2004 Annual
Coalbed Methane Regional Ground-Water Monitoring Report:
Montana Portion of the Powder River Basin

OPEN-FILE REPORT 528

John Wheaton
Teresa Donato
Shawn Reddish
Licette Hammer

Montana Bureau of Mines and Geology

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Abstract

This report presents data and interpretations from 2004, the second year in which Montana coalbed-methane (CBM) regional ground-water monitoring network has been fully active. The network was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to determine actual ground-water impacts and recovery, to dispel rumors of impacts, and to provide data and interpretations to aid environmental analysis and permitting decisions. Detailed discussions of the regional ground-water systems were presented in the first annual report (Wheaton and Donato, 2004). The current network consists of a combination of pre-existing monitoring wells installed during the late 1970’s and early 1980’s in response to actual and potential coal mining; and recently installed wells specific to CBM impacts. New monitoring wells continue to be added to the network.

Methane (natural gas) production from coal beds is a potentially important industry in Montana. One operator has been producing from one CBM field (the CX field, Plate 1) in Montana since October, 1999. This field now includes about 600 wells, of which about 439 produced methane, water or both during 2004. Twenty CBM wells were drilled during 2004. A total of 12.2 million MCF of CBM were produced in Montana during 2004.

Coalbed methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing the water pressure allows the methane to desorb from the surfaces in the coal. Water pressure is reduced by pumping ground water from the coal aquifers. Ground water is typically pumped at a rate that reduces the water pressure (head) within the coal bed to a few feet above the top of the coal. Production of CBM requires that water pressure in the coal aquifers be reduced across large areas. The extraction and subsequent management of CBM production water has raised concerns about potential for loss of stock and domestic water supplies due to ground-water drawdown, and impacts to surface-water quality and soils.

The dissolved constituents of water in methane-prospective coal beds in the Powder River Basin (PRB) of Montana are dominated by ions of sodium and bicarbonate. Across the Montana portion of the PRB, sodium adsorption ratios in CBM production water will likely be between 35 and 47, with total dissolved solids concentrations between 900 and 1,400 mg/L. Sulfate concentrations in production water will be very low. This production water is typically 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 content.

Water levels in monitored coal seams have been lowered as much as 150 feet or more within areas of production. After 5 years of CBM production, the 20-foot drawdown contour extends about 1 mile beyond the edges of the CBM field, which is somewhat less than originally predicted. The distance to the 20-foot drawdown contour will increase as the duration of production increases. 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. Less drawdown will occur at greater distances, and drawdown of 10 feet was predicted to reach as far as 5 to 10 miles beyond production fields after 20 years (Wheaton and Metesh, 2002). 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 mainly be determined 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 is the only method to determine the actual magnitude and duration of impacts. These monitoring data and interpretations are key for making informed development decisions and for determining the true causes of observed changes in ground-water availability.

Introduction

This report presents data and interpretations for 2004, the second year in which the Montana regional coalbed methane ground-water monitoring network has been active. This program was initiated to document baseline hydrogeologic conditions in current and prospective coalbed methane (CBM) areas in southeastern Montana, to quantify ground-water impacts and lack of impacts, ground-water recovery, and to provide data and interpretations for use in environmental and permitting decisions. Additional background is presented in Wheaton and Donato (2004). Future reports are anticipated to be released early each spring during the project.

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. Knowledge of baseline conditions and solid understanding of the ground-water systems are critical to guide water-quality and water-resource decisions. This report is one step in the process of providing objective scientific data concerning actual impacts to the ground-water systems CBM development in the Powder River Basin in southeastern Montana.

This report includes: 1) a description of ground-water conditions outside of CBM production areas, which provides an overview of normal variations due to weather, helps improve our understanding of the ground-water regime in southeastern MT and provides water quality information for planning CBM projects; and 2) a description of ground-water conditions within and near areas where CBM is or has been produced, which shows actual impacts from CBM production. The area covered by the CBM regional ground-water monitoring network is shown on Figure 1 and Plate 1.

Coalbed methane and production-water data used in this report were retrieved from the Montana Board of Oil and Gas Conservation (MBOGC) web page (http://www.bogc.dnrc.state.mt.us/). All hydrogeologic monitoring data presented in this report, and additional data, are available from the Montana Ground-Water Information Center (GWIC). To access data stored in GWIC, connect to http://mbmggwic.mtech.edu/. On the first visit to GWIC, select the option to create a login account. Users may access CBM related data by clicking on the picture of a CBM well head. Users may also login in to GWIC by entering the userid and selecting a purpose and then select the option “MBMG Projects” from near the top of the page. On the “MBMG Projects” page, scroll down to the subsection titled “Coal and Coalbed Methane Projects.” Choose the project and type of data by clicking on the appropriate button. For supported browsers, data can be copied and pasted from GWIC to a spreadsheet.

One operator (Fidelity Exploration and Production) has been producing from the CX field (Plate 1) in Montana since September, 1999. Based on data from the Montana Board of Oil and Gas Conservation web page (http://www..bogc.dnrc.state.mt.us/), this field near Decker now includes about 600 wells. Of those wells, 504 are listed as producing and actual gas or water production during 2004 is listed for 439 wells. Twenty new CBM wells were drilled during 2004.

Powder River Gas, LLC is developing its Coal Creek field north of the Tongue River Dam. Coalbed-methane-water production from the Coal Creek field began in April, 2005, so is not included in this reporting period. Methane and water production in the Coal Creek field is expected from Wall and Flowers-Goodale coals in T8S, R41E, sections 6 and 7. As of this writing, 59 permits have been issued and 15 wells drilled (MBOGC web page).

Acknowledgments

The landowners and coalbed methane produces who have allowed drilling and installation of monitoring wells on their land and leases, and those that are allowing monitoring access are gratefully thanked for their cooperation in this project. Funding for the current and much previous work has been provided by the U. S. Bureau of Land Management and the Montana Department of Natural Resources. The U. S. D. A. Forest Service is providing funding in support of monitoring on the Custer Ranger District. The Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal hydrologeology work.

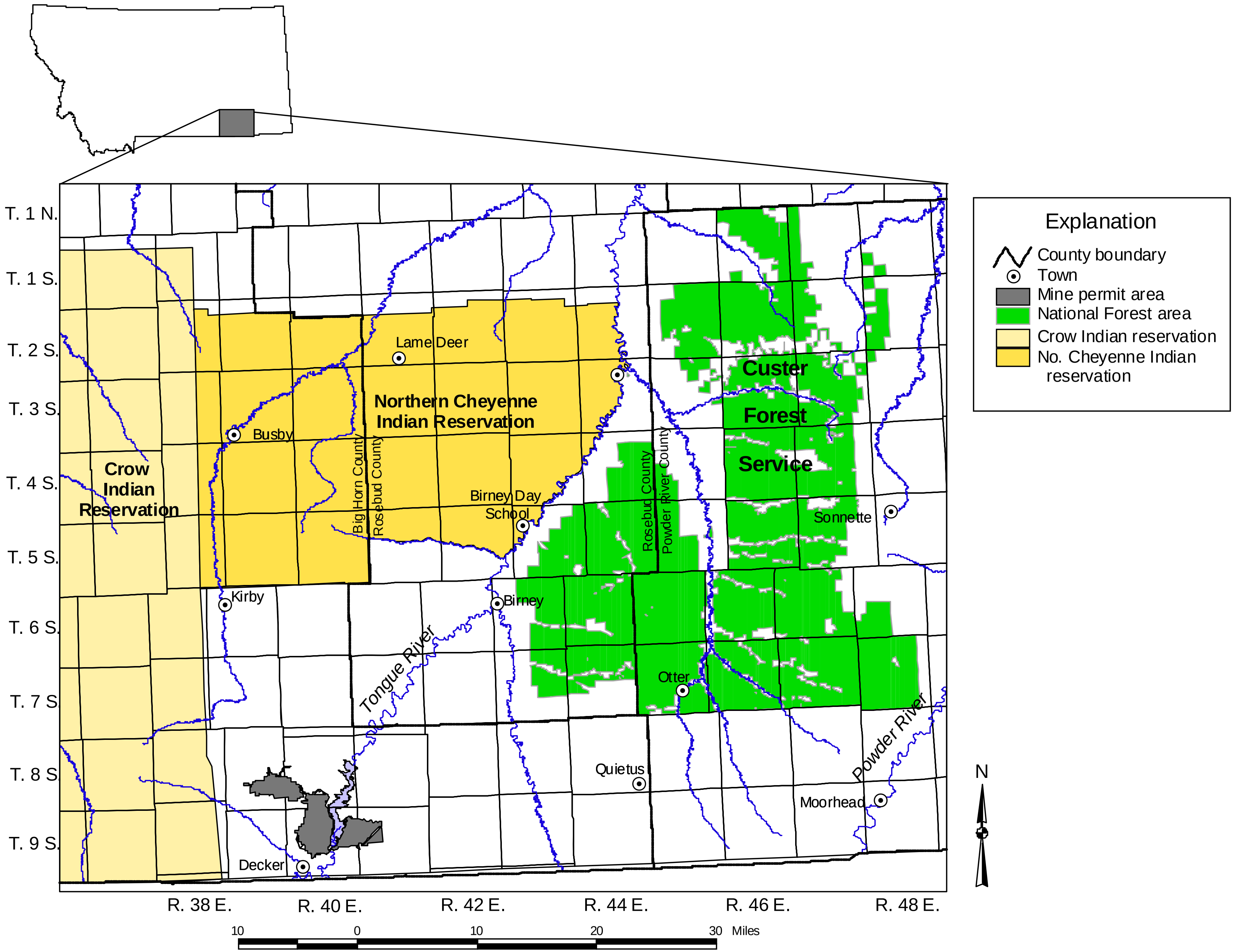


Figure 1. Location of study area.

Location and description of area

The study area 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. The area is shown on Figure 1 and Plate 1.

This area is semi-arid, receiving on average less than 15 inches of precipitation per year. May and June are the wettest months and November through March the driest. Greatest monthly snowfalls occur from November through April. The annual average high temperature is in the low 60º F range with July and August being the warmest. Annual average low temperature is about 30º F with December and January being the coolest months.

Aquifers are recharged by precipitation and shallow ground-water levels reflect both short- and long-term precipitation patterns. Due to the size of the study area two meteorological stations, one at Decker on the west and one at Moorehead to the east, were selected to represent precipitation. Meteorological data from the weather station at Decker from 1958 through 2004 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). During 2004, Decker received 8.87 inches of precipitation, about 25% less than normal (Figure 2A). On the east edge of the study area at Moorehead, average total annual precipitation is 12.3 inches, based on records from 1950 through 2004. During 2004, Moorhead received 8 inches of precipitation, which is 35% below normal (Figure 2B). 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 2A and 2B). The moisture gains through the 1970's, and the shortage of moisture since then are particularly evident in the Decker records (Figure 2A). 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.

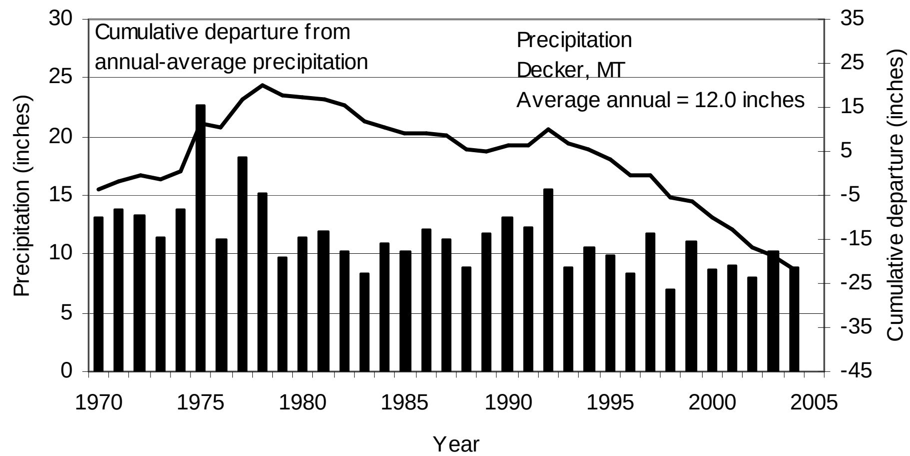


Figure 2A

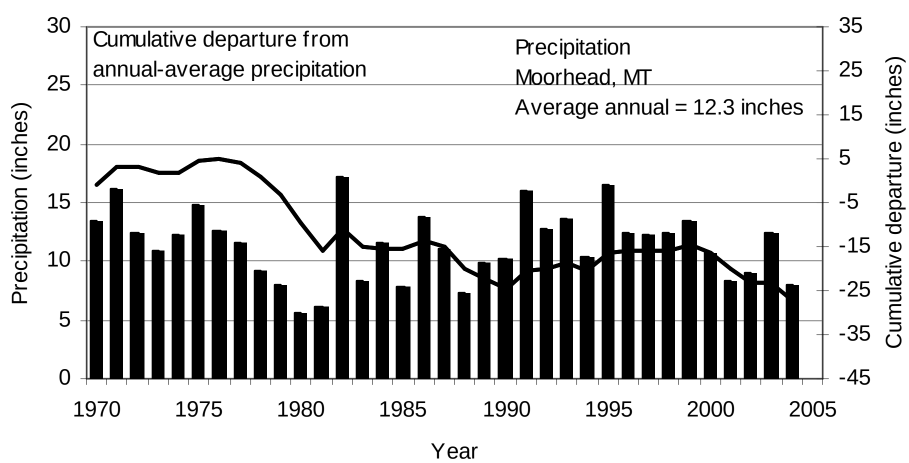


Figure 2B

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. In 2004 the Decker station received about 25% less than average while the Moorhead station received about 35% less than average.

The Powder River Basin (PRB) is a geologic structure in southeast Montana and northeast Wyoming. The Tertiary Fort Union Formation and the overlying Wasatch Formation are the dominant bedrock exposures. Both formations consist of sandstone, siltstone, shale and coal units. The Fort Union Formation is divided from, top to bottom, into the Tongue River, Lebo Shale and Tullock Members. The coal beds in the Tongue River Member are the primary targets for CBM development in Montana. Several of these coal beds merge together or split across the basin. Clastic units were deposited by streams carrying sediments off the surrounding uplifted areas. The extensive coal beds formed as a result of peat bogs on alluvial plains. Cole and others (1980) suggest that the accumulation of 1.5 to 2 feet of peat requires about 100 years. About 20 feet of peat is needed to form 6 feet of sub-bituminous coal, and therefore the formation of a 25-foot thick coal seam requires over 80 feet of peat accumulated over 4,500 to 5,000 years.

Modern streams in Montana have formed valleys that cut through the entire coal-bearing Tongue River Member. Coal seams are exposed 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, McLellan and others, 1990; Law and others, 1979; Fort Union Coal Assessment Team, 1999). A generalized stratigraphic column is presented in Figure 3. Not all coal seams shown on Figure 3 are present across the entire basin; however, the figure indicates relative stratigraphic position. The Anderson and Dietz coal seams are mined near Decker. CBM is produced from those seams as well as the Canyon and Carney seams. Generally, the coal zones between and including the Anderson and Knobloch coal seams are considered the most likely prospects for CBM in southeastern Montana (Van Voast and Thale, 2001). Ground-water monitoring wells are completed in numerous coal beds and overburden and underburden sandstone units. The monitored intervals are indicated on Figure 3, as are intervals that are the source units for monitored springs. Several sets of nomenclature are used for coal beds in the Decker, Montana area. Table 1 shows the correlation between different naming conventions.

