Coalbed-Methane Basics

Ten Years of Lessons from the Powder River Basin, Montana

Elizabeth Meredith
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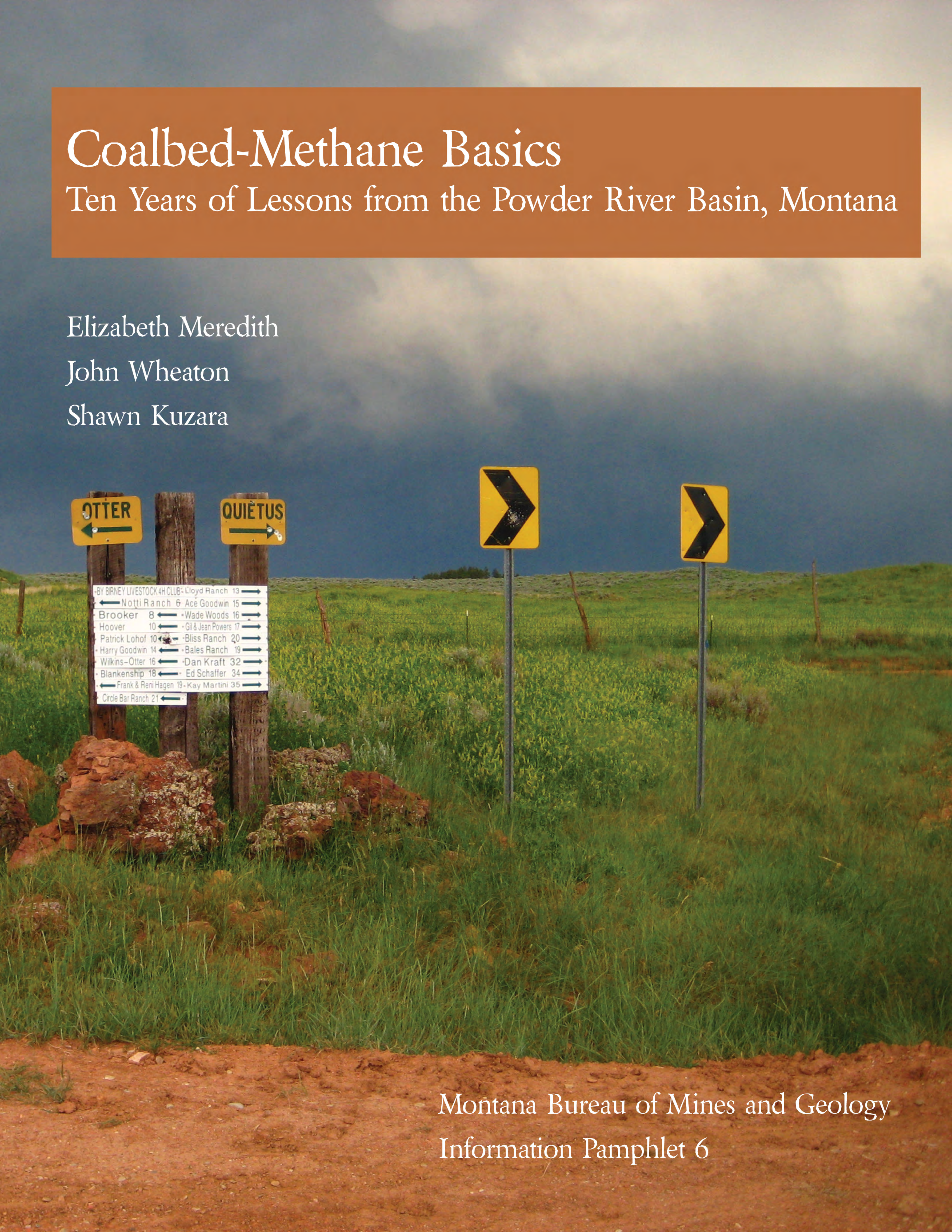

Montana Bureau of Mines and Geology
Information Pamphlet 6

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INTRODUCTION

Coalbed methane (CBM; also known as coalbed natural gas, or CBNG) is an important source of natural gas that is produced in many coal-bearing regions of the United States, including the Powder River Basin of Montana and Wyoming. Production in the Powder River Basin has been prompted by two features: (1) shallow coalbeds that make installing wells economical and (2) inexpensive disposal of coproduced water because of generally good water quality in most of the basin. Development in Montana has lagged behind that of Wyoming, largely because of smaller methane reserves and concerns about water disposal.

Methane is held in place on the cleats (small fractures) and micropores of coal by the hydrostatic pressure of the aquifer water. Pumping water from the coalbed reduces the hydrostatic pressure, which releases the methane and allows it to migrate to the well. The methane naturally separates from the water and the gas and water are brought to the surface in separate pipes within the well (fig. 1; Law and Rice, 1993; Rightmire and others, 1984). The extraction and subsequent discharge of large volumes of water associated with coalbed-methane production has raised environmental and agricultural concerns.

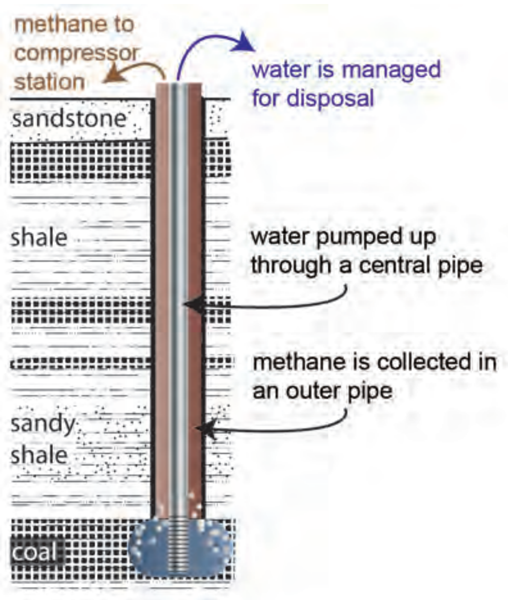

Figure 1. Coalbed methane is produced by completing a well in the target coal seam and pumping water from that coal. The stratigraphic column illustrated here is an example of typical Fort Union Formation geology.

Coalbeds are important aquifers for livestock and domestic use in southeastern Montana. Wells and springs sourced in coalbeds that are also targeted for CBM operations may see a reduction in water availability. Coproduced water is generally acceptable for livestock use; however, the high sodium content makes it undesirable for application to most soils. Thus, the quantity and quality of discharged water are concerns that must be satisfactorily addressed while making decisions that lead to beneficial and sustainable development of the CBM resource.

Coalbed-Methane Generation

Coalbed methane forms by both biogenic (biologic) and thermogenic (heat and pressure resulting from burial) processes (Law and Rice, 1993). Methane in Powder River Basin coalbeds was produced through biogenic processes. The organic material in coal is decomposed through a series of processes under anaerobic (oxygen-deprived), sulfate-depleted conditions, simplified in the following reaction (Stumm and Morgan, 1996):

Complex organic material → CH_3COOH (organic acids) → CH_4 (methane) + CO_2.

Much of the earliest formed methane may have been lost to the atmosphere because hydrostatic pressure was not sufficient to trap the gas, but in later stages, at greater depths of burial, methane is more likely to be trapped in the coal.

During later stages of burial, if an active groundwater flow system is present, additional biogenic methane may form by CO_2 reduction, as shown in the following reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O.$$

Coalbed-Methane Production

The first commercial production of CBM in the United States began in the Black Warrior Basin, Alabama, as part of an underground mine-safety program (Pashin and Hinkle, 1997). In the western United States, production of CBM is now well established in New Mexico, Arizona, Colorado, Utah, Wyoming,

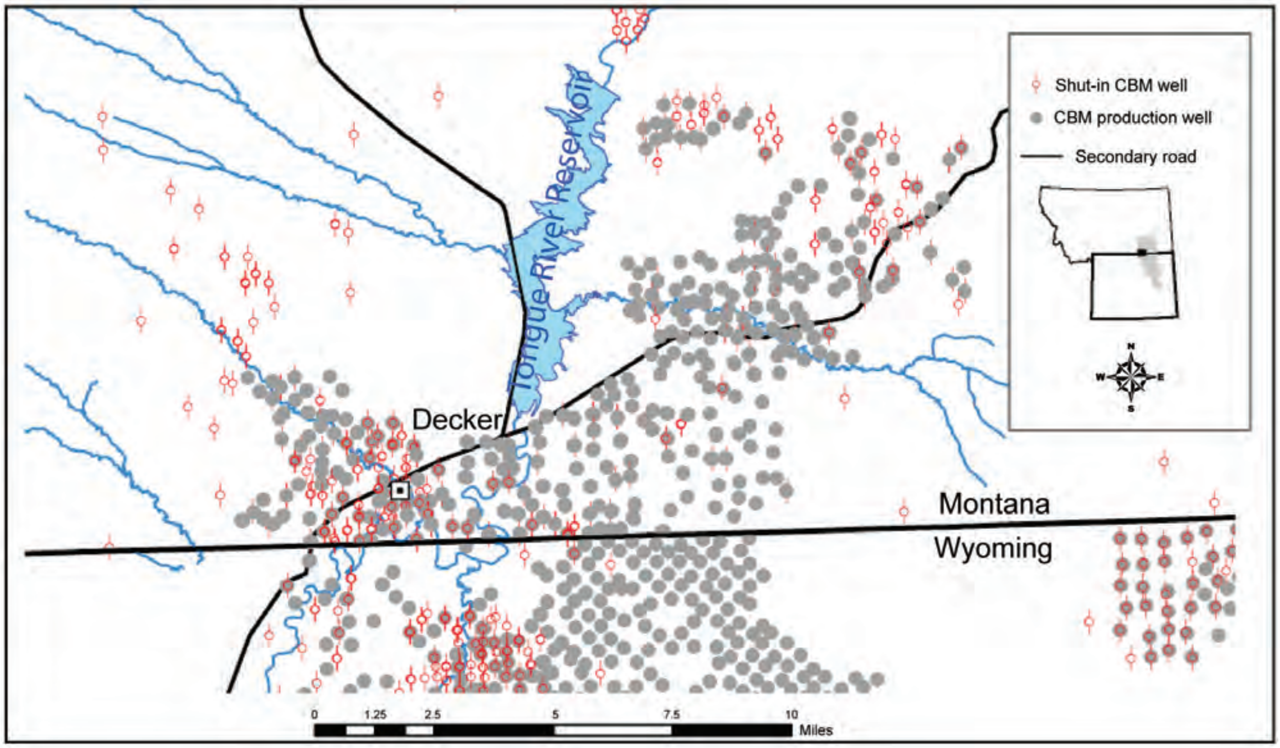

Figure 2. CBM development in Montana has remained concentrated around the Tongue River Reservoir. Wells in older and less productive fields have begun to be shut in.

and Montana. Currently, CBM is being produced over much of the Powder River Basin in Wyoming, but in Montana it is limited to areas surrounding the Tongue River Reservoir (fig. 2).

