sensitive plants	**---**	*1,200*
Little Powder R. basin CBM well water	**947**	**1,480**
Montana Tongue R. std (winter monthly ave.)	---	*1,500*
Tongue R. basin CBM well water	**1,190**	**1,860**
EPA standard for livestock water	*2,000*	---
Montana Powder R. std (summer monthly ave.)	---	*2,000*
Montana Powder R. std (winter monthly ave.)	---	*2,500*
South Dakota standards (monthly ave.)	*2,500*	*2,500*
Powder R. basin CBM well water	**1,612**	**2,520**
Big George coal seam CBM well water	**2,070-2,480**	**3,230-3,810**
San Juan Basin, Colorado CBM well water	15,000	**---**
Atlantic Ocean	35,000	43,000
Great Salt Lake	230.000	158.000

WATER MANAGEMENT, DISPOSAL, TREATMENT AND USE

Introduction

CBM water can and does provide enormous benefits for some landowners, local communities or ecosystems, and additional uses of CBM water could provide operators with flexible, cost-saving water management options. It is important to note, however, that the quality and possible uses of CBM water will vary from coal seam to coal seam, from basin to basin, and within a particular basin. In addition to water quality, applicable regulations and costs dictate potential uses and management options for CBM water. In some cases poor quality water will require treatment before disposal or use. In most regions of the West, poor quality water from oil and gas production traditionally has been injected into deep wells to prevent environmental impacts to the surface. Advances in CBM well completion technology also are making it possible to maintain desired gas production while reducing the volume of CBM water, and new treatment technologies are becoming more attractive for operators dealing with poor quality water (ALL Consulting, 2003).

In the eastern part of the PRB where CBM water is generally of good quality, most of it is discharged to surface drainages or to soil (irrigation). In the western part of the PRB, most CBM water goes to impoundments (evaporation/infiltration ponds or reservoirs). Other management options currently in use include livestock watering ponds, injection, atomization, and treatment by reverse osmosis and ion exchange. Numerous additional beneficial uses have been or could be employed including wildlife, commercial (including enhanced oil recovery), industrial, and domestic or municipal water supplies. The economic feasibility of different options depends on produced water quality, availability of cost-effective treatments, and location of the gas wells. Table 3 summarizes the use, benefits, environmental consequences, and costs, where known, of water management methods currently being used for CBM water. Additional information, including figures showing the various treatment options can be found in Hulme (2005).

An important emerging water management issue relates to the increased numbers of ponds and reservoirs containing CBM water and their potential as breeding grounds for mosquitoes carrying West Nile virus. This poses major concerns for human health as well as wildlife, because sage grouse are particularly susceptible to the West Nile virus. This issue has caused regulators and industry to reconsider the use of man-made storage ponds as a CBM water management option.

Other wildlife and native plant issues include the possible impacts of CBM water quality and quantity on prairie stream ecosystems due to changes in the flow regime, increased sodium content, and additions of water with different temperature or sediment load than the natural waters.

Table 3. Summary of common water management methods used for CBM water. Costs are summarized from Goerold (2002) and U.S. DOE (2002) unless otherwise noted.

Option	Current use estimates	Benefits	Adverse environmental issues	Costs *(in PRB)*/ Comments
Surface discharge direct to surface drainages or land application (irrigation)	• Most CBM water in the eastern PRB is discharged to surface drainages or soils	• Increased stream flow • Increased riparian habitat • Supplemental irrigation water • Water for livestock or wildlife	• Streambank erosion • Increased flow at water crossings • Riparian erosion or change in vegetation • Salt deposition • Adverse effects on established irrigation; e.g. creation of hardpan soil • Can dilute naturally turbid waters impacting native aquatic species	Average for PRB: • $1,400/well capital cost • $0.02/bbl operation & maintenance cost
Managed irrigation with amendments	• According to industry sources, more than 50 systems are in place in the PRB	• New areas brought under irrigation • Increased native perennial grass production (sites < 5 yrs old) (King et al., 2005)	• Sodium build-up in plant root zone (Ganjegunte et al., 2005) • Plant diversity reduced (King et al., 2005) • Water source is temporary	• $0.06 to $0.11/bbl for a 100-acre system (Paetz and Maloney, 2002)
Impoundments Off channel (can be lined or unlined)	• Most CBM water in the western PRB goes to impoundments • 121 bonded & permitted by WOGCC as of 8/04	• Stock water • Surface aquifer recharge • Wildlife habitat • Wetlands • Recreation • Fisheries	• Mobilization of salts and other elements by infiltration from unlined pits • Possible water table degradation from unlined pits • Evaporation increases water salinity (lined pits) • Water source is temporary • Increased mosquito habitat brings West Nile virus concerns	Average for PRB: • ~$10,000-$19,000 per impoundment (unlined) capital cost • $0.06/bbl operation & maintenance costs

Option	Current use estimates	Benefits	Adverse environmental issues	Costs *(in PRB)*/ Comments
On channel	• Approx 1,629 permitted as of 12/04 by SEO (Feltner, 2004) • 2,682 permitted by SEO as of 5/05 (LaBonde, 2005)	• Same as above for unlined pits	• Same as above for unlined pits, plus captures flow from natural runoff • Potentially blocks natural flow from storm and snowmelt runoff (though newer ponds now require by-pass)	• Cost estimate not available at this time, but likely similar to unlined off channel costs
Injection Class V DEQ permits (injection to coal or non-coal aquifer for re-use)	• 308 wells statewide (most in PRB) permitted by DEQ with 60 actively reporting (Frederick, 2005) • Gillette drinking water aquifer	• Aquifer recharge • Aquifer storage for recovery and re-use • Avoids environmental impacts of surface discharge	• Water not immediately available for additional beneficial surface uses (e.g., stock and wildlife watering) • Requires additional surface disturbance for new injection well sites and storage ponds	• ~$6,300-$15,000/injection well capital costs, depending on depth • $0.045-$0.098/bbl operation & maintenance costs
Class II WOGCC permits (deep well injection, including disposal and/or water flood enhanced oil recovery (EOR))	• Approx 5,000 permits statewide, including conventional oil and gas and CBM (Marvel, 2005) • 4 injection wells permitted for EOR	• Avoids environmental impacts of surface discharge • Provides a water source for EOR	• Potential for migration and contamination of other aquifers if well is improperly completed • Requires additional surface disturbance for new injection well sites and storage ponds	• ~$35,000-$63,000/injection well capital costs presumably for rework of existing oil & gas well to injection well • Up to > $1 million for new installation of deep disposal well (George, 2005b) • $0.095-$0.14/barrel for deep injection and $0.24/barrel for trucking

Option	Current use estimates	Benefits	Adverse environmental issues	Costs *(in PRB)*/ Comments
Treatment Reverse osmosis	• Pilot project on Tongue River • Full operation on Prairie Dog Creek • Permit pending on Crazy Woman Creek (Thomas, 2004)	• Treatment results in high quality water for re-use	• Finding waste brine disposal locations • High cost for brine disposal • Energy-intensive process	• ~$450,000-$1 million capital costs w/commercial brine disposal • ~$744,000-$1.3 million w/brine injection • $0.19-$0.73 net present value cost/bbl w/commercial brine disposal • $0.26-$0.34 net present value cost/bbl w/brine injection (Kuipers, 2004; CDM, 2004)
Ion Exchange (IX) • w/Higgins Loop • Counter-current (CC) • Hydro process • Zeolites (Z)	• IX w/Higgins loop permitted by WYPDES for 20 cfs operation on the Powder R. (Wagner, 2004) • CC IX used in several locations in PRB • Hydro IX and Z not in use yet	• IX systems remove cations and bicarbonate • Approximately >90% water recovery	• Brine disposal requires a Class I injection permit • Warm, non-turbid effluent water may affect Powder R. fish • IX will not remove unwanted anions • Waste brine can be acidic requiring neutralization prior to disposal • Brine disposal costs	• IX w/Higgins loop = $0.10 to $0.30/bbl (Beagle, 2005) • CC = $0.35/bbl net present value cost • Hydro = $0.63/bbl net present value cost (CDM, 2004)
Deionization or capacitive desalination	• Plans for desalination unit for WY, no permit as yet (Thomas, 2004)	• Does not require acid/base regeneration of exchanger	• Energy intensive process • Location and costs for brine disposal • Warm temp, non-turbid effluent water may affect Powder R. fish	• Costly process • Not suitable for CBM water greater than 2,500 mg/L TDS
Atomization (water droplets are dispersed under pressure through a nozzle atop a tower)	• Used some in the PRB	• Reduced water volume	• Ice can form below atomizer • Concentrates contaminants on soil • Water is wasted • Plume wind drift causes salt deposition in areas not intended for disposal	• Less costly than other treatment options

Surface Discharge

Direct discharge to perennial or intermittent streambeds

The design used for discharge to surface drainages requires site-specific characterization of the following (ALL Consulting, 2003):

- quality and quantity of CBM water;
- quality and flow of existing stream water (including DEQ stream classification);
- stream channel vulnerability to erosion;
- water crossings (bridges and culverts);
- channel soil chemistry;
- changes to biota along the drainage;
- consideration of downstream landowners; and
- existing irrigation.

Direct discharge to surface water channels is a common and economical practice for disposing of CBM water in Wyoming's Powder River Basin (EPA, 2003a). Equipment costs include pipelines to transport the water to the discharge point. Filtering, treatment, and characterization of effluent flow and quality may be required by the permitting agency.

Discharge to surface soils

Irrigation is used to manage disposal of CBM water through evaporation, plant uptake, and infiltration into the soil. Water quality, existing land uses, landowner plans for use, soil type, vegetative cover, and other factors all affect the land's ability to accept CBM water. With managed irrigation systems, amendments such as gypsum or sulfur are added to the soil or in the water to mitigate the effects of CBM water on vegetation and soils (DeJoia, 2002). Studies of several managed irrigation sites in the PRB with less than 5 years of CBM water application have revealed increased forage production of native perennial grasses while overall species diversity of native plants decreased (King et al., 2005), decreased surface infiltration rates (King et al., 2005), and a build-up of salts in the plant root zone and deeper in some soils (Ganjegunte et al., 2005).

Depending on local conditions, some portion of the discharged water may eventually reach existing surface water (ALL Consulting, 2003). Erosion control measures also may be needed. Costs associated with erosion control, such as filling in eroded channels and gullies, reclaiming salty soils, and re-vegetation, may be incurred during production and postproduction periods (ALL Consulting, 2003).

Off- and On-Channel Impoundments

In some basins, such as the PRB, impoundments play a large role while in other basins impoundments only may be used during drilling operations. Storage ponds in the PRB are designed to contain CBM water without discharge to surface drainages.

Off-channel impoundments can be lined or unlined and usually are constructed away from natural streams and coulees. Berms are used to prevent surface runoff from entering the ponds (ALL Consulting, 2003). With unlined impoundments there must be reasonable assurance that no direct subsurface hydrologic connection exists between produced water pits and surface waters before a permit is issued. Discharge of CBM water to unlined containment structures may adversely affect the water quality in shallow aquifers and/or nearby surface streams if the infiltrated water reemerges down-gradient.

