Coalbed Methane Development in Wyoming’s Powder River Basin

Diana Hulme

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I. Introduction

The western United States abounds with natural resources. People are drawn to the scenic vistas, diverse wildlife, clean air, clean water, and recreational opportunities. People have also been lured by the economic potential of the vast mineral resources that reside in the West. The early Euroamerican settlers came to the West and used coal for heat. Coal consumption began to dominate the energy scene in the second half of the 1800’s with the advent of the transcontinental railroad. Later, coal use became overshadowed by the discovery of crude oil, which carried the nation through two world wars in the mid 1900’s. The environmental movement of the early 1970’s saw a shift back to coal, but to cleaner burning low sulfur coal that is found in parts of the West. Uranium was also mined in the West in the 1940’s through the late 1970’s for nuclear power generation of electricity and for the military.

Natural gas is another energy source produced in the West throughout most of the 20th century. Natural gas has become the fossil fuel of choice in the United States in the last two decades, as it burns cleaner than oil or coal. While there have been some significant discoveries of conventional natural gas fields in Wyoming and Montana in the recent years, a new energy source has emerged. Technology has finally allowed for the economic extraction of coalbed methane (CBM).

It has been known for centuries that methane gas is found in association with coal, but until the 1970’s, CBM was considered more of a safety hazard than a potential energy source. The huge coal deposits found in Montana, Wyoming, Colorado, New Mexico and Utah have become new energy reservoirs for the United States, not only for the coal, but also for the methane associated with it. While development of this resource has benefits for the country as a whole, it does not come without impacts to the western environment, the communities and the culture in the areas where it is produced.

The Powder River Basin (PRB), located in northeastern Wyoming and stretching north into southeastern Montana, has become recognized as the premier provider of low sulfur coal, and has contributed oil and gas resources for the United States’ energy needs. But since the mid-1980’s, the focus of mineral production in the PRB has turned from coal to CBM. Since the first CBM well was tapped in Wyoming’s PRB in 1986, the industry has boomed in Wyoming, but development has occurred to a much lesser extent in Montana due to regulatory constraints imposed by the state.

This case study will discuss the issues surrounding CBM development in the Powder River Basin, primarily focusing on the more aggressive development that has occurred in Wyoming. The first section will describe the environment and mineral resources in the area of development, relying heavily on the resource information provided in Chapter 3 of the Bureau of Land Management, Draft Environmental Impact Statement for the Powder River Basin Oil and Gas Project, January, 2002,1 and Chapter 3 of the Montana Statewide Draft Oil and Gas Environmental Impact Statement and Amendment of the Powder River Basin and Billings Resource Management Plans, January, 2002.2 The second section will examine the energy potential of CBM, the net energy value and cost-benefit of the resource, the environmental and socioeconomic issues surrounding CBM development in the PRB, the trade-off between the environment and the mineral resource value, and technological advances in CBM development that have the potential to minimize impacts to the environment. The last section will examine lessons learned from the development to date, and the potential for future development.

Environmental Resources

Geography1

The PRB is a rolling upland plain, extending 220 miles from north to south across eastern Wyoming and Montana, and is generally less than 95 miles wide from east to west. The topography is relatively flat, but is broken up by hills, buttes and mesas. The PRB is bordered by the Big Horn
Mountain range to the west; the Black Hills to the east; and the Casper Arch, Laramie Range, and Hartville Uplift to the south. Elevation in the PRB ranges from 3,000 to 5,000 feet above mean sea level. The basin is drained to the north and east by six major rivers that all contribute to the Missouri River System: the Tongue River, Powder River, Little Powder River, Yellowstone River, Belle Fourche River and Cheyenne River (Figure 1).

The climate in the region is arid, receiving an average of 14 inches per year of precipitation. The average daily temperature ranges from a low of 5–10 degrees Fahrenheit (°F) to a high of 30–35 °F in mid-winter, and lows of 55–60 °F to highs of 80–85 °F in mid-summer. Prevailing winds are from the southwest at an average annual speed of 15 miles per hour. Wind speeds tend to peak in late morning and afternoon and usually become calm in the evening due to cooling temperatures.

**Figure 1** The Powder River Basin in Wyoming and Montana showing major towns and rivers (produced by Scott Lieske, University of Wyoming, Department of Agriculture and Applied Economics, 2002).

**Water**

**Surface Water**

Wyoming’s PRB can be divided up into 18 sub-watersheds, including the mountainous and plains regions of the PRB. Streambeds in the mountainous areas are primarily recharged by snowmelt and those in the plains region are largely influenced by runoff as a result of heavy rainstorms. Stream flows are typically highest in May, June, and July and lowest January through March. Stream infiltration, evaporation, and evapotranspiration rates are higher in the plains areas of the PRB, especially during the summer months.

Surface water quality varies across the PRB. Lowland waters tend to be high in sodium sulfate whereas waters in higher elevations are often high in calcium bicarbonate. Surface water quality in the PRB is affected by irrigation return flows, runoff from erosive soils and other natural background conditions. This results in surface waters with elevated concentrations of total dissolved solids (TDS). TDS represents the sum of all dissolved constituents in a water sample and is often used as an overall indicator of water quality. The drinking water standard for TDS is 500 mg/L. Most surface waters in the PRB exceed this level, ranging from 500–2500 milligrams per liter (mg/L) TDS.

PRB surface waters tend to have a high sodium absorption ratio (SAR). SAR represents the proportion of sodium ions to calcium and magnesium ions in water. Water with a high SAR can impact the structure of certain soils through sodium accumulation and negatively affect vegetative growth. The SAR value of water becomes important when the water is going to be discharged onto the ground or used for irrigation. In these cases, the character of the soil has to be considered in relation to the SAR of the water. The soils in the PRB tend to have a high clay content that reacts negatively with high SAR waters and caution must be used when considering the use of this type of water for crop irrigation.
GROUNDWATER
Groundwater in the PRB is part of the Northern Great Plains Aquifer System. There is an alluvial unconfined aquifer exposed to the surface throughout much of the PRB, and underlying layers of aquifers separated by complete or partial confining layers. The underlying aquifers, such as the Wasatch, Fort Union and Tullock formations, are located primarily in sandstones and coals, which offer substantial water storage. These are also the aquifers that have been tapped for CBM.

Groundwater quality varies across the PRB and between aquifers. The alluvial aquifer has varying concentrations of total dissolved solids (TDS), with values ranging from 106 to 6,600 mg/L. The high TDS values are typically attributed to excess sodium and sulfate ions. In general, waters within unconfined portions of the coal aquifer are calcium-magnesium-sulfate types and those within confined portions of the aquifer are sodium bicarbonate types. Groundwater samples from confined aquifers show an average TDS of 740 mg/L and average bicarbonate and sodium concentrations of 850 and 240 mg/L, respectively.