Data published by the Potential Gas Committee (Decker, 2001) indicate that coalbed methane has become a major factor in the domestic production of energy and may represent 10 to 15 percent of total natural gas reserves in the United States. Natural gas meets roughly 25 percent of the nation's energy needs, and about 89 percent of natural gas used in the U.S. is produced domestically. For comparison, oil provides about 37 percent of the energy needs of the U.S., with about half produced domestically (U.S. Energy Information Administration, 2011a).

The proved reserves of CBM in the Powder River Basin are 2,418 billion cubic feet, while the estimated recoverable resource (which does not include the proven reserves or what has been produced) is 18.5 trillion cubic feet (TCF; U.S. Energy Information Administration, 2007). This is approximately the annual demand for natural gas by the United States, which was 24 TCF in 2010 (U.S. Energy Information Administration, 2011b). The portion of total recoverable resources that occur in the Montana portion of the Powder River Basin is estimated at 0.86 TCF (U.S. Department of Energy, 2002). This relatively small value reflects the unfavorable geologic setting in Montana, where many coalbeds are too shallow or thin to produce economic volumes of methane. Total CBM production from the Montana side of the Powder River Basin through October 2010 was 0.11 TCF. The lifetime production through October 2010 for the Wyoming side of the Basin was 4.18 TCF. Total water production from the Powder River Basin during this time was 0.27 and 6.45 billion barrels in Montana and Wyoming, respectively (Montana DNRC, 2011; Wyoming OGCC, 2011).

The Department of Energy (2006) prepared an economic review on coalbed-methane development in the Powder River Basin and determined that the cost associated with CBM coproduced water management strongly determines the volume of CBM that is economically recoverable. Surface discharge, the most economical choice for producers, would result in an estimated 17.4 TCF of economically recoverable CBM in the Powder River Basin (Department of Energy, 2006).

Efficient coalbed depressurization is best achieved by completing groups of wells in a grid pattern. CBM wells in Montana are installed on 80 or 160 acre spacing (8 or 4 per section). Initially, individual CBM wells were completed in each coal seam. In some areas up to five coal seams were targeted, which resulted in up to 20 wells being installed per section. Single CBM wells are now completed in multiple coalbeds, which reduces the surface footprint and drilling costs of the development. The well casing is perforated at each methane-bearing zone and water is pumped from all coals with a single pump. An emerging well completion technique that may increase the efficiency of CBM wells is directional drilling, where the well bore angles to drill along the coalbed, allowing more of the coal to be produced with a smaller surface footprint. The methane gas from the CBM wells is initially compressed through a local compressor station that typically increases the gas pressure to about 70 or 80 pounds per square inch (psi) followed by a high-pressure station, which increases the pressure to about 1,200 psi. The high-pressure gas is then moved to market through a network of pipelines.

The useful life of a CBM well, on average, is currently less than 10 years. The gas produced from an average well peaks around the well's second year of production at approximately 2,000 thousand cubic feet (MCF) per month. From there the production rate drops until it levels out at 800 MCF per month around the seventh year (Meredith and others, 2011).

New research on enhanced CBM generation

Several commercial and academic research groups are looking into ways to increase the rate of methane generation from the microbial community in the coal. Two companies in Wyoming are currently moving into the field-testing stage. One company is attempting to increase microbial activity by injecting nutrients into the coalbed, while another company is trying to achieve the same goal by breaking down the coal into a solution that the microbes can more easily process. Wyoming must first put in place the rules and bonding necessary for full testing to take place (Fugleberg, 2011). Other work is being done to try to minimize the rate-limiting step of the breakdown of the coal by working with enzymes that help speed the coal biodegradation (Strapoc and others, 2011). Research groups at Montana State University, the University of Montana, and the University of Wyoming are all looking at ways to increase the methanogenic potential of the Powder River Basin coals.

The successful application of any of these methods could revolutionize the CBM industry. Being able to generate commercially significant volumes of methane would increase the useful life of the CBM infrastructure (wells, roads, powerlines, pipelines, and compressor stations), making CBM more of a long-term prospect.

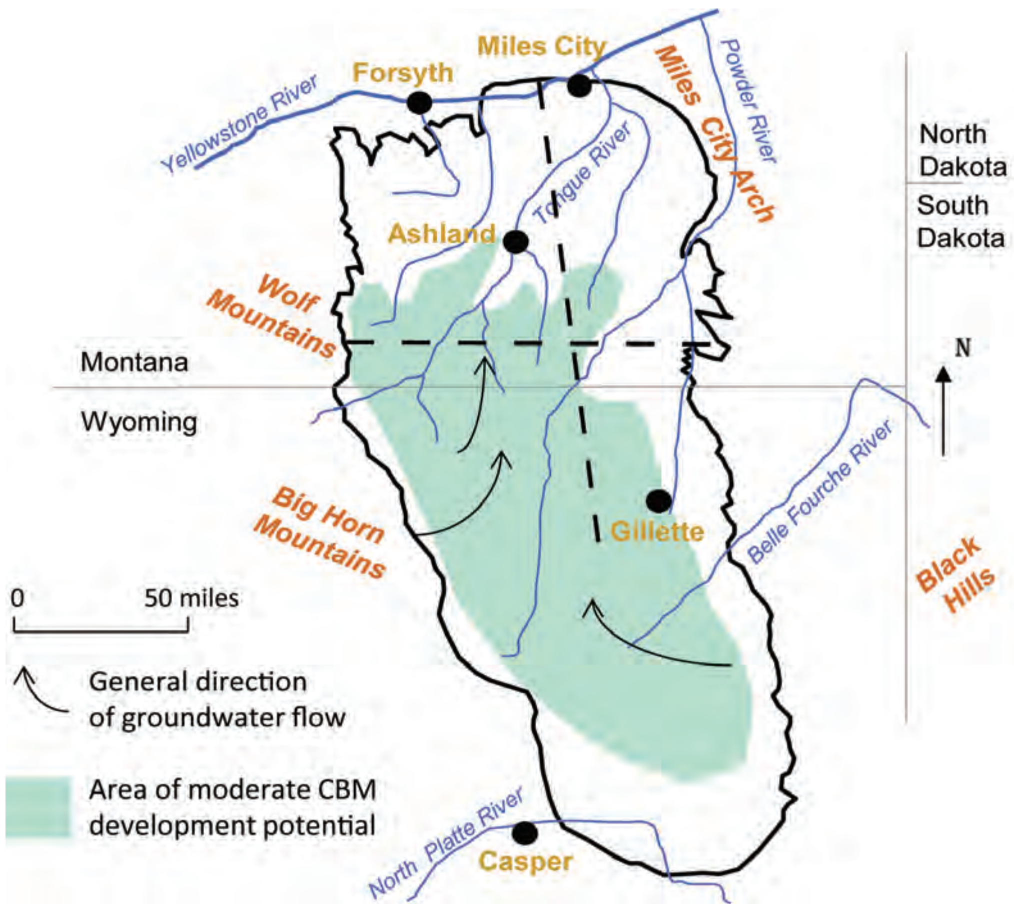

Figure 3. About one-third of the Powder River Basin is in Montana; however, less than 4 percent of the CBM resource is in Montana (Department of Energy, 2002; Van Voast and Thale, 2001). Dashed lines indicate locations of geologic cross sections shown in figure 5.

REGIONAL SETTING FOR THE POWDER RIVER BASIN

Geologic Setting

The Powder River Basin is bounded by the Black Hills to the east, the Big Horn Mountains to the west, and the Miles City Arch to the north. About one-third of the Basin lies in Montana, and two-thirds is in Wyoming (fig. 3). The land surface in the Powder River Basin slopes northward from higher elevations in Wyoming toward the Yellowstone River.

Coalbed-methane development is most favorable in thick coal seams that are deep enough to prevent the methane from venting to the atmosphere but shallow enough to make installing wells economical. These geologic conditions are more common in Wyoming than in Montana due to geologic structure and erosional level of the basin. The highest potential for development in the Powder River Basin in Montana is within about 10 to 12 miles north of the state line, between the Wolf Mountains to the west and the Powder River to the east (fig. 3). Moderate development potential also exists as far north as Ashland. Currently all CBM development in Montana is in the first two townships north of the state line (Townships 8 and 9 South) and within 10 miles on either side of the Tongue River Reservoir (fig. 2).

Of the numerous coalbeds in the Powder River Basin, the primary targets for CBM development in Montana have been the Anderson, Dietz, Canyon, and Carney coalbeds within the Tongue River Member of the Fort Union Formation. Some development has also occurred in the Cook, Wall, Brewster–Arnold, and Flowers–Goodale coalbeds (fig. 4).

Geologic and geochemical differences between Montana and Wyoming also impact how produced water from CBM wells can be handled. The produced water quality tends to be higher in sodium and dissolved salts in Montana than in Wyoming. Also, the resultant soils from the Wasatch Formation, widely exposed at the surface in Wyoming, have a sandy consistency. By contrast, in Montana the soils have developed from interbedded claystone and sandstone units in the Tongue