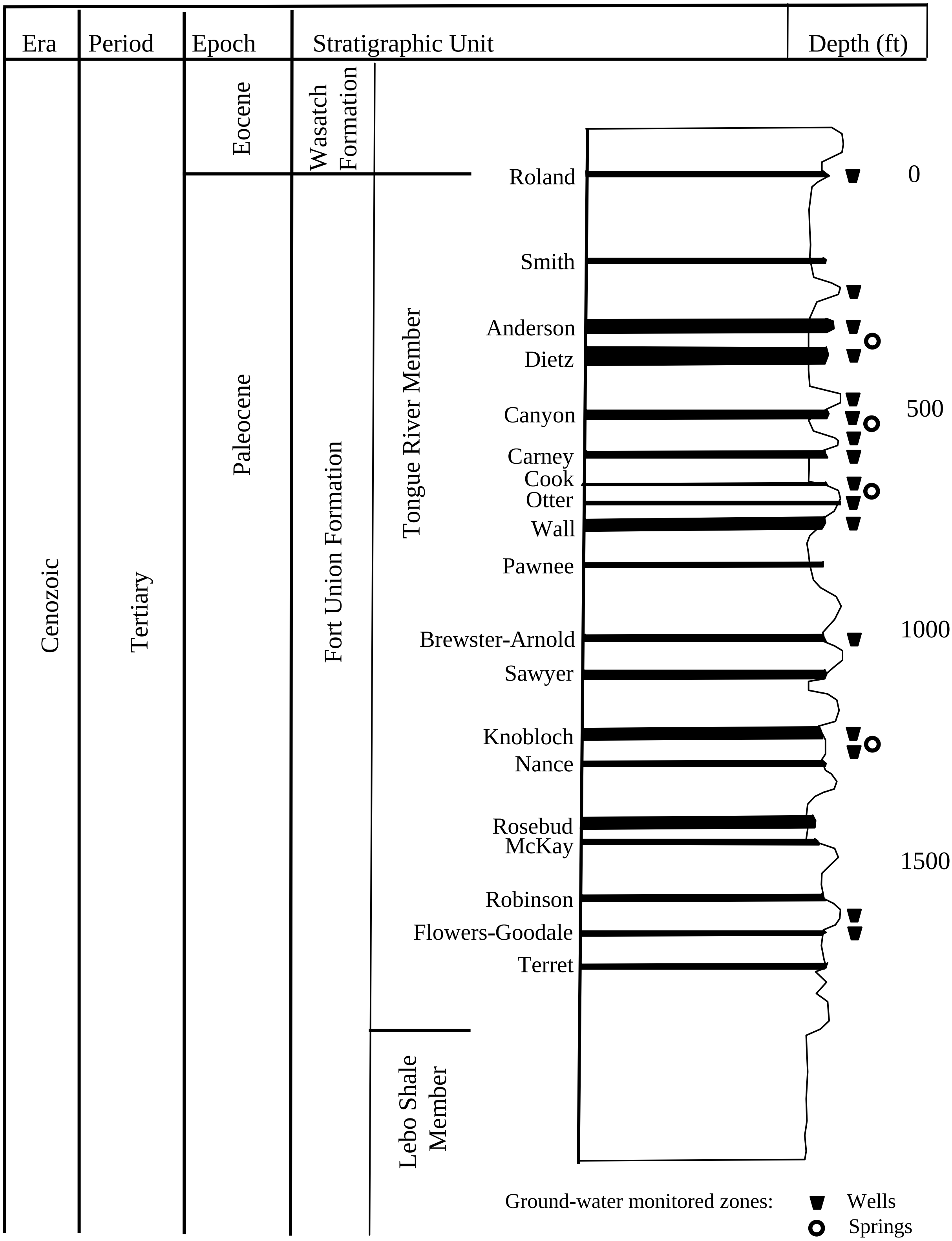


Figure 3. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation. The general relative positions are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Not all coals exist across 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).

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

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

Sources:

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

Ground-water conditions outside of areas of coalbed-methane production and influence

Hydrogeologic data were collected at 138 wells and 24 springs during 2004. Completion records for two alluvial monitoring wells that were drilled during 2004 are contained in Appendix A. Additional monitoring wells are being drilled during 2005, which will be included in the 2005 annual report. Descriptions of all wells included in the regular monitoring program and the most recent data are listed in Appendix B. Site descriptions for springs and the most recent flow data are listed in Appendix C. Water-quality data collected during 2004 are listed in Appendix D. All data were entered in and are available electronically from GWIC (http://mbmggwic.mtech.edu/).

Three distinct ground-water flow patterns are present in the Powder River Basin: shallow and deep bedrock flow systems, and alluvial aquifers. Locally, recharge along high, clinker-capped ridges produces shallow bedrock flow systems that follow topography. This local recharge either discharges to alluvial aquifers, forms springs at bedrock outcrops or seeps vertically into the deeper bedrock aquifers. Alluvial aquifers consist of unconsolidated sediments in valleys.

Ground-water quality in the Powder River Basin has been well documented. The general chemical characteristics of ground water in different parts of the flow systems and an overview of baseline water quality across the PRB are briefly discussed in Wheaton and Donato (2004). In the Powder River Basin, coalbed methane exists only in reduced zones where the water quality is characterized by ions of Na^+ and HCO_3^- (Van Voast, 2003).

Bedrock aquifers

Bedrock aquifer water levels and flow

In deeper bedrock units, ground-water flows from Wyoming northward toward the Yellowstone River. The coal-bearing Tongue River Member is bounded on the bottom by the Lebo Shale aquitard. Limited vertical flow through this aquitard presumably forces most ground water in the Tongue River Member to discharge along crop lines south of the Yellowstone River, adding baseflow to streams, and supporting springs. In terms of coalbed methane development, the Lebo Shale effectively limits likely impacts of dewatering coal seams and infiltration of produced water to those areas lying stratigraphically above this aquitard.

An example of ground-water flow directions in the Dietz coal of the Tongue River Member is shown on Plate 2. Other aquifers should have similar flow patterns;

however, there is less topographic control of flow patterns with increasing depth of the aquifer. Aquifers that have not been impacted by coal mining or CBM production will not have the distinct drawdown areas that are apparent in the Dietz coal near Decker.

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.

In the western part of the study area, recharge occurs in the topographically high areas on the Crow Indian Reservation. Ground water flows to the east, toward the Tongue River, but is interrupted by coal mines and coalbed methane production. The effects of CBM production on the potentiometric surface of the Dietz coal is discussed in the following section of this report.

Water levels in shallow aquifers respond to seasonal variations in precipitation. Deeper aquifers show little if any measurable seasonal changes in water level except for long periods of low or high precipitation. Hydrographs for selected monitoring sites that are outside of potential coalbed-methane impacts are presented in figures 4 through 9.

At monitoring site CBM03-12, data from 1974 through 2003 from an overburden sandstone, the Canyon coal and the Cook coal indicate a downward gradient (Figure 4). In response to long-term regional precipitation trends, water levels in the overburden and Canyon coal have decreased. The long-term precipitation trend for Moorhead is presented on Figure 2B. These wells are located in the eastern part of the study area near Bear Creek.

At site CBM03-11, the Anderson, Dietz and Canyon coals also show a downward gradient, but the record is too short to define a relationship with precipitation trends (Figure 5). This site is in the south-central portion of the monitoring area, near the Anderson coal outcrop.

Two miles west of the Tongue River and about 4 miles north of the Tongue River Dam, at site CBM02-4, water levels in the Canyon underburden, Wall overburden and Wall coal (Figure 6) indicate a downward gradient. The Tongue River altitude near this site is 3320 feet, and therefore shallow ground-water (CBM02-4SS2 and CBM02-SS1) is discharges to the river. The Wall coal is below the river and ground-water flow is probably roughly parallel to the river valley in this area. Powder River Gas, LLC is developing the Coal Creek field about 1.3-miles south of this site. Coalbed-methane-water production began in April, 2005 so was not monitored during this reporting period. Methane and water production is expected from Wall and Flowers-Goodale coal wells in T8S, R41E, sections 6 and 7. A data logger and transducers have been installed at this site to determine the extent of drawdown.

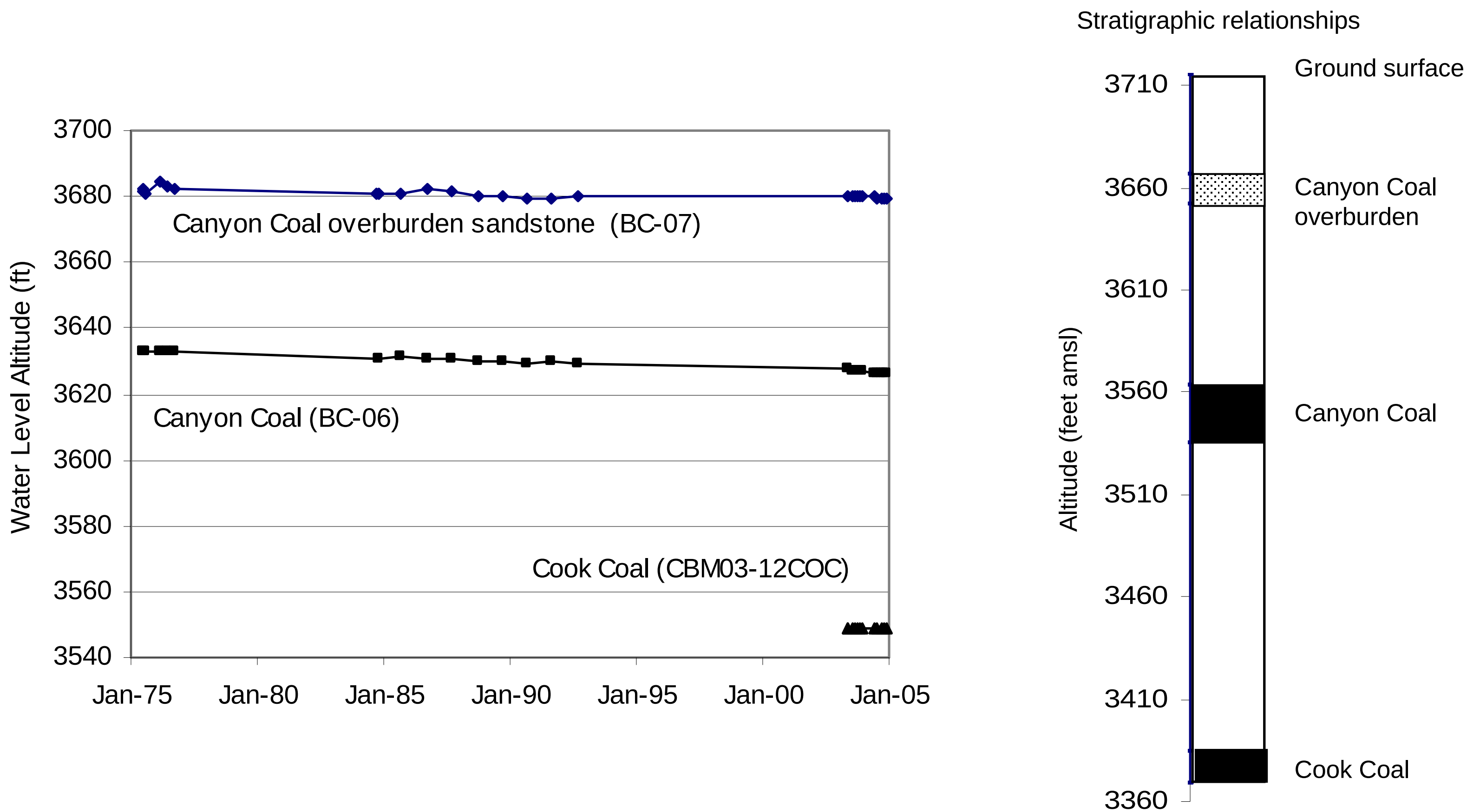


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07 0-43), and Canyon coal (BC-06 0-42), relates to precipitation patterns shown on Figure 2B. The short period of record for the Cook coal (CBM03-12COC) at this site does not indicate meteorological influence.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