Alluvial groundwater in the PRB is typically not suitable for drinking water. It’s marginal for irrigation but acceptable for use by livestock and wildlife. Domestic water wells in the PRB are generally less than 500 feet deep and produce from the Fort Union or Wasatch aquifers, the same aquifers where CBM is produced.

AIR
Air pollutants in the PRB are generated from mobile and stationary sources. Pollutants from mobile sources, such as gasoline and diesel fired automobiles, trucks, and trains include nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), particulate matter (PM) and sulfur dioxide (SO2). PM is also generated from vehicle traffic on unpaved roads and from wind. Stationary sources and their pollutants in the PRB include: PM from surface coal mining; NOx, SO2 and PM from coal fired power plants; and NOx, SO2, CO and VOC from gas fired compressor stations and gas processing plants. Pollutants from these stationary sources are generated in isolated areas. The flat topography and moderate to high winds in the PRB aid in the dispersion of these pollutants.

Visibility, defined as the distance one can see and the ability to perceive color, contrast and detail, can be impacted by meteorological conditions and air pollutants. Visibility in the PRB is considered good, but there may be localized areas of poor visibility depending on wind speeds and industrial activity.

SOIL
The soil in the PRB is generally low in organic matter and tends to be alkaline. Agricultural crops are difficult to grow without irrigation. Some localized areas of the PRB around the confluence of the Powder River, the South Fork of the Powder River, and along the Belle Fourche River contain high salinity soils while other areas have clay type soils. When water with a high SAR is introduced to these soils, vegetative growth can become impaired, inhibiting water uptake by plants. The revegetation potential is poor in disturbed areas containing these types of soils.

VEGETATION
Most of the vegetative ground cover in the PRB consists of shortgrass and mixed-grass prairie and sagebrush shrubland. There are areas of coniferous forest on the extreme east and west fringes of the PRB and riparian areas are found along major streams and water bodies.

THREATENED AND ENDANGERED SPECIES
As mandated by the Endangered Species Act (ESA), the United States Fish and Wildlife Service (USFWS), is charged with identifying and protecting threatened and endangered plant and animal species. The ESA defines an endangered species as any species that is in danger of extinction throughout all or a significant portion of its range. The ESA defines a threatened species as any...
species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

The Ute ladies'-tresses is the only plant species on the threatened list that is found in the PRB (Figure 2). This plant is a perennial herb that flowers from late July to September and is found in moist, sub-irrigated valley floors.

**Wildlife**

The shortgrass and mixed-grass prairie habitat supports a variety of terrestrial and aquatic wildlife. Terrestrial species include big game animals such as pronghorn, deer, and elk; predators such as coyote, fox, eagles, and hawks; upland and migratory game birds such as sage grouse, ducks and geese; and a variety of other birds and rodents. Aquatic species include various species of trout, bass, catfish, perch and chub. Figures 3–5 show some of the wildlife common to the PRB.

**Threatened, endangered or sensitive species**

The Wyoming PRB Draft EIS issued in January 2002 listed the sturgeon chub (Figure 6) as the only animal species considered to be endangered in the PRB. Since issuance of the Draft EIS, the Wyoming State Engineer’s Office has stated that additional sturgeon chub populations have been found in Montana and the species has now been given “status 1” by the Wyoming Game and Fish Department, meaning the populations are restricted or declining and extirpation is possible (personal communication with S. Lowry, May 2, 2002). The Preble’s jumping mouse and bald eagle are listed as threatened species, and candidate species for listing in the PRB include the black-tailed prairie dog and mountain plover.

**Historical resources**

**Paleontologic resources**

Scientifically significant paleontologic resources, including vertebrate, invertebrate, plant, and trace fossils are thought to occur within the PRB, especially in the Pumpkin Buttes area, located in southwestern Campbell County, Wyoming. However, much of the PRB has not been extensively explored for fossils and the potential exists for future finds.

**Cultural history**

Prior to Euroamerican settlement, many Native American tribes passed through or temporarily settled in the PRB to take advantage of the vast herds of bison. About 200 years ago, European explorers and fur traders entered the area and established the Rocky Mountain Fur Trade in what is now Fort Laramie, Wyoming. The fur trade declined in the 1830’s and emigrant trails were developed in the southern portion of the PRB. The discovery of gold in Montana in the 1860’s, and in the Black Hills in the 1870’s, created increased conflicts between tribes and prospectors who were trying to move through the PRB to find their fortunes.

Sheep and cattle ranching moved into the PRB with the passage of the Homestead Act of 1862. This act also granted subsurface mineral rights to the homesteader. Subsequent homestead acts, passed in 1909 and 1916, allowed for larger tract homestead entries, but partially or entirely reserved federal mineral rights while granting surface rights to the patent. This created what is known...
as a “split estate,” or an area of contrasting surface and mineral ownership. In most cases, the surface is private and the minerals are federal.

Throughout most of the 1900’s, mining and mineral extraction became an important element in the regional economy. The large shallow deposits of coal in the eastern PRB has brought surface coal mining to the region in addition to oil and gas development.

**MINERAL RESOURCES**

The PRB is one of the major mineral development areas in North America. Oil, gas, coal, uranium and CBM are the primary mineral resources found there.

**COAL**

The PRB contains some of the largest accumulations of low sulfur sub-bituminous coal in the world. Thick coal deposits occur at or near the surface along the eastern boundary of the PRB, in a north-south trend west of the towns of Gillette and Wright, Wyoming and in the northwestern portion of the PRB. Wyoming has been the largest producer of coal in the United States for over ten years, with the PRB producing over 80% of the state’s coal (http://lmi.state.wy.us). Currently, there are 17 surface coal mines in operation in the eastern portion of the PRB in Wyoming (www.wma-minelife.com). The primary coal seam that is mined is the Wyodak seam, which is 100 feet thick on average.

The state of Montana has the largest reserves of low sulfur coal in the United States. There are five active mines in the PRB of Montana near the towns of Decker and Colstrip.

**OIL AND GAS (NON-CBM)**

Conventional oil and gas development became significant in the southwestern portion of the PRB in the Salt Creek and Teapot Dome areas of Wyoming in the 1950’s and 1960’s. Oil production from this area peaked at 160 million barrels in the early 1970’s and has been steadily declining since. Oil has been produced to a lesser extent in the southern, central and northeast areas of the PRB, but production is in decline there as well. Currently, there are approximately 2,546 productive conventional gas wells operating in the Wyoming portion of the PRB.