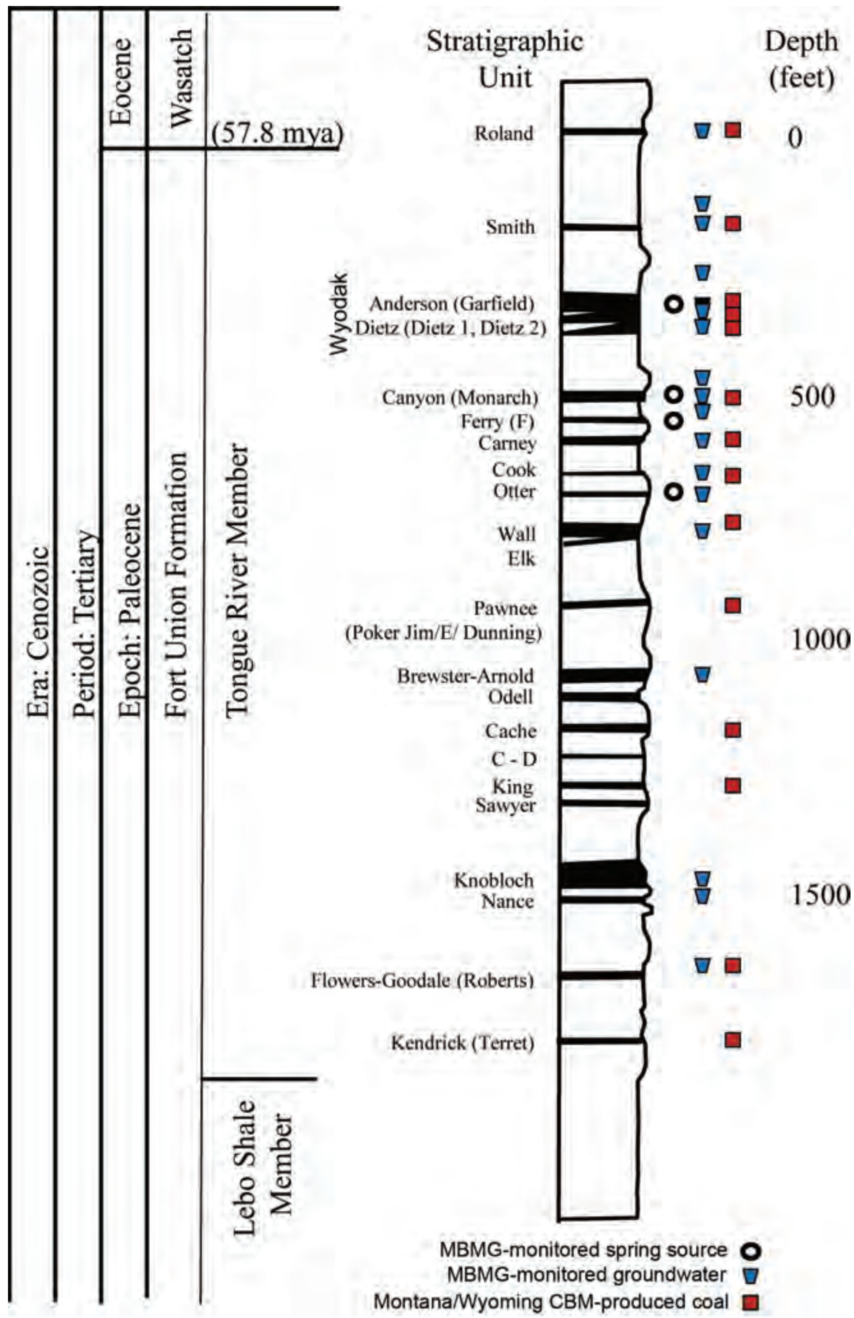

Figure 4. The relative positions of selected coalbeds are shown here, with the right edge of the column indicating generally sandy interburden (curves right) or shale (curves left). Most coals are not present across the entire basin and the interburden thickness varies considerably. The indicated depths are only approximations (Culbertson, 1987; Fort Union Coal Assessment Team, 1999; Law and others, 1979; Matson and Blumer, 1973; McLellan, 1991; McLellan and Beiwick, 1988; McLellan and others, 1990; and Colorado School of Mines Research Institute, 1979a,b,c,d,e,f,g).

River Member of the Fort Union Formation, resulting in a finer soil structure. Clay-rich soils are more sensitive to sodium, which causes the clays to swell and/or disperse. Discharging CBM coproduced water to the surface, either through irrigation or through discharge to existing drainages, could have negative effects in Montana that may not be seen in Wyoming.

Hydrogeologic Setting

Groundwater flow in the Powder River Basin is generally from south to north and from the edges of the basin toward the center. Coal seams, because of their lateral continuity and productivity, provide an important groundwater resource. Due to the basin's structural and topographic relationships, coal seams in Montana commonly crop out along valley walls and groundwater discharge forms springs (fig. 5).

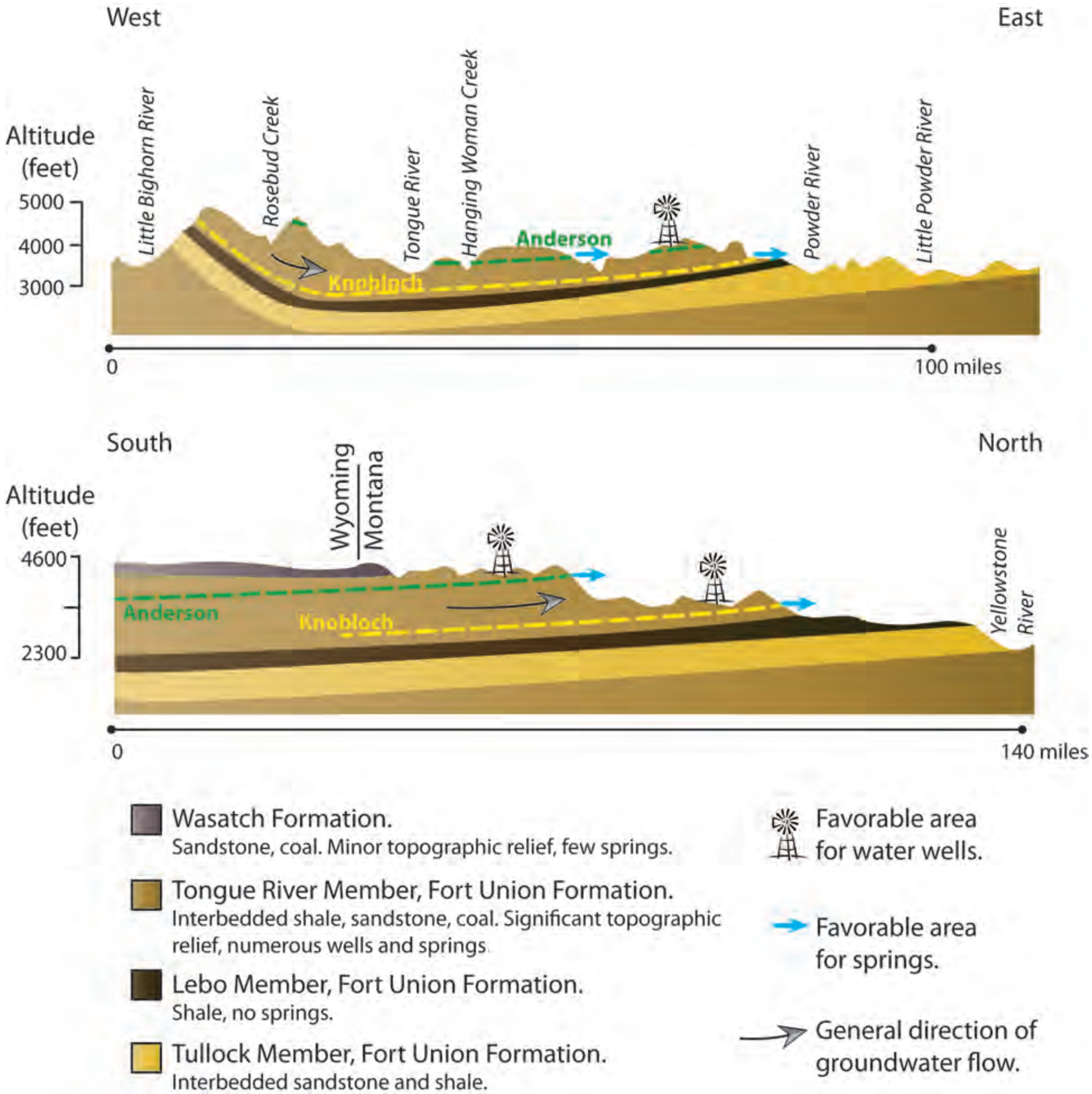

Figure 5. Both groundwater and surface water in the Powder River Basin generally flow to the north, toward the Yellowstone River in Montana. Coalbeds such as the Anderson are deeply buried in the Powder River Basin in Wyoming, but crop out in Montana. Farther north, stratigraphically deeper beds are exposed at the land surface. Areas where aquifers are shallow are favorable for water well drilling. Springs occur in outcrop areas along hillsides. Hydrostatic pressure is naturally low near areas of outcrop, which allows the methane to escape to the atmosphere. Coalbeds are dashed because they split, merge, pinch out, and are faulted, which complicates the hydrologic picture. Locations of cross sections are shown in figure 3.

Therefore, coal seams and associated clinker units are not only important targets for water wells, but also provide surface water through springs.

Evolution of sodium-bicarbonate water

The chemical composition of coal-aquifer groundwater reflects chemical and biological reactions that occur along flow paths. As water recharges the coal aquifer it dissolves calcium and magnesium salts present in the soil and shallow substrate. The water exchanges cations with the prevalent clays of the Fort Union Formation, which increases the sodium and decreases the calcium and magnesium concentrations. The aqueous concentration of sulfate initially increases through dissolution of gypsum and pyrite oxidation before bacterially mediated sulfate reduction reduces the sulfate concentration, generating bicarbonate. The increase in bicarbonate drives the precipitation of calcite, which lowers the bicarbonate and calcium concentrations.

These geochemical processes result in mature coal-aquifer groundwater that has a chemical composition dominated by sodium and bicarbonate; the presence of methane is not uncommon. A detectable amount of sulfate (approximately >10 mg/L) present in the coal groundwater is an indication that methane will not be present, because the reduction of sulfate precedes the reduction of bicarbonate into methane (Brinck and others, 2008; Van Voast, 2003). The salinity of mature coal groundwater, as measured by the total dissolved solids (TDS), generally falls between 1,500 and 2,500 mg/L (recommended levels for human drinking water is less than 1,000 mg/L).

The increased sodium concentration and decreased calcium and magnesium concentrations found in mature coal-aquifer water result in a high sodium adsorption ratio (SAR), a parameter used to estimate a water's potential impact on soils. The ratio is defined by the following equation, where the concentrations of sodium [Na], calcium [Ca], and magnesium [Mg] are in milliequivalents per liter:

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca] + [Mg]}{2}}}$$

Coalbed methane can only exist in sulfate-depleted, anaerobic conditions (Van Voast, 2003). Therefore, all CBM coproduced water has sodium as its dominant cation and, consequently, a high SAR value. Sodium adsorption ratios indicate how water will affect the clays in soils: irrigating with water that has a high SAR may cause clay-rich soils to be less permeable, thereby greatly reducing the productivity of the soil (Hanson and others, 1999).

WATER ISSUES RELATED TO CBM DEVELOPMENT

In traditional oil and gas activities, interaction with shallow aquifers is not an issue in properly designed and maintained wells. Production is from deep reservoirs and the quality of coproduced waters is typically so poor that surface disposal is not an option. However, CBM production reduces both the volume and hydrostatic pressure of water in coalbeds that in some places are also used for domestic and stock purposes (fig. 6). In locations where groundwater use overlaps between domestic use and CBM production, well water levels will be lowered within a radius of approximately 1 to 2 miles of CBM development. Lower groundwater levels reduce flow through the aquifer, which may reduce discharges at springs. However, impacts to springs have not been observed in Montana, and Montana Bureau of Mines and Geology (MBMG) data do not indicate any unforeseen impacts to wells (Meredith and others, 2011). In development areas, water resources will be reduced for the duration of CBM production plus a recovery time that may be years or decades long (Wheaton and Metesh, 2002).