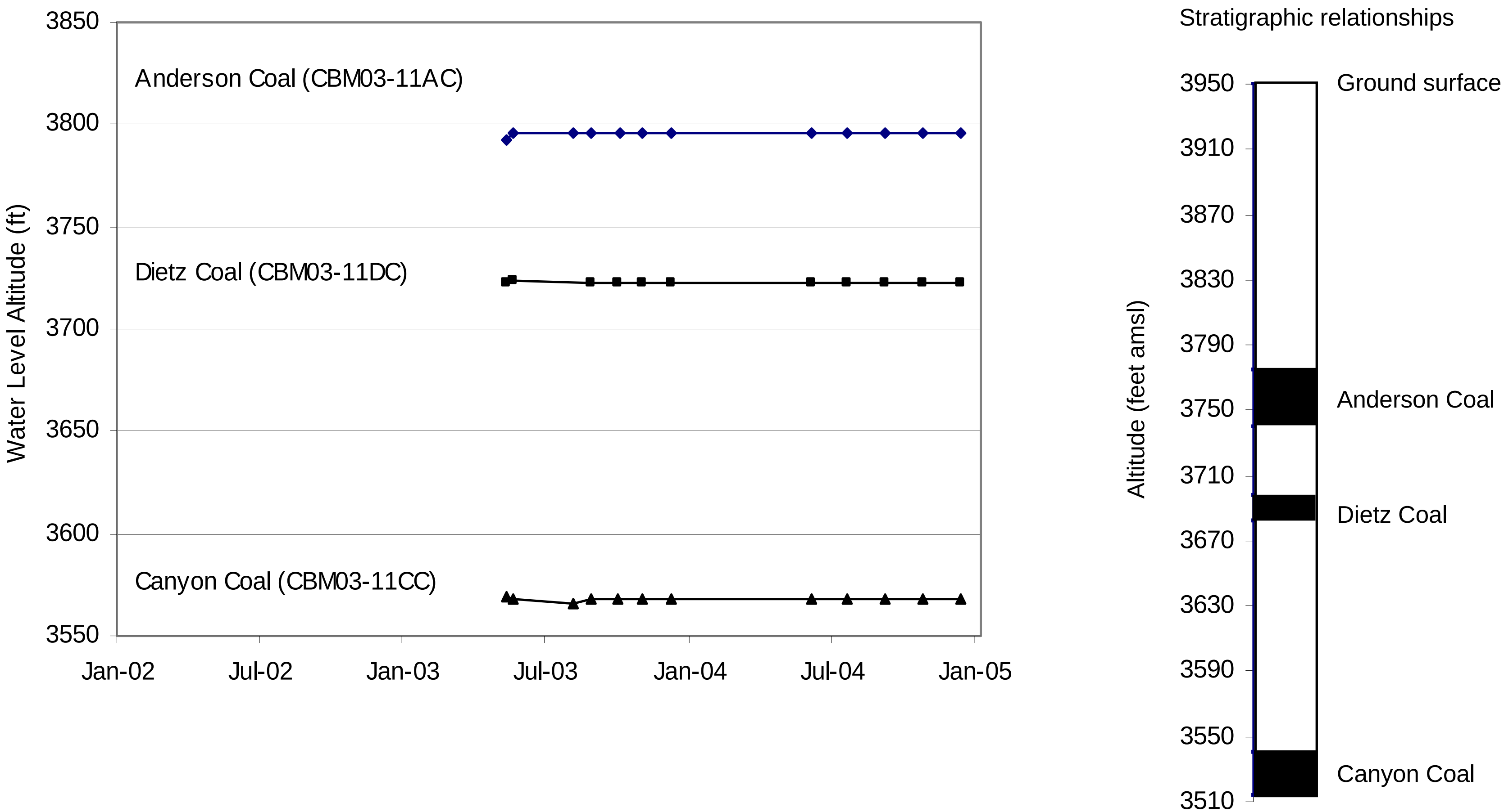
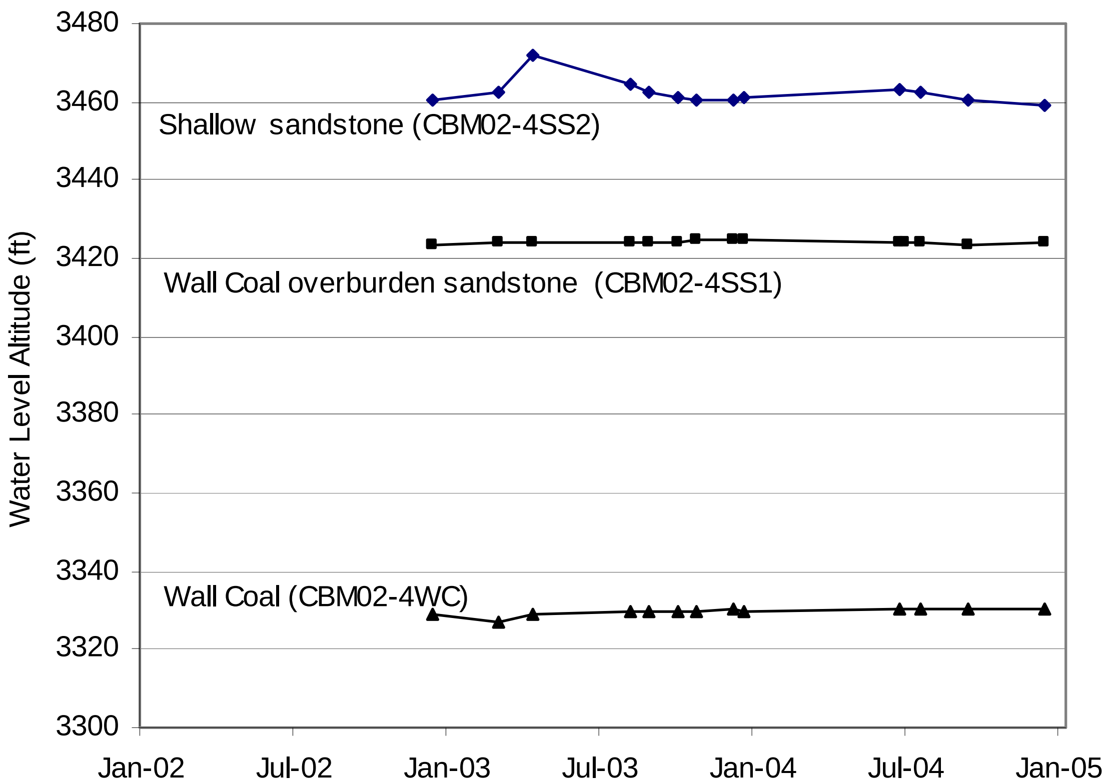


Figure 5. A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.



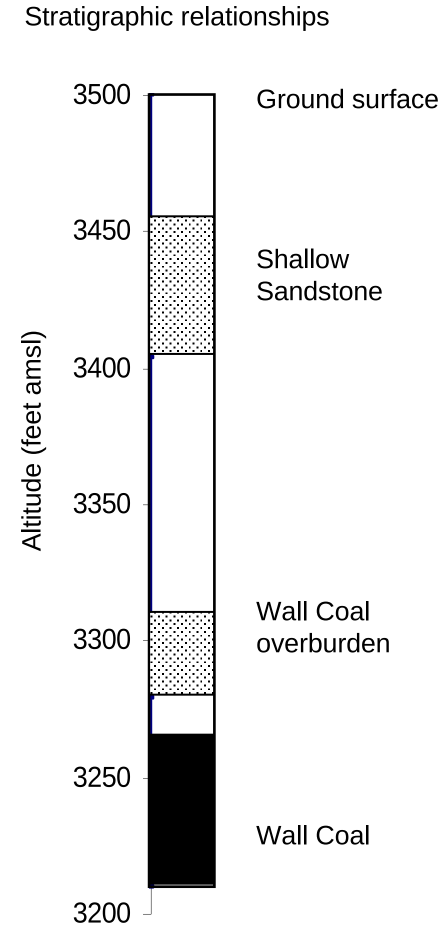


Figure 6. A downward hydraulic gradient is evident between the Canyon underburden sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower sandstone may be.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

Monitoring site CBM02-8 is just west of the Tongue River near the outcrop of the Knobloch coal. Hydrostatic pressures in the Knobloch coal and Knobloch overburden have been reduced by discharge to nearby outcrops in Coal Creek and along the Tongue River. The Knobloch coal may be the source for a large spring near the mouth of Coal Creek, north of this site. Water levels in wells completed in the deeper Flowers-Goodale overburden and Flowers-Goodale coal are higher than those measured in the Knobloch overburden and coal due to the reduced hydrostatic pressure in the shallower units (Figure 7). Several flowing wells exist near Birney, including the town water supply well. These deeper wells flow at ground surface due to the high hydrostatic pressure at depth and the relatively low land surface near the Tongue River.

At monitoring site CBM02-1, near the community of Kirby, just east of Rosebud Creek, a downward gradient exists between the Brewster-Arnold coal, a local unnamed coal and the Knobloch coal (Figure 8). The data do not indicate trends that relate to precipitation patterns and therefore the aquifers appear to be part of a regional ground-water flow system.

Bedrock aquifer water quality

Water quality from sandstone aquifers sampled during 2004 indicate total dissolved solids (TDS) concentrations between 837 and 1,134 mg/L and SAR values between 12 and 65 (Appendix D). Deeper sandstone aquifers have higher concentrations of Na^+ ions and higher SAR values.

Water-quality samples were collected from the Wall, Flowers-Goodale and Knobloch coal seams (Appendix D). Concentrations of TDS ranged from 896 to 1,321 mg/L and SAR values were between 68 and 82. Using criteria developed by Van Voast (2001) sulfate (SO_4^-) concentrations in less than 11 mg/L in 2 coal aquifer samples (Wall and Knobloch) indicate favorable conditions for the presence of CBM (Van Voast, 2001). In the Flowers-Goodale at CBM02-8FG the SO_4^- concentration was 268 mg/L and therefore this coal may not be favorable for CBM near this site. The overlying Knobloch coal seam, monitored at CBM02-8KC, has a SO_4^- concentration of 10 mg/L and does appear to have favorable methane conditions (Wheaton and Donato, 2004).

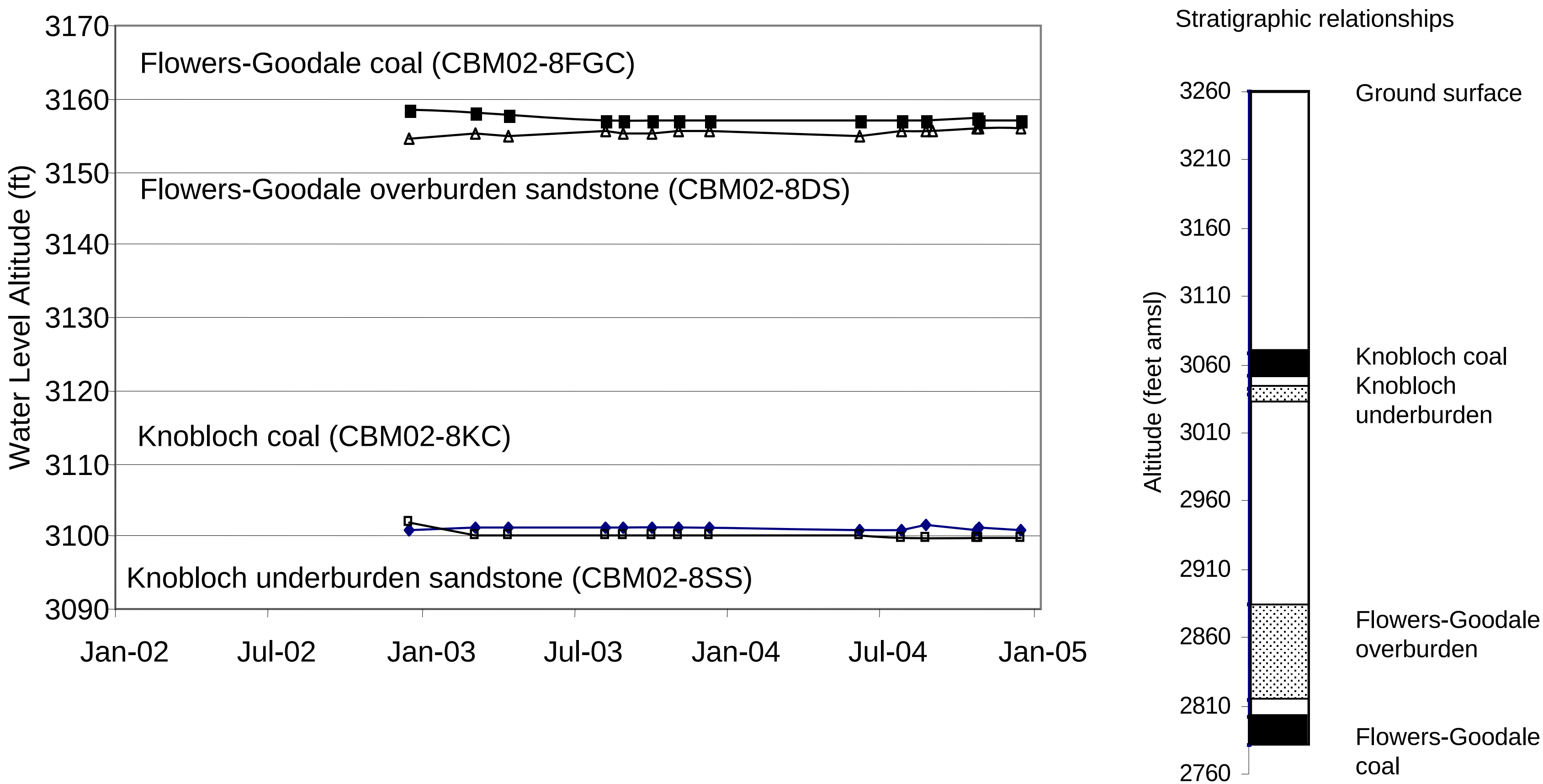
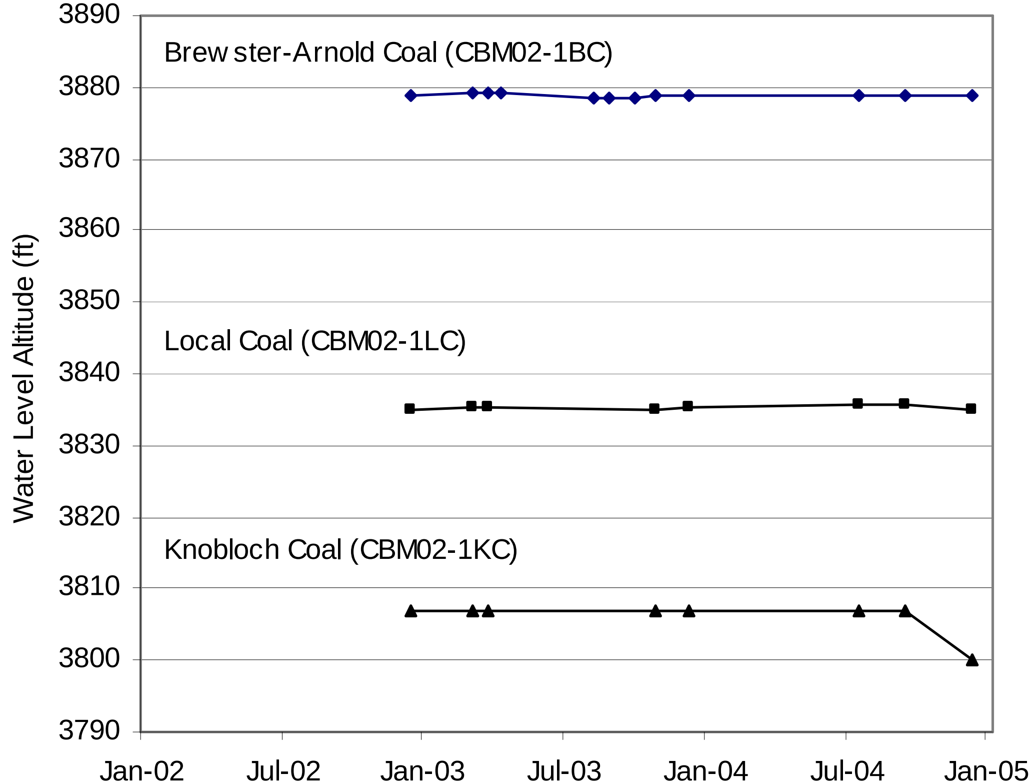


Figure 7. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. Water-level trends are probably not related to meteorological patterns.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.



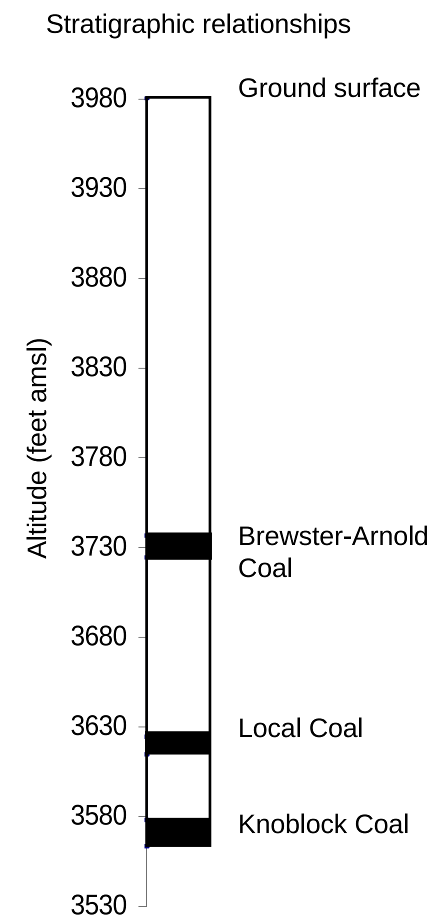


Figure 8. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site. Water-level trends are probably not related to meteorological patterns.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

Alluvial aquifers

Streams associated with alluvial aquifers may be perennial, intermittent, or ephemeral. Generally, perennial streams are in the larger and low lying valleys such as the Tongue River, and streams in the upper-most valleys are ephemeral.