The Montana PRB only produces small amounts of oil at the eastern edge of the basin and very small amounts of conventional natural gas from shallow reservoirs. The majority of the oil in Montana is produced in the Williston Basin, located in northeast Montana.

**URANIUM**

Uranium deposits are located in the southern PRB in Wyoming. In the 1950’s and 1960’s, 55 different small surface uranium mines removed over 36,000 tons of ore. Many of these mines remain abandoned. Until recently, two in-situ leach mines were in operation in the southern and southwestern part of the PRB.

Small deposits of uranium are found in Montana’s PRB but it has not been commercially mined in Montana.

**COALBED METHANE**

Coalbed methane is natural gas (methane) that is produced in underground coal seams by either biological or thermogenic processes. During the decay and pressurization of plant matter, methanogenic bacteria break down the matter and produce methane as a by-product. Methane is also generated when underground coal seams undergo excessive heat and pressure. If possible, the methane will escape or migrate to the surface through large fractures in the formation. It is also stored or trapped in coal beds as either free gas in tiny pores or cleats in the coal, as dissolved gas in water within the coal, as adsorbed gas on coal surfaces or as absorbed gas within coal molecules. There is estimated to be 25 trillion cubic feet of recoverable CBM in the Wyoming PRB and 4.5 tcf in the Montana PRB.

**OTHER MINERALS**

Other mineral resources mined in the Wyoming and Montana PRB include aggregate used in construction, clinker or deposits of burned coal, sand and gravel, clay for brick and tile manufacturing, bentonite, limestone, and gypsum.
Land use

Land ownership

Land ownership in the state of Wyoming is 47.7% federally owned, 42.8% privately owned, 6.2% state or locally owned, and 3.3% tribally owned. As Figure 7 shows, most of the federally owned land occurs in the western half of the state and the vast majority of private land ownership is located in the eastern part of the state, including the PRB. However, during settlement of the PRB under the homestead acts of 1909 and 1916, minerals were partially or entirely reserved for the federal government and surface rights were granted to the patent. This created what is known as a split estate, or areas of contrasting surface and mineral ownership. In split estate, the surface is private and the minerals are federal. Even though CBM is associated with coal seams, it is managed by the federal government as an oil and gas right and not a coal right.

Surface land ownership in Montana’s PRB is 65% privately owned, 20% federally owned, 10% tribally owned and the remaining 5% belonging to the state. Figure 8 shows the surface ownership for the Montana PRB.

Federal oil and gas, including CBM rights for the Wyoming and Montana PRB are shown in Figure 9. Federal oil and gas ownership constitutes 63% of the total oil and gas ownership in the Wyoming PRB, and less than 50% in Montana.

Land uses

The BLM, USFS, and State of Wyoming manage land in the PRB along with private landowners. The primary use of private land in the PRB is agricultural rangeland, and the majority of the BLM and USFS land in the PRB is leased for grazing. Extensive surface coal mines are located on the eastern side of the PRB in Wyoming. There are areas of urban and residential land use that are primarily concentrated in or immediately adjacent to incorporated areas. The PRB is also traversed by underground gas.
pipelines and other utilities, and by above-ground transportation corridors for vehicles and trains.

Recreation areas are limited in the PRB as more than 75% of the land is privately owned. However, the PRB does have attractions such as the Thunder Basin National Grassland, several state historic sites, and the historic Bozeman Trail. The majority of the recreation opportunities are located in the Big Horn Mountains that border the PRB on the west and the Black Hills area, including Devil’s Tower National Monument, to the east. There are no wilderness areas in the PRB, but the Cloud Peak Wilderness area is located to the west in the Big Horn Mountains. Figure 10 shows the recreational lands and other points of interest in the Montana and Wyoming PRB.

Figure 8 Bureau of Land Management surface ownership map for the Montana PRB. Source: Montana State Library website, 2002, http://nris.state.mt.us/gis/datalist.htm.

Figure 9 United States Geological Survey map showing federal oil and gas, and coal ownership in the Montana and Wyoming PRB. (From the USGS website, 2002, http://dss1.er.usgs.gov/download/info_prb.htm.)

Socioeconomics

Figure 11 shows the counties and county seats in the Montana and Wyoming PRB. The total population of the Wyoming counties is 79,385 people, or 16% of the total population of the state of Wyoming. Most of the population is concentrated in the incorporated areas. The 2000 census showed that the total population increased by 12.7% from 1990–2000 on average in the Wyoming counties.

The employment sectors that dominate the Wyoming counties are mining, local government, retail trade, and services. Mining is the primary employment sector in Campbell and Converse counties, local government employs the most people in Johnson County and jobs in the service industry dominate Sheridan County. The mining industry tends to pay the highest wages and agriculture the lowest.

Demographics show that the majority of the population in the Wyoming counties is white, between the ages of 25–44 years old, and earns an average annual income of $33,000. These counties experience a poverty rate slightly higher than the state average of 12%.

The Montana counties located in the PRB include Big Horn, Carter, Custer, Powder River, and Rosebud. The PRB area of Montana experienced only 1.5% population growth during the 2000 census period.

Primary employment sectors in Montana’s PRB are services, retail, government and agriculture. Mining was only a significant employment sector in Rosebud County where the surface coal mines are located.

Over 90% of the population in the Montana PRB is white and 6.6% of the population is Native American. The average poverty rate for the area is 17%, over 2% higher than the state average. The average per capita income in the PRB is $17,700 compared to the state average of $21,200.

II. Issues and trade-offs of CBM development in the PRB

This section of the case study will discuss the following economic, environmental, and social issues surrounding CBM development in the PRB:

- Review of the energy potential of the CBM resource
- The net energy available from the development and the net cost benefit
- The environmental and societal trade-offs associated with CBM development
- Techniques being used to minimize environmental impact
- Opportunities for the use of new technologies to minimize environmental impacts

Energy potential of CBM in the PRB

Production of CBM

As previously described, CBM is found in coal seams, which also contain CBM but also large volumes of water that trap the adsorbed CBM under pressure. CBM is produced from wells similar to those used for conventional natural gas, but before CBM will flow from a well, the water must first be removed to depressurize the formation.
As a result, large quantities of groundwater are produced as a by-product of CBM development. Upon start up of a CBM well, there is an initial flow of water, followed by a spike in gas flow as the hydrostatic pressure is diminished. Produced water volume and gas flow will decrease over time as shown in Figure 12.

CBM wells have been relatively easy to construct in the PRB. The initial CBM development has taken place in shallow coal seams, which allows for wells to be drilled in a day with truck-mounted rigs. The wells are constructed to allow water to flow to an outlet for discharge while allowing CBM flow into a different header for gathering. A typical CBM well schematic is shown in Figure 13.