How coproduced water is managed can affect the shallow groundwater that supports the agricultural community in southeastern Montana; understanding the potential impacts is not straightforward, particularly because impacts are not uniform across the Basin. Coproduced water has both positive and negative aspects. Discharge of this water may cause soil erosion downstream from the discharge point, and chemical reactions may cause changes in soil structure or alter the chemistry of receiving surface and groundwater. On the other hand, some shallow aquifers may be beneficially recharged by infiltration from holding ponds that receive CBM discharge water and, if the water quality is suitable, farmers and ranchers may

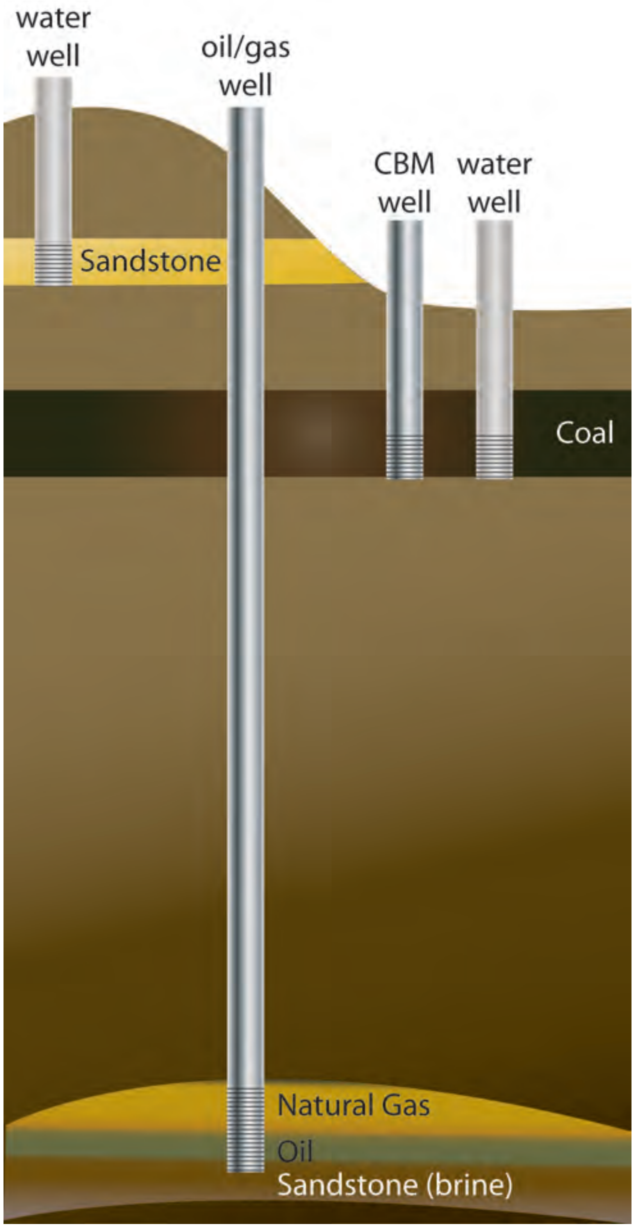

Figure 6. Traditional oil and gas activities usually take place at much greater depths than coalbed methane or domestic and stock water wells.

benefit by expanding stock water availability.

In response to these possible issues, CBM companies have been required to submit their plans for development for State or Federal review, depending upon the mineral ownership. The Montana Board of Oil and Gas and the United States Bureau of Land Management perform environmental assessments on the proposed developments and the companies agree to a monitoring protocol based upon that assessment.

Quantity of Coproduced Water

Water withdrawal for CBM production has the potential to draw down aquifers used for domestic and stock purposes, and that water must be managed once it reaches the surface. The amount of water produced by an individual CBM well varies considerably between wells and throughout the life of the well (fig. 7). After an initial development stage of between 0 and 6 months, the average CBM well produces around 7 gallons per minute (gpm), but this can range from less than 1 to greater than 20 gpm. The average rate slows to around 4 gpm by the fifth year of production (fig. 7).

The average water production rate is lower than that which was predicted by the U.S. Bureau of Land Management's Environmental Impact Statement for the first 6 years of a well's life (dashed line in fig. 7). Therefore, the amount of water that has been withdrawn and managed has been approximately half what was originally predicted in 2001.

In 2010, CBM fields in Montana produced 33.5 million barrels (4,300 acre-feet) of water, down from a high of 40 million barrels (5,000 acre-feet) in 2008 (Meredith and others, 2011). In contrast, the 2010 production for the Wyoming portion of the Powder River Basin was 534 million barrels (68,800 acre-feet) of water.

Groundwater Drawdown

Forty years of coal hydrogeology study by the MBMG has produced a good understanding of the groundwater in southeastern Montana coalbeds. Drawdown related to coal mining was monitored for decades prior to CBM production in Montana. Coalbed-methane development in Montana was first introduced to the west of Decker and Spring Creek mines in 1999, and production from those early fields has begun to slow and shut down. Figure 8 illustrates the difference in aquifer drawdown caused by coal mining and CBM development as well as water-level recovery due to cessation of CBM activities. Monitoring wells in this area are used to predict recovery rates in other CBM fields. In contrast, monitoring has also documented shallow groundwater recharge from CBM holding ponds (green chart, fig. 8).

Figure 9 displays the comparative effects of drawdown on water levels from coal mining and CBM pro-

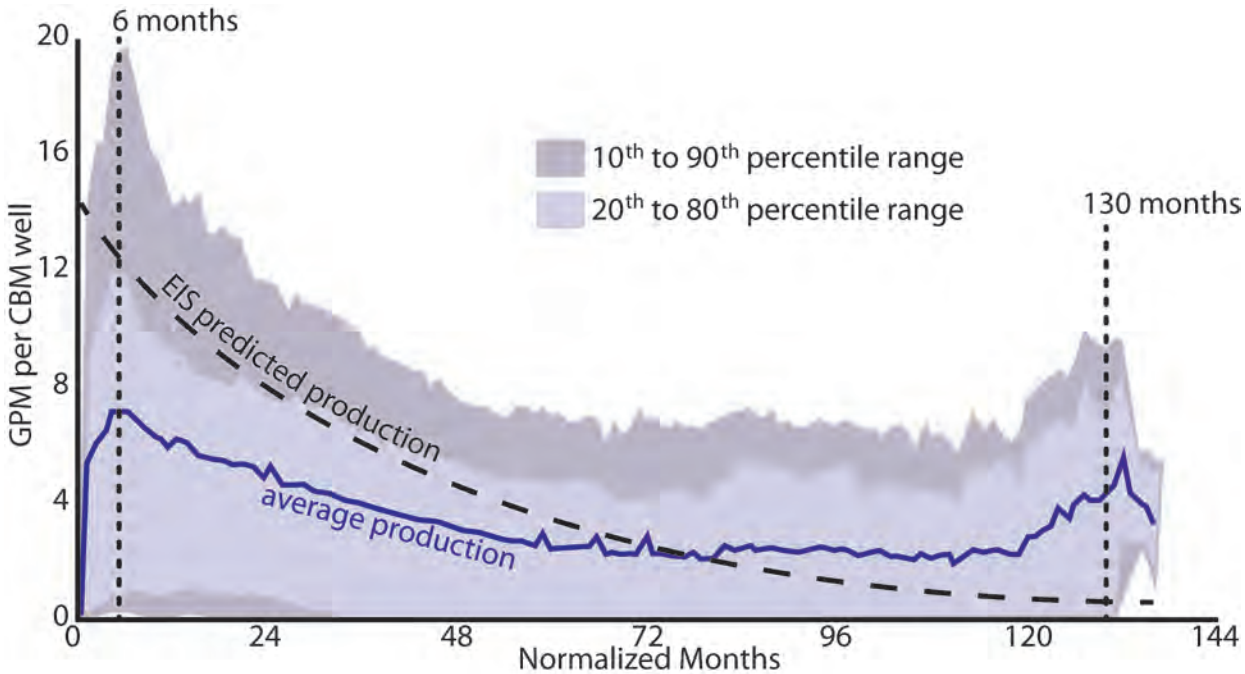

Figure 7. The average CBM well produces less water than the environmental impact statement (EIS) predicted for the first 6 years. Water production levels off in about 4 years at approximately 4 gpm. The range in production rates is shown by the shaded fields (data from the 2010 water year; Meredith and others, 2011).

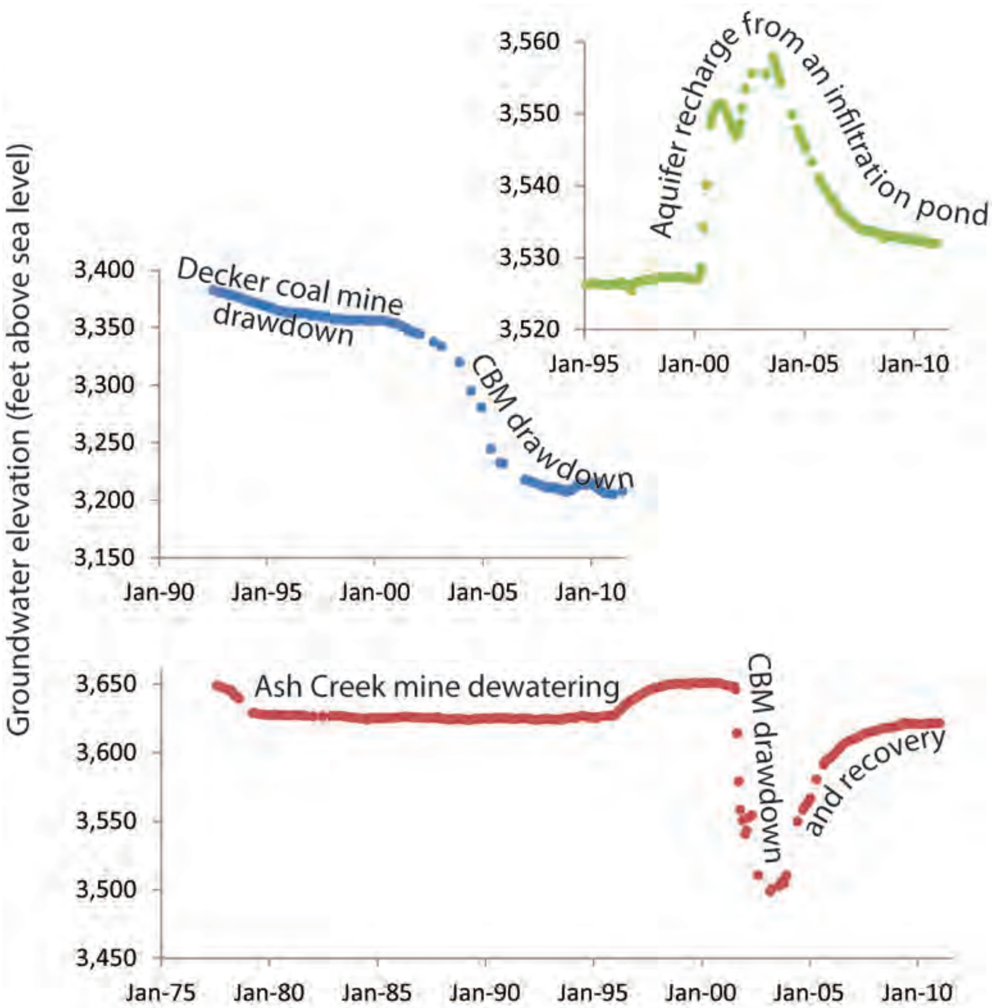

Figure 8. Groundwater levels in the Anderson–Dietz coal were lowered during the active dewatering of Ash Creek mine (red). Drawdown from CBM has begun to recover as production in the area slows. Groundwater decline due to coal mine operations is generally slower than the dewatering required for CBM production (blue). In contrast, unlined CBM impoundments can recharge shallow aquifers (green). After the pond was no longer used, water levels began to return to their normal conditions. The GWIC ID (see Additional Sources of Information) of the wells presented here are, top to bottom: 132909, 123796, and 132973. Note: the vertical axes for the three charts are different scales to show detail.

