Ground-Water Monitoring Program in Prospective Coalbed-Methane Areas of Southeastern Montana: Year One

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Abstract

Methane (natural gas) production from coal beds is a new and potentially important industry in Montana. Coalbed methane (CBM) is held in coal beds by adsorption on the coal due to weak bonding and hydrostatic pressure of water in the coal. Reducing the water pressure allows the methane to desorb from the cleat faces and micro-pores in the coal. Production of CBM requires that water pressure in the coal aquifers be reduced across large areas. Water pressure is reduced by the removal of large volumes of water which must be managed once it reaches the ground surface. The extraction and subsequent management of CBM production water has raised many concerns. In the Montana portion of the Powder River Basin CBM production water is of acceptable quality for domestic and livestock use, however its high sodium content makes it undesirable for application to soils, particularly those with a significant clay component. High sodium content can cause clays to become deflocculated, thereby decreasing the infiltration capacity of the soil.

This report introduces the Montana coalbed-methane ground-water monitoring program and presents the first year of data. This program was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to determine actual ground-water impacts and recovery, and to provide data and interpretations for permitting and exploration decisions.

Two types of ground-water flow systems are present in the Powder River Basin in Montana: the regional systems flowing from Wyoming, north into Montana; and local

systems that are recharged along areas of outcrop and clinker-capped ridges, and flow toward topographically lower areas. The quality of the water moving along these flow systems changes in a predictable fashion with an end result being moderate concentrations of sodium and bicarbonate, with little else in the water. Coalbed methane production occurs only where this sodium-bicarbonate-dominated water exists in the coal beds.

Ground-water flow occurs in two distinct modes, local systems recharged in topographically high areas and flowing toward topographically low areas such as rivers, and regional flow primarily recharged in Wyoming and flowing north into Montana. Geometric mean values for hydraulic conductivity are 61.4 feet square per day (ft^2/day) for alluvium, 1.0 ft^2/day for coal and 0.06 ft^2/day for sandstone. Flow in the Dietz coal is estimated at 5,430 ft^3/day per mile width in the Squirrel Creek area, and 160 ft^3/day per mile width across the state line between Montana and Wyoming. Ground-water flow in other coal beds is probably similar, if differences in thickness are considered.

The quality of water in coal beds in the project area is typically dominated by ions of sodium and bicarbonate, with sodium adsorption ratios between 4 and 80 and dissolved solids concentrations from less than 1,000 mg/L to nearly 9,000 mg/L. Calcium, magnesium and sulfate concentrations are found at varying concentrations throughout the basin. Coalbed methane production water will have high sodium adsorption ratios, probably averaging 30 to 40, and low dissolved solids concentrations, probably averaging around 1,500 mg/L.

One operator has been producing from one CBM field (the CX field, Plate 1) in Montana since October, 1999. This field now includes about 250 wells near Decker. Water levels in monitored coal beds have been lowered as much as 150 feet during about 4 years of production. The area where greater than 5 feet of drawdown has been measured extends 1 to 2 miles beyond the edges of the production field. An additional 178 CBM wells were drilled and completed for production adjacent to this field in 2003 and 2004 (the Badger Hills expansion, Plate 1). Production has not yet begun in this field.

Based on computer modeling and reviews of current data from mines and other CBM production fields, drawdown of 20 feet is expected to eventually reach as far as 4 miles beyond the edges of large production fields, and drawdown of 10 feet is expected to reach 5 to 10 miles (Wheaton and Metesh, 2002). Less drawdown will occur at greater distances. Water levels will recover, but it may take decades for them to return to the original levels. The extent of drawdown and rates of recovery will be determined in large part by the rate, size and continuity of CBM development, and the site specific aquifer characteristics.

Models and predictions are important for evaluating potential hydrogeologic impacts. However, inventories of existing resources and long-term monitoring of aquifer responses will be the method to determine actual magnitude and duration of impacts. Development decisions will be based in large part upon previous hydrogeologic data and interpretations.

Introduction

Purpose and need

This report introduces the Montana coalbed-methane ground-water monitoring program and presents the first year of data. This program was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to determine actual ground-water impacts and recovery, and to provide data and interpretations for permitting and exploration decisions.

Southeastern Montana is a semi-arid region that supports a rural economy based mainly on agriculture. Coal mining, electricity generation and natural gas production add to the local economy. Agriculture and coal mining successfully operate on adjacent lands, in part by directing considerable effort toward managing the water resources. The balance between domestic water needs, livestock, irrigation, wildlife, and energy development is maintained by acquiring accurate scientific data, and correctly evaluating those data in support of responsible management decisions. Following successes in mining areas, ground-water monitoring and reporting have been initiated in response to planned CBM production in Montana and Wyoming.

Based on data published by the Potential Gas Committee (Pierce, 2003) coalbed methane (CBM) may represent about 7.5 percent of total natural gas reserves in the United States; reserves in the Powder River Basin total about 26.7 trillion cubic feet (tcf). Reserves in the Montana portion of the Powder River Basin have been estimated at about 0.9 tcf (U. S. Department of Energy, 2002). Current estimates indicate that approximately 60,000 CBM wells may eventually be installed in the Powder River Basin (Wyoming and Montana), with about 26,000 wells anticipated in Montana (U. S. Bureau of Land Management, 2003). Estimated pumping rates for each well range from 5 to 20 gallons per minute with the rate of water production declining with time from each well (U. S. Bureau of Land Management, 2003). The likely duration of CBM production in the Powder River Basin is not yet known.

Methane is held on cleat surfaces and in micropores in coal (Rightmire, and others, 1984; Law and Rice, 1993). The gas is held in place by physical sorption, in addition to hydrostatic pressure from ground water in the coal. The gas can be released from the coal surface by reducing the water pressure in the coal bed. Wells, drilled and completed in the coal, are used to reduce hydrostatic pressure by pumping water from the coal. The released methane is captured in the same wells. Greater efficiency in reducing water pressure in the coal beds is achieved by completing wells in grid patterns called pods. The well spacing is typically 1 well per 80 or 160 acres, for each coal bed. Pods in Montana are expected to cover areas of about 800 acres, and will consist of 10 to 15 wells in each coal bed. In some areas, as many as four coal beds are targeted, and separate wells will be drilled to each bed from a single location. A central, low-pressure compressor receives gas produced from the wells within a pod, advancing the gas to a high-pressure compressor station that receives gas from several pods and moves it to the market.

The co-production of water with coalbed methane can cause impacts due to: 1) reduction of water in aquifers; and 2) inappropriate management of the produced water. Water removed from aquifers lowers water levels, reducing flow through the aquifer and in some cases reducing water yield at springs and private wells. In these cases, water resources will be reduced for the duration of CBM production plus a recovery time that will be years or decades long (Wheaton and Metesh, 2002). Produced water contains high concentrations of sodium relative to other constituents, creating high sodium adsorption ratios (SAR) which can impact soils. Inappropriate water management plans can allow situations to arise where soils and surface-water resources are impacted.

Decision makers, including landowners, mineral-estate holders, resource managers and governmental representatives need a scientific basis from which to make and support decisions regarding CBM development. Establishment of scientific baselines, and scientifically based understanding of the hydrogeologic systems are critical to guide water-quality and water-resource decisions related to CBM development in the Powder River Basin. The purpose of this report is to provide objective scientific data concerning impacts to ground-water resources due to CBM development in Montana. This report represents one step in the process of providing for environmentally responsible CBM development.

Location and description of area

The study area (Figure 1 and Plate 1) is that part of the Powder River Basin bounded by the Montana Wyoming line on the south, roughly the Powder River on the east, the Wolf Mountains on the west, and extending north to about Ashland. This is the area of Montana that has the greatest potential for CBM development (Van Voast and Thale, 2001).

Geographic setting and climate

The study area in southeastern Montana is a grassland region with rolling to ruggedly dissected topography. Land surface altitude is generally highest in the south, sloping down toward the Yellowstone River in the north. Most of the land is used for agriculture. More than 80 percent of the land is used for grazing stock and about 6 percent is used for raising dryland and irrigated crops (Slagle and others, 1983).

The area is semi-arid, averaging less than 15 inches of precipitation per year. Meteorological data from the weather station at Decker from 1958 through 2003 indicate average total annual precipitation in the western part of the study area is 12.0 inches (http://www.wrcc.dri.edu/summary/climsmmt.html). On the east edge of the study area at Moorhead, records from 1950 through 2003 showed average total annual precipitation of 12.4 inches. May and June are the wettest months and November through March are the driest. Greatest monthly snowfalls occur from November through

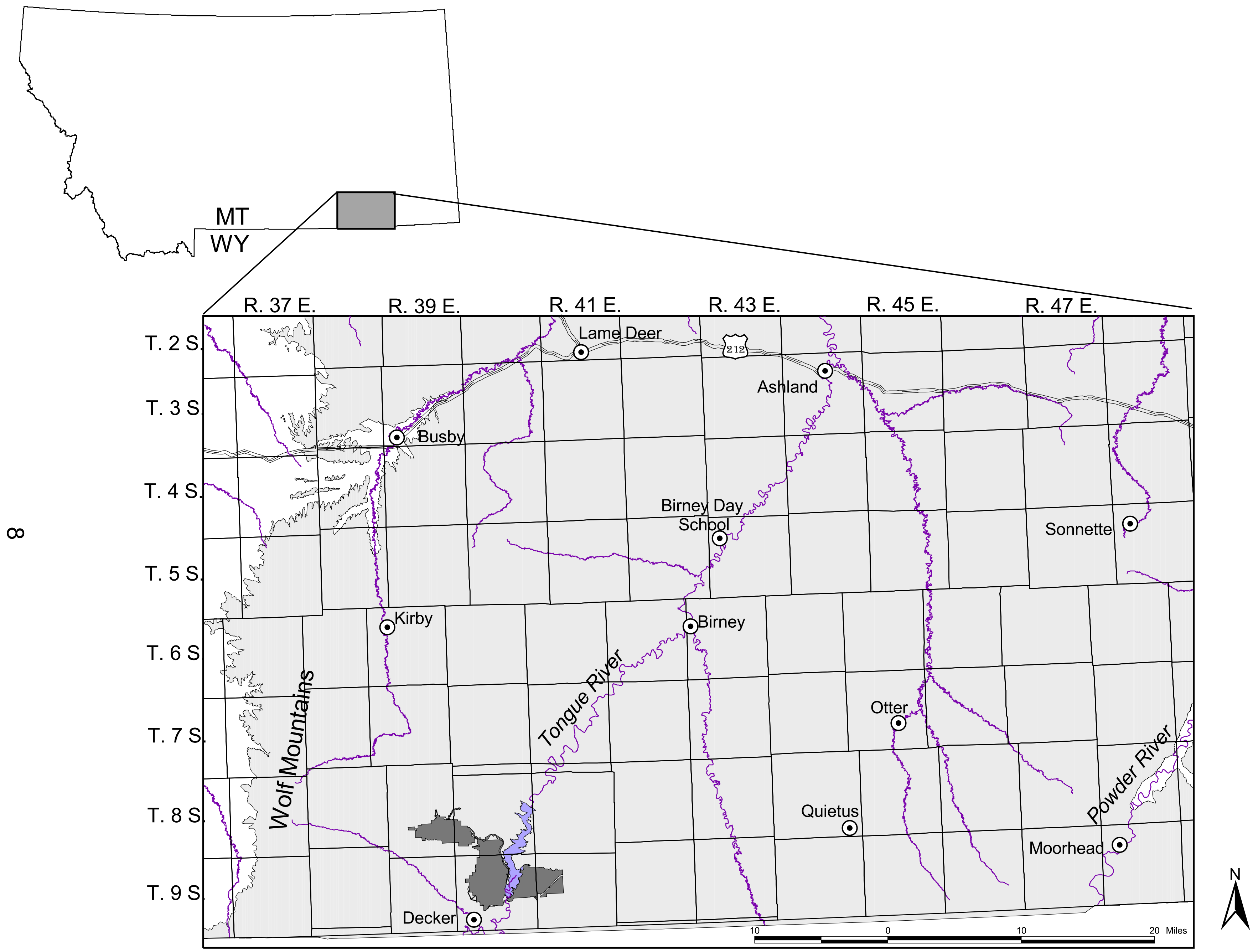
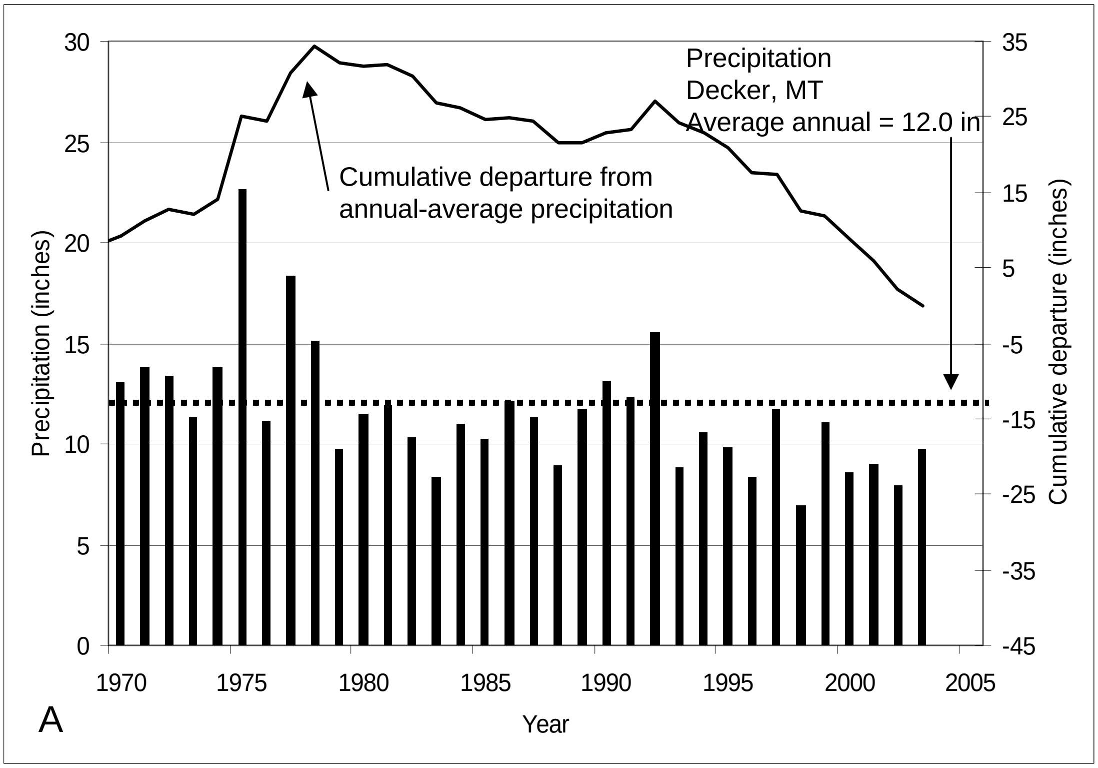


Figure 1. The study site is the Powder River Basin, south of Ashland, in southeastern Montana. Areas of surface coal mining are identified by shading, near Decker.

April. The annual average of monthly high temperatures is in the low 60° F range with July and August being the warmest. Annual average of monthly low temperatures is about 30° F with December and January being the coolest months. The annual mean temperature in the project area is 46° F.

Aquifers are recharged by precipitation, and shallow ground-water levels reflect both short- and long-term precipitation patterns, so interpretation of hydrographs must include an understanding of precipitation records. Due to the size of the study area two meteorological stations, Decker on the west and Moorhead on the east, were selected to represent precipitation. Bar graphs on figures 2-A and 2-B indicate total annual precipitation for Decker and Moorhead since 1970 (NOAA climatic data, http://www.wrcc.dri.edu/summary/climsmmt.html). Long-term trends that may affect ground-water levels become more evident when the departure-from-average precipitation for each year is combined to show the cumulative departure (line graph on figures 2-A and 2-B). Moisture gains through the 1970's, and a below-average precipitation since then are particularly evident in the Decker records (Figure 2-A). Cumulative departure from annual-average precipitation does not provide a quantitative measure of potential recharge, but rather an indication of periods of decreasing and increasing moisture in possible recharge areas.



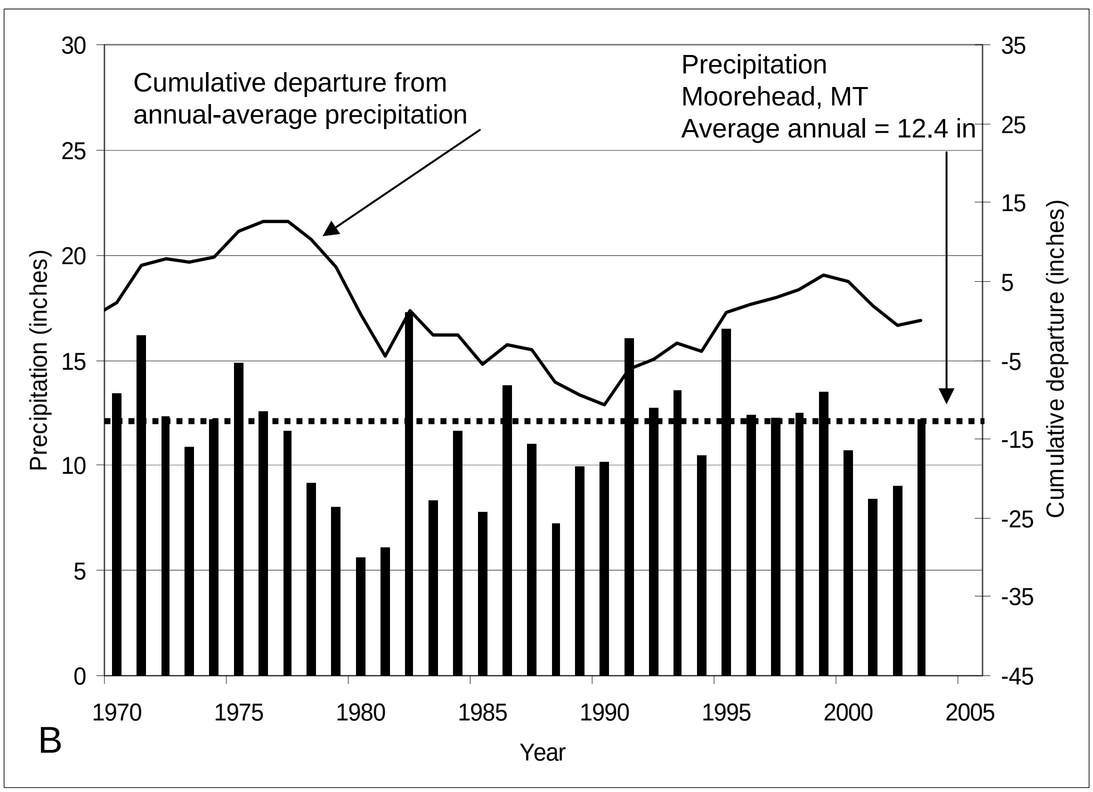


Figure 2. Annual precipitation varies across the study area (bar graphs). During the 1990's the western area near Decker (A) received well below average precipitation while the eastern area near Moorehead (B) received approximately average amounts. Cumulative departure from average precipitation provides a perspective on the long- term moisture trends that may effect ground-water recharge.

Geologic setting

The Powder River Basin is a structural and sedimentary basin in southeast Montana and northeast Wyoming (Biewick, 1994). About one-third of the basin lies in Montana and two-thirds in Wyoming (Figure 3). It is situated between the Black Hills to the east, the Big Horn Mountains to the west and the Miles City Arch to the north. The Paleocene Fort Union Formation and the overlying Eocene Wasatch Formation are the dominant bedrock exposures. Both formations consist of sandstone, siltstone, shale and coal beds. The clastic units were fluvially deposited whereas the extensive coal beds formed from extensive peat-forming swamps. In Montana, modern stream valleys have cut through the entire coal-bearing Tongue River Member of the Fort Union Formation, exposing coal along valley and canyon walls, allowing ground-water seepage to form springs, and allowing methane to leak to the atmosphere.

Numerous coal beds have been mapped in the Fort Union Formation (Matson and Blumer, 1973). A generalized stratigraphic column is presented in Figure 4. Not all coal beds shown on Figure 4 are present across the entire basin; however, the figure indicates relative stratigraphic position. The Anderson and Dietz coal beds are beomg mined near Decker. Methane is currently being produced from these same coal beds in Montana as well as the Canyon and Carney seams. Generally, the coal beds in the Anderson through Knobloch interval are considered the most likely prospects for CBM in southeastern Montana. Various names have been used to describe the seams in the Decker area, as shown in the correlation chart is presented in Table 1.

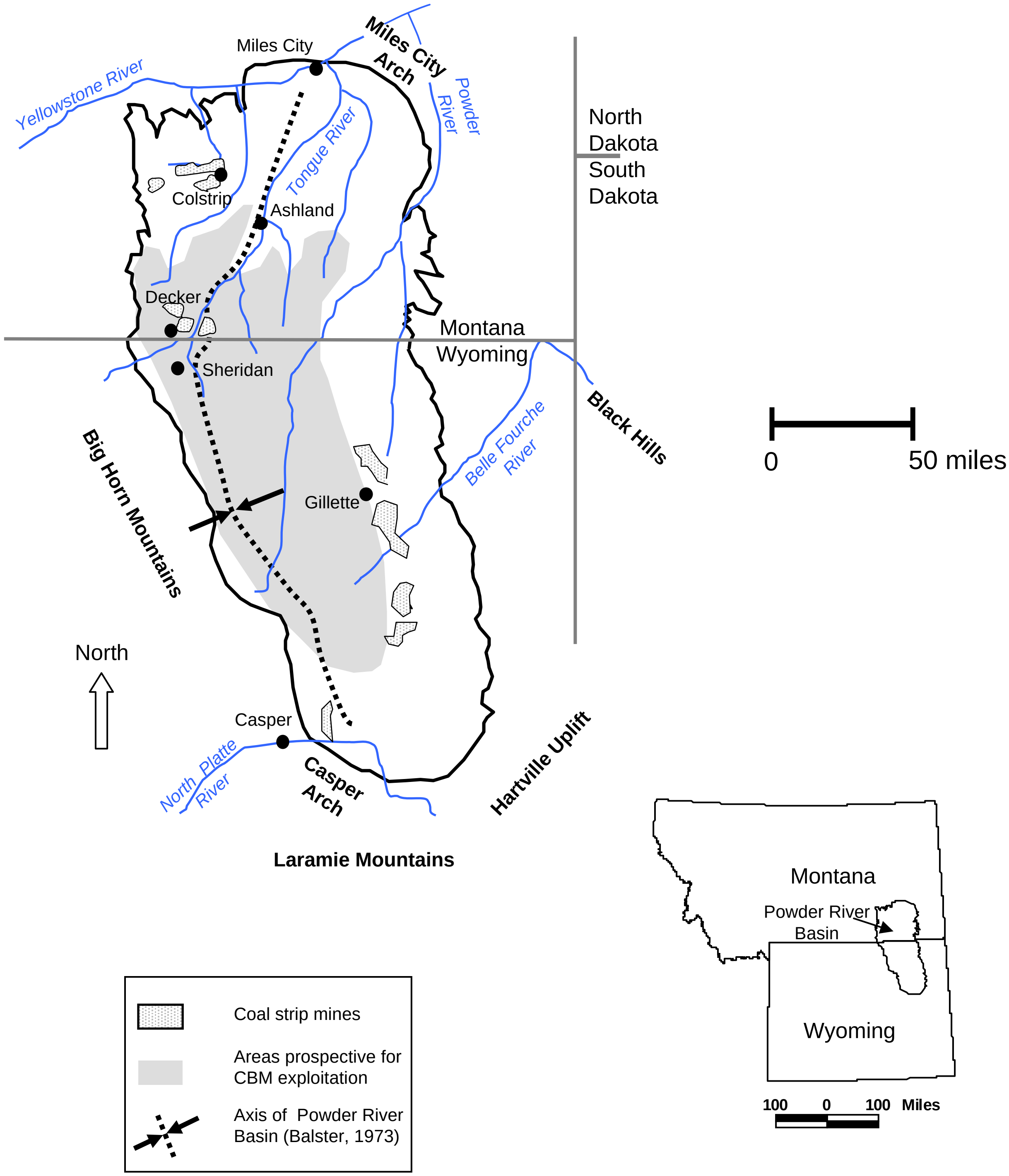


Figure 3. The Powder River Basin is in southeastern Montana and northeastern Wyoming. Vast quantities of minable coal and coalbed methane exist in the Fort Union Formation within the Basin.