Water levels in Rosebud Creek alluvium, like most alluvial systems, are directly tied to the surface water levels (Figure 9). Flow data for Rosebud Creek are from the U. S. Geological Survey gaging station near Kirby (station number 06295113) and are available from the web site http://waterdata.usgs.gov/mt/nwis/uv?06295113. Well RBC-1 is farther from the creek than is RBC-2. On Figure 9, periods of higher stream flow correspond with higher water-table levels, indicating a close hydrologic connection between the surface and ground water systems. To improve the data set and the ability to correlate stream flow and ground-water levels at this site the Rosebud Conservation District has sponsored a meteorological station and a data logger. The data logger records precipitation, air temperature, ground-water levels, ground-water specific conductance and temperature. These additional data will improve the trend analysis at this site.

Ground-water conditions within areas of coalbed-methane production and influence

Water levels in coal aquifers are lowered during coalbed methane production. The magnitude, distance outside the producing field and duration of the change in water levels is a primary focus of the regional monitoring program. Removal of water during CBM production does not dewater the coal aquifers, rather it reduces the hydrostatic pressure in the aquifer which is reflected in the water levels measured in monitoring wells.

Ground-water quality in coal seams is not expected to change in response to CBM production, and repeat samples are not planned from producing zones. Infiltration of produced water may cause changes in ground-water quality, and in selected locations, water-quality data are collected in shallow aquifers and briefly discussed here. Additional data and discussions of infiltration of CBM-produced water are available in Wheaton and Brown (in press).

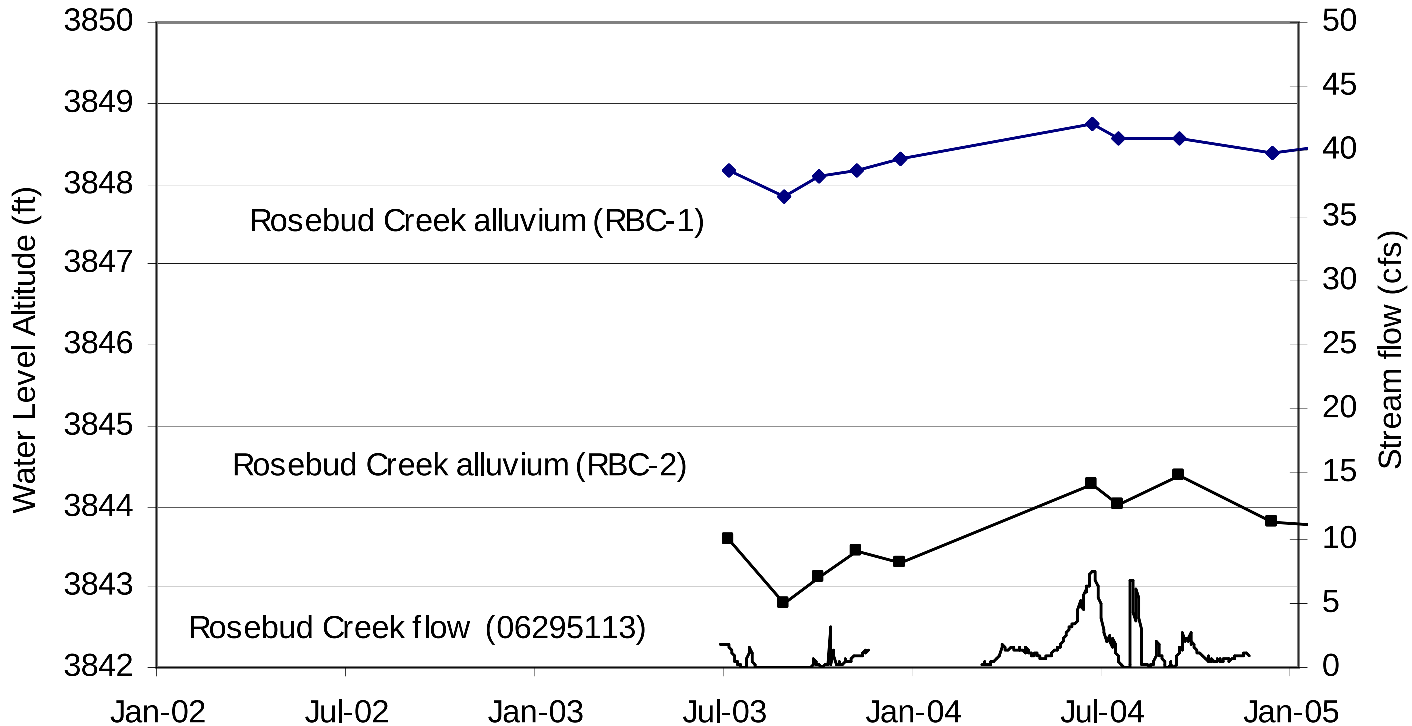


Figure 9. This Rosebud Creek alluvial monitoring site is near Kirby, Montana. Water levels in the alluvial aquifer adjacent to Rosebud Creek follow surface water flow trends, typically higher during wetter times of the year.

Coalbed-methane-water production

Data from CBM production wells were retrieved from the Montana Board of Oil and Gas Conservation web page (http://www..bogc.dnrc.state.mt.us/). During 2004, a total of 439 CBM wells produced either water, gas, or both in the CX field. The number of producing wells and the total gas produced each month during 2004 is shown on Figure 10A. The maximum number of productive wells in any one month was 438 in December.

The average water production per well, and the total water production per month for all wells is shown on Figure 10B. The average water production rate for all wells over the entire year was 3.2 gpm. The highest water production rate for a single well over a one month period was 40.2 gallons per minute (gpm). Cumulative water production per month was least in February at 4.6 x 10^7 gallons and reached the maximum for 2004 in July at 6.4 x 10^7 gallons. The total water production for the year was 67.3 x 10^7 gallons or 9 x 10^7 cubic feet (ft^3).

The CX field covers an area of approximately 19.5 square miles and the area where a total of 20 feet or more of drawdown has occurred is about 26 square miles. Approximately 0.13 cubic feet of water has been removed from each square foot of the area of 20 feet or more drawdown. Drawdown for a confined aquifer is equal to the water removed from a unit area divided by the storativity of the aquifer. Assuming the storativity value for the coal is similar to that of the basin-wide average of 9E-4 (Wheaton and Metesh, 2002, page 7) and that 4 coal seams are producing across the field, the average drawdown for each coal seam is calculated to be 35 feet. Since some of the pumped water would have come from that area outside of the 20-foot drawdown contour, the observed drawdown appears to be roughly in line with that which would be calculated with the given pumping rates.

Average discharge rates per well have been used to predict impacts from CBM development. Wheaton and Metesh (2002) did not address water discharge rates for each year, but expected pumping rates to decline from about 20 gpm to 3 gpm over 20 years. The Montana CBM environmental impact statement (EIS) described an anticipated average per-well-pumping rate of 6.2 gpm in year 6 (U. S. Bureau of Land Management, 2003, page 4-61) Current average discharge rates per well include wells that began production during 2004 and wells that have been online for up to 5 years. The discharge rates at the beginning of production appear to be similar to those used for predictive purposes, but the decline in water production has exceeded expectations and the current average discharge rates are significantly less than expected. The lower than expected discharge rates will decrease both the amount and the area of drawdown in the coal aquifers and the amount of produced water to be managed.

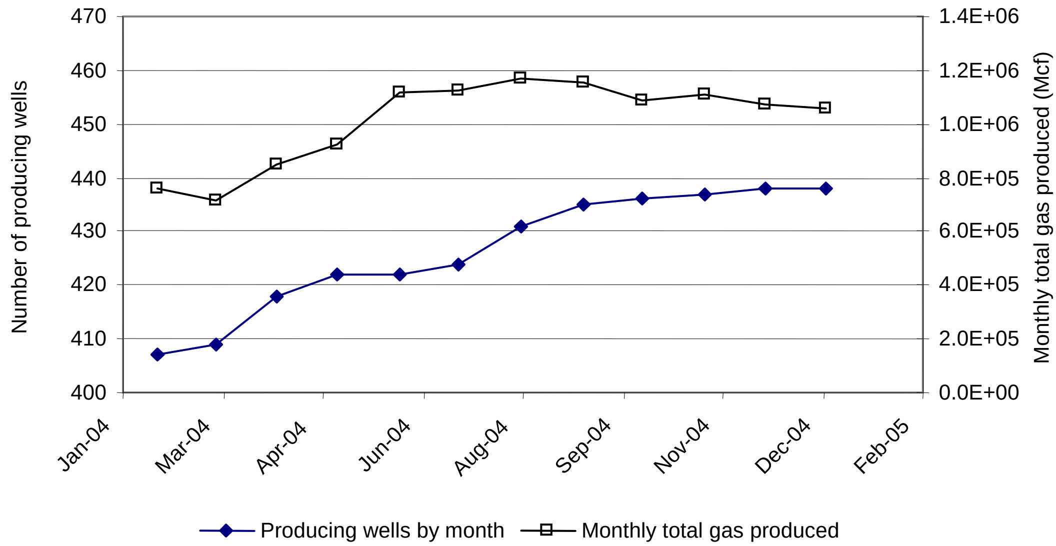


Figure 10A

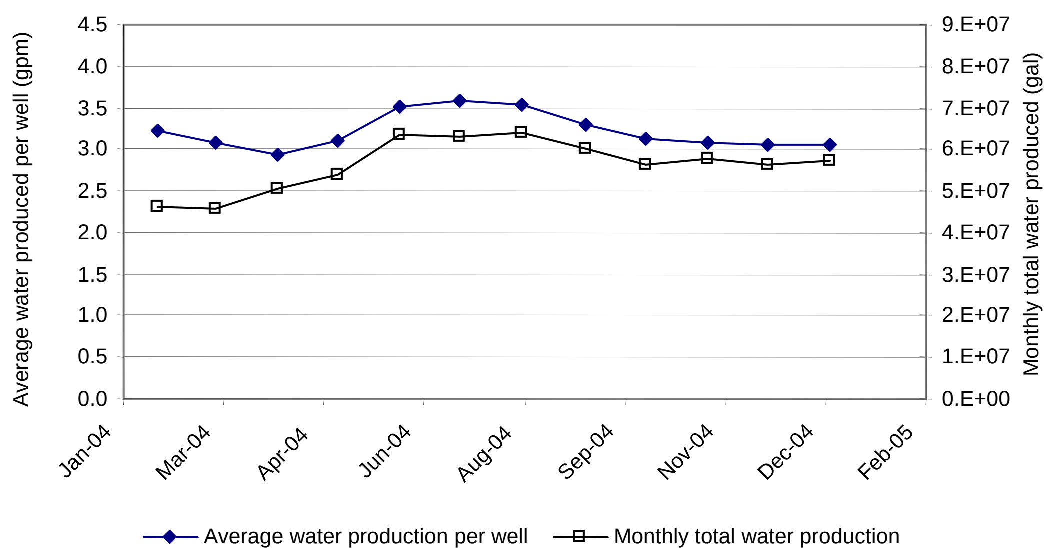


Figure 10B

Figure 10. During 2004 the amount of methane produced each month increased as additional wells were added. Average water production per well varied little over the year and the monthly total water production reached its peak in August.

Bedrock aquifers

Bedrock aquifer water levels and flow

Coal beds in the Powder River Basin are generally separated from other aquifers by shale units. Due to these confining shales, water-level drawdown in response to CBM production is only expected to occur within the coal aquifers. At a few selected locations, overburden and underburden aquifers are monitored for verification of impacts on 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 17 and 19. 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 created large areas of lowered ground-water levels in the coal seams.

Hydrostatic pressure in the Dietz coal has been reduced by at least 20 feet over an area of approximately 26 square miles in and adjacent to the CX field (Plate 3). The locations of active CBM wells at any specific time is not available, however, it appears that drawdown of at least 20 feet has reached a distance of about 1 mile beyond the active field in most areas. Drawdown in other monitored coal seams is similar to that shown for the Dietz coal. Within the regional monitoring program area more monitoring wells are completed in the Dietz than in other coal seams. Therefore the best data set to develop a drawdown map is from the Dietz coal. Drawdown was expected to reach 20 feet at a distance of 2 miles after 10 years of CBM production (Wheaton and Metesh, 2002) and a distance of 4 to 5 miles after 20 years (U. S. Bureau of Land Management, 2003, page 4-62). The CBM-production area is surrounded by monitoring wells where no drawdown has been measured. It is known, therefore, that the extent of drawdown due to CBM production in the CX field has not exceeded the distances to these monitoring wells. Current measured drawdown is similar to, but somewhat less than, expected. Therefore, monitoring data to date support the methods used and conclusions reached in the original evaluations of impacts.

Declining water levels (hydrostatic pressure) in coal seams is an expected response to both coal mining and CBM production. Hydrostatic pressure in the combined Anderson and Dietz coal in well WR-34 near the Ash Creek mine declined about 21 feet between 1977 and 1979 due to mine dewatering. The Ash Creek mine pit reached a maximum size of about 5 acres. Pit dewatering maintained a reduced level until reclamation began in 1995 when it began a full recovery, reaching baseline conditions in 1998 (Figure 11). Between 2001 and 2003 ground-water levels at this site were lowered to about 150 feet below baseline conditions by CBM production. Since 2003, the water levels have recovered to within 70 feet of baseline conditions. This recovery is presumably due to a reduction in the amount of water pumped in this area by CBM wells.

The greater magnitude of drawdown at this well due to CBM development is primarily due to the proximity of, and area affected by, CBM production.

In southeastern Montana, faults in the Fort Union Formation are considered aquitards that limit the aerial extent of drawdown (Van Voast and Reiten, 1988). A series of monitoring wells was installed south of the east Decker mine in the early 1970's to document this effect (Van Voast and Hedges, 1975). Monitoring data (Figure 12) show response to precipitation patterns (Figure 2A) in the Smith and Anderson coal seams south of the fault but no response to mining across the fault; drawdown in response to mining is apparent north of the fault. Methane production south of the fault shows the inverse response as water levels in the Anderson coal south of the fault are about 45 feet lower since 2001 while water levels in the Anderson coal north of the fault have dropped about 7 feet, possibly in response to mining.

Near the western edge of 2004 CBM production, but across a fault from active CBM wells, the Canyon (WR-24) and Carney (CBM02-2WC) coals began responding to CBM-related drawdown during 2004 (Figure 13). The Roland coal (CBM02-2RC) is stratigraphically higher than the CBM production zones and is not showing a response. The delayed water level responses shown on Figure 13 probably reflect drawdown migrating around the ends of the fault. Near coal strip mines in Montana, drawdown has been greater in deeper coal seams than in shallower ones (Van Voast and Reiten, 1988). The reason for this response is not well understood but is speculated to correspond to either the differences in storativity between the aquifers or a greater initial head in the deeper coal that must be drawn down thereby creating a steeper cone of depression. On Figure 13, the deeper Carney coal is showing a greater response than is the Canyon coal. Longer-term monitoring will be required to determine if this is the same trend as documented around coal strip mines.

Near the East Decker mine water levels respond to coal mining in the Anderson, Dietz 1 and Dietz 2 coals (Figure 14). Drawdown increases in response to CBM production in the area. This site provides another example of the increased drawdown in deeper aquifers. Note the far greater rate of drawdown in the Dietz 2 coal than in the other producing coal seams at this site.