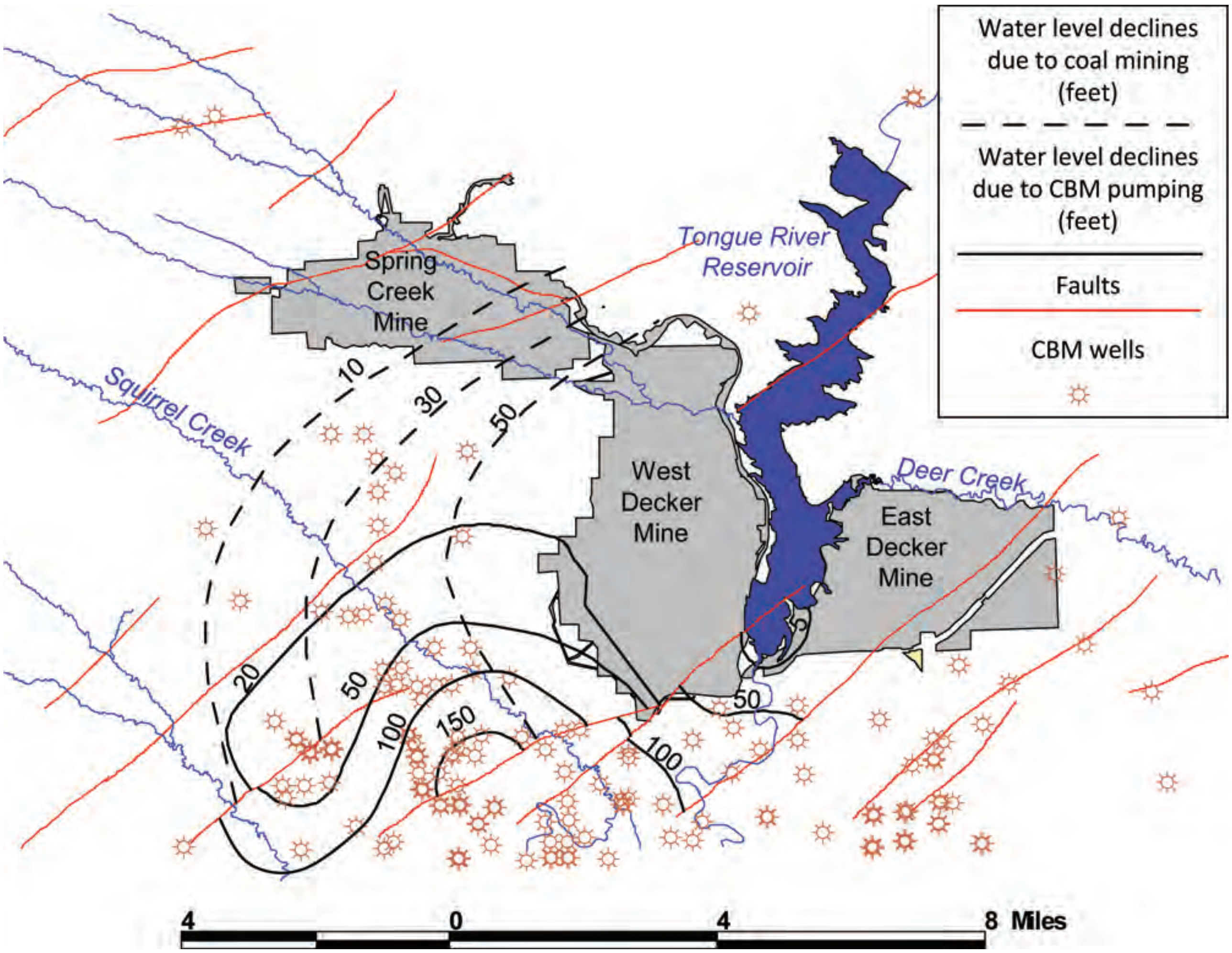

Figure 9. Water-level declines from mining of 10 feet extend farther than 5 miles beyond the West Decker coal mine after 25 years of mining. Aquifer drawdown from CBM production is approximately 20 feet at distances of 1 to 2 miles beyond the active CBM development area after 10 years of production.

duction adjacent to the Decker coal mines. Monitoring data show that 25 years of coal mining produced drawdowns in water levels of 10 feet at a distance of about 5 miles from the mines. CBM production began in the same area in October 1999, and after 12 years of production has resulted in 20 feet of drawdown at a distance of 1–2 miles from the edge of development and no measureable drawdown at 5 miles from development.

Computer models constructed early in Montana's CBM development that were based on the hydrology associated with traditional open-pit coal mining in the Powder River Basin predicted wells within 5 miles of CBM development may have 20 feet of drawdown (Wheaton and Metesh, 2002). Ten years of monitoring has shown that 20 feet of drawdown rarely extends beyond 2 miles of development. The lateral extent of drawdown is determined by geologic factors such as faulting, coalbed continuity, and aquifer transmissivity, and production factors such as the rate and duration of groundwater withdrawal.

The Montana Department of Natural Resources and Conservation has designated the area being developed for coalbed methane a Controlled Ground Water Area. This designation is limited to those wells installed for the extraction of CBM and requires CBM operators to offer water mitigation agreements to owners of water wells or springs that fall within a half mile of a CBM operation. The area subject to mitigation agreements extends an additional half mile beyond any adversely affected well. As part of the Controlled Ground Water Area, a technical advisory committee was established to oversee groundwater monitoring and reporting. Hydrogeologists from the MBMG are members of this committee, and the annual report of CBM monitoring drafted by the MBMG currently serves as the reporting requirement (see Additional Sources of Information).

Aquifer connectivity

The Fort Union Formation is composed of alternating coal, sandstone, and shale. Shale layers generally have low permeability and therefore serve as hydrologic barriers that isolate aquifers. Shale plays an important role in protecting other aquifers from CBM-related drawdown. Water-level drawdown in coal aquifers from CBM production is rarely transmitted to adjacent aquifers because low-transmissivity shale layers are common in the Powder River Basin (fig. 10).

Initial drawdown and aquifer communication predictions were based on work done by Van Voast and Reiten (1988) that showed faults to be hydrologic barriers because of the smearing of clays and offset of coal against shale. Ongoing monitoring has demonstrated that some faults have variable restriction to groundwater flow depending upon the amount of offset. For example, along scissor faults the amount of offset varies along the fault, so there is communication across the fault at some points and restriction of flow at other points. Groundwater can also migrate around the end of faults in some locations.

Anticipated and observed recovery

Estimates of water-level recovery time vary from tens to hundreds of years. This uncertainty is driven by lack of available data concerning the aquifer recharge rates and primary recharge locations. Several monitored wells in CBM fields that have begun to be shut in show that water levels have recovered 70 to 80 percent of maximum drawdown within 5 years of the slowing of CBM production in the area (red chart in fig. 8). This does not represent a true recovery rate because CBM wells in the area continue to produce water, but at a lesser rate. A water chemistry study performed in 2010 on wells that have recovered to near baseline levels shows that the groundwater chemistry has not changed from before development began (Meredith and others, 2011). This implies that the water-level recovery is most likely from redistribution of the existing groundwater or that the recharge pathways have not been significantly shortened by water-level drawdown.

WATER MANAGEMENT GOALS AND TECHNIQUES

Near Gillette, Wyoming, where production of CBM initially commenced in the Powder River Basin, concentrations of dissolved constituents in CBM waters are lower than those found in Montana (fig. 11). In CBM waters, the dissolved constituents are predominantly sodium and bicarbonate ions (Van Voast, 2003). The CBM waters in Montana typically have SAR values greater than 30, and the TDS ranges from 1,000

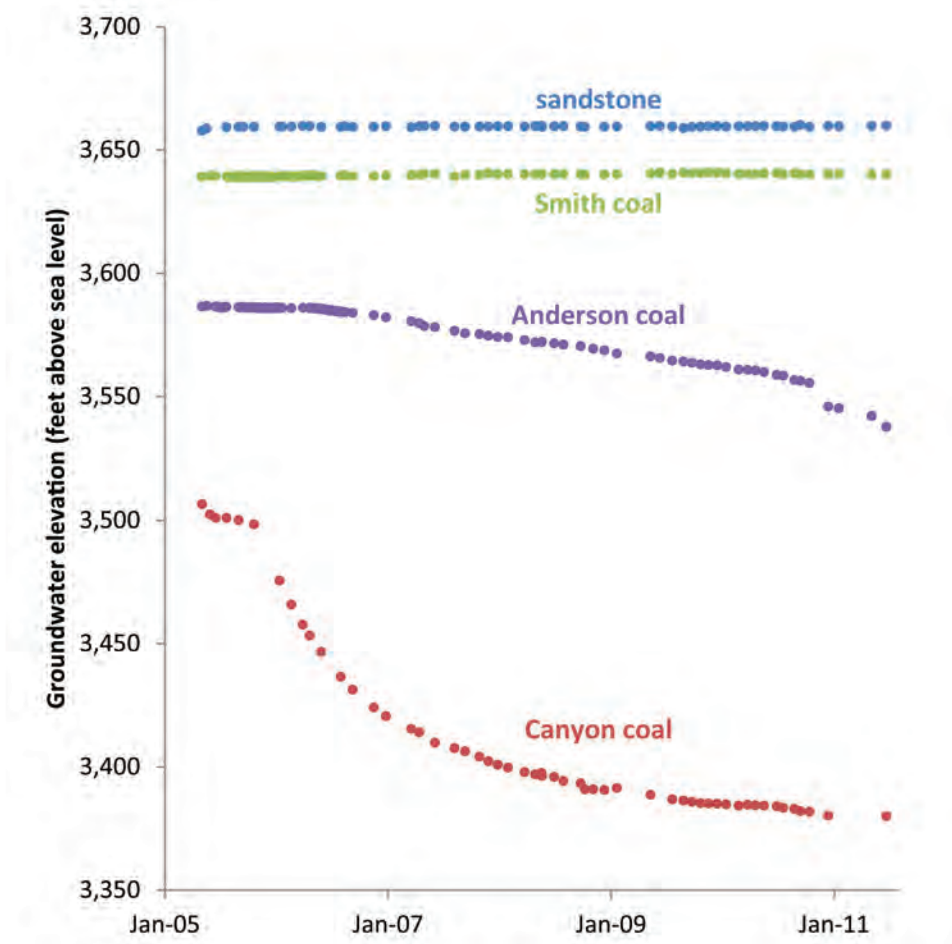

Figure 10. Drawdown in the Anderson and Canyon coals due to CBM production is not typically translated to the overlying coal and sandstone aquifers. GWIC ID numbers of the nested well set presented here are, top to bottom: 219617, 219138, 219139, and 219140.