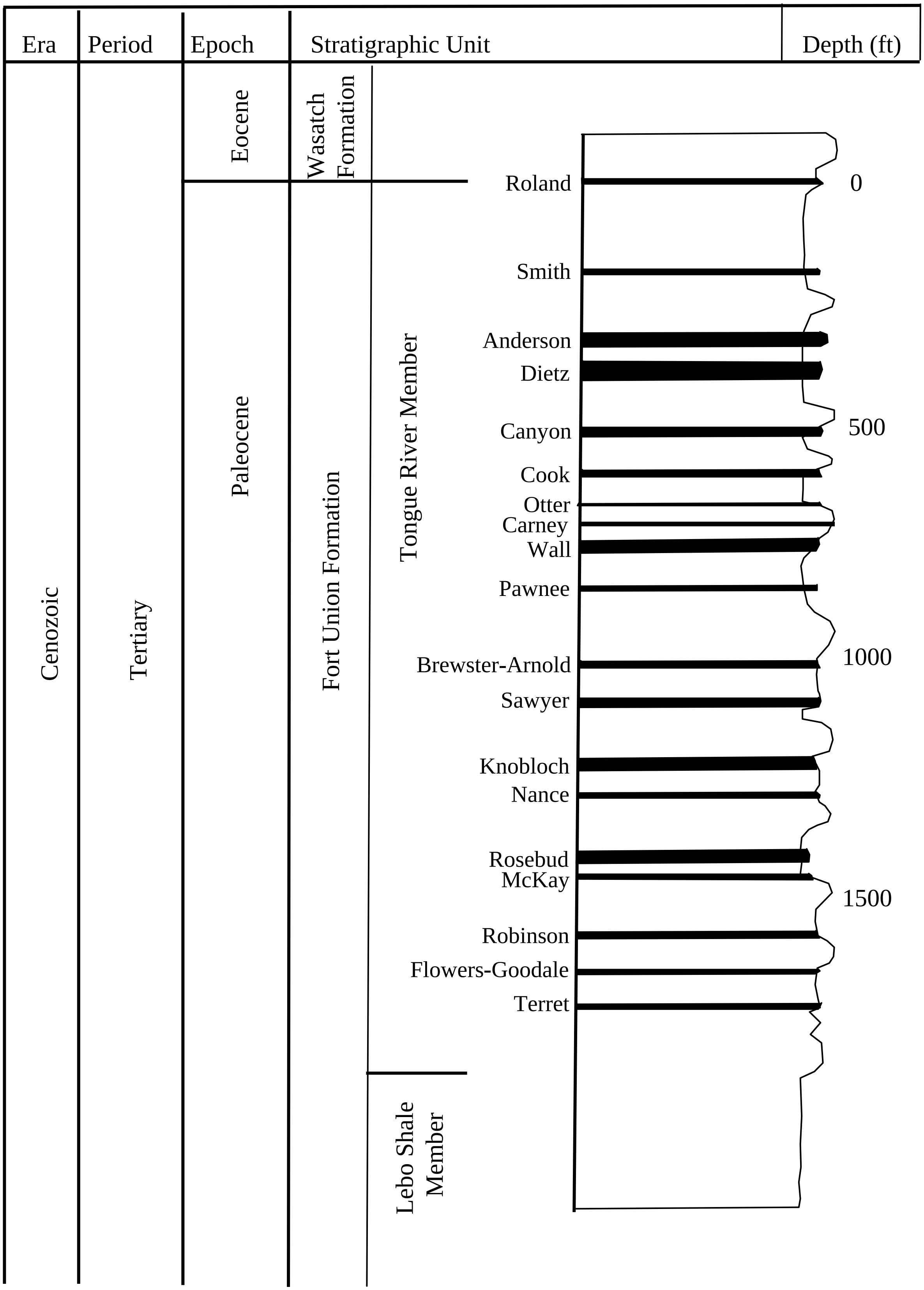


Figure 4. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation. The general relative positions are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Not all coals exist across the entire basin, and the interburden thickness varies considerably.The indicated depths are only approximations (Matson and Blumer, 1973; McLellan and others, 1990; Law and others, 1979; Fort Union Coal Assessment Team, 1999).

Water resources and uses

The Tongue River, Powder River, and several smaller streams and tributaries provide surface water to limited areas of southeastern Montana. Where surface water is not available, domestic and livestock water supplies are dependent on ground-water resources. Wells are typically less than about 300 feet deep and penetrate alluvium in valley bottoms, and coalbeds and sandstone throughout the area. The Montana Ground-Water Information Center (GWIC): website (http://mbmggwic.mtech.edu/) lists 4,520 wells within the 5,321 square-mile area of the Tongue River Member in the Powder River Basin that lies within Montana. This is an average density of 1 well per 1.2 square miles. The total number and the density include 162 observations wells. Water-supply wells completed in coal beds tend to be located within 2 to 4 miles of the major coal outcrops, where drilling depths are shallowest (Kennelly and Donato, 2001). Spring data for this same area indicate an average density of at least 1 spring per 5 square miles (Kennelly and Donato, 2001). Ongoing spring-inventory work by the Montana Bureau of Mines and Geology indicate the density of springs in the area is much higher. Springs occur throughout the Powder River Basin but are particularly prevalent along geologic contacts at the bases of clinker zones and coal outcrops.

Table 1. Correlation of nomenclature used by MBMG, USGS and industry in the Decker, Montana area.

MBMG This report and B-91	MBMG RI-4	USGS C-113 I-1128 I-1959-A	DECKER COAL MINE PERMITS	SPRING CREEK COAL MINE PREMITS	FIDELITY GAS PRODUCTION REPORT
ROLAND	A	ROLAND		ROLAND	ROLAND
SMITH	C - D	SMITH		SMITH	SMITH
ANDERSON	G	ANDERSON / D1	D1 UPPER		D1
DIETZ 1	M	D2 UPPER	D1 LOWER	ANDERSON - DIETZ	D2
DIETZ 2	M	D2 LOWER / D3	D2		D3
CANYON	O	MONARCH/CANYON	CANYON / D3	CANYON	MONARCH
COOK/CARNEY	R	COOK/CARNEY	D4	D4	CARNEY
WALL		WALL	D6	D6	WALL

Sources:

Matson and Blumer, 1973	MBMG B-91
Law and others, 1979	USGS I-1128
Culbertson, 1987	USGS C-113
McLellan and others, 1990	USGS I-1959-A
Hedges and others, 1998	MBMG RI-4

Coal beds are important aquifers in southeastern Montana because they are laterally far more continuous than sandstone units in the Tongue River Member. They crop out along valley walls and subcrop beneath valley fill and surface water bodies, providing baseflow to surface water bodies. It is the ability to transmit water, and the extensive nature of the coal beds that make them the targets for stock and domestic well drilling, while outcrop and subcrop areas provide springs for livestock and wildlife, and baseflow to water courses. Sandstone units are also aquifers, though used to a lesser degree than coal. Alluvium has a much higher ability to transmit water than do bedrock units. However, the small areal extent of alluvial aquifers limits their geographic usefulness as water resources.

Previous investigations

The Powder River Basin has been the focus of many hydrogeologic studies that were completed during the coal assessment work of the 1970's and early 1980's. Also, the Montana Bureau of Mines and Geology (MBMG) has maintained a continuous ground-water monitoring program near the Decker and Colstrip coal mines since 1970. Studies of particular interest include: Ground-water Subgroup of Water Group Northern Plains Research Program (1974); U. S. Bureau of Land Management (1975, 1977a, 1977b); Delk and Waldhaus (1977); McClymonds (1982, 1984a, 1984b, 1985, 1986); McClymonds and Moreland,1988; Daddow (1986); Cannon (1985, 1989); Van Voast and Reiten (1988); Hedges and others (1998); Van Voast and Thale (2001); and Van Voast (2003). Data include aquifer-test results, water-level measurements, water-quality data, lithologic descriptions and hydrogeologic interpretations. Most data from the coal studies are from those portions of the coal fields with less than about 200 feet of overburden, since the purpose has been to identify hydrologic conditions where strip mining could be economically feasible. Additional data are available on the Internet at http://mbmggwic.mtech.edu/. References for additional studies can be found on the MBMG coalbed methane bibliography at http://www.mbmg.mtech.edu/coal/DEFAULT.htm.

Acknowledgments

The landowners who have allowed drilling and installation of monitoring wells on their land, and those that are allowing monitoring access are gratefully thanked for their cooperation in this project. Funding for the current and much of the previous work has been provided by the U. S. Bureau of Land Management. The Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal-hydrologeology work. And a special thanks to Wayne Van Voast for his insights into the coal hydrogeology in southeastern Montana.

Hydrogeologic conditions prior to coalbed-methane production

Monitoring Program

Hydrogeologic data were collected at wells installed during the previous projects referenced above, at wells maintained as part of the BLM and MBMG 30-year coal-mine hydrogeology program, and at wells drilled during 2002 and 2003 specifically for this project. Lithologic and location records for newly drilled wells are in Appendix A. Records for previously existing wells were published in the original reports. Location and completion data for all wells are also available on line at: http://mbmggwic.mtech.edu/. All previously-drilled monitoring wells were inventoried. All new wells drilled for this project and appropriate existing wells were included in the regular monitoring program, and are listed in Appendix B. Water levels are measured approximately monthly at each monitoring well. Springs located on Federal land were visited and inventoried. Data from these springs are listed in Appendix C. Water-quality data are available for many of the existing wells, and additional samples have been collected at selected wells that had not been previously sampled. Water-quality data are listed in Appendix D. Data from previous reports were entered in GWIC to provide a longer period of record.

Monitoring locations and completions, including wells drilled as part of this project, were specifically chosen to provide geologic and hydrogeologic data about coal beds that may be developed for CBM production, and aquifers that underlie or overlie potential production zones. To the extent possible, monitoring locations have been chosen to be outside future CBM production fields. Consistent with standard hydrogeologic methods, monitoring is best performed between areas of potential impacts and points of water usage.

Aquifer characteristics

In southeast Montana ground water is obtained from springs and wells completed in alluvium, fine-grained sandstone, and coal units. These aquifers were the focus of the hydrogeologic studies listed earlier. Hydraulic conductivity is a measure of the ability of an aquifer to transmit water and is determined in the field by means of aquifer testing. Hydraulic conductivity values from all available tests in the Montana Powder River Basin were analyzed and the results presented on Figure 4 (MBMG file data). Tests performed by MBMG, USGS and mine companies have been published in hydrogeologic studies listed above and are on file at MBMG.

Water supplies have been developed in the alluvium of the Tongue River, and to a lesser degree in the Powder River and its tributaries. The geometric-mean hydraulic-conductivity value for alluvium is 61.4 feet per day (ft/day). Saturated thickness for alluvium, reported from tests, averages 17 feet and reaches a maximum of 50 feet. Throughout the region, sandstone units in the Tongue River Member are used for ground-water supplies. Reported hydraulic-conductivity values in sandstone units have a geometric mean of 0.06 ft/day. Aquifer thickness averages 36 feet and reaches a

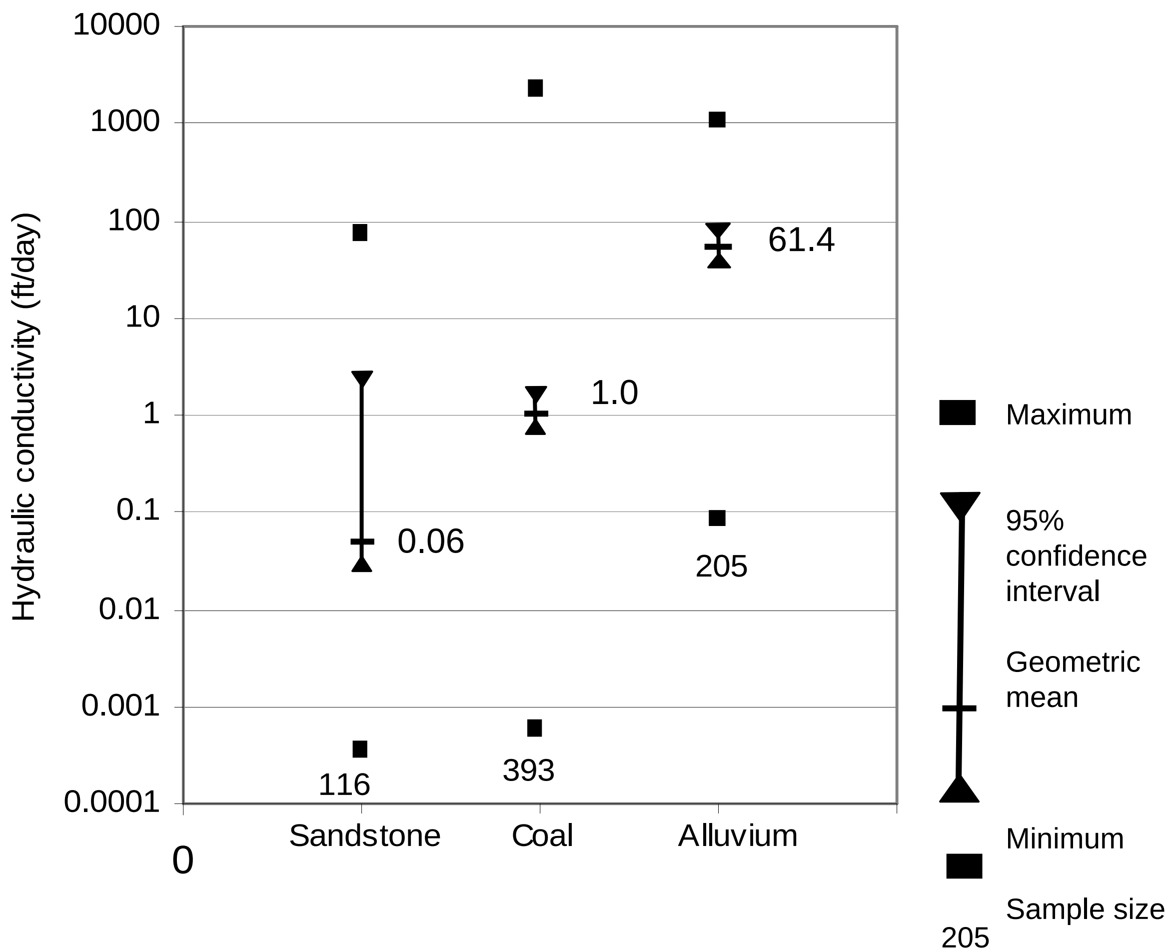


Figure 5. Hydraulic conductivity values in coal are typically higher than that determined in sandstone. Values for alluvium are far higher than either coal or sandstone.

maximum of 110 feet. Due to extensive lateral continuity, and generally higher hydraulic conductivity as compared to sandstone, coal beds are the primary target for water well completions in Montana's portion of the Powder River Basin. The geometric mean for hydraulic conductivity from tests in coal is 1.0 ft/day. Average thickness of tested coal beds is 27 feet and the maximum is 96 feet.

Ground-water flow

Two distinct types of ground-water flow systems are present in the Montana portion of the Powder River Basin. In deeper units, flow is from the south in Wyoming to the north. Recharge along high, clinker-capped ridges produces local flow systems that follow topography. An example of flow directions is shown for the Dietz coal on Plate 2. Other aquifers should have similar trends, with the exception that deeper units will have less topographic control than shallower units. Ground-water flow is perpendicular to equipotential lines. In the eastern part of the study area, ground water in the Dietz coal flows from distant regional recharge areas in Wyoming, northward to outcrop areas in Montana. As the ground-water flows north, discharge areas along outcrops exert strong control on the flow directions. The gradient in the area of Hanging Woman Creek is about 0.007, typical hydraulic conductivity for the Dietz coal in this area is 0.4 ft/day, and a porosity value of 0.1 is assumed. Average aquifer thickness for the Dietz coal in the Hanging Woman Creek area is 11 feet. Using Darcy's equation, ground-water flow through a one-mile width of the Dietz coal bed is about 160 ft^3/day, or 0.8 gpm.Based on these assumptions, the average ground-water velocity is about 0.03ft/day or about 10 feet per year.

In the western part of the study area recharge occurs along the topographically high areas on the Crow Indian Reservation in the Wolf Mountains. Ground-water flow is to the east, toward the Tongue River, but is interrupted by coal mines and coalbed methane production. Based on data from the Squirrel Creek area (Hedges and others, 1998) the Dietz coal has a mean hydraulic conductivity value of 1.2 ft/day, average thickness of 48 feet, gradient of 0.02 (Plate 2) and a porosity of 0.1 is assumed. The calculated flow through a 1-mile wide section of aquifer is 5,450 ft^3/day or 28 gpm and the average velocity is about 0.2 ft/day or 80 ft/year.

Water levels in shallow aquifers respond to seasonal variations in precipitation. Deeper aquifers show little if any measurable change in water level except for long periods of low or high precipitation. In addition to temporal conditions, the vertical gradient of hydrostatic pressure is evident by comparing water-level altitudes in wells with different depths at the same location. Deeper water levels at deeper wells characterize downward gradients. Shallower levels in deeper wells characterize upward gradients.

Hydrographs for precipitation at Moorhead and water levels at selected monitoring sites that are outside of potential coalbed-methane impacts are presented in figures 6 through 10. The long-term precipitation trend for Moorhead is summarized from NOAA climatic summaries for Montana (http://www.wrcc.dri.edu/summary/climsmmt.html). Data from 1974 through 2003 from an overburden sandstone (Figure 5-B), the Canyon coal (Figure 5-C) and the Cook coal (Figure 5-D) indicate a downward gradient and a lowering of water levels that follows the regional precipitation trend. These wells are located in the eastern part of

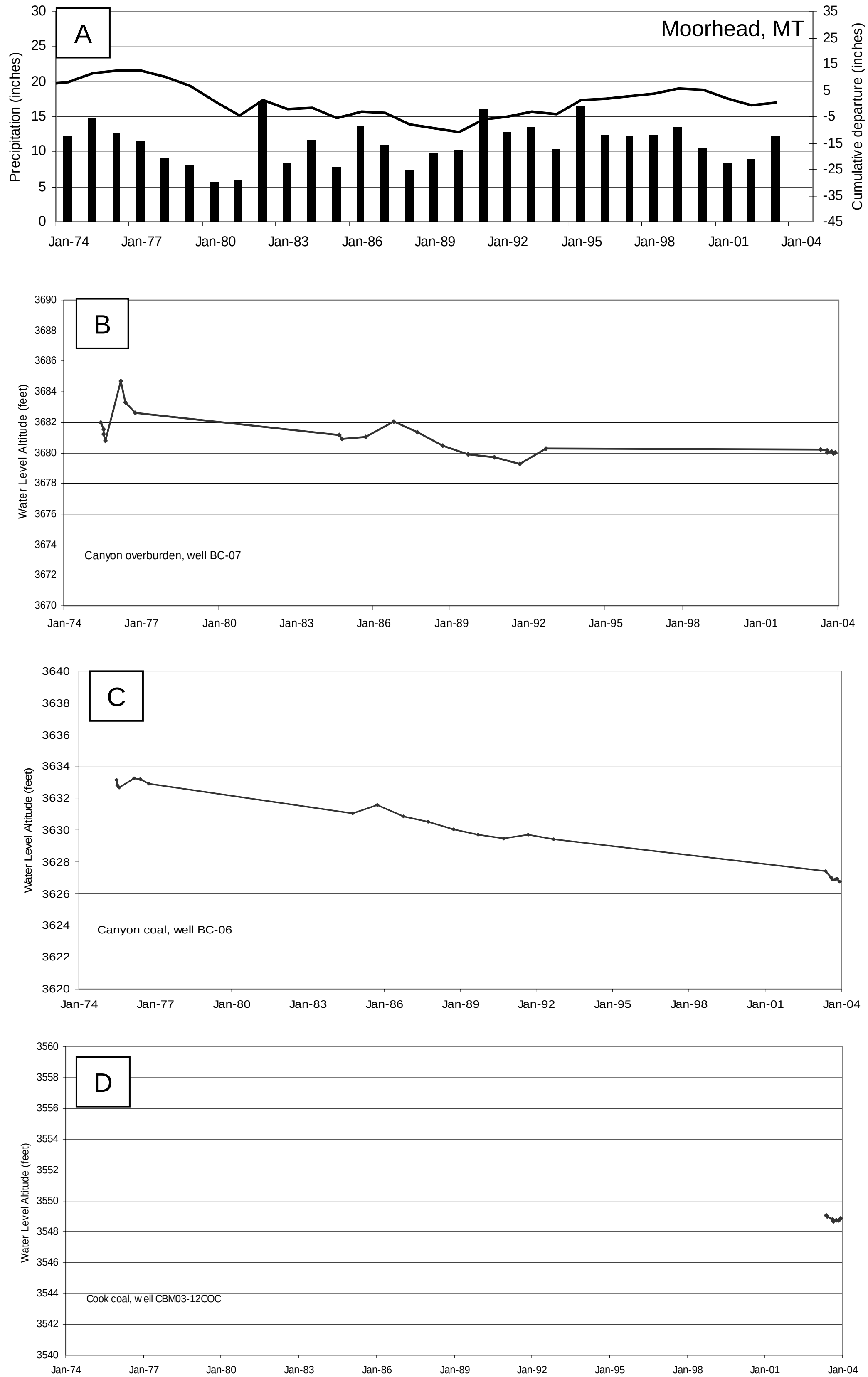


Figure 6. Graph (A) shows average annual and cumulative departure from average precipitation at Moorhead, Montana. The long-term decrease in water levels in the Canyon overburden sandstone (B), and Canyon coal (C), likely relate to precipitation patterns. The short period of record for the Cook coal (D) at the CBM03-12 site does not indicate meteorological influence.

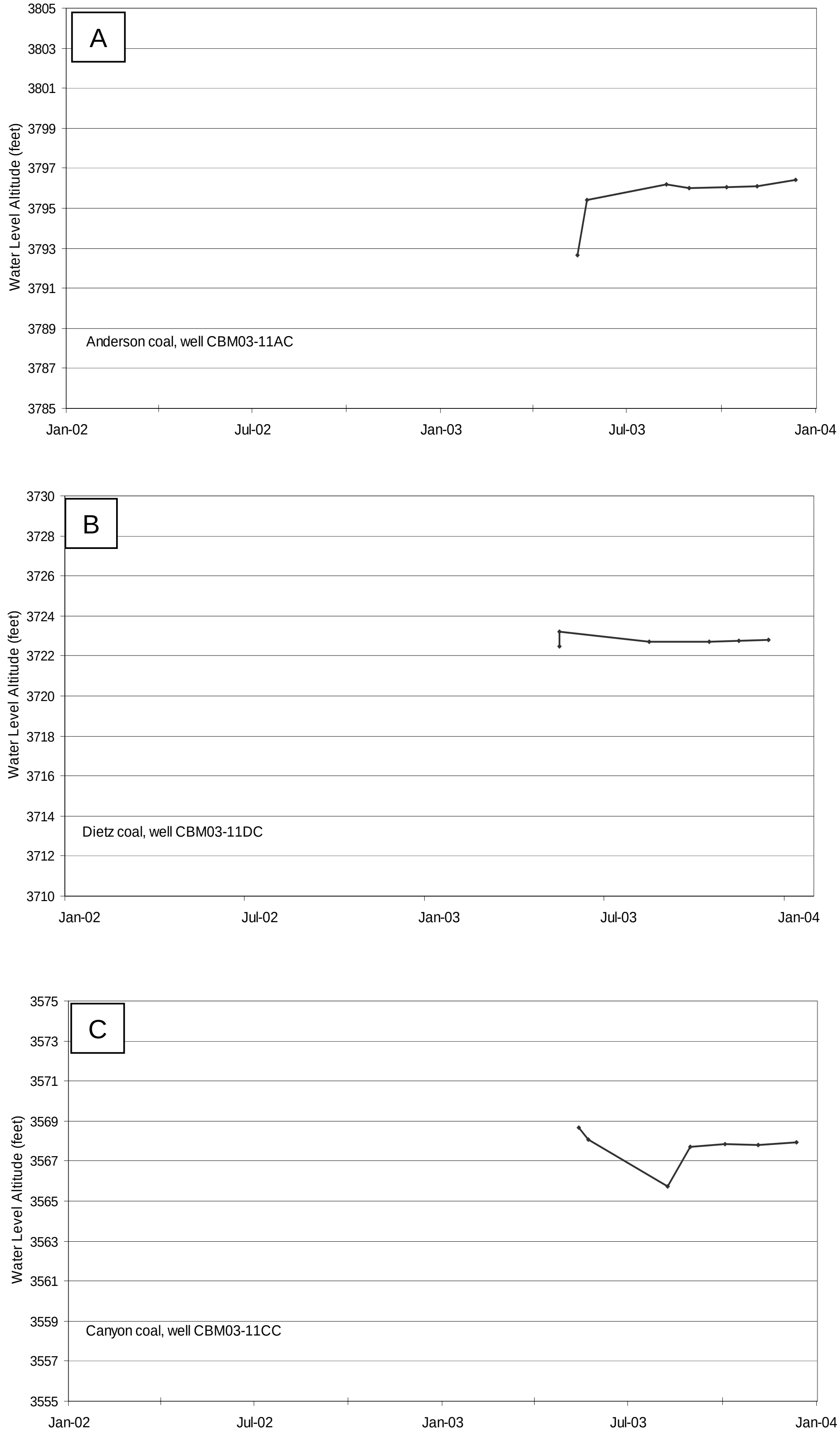


Figure 7. A downward hydrostatic gradient is evident by comparing water-level altitudes for the Anderson (A), Dietz (B), and Canyon (C) coalbeds at the CBM03-11 site.