Estimated recoverable CBM reserve in the PRB

There have been several estimates of CBM reserves in the PRB. Figure 14 shows estimated reserve values from several government and industry sources. Most of the estimates are comparable and show an average value between 20–25 trillion cubic feet (tcf) of recoverable CBM.

According to the Wyoming State Geological Survey, these estimates are typically based on coal seams that are greater than 20 feet thick, an assumed recovery factor of 67%, coal seam permeability of approximately one darcy, and a production area of 3.4 million acres.5

The average life span of a CBM well is 7.5 years. Over that time, a typical CBM well will produce an average of 150 barrels per day of water and 310 tcf per day of gas.5

The 1999 summary report from the National Petroleum Council estimates the natural gas demand for the United

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**Figure 12** Typical CBM/Water production curve. Source: Wyoming State Geological Survey, 2001.

**Figure 13** Schematic of typical CBM well. (From the Wyoming State Geological Survey, 2002)

**Figure 14** Estimates of CBM reserves from different sources. Source: Wyoming State Geological Survey, 2002.
States will be 24 tcf, meaning the Wyoming PRB has enough gas to supply one year of the nation’s current gas demand. The Montana BLM estimates that there are 4.5 tcf of recoverable CBM reserves for the Montana PRB. The Gas Technology Institute estimates 17.7 tcf of recoverable CBM from the entire state of Montana (personal communication with C. Lawson, Montana BLM, May 7, 2002).

**Current CBM Development in the Wyoming PRB**

Figure 15 shows the producing wells, compressor stations, and pipelines in the Wyoming PRB from CBM development. At the time of this publication, there are an estimated 12,100 producing wells in Wyoming’s PRB and over 5,800 wells permitted to be drilled. (From the Wyoming Oil and Gas Conservation Commission website, http://www.wogcc.state.wy.us) As Figure 15 shows, most of the development to date is located in eastern Campbell County around the town of Gillette. The first wells that were installed were required to be spaced at one for every 40 acres. Recent changes in regulations now require that wells be spaced at one for every 80 acres.
Net energy available and net cost benefit of CBM

Energy cost/benefit

CBM promises to be a significant source of energy for the nation, but it takes energy to produce energy. The estimated 25 tcf of CBM reserves in the PRB convert to 25 quadrillion British thermal units (Btu) of energy, assuming a CBM heat value of 1000 Btu per standard cubic foot of gas (Btu/scf) (personal communication with C. Schlichtemeier, Wyoming Air Quality Division, May 2, 2002). Approximately 2% (0.5 quadrillion Btu) of the total CBM produced at the well is used to fuel other associated production equipment, including compressor engines and micro-turbines (http://wogcc.state.wy.us). Some other production energy demands include the following:

- Fuel for drilling rigs
- Fuel for trenching and ground clearing equipment for underground utilities, roads and compressor stations
- Construction of discharge water retention ponds
- Fuel for diesel fired generators

Even with the energy inputs, there is a substantial net gain of Btu’s from CBM production. It would be interesting to further investigate the energy inputs on a Btu basis to determine how much energy is expended in production of this energy resource.

Cost/benefit analysis

The economic benefits of CBM development are many. Federal and state governments collect severance taxes and the county receives ad valorem tax revenue from the industry. The development brings jobs to the area and increased labor income. Additional population results in an increase in the number of people paying property and sales taxes. There is an increase in the costs to the government to provide services for the additional population, but the revenue exceeds this cost.

The Department of Agriculture and Applied Economics at the University of Wyoming, is conducting a study on the local benefits and costs of 17 years of CBM development in the PRB. The study assumed installation of 39,372 CBM wells and took the cost of the value of the lost water, recreation losses, and government costs into account. Preliminary results show that CBM development in Campbell, Converse, Johnson and Sheridan Counties for the next 17 years has a net benefit of $688.5 million dollars. However, the analysis assumes that all reclamation and mitigation costs are carried by state and federal governments and the value of the water is $275 per acre foot. The conclusion is that CBM is inexpensive to produce and results in a net economic gain to the counties, the state, and federal government.

Environmental and societal trade-offs of CBM development

The previous section illustrates the energy and economic benefits of CBM development. However, CBM production does not occur without some disruption to the landscape, the wildlife and the people that live in the development area. This section will weigh the economic benefits of CBM against the major environmental and societal impacts of the industry to the PRB.

Environmental impacts

Water

Without a doubt, the most notable environmental concern associated with CBM development centers around water quality and quantity. The PRB is an arid region where effort is taken to conserve water for people, livestock and crops. CBM development has brought

<table>
<thead>
<tr>
<th>Bottled Water</th>
<th>CBM Product Water</th>
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<tbody>
<tr>
<td>Crystal Geyser ~ 200</td>
<td>Wyoming PRB ~ 800</td>
</tr>
<tr>
<td>Perrier ~ 500</td>
<td>Black Warrior Basin, AL ~ 12,500</td>
</tr>
<tr>
<td>Club Soda ~ 750</td>
<td>San Juan Basin, CO ~ 15,000</td>
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groundwater to the surface, but it has been a blessing for some and a curse for others.

**WATER QUALITY**

Water quality from CBM production varies with depth and region across the PRB. In general, water produced on the eastern side of the PRB is of good quality with respect to drinking water standards, but TDS concentrations tend to be higher on the west side of the basin. The city of Gillette in Campbell County gathers CBM product water to supplement their municipal water supply. Many ranchers use water from these same aquifers as stock water. A comparison of parts per million (ppm) TDS values between produced water from other CBM developments in Colorado, Utah, and New Mexico, and even to bottled water, show the water from the PRB is good quality drinking water. In some areas, the water may be questionable as a potable water source, but it is more than adequate for stock water.

CBM product water quality becomes problematic when the water is used for irrigation. The soils in the PRB have a high clay and sodium content. Produced water from the PRB also tends to have a high sodium concentration relative to other ions. The combination of clay soils and high sodium concentrations in both the soil and the water hampers vegetative growth. Sodium accumulates in the root zone of clay soils and inhibits the ability of plants to take in water. Continued application of high sodium water can inhibit native plant growth, create hardpan areas in the soil, and allow for invasion of salt tolerant species of weeds. Produced water from CBM wells that is discharged into a common drainage can have a negative impact on the quality of the stream. The Wyoming Department of Environmental Quality, Water Quality Division (WWQD) issues permits for surface discharge of CBM product water. These permits are issued under the State’s National Pollutant Discharge and Elimination System (NPDES) program. The discharged water must meet certain standards for designated constituents prior to discharge into any existing stream or ephemeral drainage. In some cases, the produced water must be treated, usually by retention in a settling pond, prior to discharge.