Changes in stage in the Tongue River Reservoir affect water levels in adjacent aquifers. Water levels in the Dietz coal south of the Reservoir are more strongly influenced by mining and CBM production than by the stage levels (Figure 15). Average reservoir stage is about 3420 ft, which when compared to the Dietz potentiometric surface (Figure 15 and Plate 2) indicates some water has always seeped from the Tongue River Reservoir to the coal seam. Drawdown in coal seams beneath the Reservoir appears to be controlled by a fault (no-flow boundary) and is probably intercepted by the East Decker Mine pit (Plate 2).

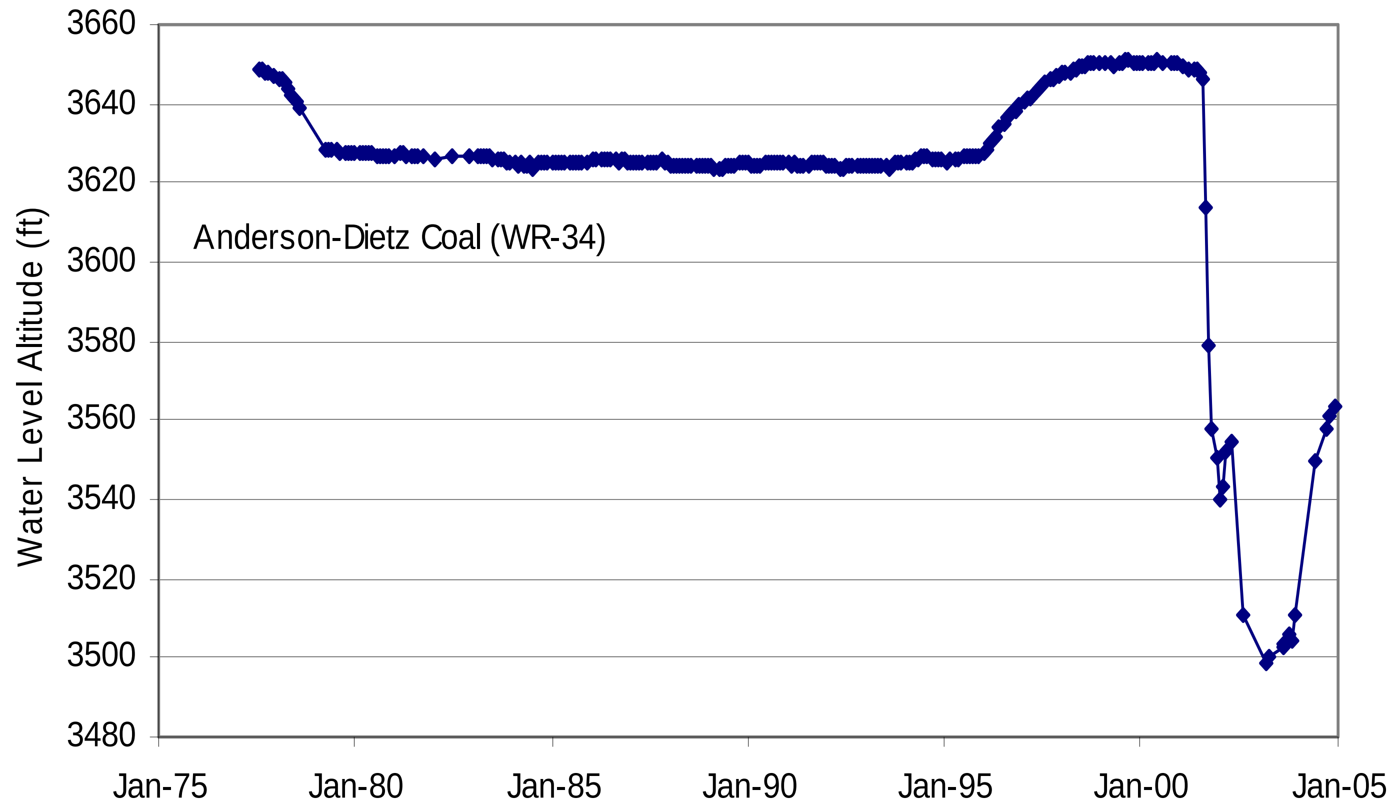
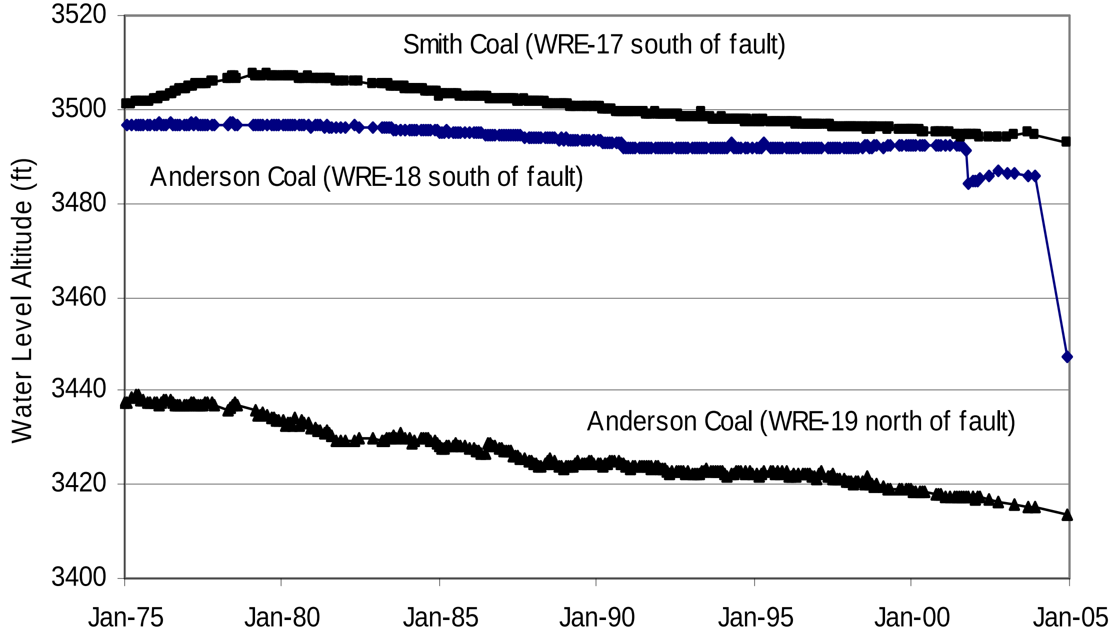


Figure 11. Water levels in the combined Anderson and Dietz coal (WR-34) in the Squirrel Creek area respond to both coal mining and coalbed methane production. The water level recovered during 2004 in response to water production decreases in this portion of the CX field.



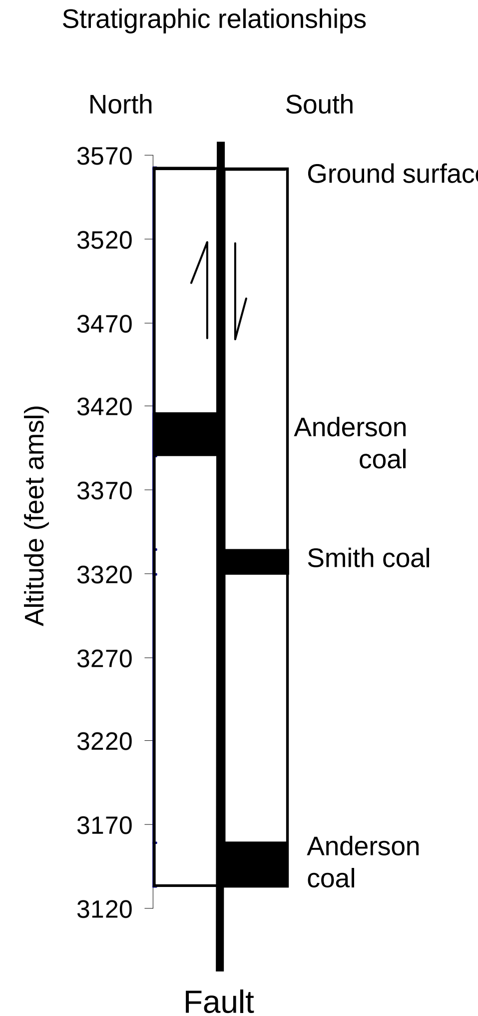


Figure 12. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured at WRE-18 since the mid-1980's. The pressure reduction has probably migrated around the end of the fault. Coalbed methane production south of the fault is apparent in WRE-18 but not across the fault in WRE-19.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

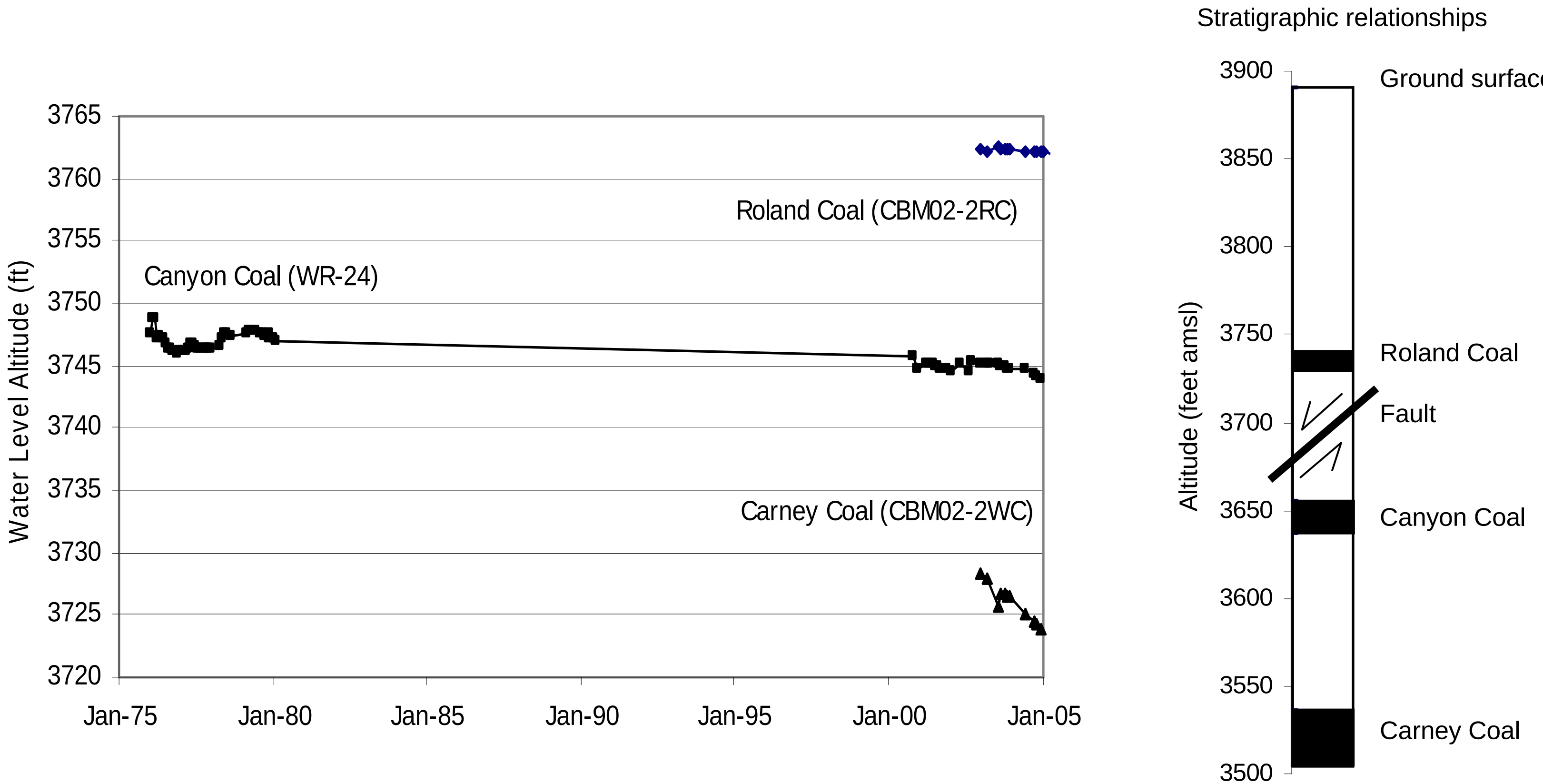
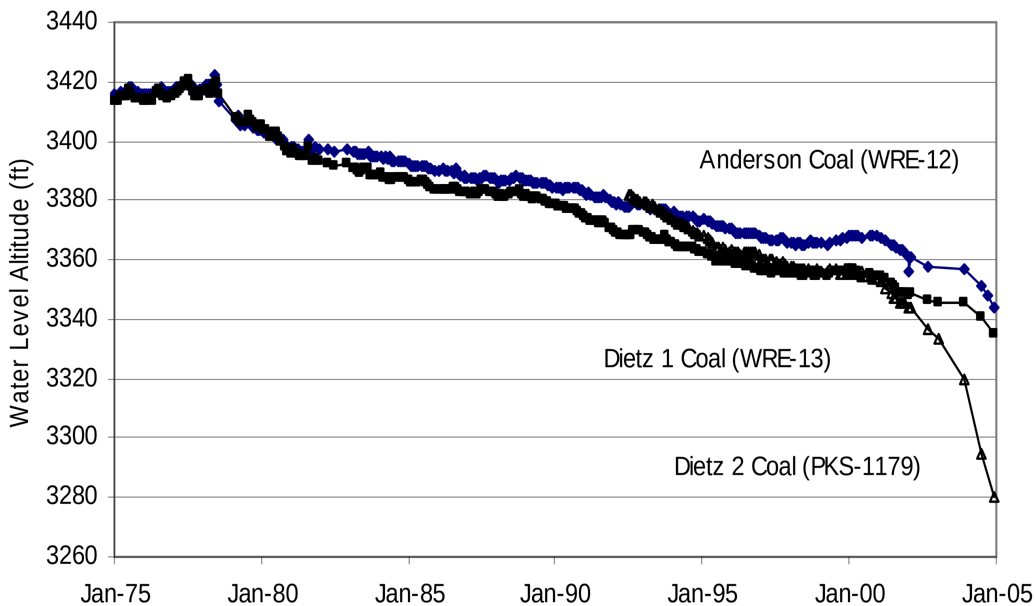


Figure 13. The long-term decrease in water levels in the Canyon Coal is probably related to precipitation patterns. The short period of record for the Carney coal at the CBM02-02 site does not indicate meteorological influence but may be showing the beginning of CBM related drawdown during 2004. The Roland Coal is not developed for CBM production and shows no response.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.