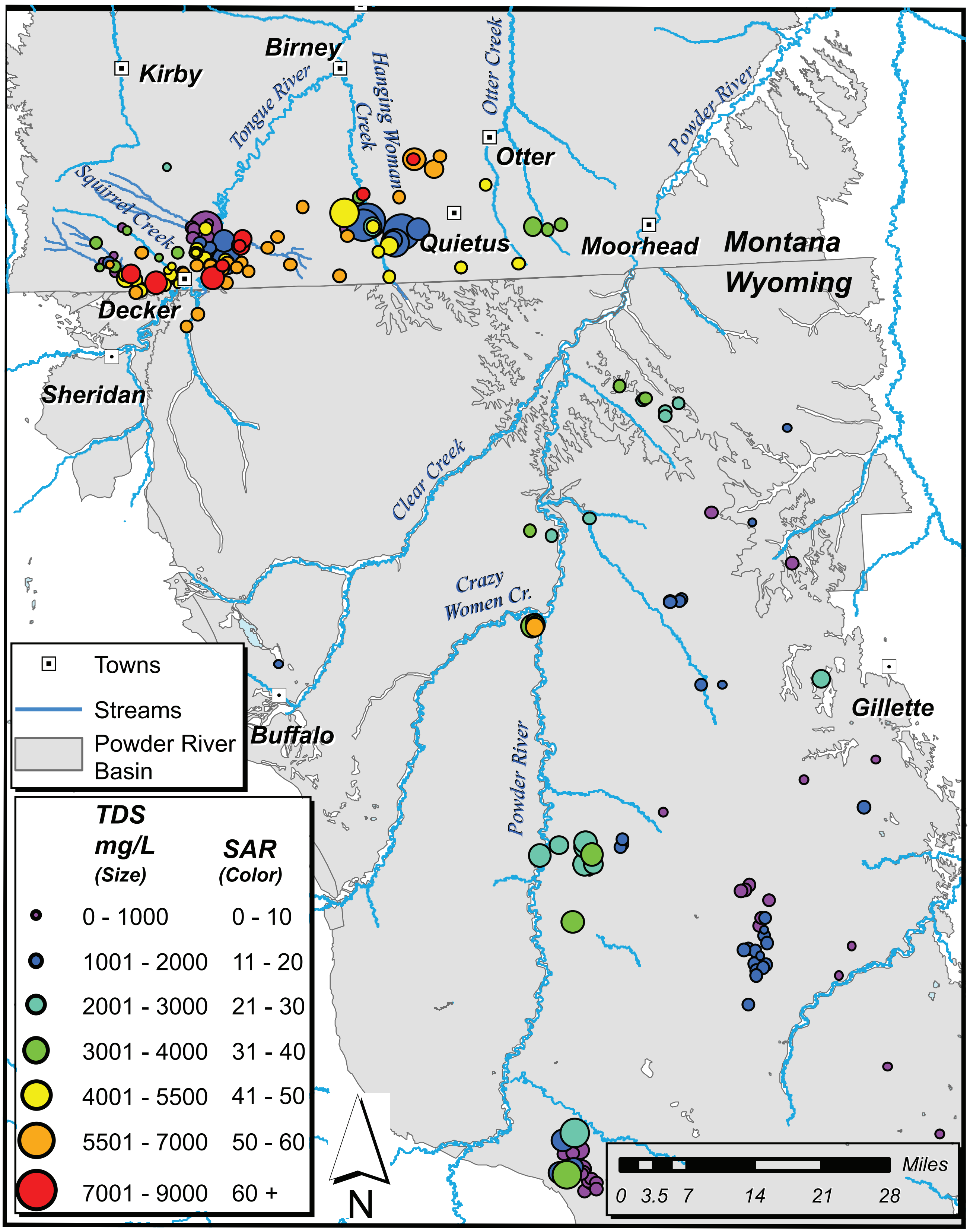

Figure 11. Sodium adsorption ratio (SAR) tends to increase with distance away from recharge. Mature coal aquifer water has TDS values between 1,500 and 2,500 mg/L, with sodium and bicarbonate being the dominant ions. Montana coal aquifer data from the Montana Bureau of Mines and Geology GWIC database. Wyoming coal aquifer data from Campbell and others (2008).

to more than 2,500 mg/L (table 1). The water is usable for stock or domestic supplies but cannot be used for irrigation without treatment of the water or soils.

Disposal of coproduced water is an issue in all CBM fields, and site-specific methods of disposal are based on water quality, soil types, and State and Federal regulations. In most CBM fields outside of the Powder River Basin, the coproduced water is more saline and is not used for livestock or drinking water. In those areas CBM production is not in competition with existing water users, and most coproduced water is injected into deep aquifers. In the Powder River Basin where the coproduced water is a resource, not simply a waste product, managing the water for disposal is a complex issue.

Water disposal is a concern throughout the life of most coalbed-methane wells. Well discharge rates vary with field size, well location, and start-up time, but average about 4 gpm after 5 years. Rates vary significantly, however, and many wells produce no water at all after 3 years (fig. 7; Meredith and others, 2011). Water management in Montana has been an iterative process, where techniques were evaluated for efficacy by the CBM industry, landowners, and environmental groups. Management strategies that were tried in Montana include direct discharge to streams, discharge to lined and unlined impoundments with and without atomizers, treatment with Higgins Loop ion exchange, and as dust suppression at the nearby coal mines. Since 2010, only treated coproduced water is discharged to streams, water is impounded in lined ponds without atomizers, and water is still used by the coal mines for dust suppression. In Wyoming, additional methods of water management include sprinkler and subsurface-drip irrigation, impoundment in unlined ponds for infiltration to the shallow aquifer, held in on-channel reservoirs that spill to the channel during larger runoff events, injection into deep aquifers, and direct discharge to ephemeral and perennial streams. Each of these management options has both benefits and disadvantages, and no single technology works best at all sites. Understanding the potential benefits and disadvantages is vital to developing appropriate water management strategies.

Direct Discharge to Streams and Rivers

Mixed with river water in small enough volumes, coproduced water can have very little negative effect when used for irrigation; however, the volume of coproduced water that can be discharged to surface streams is specific to the receiving streams' natural, seasonally variable salt concentrations and flow rates. The salinity and SAR of the Tongue River decrease

Table 1. Water-quality summary for coalbed aquifers in the Powder River Basin of Montana.

Coalbed (No. of samples)	Sodium (mg/L)			TDS (mg/L)			SAR		
	Avg. (std dev)	Max	Min	Avg. (std dev)	Max	Min	Median	Max	Min
Anderson (23)	815 (323)	1660	416	2530 (1748)	8802	1027	42.0	56.3	11.1
Anderson–Dietz 1 (7)	426 (345)	1025	106	1560 (600)	2766	1008	37.9	65.1	1.8
Anderson–Dietz 1, 2 (10)	584 (226)	1126	339	1479 (620)	3020	832	49.7	79.2	28.2
Dietz (12)	505 (280)	1058	139	1591 (706)	3037	671	25.6	54.2	2.9
Dietz 1, 2 (10)	365 (189)	608	20	966 (350)	1596	393	37.7	51.2	0.5
Dietz 2 (11)	516 (193)	806	248	1921 (1566)	6057	890	14.4	67.9	4.3
Canyon (12)	547 (138)	780	330	1366 (268)	1778	888	41.6	67.7	7.3

with increasing flow in the spring and summer, which means the river has an increased capacity to accept CBM coproduced water discharge without exceeding the maximum salinity and SAR thresholds (fig. 12). Direct discharge to surface-water bodies is regulated by State rules under the Clean Water Act. The Montana Board of Environmental Review set a maximum allowable monthly average SAR value for the Tongue River of 3 during the irrigation season (March through October) and 5 for the remainder of the year. Prior to 2011, the CBM industry treated a fraction of the discharged water and blended it back into the discharge stream in proportions necessary to meet these salinity and SAR regulations. In 2010, the Montana Supreme Court ruled that all coproduced water must be treated prior to discharge to surface drainages (Johnson, 2010). There is one Higgins Loop treatment facility currently in use along the Tongue River in Montana that treats coproduced water prior to discharge to the river.

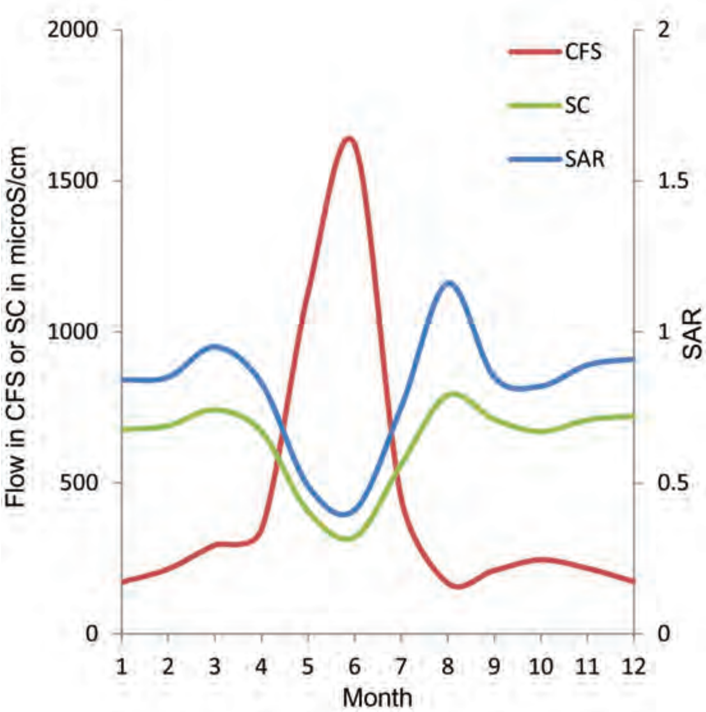

Figure 12. Average monthly flow rate, salinity (SC), and sodium adsorption ratio (SAR) for the Tongue River at the state line (U.S. Geological Survey, 2011).