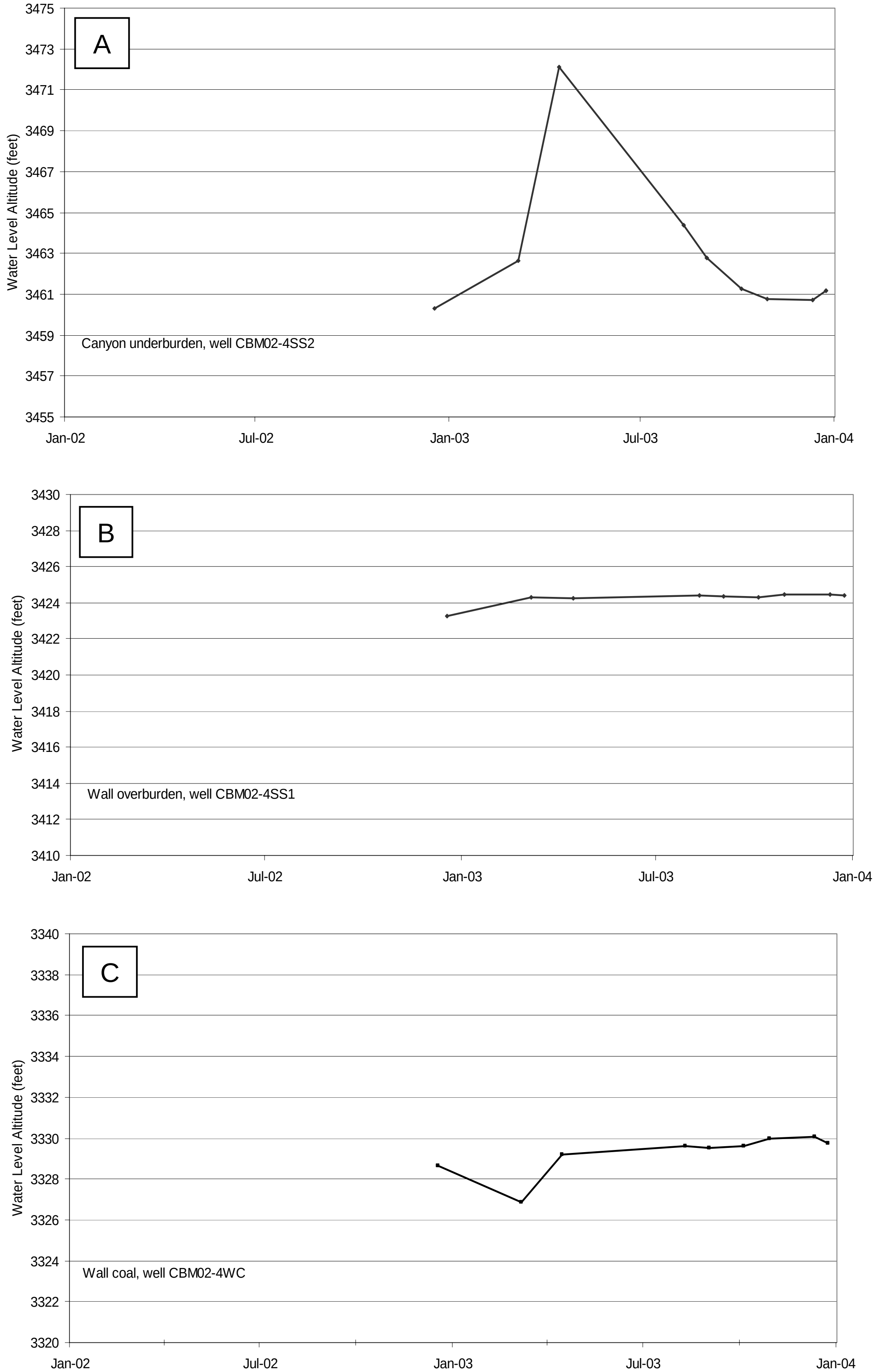


Figure 8. A downward hydrostatic gradient is evident between the Canyon underburden sandstone (A), Wall overburden sandstone (B), and Wall coal (C) at the CBM02-4 site. Water levels trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower Canyon Coal may be.

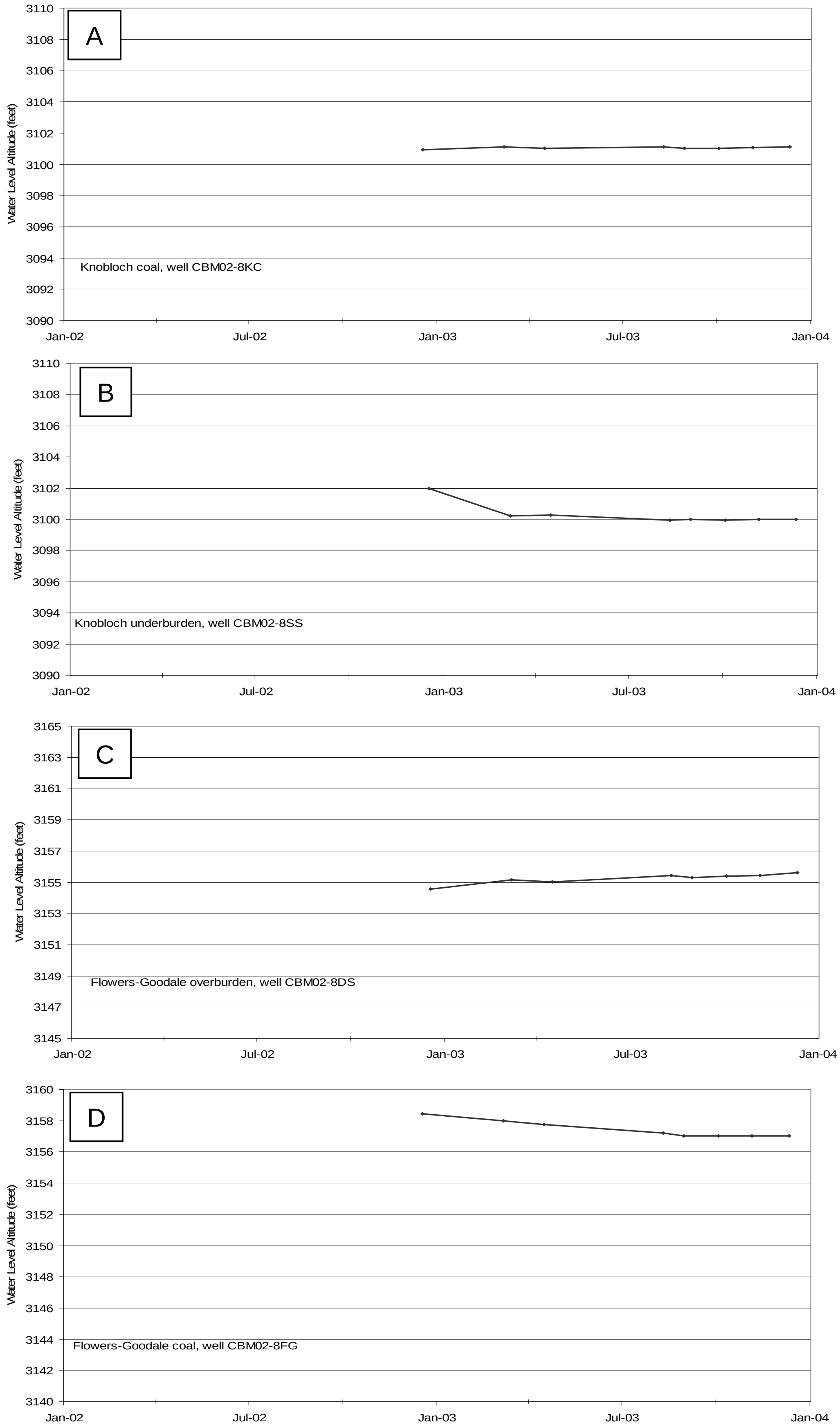


Figure 9. An upward hydrostatic gradient is evident by comparing water-level altitudes for the Knobloch coal (A) and Knobloch underburden sandstone (B), and the deeper Flowers-Goodale overburden (C) and Flowers-Goodale coal (D) at the CBM02-08 site. Water levels trends are probably not related to meteorological patterns.

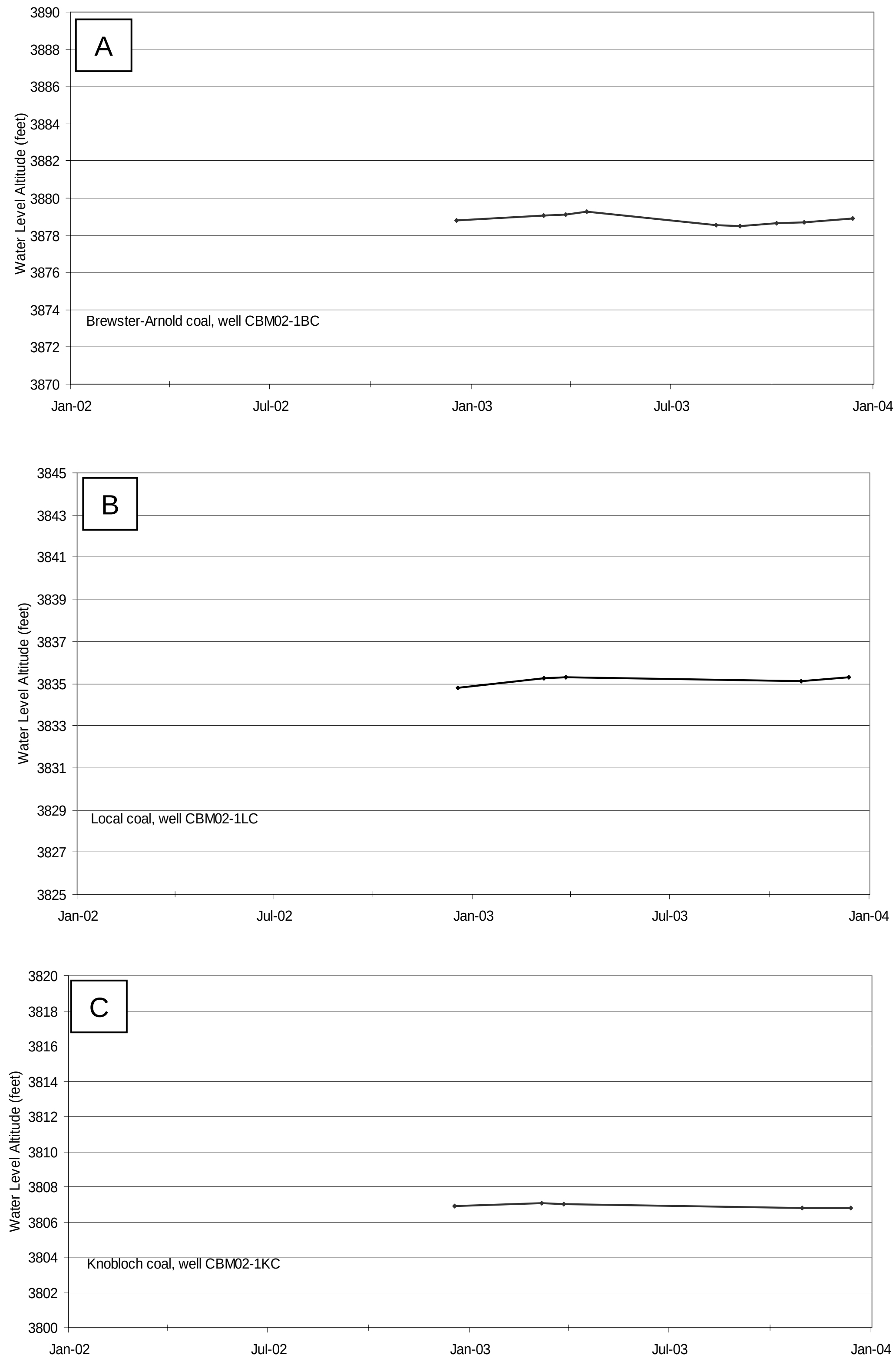


Figure 10. An downward hydrostatic gradient is evident by comparing water-level altitudes for the Brewster-Arnold coal (A), Local coal (B), and Knobloch coal (C) at the CBM02-1 site. Water levels trends are probably not related to meteorological patterns.

the study area near Bear Creek. At site CBM02-11, the Anderson (Figure 7-A), Dietz (Figure 7-B) and Canyon (Figure 7-C) coals also show a downward gradient, but too little record to indicate any relationship with precipitation trends. West of the Tongue River at site CBM02-4, water levels in the Canyon underburden (Figure 8-A), Wall overburden (Figure 8-B) and Wall coal (Figure 8-C) indicate a downward gradient. A water-level rise during spring, 2003 of about 11 feet in the shallow Canyon underburden may indicate a response in this shallow aquifer to precipitation. Water-level data in the Knobloch coal (Figure 9-A), Knobloch overburden (Figure 9-B), Flowers-Goodale overburden (Figure 9-C) and Flowers-Goodale coal (Figure 9-D) show a general upward gradient indicating a ground-water discharge zone. This site is just west of the Tongue River near the outcrop of the Knobloch coal. Near the community of Kirby, just east of Rosebud Creek, a downward gradient exists between the Brewster-Arnold coal (Figure 10-A), a local unnamed coal (Figure 10-B) and the Knobloch coal (Figure 10-C).

Ground-water quality

Ground-water quality in the Powder River Basin changes in a predictable fashion along flow paths (Van Voast and Reiten, 1988). In recharge areas, water quality is dominated by ions of calcium (Ca^{+2}), magnesium (Mg^{+2}) and bicarbonate ($HCO3^{-}$). Further along the flow path, sulfate (SO_4) concentrations increase due to dissolution of sulfate minerals (such as gypsum) and oxidation of sulfide minerals (such as pyrite). Cation exchange with shales increases the sodium (Na^{+}) concentrations while decreasing Ca^{+2} and Mg^{+2} concentrations. In deep coal aquifers sulfate reduction and carbonate precipitation produce water quality that is dominated by Na^+ and HCO^{3-} ions, with little else. Coalbed methane exists only in reduced zones where the water quality is characterized by ions of Na^+ and HCO^{3-} (Van Voast, 2003).

Data from laboratory analyses for major ions in samples from monitor wells included in this project are listed in Appendix D. Water from alluvium generally has a low sodium adsorption ratio (SAR), less than 7 and averaging 3.8. This water has a wide range in calculated dissolved-solids (CDS) concentrations from 572 to 6,836 mg/L, averaging 3,190 mg/L. Alluvium receives leakage from streams (which are typically loosing within the study area), local infiltration of precipitation and discharge from outcrops and subcrops of bedrock aquifers. These sources represent a wide range of possible water quality, and as expected, alluvium has highly varied water quality.

Water quality from the Anderson coal, throughout the study area, is generally dominated by Na^+ and HCO^{3-} ions. The only areas with significant amounts of Ca^{+2} and Mg^{+2} occur where the coal is shallow east of the Tongue River near the East Decker Coal Mine and in the Hanging Woman Creek area. These sites had concentrations of SO_4 that indicate the ground water has not reached fully chemically reduced conditions, or it is influenced by local recharge. In either case the coal at these locations is not likely to contain methane. Concentrations of CDS are between 1,023 and 8,788 mg/L, averaging 2,489 mg/L. Sodium adsorption ratio in the Anderson coal is high, ranging from 11 to 65, with an average value of 39.

Water quality in the Dietz coal is similar to that found in the Anderson coal, typically dominated by ions of Na^+ and HCO^{3-}. Stiff diagrams on Plate 2 indicate concentrations of major ion chemistry in samples from Dietz coal monitoring wells. Some higher concentrations of SO_4, however, were found in many parts of the study area. Dissolved-solids concentrations in the Dietz coal are generally lower than those in the Anderson, ranging from 667 to 2,597 mg/L with an average of 1,498 mg/L. Ground water in the Dietz coal has a wider range of SAR values than does the Anderson coal, ranging from 4 to 80 and averaging 37.

With the exception of samples from two wells that may be in areas where local recharge may influence water quality, ground water in the Canyon coal contains exclusively Na^+ and $HCO3^-$ ions in all monitoring wells. The concentrations of CDS range from 941 to 1,761 mg/L and average 1,415 mg/L. Sodium adsorption ratios are between 30 and 66, with an average of 47.

At several locations, the normal change in water quality along flow paths is evident. For example, at wells BC-07 and BC-08, the water quality in the overburden sandstone is dominated by Ca^{+2}, Mg^{+2}, Na^+ and SO_4 ions, while the underlying Canyon coal water quality is dominated by Na^+ and HCO^{3-} ions due to ion exchange and SO_4 reduction.

Hydrogeologic conditions after three-years of coalbed-methane production

Ground-water levels

Water-level trends in aquifers that are susceptible to CBM impacts in and adjacent to the CX field are presented in figures 11 through 15. Ground-water levels in this area respond to a combination of precipitation patterns, coal mining and CBM production. Both coal mining and CBM production have caused large areas of lowered ground-water levels to occur in the coal beds.

On Figure 10 the annual high and low water levels in the Squirrel Creek alluvium correspond to wetter and dryer times of each year, typical for shallow water-table aquifers. The long-term precipitation trend shown on Figure 11-A appears to explain the subtle water-level trends in the alluvium upstream from CBM production (Figure 11-B). Note that since 1999 the alluvial water levels have become lower in response to drought conditions. Mining at the West Decker mine has not lowered the water levels in the Squirrel Creek alluvium, which indicates a lack of vertical communication between the coal and shallow aquifers (Van Voast and Reiten, 1988). For the same reason, CBM production has not lowered water levels in the alluvium. Within the CBM production area (Figure 11-C) since 1999, the water level in some reaches of the alluvium has increased, probably in response to CBM-production-water infiltrating from nearby holding ponds.

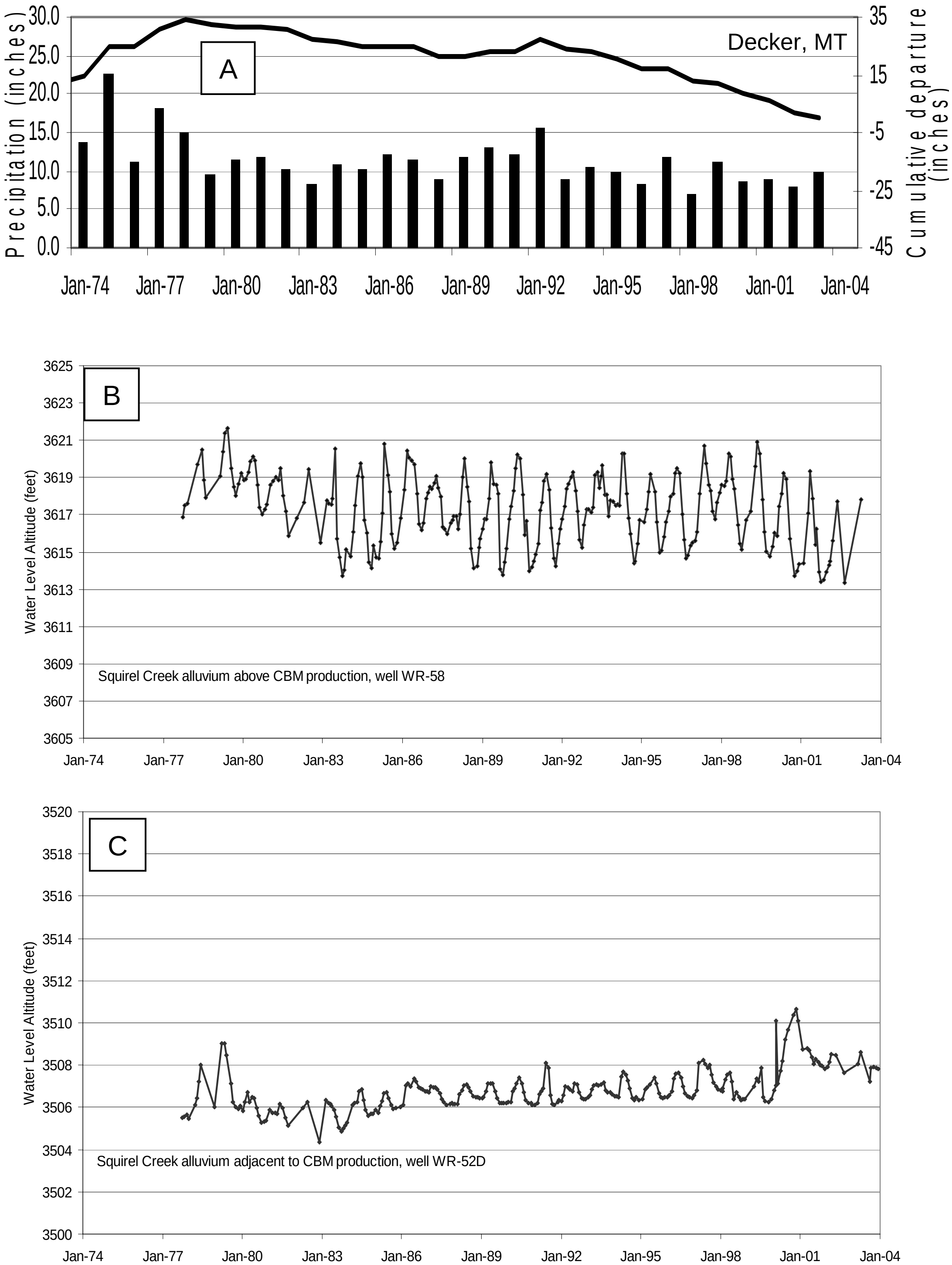


Figure 11. In addition to normal annual cycles, long-term precipitation trends (A) effect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (B), but adjacent to CBM production the water level rise since 1999 likely relates to infiltration ponds (C).

Water levels in Anderson overburden in the Squirrel Creek area (Figure 12) show possible correlation with precipitation patterns (Figure 12-A), and no drawdown due to CBM production. The lack of drawdown in overburden sandstone indicates the slowness of vertical responses. The shallow, water-table aquifer (Figure 12-B) shows a rapid rise, totaling about 30 feet, in response to vertical migration of CBM-production water from an infiltration pond. The pond is located approximately 250 feet northeast of the monitoring well, is unlined and is 1 to 2 acres in size. The deeper overburden aquifer (Figure 12-C) at this site shows no response to the infiltration pond. The additional water in the shallow aquifer may be moving laterally with little vertical communication, or the slow rate of vertical movement may create such a delay that the response has not yet been measured in the deeper aquifer.

Declining water levels (hydrostatic pressure) in coal beds are expected responses to both coal mining and CBM production. Near the Ash Creek coal mine (Wyoming, Township 58 north, Range 84 west, section 22), hydrostatic pressure in the Anderson and Dietz coal beds declined from 1977 to 1979 due to mining. Pit dewatering through 1995 maintained reduced ground-water levels until reclamation began. After pit dewatering ended, the ground-water levels recovered. Since 2001, CBM production has reduced ground-water levels at this site by about 150 feet (Figure 13-A). In the Squirrel Creek area hydrostatic pressure in the Anderson-Dietz coal has declined continuously due to coal mining since the 1970’s. Starting in 1998 a rapid decline in hydrostatic pressure has occurred in response to CBM production (Figure 13-B). The much faster decline in hydrostatic pressure due to CBM production, as

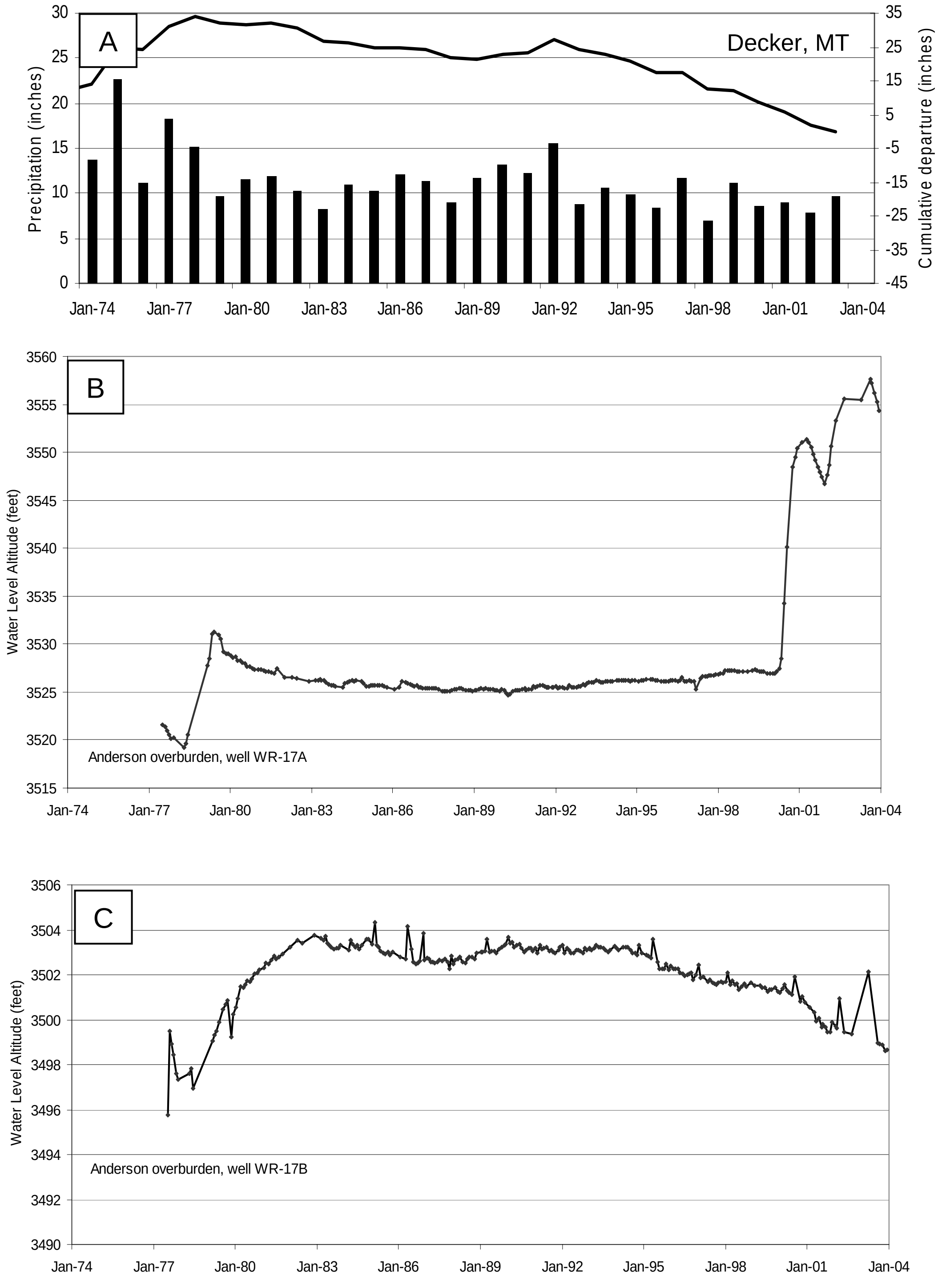
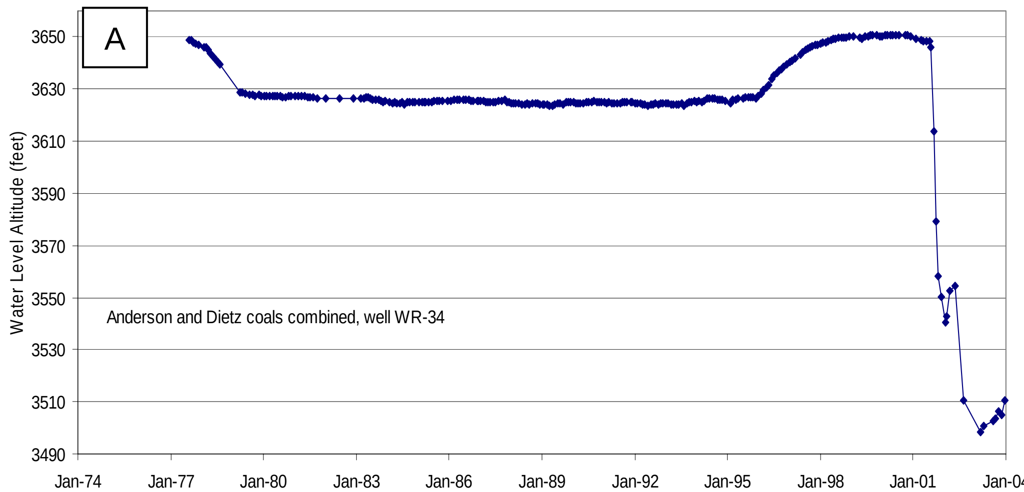


Figure 12. Graph A shows average annual and cumulative departure from average precipitation for Decker, Montana. Long-term water-level trends in the Anderson overburden(B and C) in the Squirrel Creek area, may relate to precipitation patterns. The rise starting in 1999 in the water table at WR-17A (B) is a response to infiltration of water from a CBM holding pond.