On-channel impoundments are constructed by damming natural drainages where water runoff occurs at least part of the year. Thus, on-channel ponds can affect downstream water rights by capturing natural runoff in the impoundment. Discharges of poor quality water from an on-channel impoundment can affect water quality downstream and in shallow aquifers (EPA, 2003a). Recently, the SEO has begun to require consideration of downstream water rights in the permitting of new reservoirs. These considerations may include channel by-passes to route natural flow around facilities, water level control structures (agri-drains) to route natural flow events through the reservoirs, or water administration plans to keep the downstream water right holder whole. If downstream water rights are not present, these considerations are not required (LaBonde, 2005).

Off- and on-channel impoundments can also provide the following uses (ALL Consulting, 2003):

- wildlife and livestock water (water is diverted to a nearby stock tank);
- fisheries (off- or on-channel);
- recreation (off-channel); and
- constructed wetlands (off- or on-channel).

In general, all these uses are limited by water quality and the availability of a long-term supply of water.

Injection

Injecting water into the subsurface is a proven technology for disposal of waste water or for storage of potable water. Alternatives for injection of CBM water include aquifer recharge, aquifer storage and recovery, and deep injection for disposal and/or enhanced oil recovery. The injection of co-produced water into deep reservoirs is a standard disposal practice in the conventional oil and gas industry. It is regulated by state agencies and the EPA (ALL Consulting, 2003).

The Wyoming Oil and Gas Conservation Commission (WOGCC) issues Class II injection/disposal permits for oil and gas produced water, including CBM water. At this time, there are estimated to be over 5,000 injection/disposal wells for conventional oil and gas and CBM statewide. The WOGCC has also issued four Class II injection permits in the PRB for the use of CBM water for enhanced oil recovery (EOR) (Nelson, 2005).

The Wyoming DEQ has written three general Class V injection well permits (5C5-1, 5C5-2, 5C5-3) for CBM operators in Campbell, Johnson, and Sheridan counties (DEQ, 2004). Statewide to date, there are 308 permitted Class V CBM wells, with the vast majority of these falling under one of the three general permits in the PRB mentioned above. There are 60 of the 308 permitted wells reporting activity at this time. Of the 60 actively reporting wells, the combined injection volume of CBM water is 14.6 million barrels (1,882 acre feet) per year (Frederick, 2005).

Through well design and periodic monitoring, operators must show there is no significant movement of the injected fluid into an underground drinking water aquifer. Important factors influencing the economics of injection include depth of the injection zone, pre-treatment, injection pressures, and needs for transportation of water (ALL Consulting, 2003). In some development areas, several injection wells may be required for each CBM production well due to the large volumes of CBM water, with associated surface disturbances for each injection well.

Atomization

Water particles are separated into small droplets and dispersed under pressure through a specialized nozzle atop a tower. In warm, dry climates these droplets are more easily evaporated than water stored in impoundments. Evaporation reduces the volume of water that would have to be managed using other options. However, windy conditions can create drifting and downwind deposition of salts and other constituents to the soil and other water bodies. In addition, freezing conditions can transform the atomized mist into large ice mounds, rendering the technology ineffective. Such ice mounds become freeze/thaw/evaporation systems that concentrate salts and other constituents, damaging the soils underneath the atomizer tower (Powder River Basin Resource Council, 2004).

Treatment and Re-use Alternatives

Treatment technologies exist to improve water quality and allow for increased beneficial use, all having advantages and disadvantages. Water treatment technologies can be used alone or in tandem, depending on the quality of the influent water and the desired quality of the effluent. Some treatment technologies that have been attempted or are used for CBM water are shown below; the list is not all-inclusive nor is it intended to show preferred treatment methods:

- reverse osmosis;
- chemical treatment;
- freeze/thaw/evaporation;
- ion exchange;
- deionization or capacitive desalination;
- electrodialysis reversal; and
- distillation.

Agricultural Uses

CBM water has and continues to create opportunities for landowners to develop additional uses of their land such as livestock watering, irrigation, and aquaponics (combination of aquaculture and hydroponic systems) (Arthur, 2002). These opportunities are only available if water quality is suitable. Also, water production generally declines over time meaning the opportunity to use CBM water for agricultural purposes may be limited to 10-20 years or less.

Commercial/Industrial Uses

A variety of existing industries or commercial ventures could benefit from CBM water including:

- coal mines;

- coal conversion plants (such as the recently proposed coal to synthetic diesel plants);
- road dust suppression;
- enhanced oil recovery;
- animal feeding operations;
- cooling tower water for various industrial applications;
- commercial fisheries; and
- fire protection.

Industrial applications of CBM water that have potential and have been considered or demonstrated by industry include bottled drinking water, brewery water, and solution mining of minerals. However, declining CBM water production over time may limit the economic viability of these options.

Domestic and Municipal Water Use

CBM water meeting or approaching drinking water standards could replace or augment rural wells, springs, and municipal water supplies already strained from over-appropriation and drought conditions. Such water could replace residential wells of lesser quality water, or supplement other surface or groundwater sources.

New and Emerging Technologies

Below are some new technologies that are not yet implemented in CBM development on a large scale but many hold significant promise for improvements in process efficiency and cost for the removal of CBM gas while reducing the volume of CBM water (Kuipers et al., 2004). Since these are new technologies they may or may not work out in actual CBM field operations.

<u>Downhole water/gas separation</u>

This approach uses semi-permeable membranes to separate water and gas. Carbon dioxide and /or nitrogen is injected into adjacent wells to facilitate two-phase flow across the coal formation. Carbon dioxide has a greater adsorption affinity for coal than methane and preferentially binds to the coal, desorbing the methane. Nitrogen stripping of the methane may also occur. Gas permeable membranes located within the well bore are used to recover the methane gas. Since the approach does not require the aquifer to be depressurized, the volume of produced water would be significantly reduced. The approach may also provide an economically feasible means of carbon sequestration. The feasibility of downhole membrane separation is currently being investigated by researchers at the University of Wyoming (Urynowicz, 2005)

<u>Alternative wellbore completion methods</u>

A common well completion technique in the PRB is to drill to the coal seam and then under-ream the coal section, enlarging the hole and minimizing the effects of any formation damage. In many cases water is then pumped into the wellbore to “clean it out” and “enhance” production (water-enhancement) and if the applied pressure results in vertical fracturing into the formation above or below the coal, excess CBM water production could occur (Colmenares and Zoback, 2004).

Researchers recommend that in areas of known vertical fracture propagation it is necessary to limit the injection during water-enhancement. In areas where the type and amount of fracturing are unknown, a low pressure, short-duration fracturing test (mini-frac) should be done to determine whether fracture propagation would be vertical or horizontal. If the test indicates that vertical fracturing could occur, injection during water-enhancement should be limited (Zoback and Colmenares, 2004). This simple test prior to well completion could result in substantially reduced produced water volumes, saving the developer the cost of water treatment and disposal.

Preliminary findings from well-completion research sponsored by several major CBM producers in over 500 CBM wells in the PRB indicates that all of the wells with exceptionally high water production are associated with vertical fracture propagation, and these wells have significant delays in gas production apparently due to inefficient depressurization of the coals (Zoback and Colmenares, 2004).

Downhole raman spectroscopy tool

This technique involves directing a laser beam at a fluid sample and plotting the reflected light as a color spectrum to provide the average chemical makeup of the fluid. One Wyoming-owned company, for example, has developed a proprietary downhole tool that uses raman spectroscopy to quantify chemicals in water, including methane, in a CBM well (WellDog, Inc., 2004). According to the designer, this technique could quickly identify wells with higher levels of methane saturation that will typically produce natural gas faster with less dewatering. From the test results, the designer claims that an operator can prioritize development, maximize resources, more efficiently plan infrastructure, accelerate the booking of reserves and optimize the permitting process (WellDog, Inc., 2004).

Horizontal drilling

Horizontal drilling involves first drilling vertically to the gas producing formation, then drilling horizontal gas collection bores through the producing formation, increasing the likelihood of intersecting more vertical fractures in the coal (Wight, 2004). Production time can be minimized and multiple drainage networks can be nested and drilled from a single well site to drain up to 1,200 acres of coal. By comparison, traditional vertical drilling and fracturing recovery methods require one well for every 40-80 acres (Wight, 2004). According to claims by its proponents, horizontal drilling can accelerate recovery rates, provide significant economic benefits, minimize surface disruption, and achieve uniform drainage. Problems relating to dewatering and cost remain, and it may not work in all areas due to the nature of the geologic formations.

ECONOMIC ISSUES

Central to the conflicts surrounding CBM development are the economics of gas production and water management and disposal. As discussed earlier in this report, CBM gas production produces substantial tax revenues that fund public services such as education, road maintenance, law enforcement, and other state and local government services. And as summarized earlier in Table 3, water produced with CBM gas is a by-product managed with surface discharge, infiltration ponds, and other methods including managed irrigation or injection.

Two economic issues related to water production generate controversy associated with CBM development. The first is that water disposal can represent the loss of an important resource in an arid region like the PRB. Second, if water of poor quality is released it can damage pastures and intermittent streambeds, which then can represent a loss in economic value to affected surface owners. CBM development does compensate on-site surface owners for damage, though the appropriate level of compensation is sometimes controversial. Where water enters off-site property from intermittent stream beds, surface owners generally are not compensated. So the benefits of CBM development including beneficial uses of CBM water (e.g., irrigation, stock water) as well as labor income and tax revenues, need to be compared with the costs of that development, including but not limited to the cost of water lost and the cost of environmental impacts related to poor quality water and erosion.

As new technologies are developed to manage CBM water, job creation and tax revenues associated with these water management advancements could occur. The number of companies offering disposal, storage, and treatment services may also grow as the need grows, and these services may be transferable to other energy development sectors, with even greater potential for job and income creation. It is important to note, however, that as CBM production drops off, so will the need for product water services and, thus, the jobs and income created through these services.

Integral to understanding water's "opportunity cost" is how water is valued for the purposes of the policy question. This value can become an important factor in assessing the regional economics of CBM development. The estimated value depends upon the quality of water, the distance to a potential user, the type of user (e.g., ranching, commercial, residential, etc.) and substitute supplies. As far as we are aware, the overall market potential of CBM water has not been evaluated in any study to date.

Little information has been compiled on how the costs of CBM development and regulations affect socioeconomic conditions in communities and throughout the state. Coupal (2005) reviewed some of the available information, but the studies reviewed do not address community or regional impacts, nor the issue of whether communities gain in the long run. CBM development generates significant positive economic impacts reflected in labor income and increased financing for local and state public services. However, depleting a resource such as water that could be an important factor in future economic health and development in communities is an opportunity cost that policy makers need to consider against the short-term benefit of local and state tax revenues.