Early in the development of CBM in the Wyoming PRB, the state issued numerous NPDES permits to facilitate development, but did not consider the potential cumulative impact of multiple discharges into the same waterway. A specific example of the problems this caused is the case of the Powder River, which was listed sixth in the American Rivers publication, “America’s Most Endangered Rivers of 2002.” The Powder and Little Powder Rivers flow north from Wyoming into Montana. As the state of Wyoming continued to issue NPDES permits for discharge into the Powder and Little Powder Rivers, salinity levels continued to increase. The state of Montana became concerned that they would not be able to discharge CBM product water into the Powder River and still be able to comply with federal standards for total maximum daily loads (TMDLs).

In September of 2001, Montana and Wyoming signed a memorandum of cooperation whereby Wyoming would be allowed to proceed with CBM development and issuance of discharge permits, but must ensure the protection of the downstream users in Montana. As CBM development proceeds in Montana, the two states will continue to monitor the water quality of the Powder River Drainage.

**WATER QUANTITY**

With CBM development, water quality issues seem to get the most attention, but mismanagement of water quantity has created serious long-term environmental problems as well. According to the Wyoming Oil and Gas Conservation Commission, the average flow of water from a Wyoming PRB CBM well is between 12–15 gallons per minute (gpm). Produced water volume will decrease over time as the hydraulic pressure is relieved in the aquifer and the gas continues to flow. A typical water production curve over the life of an average CBM well in the Wyoming PRB was shown in Figure 12. Even with the decline in water production over time, aquifer drawdown or depletion becomes a concern considering that more than 50,000 CBM wells are expected to be installed in the Wyoming PRB by the year 2010.

Since the PRB began to experience large scale CBM development, there have been accounts of ranchers blaming CBM production for their stock and domestic wells going dry. Ranchers worry that the water is being wasted and that aquifers will take hundreds or thousands of years to recharge, especially when the PRB has experienced drought conditions in recent years.
The primary method of CBM water disposal in Wyoming’s PRB is surface discharge. Many people in Wyoming are critical of a perceived wasting of water in a region where water is a precious commodity. Some CBM developers have built retention ponds to store produced water and provide it to ranchers for stock water and in some cases, irrigation. However, most of the produced water is lost down a drainage, or by infiltration into the ground or to evaporation.

Flooding and erosion have also been concerns in the PRB. As produced water is discharged into channels that normally experience low or periodic flows, erosion can occur, causing changes in stream morphology, mobilization of metals, and transportation of silt and sediment downstream (Figure 16). However, not all discharged water flows downstream. There is a certain amount of infiltration back into the ground that takes place. The BLM’s PRB Draft Environmental Impact Statement estimates an average infiltration rate of 80%, but the percentage varies depending on soil conditions, the amount of vegetative cover, and water flow rate.

As the CBM development in the PRB proceeds, it appears that public pressure has encouraged consideration of better management and uses for produced water. The City of Gillette has added produced water to their municipal water supply. Some ranchers have benefited from the water and used it for their livestock and irrigation where appropriate. Developers have used produced water mixed with magnesium chloride as a dust suppressant on access roads. The water can also have benefits for wildlife as a source of drinking water and for creating wetland and riparian habitat.

Air

It is true that CBM burns cleaner than other fossil fuels, which is an important factor for energy consumers around the country. However, on the production side, CBM development contributes to air pollution. Below is a list of emission sources from CBM development. These emission sources combined with emissions from coal mines and gas processing plants, contribute to deterioration of air quality and visibility in the PRB.

- Particulate matter (PM) from vehicles and heavy equipment traveling on unpaved roads and from wind blowing across areas of disturbed land
- Oxides of nitrogen (NOx) from compressor engines, diesel fired generators and vehicle tailpipes
- Carbon monoxide (CO) from compressor engines, diesel fired generators and vehicle tailpipes
- Sulfur dioxide (SO2) from diesel fired generators, vehicles and heavy equipment
- Formaldehyde from lean burn compressor engines

According to the Wyoming Air Quality Division (WAQD), which has primacy for implementation of the Clean Air Act in Wyoming, particulate emissions from industrial sources are a growing concern. Recent monitoring
has shown periodic exceedences of the 24-hour national and state ambient air quality standard for particulate matter less than 10 microns in diameter (PM-10). Exposure to PM-10 poses increased health risks to people and animals, as these smaller particles are able to penetrate deep into the lungs and cause respiratory problems.

Particulate emissions can be controlled using dust suppression. In some areas, CBM product water is used as a dust suppressant on unpaved roads and areas prone to wind erosion. Magnesium chloride is another common dust suppressant that is widely used. However, controlling dust in the PRB is prohibitively time consuming and costly due to the arid climate, persistent winds, the hundreds of miles of unpaved roads across the PRB. Figure 17 shows an example of the extensive road system that CBM development has created in the PRB and the effort that would be involved to continually keep roads wetted down to control dust.

In addition to potential health impacts, PM-10 is also a major contributor to visibility impairment. Most of the visibility issues associated with CBM development tend to be localized and short term. Visibility is locally impaired if an unpaved road experiences heavy traffic flow or if it is excessively windy. Regional visibility can also be impacted by PM-10 that does not deposit back on the ground but gets trapped in the atmosphere. Visibility may not be impaired in the immediate area, but in regions downwind of the activity.

Compressor engines primarily emit NOx and CO. Figure 18 shows a typical compressor station. Lean burn engine technology has been able to lower NOx emissions from compressor engines, but at the expense of increased CO emissions and generation of formaldehyde emissions. The WAQD requires review of best available control technology (BACT) for construction of new, and modification of existing compressor engines. Depending on the size of the engine, BACT would require a lean burn engine to reduce NOx emissions and the addition of oxidation catalysts to reduce CO and formaldehyde emissions. These requirements are necessary considering the number of compressors required for CBM transmission. The WAQD estimates that 3700 engines are operating in the PRB and they emit an estimated 26,000 tons per year of NOx (personal communication with Chad Schlichtemeier, WAQD, May 2, 2002). The WAQD has indicated concerned with approaching the ambient air quality standard for NOx considering the cumulative emissions from compressor engines, gas plants and proposed coal-fired power plants in the area.