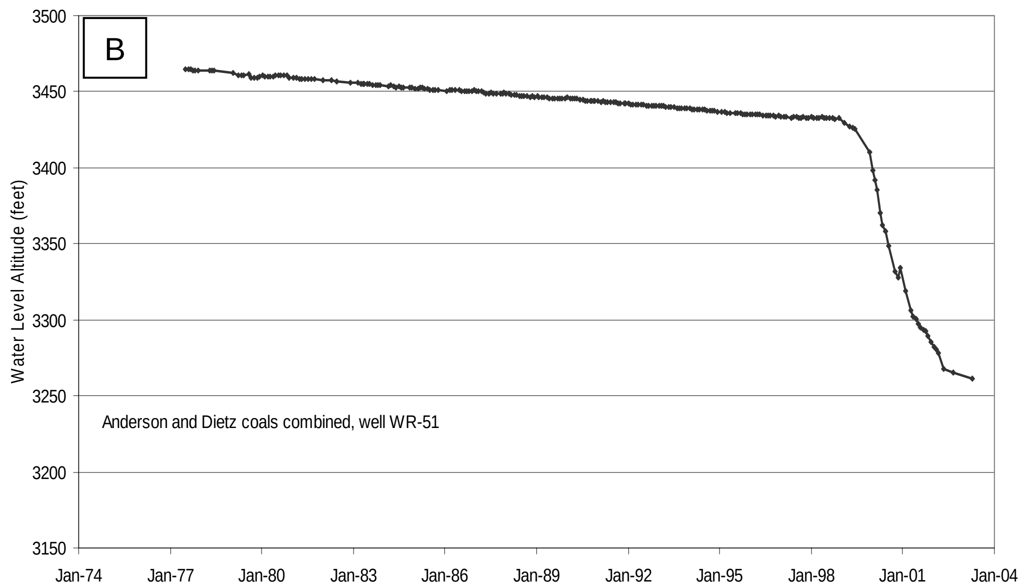


Figure 13. Water levels in the combined Anderson and Dietz coal (A and B) in the Squirrel Creek area respond to both coal mining and coalbed methane production.

compared to coal mining, is a function of the rate of movement of development and proximity of production to monitoring. The arrival of the cone of depression is clearly marked by the changes in water levels, indicated on the figures. The site-specific rate of change will be determined by several factors, including distance to the nearest production well, proximity to a source of recharge, and aquifer physical characteristics. Mining advances very slowly, whereas CBM production can move rapidly, covering a larger area, moving closer to monitoring wells and creating a larger cone of depression. Also, in this case, CBM production was initiated about midway between well WR-51 and the West Decker Mine.

Near the western edge of current CBM production, but across a fault from active CBM wells, the Canyon and Carney coals show no response to CBM-related drawdown (Figure 13). Faults in this area are known to be aquitards, and hydrostatic pressure responses to mining varies tremendously across faults (Van Voast and Reiten, 1988). The water level in the Canyon coal has slowly decreased, along with decreased precipitation (figures 14-A and 14-B).

Changes in stage in the Tongue River Reservoir affect water levels in the Dietz coal near the reservoir. Stage levels in the reservoir have been higher since a new spillway was put to use in 1999 (Figure 14-A). However, water levels in the Dietz coal since the year 2000 are influenced more by CBM production than by the higher stage levels (figures 15-B and 15-C). Drawdown in coal beds beneath the reservoir may increase leakage from the reservoir, thus increasing CBM pumping costs and possibly causing water that is not under reduced conditions to migrate into the CBM field. The

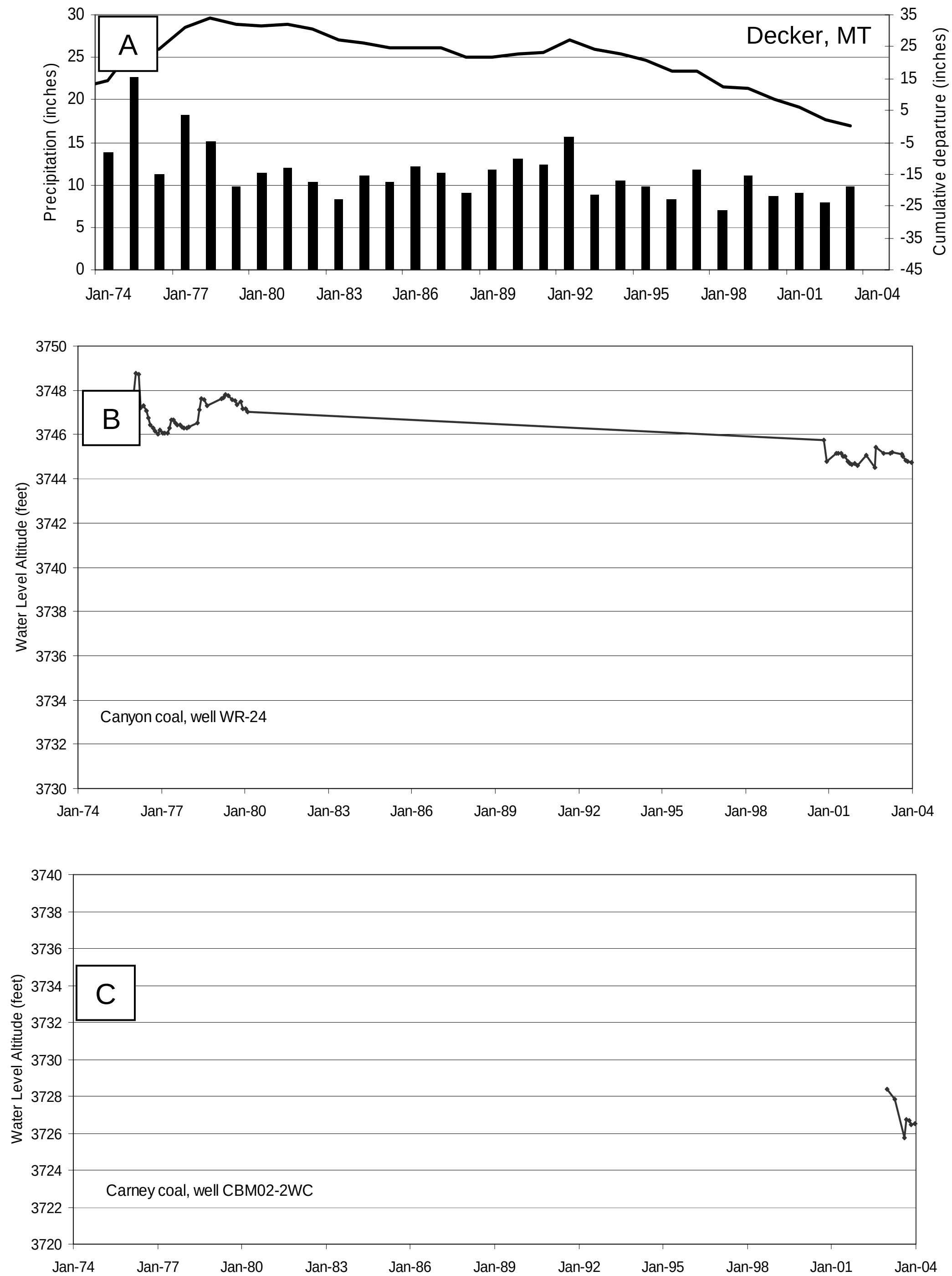


Figure 14. Graph A shows average annual and cumulative departure from average precipitation for Decker, Montana. The long-term decrease in water levels in the Canyon Coal (B), is probably related to precipitation patterns. The short period of record for the Carney coal (C) at the CBM02-02 site does not indicate meteorological influence.

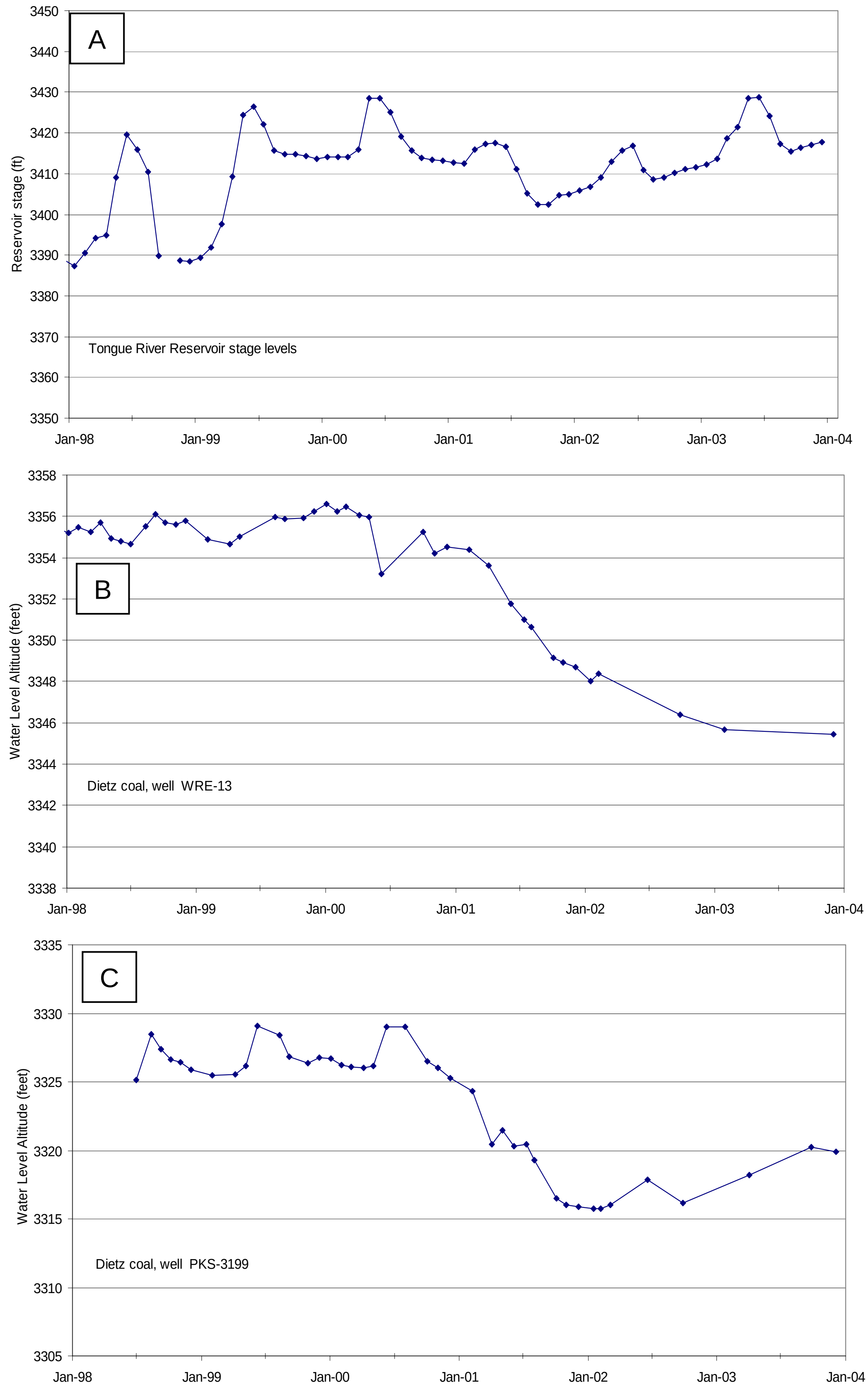


Figure 15. Annual fluctuations of stage level in the Tongue River Reservoir (A), and water levels in the Dietz coal (B and C) correlate well until CBM influence reached the area in about the year 2000.

introduction of SO_4 into the CBM field can create a situation where sulfate-reducing bacteria oxidize the methane to carbon dioxide, thereby reducing the gas reserves.

Hydrostatic pressure in the Dietz coal has been reduced over an area of nearly 30 square miles in and adjacent to the CX field (Plate 3). The locations of producing CBM wells at any specific time are not available, however the production area at the end of 2002 is marked on Plate 3 (Fidelity Exploration and Production Company, 2002). Drawdown of at least 5 feet has reached a distance of 1.5 to 2.5 miles beyond wells in the active field. Drawdown of 20 feet extends a maximum of 1.9 miles where ground-water flow is fault bounded (WR-47) and as far as 1.2 miles where faults are not creating no-flow boundaries (PKS-2061). Drawdowns in other monitored coal beds are similar to that shown for the Dietz coal.

Quality of produced water

Coalbed-methane-produced water quality in the Powder River Basin is dominated by ions of Na^+ and HCO_3^- (Rice and others., 2002). Water quality parameters include: pH from 6.8 to 8.0, specific conductance levels from 400 to 4,000 uS/cm, SAR ranging between about 5 to about 70, and CDS from about 300 to more than 2,000 mg/L. In the southeastern PRB in Wyoming, CBM water generally has low CDS and SAR, increasing to the north and west into Montana.

Based on data from monitoring wells within the CX coalbed-methane field, water quality in the Anderson and Dietz coals has high SAR values (37 to 53) and moderate CDS concentrations (703 to 1,806 mg/L). This is typical for ground water in coal beds throughout the study area where SO_4 concentrations are less than about 100 mg/L, indicating reduced conditions where methane can exist in the coal.

Anticipated hydrogeologic changes with continued coalbed-methane production

Water production

During CBM production, wells are pumped to lower the hydrostatic pressure to near the top of the coal. Water levels are then maintained at this elevation during production. Individual well-discharge rates are highest at the start of pumping, and decrease with time. The equations for constant drawdown tests for flowing wells can be applied to calculate the discharge rates for a well where the drawdown is held constant and the discharge is varied (Jacob and Lohman, 1952 in Lohman, 1972, p. 23). For the purpose of a CBM field, an approximation of discharge can be calculated if the entire field is assumed to act as a single well with diameter equal to the diameter of the field. Using the Hanging Woman Creek area as an example, this equation estimates discharge per well from a 100-well field (12.5 square miles) to be 20 gpm during startup, decreasing to 0.5 gpm after 10 years (Figure 16). The constant drawdown equation, as applied here is:

$$a = Kbt/Sr_w^2$$

Where: K = hydraulic conductivity (0.4 ft/day)

b = aquifer thickness (11 ft)

t = time (0.8 to 3,650 days)

S = Storativity (2 E -4)

r_w = Well radius (10,500 ft)

And:

$$Q_T = Kb2piG(a)s_w$$

Where: Q_T = Total discharge from the well field (100 wells)

G(a) = the function of a, available in tables (Lohman, 1972)

s_w = constant drawdown in well

It is important to note in discussions of well discharge that the rate of discharge decreases with time, so discussions of average discharge rates have little value. Discharge rates from individual CBM wells will vary depending upon time since pumping began, position in the field, size of the CBM field, and local aquifer conditions. As the area of production increases, and cones of depression for fields overlap, discharge from individual CBM wells will decrease in response to the generally lower hydrostatic pressure. However, total discharge from all wells will increase as new wells are completed and as ground water is withdrawn from larger areas.

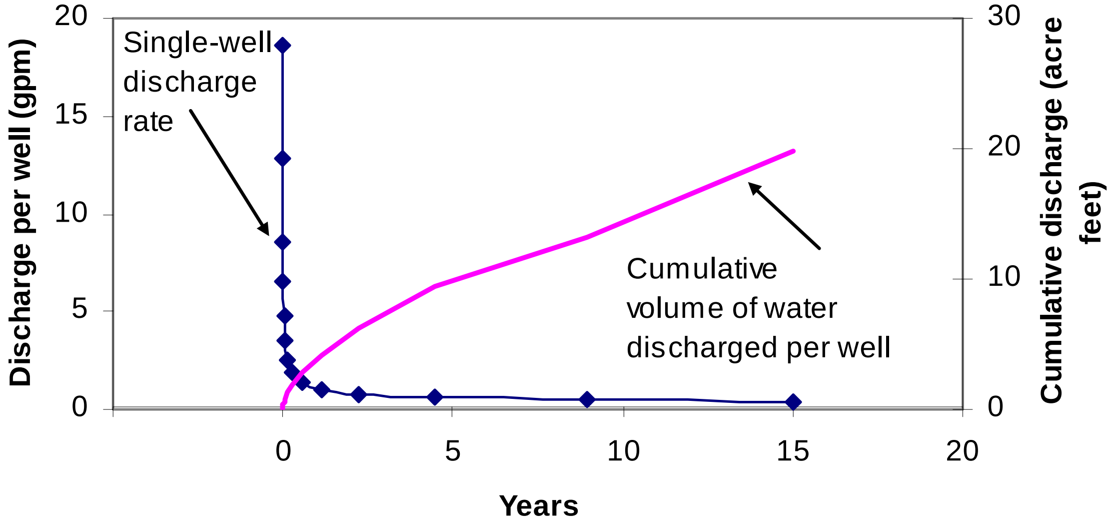


Figure 16. Approximation of discharge from a single CBM production well, using the constant-head equation developed by Jacob and Lohman (1952, in Lohman, 1972) demonstrates the decline curve. Based on these calculations, most of the water produced will actually be at the lower production rates.

Ground-water levels

Data collected during this project show that drawdown within the coal aquifers during the first 4 years of production may reach 20 ft at distances of 1 to 2 miles outside the producing fields (Plate 3). Computer modeling, using geometric mean values of aquifer characteristics for Montana coal beds indicates that after 20 years of production, drawdowns of 20 feet or more are expected to reach distances of 2 to 4 or more miles, (Wheaton and Metesh, 2002). Drawdown may occur in overburden and interburden aquifers, but to a lesser degree than that in the producing coal beds. Flow from springs and water available at water-supply wells will be diminished proportionally to the decrease in hydrostatic pressure in the aquifer at the well or spring.

Recovery of water levels in affected aquifers will begin when CBM production ends. Complete recovery will require much more time within the CBM well field than outside the field. Based on a modeled scenario (Wheaton and Metesh, 2002) using an isolated CBM well field 1-township in size, the available head outside the production area may approach 90 percent of pre-development levels about 5 years after production ceases. Within the CBM field, recovery of hydrostatic pressure will take longer, and may approach 70 percent of pre-development levels within 10 to 15 years. Partial recovery will occur as hydrostatic pressures of water in storage in the coal bed redistribute to fill the cone of depression. Complete recovery, however, will require recharge water to reach the impacted area along with replenishment of hydrostatic pressures in to the recharge area. Ground-water velocity is naturally slow, and travel time from recharge areas will likely be measured in decades.

Quality of produced water

Coalbed methane exists only in areas of chemically reducing conditions, indicated by a dominance of sodium and a lack of sulfate in the water (Van Voast, 2003). Across the study area, where sulfate concentrations are less than 100 mg/L, water quality in coal beds has SAR values between 32 and 68, with an average of 49. Concentrations of CDS in these aquifers range from 703 to 2,000 mg/L with an average of 1,472 mg/L. The quality of CBM-production water throughout the Montana portion of the Powder River Basin is expected to be similar to this. Both SAR and CDS (as represented by specific conductance) are commonly used as indicators of the usability of water for irrigation (Hanson and others, 1999). These constituents are noted here as both indicators of areas where CBM may exist and as considerations for water-management design.

Summary

Coalbed-methane production is expected to occur across much of the southern portion of the Powder River Basin in Montana (Van Voast and Thale, 2001). Related to this production are concerns that ground-water levels will be reduced, causing a loss of local ground-water resources for the agricultural community, and concerns that disposal of CBM-production water, if handled inappropriately, will cause detrimental impacts to soils and surface-water resources.

Ground-water levels in producing coal beds in and near CBM-production fields will be lowered for the duration of production and may require decades to recover. Ground-water levels in overlying and underlying aquifers are expected to show little response to drawdown in the producing coal beds due to the presence of shale-dominated stratigraphic sequences. During periods of production and recovery, water availability at some springs and wells which derive their water from the producing coal beds will be reduced. Ground-water discharge where aquifers subcrop in alluvium provides baseflow to support perennial streams. During CBM production and aquifer recovery, streams that receive significant portions of their flow from ground-water discharge from coal beds may decline due to the loss of ground-water base flow. In larger surface-water bodies, such as the Tongue River, this impact will not likely be measurable.

After 4 years of production from the CX field, water levels have been lowered by 20 feet at distances of less than 1 mile to as much as 2 miles outside the production area. Within the production area water levels are as much as 150 feet lower than baseline conditions. As production continues, and as field sizes enlarge, greater drawdown is expected to occur, and at greater distances from the well fields. Drawdown of 20 feet may eventually reach 4 or more miles, outside production fields. These estimated ranges of drawdowns for CBM fields will be refined with continued monitoring. Accurate estimates of drawdown for specific fields will need to be based on very site-specific data. As shown in this report, the physical characteristics of coal aquifers vary widely, including hydraulic conductivity, saturated thickness, proximity to outcrop and starting hydrostatic pressure. Gas-field-development designs will be adjusted to fit local characteristics rather than being generic.

CBM-production-water management practices will depend on the quantity of water and the quality of the water released. The discharge rates from individual CBM wells will depend on time since pumping began, size of the well field, position in the well field, and coal-aquifer characteristics in the field. Typical discharge rates may range from highs of 20 or more gpm during startup, and decrease to possibly as low as 1 gpm after 10 years, depending on local aquifer characteristics. Water discharged from CBM wells is dominated by sodium and bicarbonate ions. Based on existing data, SAR values in CBM production water in Montana are expected to be higher than 30 and in some areas approach 70. Concentrations of CDS in production water are expected to be greater than 1,000 mg/L but less than 2,000 mg/L.

Ground-water models are useful tools in interpreting drawdown and recovery trends and for anticipating the general types and magnitudes of potential impacts.

However, data from monitoring wells are required to calibrate models, and make actual determinations of impacts and recovery. The importance of regular monitoring at dedicated wells cannot be overemphasized. Wells for monitoring regional impacts should be located outside producing fields. Water-level measurements within CBM fields only indicate the effectiveness of the reduction in hydrostatic pressure; and do not indicate the extent or magnitude of drawdown outside the production field. Monitoring of water levels in sandstone units above and below a producing seam, adjacent to and within a producing field can provide valuable information on the rates and extent of vertical leakage between aquifers. Continued collection of data and interpretation of those data will provide an understanding of the ground-water systems and their response to CBM production.

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Appendix A.