Other social costs would need to be factored in as well, including downstream property rights impacts, increased congestion, housing needs, etc. There has not been any evaluation of whether surface owner compensation and access fees adequately mitigate the net loss of agricultural production. Finally, estimates of how much money stays in Wyoming versus how much leaves with nonresident energy developers and nonresident employees also do not yet exist. These and other economic benefit and cost issues are not addressed in the studies reviewed or in the CBM literature in general, indicating areas needing additional study. The appropriate structure of an economic analysis of CBM development should account for the opportunity costs of development described above, both water-based and activity-based, compared with the public benefits generated by local and state taxes, and increased labor income in the region.

REGULATORY AND LEGAL ISSUES

The Wyoming regulatory framework only partially accommodates CBM development. The State Engineer's Office, Department of Environmental Quality, Wyoming Oil & Gas Conservation Commission, and the Wyoming offices of the Bureau of Land Management each have management roles in oil and gas development, but CBM development brings unique challenges and requires much more agency coordination. CBM water use and disposal has been one of the main cross-cutting issues. Methods for handling the water are permitted by different agencies (e.g., discharge to drainages is permitted by DEQ, on-channel reservoirs by SEO). Furthermore, the scale of development has placed stress on the regulatory framework currently in place. State and federal agencies might have forseen some of the potential consequences of CBM development, such as cumulative environmental or socioeconomic impacts, but may not have sufficient personnel and resources to keep up with the issues. As a result, state and federal agencies have been, and continue to be, challenged by the sheer magnitude and consequences of CBM development.

Most recently, management of regulatory responsibilities and cooperation among state and federal agencies with regard to CBM development has begun to improve. Examples of this cooperation include the Governor's Strengthening and Streamlining Environmental Working Group and Industry Working Group on oil and gas, and the Governor's Strengthening and Streamlining Working Group on electronic permitting and data sharing for oil and gas. The Wyoming/Montana BLM Powder River Basin Interagency Working Group is evaluating monitoring, mitigation and planning efforts related to CBM. To build on these important efforts, much continued attention is needed on the development of CBM in the PRB as well as future development of CBM in other basins of Wyoming to ensure that the proper regulatory framework exists to allow for production, environmental protection and sustainable development.

The following sections provide a brief overview of the current regulatory environment and recent legal developments related to CBM development in Wyoming; they do not propose new regulations or other legal reforms.

Existing State Regulatory Structure

Three state agencies share the main responsibility for regulating CBM development in Wyoming: the State Engineers' Office, the Department of Environmental Quality, and the Oil and Gas Conservation Commission. In addition, the Game and Fish Department plays a role in recommending measures to mitigate the impact of oil and gas development on wildlife and the Bureau of Land Management oversees the development of federally owned minerals.

<u>State Engineer's Office (SEO)</u>

In Wyoming, water is the property of the state, and individuals are allowed to use this resource if they can put it to beneficial use. The SEO is charged with administering the water resources of the state through a permit system. The permit application requires that the proposed beneficial use of the water be identified. Beneficial uses of water are not prioritized but rather are given equal consideration by the SEO. The SEO has determined that reducing water pressure in an aquifer to produce coalbed methane gas is a beneficial use of the State's water. The agency also permits on-channel reservoirs associated with CBM production and off-channel permits if there are beneficial uses of the water in addition to its use as “water produced in the production of coal bed methane gas” (e.g., stock watering) (Wyoming State Engineer’s Office, 2004).

Department of Environmental Quality (DEQ)

DEQ Water Quality Division administers the Wyoming Pollutant Discharge Elimination System or WYPDES (previously referred to as the National Pollutant Discharge Elimination System [NPDES] program). This is a state delegated program that authorizes point-source discharges of pollutants under section 402 of the Clean Water Act.[2] The reason for the section 402 permit stems from the pollutants carried by the CBM discharge water that accompanies each well.[3] The permit system ensures that state water quality standards of Wyoming and its neighboring states are protected.

DEQ recently launched a new watershed approach to permitting CBM discharges (Wagner, 2005). This new approach is currently being implemented on eight of thirty scheduled watersheds in accordance with a tentative three year schedule developed by DEQ. The Wyoming Game and Fish Department and other state agencies are also participants in this process.

Under some circumstances where a water containment pit may degrade higher quality groundwater aquifers, DEQ may require a Chapter 3 construction permit (WY DEQ, WOGCC, U.S. BLM, and WY SEO, 2002). DEQ also requires Permits to Construct for all produced water (including CBM) treatment plant and land application systems, including irrigation systems and atomization disposal systems, commonly called “misters.” DEQ has also issued implementation guidance for the reclamation and bonding of on-channel reservoirs that store CBM water.

Wyoming Oil and Gas Conservation Commission (WOGCC)

The WOGCC is responsible for permitting aspects of oil and gas well construction, well spacing and density, and bonding and reclamation.[4] It also permits off-channel reservoir containment pits when the only use of the water will be “water produced in the production of coalbed methane gas” (Tyrell, 2004). Off-channel reservoirs or pits also require a separate bond by the WOGCC that is based on engineering estimates for closure and reclamation of the reservoir or pit when its use is complete (Nelson, 2005).

The WOGCC generally requires (absent demonstration by the operator of a satisfactory bond that meets state, federal or Indian lease requirements) a bond of either $10,000-$20,000 per well (depending on well depth) or a blanket bond of $75,000 for multiple well developments. The bond is designed to ensure that wells are operated and reclaimed in accordance with state regulations.

Wyoming Game and Fish Department (WGFD)

WGFD plays a consultation role in federal oil and gas projects pursuant to both the BLM and Forest Service management guidelines.[5] In 2004, the WGFD developed a set of recommended mitigation measures for oil and gas development based on habitat function and surface disturbance (WGFD, 2004).

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[2] 33 U.S.C. § 1342.
[3] *Northern Plains Resource Council v. Fidelity Exploration*, 325 F.3d 115, 1160-61 (9th Cir. 2003).
[4] Wyo Rev. Stat. § 30-5-104(d)(i).
[5] 43 U.S.C. § 1712 (c)(9).

U.S. Department of the Interior, Bureau of Land Management (BLM)

BLM regulates development of federally owned minerals, whether the minerals are under public or private lands. Each state has its own BLM offices that work with the state agencies. The BLM requires their leaseholders to obtain an application for permit to drill (APD) prior to oil or gas production. The BLM also requires bonding, monitoring and reclamation.

Regulatory Issues

The following is a list of several more specific issues that arise within the current regulatory approach.

CBM water and beneficial use

In Wyoming, groundwater appropriation permits "shall be granted as a matter of course, if the proposed use is beneficial, and if the SEO finds that the proposed means of diversion and construction are adequate."[6] In 1997, the SEO declared the production of water for CBM development to be a beneficial use. Water produced from CBM development is considered a non-consumptive beneficial use, similar to water used for hydropower and instream flow in that the full amount of the water remains available for appropriation after the initial use has been completed. Unless put to beneficial use, produced water from conventional oil and gas development is not regulated by the SEO and remains the regulatory responsibility of the WOGCC (LaBonde, 2005).

Despite the regulatory determination that the co-production of water with CBM development is a beneficial use of that water, some have argued that this model is problematic because, in most cases, only a fraction of the water associated with CBM production is "beneficially" used (Darin, 2002). Historically, western water law did not include the production of byproduct water to allow gas or oil to flow to the surface in the definition of "beneficial use." Rather, the beneficial use is the use to which the water itself is put.[7] In Wyoming, as in the other states, water that is not beneficially used is referred to as impermissible "waste" (Darin, 2002).

Some argue that, under the state's water quality regulations, a quantity parameter must be included in the beneficial use standard to have it serve any useful purpose. Several ranchers recently petitioned the Environmental Quality Council for rulemaking to place such a parameter on DEQ's "beneficial use" requirement for point source discharges.[8]

In the case of irrigation with surface water, a "duty of water" was developed by the Territorial Engineer's Office working with actual field testing, and adopted in the first state water code in 1890, setting the familiar "1 cubic foot per second for each 70 acres of land" standard which is applied in the absence of evidence that a different "duty of water" is appropriate to particular lands (Fox and MacKinnon, 2005). A similar standard may be needed to establish the "duty of water" for CBM production (i.e., sufficient to produce the CBM gas).

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[6] Wyo Rev. Stat. § 41-3-931.

[7] In his article, Darin argues that this notion is supported by the fact that Utah, New Mexico, Colorado, and Montana all have placed oil and gas produced water under the jurisdiction of the state oil and gas commissions and do not require a beneficial use permit for the point of first diversion.

[8] Petition to Amend Wyoming Water Quality Rule Chapter 2, Appendix H. Submitted to the Wyoming Environmental Quality Council, December 7, 2005.

Public interest review requirement

A separate but related issue to the beneficial use requirement is the requirement that water use in the state be in the public interest. Both Wyoming's Constitution and statutes require the SEO to ensure that "Priority of appropriation for beneficial uses shall give the better right. No appropriation shall be denied except when such denial is demanded by the public interests."[9] Specifically with respect to groundwater, the statutory provision provides that:

> An application for a permit for a well in any area not designated as a critical area shall be granted as a matter of course, if the proposed use is beneficial and, if the state engineer finds that the proposed means of diversion and construction are adequate. If the state engineer finds that to grant the application as a matter of course, would not be in public's water interest, then he may deny the application subject to review at the next meeting of the state board of control.[10]

Despite this language, the SEO has no formal public interest review process. This makes the SEO vulnerable to arguments that any determinations of public interest are arbitrary and capricious.[11] Use of the public interest standard would allow the SEO to deny or require modification to an individual permit if it appears that the applicant has no plans to employ readily available and economically feasible technology to produce less groundwater withdrawals while producing CBM (Fox and MacKinnon, 2005).

Groundwater protection

As CBM development progresses in the western Powder River Basin and produced water is stored in unlined impoundments, groundwater impacts by CBM infiltration reservoirs have become a topic of discussion. Researchers have documented, as in the case of Skewed Reservoir in Johnson County, that the infiltration of CBM water from unlined impoundments can mobilize salts and metals inherent in the underlying soils, and degrade underground water from a high to lower use classification (Frederick, 2004). Some argue that the state DEQ fails to adequately regulate on- and off- channel reservoirs, and that CBM reservoirs require construction permits to protect groundwater and provide for reclamation (Buccino and Jones, 2004).