Some remote areas of the PRB do not have electrical service and until service can be provided, power is supplied to these sites by portable diesel-fired generators. These generators are small in size, but are not efficient combustion sources. Depending on the make and model of generator, diesel fired generators can emit over seven times as much NOx as a compressor engine based on grams of NOx per horsepower-hour. At any one time, there may be more than 400 diesel-fired generators operating in the PRB. Diesel-fired generators also emit SO2, a by-product of the sulfur contained in the diesel fuel. The SO2 contribution from these generators does not have a significant impact due to the temporary nature of the generators and the national trend toward lower sulfur concentrations in diesel fuel.

**Noise**

Air pollutants are not the only concern with compressor engines. Conflicts have arisen between CBM transmission companies and local residents over excess noise and vibrations from compressor engines. In March, 2001, a rancher shot at a nearby compressor engine seven times with a high power rifle after his persistent complaints to the company about noise from the engines were ignored. In an area where residents are accustomed to a quiet environment, the constant whine from a bank of large compressor engines can be a nuisance. Since that episode,
industry has been working on noise-proofing engines and working with residents on siting of the engines.

**Methane Seepage**

Depressurization of CBM containing formations by the removal of water allows the gas to become mobile in the sub-surface. Obviously, the preferred path of the migrating methane is into a CBM well bore, but methane, like water, will take the path of least resistance. Sub-surface faults allow the methane to migrate laterally and come to the surface where possible. Migrating methane has been an issue since CBM development began and it has serious implications. Methane has been known to find its way into crawl spaces or basements of homes and into stock or domestic water wells. Because methane is colorless, odorless, and highly flammable, methane seepage can be dangerous. Figure 21 shows the impact of methane migration on a domestic water well in the PRB. Methane infiltration into domestic wells usually results in the developer drilling a new well for the landowner. Sub-surface methane migration is difficult to control making it a serious safety issue.

**Wildlife**

There are over 180 wildlife species that make their home in the PRB. CBM development impacts wildlife habitat and increases the amount of human contact. Discharge of produced water into rivers and streams alters the habitat for aquatic species and waterfowl. Most of the disturbance to wildlife habitat occurs during installation of wells, power lines, pipelines, and compressor stations; and during construction of retention ponds and access roads. Even though areas are reclaimed where possible and human activity is reduced after the wells and accompanying infrastructure are in place, wildlife is still impacted.

CBM impacts include habitat fragmentation due to roads (see Figure 17), well pads and compressor stations; increased human activity and noise; increased traffic; decline in prey species due to habitat changes; and obstruction of flight paths by utility lines. Migrating species, such as elk and pronghorn are affected by the presence of roads across migration routes, critical winter range and birthing areas. Figure 19 shows the migration routes for antelope superimposed on existing CBM development. The map shows that most of the existing development does not significantly interfere with migration routes, but future development may. The incidence of collisions with vehicles increases for these species and also for rabbits, prairie dogs and birds. Ground disturbance reduces habitat for burrowing species and upland birds, which can cause a decline in their numbers and in turn, a decline in food source for predators.

Fish and other aquatic species can be impacted by the increase in sediment caused by erosion. Some CBM product water contains concentrations of sodium, bicarbonate, arsenic, barium and selenium above levels found in ambient water, which can have an impact on water chemistry and the aquatic ecosystem. Toxic metals like selenium, can concentrate in retention ponds that hold CBM product water. Selenium bioaccumulates and becomes concentrated higher in the food chain. Waterfowl and shorebirds can experience reproductive impairment and even death from consuming insects or vegetation that have accumulated selenium.

**Figure 19** Antelope migration routes and existing CBM well development (developed by Scott Lieske and Dennis Feeney, University of Wyoming, Department of Agriculture and Applied Economics, 2002).
Soil and vegetation

Impacts to vegetation occur from ground disturbance and from CBM discharge water degrading the soil. Clearing native vegetation and topsoil for roads, well pads and compressor stations can change the vegetation in those localized areas. Late successional vegetation will not return to the disturbed area for years, allowing for more opportunistic plant species to invade the area. More often than not, the invasive plant species are noxious weeds that, once established, will spread throughout the native vegetation.

When high sodium CBM product water is released onto the clay soils found in the PRB, vegetation can be negatively impacted. The positively charged sodium ions from the water become bound to the negatively charged clay particles in the soil. As more and more sodium ions bind to the clay, water is excluded from the system. This makes water unavailable to plant root systems and the vegetation dies. For this reason, produced CBM water is not usually suitable for crop irrigation.

Societal impacts

Split estate

Just as water is probably the most talked about environmental issue, split estate is likely the most prominent societal conflict in the PRB CBM development. As discussed earlier, split estate was created as a result of the Stock Raising Homestead Act of 1916, which severed mineral rights from the surface and reserved some or all of the minerals for the federal government. The act was meant to reduce the incidence of prior homestead abuses, but in recent times, it has created a whole new set of problems.4 In the Wyoming PRB, the BLM administers 10% of the land surface, but controls over 50% of the natural gas reserves, meaning over half of the landowners in Wyoming’s PRB are subject to split estate.4

The development of CBM as an energy source for the nation is important for meeting consumer demand. Some ranchers who own the mineral estate have seen financial windfalls that, in some cases, has saved their ranches or allowed them to give up ranching all together. Ranchers that own mineral rights also have complete autonomy in deciding how the development will occur on their land. Conversely, ranchers that are severed from the mineral estate have less control over the extraction process and realize less financial gain.

The BLM leases out the minerals in a competitive bidding process. The Stock Raising Homestead Act of 1916 provides for a right of entry for the mineral lessee.4 This means the surface owner has little or no control over when or where the mineral lessee will develop the mineral. In the early stages of CBM development in the PRB, developers rushed to take advantage of the high gas prices creating rapid change in lifestyle for ranchers and landowners. Some landowners saw roads, dams, power lines and reservoirs built on their land with little regard for the land or their ranching operations. Some ranchers reported dried up stock wells and flooding, erosion, and impacts to vegetation once CBM development started. The land was disturbed by the construction of new roads, well pads, and water impoundments. There have been accounts of methane contamination in domestic water wells and of...
methane seepage into houses. Figures 20–22 show some of the damage done to private land by CBM development.

Landowners can and should insist on a surface agreement and bond with developers as early in the development process as possible. Most of the damage created on private land by CBM occurred early in the development when there was a “gold rush” mentality to grab some of the CBM wealth. The booming development caught many ranchers by surprise and unfortunately, some ranchers became the guinea pigs for others that would soon see development on their land. The ranching lifestyle requires one be adept at veterinary medicine, business, accounting, farming, plumbing, etc; basically a Jack-of-all-trades.

CBM development required landowners to quickly become experts in mineral law and gas development as well. The trade-offs of split estate can be summarized as production of an energy source for the nation and disruption of lifestyle and livelihood for some of the local people.