Monitoring well drilling and completion records

Site: CBM02-1 **Completion Date:** October 2002 **Location:** 06S 39E 16 DBCA

Latitude 45.3186
Longitude 106.9671
Altitude 3980 Ft

Well ID	GWIC ID	Total Depth (ft)	Casing	Aquifer	Screens (ft)
CBM02-1BC	203655	255.50	4.5 PVC	Brewster-Arnold Coal	237-255
CBM02-1LC	203658	366.00	5.0 Steel	Local Coal	356-366
CBM02-1KC	203646	417.00	5.0 Steel	Knobloch Coal	403-417

	To	Description
0.0	43.0	COLLUVIUM, SANDY, WEATHERED
43.0	74.5	COAL (WALL)
74.5	91.0	SHALE, LIGHT GRAY
91.0	96.0	COAL (0.25 GPM)
96.0	115.0	SHALE, GRAY
115.0	159.0	SANDSTONE, LIGHT GRAY, FINE GRAINED
159.0	165.5	SHALE, TAN, HARD
165.5	172.0	COAL (PAWNEE)
172.0	177.0	SHALE, MEDIUM GREEN-GRAY, SOFT
177.0	218.0	SANDSTONE, MEDIUM GRAY, FINE GRAINED, FRIABLE (6 GPM)
218.0	230.0	SILTSTONE, MEDIUM GRAY
230.0	235.0	SHALE, GRAY
235.0	238.0	COAL
238.0	242.5	SHALE, MEDIUM GRAY, FIRM
242.5	253.5	COAL (BREWSTER_ARNOLD) (13 GPM)
253.5	260.0	SHALE, MEDIUM GRAY, FIRM
260.0	270.0	SANDSTONE, GRAY
270.0	298.0	SHALE, GRAY WITH INTERBEDDED SILTSTONE
298.0	309.5	SHALE, MEDIUM GRAY, SILTY
309.5	313.5	COAL
313.5	354.5	SHALE, MEDIUM GRAY, WITH INTERBEDDED SILTSTONE
354.5	363.5	COAL(LOCAL UNNAMED)
363.5	403.0	SHALE, MEDIUM GRAY, FIRM
403.0	416.5	COAL (KNOBLOCH) (< 1 GPM)
416.5	421.5	SHALE, MEDIUM GRAY
421.5	426.0	SILTSTONE, MEDIUM GRAY
425.0	460.0	SANDSTONE, GRAY, FRIABLE
426.0	430.0	SHALE, MEDIUM GRAY, FIRM
430.0	435.0	COAL
435.0	452.0	SHALE, RED-BROWN, SILTY, SOFT (TOTAL AT 450 FT CONNECTION: 20 GPM)
460.0	472.0	SHALE, MEDIUM GRAY AND RED-BROWN (20 GPM AT 450 CONNECTION)
472.0	476.0	SANDSTONE, MEDIUM GRAY, VERY FINE GRAINED, FRIABLE
476.0	493.0	SHALE, GRAY, WITH INTERBEDDED SILTSTONE
493.0	527.0	SHALE, DARK GRAY, WITH SANDSTONE STRINGERS
527.0	557.0	SANDSTONE, POOR RETURNS
557.0	560.0	SHALE, DARK GRAY
560.0	600.0	SANDSTONE, INTERBEDDED WITH SHALE AND SILTSTONE (SIGNIFICANT WATER)
600.0	630.0	SANDSTONE, GRAY, FINE GRAINED, FRIABLE (TOTAL 50 GPM)

Site: CBM02-2 **Completion Date:** September 2002 **Location:** 09S 39E 29 BBDC

Latitude 45.0207
Longitude –106.9884
Altitude 3792 Ft

Well ID	GWIC ID	Total Depth (ft)	Casing	Aquifer	Screens (ft)
CBM02-2WC	203669	290.00	5.0 Steel	Carney Coal	259-290

From	To	Description
0.0	4.0	TOPSOIL
4.0	18.0	COLLUVIUM, TAN SANDY
18.0	34.0	CLINKER (FIRST WATER MAKING 8 GPM)
35.0	44.0	SANDSTONE (10 GPM)
44.0	49.0	SHALE
49.0	59.0	SILTSTONE, GRAY
59.0	62.0	SANDSTONE, GRAY
62.0	67.0	SHALE, MEDIUM BROWN-GRAY, SOFT
67.0	71.0	SHALE, LIGHT GRAY, SILTY
71.0	74.0	SHALE, LIGHT GRAY
74.0	81.0	SILTSTONE, LIGHT GRAY
81.0	88.0	SHALE, MEDIUM GRAY, CARBANACEOUS STREAKS
88.0	101.0	SILTSTONE, LIGHT GRAY
101.0	104.0	SHALE, LIGHT GRAY
104.0	116.0	SILTSTONE, MEDIUM GRAY
116.0	127.0	SHALE, MEDIUM GRAY, INTERBEDDED SILTSTONE
127.0	142.0	COAL (CANYON)
142.0	144.0	SHALE, LIGHT GRAY, FIRM
144.0	147.0	COAL
147.0	160.0	SHALE, LIGHT GRAY, INTERBEDDED SILTSTONE
160.0	208.0	SILSTONE, MEDIUM GRAY, HARD FROM 180-186
208.0	212.0	SILTSTONE, MEDIUM GRAY, FIRM
212.0	221.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED
221.0	223.0	SHALE, GRAY
223.0	236.0	SANDSTONE, MEDIUM GRAY, FINE GRAINED, POORLY SORTED
236.0	244.0	SILTSTONE, GRAY
244.0	256.0	SHALE, GRAY
256.0	288.0	COAL (CARNEY) (10 GPM)
288.0	290.0	SHALE, GRAY

Site: CBM02-2 **Completion Date:** September 2002 **Location:** 09S 39E 29 BCBD

Latitude 45.0185
Longitude –106.9889
Altitude 3890 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM02-2RC	203670	159.00	4.5 PVC	Roland Coal	149-159

From	To	Description
0.0	6.0	SOIL AND COLLUVIUM
6.0	21.0	SHALE, BROWN AND ORGANGE-BROWN
21.0	24.0	COAL
24.0	27.0	SHALE, MEDIUM GRAY
27.0	31.0	SANDSTONE, LIGHT TAN, VERY-FINE GRAINED
31.0	55.0	SHALE, MEDIUM GRAY WITH INTERBEDDED SILTSTONE
55.0	72.0	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED, DAMP
72.0	76.0	SHALE, GRAY, SOFT
76.0	99.0	SHALE, LIGHT GRAY, BROWN AND REDDISH-BROWN
99.0	126.0	SHALE, LIGHT AND DARK GRAY, DARK BROWN
126.0	128.0	COAL
128.0	149.0	SHALE, LIGHT AND MEDIUM GRAY, MINOR SANDSTONE
149.0	150.5	SILTSTONE, MEDIUM GRAY (BASE OF WASATCH FM)
150.5	154.0	COAL (FIRST WATER) (TOP OF FT UNION FM)
154.0	158.0	SHALE, MEDIUM GRAY
158.0	160.0	COAL (MAKING WATER)
160.0	166.0	SHALE, MEDIUM GRAY
166.0	169.0	COAL (MAKING WATER)
169.0	178.0	SILTSTONE, MEDIUM GRAY
178.0	180.0	SHALE, MEDIUM GRAY, SOFT

Site: CBM02-3 **Completion Date:** October 2002 **Location:** 08S 39E 16 BAAA

Latitude 45.1392
Longitude -106.9608
Altitude 3920 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM02-3DC	203678	235.00	5.0 Steel	Dietz Coal	186-235
CBM02-3CC	203676	376.40	5.0 Steel	Canyon Coal	356-376

From	To	Description
0.0	9.0	TOPSOIL, BROWN, SANDY
9.0	16.0	SAND, TAN, FINE GRAINED, LOOSE, DRY
16.0	36.0	COAL
36.0	48.0	SANDSTONE, ORANGE-BROWN, VERY-FINE GRAINED, LOOSE
48.0	57.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED, DAMP
57.0	61.0	SHALE, BROWN-BLACK, CARBONACEOUS, SOFT
61.0	70.0	SHALE, DARK BROWN-GRAY, SOFT
70.0	74.0	SILTSTONE, MEDIUM GRAY, LOOSE
74.0	78.0	SHALE, MEDIUM GRAY, BRITTLE
78.0	113.0	SHALE, DARK GRAY, INTERBEDDED WITH RED-BROWN SHALE AND THIN SANDSTONE
113.0	145.0	COAL (ANDERSON)
145.0	150.0	SHALE, DARK BROWN, CARBONACEOUS, FIRM
150.0	157.0	SANDSTONE, MEDIUM GRAY, VERY FINE GRAINED, FRIABLE (MINOR WATER FIRST WATER)
157.0	186.0	SHALE, LIGHT GRAY, FIRM
186.0	234.0	COAL (DIETZ) (4.5 GPM AT 230 CONNECTION IN CBMO2-3CC BOREHOLE)
234.0	252.0	SILTSTONE, LIGHT GRAY, CLAYEY, FIRM
252.0	260.0	SHALE, LIGHT GRAY, SILTY
260.0	271.0	SHALE, LIGHT AND MEDIUM GRAY
271.0	277.0	SILTSTONE, LIGHT GRAY
277.0	280.0	SHALE, DARK GRAY
280.0	297.0	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED WITH SILTSTONE
297.0	300.0	SHALE, MEDIUM GRAY, FIRM
300.0	314.0	SILTSTONE, LIGHT GRAY
314.0	341.0	SANDSTONE, LIGHT GRAY, FINE GRAINED, WITH SILTSTONE AND SHALE INTERBEDS (6 GPM AT 330 CONNECTION)
341.0	354.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED, WITH SILTSTONE
354.0	356.0	SHALE
356.0	376.0	COAL (CANYON)
376.0	376.4	SHALE, DARK BROWN-GRAY, FIRM

Site: CBM02-4 **Completion Date:** October 2002 **Location:** 07S 40E 36 CDDC

Latitude 45.1798
Longitude -106.7803
Altitude 3500 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing Info	Aquifer	Screens (ft)
CBM02-4SS2	203690	96.60	4.5 PVC	Sub-Canyon Coal	53-96
CBM02-4SS1	203681	221.00	4.5 PVC	Wall Coal Overburden	191-221
CBM02-4WC	203680	291.00	5.0 Steel	Wall Coal	234-291

From	To	Description
0.0	1.0	TOPSOIL, DARK RED-BROWN, SANDY
1.0	26.0	ALLUVIUM, CLINKER COBBLES IN SANDY MATRIX (DRY)
26.0	31.0	SILTSONE, ORANGE-TAN, WEATHERED
31.0	41.0	SHALE, MEDIUM GRAY, SOFT
41.0	46.0	SILTSTONE, MEDIUM GRAY, FRIABLE
46.0	100.0	SANDSTONE, DARK GRAY, VERY-FINE GRAINED (38 GPM)
100.0	106.0	COAL
106.0	119.0	SHALE, MEDIUM GRAY, INTERBEDDED SILTSTONE
119.0	121.0	COAL
121.0	129.0	SHALE, LIGHT GRAY, SILTY STRINGERS
129.0	144.0	SILTSTONE, WHITE, SOFT, INTERBEDDED WITH SHALE
144.0	148.0	SHALE, GRAY
148.0	151.0	COAL
151.0	187.0	SILTSTONE WITH SHALE STRINGERS
187.0	191.0	SHALE, MEDIUM GRAY
191.0	217.0	SANDSTONE, LIGHT GRAY, FINE AND MEDIUM GRAINED, FRIABLE
217.0	218.0	SILTSTONE, DARK GRAY, HARD
218.0	222.0	SANDSTONE, MEDIUM GRAY, FINE GRAINED
222.0	231.0	SHALE, MEDIUM GRAY, SOFT
231.0	236.0	SILTSTONE
236.0	290.5	COAL (WALL) SHALE STRINGER 237.5 TO 328.5
290.5	291.0	SILTSTONE, LIGHT TAN AND GRAY

Site: CBM02-7 **Completion Date:** September 2002 **Location:** 08S 39E 01 AAAA

Latitude 45.1801
Longitude -106.8906
Altitude 3900 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM02-7SS	203695	190.30	4.5 PVC	Canyon Coal Overburden	170-190
CBM02-7CC	203693	263.40	5.0 Steel	Canyon Coal	246-263

From	To	Description
0.0	19.0	SOIL AND COLLUVIUM, TAN, SANDY
19.0	55.0	CLINKER (ANDERSON AND DIETZ)
55.0	68.0	SANDSTONE, TAN, POOR RETURNS
68.0	74.0	SHALE, GRAY
74.0	75.0	COAL
75.0	80.0	SHALE, MEDIUM GRAY, SILTY, FIRM
80.0	108.0	SILTSTONE, MEDIUM TAN AND GRAY, HARD, WITH INTERBEDDED SHALE
108.0	128.0	SHALE, MEDIUM GRAY AND BROWN, FIRM
128.0	129.0	COAL
129.0	138.0	SHALE, LIGHT GRAY, SILTY
138.0	142.0	SHALE, LIGHT GRAY AND TAN
142.0	154.0	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED
154.0	192.0	SANDSTONE, MEDIUM GRAY, FINE GRAINED (MINOR WATER)
192.0	204.0	SHALE, DARK GRAY, MINOR COAL STRINGERS
204.0	221.0	SANDSTONE, DARK GRAY, VERY-FINE GRAINED, HARD
221.0	242.0	SHALE, MEDIUM GRAY, FIRM (5 GPM AT 230 CONNECTION)
242.0	259.0	COAL (CANYON) SHALE AT 243.5 TO 244.5
259.0	263.5	SHALE, MEDIUM GRAY

Site: CBM02-8 **Completion Date:** November 2002 **Location:** 05S 42E 28 DDAC

Latitude 45.3688
Longitude -106.5471
Altitude 3260 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM02-8KC	203697	208.00	4.5 PVC	Knoblock Coal	190-208
CBM02-8SS	203699	224.00	4.5 PVC	Knoblock Underburden	219-224
CBM02-8DS	203700	446.00	5.0 PVC	Flowers-Goodale Overburden	388-446
CBM02-8FG	203701	480.46	5.0 Steel	Flowers-Goodale Coal	459-482

From	To	Description
0.0	3.0	TOPSOIL, MEDIUM BROWN, SANDY
3.0	18.0	SAND, ORANGE-BROWN, LOOSE, FINE GRAINED
18.0	19.0	GRAVEL, CLINKER
19.0	21.0	SAND, ORANGE-BROWN, MINOR CLINKER
21.0	25.5	COAL (BREWSTER-ARNOLD) DAMP AT BASE
25.5	28.0	SHALE, MEDIUM BROWN-GRAY
28.0	42.0	SILTSTONE, LIGHT GRAY, SHALEY
42.0	55.0	SHALE, MEDIUM GRAY AND DARK GRAY, SOFT TO HARD
55.0	57.0	COAL
57.0	121.0	SHALE, DARK GRAY, SOFT
121.0	127.0	COAL
127.0	132.0	SILTSTONE, LIGHT GRAY, SOFT
132.0	137.0	SHALE, MEDIUM GRAY, FIRM
137.0	149.0	SHALE, MEDIUM BROWN-GRAY AND LIGHT GRAY, FIRM
149.0	169.0	SANDSTONE, LIGHT GRAY, FINE GRAINED
169.0	171.5	SHALE, LIGHT GRAY, FIRM (1.5 GPM AT 170 CONNECTION)
171.5	173.5	COAL
173.5	180.0	SHALE, MEDIUM GRAY, FIRM
180.0	190.0	SILTSTONE, INTERBEDDED WITH SHALE
190.0	207.0	COAL (KNOBLOCH)
207.0	208.0	SILTSTONE, LIGHT GRAY, SILTY, SOFT
208.0	211.5	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED (12 GPM AT 210)
211.5	218.0	SHALE, LIGHT TAN AND LIGHT GRAY, FIRM
218.0	223.0	SANDSTONE, LIGHT GRAY, FINE GRAINED
223.0	227.0	SHALE, LIGHT GRAY, FIRM
227.0	233.0	SILTSTONE, LIGHT TAN WITH GRAY SHALE (4.25 GPM AT 230 CONNECTION0
233.0	238.0	COAL, WITH SHALE STRINGER 235 TO 236.5
238.0	245.0	SHALE, DARK BROWN, SOFT
245.0	264.0	SILTSTONE, LIGHT GREEN-GRAY, SHALEY, SOFT
264.0	344.0	SANDSTONE MEDIUM GRAY, VERY-FINE GRAINED, FRIABLE, SILTY ZONE 317 TO 324.5
344.0	350.0	COAL (6 GPM AT 350 CONNECTION)
350.0	354.0	SHALE, DARK BROWN
354.0	359.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED
359.0	370.0	SHALE, DARK GRAY, FIRM
370.0	373.0	SILTSTONE, MEDIUM GRAY, HARD
373.0	377.0	SHALE, DARK BROWN, FIRM
377.0	459.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED (24 GPM AT 390 CONNECTION)
459.0	479.0	COAL (FLOWERS-GOODALE) (60 GPM AT 470 CONNECTION IS APPARENTLY COMING FROM OVERLYING SANDSTONE)
79.0	482.0	SHALE, DARK BROWN AND DARK GRAY, MINOR COAL

Site: CBM03-10 **Completion Date:** April 2003 **Location:** 08S 42E 29 ADAD

Latitude 45.1141
Longitude -106.6045
Altitude 4130 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM03-10SS	203704	462.00	5.0 Steel	Anderson-Dietz Overburden	429-462
CBM03-10AC	203703	560.00	5.0 Steel	Anderson Coal	523-560

From	To	Description
0.0	5.0	TOPSOIL AND COLLUVIUM
5.0	16.0	SHALE, TAN, RED-BROWN, WEATHERED
16.0	61.0	SHALE, MEDIUM GRAY, MINOR CARBONACEOUS, FIRM
61.0	66.0	SANDSTONE, DARK GRAY, FINE GRAINED, SLIGHTLY CALCAREOUS
66.0	76.0	SHALE, MEDIUM GRAY, SOFT
76.0	79.0	SILTSTONE, MEDIUM GRAY, CLAYER, HARD
79.0	106.0	SHALE, MEDIUM GRAY, FIRM (BASE OF WASATCH FM)
106.0	113.0	COAL (ROLAND)
113.0	162.5	SHALE, MEDIUM BROWN-GRAY, SILTY, SOFT
162.5	164.0	COAL
164.0	187.0	SHALE, MEDIUM GRAY, SOFT
187.0	219.0	SILTSTONE, MEDIUM GRAY, INTERBEDDED WITH SILTSTONE
219.0	224.0	SILTSTONE, GRAY, HARD AT TOP
224.0	240.0	SHALE, MEDIUM GRAY, SOFT
240.0	251.0	SILTSTONE, GRAY
251.0	268.0	SHALE, MEDIUM BROWN, SOFT, CARBONACEOUS, COAL AT 261 TO 263
268.0	288.0	SHALE, MEDIUM GRAY, SOFT
288.0	299.0	SHALE, LIGHT BROWN, SILTY
299.0	305.0	SANDSTONE, MEDIUM GRAY, MEDIUM GRAINED, CLAY FILLED
305.0	310.0	SHALE, GRAY AND BROWN
310.0	350.0	SHALE, MEDIUM GRAY AND GRAY-BROWN
350.0	367.0	COAL (SMITH) (1/4 GPM, FIRST WATER)
367.0	408.0	SHALE, MEDIUM GRAY, FIRM, THIN SILTY STRINGERS
408.0	428.0	SANDSTONE, INTERBEDDED WITH SHALE, POOR RETURNS
428.0	463.0	SANDSTONE, MEDIUM GRAY, FRIABLE (1 GPM)
463.0	485.0	SHALE, MEDIUM BROWN, BRITTLE
485.0	486.0	SILTSTONE, HARD, NO RETURNS
486.0	522.0	SHALE, POOR RETURNS
522.0	557.0	COAL (ANDERSON) SHALE PARTING AT 550 TO 554 (0.3 GPM)
557.0	560.0	SHALE, DARK GRAY, MINOR CARBONACEOUS

Site: CBM03-11 **Completion Date:** April 2003 **Location:** 08S 44E 05 BBBB

Latitude 45.1793
Longitude -106.3647
Altitude 3950 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM03-11AC	203705	211.00	4.5 PVC	Anderson Coal	177-211
CBM03-11DC	203707	271.00	4.5 PVC	Dietz Coal	254-271
CBM03-11CC	203708	438.00	5.0 Steel	Canyon Coal	410-413, 421-437

From	To	Description
0.0	4.0	TOP SOIL, LIGHT BROWN AND GRAY-TAN, SANDY
4.0	16.5	CLAY, GRAY-TAN, SOFT
16.5	31.5	SANDSTONE, LIGHT ORANGE-TAN, VERY-FINE GRAINED, WEATHERED
31.5	41.0	SHALE, MEDIUM ORANGE-GRAY BECOMING GRAY WITH DEPTH, SOFT, COAL AT 33 TO 34
41.0	58.0	SHALE, MEDIUM GRAY, SILTY
58.0	63.0	SANDSTONE, DARK GRAY, VERY-FINE GRAINED, CLAY FILLED
63.0	73.0	SHALE, MEDIUM GRAY, SOFT
73.0	76.5	SANDSTONE, DARK GRAY, VERY-FINE GRAINED
76.5	88.0	SHALE, MEDIUM GRAY, SOFT
88.0	124.0	SHALE, MEDIUM GRAY, SOFT, THIN STRINGERS OF COAL AND CARBONACEOUS SHALE AND SILTSTONE
124.0	136.5	SANDSTONE, DARK GRAY, VERY-FINE GRAINED
136.5	149.0	SHALE, DARK GRAY, VERY SILTY
149.0	154.0	SHALE, MEDIUM GRAY, SOFT
154.0	162.0	SILTSTONE, DARK-BROWN-GRAY, MEDIUM HARD
162.0	168.0	SANDSTONE, MEDIUM GRAY, FINE GRAINED, FRIABLE
168.0	176.0	SHALE, MEDIUM BROWN, SOFT
176.0	210.5	COAL (ANDERSON) (1 GPM)
210.5	242.5	SHALE, MEDIUM GRAY AND BROWN-GRAY, SOFT
242.5	246.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED, CLAY FILLED
246.0	253.0	SHALE, GRAY, SOFT
253.0	268.5	COAL (DIETZ) (MINOR WATER)
268.5	300.0	SHALE, LIGHT GRAY, WITH INTERBEDDED SILTSTONE AND SANDSTONE STRINGERS
300.0	306.0	SHALE, MEDIUM GRAY, FIRM, COAL AT 303.5 TO 304
306.0	315.5	SHALE, LIGHT GREEN-GRAY, WITH SILTSTONE STRINGERS
315.5	331.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED, CLAY FILLED
331.0	336.0	SHALE, MEDIUM GRAY, FIRM
336.0	341.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED
341.0	343.0	SHALE, MEDIUM GRAY
343.0	347.0	COAL (MINOR WATER)
347.0	357.0	SHALE, MEDIUM GRAY, FIRM
357.0	362.0	SILTSTONE, MEDIUM GRAY, HARD
362.0	367.0	SANDSTONE, MEDIUM GRAY, VERY-FINE GRAINED
367.0	379.0	SHALE, MEDIUM GRAY, INTERBEDDED SILTSTONE
379.0	409.5	SHALE, MEDIUM GRAY, FIRM
409.5	436.0	COAL (CANYON) (1.5 GPM)
436.0	438.0	SHALE, LIGHT GRAY, SILTY, SOFT

Site: CBM03-12 **Completion Date:** May 2003 **Location:** 08S 45E 16 DBCB

Latitude 45.1352
Longitude -106.2121
Altitude 3715 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM03-12COC	203709	351.00	5.0 Steel	Cook Coal	332-351

From	To	Description
0.0	30.0	COLLUVIUM, SANDY CLAY WITH CLINKER BOULDERS
30.0	35.0	CLAY, TAN, SILTY, VERY SOFT
35.0	37.0	COAL
37.0	46.0	SHALE, GRAY, VERY SOFT
46.0	49.0	COAL
49.0	60.0	SANDSTONE, POOR RETURNS
60.0	91.0	CLAY, MEDIUM BROWN-GRAY, VERY SOFT
91.0	94.0	SANDSTONE, POOR RETURNS
94.0	101.0	CLAY, MEDIUM GRAY, SILTY
101.0	117.5	SANDSTONE, MEDIUM GRAY, VERY FINE GRAINED, CLAY FILLED, SHALE 105.5 TO 107.5 (FIRST WATER MINOR AMOUNT)
117.5	121.0	SHALE, MEDIUM GRAY
121.0	124.0	SANDSTONE, MEDIUM TAN-GRAY, VERY FINE GRAINED (MINOR WATER)
124.0	135.0	SHALE, MEDIUMG GRAY
135.0	142.0	SANDSTONE (MAKING ABOUT 1 GPM)
142.0	149.0	SHALE, MEDIUM GRAY, FIRM
149.0	177.0	COAL (CANYON) SHALE AT 174 TO 176 (MAKING WATER)
177.0	183.0	SHALE, TAN, CARBONACEOUS
183.0	210.5	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED, CLAY FILLED
210.5	222.0	SHALE, LIGHT TO MEDIUM GRAY, SILTY, MINOR COAL STRINGERS
222.0	223.5	COAL
223.5	244.0	SHALE, MEDIUM GRAY, WITH SILTSTONE STRINGERS
244.0	246.5	SANDSTONE MEDIUM GRAY, VERY-FINE GRAINED
246.5	252.0	SHALE, MEDIUM GRAY, FIRM
252.0	278.0	SILTSTONE, MEDIUM GRAY
278.0	286.0	SANDSTONE, DARK BROWN-GRAY, VERY-FINE GRAINED, CLAY FILLED
286.0	293.0	SHALE, MEDIUM GRAY, SILTY
293.0	303.0	SANDSTONE
303.0	322.0	SHALE, MEDIUM GRAY, SILTY
322.0	330.5	SHALE, MEDIUM BROWN-GRAY, FIRM
330.5	346.0	COAL (COOK) (MAKING ABOUT 2 GPM)
346.0	351.0	SHALE, MEDIUM BROWN-GRAY, SOFT

Site: CBM03-13 **Completion Date:** May 2003 **Location:** 09S 46E 11 BBBA

Latitude 45.0722
Longitude -106.0572
Altitude 3931 Ft

Well ID	GWIC ID	Total Depth(ft)	Casing	Aquifer	Screens (ft)
CBM03-13OC	203710	500.00	5.0 Steel	Otter Coal	487-500

From	To	Description
0.0	3.0	TOPSOIL, BROWN, SANDY
3.0	10.0	COLLUVIUM, TAN, CLAY AND SILT
10.0	15.0	CLAY, TAN, SOFT
15.0	28.0	CLAY, MEDIUM GRAY, SOFT
28.0	40.0	CLAY, MEDIUM BROWN, SOFT
40.0	69.5	COAL (ANDERSON) SHALE PARTINGS 54.5 TO 55.5, 64 TO 66.5, CREATE THREE BENCHES
69.5	95.0	SHALE, MEDIUM GRAY, WITH SANDSTONE LENSES
95.0	111.0	SHALE, MEDIUM GRAY
111.0	115.0	SHALE, MEDIUM BROWN, CARBONACEOUS, SOFT
115.0	128.0	COAL (DIETZ) SHALE PARTING AT 116.5 TO 118 CREATES TWO BENCHES
128.0	131.0	SHALE, LIGHT GRAY, SOFT
131.0	150.0	SILTSTONE, LIGHT GRAY, VERY CLAYEY, SOFT
150.0	204.0	SANDSTONE, LIGHT GRAY, VERY-FINE GRAINED, MINOR SHALE STRINGERS
204.0	226.0	SHALE, LIGHT GRAY, SILTY, SOFT
226.0	229.0	SHALE, MEDIUM GRAY, FIRM
229.0	259.0	COAL (CANYON) SHALE PARTING AT 236 TO 240
259.0	262.0	SHALE, MEDIUM GRAY, FIRM
262.0	280.0	SILTSTONE, LIGHT GRAY, CLAY FILLED
280.0	289.5	SHALE, LIGHT TAN-GRAY, FIRM
289.5	291.0	COAL
291.0	304.0	SHALE, LIGHT GRAY, FIRM
304.0	332.0	SANDSTONE, MED GRAY, FINE GRAINED, INTERBEDDED SILTSTONE
332.0	341.0	SANDSTONE, MEDIUM GRAY
341.0	369.5	SILTSTONE, MEDIUM GRAY
369.5	387.5	SHALE, MEDIUM GRAY, SILTY, FIRM, MINOR CARBONACEOUS STRINGERS
387.5	389.5	COAL
389.5	393.0	SILTSTONE, MEDIUM GRAY, CLAYEY
393.0	402.0	SANDSTONE,
402.0	405.0	SHALE, MEDIUM BROWN-GRAY, SILTY, SOFT
405.0	408.0	COAL (COOK)
408.0	411.0	SHALE, BROWN-GRAY, SOFT
411.0	416.0	SANDSTONE
416.0	432.5	SHALE, LIGHT GRAY, FIRM
432.5	439.0	COAL (MAKING 17 GPM PROBABLY FROM OVERLYING SANDSTONE)
439.0	440.0	SILTSTONE, MEDIUM GRAY
440.0	451.5	SANDSTONE, LIGHT GRAY, FINE GRAINED, FRIABLE
451.5	455.5	SHALE, LIGHT TAN, HARD
455.5	466.5	SANDSTONE, MEDIUM GRAY, FINE GRAINED, FRIABLE
466.5	471.0	SHALE, DARK BROWN TO GRAY BROWN, FIRM
471.0	484.0	SILTSTONE, POOR RETURNS
484.0	487.0	SHALE
487.0	498.0	COAL (OTTER)
498.0	501.5	SHALE
501.5	530.0	SILTSTONE

Appendix B.