Title 35, chapter 11, section 301(a)(iii) of the Wyoming statutes provides that "(n)o person, except when authorized by a permit issued pursuant to the provisions of this act, shall . . . construct, install, modify or operate any sewerage system, treatment works, disposal system or other facility, excluding uranium mill tailing facilities, capable of causing or contributing to pollution." The statute defines "treatment works" as "any plant or other works used for the purpose of treating, stabilizing or holding wastes."[12]

Rather than regulating the off-channel reservoirs as treatment works, DEQ has treated the reservoirs themselves as part of the "waters of the state," rather than as a mechanism contributing pollution to the waters of the state. Buccino and Jones (2004) argue that Wyoming law simply does not support DEQ's interpretation and that DEQ's own regulations define "surface waters of the state," as "all perennial, intermittent and ephemeral defined drainages, lakes, reservoirs and

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[9] Wyo Const. § 97 8 003.
[10] Wyo. Rev. Stat. § 41-3-931.
[11] *Rissler & McMurray vs. Envtl. Quality Council*, 856 P.2d 450 (Wyo. 1993) (holding the Environmental Quality Council's classification of lands as "very rare or uncommon" arbitrary and capricious where they failed to "first establishing by regulation the criteria and factors which will set the standard for that classification."
[12] Wyo. Rev. Stat. § 35-11-103(c)(iv).

wetlands which are not man-made retention ponds used for the treatment of municipal, agricultural or industrial waste" and therefore explicitly exclude the man-made reservoirs constructed to retain the industrial waste water produced by CBM operations.[13] A construction permit ensures that "the facility poses no threat of discharge to groundwater" and provides the necessary data collection and studies to protect groundwater.[14]

CBM water as by-product water

In an administrative appeal currently pending before the Environmental Quality Council, Wyoming conservationists have taken issue with DEQ's use of this as a special exemption for produced water discharges under 40 CFR Part 435 Subpart E, promulgated pursuant to the Clean Water Act. In general, these regulations prohibit the discharge of water associated with the production of oil and gas and provide an exception where the operator can demonstrate that "(1) the total effluent limitation for oil and grease is less than 35 mg/l and (2) the produced water is used 'in agricultural or wildlife propagation.'" The regulation requires that "the produced water is of good enough quality to be used for wildlife or livestock watering or other agricultural uses and that the produced water is actually put to such use during periods of discharge."[15] Conservationists argue that these federal regulations were put in place before CBM technologies were in existence and did not contemplate the type of water production associated with CBM development.[16] They also argue that, even if the regulation is deemed applicable, the "beneficial use" requirement is not being met for virtually all permits issued because there must be some demonstration of *actual* beneficial use for the discharged water for agriculture or wildlife.

Requirement to consider Best Available Technologies

In the same administrative appeal, conservationists also argue that DEQ does not require WYDPES permit applicants to consider Best Available Technology (BAT) requirements, as required by the 40 C.F.R. § 125.3(c)(3). The regulations state: "the permit writer must consider the following factors: . . . *for BAT requirements*: (i) The age of the equipment and facilities involved; (ii) The process employed; (iii) The engineering aspects of the application of various types of control techniques; (iv) Process changes; (v) The cost of achieving such effluent reduction; and (vi) non-water quality environmental impacts (including energy requirements)."[17] DEQ is generally not requiring operators to consider treatment options for sodium adsorption ratio (SAR), specific conductance (SC -- also know as electrical conductivity, or "EC") and other pollutants that are typical of some CBM waters.

DEQ does place EC limits on all CBM discharges based on the proximity to irrigation, and SAR limits where there is an irrigation use that may be impacted and where the discharge may reach a mainstem river. It is up to the operator to determine how they will achieve compliance, and to provide that information in the application. If treatment is necessary, the operator is also required to obtain a permit to construct from DEQ's Water Quality Division (Parfitt, 2005).

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[13] Wyo. Rules & Regs, Dep't of Envtl. Quality, Water Quality, Ch. 1, § 2(a)(xlv).
[14] Wyo. Rules & Regs, Dep't of Envt.. Quality, Water Quality, Ch. 3, § 17 (a).
[15] 40 CFR § 435.51.
[16] *See* Notice of Appeal for Issuance of Permits and Request for Hearing In the matter of: NPDES Permits WY0051217 AND WY0051233 (June 4, 2004) (on file with authors).
[17] 40 C.F.R. § 125.3(d)(3) (emphasis in original).

Legal Developments

Several lawsuits filed in federal courts have challenged various aspects of CBM development and its associated impacts. While based on federal, rather than state obligations, these lawsuits may nevertheless have a significant impact on how development continues in the state.

The litigation can be divided into four categories. The first three are based on the laws at issue: National Environmental Policy Act, Clean Water Act, and Clean Air Act. The fourth category—exemplified by the *Swartz v. Beach* case—addresses civil litigation by private landowners against both state agencies and individual CBM operators based on numerous theories, including nuisance and trespass.

National Environmental Policy Act (NEPA)

NEPA prescribes the necessary process by which federal agencies must "take a 'hard look' at the environmental consequences" of the proposed courses of action.[18] While the statute does not impose substantive limits on agency conduct, agencies must prepare an environmental impact statement (EIS) in which they consider the environmental impact of the proposed action and compare this impact with a reasonable range of alternatives.[19]

Late in 2004, the Court of Appeals for the Tenth Circuit held that before the BLM may issue oil and gas leases in the Powder River Basin in Wyoming, they must first look at the unique impacts of coalbed methane development. This decision calls into question the legality of hundreds of leases issued by the BLM.[20] On the heels of this decision, another lawsuit has been filed in Wyoming District Court in an attempt to force the BLM to more broadly implement the ruling by the Tenth Circuit (Daggett, 2005).

Another NEPA case, still pending before Judge Johnson in Wyoming Federal District Court, challenges the recently issued Buffalo Field Office's Final Environmental Impact Statement and Proposed Plan Amendment for the Powder River Basin Oil and Gas Project (U.S. BLM, 2003). While the Buffalo Plan Amendment FEIS does look at the impact of CBM development, the underlying environmental analysis has been challenged as inadequate. The case was originally filed in Montana because the suit challenged the Final Environmental Impact Statement for the Powder River Basin Oil and Gas Project, which shared analysis for both the Wyoming and Montana portions of the Powder River Basin. The Wyoming portion of the case was transferred to Wyoming Federal District Court. The Montana portion of the case has proceeded more quickly, and on February 25, 2005, Judge Anderson held that the BLM failed to adequately assess the "phased development alternative."[21] On May 31, 2005, the Ninth Circuit Court of Appeals granted an injunction halting new CBM development in Montana's portion of the PRB pending resolution of the appeal.

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[18] 42 U.S.C. §§ 4321-70; Utahns for Better Transp. v. U.S. Dept. of Transp., 305 F.3d 1152, 1162-63 (10th Cir.2002).
[19] 42 U.S.C. § 4332(2)(C).
[20] Pennaco Energy, Inc. v. U.S. Dept. of Interior, 377 F.3d 1147 (10th Cir. 2004).
[21] *Northern Plains Resource Council v. U.S. Bureau of Land Management*, CV-03-69-BLG-RWA, Order (February 25, 2005).

Clean Water Act (CWA)

The Clean Water Act's objective is "to restore and maintain the chemical, physical, and biological integrity of the Nation's water."[22] Section 404 of the CWA authorized the U.S. Army Corps of Engineers to regulate discharges of dredged and fill material into navigable waters through the issuance of permits. Recently the Corps' general permit that governs the construction of dams and reservoirs to dispose of wastewater from coalbed methane production wells was challenged.[23] Wyoming's Judge Downes ruled that the federal government failed to consider cumulative impacts that multiple gas-water reservoirs had on non-wetland resources under both NEPA and the CWA.

Clean Air Act (CAA)

Another challenge to the Buffalo RMP FEIS is focused almost exclusively on air quality concerns. The case was filed in Montana Federal District court (though a motion to transfer the Wyoming portion of the case to Wyoming Federal District Court is pending) and briefing is underway (Bleizeffer, 2004).

Private litigation—nuisance, trespass, etc.

In situations where mineral and surface rights are owned by different parties (severed) the mineral estate owner generally has the right to reasonable use of the surface estate to access and extract the minerals.[24] The Wyoming Legislature recently enacted legislation in the 2005 session to facilitate more effective surface use agreements between surface landowners and CBM developers.[25]

In the *Swartz v. Beach* case, a landowner brought an action against the Wyoming Department of Environmental Quality and the gas company discharging CBM water upstream from his ranch, alleging constitutional and CWA violations stemming from methane production activities.[26] Rejecting defendants' motions to dismiss, Wyoming Federal District Court Judge Brimmer held that: (1) action was not entirely barred by the Eleventh Amendment and state agency officials could therefore be sued in federal court, and (2) the landowners had the ability to bring federal CWA claims, Fifth Amendment takings claims, and state law claims of nuisance and trespass. After this initial victory by Swartz, the case was settled out of court.

Recently, the Wyoming Eighth Judicial District held that "CBM water is water belonging to the state once that water is legally placed in a watercourse."[27] The state, therefore, has an "easement for its water flowing down watercourses [extending] . . . to the normal carrying capacity of the watercourse." This holding followed plaintiff Williams Production RMT Company's reasoning that it has a right to discharge its CBM water into a natural water course as part of its mineral development.[28] At this time, the case is still in district court pending a

[22] 33 U.S.C. 1251(a).
[23] *Wyoming Outdoor Council v. U.S. Army Corps of Engineers*, Case No. 02-CV-155-D (January 7, 2005).
[24] *Mingo Oil Producers v. Kamp Cattle Co.*, 776 P.2d 736 (Wyo. 1989).
[25] Wyoming Legislature, Senate File 60, 2005. *See also* U.S. IECR (2003) and WGA (2004) on split estate and landowner relations issues.
[26] *Swartz v. Beach*, 229 F.Supp.2d 1239 (D. Wyo. 2002).
[27] *Williams Production RMT Company v. Maycock*, Campbell County No. 26099, Decision Letter, October 11, 2005 (on file with author).
[28] *Williams Production RMT Company v. Maycock*, Complaint. January 18, 2005 (on file with author).

factual determination regarding whether the water discharges are into channels that meet the legal definition of "watercourse."

Interstate Issues with CBM Water

Interstate environmental issues related to CBM development are primarily related to water quality. The Clean Water Act requires a National Pollutant Discharge Elimination System (NPDES) permit for CBM operations that result in a point-source discharge into waters of the United States.[29] When those discharges have the potential to cross interstate boundaries, the permitting state must ensure that the downstream state's water quality standards are protected.[30] In addition, interstate agreements can also limit Wyoming's development options (Colorado River Basin Salinity Forum, 2002).

<u>Montana</u>

Several rivers with CBM development flow north from Wyoming into Montana including the Tongue, Powder, and Little Powder Rivers. Montana has adopted numeric standards for electrical conductivity (EC) and sodium absorption ratio (SAR) for these rivers and their tributaries that are not to be exceeded as water crosses from Wyoming into Montana, with limits set as shown in Figures 4 and 5. Currently, Wyoming is participating in Montana's development of Total Maximum Daily Load assessments (TMDLs) for the Powder and Tongue Rivers, which will allocate assimilative capacity (the ability of a body of water to degrade or disperse chemical substances) between the two states (Hengel, 2004). CBM development in these watersheds has relied in part on discharge to surface waters as a water management option. Montana's implementation of numerical standards for EC and SAR forces Wyoming CBM developers to consider other, possibly more costly, water management options.

Montana recently granted a petition by conservationists to modify its antidegradation criteria for EC and SAR (Montana Board of Environmental Review, 2005). "Antidegradation" is a provision in the CWA that is a component of each state's water quality standards and enables states to maintain water quality. This rulemaking has the potential to severely limit the capacity of the Powder, Tongue, and other interstate rivers for EC and SAR.