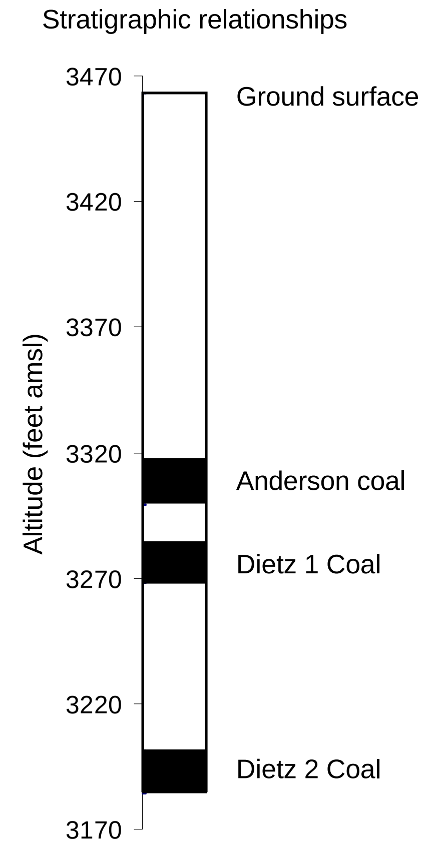


Figure 14. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

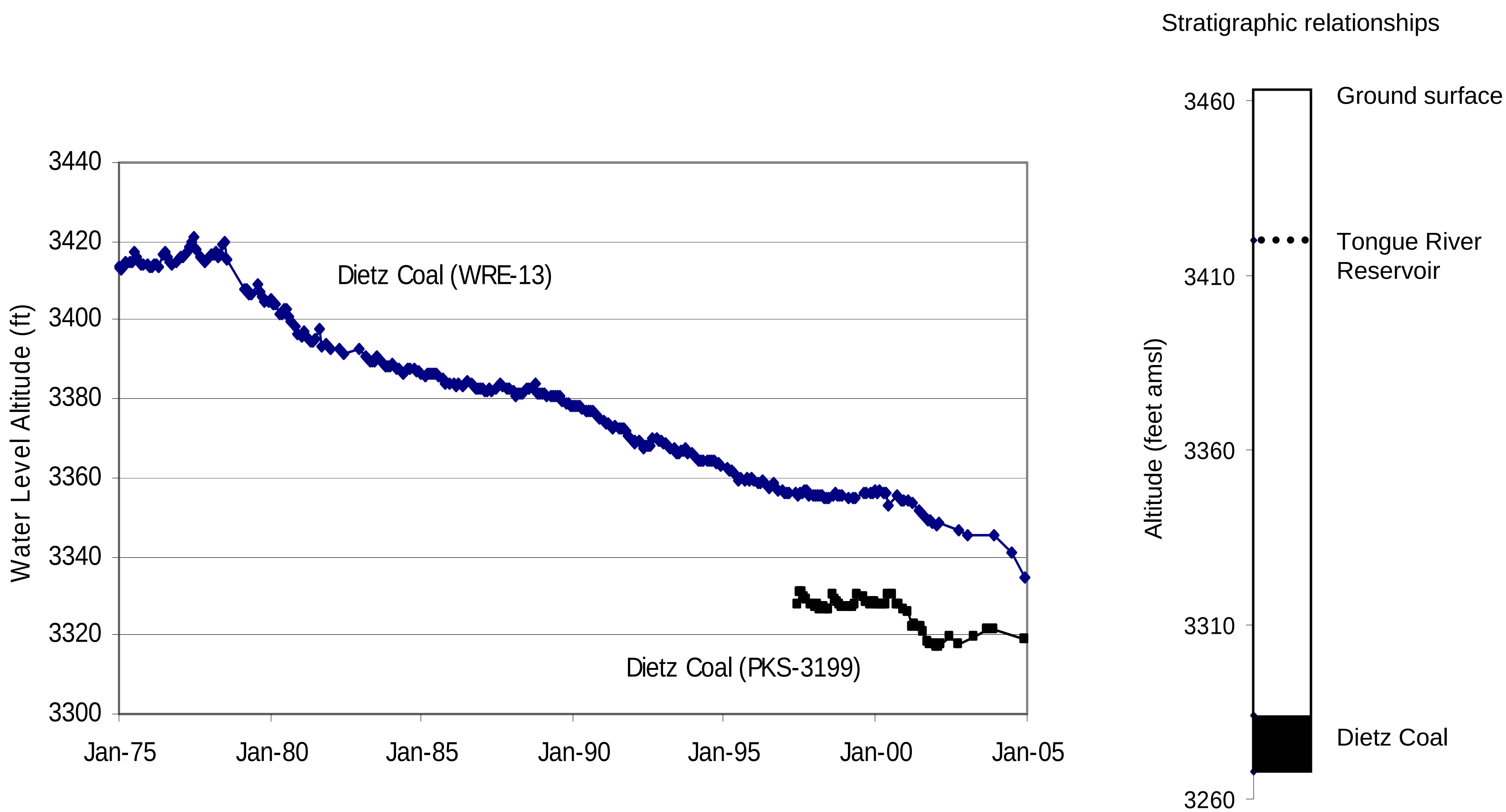


Figure 15. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

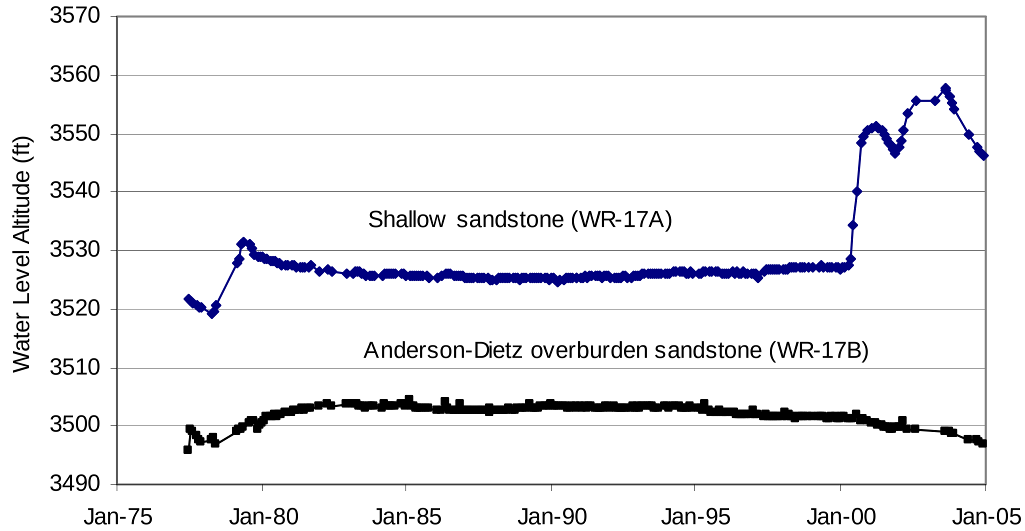
Water levels in Anderson overburden in the Squirrel Creek watershed (Figure 16) show possible correlation with precipitation patterns (Figure 2A) and no drawdown due to CBM production. The shallow, water-table aquifer (WR-17A) shows a rapid rise, totaling about 30 feet, in response to infiltration of CBM-production water from an adjacent holding pond. This pond held very little water during 2004 and the shallow water table dropped to less than 20 feet above baseline. The deeper overburden aquifer (WR-17B) at this site shows no response to the holding 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. The deeper overburden aquifer is separated from the Anderson coal by over 50 feet of shale, siltstone and coal. The deeper water-level trend appears to be in response to the local drought conditions (Figure 2B).

Bedrock aquifer water quality

Coalbed-methane-produced-water quality in the Powder River Basin is dominated by ions of Na^+ and HCO_3^- (Van Voast, 2003, Rice et al., 2002). In the southeastern PRB in Wyoming, CBM water generally has low TDS and SAR, increasing to the north and west into Montana.

Water-quality samples are collected from monitoring wells as part of the regional ground-water monitoring project and have been collected during previous projects in southeastern Montana. Water-quality data are available in GWIC for 100 samples from coal bed monitoring wells located in the area where CBM development is probable in southeastern Montana. Summary statistics for these data are presented in Table 2. Based on these data, CBM production water in Montana can be expected to have TDS concentrations between about 900 and 1,400 mg/L and SAR values between 35 and 65. Low $SO^2{}_4^-$ concentrations in coal-bed water indicate reducing conditions and are an important tool for CBM exploration (Van Voast, 2003). The median value of $SO^2{}_4^-$ for the samples included in this summary is 4.5 mg/L, though samples with concentrations as high as 471 mg/L were included in the selected data set.

Infiltration of $Na^+ – HCO_3^-$, CBM-produced water may impact receiving ground-water quality. Three monitoring wells in the CX field indicate possible influence from infiltrated CBM water. Near an infiltration pond, TDS concentrations in a shallow sandstone aquifer initially increased and have since decreased (Figure 17). These TDS values correspond to changes in water levels (Figure 16) and are expected to continue to decrease as the water level water drops and the loading of soluble salts from overlying sediments decrease. Values for SAR in this aquifer decreased dramatically in response to dissolution of magnesium and calcium minerals in the overburden (Figure 17). Minerals in the overlying sediments are dissolved by the infiltrating water thus increasing TDS. The increase in TDS at this site is primarily the result of increased concentrations of Mg^{++} and SO_4^-, with lesser increases in Ca^{++} and Na^+ concentrations. The increased concentrations of Mg^{++} and Ca^{++} cause a corresponding decrease in SAR.



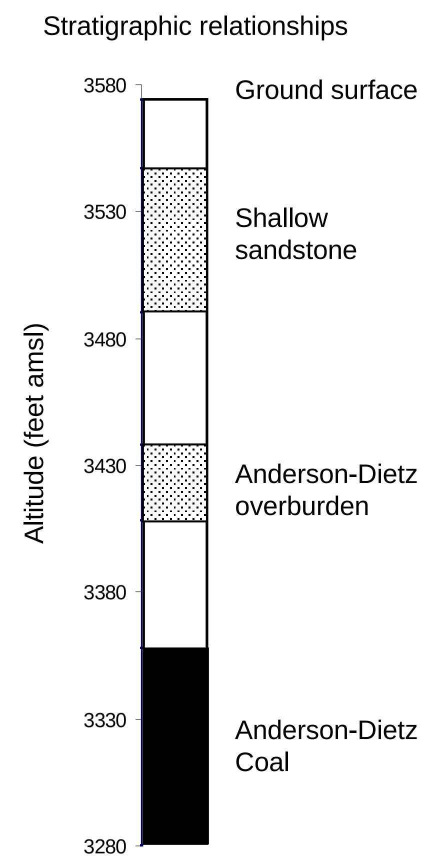


Figure 16. Long-term water-level trends in the Anderson overburden(WR-17A and WR-17B) in the Squirrel Creek area, may relate to precipitation patterns. The rise starting in 1999 in the water table at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The water level in this aquifer is now dropping as the pond receives less water.

Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

Table 2. Water-quality summary for coal bed aquifers in the portion of the Powder River Basin with coalbed methane potential in Montana.

	Specific Conductance (umhos/cm^2)	pH	Total Dissolved Solids (mg/L)	Sodium Adsorption Ratio	Sulfate (mg/L)
Median	1821	8.14	1201.0	45.8	4.5
Standard Deviation	494	0.40	322.8	11.4	64.4
Minimum	1055	7.45	568.2	11.3	0.0
Maximum	3061	9.36	2028.6	82.4	471.0
Count	100	100	100	100	100

Data source: Montana Ground-Water Information Center, Montana Bureau of Mines and Geology

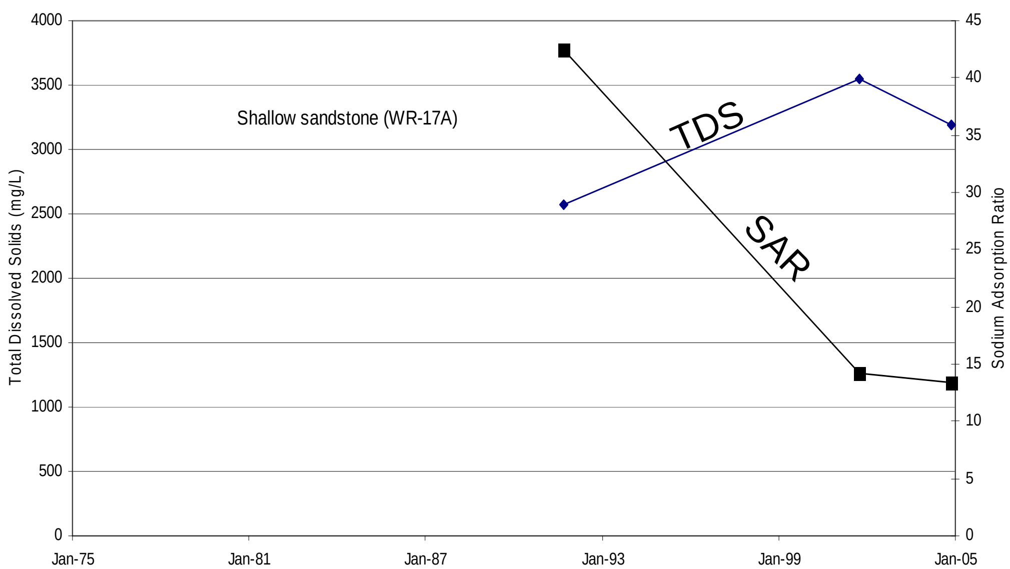


Figure 17. Both total dissolved solids (TDS) and sodium adsorption ratio (SAR) in the shallow sandstone aquifer (WR-17A) have responded to infiltration of CBM-production water. The salt load increased and is now decreasing, while the SAR has steadily decreased.

Alluvial aquifers

Alluvial aquifer water levels and flow

On Figure 18 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 2A appears to explain the subtle alluvial water-level trends in the upstream area of CBM production (Figure 18). Note that since 1999 the alluvial water levels have declined in response to drought conditions. Farther downstream in the CBM production area (Figure 18) since 1999, the water level in the alluvium increased and is now approaching baseline levels. This rise and subsequent fall is likely in response to CBM-production water seepage from nearby infiltration ponds which are no longer in use.

Alluvial aquifer water quality

In the Squirrel Creek alluvial aquifer (WR-52B and WR-52D), baseline TDS concentrations were in excess of 6,000 mg/L (Figure 19). In 2002, the TDS concentration at WR-52B had decreased to 5,261 mg/L and in 2004 increased to 6,418 mg/L which is similar to baseline conditions at this well. Farther from the stream channel (WR-52D) no baseline data were collected. The concentration of TDS at WR-52D decreased from 6,873 mg/L in 2002 to 2,601 mg/L in 2004. Apparently, soluble minerals in the aquifer material are flushed from the system, resulting in a decrease in the total salt load carried by the ground water. Sodium adsorption ratios at both wells have increased from approximately 5 to about 13 during this time (Figure 19).