Infiltration and Evaporation Ponds

Holding ponds can be unlined, which allows impounded water to infiltrate to shallow aquifers and to evaporate, or lined, which restricts the water to evaporation. Both lined and unlined ponds are used extensively in Wyoming; however, ponds in Montana are currently all lined. Water infiltrating from unlined holding ponds recharges shallow aquifers and, in some settings, may result in increased availability of usable groundwater. In other settings, infiltration from holding ponds may cause deterioration of shallow groundwater quality due to dissolution of soluble salts in shallow strata beneath the ponds. Some monitored unlined ponds in Wyoming have shown salinity spikes in the shallow aquifer below and downgradient from the ponds. These spikes usually take several years to dissipate.

The utility of infiltration ponds can be reduced if the interaction of sodium in the coproduced water with the floor of the pond causes the floor to seal, greatly restricting infiltration. Additionally, if an impermeable layer such as shale is present, the infiltrating water may be diverted horizontally to form unwanted saline seeps.

To increase evaporation rates from lined ponds, atomizers have been used to spray the water into the air, but this method was discontinued after the Helena District Court prohibited their use in Montana (McKee, 2010). Successful holding ponds require site-specific planning to minimize reduction of infiltration capacity and to evaluate potential effects on groundwater and surface waters.

Sprinkler and Subsurface-Drip Irrigation

The high concentration of sodium as compared to the calcium and magnesium concentrations, or SAR, of CBM coproduced water can cause the clay in irrigated soil to swell and disperse. This reduces the infiltration rate of soil and reduces the irrigated field's productivity (fig. 13). Use of CBM coproduced water for irrigation requires intensive soil management, overseen by soil scientists and agronomists, for the duration of coproduced water application and for some duration of recovery. The soil's recovery time depends upon the quality of water used and the type of soil irrigated. One study of CBM-irrigated fields, 2 years after

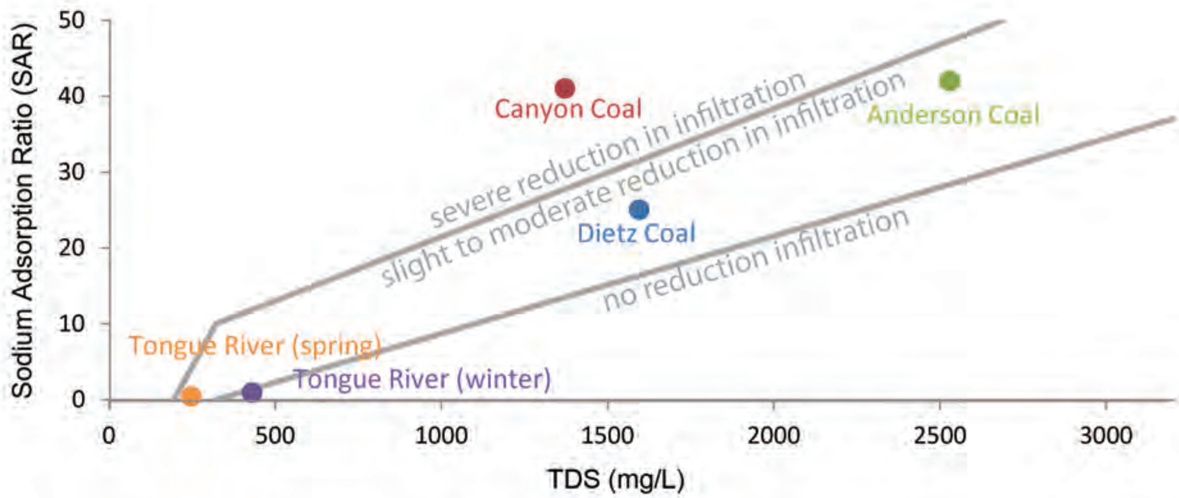

Figure 13. The effect of irrigation water on soil structure is dependent upon the TDS, the SAR, the soil type, and clay mineralogy (based on Hanson and others, 1999). Tongue River chemistry is reported from a station at the Wyoming/Montana state line maintained by the U.S. Geological Survey.

soil amendments and irrigation stopped, found that the field was not at baseline salinity and sodium levels (Johnson and others, 2011). Amendments used during sprinkler irrigation with coproduced water include a combination of amending the soil with gypsum and/or sulfur and acidifying the water with sulfuric acid. Management of subsurface-drip irrigation generally depends upon lowering the pH of the water with sulfuric acid and relying upon the natural buffering capacity of the soils to minimize the sodium hazard. Proper management must take into account the quantity and timing of water applications, soil type, natural salt levels, and crop selection (Beletse and others, 2008; Brinck and Frost, 2009; Ganjegunte and others, 2008; Johnson and others, 2008, 2011; Vance and others, 2008).

Injection Wells

Coproduced water can be injected into aquifers that meet certain conditions. The aquifer must be hydrologically isolated from the coal being developed for CBM to avoid interference from injected water migrating into the depressurized CBM production zone. The aquifer must be reasonably permeable and able to accept a large quantity of water. The water quality must be compatible to prevent the precipitation of minerals and salts that would clog the water pathways, and the injected water must not change the class of use of the water, a measurement based primarily on salinity. In some geologic settings, recharge to aquifers that are shallower or slightly deeper than the producing coal seams will increase local water resources and might aid the recovery of water levels in coal aquifers. Injection to deep geologic strata will generally result in a loss of water resources, as deep aquifers typically have poor water quality and are too deep to be utilized for stock or domestic supplies. To design an injection system, the hydrogeologic properties of the receiving units and the combined water quality need to be carefully considered on a site-specific basis. Coproduced water is currently injected in several locations in Wyoming and to an unsaturated coalbed in Montana. Other injection sites are also being evaluated in Montana. Permitting policies differ between the two states in that it is handled at the State level in Wyoming and, for all but class II oil and gas wells, at the Federal level (by the EPA) in Montana.

Treatment

One treatment facility is used in Montana to treat water prior to release to the Tongue River. The Higgins Loop process reduces sodium and salinity through ion exchange. The first step in the ion exchange process includes exposing the coproduced water to a resin that attracts sodium ions and releases hydrogen ions (acid). The treated water is then neutralized to raise the pH. Calcium and magnesium are added to lower the SAR of the water so it meets the standards for release to surface drainages. The sodium-loaded resin is then recharged with a strong acid, and concentrated brine is collected as waste.

Other treatment alternatives that are used in Wyoming and other CBM basins throughout the country include:

- reverse osmosis, which uses a semi-permeable membrane to separate the salts from the water;
- freeze/thaw/evaporation, which is uniquely suited to northern climates as it uses natural freezing temperatures to freeze coproduced water, leaving behind a brine;
- electrodialysis reversal;
- electro-pressure membranes;
- zeolites; and
- zirconium phosphate.

WATER-QUALITY CONCERNS

One of the primary concerns with CBM coproduced water, in addition to the possible loss of groundwater resources, is its water quality and how it affects surface water, groundwater, and soils. The chemistry of the water determines how the water can be used, but it is not a static parameter. The chemistry of the coproduced water changes with interaction with the atmosphere, with other waters, and with soils. Additionally, ultimate water chemistry is not a simple matter of mixing or dilution; depending upon the chemical makeup of the water, minerals can precipitate or be mobilized from the environment.

Geochemical Changes in Ponds

The two types of ponds, lined and unlined, are used extensively throughout the Powder River Basin. Several studies have been done that look at how the water chemistry changes with time in these impoundments. Some changes are immediate, such as the increase in pH from around 7 in CBM coproduced water to around 8 in ponds. Additionally, the precipitation of iron, which results in red-stained rip-rap around discharge points, and carbonate minerals, such as calcite, occurs very quickly. Other changes depend upon the age of the pond, such as increasing concentrations of arsenic, sodium, boron, selenium, and fluoride that have been documented at some sites. In most of the studied ponds, none of the increasing constituents had reached levels of concern; however, one pond had arsenic levels of 146 micrograms per liter (μg/L), which exceeds the drinking water limit of 10 μg/L (Sowder and others, 2010). Sowder and others (2010) determined that the high levels of arsenic in this pond were caused by evaporative concentration of the low levels (0.20–0.48 μg/L) of naturally occurring arsenic in CBM coproduced water. The evaporative concentration was exacerbated by the lowered infiltration rate of the pond floor caused by the soil's interaction with the sodium in the coproduced water.

Geochemical evolution after infiltration from unlined ponds

Infiltration ponds have the ability to retain the water resource by allowing it to recharge shallow aquifers. However, depending upon the pond-site location, the infiltrating water can mobilize significant levels of soluble salts from the soil and geologic material. Ponds constructed on existing drainages were found to have smaller salinity spikes in the groundwater below them than ponds constructed off existing channels. Typically the salinity increases include high levels of calcium and magnesium, resulting in lower SAR values in the affected groundwater despite the higher salinity.

The timeframe for the salinity spikes to dissipate depends upon the pond site, local soil types, initial coproduced water chemistry, infiltration rate, and groundwater flow rates. Some ponds have been shown to have reduced infiltration with time due to the interaction of the sodium in the coproduced water with the clays in the pond floor. This limits the useful capacity of a pond considerably and illustrates the importance of proper site selection (Brinck and Frost, 2007; Brinck and others, 2008; Jackson and Reddy, 2007a,b; McBeth and others, 2003; Milligan and Reddy, 2007; Patz and others, 2006; Wheaton and Brown, 2005; Wheaton and others, 2005).

Wyoming Department of Environmental Quality maintains a database of groundwater monitoring around CBM impoundments (written commun., Carrie Steinhorst, Wyoming DEQ, January 18, 2012). Included are data from 37 monitoring wells representing 27 impoundments that have baseline samples, or adjacent wells with baseline samples, and a sample history of at least 4 years. The represented impoundments are an even mix of on-channel (15) and off-channel (12). Results from these wells illustrate a mix of responses in groundwater to the effects of infiltration ponds. Approximately 7 wells showed no impact to water quality, 6 wells had salinity levels consistently below baseline with no initial spike in salinity, and 4 wells had rising salinity over the monitored period, which ranged from 4 years 8 months to 6 years. The remaining 20 wells showed a spike in salinity. The timing from initial discharge to the pond and the salinity peak in the monitored groundwater ranged from 1 month to 5 years. This timing depended primarily upon the distance of the monitoring well from the pond. Of the wells that had a spike in salinity, 7 recovered to baseline salinity levels during the monitoring period. The timing for recovery varied from 1 year to 5 years 2 months. Two of these wells were flushed to below baseline salinity levels. Thirteen of the monitoring wells had not recovered to baseline during the monitored period, generally 4 to 5.5 years. This summary of the Wyoming database is not statistically significant; it simply provides a general idea of the behavior and timing of groundwater changes associated with infiltration ponds.

Issues Associated with Surface and Subsurface-Drip Irrigation

Excess sodium is the primary concern when using CBM coproduced water for irrigation. When the concentration of sodium greatly exceeds that of calcium and magnesium (a high SAR value), the sodium can displace calcium and magnesium from the soil's cation exchange sites. The sodium degrades the structure of some clay-rich soils by causing the clays to swell and disperse, which reduces the infiltration rate and water-holding capacity of the soil. While these problems can be accounted for and mitigated while the irrigation is ongoing, the secession of irrigation and soil amendment can lead to long-term damage that is extremely hard to reverse (Brinck and others, 2008).