<u>Colorado and Utah</u>

The Little Snake and Green Rivers flow south from Wyoming to Colorado and Utah, respectively. CBM operations in the Little Snake and Green River watersheds of Wyoming will have to comply with an interstate agreement for salinity control developed by the seven states, including Wyoming, that comprise the Colorado River watershed.[31] This agreement limits NPDES permitting for industrial discharges to one ton of salt per day (Colorado River Basin Salinity Control Forum, 2002). To date, CBM projects in Wyoming's Atlantic Rim area (Little Snake River watershed) primarily rely on injection of CBM water.

<u>South Dakota</u>

The Cheyenne and Belle Fourche rivers flow east from Wyoming into South Dakota and both are potentially affected by Wyoming's CBM development. South Dakota has adopted numeric water quality standards for TDS, EC and SAR as shown in Figures 3, 4 and 5. Moreover, South Dakota is also currently developing a TMDL for the Cheyenne River. While

[29] 33 U.S.C. § 1342.
[30] 503 U.S. 91, 1992.
[31] 33 U.S.C. § 1342.

the Cheyenne River is not currently listed as impaired for SAR or EC, those parameters may be addressed by the TMDL standards. The Wyoming DEQ is discussing monitoring networks with South Dakota and the EPA, and a draft monitoring plan was delivered to the EPA in June of 2005.[32]

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[32] 33 U.S.C. § 1342.

ALTERNATIVE TECHNICAL, REGULATORY AND STATUTORY STRATEGIES RELATED TO CBM WATER MANAGEMENT

Currently, industry and agencies can draw from a limited number of options for management and disposal of CBM water in the Powder River Basin and in the newer CBM plays in other Wyoming coal fields. As summarized in Table 3 and in Hulme (2005), approaches most often used include direct discharge with or without prior treatment into a flowing or dry streambed, lined or un-lined impoundments or holding pits for infiltration and/or evaporation, managed irrigation, atomization, and injection. But concerns over the consequences and lost opportunities associated with some of these methods suggest the need for reconsidering and expanding the available options, especially at a time when the vast majority (95%) of Wyoming's recoverable CBM resources remain to be produced. The last 15 years of CBM development in Wyoming, while resulting in important experience on how to produce CBM, also provide a wealth of experience to direct improved CBM water management in the future.

Minimization of negative impacts and maximization of water uses are two sides of the same coin in CBM water management. Beneficial use, which is especially important in arid regions like Wyoming, can be achieved through minimizing water production in the first place (making water available for future uses) or finding additional beneficial uses for the water once it is produced. For the CBM water that is produced, best management practices should be employed to promote the sound, efficient and environmentally appropriate development of CBM. The Western Governors' Association has produced a best management practices handbook for CBM as a tool for coordination and sharing of this information (see Best Management Practices section below).

Pumping CBM water from coal aquifers to produce natural gas has, in itself, been officially recognized by the State Engineer's Office as a beneficial use of the water. Agency and industry representatives argue that only a small percentage (5% or less) of the water in the coal aquifers is being removed to produce the gas, but some consider the discharge and loss of this water supply unfortunate. Since CBM development in the Powder River Basin began in earnest in 1987, CBM water has been put to many good uses beyond CBM production, including stock and wildlife watering, irrigation, and adding to the groundwater aquifer used for Gillette's drinking water supply. Additional options would build on these existing strategies of using CBM product water for uses above and beyond the production of CBM gas.

But while post-production uses are desirable, they are not always possible, particularly where CBM water is of poor quality or not in a location amenable to many post-production uses. Again, minimizing water production is a first step in dealing with the problem, but additional options are needed to treat or dispose of the water in a way that minimizes environmental and socioeconomic effects at the same time as allowing the continuation of CBM production.

The water management alternatives for CBM product water presented in this report (see Table 3) were drawn, in part, from a review of several recent studies on CBM water management (U.S. DOE, 2002; ALL Consulting, 2003; Argonne National Laboratory, 2003; Kuipers, 2004; Kuipers et al., 2004; CDM, 2004). Each of these reports addresses current management practices for CBM waters and most reports include innovative and alternative strategies as well. This section briefly describes many of these alternative strategies, as well as several additional ideas that have emerged in the preparation of this report.

Options presented below vary from technology-based solutions to changes in the regulatory and statutory framework that surround the management of CBM development. Of course, no single method will address all of the concerns and opportunities associated with CBM water production. Rather, managing CBM water likely will continue to require a suite of management approaches, to be tailored on a regional and even site-specific basis. This in turn requires the technological and regulatory flexibility to draw from a range of potential approaches.

Minimize Water Production

The first step in managing CBM produced water is to minimize the amount of water brought to the surface. The New and Emerging Technologies section of this report describes four technologies that have the potential to minimize water production while maintaining a profitable gas flow. Use of produced water minimization technologies decreases the operator's costs for water management and reduces the environmental and socioeconomic impacts seen in previous years with surface discharge and water impoundments. Of those new technologies, the first two listed below are currently in use by some CBM producers.

<u>Alternative wellbore completion methods</u>

As described in the New and Emerging Technologies section, a common well completion technique in the PRB is to drill to the coal seam and then under-ream the coal section. In many cases water is then pumped into the wellbore to "flush" or "clean it out" and "enhance" production (water-enhancement), and if the applied pressure results in vertical fracturing into the formations above or below the coal, excess CBM water production could occur (Colmenares and Zoback, 2004).

Preliminary findings from well-completion research sponsored by several major CBM producers using data from over 500 CBM wells in the PRB indicate that all of the wells with exceptionally high water production are associated with vertical fracture propagation, and have significant delays in gas production apparently due to inefficient depressurization of the coals (Colmenares and Zoback, 2004). Researchers recommend that in areas of known vertical fracture propagation it is necessary to limit the injection pressure during water-enhancement. In areas where the type and amount of fracturing are unknown, a low-pressure, short-duration test (mini-frac test) should be done to determine whether fracture propagation would be vertical or horizontal. If the test indicates that vertical fracturing could occur, injection pressure during water-enhancement should be limited (Zoback and Colmenares, 2004).

- **<u>Pros:</u>** It appears that completing a "mini-frac" test, and using test results to guide selection of water enhancement pressures during well completion, could result in substantially reduced produced water volumes, saving the developer the cost of water treatment and disposal.

- **<u>Cons:</u>** Unless some regulatory mechanism is put in place to require developers to conduct "mini-frac" testing during well completion, the technology may not be widely used, possibly resulting in the over production of CBM water in some wells.

Use of raman spectroscopy tool during well field completion

One example of using raman spectroscopy comes from a Wyoming-owned company that has developed a proprietary downhole tool to quantify chemicals in water, including methane, in a CBM well (WellDog, Inc., 2004). According to the designer, this technique could quickly identify wells with higher levels of methane saturation that will typically produce natural gas faster with less dewatering.

- **Pros:** From the test results, the designer claims that an operator can prioritize development, maximize resources, more efficiently plan infrastructure, accelerate the booking of reserves and optimize the permitting process (WellDog, Inc. 2004).

- **Cons:** There may not be enough field data to prove that this technology is a reliable method for reducing the amount of water produced from a CBM well.

Best available water minimization technology

To promote wide-scale use of the water minimizing well completion technologies described above, or other new technologies as they emerge, statutory and/or regulatory changes for the appropriate implementing agency (SEO or WOGCC) could be adopted to require "best available water minimization technology" review prior to issuing new well permits to assess the technical feasibility and economic practicability of using these technologies. This concept is similar to the best available control technology (BACT) review that is required for all air quality permits by the Department of Environmental Quality, Air Quality Division, to ensure reduced air emissions from stationary sources of air pollution.

Under this concept, which would apply to CBM well permits only, developers would be required to submit a comparative review of water minimization practice(s) they could use based on the technical feasibility and economic practicability of the options. The implementing agency would not dictate which water minimization technology would have to be used; rather, developers would do their own review of the technical and economic aspects of the potential technologies and justify their selection in their permit application to the agency. Applications to drill for CBM could be rejected if a review of best available water minimization technology is not included in the application.

- **Pros:** This review process would allow the developer some flexibility in selecting a water minimization technology, which is important given the site-specific nature of CBM development and given that some technologies may be feasible in some locations but not in others. A mandatory review process by the responsible agency would promote and require more attention to minimizing CBM water production.

- **Cons:** The implementation of this review will likely require additional time and effort by developers in preparation of their permit application and also by the reviewing agency for processing the permit. The use of produced water minimization technologies may result in additional cost to developers; however, these up-front costs might be off-set by the reduction in water management costs.

  A determination would need to be made as to which agency should implement this program, whether it be the SEO or WOGCC. Consideration would also need to be given to how this might interface with BLM's permitting of wells.

The existing oil and gas rules and regulations have been applied to and “made to fit” CBM development. If a “best available water minimization technology” review process were to be implemented, the regulation would have to be written specifically for CBM well permits and exclude conventional oil and gas production.

Best Management Practices

With respect to CBM development, best management practices (BMPs) are a method of operation that can eliminate or minimize adverse impacts to public health and the environment, landowners, and natural resources while enhancing the value of natural and landowner resources and reduce conflict (WGA, 2004). The use of BMPs extends beyond water management to all aspects of CBM development. It is important to keep in mind that at this time, BMPs are voluntary and not required by regulation.

The CBM BMP Handbook published by the Western Governors’ Association (WGA) in 2004 has been used as a tool for outlining and promoting the use of BMPs in CBM development. This handbook is a living document and should be updated as necessary to incorporate new practices and technologies as they emerge. Efforts to this end are currently being considered by WGA (WGA, 2005).

- **Pros:** BMPs are intended to reduce the environmental impacts of CBM development while still maintaining efficiency, cost effectiveness and competitiveness in producing the resource (WGA, 2004). Sharing this information broadly across industry and landowner groups through publications, technical workshops and conferences helps reduce conflicts associated with development.

- **Cons:** BMPs are not required or enforceable. Currently, they are used through the voluntary action of the producers. The effectiveness of BMPs is limited without regulatory requirements, incentives, or other mechanisms to further encourage their widespread use in CBM development.

Injection of CBM Water for Storage or Disposal

Injection involves gathering CBM water from wells and transporting that water to one or more injection wells. The water could be injected into coal seams where the economically recoverable CBM has been depleted or into other geologic formations for reuse, or into deep geologic formations for disposal. Developers in other CBM producing basins, such as the San Juan Basin in Colorado and New Mexico, are required to inject CBM water into deep formations for disposal, and injection requirements for CBM water are being considered by Montana for the Montana portion of the PRB Usually, these deep formations contain water of poorer quality than the injected CBM water. The state of Wyoming does not require injection in the Powder River Basin primarily because injection into most formations in that area apparently will not accept additional water (i.e., sand formation aquifers are “full”). However, the BLM has indicated that injection for disposal will be required in the Wyoming basins (Green River and Little Snake drainages) that are part of the Colorado River watershed. CBM water from southern and southwestern Wyoming is of much lower quality than water from the Powder River Basin.