Well data for monitoring wells

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana

Site designation	Township	Range	Section	Tract	Latitude	Longitude	Land surface altitude (ft)	Aquifer
OC-28	04S	45E	21	CCBD	45.4717	-106.1928	3171.0	KNOBLOCH COAL
OC-13	04S	45E	8	DDAA	45.4983	-106.1945	3230.0	KNOBLOCH COAL
CBM02-8DS	05S	42E	28	DDAC	45.3687	-106.5470	3259.0	FLOWERS-GOODALE OVERBURDEN
CBM02-8FG	05S	42E	28	DDAC	45.3688	-106.5471	3260.0	FLOWERS-GOODALE COAL
CBM02-8KC	05S	42E	28	DDAC	45.3689	-106.5473	3261.0	KNOBLOCH COAL
CBM02-8SS	05S	42E	28	DDAC	45.3688	-106.5472	3260.0	KNOBLOCH COAL COAL UNDERBURDEN
IB-2	05S	43E	21	BBDB	45.3930	-106.4372	3191.6	KNOBLOCH COAL COAL UNDERBURDEN
MK-4	05S	43E	21	BBDC	45.3919	-106.4363	3195.3	KNOBLOCH COAL
WL-2	05S	43E	21	BBDC	45.3919	-106.4358	3187.6	KNOBLOCH COAL
77-26	05S	45E	4	ABCC	45.4352	-106.1839	3284.0	KNOBLOCH COAL
CBM02-1BC	06S	39E	16	DBCA	45.3186	-106.9671	3980.0	BREWSTER-ARNOLD COAL
CBM02-1KC	06S	39E	16	DBCA	45.3186	-106.9671	3980.0	KNOBLOCH COAL
CBM02-1LC	06S	39E	16	DBCA	45.3186	-106.9671	3980.0	LOCAL COAL
RBC-3	06S	39E	8	BDCD	45.3331	-106.9868	3840.0	ALLUVIUM (QUATERNARY)
RBC-1	06S	39E	8	CAAA	45.3327	-106.9836	3860.0	ALLUVIUM (QUATERNARY)
RBC-2	06S	39E	8	CAAA	45.3327	-106.9844	3860.0	ALLUVIUM (QUATERNARY)
20-LW	06S	40E	1	CCDC	45.3391	-106.7801	3940.0	WALL COAL
28-W	06S	41E	16	BBCC	45.3211	-106.7292	3715.0	WALL COAL
32-LW	06S	41E	21	DDDC	45.2955	-106.7098	3530.0	WALL COAL
22-BA	06S	41E	3	BADD	45.3484	-106.6954	3530.0	BREWSTER-ARNOLD COAL
CBM02-4SS1	07S	40E	36	CDDC	45.1798	-106.7803	3500.0	WALL COAL OVERBURDEN
CBM02-4SS2	07S	40E	36	CDDC	45.1798	-106.7803	3500.0	SUB-CANYON COAL SANDSTONE
CBM02-4WC	07S	40E	36	CDDC	45.1798	-106.7802	3500.0	WALL COAL
625	08S	38E	28	DADB	45.1133	-107.0522	4186.6	DIETZ COAL
625A	08S	38E	28	DADB	45.1133	-107.0522	4186.7	ANDERSON COAL
CBM02-7CC	08S	39E	1	AAAA	45.1801	-106.8906	3900.0	CANYON COAL
CBM02-7SS	08S	39E	1	AAAA	45.1799	-106.8906	3900.0	CANYON COAL OVERBURDEN
CBM02-3CC	08S	39E	16	BAAA	45.1392	-106.9608	3920.0	CANYON COAL
CBM02-3DC	08S	39E	16	BAAA	45.1391	-106.9607	3920.0	DIETZ COAL
WR-21	08S	39E	32	DBBC	45.0877	-106.9791	3890.0	DIETZ 1 AND 2 COALS COMBINED
PKS 3203	08S	40E	28	ADA	45.1068	-106.8302	3500.0	CANYON COAL
PKS-3204	08S	40E	28	ADA	45.1067	-106.8299	3500.0	ANDERSON-DIETZ COAL AND CLINKER
CBM03-10AC	08S	42E	29	ADAD	45.1141	-106.6045	4130.0	ANDERSON COAL
CBM03-10SS	08S	42E	29	ADAD	45.1141	-106.6045	4130.0	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
HC-01	08S	43E	21	BBDA	45.1314	-106.4750	3457.0	ALLUVIUM (QUATERNARY)
HC-23	08S	43E	21	BDBB	45.1297	-106.4747	3530.0	CANYON COAL
HC-24	08S	43E	21	BDBB	45.1297	-106.4747	3500.0	CANYON COAL OVERBURDEN

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana (continued)

(CONTINUED) Site designation	Well Depth (ft below land surface)	Water level (ft)	Date of water level measurement	Well discharge (gpm)	Hydraulic conductivity (ft/day)	GWIC No.
OC-28	229.0	68.88	12/14/2003			207101
OC-13	268.0	180.34	12/14/2003	2.1	0.1	207100
CBM02-8DS	446.0	104.40	12/11/2003	0.3		203700
CBM02-8FG	480.4	103.87	12/11/2003	0.5		203701
CBM02-8KC	208.0	159.59	12/11/2003	1.0		203697
CBM02-8SS	259.0	160.51	12/11/2003	10.0		203699
IB-2	245.0	122.97	12/11/2003		0.19	207096
MK-4	188.0	123.12	12/11/2003			207097
WL-2	199.0	120.94	12/11/2003			207099
77-26	223.0	149.62	12/14/2003	3.6	0.2	7755
CBM02-1BC	255.5	102.18	12/13/2003	5.0		203655
CBM02-1KC	417.0	174.40	12/13/2003	0.5		203646
CBM02-1LC	366.0	145.98	12/13/2003	2.0		203658
RBC-3	24.6	12.97	12/22/2003			207068
RBC-1	26.8	14.10	12/22/2003			207064
RBC-2	16.9	11.22	12/22/2003			207066
20-LW	253.0	88.79	12/11/2003	0.2	0.02	191139
28-W	144.0	109.26	12/11/2003	1.3	0.35	191163
32-LW	51.0	37.38	12/11/2003	0.2	0.07	191169
22-BA	262.0	110.11	12/11/2003	0.4	0.02	191155
CBM02-4SS1	221.0	76.91	12/24/2003	5.0		203681
CBM02-4SS2	96.6	40.23	12/24/2003	30.0		203690
CBM02-4WC	291.0	171.74	12/24/2003	0.2		203680
625	186.0	49.18	12/13/2003			184223
625A	90.6	56.80	12/13/2003			184224
CBM02-7CC	263.4	164.92	12/23/2003	1.5		203693
CBM02-7SS	190.3	90.17	12/23/2003	5.0		203695
CBM02-3CC	376.4	303.29	12/13/2003	0.3		203676
CBM02-3DC	235.0	183.56	12/13/2003	0.1		203678
WR-21	206.0	58.85	12/13/2003	4.0	1.2	8074
PKS 3203	201.0	113.66	12/3/2003			207087
PKS-3204	82.0	73.22	12/3/2003			163657
CBM03-10AC	560.0	531.16	12/11/2003	0.3		203703
CBM03-10SS	462.0	372.46	12/12/2003	1.0		203704
HC-01	19.7	11.18	11/7/2003	17.0		207143
HC-23	223.0	58.80	12/12/2003	16.5	1.5	8117
HC-24	150.0	48.36	12/12/2003	7.1	0.2	8118

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana

Site designation	Township	Range	Section	Tract	Latitude	Longitude	Land surface altitude (ft)	Aquifer
FC-01	08S	43E	31	BBDA	45.1025	-106.5166	3735.0	ANDERSON COAL
FC-02	08S	43E	31	BBDA	45.1025	-106.5166	3735.0	DIETZ COAL
CBM03-11AC	08S	44E	5	BBBB	45.1793	-106.3632	3950.0	ANDERSON COAL
CBM03-11CC	08S	44E	5	BBBB	45.1793	-106.3647	3950.0	CANYON COAL
CBM03-11DC	08S	44E	5	BBBB	45.1793	-106.3641	3950.0	DIETZ COAL
BC-06	08S	45E	16	DBCB	45.1387	-106.2100	3715.0	CANYON COAL
BC-07	08S	45E	16	DBCB	45.1387	-106.2100	3715.0	CANYON COAL OVERBURDEN
CBM03-12COC	08S	45E	16	DBCB	45.1352	-106.2121	3715.0	COOK COAL
396	09S	38E	24	BBBC	45.0491	-107.0088	3939.0	DIETZ COAL
WR-23	09S	38E	1	AADC	45.0922	-106.9905	3960.0	DIETZ 1 AND 2 COALS COMBINED
YA-106	09S	38E	22	ADBD	45.0464	-107.0536	4010.0	ALLUVIUM (QUATERNARY)
391	09S	38E	22	DADC	45.0413	-107.0313	3987.0	DIETZ 1 AND 2 COALS COMBINED
421	09S	38E	24	BCAC	45.0472	-107.0058	3918.0	DIETZ COAL
394	09S	38E	25	BCBA	45.0330	-107.0075	3909.0	DIETZ COAL
422	09S	38E	25	CBDC	45.0261	-107.0061	3917.0	DIETZ COAL
YA-108	09S	38E	26	AACD	45.0335	-107.0120	3830.0	ALLUVIUM (QUATERNARY)
YA-107	09S	38E	26	AADC	45.0337	-107.0118	3840.0	ALLUVIUM (QUATERNARY)
YA-109	09S	38E	26	AADC	45.0407	-107.0312	3830.0	ALLUVIUM (QUATERNARY)
395	09S	38E	26	ABAB	45.0363	-107.0161	3900.5	DIETZ COAL
401	09S	38E	35	AABD	45.0217	-107.0131	4070.0	DIETZ COAL
624	09S	38E	7	DADB	45.0725	-107.0917	4644.7	ANDERSON-DIETZ 1 COALS COMBINED
WCY-44	09S	39E	11	CCCA	45.0540	-106.9284	3680.0	ALLUVIUM (QUATERNARY)
WR-22A	09S	39E	14	DABD	45.0447	-106.9125	3700.7	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-58D	09S	39E	14	DDCC	45.0394	-106.9138	3627.4	ALLUVIUM (QUATERNARY)
WR-58C	09S	39E	14	DDCD	45.0384	-106.9123	3632.6	ALLUVIUM (QUATERNARY)
WR-19	09S	39E	16	AABA	45.0525	-106.9505	3835.4	DIETZ 1 AND 2 COALS COMBINED
WR-20	09S	39E	16	AABA	45.0525	-106.9505	3835.3	ANDERSON COAL
WR-35	09S	39E	20	DABB	45.0306	-106.9742	3886.7	DIETZ 1 AND 2 COALS COMBINED
WR-54A	09S	39E	25	DADB	45.0147	-106.8902	3631.2	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-53A	09S	39E	25	DDAA	45.0122	-106.8888	3607.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-36A	09S	39E	28	CCAD	45.0122	-106.9650	3716.3	DIETZ 1 AND 2 COALS COMBINED
WR-37	09S	39E	28	CCAD	45.0122	-106.9650	3715.8	ANDERSON-DIETZ 1 COALS COMBINED
WR-47	09S	39E	28	DACD	45.0131	-106.9528	3815.9	ANDERSON-DIETZ 1 AND 2 COALS
WR-26	09S	39E	29	ABAA	45.0225	-106.9761	3770.0	ANDERSON-DIETZ 1 COALS COMBINED
CBM02-2WC	09S	39E	29	BBDC	45.0207	-106.9884	3792.0	CARNEY COAL BED
WR-24	09S	39E	29	BBDD	45.0202	-106.9877	3777.2	CANYON COAL
CBM02-2RC	09S	39E	29	BCBD	45.0185	-106.9889	3890.0	ROLAND COAL

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana (continued)

Site designation	Well Depth (ft below land surface)	Water level (ft)	Date of water level measurement	Well discharge (gpm)	Hydraulic conductivity (ft/day)	GWIC No.
FC-01	133.0	129.14	12/12/2003		0.05	8140
FC-02	260.0	244.69	12/12/2003			8141
CBM03-11AC	211.0	154.08	12/12/2003	1.0		203705
CBM03-11CC	438.0	383.08	12/12/2003	1.5		203708
CBM03-11DC	271.0	228.70	12/12/2003	0.2		203707
BC-06	188.0	90.26	12/12/2003	4.6	0.7	8191
BC-07	66.0	36.94	12/12/2003	0.8		8192
CBM03-12COC	351.0	167.65	12/12/2003	3.0		203709
396	280.0	54.40	12/14/2003	25.0	3.6	8372
WR-23	322.0	84.84	12/13/2003	6.0	0.9	8347
YA-106	58.6	16.08	12/14/2003			192869
391	175.0	62.58	4/7/2003		0.4	8368
421	264.1	17.93	12/14/2003			184221
394	242.0	91.93	12/14/2003	5.0	0.75	8377
422	187.0	123.71	12/14/2003			8379
YA-108	45.3	19.29	12/14/2003			192901
YA-107	32.5	26.93	12/14/2003			192898
YA-109	43.8	7.43	12/14/2003			192874
395	299.0	63.97	4/7/2003	15.0	0.8	8387
401	259.9	190.75	12/14/2003			184220
624	435.1	349.32	12/14/2003			184222
WCY-44	48.0	9.48	11/9/2003			207086
WR-22A	185.0	140.49	12/13/2003			130472
WR-58D	27.0	15.86	12/13/2003	15.0	75	8413
WR-58C	23.0	Dry	12/13/2003	2.0	83	132905
WR-19	305.0	140.45	12/13/2003	20.0	1.6	8417
WR-20	166.0	115.63	12/13/2003	15.0	3.9	8419
WR-35	273.0	127.00	12/14/2003			184199
WR-54A	211.0	128.58	12/13/2003	1.0		8428
WR-53A	187.0	112.36	12/13/2003			8430
WR-36A	192.0	36.65	12/14/2003		1.05	184200
WR-37	126.0	33.40	12/14/2003		0.5	8432
WR-47	367.0	235.59	12/14/2003			184197
WR-26	267.0	81.55	12/14/2003		0.1	8434
CBM02-2WC	290.0	66.99	12/14/2003	10.0		203669
WR-24	146.0	32.73	12/14/2003		3.2	8436
CBM02-2RC	159.0	128.89	12/14/2003	1.0		203670

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana

Site designation	Township	Range	Section	Tract	Latitude	Longitude	Land surface altitude (ft)	Aquifer
WR-31	09S	39E	29	CBAA	45.0163	-106.9863	3895.2	ANDERSON COAL
WR-30	09S	39E	29	CBAB	45.0165	-106.9874	3894.6	DIETZ 1 AND 2 COALS COMBINED
WR-33	09S	39E	32	ACAA	45.0066	-106.9758	3732.3	ANDERSON-DIETZ1 CLINKER AND COAL
WR-32	09S	39E	32	BCAC	45.0050	-106.9875	3849.0	DIETZ 1 AND 2 COALS COMBINED
WR-34	09S	39E	33	CBBB	45.0015	-106.9702	3772.1	ANDERSON-DIETZ 1 AND 2 COALS
WR-45	09S	39E	33	DDCC	44.9966	-106.9538	3638.2	ALLUVIUM (QUATERNARY)
WR-44	09S	39E	33	DDCD	44.9966	-106.9522	3636.9	ALLUVIUM (QUATERNARY)
WR-41	09S	39E	34	CCCC	44.9950	-106.9498	3642.7	ALLUVIUM (QUATERNARY)
WRE-01	09S	40E	1	DBCC	45.0711	-106.7741	3457.4	ALLUVIUM (QUATERNARY)
WRE-02	09S	40E	1	DBCC	45.0712	-106.7756	3456.8	ALLUVIUM (QUATERNARY)
WRE-09	09S	40E	13	DCBC	45.0397	-106.7741	3510.7	DIETZ 2 COAL
WRE-10	09S	40E	13	DCCB	45.0383	-106.7741	3518.5	DIETZ COAL
WRE-11	09S	40E	13	DCCD	45.0383	-106.7736	3508.9	ANDERSON COAL
PKS-3201	09S	40E	14	BAA	45.0437	-106.7971	3438.0	CANYON COAL
PKS-3198	09S	40E	14	CAA	45.0446	-106.7964	3440.0	ANDERSON COAL
PKS-3199	09S	40E	14	CAA	45.0443	-106.7966	3439.0	DIETZ COAL
PKS-3200	09S	40E	14	CAA	45.0440	-106.7969	3438.0	DIETZ 2 COAL
PKS-3202	09S	40E	14	CAA	45.0451	-106.7981	3438.0	ALLUVIUM (QUATERNARY)
PKS-2061	09S	40E	17	BBD	45.0507	-106.8649	3604.8	ANDERSON-DIETZ 1 COALS COMBINED
WR-55A	09S	40E	19	CBBD	45.0302	-106.8863	3591.1	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WRE-12	09S	40E	23	BCCD	45.0311	-106.8038	3463.2	ANDERSON COAL
WRE-13	09S	40E	23	BCCD	45.0311	-106.8044	3462.6	DIETZ COAL
PKS-1179	09S	40E	23	CBBB	45.0313	-106.8067	3458.0	DIETZ 2 COAL
WRE-16	09S	40E	24	AACB	45.0352	-106.7697	3550.5	ANDERSON COAL
WRE-17	09S	40E	24	AACD	45.0347	-106.7683	3561.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WRE-18	09S	40E	24	AACD	45.0347	-106.7683	3573.1	ANDERSON COAL
WRE-20	09S	40E	24	ABAB	45.0369	-106.7716	3519.4	ANDERSON COAL
WRE-21	09S	40E	24	ABAB	45.0386	-106.7730	3529.4	ANDERSON COAL
WRE-19	09S	40E	24	ABBA	45.0369	-106.7736	3520.3	ANDERSON COAL
WR-17A	09S	40E	29	BBAC	45.0216	-106.8641	3573.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-17B	09S	40E	29	BBAC	45.0216	-106.8641	3574.7	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-51A	09S	40E	29	BDCB	45.0186	-106.8622	3541.3	ANDERSON-DIETZ 1 AND 2 OVERBURDEN
WR-52C	09S	40E	29	CABC	45.0164	-106.8629	3530.0	ALLUVIUM (QUATERNARY)
WR-52D	09S	40E	29	CABD	45.0164	-106.8616	3529.3	ALLUVIUM (QUATERNARY)
WR-52B	09S	40E	29	CACB	45.0150	-106.8627	3525.0	ALLUVIUM (QUATERNARY)
WR-52A	09S	40E	29	CBDA	45.0147	-106.8636	3520.0	ALLUVIUM (QUATERNARY)
WR-52F	09S	40E	29	CBDC	45.0144	-106.8644	3520.0	ALLUVIUM (QUATERNARY)

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana (continued)

Site designation	Well Depth (ft below land surface)	Water level (ft)	Date of water level measurement	Well discharge (gpm)	Hydraulic conductivity (ft/day)	GWIC No.
WR-31	316.0	185.36	12/14/2003	2.0		130476
WR-30	428.0	202.32	12/14/2003	5.0		132908
WR-33	165.0	51.85	12/14/2003		48	8441
WR-32	171.0	101.80	12/14/2003	2.0		184196
WR-34	522.0	264.13	12/14/2003			132909
WR-45	64.0	10.58	12/14/2003	30.0	70.2	8446
WR-44	64.0	8.90	12/14/2003	30.0	46.6	8447
WR-41	40.0	15.89	12/14/2003	1.0		186195
WRE-01	80.0	36.62	12/5/2003			8454
WRE-02	79.0	37.18	12/5/2003			132910
WRE-09	232.0	210.09	12/5/2003		0.5	8500
WRE-10	183.0	172.99	12/5/2003		1.1	8501
WRE-11	127.0	94.62	12/5/2003		0.9	8504
PKS-3201	390.0	79.88	12/5/2003	50.0		163658
PKS-3198	112.0	83.63	12/5/2003	2.0		163659
PKS-3199	165.0	117.63	12/5/2003	20.0		163660
PKS-3200	242.0	163.06	12/5/2003	20.0		163661
PKS-3202	60.0	37.32	12/5/2003	5.0		163662
PKS-2061	244.0	232.89	12/5/2003	3.0		106228
WR-55A	72.0	46.21	12/13/2003			8651
WRE-12	172.0	106.54	12/3/2003		0.7	8687
WRE-13	206.0	117.59	12/3/2003		8.7	8692
PKS-1179	282.0	138.92	12/3/2003	5.0		132973
WRE-16	458.0	66.47	12/3/2003		1	8698
WRE-17	250.0	68.82	12/3/2003		1.6	132959
WRE-18	445.0	89.06	12/3/2003			121669
WRE-20	120.0	106.27	12/5/2003			122767
WRE-21	130.0	112.64	12/5/2003			132958
WRE-19	140.0	107.39	12/5/2003			123797
WR-17A	88.0	20.93	12/13/2003			123796
WR-17B	160.0	76.89	12/13/2003			8706
WR-51A	187.0	28.97	12/13/2003		0.7	8709
WR-52C	62.0	18.27	12/13/2003	20.0	438	132960
WR-52D	40.0	22.34	12/12/2003	1.0		132961
WR-52B	55.0	11.98	12/13/2003	59.7	295.3	8710
WR-52A	57.0	4.03	11/7/2003	80.0	114.5	8712
WR-52F	46.0	5.13	12/13/2003	54.8	91.3	8713