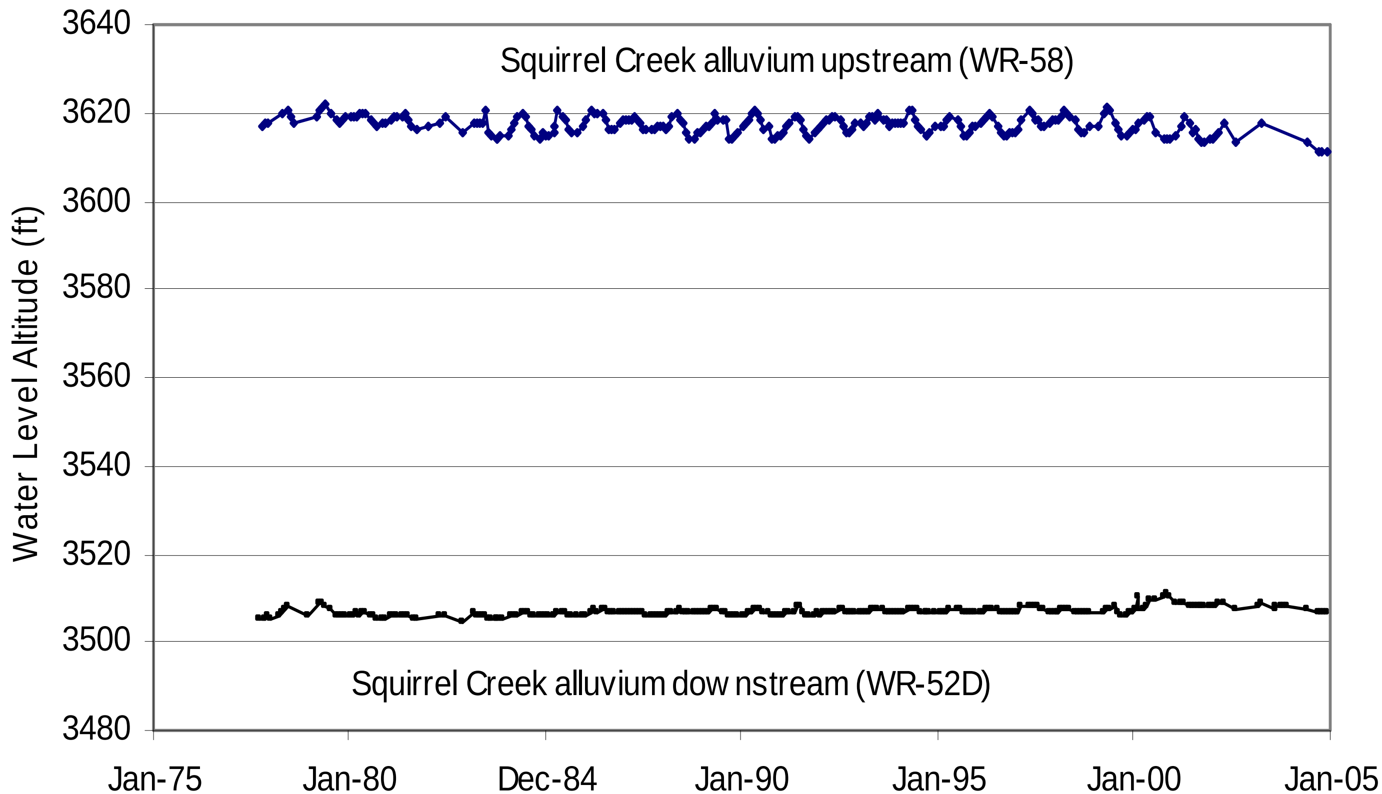


Figure 18. In addition to normal annual cycles, long-term precipitation trends (Figure 12A) affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall during 2004 likely relates to infiltration ponds (WR-52D).

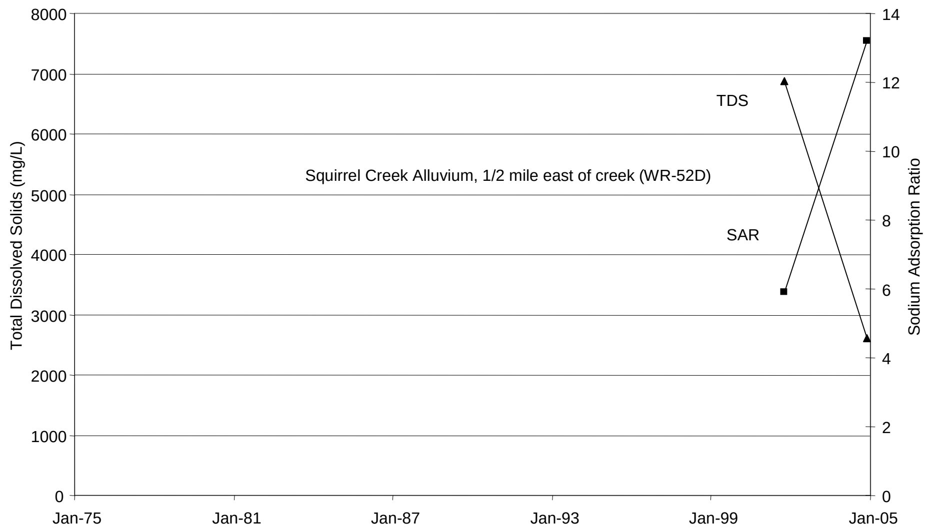


Figure 19A

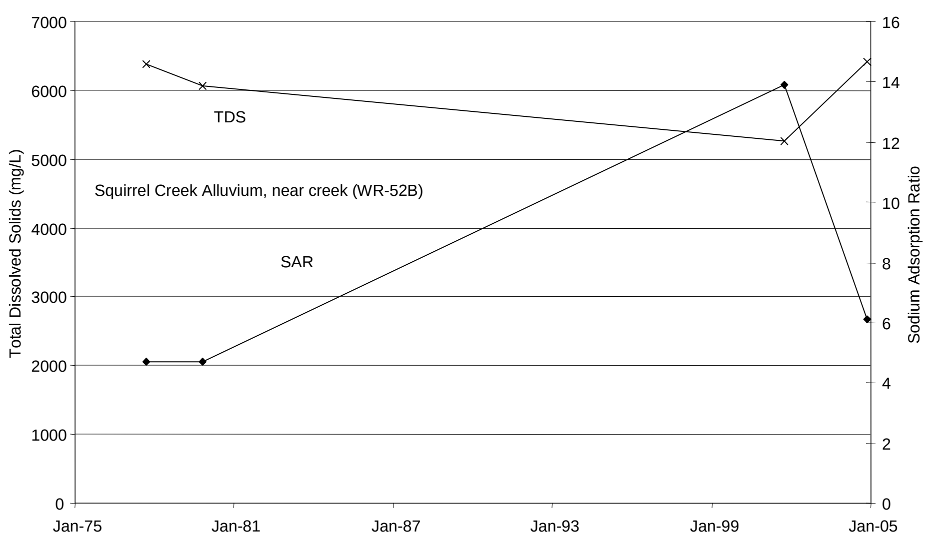


Figure 19B

Figure 19. Both total dissolved solids (TDS) and sodium adsorption ratio (SAR) in the Squirrel Creek alluvial aquifer appear to be responding to infiltration of CBM-production water. The TDS has decreased and SAR has increased at the well farthest from the creek. Near the creek TDS initially decreased then returned to near baseline and the SAR increased then returned to near baseline.

Summary and recommended network changes

Coalbed methane production continues in the CX field, the only producing field in Montana during 2004. The regional ground-water monitoring network documents baseline conditions outside production areas, changes to the ground-water systems within the area of influence, and the aerial limits of drawdown. Outside the area of influence of CBM production, ground-water conditions reflect normal response to precipitation and the long-term response to coal mining.

Water discharge rates from individual CBM wells is less than predicted, averaging 3.2 gpm during 2004 from 439 wells. Some wells are producing methane without pumping water and the highest water production rate was 40.2 gpm from one well, averaged over a 1-month period. Within the CX field, ground-water levels have been drawdown by over 150 feet in the producing coal beds. After 5 years of CBM production, drawdown of up to 20 feet has been measured in the coal seams at a distance of roughly 1 mile outside the production areas, close to, but slightly less than, the drawdown predicted in the Montana CBM environmental impact statement.

Water from production wells is expected to have TDS concentrations generally between 900 mg/L and 1,400 mg/L. Data collected from coal seams outside production areas during 2004 support those values with the highest measured TDS being 1,134 mg/L. Sodium adsorption ratios in methane bearing coal seams are high, and data collected during 2004 indicate values in excess of 80 in some areas.

Changes have occurred in the quality of water in shallow aquifers, in response to infiltrated CBM produced water. Total dissolved solids increased partially and are now decreasing as the available salts are flushed from the systems. The trend of decreasing concentration of TDS is expected to continue. Sodium adsorption ratios have increased in the Squirrel Creek alluvium and decreased in a sandstone aquifer. Continued monitoring will determine the significance of these changes.

New monitoring wells were installed along the Montana – Wyoming state line in 2005. Data from these wells will be included in future annual reports, beginning with the 2005 report. These wells enhance the monitoring program and assessment of resources near Wyoming CBM production.

Data loggers have been installed at three well sites to provide better resolution of water-level changes and correlation with weather patterns. Drawdown in response to methane production may eventually be recorded at two of these sites. A datalogger will be installed at a stream site on the Custer National Forest, Ashland Ranger District during 2005 as part of a spring study.

During 2005, monitoring sites outside of active production (generally north of township 9 north) will be measured quarterly. Near production areas monthly monitoring will continue. As water production begins at new fields (Coal Creek field and possibly the Sonnette area, Powder River Gas, LLC,) monitoring priorities will be adjusted. Thorough assessment of hydrogeologic changes associated with CBM production, both impacts and lack of impacts, requires complete sets of CBM-water-production records including mapping-software-compatible locations. As more wells are drilled in Montana, a more efficient method of retrieving CBM data will be required. This need will be addressed during the coming year.

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Appendix A. Completion records for monitoring wells installed during 2004.

Montana Bureau of Mines and Geology
Ground-Water Information Center Site Report
HWCQ-1

Location Information

GWIC Id:	214097	Source of Data:	LOG
Location (TRS):	07S 43E 32	Latitude (dd):	45.1912
County (MT):	ROSEBUD	Longitude (dd):	-106.5005
DNRC Water Right:		Geomethod:	NAV-GPS
PWS Id:		Datum:	NAD27
Block:		Altitude (feet):	3340.00
Lot:		Certificate of Survey:	
Addition:		Type of Site:	WELL

Well Construction and Performance Data

Total Depth (ft):	19.50	How Drilled:	AUGER
Static Water Level (ft):	12.52	Driller's Name:	JOHN WHEATON
Pumping Water Level (ft):		Driller License:	046
Yield (gpm):		Completion Date (m/d/y):	9/10/2004
Test Type:		Special Conditions:	
Test Duration:		Is Well Flowing?:	
Drill Stem Setting (ft):		Shut-In Pressure:	
Recovery Water Level (ft):		Geology/Aquifer:	110ALVM
Recovery Time (hrs):		Well/Water Use:	MONITORING
Well Notes:			

Hole Diameter Information

From	To	Diameter
0.0	19.5	3.0

Casing Information[1]

From	To	Dia	Wall Thickness	Pressure Rating	Joint	Type
0.0	9.0	1.3	SCHED 40			PVC

Annular Seal Information

From	To	Description
0.0	9.0	BENTONITE
9.0	19.5	GRAVEL

Completion Information[1]

From	To	Dia	# of Openings	Size of Openings	Description
9.5	19.5	1.3		.015	PVC

Lithology Information

From	To	Description
0.0	4.0	SAND TAN FINE GRAINED DRY
4.0	18.5	SAND (AA) AND GRAVEL LENSES WET BELOW 13 FEET
18.5	20.0	CLAY GRAY
20.0	21.0	SAND STONE, YELLOW-TAN, FINE GRAINED WEATHERED BEDROCK

[1] - All diameters reported are **inside** diameter of the casing.

Appendix A. Completion records for monitoring wells installed during 2004.

Montana Bureau of Mines and Geology
Ground-Water Information Center Site Report
HWCQ-2

Location Information

GWIC Id:	214096	Source of Data:	LOG
Location (TRS):	07S 43E 32	Latitude (dd):	45.1913
County (MT):	ROSEBUD	Longitude (dd):	-106.5009
DNRC Water Right:		Geomethod:	NAV-GPS
PWS Id:		Datum:	NAD27
Block:		Altitude (feet):	3340.00
Lot:		Certificate of Survey:	
Addition:		Type of Site:	WELL

Well Construction and Performance Data

Total Depth (ft):	19.00	How Drilled:	AUGER
Static Water Level (ft):	12.48	Driller's Name:	JOHN WHEATON
Pumping Water Level (ft):		Driller License:	046
Yield (gpm):		Completion Date (m/d/y):	9/10/2004
Test Type:		Special Conditions:	
Test Duration:		Is Well Flowing?:	
Drill Stem Setting (ft):		Shut-In Pressure:	
Recovery Water Level (ft):		Geology/Aquifer:	110ALVM
Recovery Time (hrs):		Well/Water Use:	MONITORING
Well Notes:			

Hole Diameter Information

From	To	Diameter
0.0	19.0	3.0

Casing Information[1]

From	To	Dia	Wall Thickness	Pressure Rating	Joint	Type
0.0	11.0	1.3	SCHED 40			PVC

Annular Seal Information

From	To	Description
0.0	9.5	BENTONITE
9.5	19.0	GRAVEL

Completion Information[1]

From	To	Dia	# of Openings	Size of Openings	Description
11.0	19.0	1.3		.015	PVC

Lithology Information

From	To	Description
0.0	4.0	SAND BROWN FINE GRAINED DRY
4.0	18.0	SAND (AA) INTERBEDDED WITH GRAVEL, POOR RETURNS
18.0	19.0	CLAY

Appendix B. Site details and water-level data ground-water monitoring wells

Site Name	GWIC ID	Latitude	Longitude	Township	Range	Section	Tract	County	Land-surface altitude (feet)
20-LW	191139	45.33910	-106.78010	06S	40E	1	CDDC	BIG HORN	3940
22-BA	191155	45.34840	-106.69540	06S	41E	3	BADD	ROSEBUD	3530
28-W	191163	45.32110	-106.72920	06S	41E	16	BBCC	ROSEBUD	3715
32-LW	191169	45.29550	-106.70980	06S	41E	21	DDDC	ROSEBUD	3530
77-26	7755	45.43520	-106.18390	05S	45E	4	ABCC	POWDER RIVER	3284
ALLEN LLOYD	191634	45.0966	-106.2011	08S	45E	34	BDBC	POWDER RIVER	3780
AMAX NO. 110	8835	45.06990	-106.11530	09S	46E	8	BACC	POWDER RIVER	3965
BC-06	8191	45.13870	-106.21000	08S	45E	16	DBCB	POWDER RIVER	3715
BC-07	8192	45.13870	-106.21000	08S	45E	16	DBCB	POWDER RIVER	3715
BF-01	161749	44.98970	-106.96670	58N	84W	22	ACCC	SHERIDAN	3680
CBM02-1BC	203655	45.31860	-106.96710	06S	39E	16	DBCA	BIG HORN	3980
CBM02-1KC	203646	45.31860	-106.96710	06S	39E	16	DBCA	BIG HORN	3980
CBM02-1LC	203658	45.31860	-106.96710	06S	39E	16	DBCA	BIG HORN	3980
CBM02-2RC	203670	45.01850	-106.98890	09S	39E	29	BCBD	BIG HORN	3890
CBM02-2WC	203669	45.02070	-106.98840	09S	39E	29	BBDC	BIG HORN	3792
CBM02-3CC	203676	45.13920	-106.96080	08S	39E	16	BAAA	BIG HORN	3920
CBM02-3DC	203678	45.13910	-106.96070	08S	39E	16	BAAA	BIG HORN	3920
CBM02-4SS1	203681	45.17980	-106.78030	07S	40E	36	CDDC	ROSEBUD	3500
CBM02-4SS2	203690	45.17980	-106.78030	07S	40E	36	CDDC	BIG HORN	3500
CBM02-4WC	203680	45.17980	-106.78020	07S	40E	36	CDDC	BIG HORN	3500
CBM02-7CC	203693	45.18010	-106.89060	08S	39E	1	AAAA	BIG HORN	3900
CBM02-7SS	203695	45.17990	-106.89060	08S	39E	1	AAAA	BIG HORN	3900
CBM02-8DS	203700	45.36870	-106.54700	05S	42E	28	DDAC	ROSEBUD	3259
CBM02-8FG	203701	45.36880	-106.54710	05S	42E	28	DDAC	ROSEBUD	3260
CBM02-8KC	203697	45.36890	-106.54730	05S	42E	28	DDAC	ROSEBUD	3261
CBM02-8SS	203699	45.36880	-106.54720	05S	42E	28	DDAC	ROSEBUD	3260
CBM03-10AC	203703	45.11410	-106.60450	08S	42E	29	ADAD	BIG HORN	4130
CBM03-10SS	203704	45.11410	-106.60450	08S	42E	29	ADAD	BIG HORN	4130
CBM03-11AC	203705	45.17930	-106.36320	08S	44E	5	BBBB	BIG HORN	3950
CBM03-11CC	203708	45.17930	-106.36470	08S	44E	5	BBBB	BIG HORN	3950
CBM03-11DC	203707	45.17930	-106.36410	08S	44E	5	BBBB	BIG HORN	3950
CBM03-12COC	203709	45.13520	-106.21210	08S	45E	16	DBCB	POWDER RIVER	3715