**BOOM ECONOMY**

Wyoming has seen its share of booms, all of them mineral related. In the last 50 years, Wyoming has seen the oil boom at Teapot Dome in the 1950’s and the oil, gas, uranium, and coal booms of the 1970’s and 1980’s. As those booms faded, the late 1980’s and early to mid-1990’s were economically depressed times for Wyoming while surrounding states were seeing immense economic growth in the technology sector. Wyoming’s primary revenue source has always been and still is mineral production. In the 1990’s, energy was cheap and Wyoming suffered. At the end of the 1990’s California was experiencing severe electrical shortages, the price of gasoline was rising, and the nation seemed on the verge of another energy crisis.

CBM production began in the mid-1980’s but with the impending energy crisis in 1999-2000, CBM development took off. Wyoming found itself in the midst of yet another boom. The boom made itself evident in the state’s economy almost immediately. In 1999, the state of Wyoming’s budget projection showed a $200 million dollar shortfall. One year later, in 2000, the state’s budget projected a $700 million dollar surplus. In a state that had been losing people and jobs, and had a stagnant economy, the CBM boom was a blessing. The state continued staunch support for more methane development. The increased revenue to the state allowed for pay raises for teachers and state employees, and for repair of dilapidated school buildings.

At that time, the price for CBM was around $10.00/thousand cubic feet (mcf) and the gas was easy to get out of the ground. This brought developers to the area in droves with as many as 80 different companies developing CBM as fast as they could. Some of these companies developed with little regard for the people and environment in the area. As the development has progressed, larger corporations have bought out the leases of smaller companies, decreasing the number of operators in the PRB. The development has appeared to become more uniform as fewer companies own more of the leases. Large corporate buy-outs tend to increase the consistency of operational and management practices.

In the last couple of years, the price of CBM has dropped to $2.00–$3.00/mcf, but another 50,000 wells are proposed for the PRB in the next ten years beyond the approximately 12,000 wells that are currently in production. At this time, the average life expectancy of a CBM well is seven years. If the last of the proposed 50,000 CBM wells is installed by 2015, production will cease around the year 2022. This gives the state of Wyoming 20 years to decide how to make the benefits of this boom last.

Other areas of Wyoming are gearing up for CBM development in the near future. Coal fields in the Hanna Basin, Green River Basin and Wind River Basin may see CBM development in the next 5–10 years. Gas in these areas will be more expensive to produce since it is deeper and the produced water is of poorer quality than that in the PRB and may require treatment prior to discharge.

A famous bumper sticker seen around Wyoming reads, “God, please let there be one more boom and I promise not to [throw] it away this time.” The CBM boom has enabled Wyoming to hurl itself out of economic depression, but for how long and at what cost to the local communities and the environment?

**CBM DEVELOPMENT ON STATE LANDS**

As shown in Figure 7, 6.2% of the land in Wyoming is owned by the state. The state of Wyoming does not have a state environmental policy act, which has allowed for rapid CBM development on state lands. The state of Wyoming adopted the slogan “Go Blue” as an enticement for developers to produce CBM on state lands,
which are typically colored blue on most land ownership maps. The rapid CBM development on state lands created some concern for the federal government who is restricted from developing their minerals on federal lands until the requirements of the National Environmental Policy Act (NEPA) are completed. The flow of CBM in the subsurface has no regard for man-made boundaries, which has allowed developers on state land to pull CBM out from under federal lands. Therefore, in some instances, the state has been able to develop CBM on state land without delay and pull potential CBM revenues away from the federal government. This issue has been resolved by imposing well placement restrictions in relation to land and mineral ownership boundaries.

CHALLENGES TO LOCAL GOVERNMENTS

Virtually everyone in the PRB has likely been impacted in some way by CBM development. The monetary benefits of the development to the state, counties and municipalities cannot be denied, however; money can’t solve all problems.

The 1990’s saw a 14.7% increase in population in Campbell County, Wyoming. The booming CBM development in Wyoming’s PRB brought a new demographic of people to the area, most of whom settled in and around the town of Gillette in Campbell County. The CBM workers tend to be men between the ages of 25–44 who are transient and will stay in the area as long as there is work. Not all workers bring their families with them. The influx of workers has resulted in increased labor income and support of the service industry in Campbell County, but has brought problems, too.

Providing services for the population growth has been a challenge. The municipalities have had to keep up with the increased demand for water, sewer, and refuse disposal. The counties have had to allocate more funds to road maintenance due to the increase in industrial traffic. Schools have seen increasing enrollment and larger class sizes. Adequate housing for the additional people has been a problem and most workers end up staying in motel rooms. Property values have risen due to housing shortages. The branches of law enforcement in Gillette and Campbell County have seen an increase in domestic disputes, drunk driving, assault and petty crime although there has been no perceptible change in violent crimes in the area. The jails are often full as a result.

To help the counties cope with these rapid changes, the Coalbed Methane Coordination Coalition was formed. The Coalition is governed by a joint powers board consisting of commissioners from five counties, representatives from two conservation districts, a representative from the State of Wyoming, and a representative from the methane operators. The Coalition hired a coordinator and assistant coordinator to be responsible for obtaining information and facilitating its flow to and from the coalbed methane coalition joint powers board and to interested and affected stakeholders. The goal of the coalition as a whole is effective information transfer for rational development of coalbed methane. The Coalition has been instrumental in helping individuals and the counties cope with the development (From the CBMCC website, 2002, http://www.cbmcc.vcn.com).

Some of the duties of the Coalition include:

- Presentation of statistics and explanatory information to the public
- Landowner complaints
- Regulatory issues
- Streamlining processes for entering into production (permitting and water handling)
- Investigating methods for optimizing resource production and recovery and minimizing negative impacts

QUALITY OF LIFE

The real trade-offs have come down to changes in quality of life brought about by CBM development. As previously discussed, the ranchers that don’t own minerals have seen what CBM development has done to their land and livelihood. The quiet rural setting they have known for most of their lives, even for generations, has turned into a light industrial zone in some areas. On the other hand, ranchers that own rights to CBM have seen financial relief and may received monthly royalty checks ranging from $10,000–$40,000.

The abundant wildlife, clean environment and scenic vistas are a major draw for people coming to Wyoming. CBM development has changed the look of the PRB and compromised wildlife habitat, air and water quality, and the scenery.

Those directly impacted by CBM development may not appreciate the way the play has proceeded, but most of the state of Wyoming has benefited financially. The revenues generated by CBM have improved the quality of
life for many Wyoming residents in the form of pay raises for government employees and for those in education. The American Federation of Teachers (AFT) 1998 salary survey ranked Wyoming 44th in the nation for teacher salaries (from the AFT website, 2002, http://www.aft.org/research/survey/tables/tableI-1.htm.). It has been difficult for the state to retain good teachers and government employees because of low pay. CBM revenue has allowed Wyoming to start paying competitive salaries to these sectors. Overall, CBM revenues have allowed for more funds to be spent on education and much needed school facility improvements.