Introducing low-salinity water in the form of irrigation or precipitation will cause the amendments, which rely in part upon a high salinity level to maintain soil structure, to lose efficacy. More research is required to determine the proper methods of soil management to successfully end CBM coproduced water irrigation without causing the field to lose agricultural value. It will probably require tapering the use of amendments for years after coproduced water irrigation has ceased (Brinck and others, 2008; Brinck and Frost, 2009; Ganjegunte and others, 2008; Johnson and others, 2008; Vance and others, 2008).

PROJECTIONS

Anticipated Geographic and Temporal Extent of CBM

Early publications of CBM development in Montana predicted the establishment of CBM fields as far north as Ashland (Township 3 South). However, after over 10 years of development, all development is still confined to the area immediately surrounding the Tongue River Reservoir (Township 8 South). It does not appear that there is currently any industry interest in extending the developments further north. Significant volumes of coalbed methane most likely exist all along the state line from the Tongue River to near the Powder River. East of the Powder River the coalbeds are thin and may not contain economically significant methane. Development to the east of the Tongue River will depend upon the establishment of the necessary infrastructure—pipelines, power lines, roads, etc.—and negotiating environmental issues such as water disposal and sage grouse habitat.

Groundwater drawdown of 20 feet or more will most likely continue to be limited to a 2-mile radius around CBM fields. Factors controlling this distance include the rate and duration of water extraction and the presence of drawdown-limiting faults. These characteristics will be poorly defined in new areas until development is well established. Similarly, water-level recovery rates also depend upon these same factors. Continued monitoring is the best way to define, track, and predict the environmental consequences of CBM development.

The useful life of CBM wells in Montana is approximately 8 years, but many wells are shut down after less than 4 years (fig. 14). The productive life of a well depends in part upon the balance between the costs of running the well—which includes labor, parts, and water disposal—and the current market price of natural gas. Coalbed methane developers are more susceptible to the whims of the market than are other, more traditional, energy developers, because CBM wells cannot be turned on and off depending upon demand. In order to maintain the lowered water pressure necessary for methane extraction, the wells (or some wells within the field) must be constantly pumping water. For this reason, CBM often fetches a lower price than traditional natural gas.

Exhaustion of the resource is another reason wells are shut in, plugged, and abandoned. This limitation will be minimized or resolved if real-time bacterial genesis of methane can be realized.

Water Management

The two court decisions handed down in 2010 have changed the way the CBM industry has approached water management. Atomizers are no longer being used, and untreated water is no longer discharged to surface drainages. Future management strategies are still in flux, but will most likely use a combination of ponds, possibly including the incorporation of infiltration ponds, treatment, and increased beneficial use. If permitting and environmental issues can be resolved, beneficial uses such as irrigation, stock water, and injection will be increasingly used in Montana.

Further challenging issues include disposing of water in a drainage other than that from which it was withdrawn. This is an issue that spans both Federal and State laws and will have to be resolved before water is transported between watersheds. Additionally, state line issues still persist that include both quantity and quality of surface and groundwater that crosses from Wyoming into Montana. These issues are currently being resolved at the Federal level.

SUMMARY

Coalbed-methane resources in Montana are volumetrically less than those in the neighboring state of Wyoming. Production in Montana has not seen proportionate growth largely because of a less favorable geologic setting, concerns over the potential loss of groundwater, and concern for impacts from the disposal of coproduced water. Loss of groundwater resources was a known possibility when CBM development began in Montana; however, after over 10 years of production, no impacts to springs have been observed and MBMG data do not indicate any unforeseen impacts to wells.

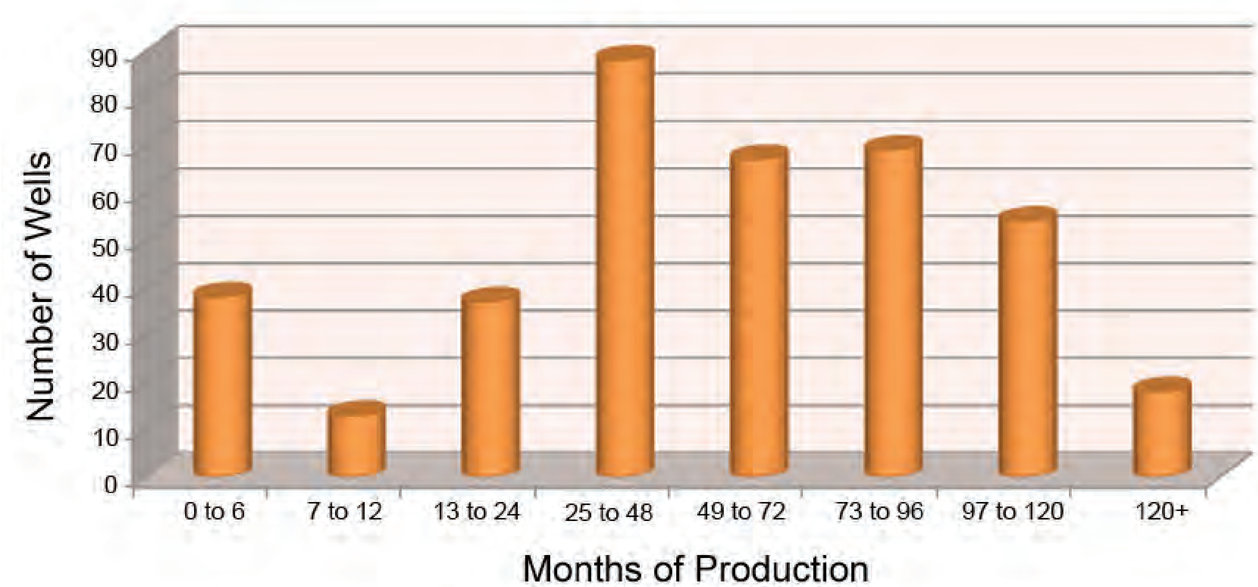

Figure 14. Producing life of wells that have not produced water or gas for 6 consecutive months (total number of wells 384).

CBM BASICS

Groundwater monitoring by the MBMG in the Powder River Basin began in the 1970s, which has enabled predictions and modeling of groundwater drawdown in the region's aquifers. Potential effects of CBM development are being evaluated by the MBMG, numerous other Federal and State government agencies, and academic and industry groups. Advanced planning accompanied by continual monitoring during and after CBM production is critical. Site-specific methods of water handling based on water quantity and quality, water use, soils, local aquifers, and surface-water characteristics will be necessary to reach solutions agreeable to all stakeholders.

What Landowners Can Do to Monitor for Changes

Landowners can inform and protect themselves by monitoring their soil and water resources for changes that may be induced by nearby CBM production. Water-monitoring kits are available in many communities in southeastern Montana, including: Hardin, Birney, Decker, Broadus, Moorhead, Lame Deer, Miles City, Forsyth, Hysham, Joliet, Ekalaka, and Baker. These kits have measuring tapes that sound a buzzer when in contact with water to measure the depth to water in wells, portable weirs to measure the flow rate in undeveloped springs, graduated buckets and stopwatches to measure the flow rate in developed springs, pressure gauges to measure the water pressure in flowing wells, salinity meters to monitor changes in water quality, and other equipment useful for private monitoring efforts. Landowners should contact their local Conservation District or the MBMG to learn more and find the nearest kit for their use. If a monitoring kit is unavailable there are still many ways to accurately monitor for water and soil changes. Landowners should contact the MBMG or their local Conservation District and USDA office for more information.

Having baseline data is crucial for determining the cause of changes to surface water, groundwater, and soils. The cause may be related to CBM development, or it may be related to climate, land-use changes, or other issues. Additionally, baseline information will be taken into account if a landowner chooses to apply for compensation through the State-funded Montana CBM Protection Act (for more information see following section on Additional CBM-Related Groups and Resources).

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ADDITIONAL SOURCES OF INFORMATION

Resources Available from the MBMG:

MBMG Website

Provides contact information for MBMG employees, details for current and past research projects, and links to the GWIC database and the publications catalog.

http://www.mbmg.mtech.edu

MBMG CBM Annual Report

Available from the MBMG publications catalog:

- Search for "Coalbed Methane" under the keyword field.
- PDF version is free for download. Must have Adobe Reader installed to view.

http://www.mbmg.mtech.edu/mbmgcat/catMain.asp

GWIC

The GWIC (Ground Water Information Center) database gives the public the resources to research well and spring ownership, well productivity, and groundwater chemistry.

- To start your research, register a user name by clicking on "create one here."

http://mbmggwic.mtech.edu

Or contact the MBMG at:

Billings Office:

1300 North 27th Street
Billings, MT 59101
Phone: 406.657.2929
Fax: 406.657.2633

Butte Office:

1300 West Park Street
Butte, MT 59701
Phone: 406.496.4167
Fax: 406.496.4451

Additional CBM-Related Groups and Resources

CBM Protection Act

The Coalbed Methane Protection Act was established by the 2001 Legislature for the purpose of "compensating private landowners and water right holders for damage to land and to water quality and availability that is attributable to the development of coalbed methane wells."

Conservation Districts whose water sources could be affected by CBM extraction and/or whose boundaries contain coalbeds are given administrative authority over the awarding and amount of funds used for landowner compensation.

For more information contact your local Conservation District or visit the affiliated webpage:

http://dnrc.mt.gov/cardd/CBM/default.asp

Powder River Basin Interagency Working Group

State and Federal agencies active in decision making in Montana and Wyoming and supporting agencies come together periodically to "work together to protect the air, water, land, fish, wildlife, plants, and cultural resources in the Powder River Basin for current and future generations while providing for natural gas development to address the nation's energy needs." An MBMG scientist advises this group on groundwater in areas of CBM development. The website includes links to available monitoring and research reports.

http://www.wy.blm.gov/prbgroup/

CBM Technical Advisory Committee and the Powder River Basin Controlled Ground Water Area

The Montana Department of Natural Resources and Conservation has designated a technical advisory committee (TAC) to oversee the groundwater characteristics and monitoring and reporting requirements for the Controlled Ground Water Area (CGWA). The CGWA only applies to wells installed for CBM extraction. An MBMG scientist sits as a technical advisor for hydrogeology on the TAC, and the MBMG's annual report of CBM monitoring currently serves as the reporting requirement.

http://dnrc.mt.gov/wrd/water_rts/cgwa/powder_riverbasin/

Montana Board of Oil and Gas

For information regarding coalbed-methane wells and production in Montana.

http://bogc.dnrc.mt.gov/

Wyoming Oil and Gas Conservation Commission

For information regarding coalbed-methane production and coproduced water in Wyoming, including information specific to the Powder River Basin.

http://wogcc.state.wy.us

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