Injection of CBM water for storage and re-use

Municipal use and/or groundwater storage of CBM water for potable use has been achieved by injecting good quality CBM water into the aquifer used by the city of Gillette. Other local PRB municipalities might also benefit from this kind of storage if their aquifers were suitable and the CBM water was of high quality or treated to acceptable quality before injection.

- **Pros:** Where it is determined to be technically feasible, injection for storage and reuse could re-establish aquifer levels for domestic and agricultural use. Injection would also eliminate many of the complications that have come from surface discharge or impoundments.

  Some experts also believe that returning water to the coal seams after CBM production may continue to induce the "biogenic" production of CBM. CBM in the PRB is known to be produced by bacteria in the coals, and some experts believe that CBM could even be a "sustainable resource" if the proper conditions, including the presence of water, could be maintained in the coal beds.

- **Cons:** Technical issues have inhibited the wide-spread use of injection in the Powder River Basin. In most areas, there is not enough "room" available in most geologic formations to accommodate the injected water. If the water is to be injected for storage and reuse, it may require treatment prior to injection which constitutes an added cost. The geographically dispersed development of the PRB CBM play makes it difficult to gather the water for injection in a systematic way, although this should be considered for new CBM plays in other parts of the state. Also, until recently, there haven't been any "played out" coal seams available in the PRB to receive the water. If produced water is injected into a coal seam that is still producing gas, it could interfere with gas production.

  In addition, details on the *in-situ* biogenic production of CBM in the PRB are not well established and additional research is warranted to test this theory and determine whether CBM production can be extended or enhanced within a reasonable time period through biogenic means.

  At some CBM development sites, several injection wells may be required due to the large volumes of CBM water being co-produced. Surface disturbances associated with these wells would include additional roads, well pads, pump houses, and storage ponds.

Injection of CBM water for disposal

As mentioned above, injection of CBM water into deep geologic formations is the mandated method of water disposal in the San Juan Basin of Colorado and New Mexico, in large part because the CBM water quality is so poor. Deep well injection is likely to be required in the Green River Basin of Wyoming as well. Some have argued that even the lesser quality CBM water produced in the Green River Basin should be treated and reused rather than disposed of in deep wells where it is, in effect, lost to future uses.

- **Pros:** Deep well injection of CBM water does eliminate the issues associated with surface discharge or surface impoundment. It also requires less land disturbance than the construction of large storage or infiltration ponds. In some cases, depending on well depth and other factors, injection may be less expensive than extensive treatment of poor quality water. Injection using existing oil wells for the purpose of water-flood enhanced oil recovery is discussed later. In some cases, if the geology is amenable, formerly producing oil wells can be converted to injection wells.

- **Cons:** Deep well injection incurs the same technical difficulties and surface disturbance as injection for storage and reuse noted above. In addition, the water in the deep formation needs to be of lesser quality than the CBM water so as not to further degrade the water quality in the receiving formation.

  Most importantly, disposal of CBM water by deep well injection means that water is taken out of circulation for most future uses since it is injected into a lesser quality and less accessible formation. This is an especially important consideration for the PRB given the large volumes of water.

Additional Beneficial Uses for CBM Water

Several beneficial uses listed in Table 3, such as stock and wildlife watering and irrigation, have been in practice in the PRB as alternatives to discharge into surface drainages, infiltration or storage ponds, or deep injection wells. But distance to suitable alternative uses, poor water quality, overall cost of alternatives to disposal, and cost considerations in light of the limited duration of water supply have likely limited the development of additional beneficial uses for CBM water in the PRB. Several, but not all, of the additional beneficial water uses listed below might require some treatment, depending on the quality of the CBM water source.

<u>Enhanced oil recovery (EOR)</u>

Using water flood methods is a well-established technology for EOR that is not as tied to water quality as are potable water uses, though chemical additions to the CBM water may be needed for some EOR operations. Several oil reservoirs in advanced stages of production in the PRB, as well as in the vicinity of CBM plays in other areas of Wyoming are proving suitable for water flood EOR. The WOGCC has permitted four wells that use CBM water for enhanced oil recovery in the PRB, and Anadarko Petroleum has announced plans to build a pipeline to transport CBM water from the PRB for disposal and/or enhanced oil recovery from the Salt Creek field near Midwest, WY.

- **Pros:** The use of CBM water for EOR has two key benefits. One is that it provides a beneficial use for CBM water and, second, it can result in additional production of oil. Attempts to extract more oil from already developed fields are often preferable to developing new oil fields in undisturbed environments.

- **Cons:** As in the case with the proposed Anadarko Petroleum project to use CBM water for EOR, water gathering and transmission lines may need to be constructed to get the water to the oil fields. Treatment of the water may be necessary in some cases to maximize oil recovery, adding to the cost of the project.

<u>New or enhanced surface water storage</u>

Surface storage projects could be considered in the vicinity of current or future CBM plays. For instance, in the PRB it might be possible to develop new surface storage projects or enhance existing reservoirs such as Lake DeSmet. Funding, possibly through the Wyoming

Water Development Commission, may be needed to finance pipeline and water treatment infrastructure and operation.

- **Pros:** CBM water could help bolster reservoir volumes that have been depleted in recent years due to regional drought. This would also provide a means for many people to benefit from the production of CBM water. It could make additional water available for agricultural uses, wildlife and recreation.

- **Cons:** Extensive pipeline networks would have to be constructed to gather CBM water which could result in additional land disturbance and costs. Consideration would need to be given to the impact of CBM water quality on an existing reservoir and whether treatment would be necessary. Another potential disadvantage for any such plans could be the limited time (decades) that CBM water might be available to supply water to such new or enhanced storage reservoirs. Coordination would likely require State involvement.

Meeting interstate water compact commitments

This option would likely require pipeline and water treatment infrastructure. But the recently negotiated Modified North Platte River Decree requires Wyoming to replace water uses by some Wyoming water users that have been determined to cause new depletions on the river.

- **Pros:** The use of CBM water over the next few decades, while the PRB CBM play is still underway, to meet Wyoming's Platte River commitments could buy time for development of additional alternatives for meeting the decree requirements in the future.

- **Cons:** Trans-basin diversions can be complicated and costly. Among the criteria for the evaluation and administration of water development projects by the Water Development Commission is the requirement to "address the impact of the diversion and recommend measures to mitigate any adverse impact identified in the basin of origin."[33]

Technology-based Limits

Water treatment is not necessary when the water already meets the requirements for which it is used. Continued discharge of some CBM waters to surface drainages, however, will continue to require some level of effluent treatment. Moreover, many of the options for alternative water use or storage discussed above also would require some level of water treatment prior to use or storage. Currently, the Wyoming DEQ relies on narrative rather than numeric water-quality discharge standards for discharges for the main CBM water quality parameters of concern (e.g., EC and SAR). Recently, Kuipers (2004) released a report evaluating "technology-based effluent limitations" for CBM water in the PRB.

Whether available treatment technologies were employed to meet effluent discharge requirements or water re-use opportunities, the cost-effectiveness of technologies such as reverse osmosis and countercurrent ion exchange for CBM water treatment should be re-evaluated. Several recent studies have reported a range of costs for some of the more plausible treatment technology options. One of these studies (U.S. DOE, 2002) indicated that current water management practices are economical except for treatment by reverse osmosis, whereas another

[33] Wyo. Rev. Stat. § 41-2-121 (a)(i)(E)(VIII).

study (Goerold, 2002) indicated that all treatment alternatives seemed to be economically feasible. But in the past year, CBM producers in the PRB and service companies working with producers have begun using reverse osmosis and countercurrent ion-exchange technologies and are pursuing plans for use of desalinization technologies (see Table 3). With this more recent experience about the effectiveness and costs of these technologies for CBM waters in the PRB, a re-evaluation of technology-based treatment would seem appropriate.

- **Pros:** Treatment would make the water available for more uses, whether it be agriculture, industrial, domestic or municipal use.

- **Cons:** Costs can be high for reverse osmosis or ion exchange. Producers would still have to be concerned with brine disposal, probably by deep well injection. Discharging treated water into some naturally turbid waters can actually degrade the stream for some fish species, (e.g., the turbidity-adapted species native to the Powder River). Because of the variation in surface water quality across the PRB, broadly applied technology-based limits may not be ideal, and limits might need to be river-basin specific.

Watershed-based Water Management – Gathering, Treatment, Storage & Use

With a coordinated multi-agency quantity/quality watershed management strategy there also may be new opportunities for more efficient gathering, treatment (as necessary), storage or use of CBM water.

As evident from the Water Quality section and water quality data in Figures 3, 4 and 5, presented above, the quality of CBM water in the PRB varies from watershed to watershed. Whereas quality of CBM water is quite good from the shallower coals found in the Cheyenne and Belle Fourche watersheds, water quality is poorer from the deeper coals found in the Little Powder, Powder, and Tongue watersheds and appears to be even poorer quality in other non-PRB CBM fields. If CBM water could be gathered within each of these watersheds, or sub-watersheds, with similar water quality characteristics, it might be possible to gain economies of scale through centralized water treatment facilities that would make the water suitable for use, storage, or discharge.

A feasibility study would be necessary to determine the economic viability of constructing systems to gather and treat water in each watershed. “Unitization” of water management, including pipeline, sewerage and treatment facilities, through creation of water management districts has been successful for household potable water delivery and effluent treatment systems. Perhaps implementation of a similar system for CBM water gathering and treatment could be aided by the Wyoming Pipeline Authority and the Wyoming Water Development Commission working with other agencies, conservation districts, CBM producers, and possible water users.

- **Pros:** Watershed-scale centralized water gathering, treatment, storage or use systems could allow for the use of CBM produced water by landowners and even municipalities. Perhaps centralized water management should be a topic of discussion during DEQ’s watershed discharge permitting process (discussed below) so that, while the key stakeholders are together, water use or management decisions could be made collaboratively. Other agencies, such as the WWDC, should participate in this process.

- **<u>Cons:</u>** Coordinated planning and allocation of monetary resources would have to be made for construction of a gathering pipeline network, treatment or storage system. The volume of produced CBM water will likely decrease over time as production declines. The lifetime of a pipeline network or treatment system may be relatively short (decades) and not justify the cost. Possible uses of the gathering lines or treatment systems after CBM development would need to be considered.

  There is also the issue of deciding which agency (e.g., Wyoming Pipeline Authority or Wyoming Water Development Commission) might manage the planning, funding and oversight of such projects. It would also be necessary to decide what public or private entity would actually conduct the operation and maintenance of a water gathering, treatment or storage system. Local governments operate municipal or regional water and wastewater treatment systems with taxpayer money funding the operation. One suggestion is to form a joint powers board to manage such a water system.