**Development techniques that minimize environmental impact**

In the PRB, developers are using techniques to minimize impacts to the environment and to lower production costs. Most techniques used today are aimed at minimizing surface disturbance. Some of these practices are discussed below.

**Remote monitoring of wells and compressors**

Monitoring of wells and compressor stations can be done from remote locations by telemetry. Operators can now obtain operational data from a central stationary location, reducing the number of trips to the well sites and compressor stations. Remote monitoring of wells and compressors helps the environment by reducing emissions from field vehicles and minimizing impacts to wildlife while saving the producer money and employee time. Access roads are traveled less, reducing vehicle generated dust and requiring less maintenance than well-traveled roads. Remote monitoring can immediately alert crews to problems on site, minimizing equipment down time.

**Methane fired microturbines to power well pumps**

Each CBM well is equipped with an electric down-hole pump to remove water and gas. Traditionally, power was provided at a new well site by a skid mounted diesel fired generator until power lines could be brought to the site. These generators are noisy and sources of air pollutants. Recently, industry has been using skid mounted CBM fired microturbines to generate electricity that can power four to six well pumps at a time. The microturbines are quiet and emit far less pollution than diesel fired generators. New well sites may still rely on diesel-fired generators until the well begins to produce enough methane to fire the microturbine. Since the generators and microturbines are skid mounted, replacement of a diesel generator with a microturbine is straightforward (personal communication with R. Cool, WOGCC and T Dall, Williams Companies, May 6, 2002).

**Well clustering and equipment siting**

In some locations of the PRB, wells are installed in a cluster of two or three wells with each well drilled into a different depth coal seam. Centralization of wells and compression sites requires fewer miles of access road and less land disturbance.

**Burying power lines**

CBM development requires miles and miles of power lines to operate pumps and compressor stations. To date, 5,300 miles of aboveground power lines have been installed for CBM development (From the Powder River Basin Resource Council website, 2002, http://www.powderriverbasin.org). If these lines were installed underground and in conjunction with pipeline corridors, it would decrease the amount of land disturbance, minimize visual impacts, and eliminate collisions between birds and power lines.

**Opportunities for the use of new technologies to minimize environmental impacts**

**Directional drilling**

Directional drilling has been used for conventional oil and gas production for several years. If this technique could be used successfully to complete CBM wells, wells could be clustered together and recover gas from the same area as several wells set on 40–80 acre spacing. This would decrease the amount of ground disturbance, reduce the
miles of access roads needed, and allow for consolidation of produced water.

Directional drilling is being evaluated in the PRB, but has not been tried in the field. There are problems with the undulating topography of the coal seams and being able to stay within the seam. Also, it may be difficult to get gas and water to flow with a horizontal well due to the relatively shallow well depths (personal communication with R. Cool, WOGCC and T. Dall, Williams Companies, May 6, 2002).

Wind and/or solar powered well pumps

There has been discussion about using wind or solar energy to power well pumps. With the persistent wind and 200+ days of sunshine per year in the PRB, this could be feasible. Wind or solar powered well pumps would eliminate the need for power lines, reduce air pollution and would allow more methane to go to sales as opposed to fuel for a microturbine.

Research on wells that could produce CBM without as much water

Research is underway at a major university to design a CBM well that will efficiently produce gas without producing the large quantities of water (statement from T. Brown, Western Research Institute, 2002, Western Governors’ Association Environmental Summit II, Salt Lake City, UT). Information about this research is limited at this time.

Industry agreement of best management practices

Although best management practices are not considered a technological advancement, unified use of specified practices to minimize impacts to the environment could minimize conflicts between developers and landowners and reduce impacts to the environment.

III Summary

CBM has become a controversial development that has far reaching impacts for the nation, the environment and the people that live with the development. This section reviews the gains, losses, lessons learned, and what the future holds.

What is being gained?

The primary gain from CBM production has been energy for the nation and money for developers, the state of Wyoming and those ranchers who own minerals under their land. Estimates indicate that PRB CBM reserves are sufficient to meet the entire nation's gas supply for one year. The state of Wyoming has been able to come out of an economic slump with the revenues that CBM has generated. Development of CBM in the West decreases the nation’s dependence on foreign energy. Produced water in some areas of the PRB has been put to use for municipal water supply and stock water.

What is being lost?

CBM development has taken a toll on the environment of the PRB. Below are some statistics listed on the Powder River Basin Resource Council website relating to environmental impacts: (http://www.powderriverbasin.org)

Since development began, the following has occurred:

- 17,000 miles of new roads, enough to cover the distance from New York to Los Angeles six times.
- 20,000 miles of pipeline have been laid
- 5,300 miles of aboveground power lines
- 200,000 acres of disturbed soil and vegetation
- 500–1,200 produced water discharge points have been established
- 1,800–4,000 produced water retention ponds have been built
- 1.4 trillion gallons of water are estimated to be lost over the life of the development. This is enough water to support the state of Wyoming for 30 years.

Lessons learned

Conversations with industry, environmentalists, state agency personnel and landowners have echoed similar sentiments on lessons learned from CBM development in the PRB to date. If time could be reversed, and people knew 15 years ago what they know now, here are some recommendations of what should be done:
• Gather baseline data on surface water quality and quantity; groundwater quality and quantity; air quality; soil chemistry; and vegetation and wildlife surveys.
• Make baseline information and monitoring data available in a central location accessible by industry, government agencies, and the public.
• Establish and enforce best management practices for industry before allowing development.
• Notify those ranchers affected by split estate about impending development and assist them in collaborating with industry on how the land should be developed.
• Closely monitor the development for impacts on the environment and change development practices when necessary (adaptive management).
• Establish a state fund with a portion of the revenues generated by CBM that can be used to mitigate environmental impacts and personal damages.

**What does the future hold?**

CBM development will continue as long as there is a demand for clean burning gas. Other areas of Wyoming are being explored for CBM development and Montana is getting ready to begin development of its resource. Those who are disenchanted with CBM development do not seem to be against gas production, but would like to see it proceed with caution and respect for the residents of the area and the environment. The recent decline in gas prices has caused the development to slow down. This could be an opportunity for industry, landowners and government to take time to resolve past conflicts and move forward with the development in a manner that will not only provide an energy resource, but also satisfy the needs of the people that have sacrificed their way of life for the benefit of the nation.

**Notes**