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana

Site designation	Township	Range	Section	Tract	Latitude	Longitude	Land surface altitude (ft)	Aquifer
WRE-24	09S	41E	5	DCCA	45.0688	-106.7333	3552.1	DIETZ COAL
WRE-25	09S	41E	5	DCCA	45.0683	-106.7333	3549.4	ANDERSON COAL
WRE-26	09S	41E	8	BBDA	45.0646	-106.7413	3478.3	ALLUVIUM (QUATERNARY)
WRE-27	09S	41E	8	CABC	45.0586	-106.7391	3523.8	ANDERSON COAL
WRE-28	09S	41E	8	CABC	45.0586	-106.7391	3525.2	DIETZ COAL
WRE-29	09S	41E	8	CBAD	45.0586	-106.7411	3523.3	DIETZ 2 COAL
HWC-39	09S	43E	12	ADBD	45.0713	-106.4004	3591.0	ALLUVIUM (QUATERNARY)
HWC-17	09S	43E	13	BCAA	45.0575	-106.4141	3610.0	ANDERSON COAL
HWC-6	09S	43E	13	CAAA	45.0536	-106.4093	3626.0	DIETZ COAL
HWC-11	09S	43E	21	BADA	45.0444	-106.4687	3615.0	ANDERSON COAL
HWC-10	09S	43E	21	BADA	45.0444	-106.4687	3610.0	DIETZ COAL
HWC-15	09S	43E	22	ACCA	45.0408	-106.4456	3600.0	ANDERSON COAL
HWC-16	09S	43E	27	DABB	45.0247	-106.4427	3665.0	ANDERSON COAL
CC-24	09S	43E	7	CADB	45.0663	-106.5122	3656.0	ANDERSON COAL
HWC-24	09S	44E	6	BBBB	45.0872	-106.3974	3720.0	DIETZ COAL
HWC-29B	09S	44E	7	BBCC	45.0688	-106.3969	3620.0	ANDERSON COAL
HWC-26	09S	44E	8	BBAA	45.0716	-106.3695	3675.0	ANDERSON COAL
UOP-09	09S	46E	11	BBAB	45.0721	-106.0571	3929.0	CANYON COAL
UOP-10	09S	46E	11	BBAB	45.0721	-106.0572	3930.0	CANYON COAL OVERBURDEN
CBM03-13OC	09S	46E	11	BBBA	45.0722	-106.0572	3931.0	OTTER COAL
AMAX-110	09S	46E	8	BACC	45.0699	-106.1153	3967.0	DIETZ COAL
BF-01	37N	63E	22	ACCC	44.9897	-106.9667	3680.0	COAL MINE SPOILS
WR-39	37N	63E	23	ABBC	44.9952	-106.9555	3666.0	ANDERSON-DIETZ 1 AND 2 COALS
WR-48	37N	63E	23	BBCB	44.9933	-106.9650	3693.8	ANDERSON COAL

Appendix B. Completion and water-level data for monitoring sites in the coalbed methane area of the Powder River Basin, Montana (continued)

Site designation	Well Depth (ft below land surface)	Water level (ft)	Date of water level measurement	Well discharge (gpm)	Hydraulic conductivity (ft/day)	GWIC No.
WRE-24	154.0	68.08	12/5/2003	20.0		130475
WRE-25	114.5	63.63	12/5/2003			123795
WRE-26	35.0	13.06	12/5/2003			132967
WRE-27	77.0	47.90	12/5/2003	0.5		8721
WRE-28	153.0	66.13	12/5/2003			8723
WRE-29	217.0	129.82	12/5/2003			8726
HWC-39	39.0	25.71	12/12/2003			189838
HWC-17	82.0	52.32	12/12/2003	6.9	1.4	8778
HWC-6	151.6	70.81	12/12/2003			198465
HWC-11	135.0	53.35	11/7/2003	8.0		190904
HWC-10	229.0	96.12	12/12/2003			190902
HWC-15	129.0	31.41	12/12/2003	10.0	10.8	8782
HWC-16	375.0	60.21	12/12/2003	5.0	0.7	8786
CC-24	222.0	90.41	12/12/2003	2.8	0.07	8771
HWC-24	201.0	180.47	12/12/2003			189703
HWC-29B	92.0	45.92	12/12/2003		0.3	8796
HWC-26	110.0	58.06	12/12/2003	4.6	6.4	8797
UOP-09	261.5	157.91	12/12/2003	0.8	0.2	8846
UOP-10	207.3	143.29	12/12/2003	4.4	0.3	8847
CBM03-13OC	500.0	347.84	12/12/2003	1.5		203710
AMAX-110	240.0	171.09	12/12/2003	1.5	4	8835
BF-01	125.0	152.67	10/7/2003			161749
WR-39	312.0	142.42	12/14/2003		0.36	122770
WR-48	167.0	49.87	12/14/2003		47.6	132716

Appendix C.

Spring inventory data

Appendix C. Spring inventory data for U.S. Bureau of Land Management lands, 2003 field season.

Spring Name	Township	Range	Section	Tract	GWIC ID	Longitude	Latitude	Altitude (feet)	USGS Quadrangle	Inventory Date
FORTUNE SPRING	04S	45E	24	DBDB	207254	45.4746	-106.1194	3240	YAGER BUTTE	10/01/03
MORELAND SPRING	05S	42E	30	CCBB	207249	45.37	-106.6051	3900	BIRNEY	10/04/03
UNNAMED SPRING	05S	48E	10	ACAA	207256	45.415	-105.7835	3790	SONNETTE	10/01/03
BREWSTER RANCH	06S	41E	1	DCCA	207241	45.3389	-106.6539	3580	BIRNEY SW	10/05/03
BREWSTER SPRING 2	06S	42E	6	ABAC	207243	45.3508	-106.6296	3740	BIRNEY SW	10/04/03
BREWSTER SPRING	06S	42E	6	BBDD	207245	45.3483	-106.6397	3880	BIRNEY SW	10/04/03
MAJOR RENO SPRING	06S	42E	8	CACB	207242	45.3287	-106.6166	3590	BIRNEY	10/05/03
CANYON CREEK SPRING	07S	41E	7	CAAB	207233	45.2441	-106.7614	3600	TONGUE RIVER DAM	10/05/03
COX RANCH - PASS SPRING	07S	42E	30	DAAA	207252	45.1989	-106.6258	3780	SPRING GULCH	10/02/03
FEEBACK SPRING	08S	43E	9	ABCC	207250	45.1606	-106.4689	3600	STROUD CREEK	10/02/03
DECKER SPRING	08S	45E	13	DAAA	207255	45.1378	-106.142	3700	OTTER	10/01/03
44 MAGNUM	09S	41E	34	CBAB	207253	45.0012	-106.7017	4040	HOLMES RANCH	10/02/03

Appendix C. Spring inventory data for U.S. Bureau of Land Management lands, 2003 field season.

Spring Name	Dis-charge (gpm)	Discharge Notes	Discharge Method	pH	Temperature (c)	Specific Conductance (umhos/cm^2 @ 25 C	Source Lithology	Nearest Overlying Coalbed Association	Recharge Origin	Site Status
FORTUNE SPRING	0.77		VOLUMETRIC	6.8	13.5	5620	ALLUVIUM	PAWNEE	REGIONAL	DEVELOPED
MORELAND SPRING	0.14		VOLUMETRIC	6.6		1440	SANDSTONE	DIETZ	LOCAL	DEVELOPED
UNNAMED SPRING	0.22		VOLUMETRIC	6.7	15.7	2504	COLLUVIUM	COOK	LOCAL	DEVELOPED
BREWSTER RANCH		DRY					SANDSTONE	CANYON	LOCAL	NOT MAINTAINED
BREWSTER SPRING 2		NO FLOW					SANDSTONE	DIETZ	LOCAL	UNDEVELOPED
BREWSTER SPRING		NO FLOW					SANDSTONE	DIETZ	LOCAL	DEVELOPED
MAJOR RENO SPRING	0.05		VOLUMETRIC	7.3	11.8	3534	SANDSTONE	CANYON	LOCAL	NOT MAINTAINED
CANYON CREEK SPRING		NO FLOW					SANDSTONE	CANYON	LOCAL	DEVELOPED
COX RANCH - PASS SPRING		NO FLOW						ANDERSON	LOCAL	
FEEBACK SPRING		NO FLOW					SANDSTONE	DIETZ	MIXED	NOT MAINTAINED
DECKER SPRING	< 0.01		ESTIMATED	6.7		3886	ALLUVIUM	DIETZ	LOCAL	DEVELOPED
44 MAGNUM		NO FLOW					COAL	WASATCH	LOCAL	

Appendix D.

Water quality data for wells completed in coal, sandstone and alluvium

Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Gwic Id	Aquifer	Lab	Date	Water Temperature (C)	Lab Specific Conductance	Lab pH	Sodium Adsorption Ratio	Calculated Dissolved Solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)
HC-01	207143	Alluvium	MBMG	09/22/81	10.0	3200	7.6	5.2	2464	150.0	180.0	400
RBC-2	207066	Alluvium	MBMG	12/22/03		958	7.5	0.9	572	69.0	65.4	41
RBC-3	207068	Alluvium	MBMG	12/22/03	8.5	1003	7.5	1.1	657	74.5	70.8	53
WCY-44	207086	Alluvium		08/08/84		1420	7.5	1.1	1666	68.0	164.0	72
WR-44	8447	Alluvium	MBMG	10/21/92	10.5	1880	8.3	1.7	1389	113.0	152.0	116
WR-45	8446	Alluvium	MBMG	10/27/77	9.5	2009	7.9	1.6	1545	100.0	194.0	120
WR-52A	8712	Alluvium	MBMG	10/23/79	9.0	5626	7.9	5.3	5633	320.0	525.0	658
WR-52B	8710	Alluvium	MBMG	10/26/79	9.0	6165	7.9	4.7	6058	325.0	631.0	633
WR-52D	132961	Alluvium	MBMG	10/02/01	11.9	6280	7.3	5.9	6836	335.0	625.0	795
WR-52F	8713	Alluvium	MBMG	10/25/79	9.0	5949	7.8	6.0	5896	307.0	543.0	751
WR-56	8652	Alluvium	MBMG	06/24/97		2920	8.3	5.8	2897	106.4	243.4	470
WR-58	8412	Alluvium	MBMG	06/22/93		1701	7.9	1.4	1313	108.0	155.0	96
WR-58B	8414	Alluvium	MBMG	03/11/80	1.0	3402	8.1	4.4	2947	176.0	261.0	391
WR-58D	8413	Alluvium	MBMG	03/13/80	9.0	3412	8.2	4.2	2576	148.0	229.0	347
WR-59	122766	Alluvium	MBMG	06/21/93	9.0	4900	7.5	5.6	5609	251.0	547.0	686
WRE-01	8454	Alluvium	MBMG	10/29/87	1.0	3861	8.0	6.5	2974	190.0	167.0	509
BF-01	161749	Mine Spoils	MBMG	06/25/97	9.0	3180	8.4	9.6	2634	116.3	144.4	656
WR-33	8441	Anderson-Dietz clinker	MBMG	06/21/93	12.0	2550	7.3	1.3	2373	211.0	277.0	122
WR-17A	123796	Anderson overburden	MBMG	10/03/01	12.7	4430	7.7	14.2	3514	50.7	154.0	898
WR-17B	8706	Anderson overburden	MBMG	09/01/77		4915	7.8	43.7	3363	34.1	19.0	1285
WR-22A	130472	Anderson overburden	MBMG	10/27/92	12.5	3150	8.5	46.0	2490	13.8	9.4	905
WR-51A	8709	Anderson overburden	MBMG	06/26/91		2422	9.0	34.3	1660	7.3	11.1	630
WR-53A	8430	Anderson overburden	MBMG	05/06/86	11.0	2409	8.0	68.9	1460	3.8	1.4	618
WR-54A	8428	Anderson overburden	MBMG	05/06/86	12.0	2599	8.2	71.1	1588	4.4	1.4	669
WR-55A	8651	Anderson overburden	MBMG	06/23/93		6550	7.5	75.2	5831	54.0	2.5	2082
WRE-17	132959	Anderson overburden	MBMG	10/11/01	13.2	2660	8.2	52.7	1690	7.4	3.7	705
CC-24	8771	Anderson coal	MBMG	05/06/86	12.5	2538	7.7	52.9	1527	5.5	3.4	640
FC-01	8140	Anderson coal	MBMG	06/16/81	14.5	6471	8.0	45.1	4417	38.8	22.4	1424
HWC-15	8782	Anderson coal	MBMG	05/07/86	11.0	2273	7.8	50.6	1399	5.1	3.2	592
HWC-16	8786	Anderson coal	MBMG	09/13/77	12.2	2118	8.0	46.4	1343	5.6	3.3	560
HWC-17	8778	Anderson coal	MBMG	04/19/77	12.0	2498	7.5	11.5	2945	98.8	117.0	715
HWC-26	8797	Anderson coal	MBMG	04/28/77	12.5	4841	7.6	11.1	3819	177.0	180.0	875
HWC-29B	8796	Anderson coal	MBMG	05/06/86	11.0	9621	7.1	12.8	8788	472.0	486.0	1660
WR-20	8419	Anderson coal	MBMG	06/23/93		1579	8.1	40.2	1023	4.0	2.5	416
WR-31	130476	Anderson coal	MBMG	10/22/92	14.0	3840	8.4	46.7	2869	17.5	10.8	1008

Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Silica (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (SO4)	Chloride (mg/L)	Nitrate (mg/L)	Flouride (mg/L)	Ortho Phosphate (mg/L)
HC-01	10.0			0.80	630		1400	13.0		0.8	
RBC-2	8.6	1.63	0.21	27.70	548		86	3.3	<0.5	0.4	<0.X25
RBC-3	6.8	0.05	0.08	20.70	574		146	2.9	<0.5	0.7	<0.05
WCY-44	9.3	<0.05	0.48		503	614.0	487	4.1		0.4	
WR-44	18.5	1.90	0.58	28.40	588	13.2	650	6.3	<0.25	1.1	<0.2
WR-45	22.0	2.49	0.38	29.00	691		727	10.0	<.1	1.3	
WR-52A	26.8	0.08	1.57	29.00	777		3675	15.7	<.1	0.8	
WR-52B	28.6	0.02	2.05	25.10	707		4050	15.7	<.1	0.8	
WR-52D	29.1	5.66	2.58	29.90	730		4655	<25.0	30.4	5.9	<2.5
WR-52F	26.5	0.02	1.32	27.60	803		3825	20.0	<.1	0.7	
WR-56	16.2	<.003	0.59	22.90	704	24.0	1667	<50.0	<1.2		<5
WR-58	10.7	0.04	0.56	26.00	624		600	10.0	<.05	0.8	<.3
WR-58B	13.5	<.01	<.01	19.00	634		1760	15.2	2.0	0.6	
WR-58D	11.0	0.06	0.01	16.80	598		1515	15.4	2.5	0.6	
WR-59	29.3	2.13	0.84	24.10	691		3700	28.5	<.1	0.8	<1.
WRE-01	13.4	0.01	0.01	21.10	461		1830	16.6	0.8	0.6	<.1
BF-01	15.5	0.52	0.57	14.66	1208	27.6	1064	<50.0	<1.2		<5.
WR-33	25.1	0.04	0.13	30.90	581		1409	12.1	2.2	0.9	<.3
WR-17A	13.3	0.85	0.09	9.68	950		1890	30.5	32.5	<2.5	<2.5
WR-17B	11.9	0.10	0.02	11.30	2993		510	20.0	<.1	0.3	
WR-22A	8.6	0.08	0.02	3.10	1512	117.0	675	14.4	0.7	1.9	<0.2
WR-51A	6.6	0.75	0.03	14.80	1691	76.8	65	16.2	2.4	1.3	<0.05
WR-53A	3.3	0.02	0.01	8.50	1623		8	19.0	0.1	0.7	<.1
WR-54A	3.9	0.06		9.80	1789		1	18.6	0.1	1.2	0.1
WR-55A	16.0	0.19	0.03	18.40	3094		2100	36.3	<.2	0.7	<1.
WRE-17	4.9	0.01	<.01	7.46	1923		<25	15.8	19.9	4.2	<.5
CC-24	3.8	0.14		9.00	1718		1	18.9	0.1	1.6	<.1
FC-01	22.2	0.03	0.12	9.50	1270		2252	23.8	0.1	1.4	
HWC-15	3.4	0.05		9.30	1562		<.5	18.3	<.1	1.6	<.1
HWC-16	4.1	0.05	<.01	9.90	1508		1	17.0	<.1	0.4	
HWC-17	10.0	0.02	0.02	10.70	694		1636	16.0	<.1	0.6	
HWC-26	12.3	0.03	0.02	14.10	1402		1832	39.5	0.2	0.6	
HWC-29B	17.1	0.64	0.23	12.80	1074		5590	21.1	0.2	3.3	<.1
WR-20	4.5	0.05		9.90	1070		53	6.8	<.02	3.7	<.113
WR-31	10.0	0.01		8.10	1220	72.0	1134	8.7	<0.25	2.5	<0.20

Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Gwic Id	Aquifer	Lab	Date	Water Temperature (C)	Lab Specific Conductance	Lab pH	Sodium Adsorption Ratio	Calculated Dissolved Solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)
WR-48	132716	Anderson coal	MBMG	06/23/97	12.5	2230	8.3	45.2	1566	6.9	3.8	594
WRE-11	8504	Anderson coal	MBMG	10/23/92		2470	8.6	46.7	1607	8.7	4.2	670
WRE-12	8687	Anderson coal	MBMG	10/30/87		2056	7.8	32.0	1247	9.3	6.2	514
WRE-16	8698	Anderson coal	MBMG	02/28/75		2878	8.1	42.0	1873	12.0	6.6	730
WRE-18	121669	Anderson coal	MBMG	10/10/01	13.5	2590	7.9	44.7	1723	9.1	5.3	686
WRE-19	123797	Anderson coal	MBMG	06/25/97	11.5	4470	8.2	19.4	4339	132.6	94.2	1196
WRE-20	122767	Anderson coal	MBMG	06/27/91	11.4	5254	8.2	18.8	4037	126.0	81.8	1100
WRE-27	8721	Anderson coal	MBMG	11/20/76		2833	7.9	39.5	1848	11.9	10.0	765
WR-26	8434	Anderson-Dietz coal	MBMG	03/10/76	15.0	3993	8.3	65.1	2763	8.4	6.3	1025
WR-37	8432	Anderson-Dietz coal	MBMG	11/04/77	12.5	1721	8.2	37.9	1186	4.3	3.1	422
WR-39	122770	Anderson-Dietz coal	MBMG	06/27/91	13.3	2011	8.6	49.4	1237	3.6	2.4	493
WR-51	8708	Anderson-Dietz coal	MBMG	10/24/90		2110	8.2	53.0	1406	5.6	2.4	594
WR-54	127605	Anderson-Dietz coal	MBMG	06/12/92	14.5	2780	8.0	47.2	1806	11.2	5.0	756
391	8368	Dietz coal	MBMG	04/25/73		944	8.5	4.4	667	17.6	45.0	154
394	8377	Dietz coal	MBMG	04/24/73	12.0	1600	8.5	39.6	1171	5.6	2.4	445
395	8387	Dietz coal	MBMG	04/24/73	14.0	1370	9.1	52.9	987	3.5	0.2	376
422	8379	Dietz coal	MBMG	06/11/73		2440	8.4	8.4	1877	30.0	113.0	450
AMAX-110	207102	Dietz coal	MBMG	07/22/83	11.0	3700	7.8	32.0	2440	27.0	16.0	850
BC-08	8154	Dietz coal	MBMG	10/13/88	14.0	3123	7.9	51.3	2001	9.6	6.4	837
BC-10	8169	Dietz coal	MBMG	05/31/86	15.5	3063	7.9	54.5	1895	8.0	5.0	798
FC-02	8141	Dietz coal	MBMG	06/16/81	15.5	3371	8.1	19.3	2255	35.1	42.9	720
LBC-36	8011	Dietz coal	MBMG	07/20/83	13.5	3078	8.1	52.5	1993	8.8	6.4	838
WR-19	8417	Dietz coal	MBMG	06/24/97		1456	8.6	48.8	1025	3.8	1.5	444
WR-21	8074	Dietz coal	MBMG	06/24/97		1181	8.5	38.1	703	3.0	1.5	323
WR-22	130470	Dietz coal	MBMG	07/30/96	14.0	1400	7.7	37.3	869	3.4	2.1	355
WR-23	8347	Dietz coal	MBMG	06/26/91		1310	8.5	6.9	839	25.5	37.5	234
WR-38	122769	Dietz coal	MBMG	06/23/97	14.0	2170	8.7	51.2	1267	6.7	2.4	608
WRE-09	8500	Dietz coal	MBMG	06/29/93		1466	7.8	11.3	888	27.1	16.7	303
WRE-10	8501	Dietz coal	MBMG	06/29/93		1085	7.7	4.0	669	47.2	43.3	160
WRE-13	8692	Dietz coal	MBMG	10/30/87		2672	7.8	54.2	1586	6.5	3.1	671
WRE-24	130475	Dietz coal	MBMG	06/29/93	13.5	3230	8.1	76.8	2379	5.9	2.9	912
WRE-28	8723	Dietz coal	MBMG	07/22/77		3784	8.0	80.1	2597	7.0	3.0	1005
WRE-29	8726	Dietz coal	MBMG	07/22/77		2886	8.2	67.9	1854	5.5	2.5	765
BC-07	8192	Canyon overburden	MBMG	10/10/88	13.5	4088	6.9	3.3	3718	294.0	342.0	355
CBM02-7SS	203695	Canyon overburden	MBMG	12/23/03	13.0	1283	8.1	10.4	799	16.3	15.6	244

Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Silica (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (SO4)	Chloride (mg/L)	Nitrate (mg/L)	Flouride (mg/L)	Ortho Phosphate (mg/L)
WR-48	4.9	<.003	<.002	9.00	970		471	<50.0	<1.2		<5.
WRE-11	5.2	0.07	0.09	8.00	1597	104.4	<40.	20.9	0.8	2.3	<.2
WRE-12	5.4	0.24	0.03	7.90	1405		3	9.5	<.1	1.4	0.1
WRE-16	6.8	0.01	0.03	8.50	1567		317	22.0	<.1	1.4	
WRE-18	5.5	0.06	0.02	9.92	1931		40	17.5	<0.5	2.9	<.5
WRE-19	12.3	<.003	0.03	12.20	925		2437	<50.0	2.7		<5.
WRE-20	11.2	0.02	0.04	11.80	898		2240	24.7	3.1	0.6	<0.05
WRE-27	8.2	0.30	0.03	12.50	2016		17	32.0	<.1	2.5	
WR-26	8.3	0.12	<.01	10.40	1758		830	10.0	<.1	2.9	
WR-37	5.3	0.44	0.01	51.80	712		343	6.0	0.2	2.1	
WR-39	4.1	0.01	0.01	8.50	986	52.8	175	12.9	1.0	4.7	0.1
WR-51	4.6	0.10	0.01	9.44	1560		2	21.0	<.07	2.2	<.1
WR-54	6.4	0.01	0.01	8.70	2000		<1	35.5	<.10	2.4	<.10
391	7.0	<.01	<.01	14.80	351	22.0	230	3.6	1.5	0.8	0.1
394	3.7	0.10	<.01	13.10	771	24.0	294	3.9	1.7	2.1	0.1
395	2.9	0.02	<.01	12.40	569	58.0	249	5.1	1.0	1.2	0.1
422	9.7	<.01	<.01	14.30	654	24.0	907	7.9	1.3	1.4	0.1
AMAX-110	6.3			7.60	1170		940	14.0		1.2	
BC-08	6.2	0.04		8.80	2241		<.5	30.6	0.1	3.1	<.1
BC-10	4.8	0.06		8.80	2106		2	33.1	<.1	2.2	<.1
FC-02	15.3	<.01	0.03	8.90	1156		844	20.4	<.1	2.4	
LBC-36	5.6		0.01	8.70	2157		41	24.1	0.1	3.7	
WR-19	3.7	0.01		9.80	1019	51.6	5	4.1	1.3		<.05
WR-21	5.2	0.02		10.30	683	24.0	<100	<20.0	2.0		<2.
WR-22	3.8	1.70	0.03	17.20	978		<2	5.0	<.05	<1.	
WR-23	9.5	0.07	0.02	12.00	632	26.4	177	5.8	0.2	0.4	<.05
WR-38	5.2	0.02	0.01	10.10	1166	61.2	<250	<50.0	<1.2		<5.
WRE-09	4.9	0.04	0.07	8.00	866		91	11.2	<.05	1.0	<.15
WRE-10	5.4	0.05	0.17	13.90	756		16	10.6	<.1	1.1	<.2
WRE-13	6.1	0.03	0.01	8.80	1790		1	9.2	0.9	0.6	0.2
WRE-24	8.3	0.07	0.01	13.70	1674		586	26.7	<.1	4.4	<.5
WRE-28	8.7	0.33	0.03	15.60	2028		528	32.0	<.1	3.8	
WRE-29	7.6	0.20	0.02	12.70	2016		66	3.0	<.1	3.8	
BC-07	13.6	22.60	0.59	27.60	573		2370	10.7	0.2	0.1	0.1
CBM02-7SS	5.9	0.07	0.02	9.50	505		259	<5.0	<0.5	1.0	<0.5

Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Gwic Id	Aquifer	Lab	Date	Water Temperature (C)	Lab Specific Conductance	Lab pH	Sodium Adsorption Ratio	Calculated Dissolved Solids (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)
HC-24	8118	Canyon overburden	MBMG	09/23/81	12.0	2549	8.1	71.3	1580	3.9	1.7	670
UOP-10	8847	Canyon overburden	MBMG	07/24/83	12.4	1915	8.1	35.5	1210	7.2	4.7	499
BC-06	8191	Canyon coal	MBMG	10/11/88	13.0	2267	7.9	47.2	1416	6.1	3.7	599
CBM02-7CC	203693	Canyon coal	MBMG	12/23/03	11.8	1438	8.2	30.1	941	6.4	2.1	345
HC-23	8117	Canyon coal	MBMG	09/22/81	13.0	2505	8.1	66.3	1557	4.5	1.9	665
HWC-01	8107	Canyon coal	MBMG	05/07/86		2726	7.8	66.1	1637	4.4	2.4	694
UOP-09	8846	Canyon coal	MBMG	07/23/83	13.8	2103	8.0	37.1	1330	8.9	4.8	553
UOP-13	8840	Canyon coal	MBMG	08/05/83	13.2	1971	7.9	39.5	1266	6.9	4.2	533
WR-24	8436	Canyon coal	MBMG	03/09/76	10.5	2653	8.0	42.6	1761	5.0	7.3	638
CBM02-4SS:	203690	Canyon underburden	MBMG	12/24/03	10.3	1008	7.7	1.0	666	77.4	68.3	51
20-LW	191139	Wall coal	MBMG	07/07/79	26.0	2700	8.0	9.1	1939	50.0	99.0	480
28-W	191163	Wall coal	USGS	10/18/78	13.5	3600	7.8	69.9	2484	8.4	2.7	910
77-26	7755	Knobloch coal	MBMG	10/27/80	14.0	3024	8.0	25.2	2017	32.1	13.7	676

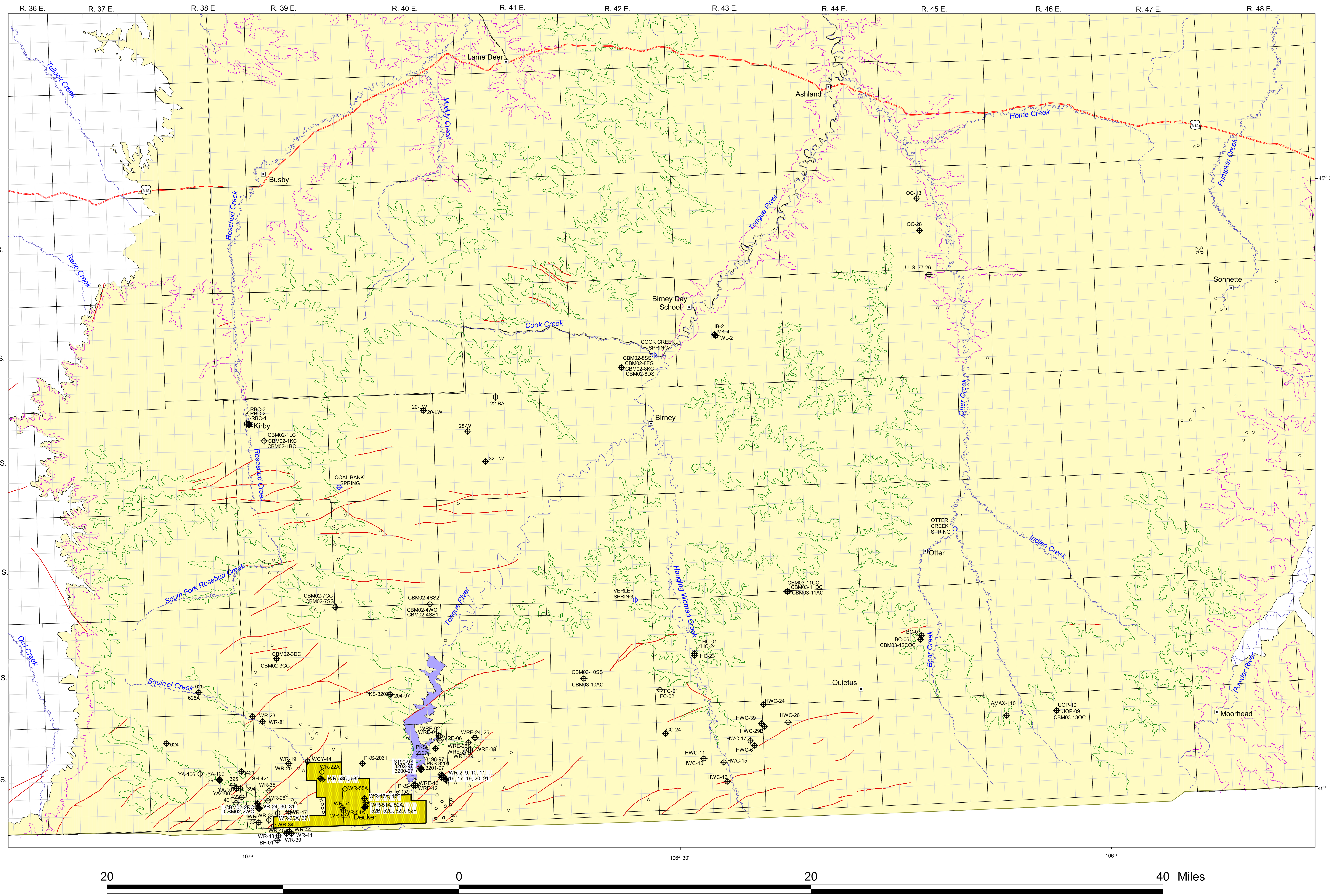
Appendix D. Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Site Name	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Silica (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Sulfate (SO4)	Chloride (mg/L)	Nitrate (mg/L)	Flouride (mg/L)	Ortho Phosphate (mg/L)
HC-24	2.9	0.01		8.00	1757		4	25.4	<.01	4.9	
UOP-10	3.4	<.002		8.80	1349		11	12.6	1.2	1.3	
BC-06	3.7	0.10		8.40	1577		<.5	19.0	<.1	2.2	<.1
CBM02-7CC	4.2	0.02	0.03	6.97	647		258	<5.0	<0.5	3.1	<0.5
HC-23	2.7	0.06		8.90	1725		3	22.8	0.1	4.0	
HWC-01	4.0	0.18		9.60	1825		3	21.9	0.1	3.4	<1.
UOP-09	3.8	<.002	0.01	8.00	1497		1	14.0	0.1	1.4	
UOP-13	3.6	<.002	0.00	8.10	1414		1	13.6	<.1	1.9	
WR-24	5.8	0.18	<.01	8.30	926		630	11.7	<.1	1.7	
CBM02-4SS:	10.6	0.43	0.03	17.10	415		231	6.7	<0.5	1.0	<0.05
20-LW	8.0	0.02		16.00	680		940	5.7	0.2	5.2	
28-W	6.0	0.05		8.00	890		1100	11.0	<.1	3.0	
77-26	5.7	0.03	0.03	9.60	1089		720	24.3	<.1	1.0	

Appendix D
Major chemical constituents for selected coal monitoring wells in the Powder River Basin

Well designation	Aquifer	Sampling date	On-site Specific conductance (umhos/cm @ 2d C)	On-site pH	CDS (1)	SAR (2)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
										0				

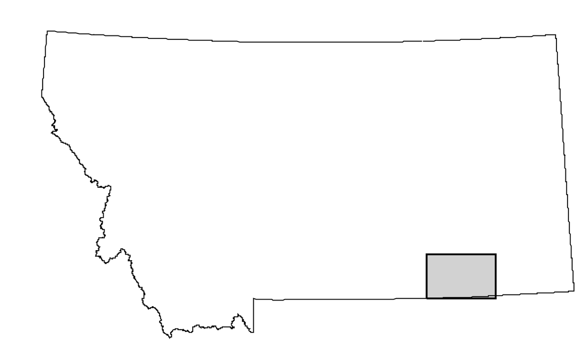
MBMG 508
Plate 1. Locations of monitoring sites and Anderson and Knobloch coal outcrop.



Explanation

- Monitor well
- Monitor spring
- Non-producing CBM wells or permits for drilling http://bogc.dnrc.state.mt.us/OnlineData.htm
- Anderson coalbed outcrop (Van Voast and Thale, 2001)
- Knobloch coalbed outcrop (Van Voast and Thale, 2001
- Reservation boundary
- Faults
- Area with current CBM production in Montana. (Fidelity Exploration and Production Company 2002 Annual Groundwater Monitoring Report)
- Undifferentiated Wasatch Formation and Tongue River Member of the Fort Union Formation (dashed where inferred). Modified from MBMG Open-File reports 291, 369, 370, 425, 426, 428 429, 431, 432.

Montana Bureau of Mines and Geology
Since 1919
Earth Science Information



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MBMG 508

Plate 2. otentiometric surface and water quality for the Dietz coal bed in the southern portion of the Powder River Basin, Montana.

Potentiometric surface
In ranges 37 and 38 east, modified from Hedges and others, 1976. Dashed where inferred.

Well name, water-level altitude (ft) December, 2003 data

Mine Pit areas

Anderson coal outcrop

Knobloch coal outcrop

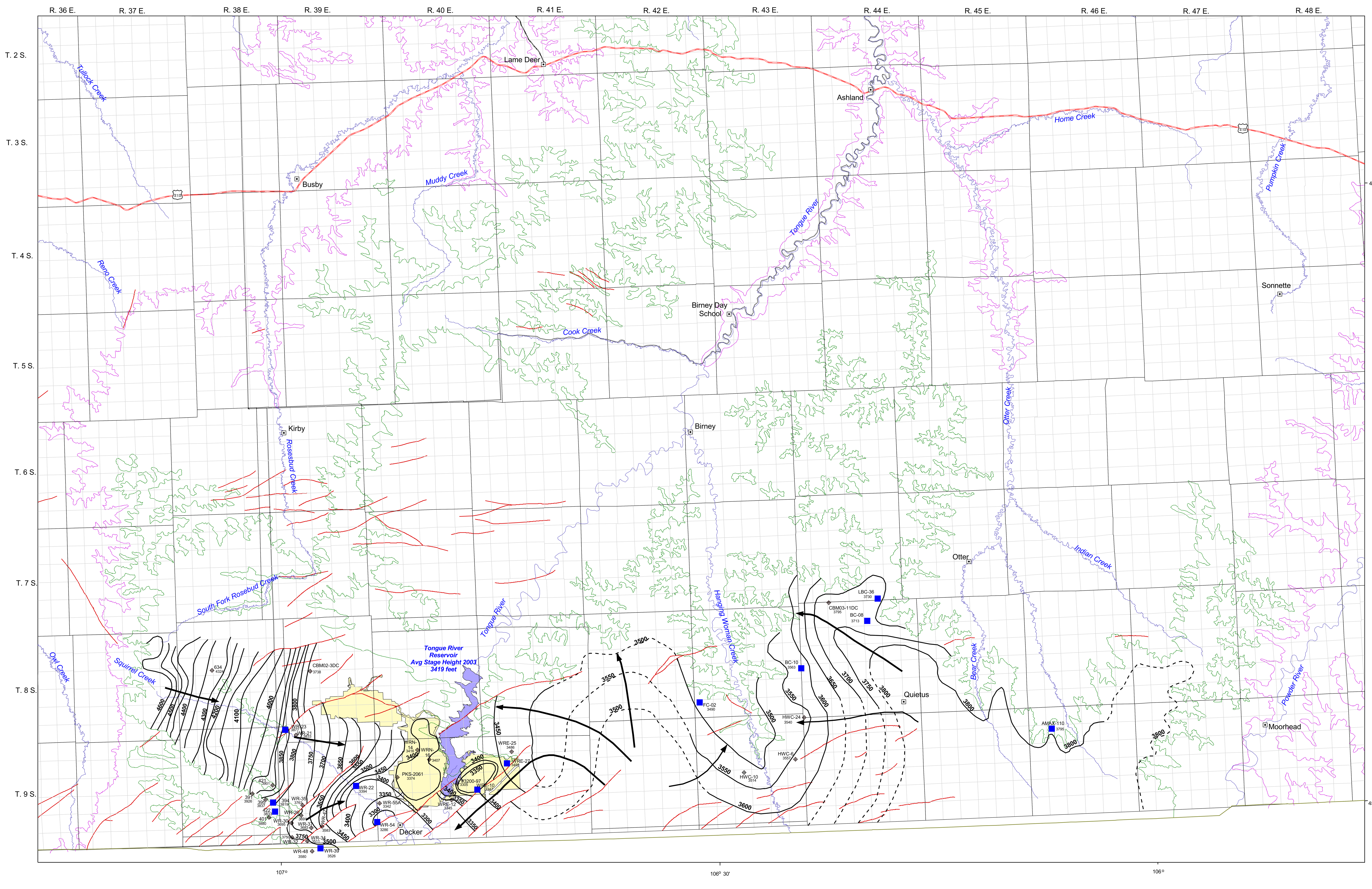
Reservation boundary

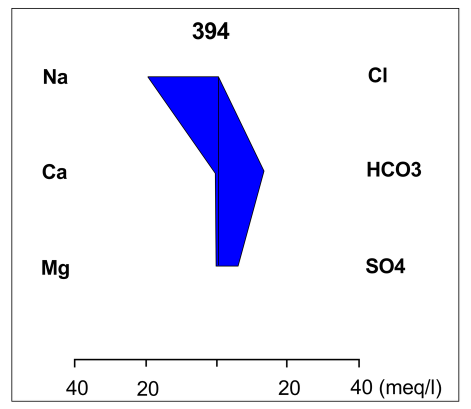
Fault

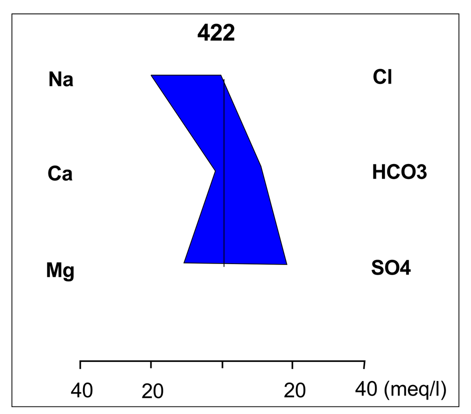
Mine permit area

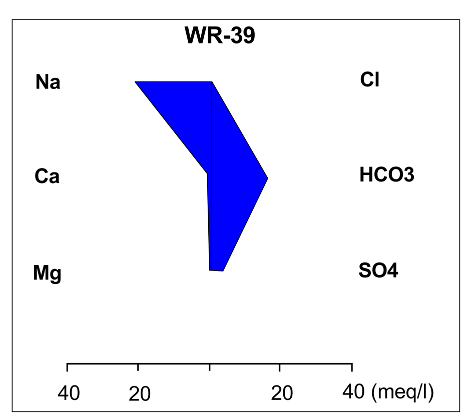
Groundwater flow lines

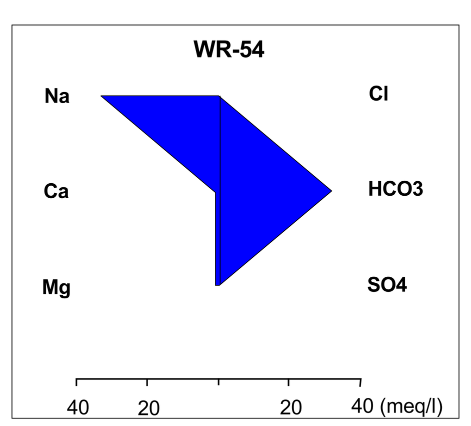
Stiff diagram associated with site

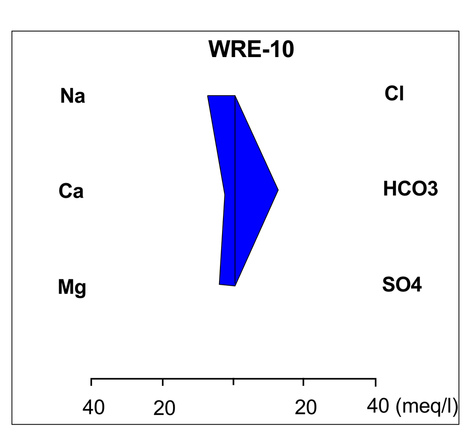


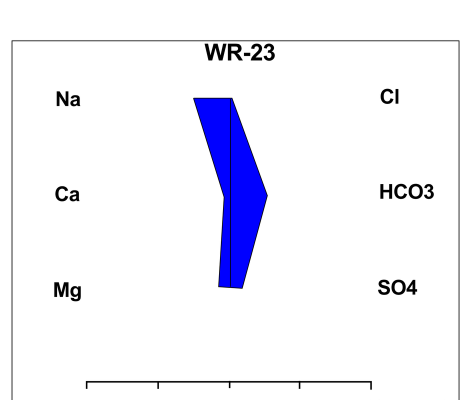


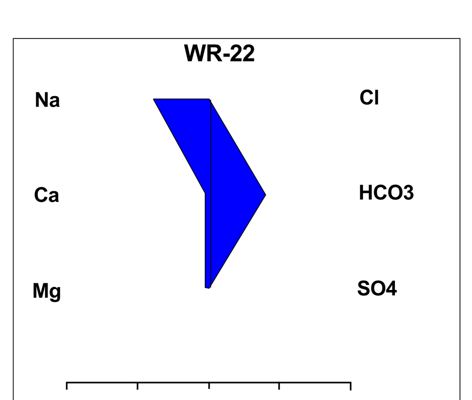


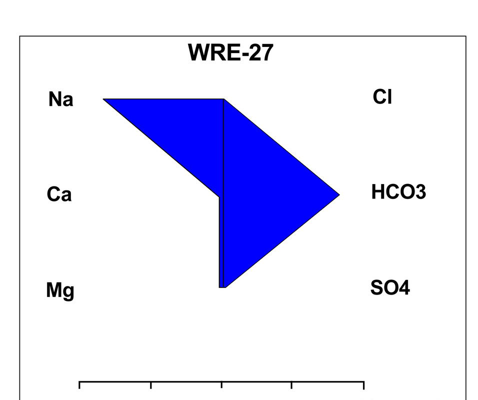


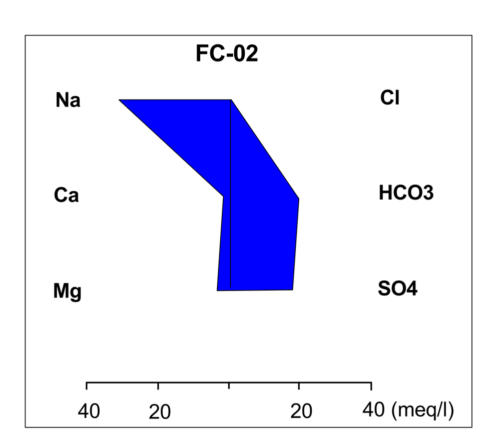


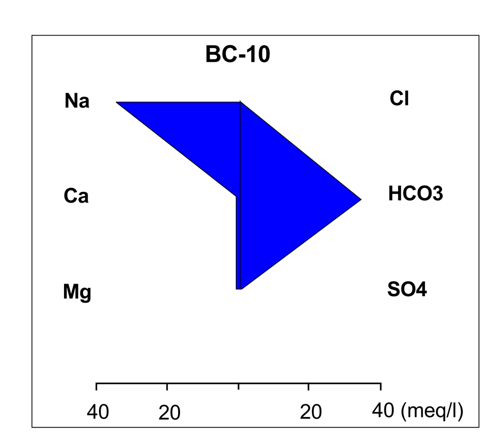


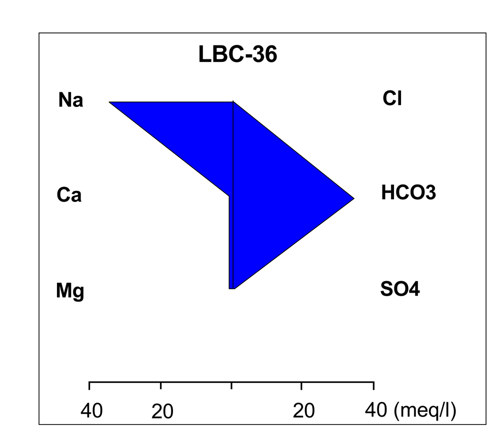


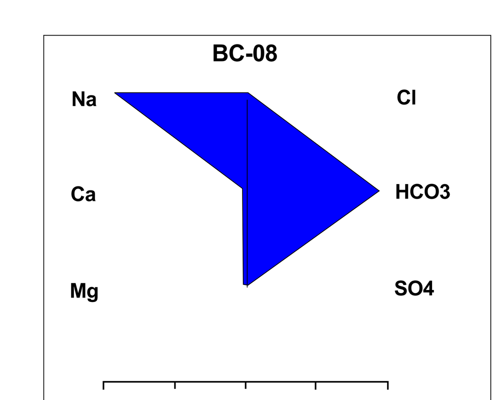


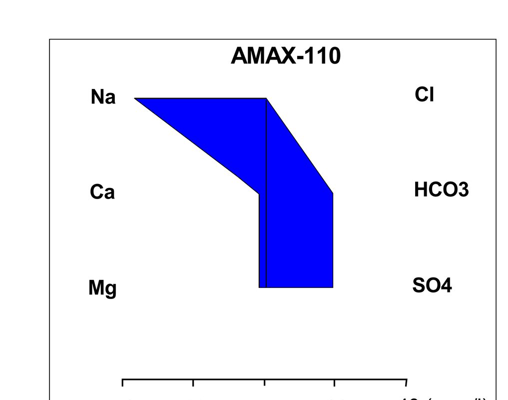


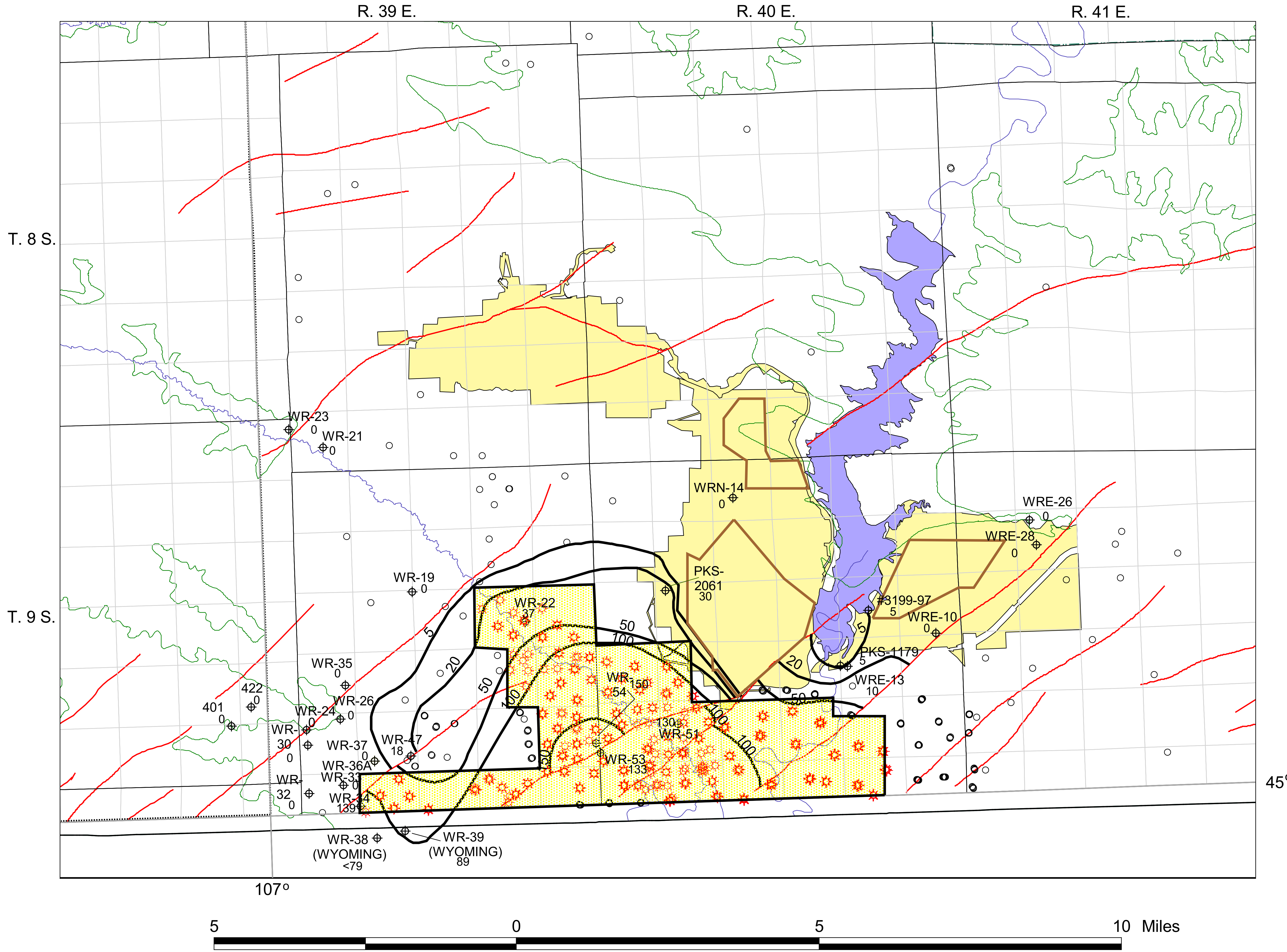












MBMG 508
Plate 3. Area of potentiometric decline for the Dietz coal bed in the CX coalbed methane gas field.

Explanation

Producing coalbed methane well (Data from Montana Oil and Gas Commission)

Non-producing coalbed methane well (includes permit to drill, abandoned and unapproved, shut-in, spudded, completed, and expired permit)

WR-53 133 Monitoring well Change in water level due to CBM production in feet (as of December, 2003)

Drawdown related to CBM production (ft)

Anderson coal outcrop

Reservation boundary

Faults

Mine permit area

Mine pit boundary

Area with current CBM production in Montana. (Fidelity Exploration and Production Company 2002 Annual Groundwater Monitoring Report)

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