Watershed-based CBM Discharge Permitting – Agency Coordination

As noted above in the section on Existing State Regulatory Structure, the Wyoming DEQ recently began implementing a new watershed-based approach for permitting CBM discharges (Wagner, 2005). As of November, 2005, watershed permits in three watersheds were expected to go out for public review in December, with two more watersheds to follow in late spring, 2006, and three others in late summer, 2006 (Parfitt, 2005). Once this new policy is fully implemented, DEQ-approved watershed discharge permitting plans for Hydrologic Unit Code (HUC) level 10 (i.e., relatively small) drainages will be required before WYPDES discharge permits for CBM water will be issued. DEQ policy already requires groundwater monitoring for unlined CBM water ponds that could threaten groundwater quality. The new policy will establish a multi-party process to evaluate the extent of groundwater problems associated with existing ponds for CBM water.

Due to the site-specific nature of the issues surrounding CBM development, DEQ's watershed permitting program seems to be a logical approach to addressing water discharge issues. However, this program only addresses discharge of CBM water and does not consider the impacts of water quantity or the potential for other water management options other than discharge (Zygmunt, 2005).

The DEQ watershed-based permitting program is also a good model for agency coordination. Representatives from the WGFD, SEO, WOGCC, local conservation districts, and the BLM also participate in the watershed-base discharge permitting program.

Up to this point, neither the SEO nor the DEQ has regulated the quantity of water discharged – often referred to as the "flow" – which has caused flooding problems due to CBM water discharges for some downstream landowners. The SEO only regulates the allocation of flow under "scarce" supply and is unable under current statutory authority to regulate "overabundance" of water encountered at times with CBM water. But according to some interpretations, DEQ does have authority to regulate flow under the Clean Water Act. In 1994 the U.S. Supreme Court held that state agencies can impose flow limitations to protect designated uses, such as fisheries.[34] Watershed-based permitting could provide an opportunity for DEQ to set flow limits to protect water uses from threats associated with too much water entering the system, though DEQ will likely need to adopt new regulatory language to implement such a new policy.

If DEQ's watershed approach for discharge permits also could be linked with a watershed approach for water withdrawal permits through the SEO's office, additional management opportunities might be achieved. Under current SEO regulatory authority, groundwater control areas can be created on a watershed basis to allow increased control over water development.[35] If watershed management plans allowed for or required such an overlay of DEQ and SEO jurisdictions, the result could be a coordinated water quantity/quality management strategy. However, the current SEO regulations for creation of a control area require formation of an independent advisory board, separate from the DEQ watershed committees, which may extend and/or complicate the permitting process (LaBonde, 2005).

Any additional coordination that could be achieved, with the WOGCC for required applications for permits to drill (APDs), and with the BLM for required APDs and water management plans, could conceivably streamline permitting and reporting requirements for producers and improve the potential for effective watershed-based water management.

- **Pros:** Watershed-based permitting allows for site-specific water discharge requirements that can be tailored to local conditions. This would promote communication and a working relationship among landowners, agency representatives and producers. Permits would have set expiration dates and would not be renewed without approved watershed management plans. This process has also promoted inter-agency coordination which is necessary to resolve multi-jurisdictional water management issues, and the process would be amenable to adaptive management principles.

- **Cons:** According to DEQ, the watershed permitting process is taking longer than anticipated, but in the meantime DEQ maintains that the current surface water discharge permitting approach is protective of the state's surface water quality standards (Wagner, 2005). Using a collaborative approach to watershed permitting can take many months or even years and can result in some participants being dissatisfied with the outcome.

  The limited number of DEQ staff and monetary resources available for the process are contributing to the slow pace of watershed permitting. Allocation of additional staffing and budget resources to the DEQ Water Quality Division for this effort could shorten the time frame.

[34] *PUD No. 1 of Jefferson County v. Washington Department of Ecology*, 511 U.S. 700, 714-17 (1994),
[35] *See* Wyo. Rev. Stat. § 41-3-912. Control areas; board member districts; designation; redesignation; duty of state engineer; hearings. (a) "Control area" means any underground water district or subdistrict that has been so designated by the board of control. The board of control may designate a control area for the following reasons: (i) The use of underground water is approaching a use equal to the current recharge rate; (ii) Ground water levels are declining or have declined excessively; (iii) Conflicts between users are occurring or are foreseeable; (iv) The waste of water is occurring or may occur; or (v) Other conditions exist or may arise that require regulation for the protection of the public interest.

Regulatory changes may be needed to give agencies the authority to fully implement watershed-based permitting. Concerns have been expressed that this watershed permitting process appears to be primarily to facilitate faster permitting while what is really needed is comprehensive watershed-based planning.

Coordinated Management and Regulation of CBM

A number of the challenges encountered with CBM development in Wyoming, including water management and disposal, likely have been due to an inadequate and sometimes confusing regulatory framework for CBM. As reviewed earlier in this report, the regulatory framework for oil and gas development and for water quantity and quality management was never really structured to handle the kinds of landscape-scale challenges posed by CBM development. So, agencies have had to "fit" CBM water issues into existing statutory and regulatory frameworks. Thus, it is not surprising that overall regulation of CBM development in general, and CBM water in particular, may include gaps in regulatory coverage and overlapping regulatory responsibilities of the state and federal agencies responsible for overseeing and permitting CBM development. An important example of a gap in regulatory coverage involves degraded water quality that can result when otherwise good quality CBM water picks up salts from the soils in an intermittent channel downstream from a permitted CBM discharge point. And several instances of regulatory overlap appear to occur, particularly between state and federal agencies.

Moreover, issues with gaps or overlaps in regulation have been exacerbated by an apparent lack of sufficient or effective agency cooperation in managing CBM development. Given the workload of agencies under a flood of CBM and other permit applications in the past few years, agencies have, without doubt, lacked the manpower and other resources to put in place successful cooperative strategies for identifying and addressing these apparent gaps and overlaps in regulation. As noted earlier in this report, efforts like the Governor's Strengthening and Streamlining Working Groups for oil and gas permitting have made strides in bringing agencies together to find solutions to cooperative data management and sharing issues. And as mentioned in the Watershed-based Discharge Permitting section, agencies are working together with other stakeholders to develop discharge requirements within watersheds. Many agree that these efforts are steps in the right direction and excellent models for additional cooperative activities.

In discussions with state agency representatives over the past few months, one response to the kinds of regulatory concerns raised above is that "we don't have statutory authority to address that issue." Based on this response, a thorough review of authorizing statutes, beyond the scope of this report, would seem to be in order. Through the years, agencies clearly have done their best to make their regulations "fit" CBM, but many agree now that this strategy has resulted in the kinds of difficulties outlined in this report. It seems that the CBM industry needs to be regulated as a unique kind of development. This would require statutory revisions or an entirely new statute that addresses CBM specifically.

Creation of something like a "CBM Management Act" or a set of coordinated statutory revisions that specifically addressed regulation of CBM, along with bolstered agency coordination and cooperation, could help remedy the kinds of challenges mentioned above related to water, but also related to all issues unique to CBM. This "act" could be modeled after the Industrial Development Information and Siting Act (IDISA) and given a sunset date to revisit the need for the act as CBM production declines. The IDISA was created in 1975 during the Herschler Administration to examine the socio-economic impacts that construction of large industrial facilities could have on nearby communities. It also requires information and recommendations from various state agencies for the impact analysis required under the statute.

Another example of coordinated management of a unique industry can be found in Colorado's "Joint Review Process" established several decades ago to achieve coordinated regulation and permitting of oil shale developments.[36] Although Colorado's Joint Review Process was established to coordinate permitting by existing agencies, such a "joint process" could also include provisions for actually having statutory authority and responsibility for setting industry-specific regulations, issuing permits, managing compliance review, etc.

A "CBM Management Act" could contain language for how the relevant state agencies are to regulate CBM development and for requiring them to coordinate and cooperate. For example, a "CBM Management Act" could take the model of DEQ's watershed-based discharge permitting one step further and require coordination of integrated DEQ, SEO and WOGCC watershed-based water management strategies. Again, because of the site-specific nature of CBM, collaborative management of produced water by watershed makes sense so that the involved stakeholders can work together to decide which water management techniques best meet their needs and are best for that particular environment.

The concept of "best available control technology" could be considered either as part of a watershed-based approach, or independently. Industry might be required to submit a water management plan that looks at other options besides discharge. Issuance of a permit would be contingent upon submittal of this review and agency approval.

Such a "CBM Management Act" could, in effect, create a "CBM super-agency" comprised of representatives from the relevant agencies or, alternatively, a "CBM coordinator" with final statutory and regulatory authority on all matters related to CBM including water. Such a "CBM super-agency" or "CBM coordinator" could be overseen by a "CBM Management Commission." Just as the WOGCC reports to their commission and the DEQ reports to the Environmental Quality Council, the CBM Management Commission could receive reports on all matters concerning CBM. Because of the complexity of creating such an "Act," it may be beneficial to convene a task force of representatives from agencies, non-governmental organizations, industry, and landowners to work with the Governor's Office and responsible Legislative Committees to outline the details of any such statutory revision.

- **Pros:** Focused revisions of existing governing statutes for relevant agencies, or, alternatively, a "CBM Management Act," could fill in the current regulatory gaps that exist from trying to "fit" CBM development to conventional oil and gas regulations. Putting statutory authority specifically behind CBM development would also add some "teeth" to the current DEQ watershed-based discharge permitting program. It could also do more to promote agency coordination and cooperation and build on the work of the Governor's Strengthening and Streamlining Working Groups for permitting to create a "one-stop permitting and reporting" process for industry. More importantly, agency coordination could increase certainty for industry about permit and compliance requirements. It would also help the agencies identify problem areas and better assess cumulative environmental impacts.

[36] *See* Col. Rev. Stat. § 34-10-1-1 et seq (1995) (repealed in 1991, effective July 1, 1995).

Wyoming is in a unique position to take this kind of action. Relative to other states trying to deal with large landscape-scale developments like CBM, Wyoming has a small government structure with most of the key agency people located in Cheyenne. This should facilitate agency cooperation and coordination.

Another advantage Wyoming has at this time is a budget surplus. The CBM industry is a major contributor to this budget surplus and it seems logical to put some of this money back into strategically managing the development to maximize future revenues for the state and protect the environment.

- **Cons:** Creation and implementation of an effective “CBM Management Act,” or coordinated statutory revisions under which agencies operate, would take time and some argue that there is no time to waste when addressing some of the issues associated with CBM development. Also, some could perceive the concept of a “CBM Management Act” as adding to government bureaucracy and making management more complex.

  In making any statutory or regulatory revisions, there is always the possibility of unintended consequences. If revisions were not specifically written to address unique CBM issues, there could be unintended consequences for other municipal, agricultural or industrial water management practices.

Possible Next Steps

Whether one believes that CBM water management and regulation is or is not in need of change, further development of CBM in Wyoming is highly controversial and may even be under some threat due to water management difficulties, as was noted in the Introduction to this report. Although Wyoming's management and regulation of CBM development, including CBM water, could be continued under current regulatory policy and procedure, some adjustment is needed. In fact, incremental changes in CBM water management and regulation are already underway, including the Governor's Strengthening and Streamlining Working Groups on oil and gas permitting, DEQ's new watershed-based approach for permitting CBM water discharges, and development of best management practices (BMPs) for the CBM industry, as discussed earlier.

To begin evaluating possible additional adjustments in the way CBM water management and regulation are addressed in Wyoming, several incremental or comprehensive strategies are probably worth considering. Based on a request from the Governor's Office, we have outlined possible next steps toward future changes in CBM water management and regulation. Many of these ideas have been suggested in discussions stimulated by earlier drafts of this report by various parties with interests or concerns about CBM development, and the ideas are offered here to stimulate thinking and foster broad discussion among CBM stakeholders.

These ideas could be pursued incrementally or comprehensively. Incremental change might be easier to achieve, although such stepwise changes also might create a "moving target" problem for all involved, which would increase uncertainty about what regulations and management strategies might look like down the road. This could lead to greater confusion and planning problems for industry and agencies, as well as confusion for landowners or the environmental community about whether possible stepwise incremental changes would really solve the problems about which they are concerned.

Comprehensive change, on the other hand, might allow agencies to "leapfrog" past the stepwise, incremental changes that might be adopted and avoid the "moving target" problem alluded to above. Of course, a set of comprehensive adjustments in management and regulation of CBM would be a difficult undertaking with major disagreements that would need to be overcome and considerable time necessary for negotiation. But the potential benefit of achieving some certainty through a comprehensive set of regulatory adjustments might be a highly desirable goal, if achievable within a reasonable time frame.

The ideas outlined below are based, in part, on earlier discussion in this report and are grouped into three general approaches: (1) technical workshops and studies; (2) incremental adjustment in water management and regulation; and (3) comprehensive review and revision of CBM management and regulation. These possible next steps are not mutually exclusive and elements of each could be pursued simultaneously.

Expert Technical and Administrative Workshops and/or Studies on Key CBM Water Management Issues

Whether or not efforts are made in the near future to consider or adopt regulatory changes for CBM, there are several water management issues that could benefit from the sharing of information among knowledgeable experts from the CBM industry, technical consultants, agencies, academics, landowners, environmental groups and others. These kinds of technical workshops often can be more productive and more open to the possibility of breakthroughs than traditional “regulatory hearings” where stakeholders often argue positions in an adversarial setting. In addition to or in conjunction with technical workshops, some of the topics listed below also could be pursued as studies performed by agencies, industry or third parties.

Separate discussions and studies certainly have been underway on some or all of the topics listed below by the CBM industry, by agencies or by other interested parties. But further collaborative discussion in a workshop setting that is open to the public could be a valuable way to share information, possibly develop agreement among stakeholder groups, and engender more public trust and acceptance of ideas for managing CBM water.

Several representatives from industry, consulting firms, agencies, academia, environmental groups and independent foundations have already expressed interest in supporting, convening or participating in workshops covering topics such as those listed below.

- Water gathering, transport, treatment, storage, use and disposal: Technical, economic, infrastructure, and innovative institutional arrangements for any or all of these water management issues.
- Treatment technology for CBM water: Technical and economic evaluation of new and emerging technologies.
- Plant and soil reclamation: Methods and costs associated with salinity and sodium-induced changes in plant/soil communities affected by CBM water discharges.
- Suitability of potential receiving formations for water flood enhanced oil recovery (EOR) or groundwater injection in the PRB and other Wyoming CBM development areas.
- “Reservoir engineering” analyses to maximize CBM gas production and minimize water production.
- Trans-basin diversions: Analysis of opportunities, costs and legal/administrative constraints for trans-basin diversion of CBM water to meet out-of-basin water needs, including interstate compact and decree commitments.
- Socioeconomic analysis of positive and negative impacts from CBM development on communities and on landowners with and without mineral rights.
- Economic analysis of revenue from, and costs associated with, CBM development including analysis of regulatory scenarios and other options for dealing with CBM water.
- Review and analysis of statutory authority and agency regulations for key agencies (SEO, WOGCC, DEQ, other ancillary state agencies such as the Wyoming Game and Fish Department and the Department of Revenue, as well as BLM and other relevant federal agencies) as they relate to CBM water management and regulation, to determine areas of potential overlap or gaps in statutory authority and/or regulation.
- Review of existing and possible new bonding authorities, and economic analysis of bonding amounts needed. New bonding authorities could be considered for CBM-relevant issues such as adverse water quality or quantity impacts that can occur offsite (e.g., downstream).
- Legal/administrative studies to determine the possibility of establishing stronger coordination between federal and state agencies for any of the current federal responsibilities for permitting and management of CBM (e.g., leasing, applications for permits to drill [APD’s] required by both BLM and WOGCC; U.S. Army Corps of Engineers and SEO authority over on-channel reservoirs).

- Multi-stakeholder and/or industry-led formulation of Best Management Practices (BMPs) for CBM water (as well as other issues), starting with BMPs developed for CBM by the Western Governors' Association (WGA, 2004).
- Review of watershed-based management approaches with representatives from all the existing watershed groups.
- Evaluate adaptive management approaches in managing CBM water.
- Review wildlife issues and monitoring needs related to water quality and quantity.

Incremental Adjustment in CBM Water Management and Regulation

As noted above, important incremental changes in CBM water management and regulation are already underway, including the Governor's Strengthening and Streamlining Environmental Working Group and Industry Working Group on oil and gas, the Governor's Strengthening and Streamlining Working Group on interagency data sharing and electronic permitting for oil and gas, the CBM Working Group comprised of state agency heads, DEQ's new watershed-based approach for permitting CBM water discharges, and development of voluntary best management practices (BMPs) for CBM development. Some of the additional incremental adjustments listed below could be achieved through voluntary actions by industry, through increased or re-directed funding within agencies, through regulatory change by agencies, and/or through cooperative efforts among agencies. But some of the incremental adjustments listed below may require statutory changes followed by promulgation of new regulations by agencies.

- Strengthen monitoring and enforcement of existing rules and regulations with additional funding for personnel in DEQ, SEO, and WOGCC.
- Speed up and strengthen DEQ's watershed-based planning and permitting program with increased staff and funding and with statutory/regulatory revision, as necessary, to formally (rather than informally) integrate CBM-related permitting and management by SEO, WOGCC and others.
- Develop and implement comprehensive data sharing and management by building on the arrangements being discussed as part of the Governor's Strengthening and Streamlining Working Group on interagency data sharing, with a comprehensive major data management clearinghouse system compatible with permitting, monitoring reports, compliance review, etc., accessible to agencies, industry and the public. This effort should also take advantage of the existing CBM Clearinghouse maintained by the University of Wyoming (www.cbmclearinghouse.info). Such efforts will also require better statewide coordination of geospatial data development and dissemination, including data content and formatting standards for spatial and non-spatial reference and resource-specific categories of data.
- Identify and fix regulatory gaps or overlaps, agency by agency, as necessary, including:
    - DEQ and/or SEO management and permitting of "flow" as part of CBM discharges, so as to avoid the apparent gap in regulation of the volume of CBM water in ephemeral and other drainages.
    - Management and regulation to cover the apparent gap in DEQ's ability to assess and regulate water quality in drainages downflow from where CBM water leaves the discharge point specified in a discharge permit.

  - SEO and WOGCC (as well as the U.S. Army Corps of Engineers and BLM) management and permitting of on- and off-channel reservoirs and infiltration/evaporation ponds.
- Consider adopting multi-stakeholder and/or industry formulated "Best Management Practices" for CBM (see above) as regulations under the authority of WOGCC or multiple agencies.

Comprehensive Review and Revision of CBM Management and Regulation

In addition to workshops, studies and incremental steps, such as those listed above, to evaluate and/or adjust specific elements of CBM management and regulation, another option could be to address these same and other issues systematically and comprehensively. In fact, any strategy to consider and possibly implement comprehensive review and revision of CBM management and regulation would likely need to be an "umbrella" for the issues covered in this report for CBM water as well as other CBM issues.

In an earlier section of this report on Coordinated Management and Regulation of CBM, and reiterated briefly below, we suggest two approaches for comprehensive review, management and regulation of CBM: 1) create a "CBM coordinator" position, and 2) adopt a new statute such as a "CBM Management Act." Either of these approaches could help coordinate all state government regulation of CBM as well as create a centralized place for coordination with BLM and the other federal agencies involved in CBM management and regulation.

- "CBM Coordinator" – Although some coordination already occurs among state agencies and even among state and federal agencies through working groups and other mechanisms, no one agency or one person currently has official responsibility to coordinate CBM management and regulation. Although it might be helpful to informally establish such a coordinator in the Office of the Governor or elsewhere in State Government, without firm and official authority to oversee and manage CBM regulation by different agencies, comprehensive management might be difficult to achieve. Rather, for a coordinator to have decision-making authority it would no doubt be necessary either to modify agency-specific authorizing statutes or to adopt some overarching new statute.
- "CBM Management Act" – Rather than attempting to "fix" each agency's regulation of CBM by adjusting authorizing statutes and/or regulations for each agency, adoption of an overarching new "umbrella" statute for management and regulation of CBM development should be considered. If this idea was to find sufficient support inside and outside Wyoming government, it would certainly require thorough analysis, evaluation and crafting through something like a Legislative interim study and/or some sort of Governor-Legislative blue ribbon committee.

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APPENDIX A – QUESTIONS FROM THE GOVERNOR'S OFFICE

Research Questions Regarding Water Production from CBM Wells

Fundamental Question:
What are the options for dealing with water produced through CBM development?

Subsequent Questions:

1. How much CBM water has been, is and will be produced in the future? What will be its quality?
   Both basin specific and state-wide.

2. An analysis of the current options for dealing with this water. These include:
   Impoundment
   Re-injection
   Treatment
   Allow the current situation to continue

3. What other options are we missing?
   Commercial uses?
   Dust mitigation?

Impacts:
This analysis needs to include the entire range of impacts for each option, including, but not limited to:

<u>The environmental consequences of each option</u>

- Increased stream flow of either or both treated and non-treated water;
- Downstream impacts on the State of Montana as well as the Colorado River;
- What is the technical process of treating the range of CBM water (explained in a simple one page block diagram format)? What are the waste products of the treating process? How long does the treating process take?

<u>The economic impact of the options to the producer, landowner and the entire region cumulatively</u>

- How do the options impact the state's financial outlook?;
- Socioeconomic implications that stem from the options (job creation, wealth creation, job losses, etc.);
- What options will allow development to continue with certainty?;

- How much will it cost per thousand gallons to do impoundment, re-injection, or treatment?;
- How much would it cost per thousand gallons to make CBM water commercially usable? (For example, as municipal water in cities, irrigation water in agriculture, delivery by pipeline to a distant location, etc.);

<u>Wildlife impacts</u>

- Can CBM ponds improve wildlife habitat by providing more watering holes?

<u>Agricultural impacts</u>

- What are the impacts of releasing treated water?
- What are the possible agricultural impacts associated with increased water volumes?;
- What are the possible agricultural impacts associated with treated water?

<u>Regulatory limitations</u>

- What are the regulatory limitations in utilizing other options?