Site Name	GWIC ID	Latitude	Longitude	Township	Range	Section	Tract	County	Land-surface altitude (feet)
CBM03-13OC	203710	45.07220	-106.05720	09S	46E	11	BBBA	POWDER RIVER	3931
DH 75-102	190897	45.08000	-106.18720	09S	45E	3	ACDD	POWDER RIVER	3815
FC-01	8140	45.10250	-106.51660	08S	43E	31	BBDA	BIG HORN	3735
FC-02	8141	45.10250	-106.51660	08S	43E	31	BBDA	BIG HORN	3735
HC-01	207143	45.13140	-106.47500	08S	43E	21	BBDA	BIG HORN	3457
HC-24	8118	45.12970	-106.47470	08S	43E	21	BDBB	BIG HORN	3500
HWC 86-13	8888	45.00200	-106.42620	10S	43E	2	ABCA	BIG HORN	3630
HWC 86-15	198489	45.00250	-106.42350	10S	43E	2	AABC	BIG HORN	3685
HWC-01	8107	45.13380	-106.48660	08S	43E	20	DDDD	BIG HORN	3530
HWC-29B	8796	45.06880	-106.39690	09S	44E	7	BBCC	BIG HORN	3620
HWC-37	189802	45.0723	-106.4017	09S	43E	12	ADBB	BIG HORN	3578
HWC-39	189838	45.07130	-106.40040	09S	43E	12	ADBD	BIG HORN	3591
HWC-86-2	8101	45.13500	-106.48270	08S	43E	17	DDCA	BIG HORN	3460
HWC-86-5	8103	45.13410	-106.48220	08S	43E	17	DDDC	BIG HORN	3455
HWCQ-1	214097	45.19120	-106.50050	07S	43E	32		ROSEBUD	3340
HWCQ-2	214096	45.19130	-106.50090	07S	43E	32		ROSEBUD	3340
IB-2	207096	45.39300	-106.43720	05S	43E	21	BBDB	ROSEBUD	3192
MK-4	207097	45.39190	-106.43630	05S	43E	21	BBDC	ROSEBUD	3195
NM-4	207098	45.39160	-106.43610	05S	43E	21	BCAB	ROSEBUD	3195
OC-13	207100	45.49830	-106.19450	04S	45E	8	DDAA	POWDER RIVER	3230
OC-28	207101	45.47170	-106.19280	04S	45E	21	CCBD	POWDER RIVER	3171
PKS-1179	132973	45.03140	-106.80400	09S	40E	23	CBBB	BIG HORN	3458
PKS-2061	106228	45.05070	-106.86490	09S	40E	17	BBD	BIG HORN	3605
PKS-3198	166389	45.04460	-106.79640	09S	40E	14	CAA	BIG HORN	3440
PKS-3199	166388	45.04430	-106.79660	09S	40E	14	CAA	BIG HORN	3439
PKS-3200	166370	45.04400	-106.79690	09S	40E	14	CAA	BIG HORN	3438
PKS-3201	166362	45.04370	-106.79710	09S	40E	14	CAA	BIG HORN	3438
PKS-3202	166359	45.04510	-106.79810	09S	40E	14	CAA	BIG HORN	3438
PKS-3203	166358	45.11270	-106.83110	08S	40E	28	ADA	BIG HORN	3500
PKS-3204	166351	45.10670	-106.82990	08S	40E	28	ADA	BIG HORN	3500
RBC-1	207064	45.33270	-106.98360	06S	39E	8	CAAA	BIG HORN	3860
RBC-2	207066	45.33270	-106.98440	06S	39E	8	CAAA	BIG HORN	3852

Site Name	GWIC ID	Latitude	Longitude	Township	Range	Section	Tract	County	Land-surface altitude (feet)
RBC-3	207068	45.33310	-106.98680	06S	39E	8	BDCD	BIG HORN	3850
UOP-09	8846	45.07200	-106.05780	09S	46E	11	BBBA	POWDER RIVER	3929
UOP-10	8847	45.07200	-106.05780	09S	46E	11	BBBA	POWDER RIVER	3930
WL-2	207099	45.39190	-106.43580	05S	43E	21	BBDC	ROSEBUD	3188
WO-1	7780	45.39470	-106.14940	05S	45E	23	BBAA	POWDER RIVER	3190
WO-10	7775	45.39250	-106.14300	05S	45E	23	ABCB	POWDER RIVER	3145
WO-11	215085	45.3927	-106.1433	05S	45E	23		POWDER RIVER	3145
WO-13	7569	45.51860	-106.18500	04S	45E	4	BDDB	POWDER RIVER	3020
WO-14	210094	45.5183	-106.1849	04S	45E	4	BDDB	POWDER RIVER	3010
WO-15	7573	45.51860	-106.18550	04S	45E	4	BDDB	POWDER RIVER	3022
WO-16	7574	45.51580	-106.18610	04S	45E	4	CAAC	POWDER RIVER	3040
WO-2	7781	45.39470	-106.14940	05S	45E	23	BBAA	POWDER RIVER	3188
WO-3	7782	45.39470	-106.14940	05S	45E	23	BBAA	POWDER RIVER	3186
WO-5	7776	45.39220	-106.13860	05S	45E	23	ABDA	POWDER RIVER	3160
WO-6	7777	45.39220	-106.13860	05S	45E	23	ABDA	POWDER RIVER	3160
WO-7	7778	45.39220	-106.13860	05S	45E	23	ABDA	POWDER RIVER	3160
WO-8	7770	45.39220	-106.14110	05S	45E	23	ABCA	POWDER RIVER	3155
WO-9	7772	45.39250	-106.14190	05S	45E	23	ABCA	POWDER RIVER	3150
WR-17A	123796	45.02160	-106.86410	09S	40E	29	BBAC	BIG HORN	3574
WR-17B	8706	45.02160	-106.86410	09S	40E	29	BBAC	BIG HORN	3575
WR-18	132906	45.02770	-106.91360	09S	39E	23	DACC	BIG HORN	3702
WR-19	8417	45.05250	-106.95050	09S	39E	16	AABA	BIG HORN	3835
WR-20	8419	45.05250	-106.95050	09S	39E	16	AABA	BIG HORN	3835
WR-21	8074	45.08770	-106.97910	08S	39E	32	DBBC	BIG HORN	3890
WR-22	130470	45.04440	-106.91250	09S	39E	14	DABD	BIG HORN	3690
WR-23	8347	45.09220	-106.99050	09S	38E	1	AADC	BIG HORN	3960
WR-24	8436	45.02020	-106.98770	09S	39E	29	BBDD	BIG HORN	3777
WR-27	8444	45.00080	-106.96580	09S	39E	33	DBBD	BIG HORN	3672
WR-29R	166761	45.04650	-106.81530	09S	40E	15	ACCD	BIG HORN	3461
WR-30	132908	45.01650	-106.98740	09S	39E	29	CBAB	BIG HORN	3895
WR-31	130476	45.01630	-106.98630	09S	39E	29	CBAA	BIG HORN	3895
WR-33	8441	45.00660	-106.97580	09S	39E	32	ACAA	BIG HORN	3732

Site Name	GWIC ID	Latitude	Longitude	Township	Range	Section	Tract	County	Land-surface altitude (feet)
WR-34	132909	45.00150	-106.97020	09S	39E	33	CBBB	BIG HORN	3772
WR-38	122769	44.99380	-106.96500	37N	63E	23	BBCB	SHERIDAN	3693
WR-39	122770	44.99520	-106.95550	37N	63E	23	ABBC	SHERIDAN	3666
WR-41	186195	44.99500	-106.94980	09S	39E	34	CCCC	BIG HORN	3643
WR-42	8451	44.99660	-106.95020	09S	39E	33	DDDD	BIG HORN	3637
WR-44	8447	44.99660	-106.95220	09S	39E	33	DDCD	BIG HORN	3637
WR-45	8446	44.99660	-106.95380	09S	39E	33	DDCC	BIG HORN	3638
WR-48	132716	44.99330	-106.96500	37N	63E	23	BBCB	SHERIDAN	3694
WR-52A	8712	45.01470	-106.86360	09S	40E	29	CBDA	BIG HORN	3520
WR-52B	8710	45.01470	-106.86270	09S	40E	29	CACB	BIG HORN	3519
WR-52C	132960	45.01640	-106.86290	09S	40E	29	CABC	BIG HORN	3530
WR-52D	132961	45.01640	-106.86160	09S	40E	29	CABD	BIG HORN	3529
WR-53	132907	45.01250	-106.88880	09S	39E	25	DDAA	BIG HORN	3607
WR-53A	8430	45.01220	-106.88880	09S	39E	25	DDAA	BIG HORN	3608
WR-54	127605	45.01470	-106.89020	09S	39E	25	DADB	BIG HORN	3630
WR-54A	8428	45.01470	-106.89020	09S	39E	25	DADB	BIG HORN	3631
WR-55	8650	45.03000	-106.88580	09S	40E	19	CBBD	BIG HORN	3591
WR-55A	8651	45.03020	-106.88630	09S	40E	19	CBBD	BIG HORN	3591
WR-58	8412	45.04080	-106.91220	09S	39E	14	DDBD	BIG HORN	3631
WR-58A	132903	45.04030	-106.91230	09S	39E	14	DDBD	BIG HORN	3631
WR-58C	132905	45.03840	-106.91230	09S	39E	14	DDCD	BIG HORN	3633
WR-58D	8413	45.03940	-106.91380	09S	39E	14	DDCC	BIG HORN	3627
WRE-01	8454	45.07110	-106.77410	09S	40E	1	DBCC	BIG HORN	3457
WRE-02	132910	45.07120	-106.77560	09S	40E	1	DBCC	BIG HORN	3457
WRE-09	8500	45.03970	-106.77410	09S	40E	13	DCBC	BIG HORN	3511
WRE-10	8501	45.03830	-106.77410	09S	40E	13	DCCB	BIG HORN	3519
WRE-11	8504	45.03830	-106.77360	09S	40E	13	DCCD	BIG HORN	3509
WRE-12	8687	45.03110	-106.80380	09S	40E	23	BCCD	BIG HORN	3463
WRE-13	8692	45.03110	-106.80440	09S	40E	23	BCCD	BIG HORN	3463
WRE-16	8698	45.03520	-106.76970	09S	40E	24	AACB	BIG HORN	3551
WRE-17	132959	45.03470	-106.76830	09S	40E	24	AACD	BIG HORN	3562
WRE-18	121669	45.03470	-106.76830	09S	40E	24	AACD	BIG HORN	3573

Site Name	GWIC ID	Latitude	Longitude	Township	Range	Section	Tract	County	Land-surface altitude (feet)
WRE-19	123797	45.03690	-106.77360	09S	40E	24	ABBA	BIG HORN	3520
WRE-20	122767	45.03690	-106.77160	09S	40E	24	ABAB	BIG HORN	3519
WRE-24	130475	45.06880	-106.73330	09S	41E	5	DCCA	BIG HORN	3552
WRE-25	123795	45.06830	-106.73330	09S	41E	5	DCCA	BIG HORN	3549
WRE-26	132967	45.06460	-106.74130	09S	41E	8	BBDA	BIG HORN	3478
WRE-27	8721	45.05860	-106.73910	09S	41E	8	CABC	BIG HORN	3524
WRE-28	8723	45.05860	-106.73910	09S	41E	8	CABC	BIG HORN	3525
WRE-29	8726	45.05860	-106.74110	09S	41E	8	CBAD	BIG HORN	3523
WRN-10	8456	45.07330	-106.80940	09S	40E	3	DABA	BIG HORN	3433
WRN-11	123798	45.07330	-106.80940	09S	40E	3	DABA	BIG HORN	3437

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)	Static water level (altitude ft)	Comments
20-LW	WALL COAL	253	0.2	12/18/2004	92.81	3847.19	
22-BA	BREWSTER-ARNOLD COAL	262	0.4	10/26/2004	110.29	3419.71	
28-W	WALL COAL	144	1.3	12/18/2004	109.81	3605.19	
32-LW	WALL COAL	51	0.2	12/18/2004	37.57	3492.43	
77-26	KNOBLOCH COAL	217	3.6	12/17/2004	146.61	3137.39	
ALLEN LLOYD		247		12/16/2004	130.03	3649.97	
AMAX NO. 110	DIETZ COAL	240	1.4	12/16/2004	169.07	3795.93	
BC-06	CANYON COAL	188	4.6	12/16/2004	88.88	3626.12	
BC-07	CANYON COAL OVERBURDEN	66	0.8	12/16/2004	35.72	3679.28	
BF-01	COAL MINE SPOILS BANK	125		12/14/2004	31.10	3648.90	
CBM02-1BC	BREWSTER-ARNOLD COAL	256	5.0	12/15/2004	101.02	3878.98	
CBM02-1KC	KNOBLOCH COAL	417	0.5	12/15/2004	179.81	3800.19	
CBM02-1LC	LOCAL COALS	366	2.0	12/15/2004	144.89	3835.11	
CBM02-2RC	ROLAND COAL	159	1.0	12/14/2004	127.89	3762.11	
CBM02-2WC	CARNEY COAL	290	10.0	12/14/2004	68.10	3723.90	
CBM02-3CC	CANYON COAL	376	0.3	12/15/2004	301.28	3618.72	
CBM02-3DC	DIETZ COAL	235	0.1	12/15/2004	183.72	3736.28	
CBM02-4SS1	WALL COAL OVERBURDEN	221	5.0	12/15/2004	75.99	3424.01	
CBM02-4SS2	SUB-CANYON COAL SANDSTONE	97	30.0	12/15/2004	40.83	3459.17	
CBM02-4WC	WALL COAL	291	0.2	12/15/2004	169.66	3330.34	
CBM02-7CC	CANYON COAL	263	1.5	12/15/2004	164.00	3736.00	
CBM02-7SS	CANYON COAL OVERBURDEN	190	5.0	12/15/2004	93.80	3806.20	
CBM02-8DS	FLOWERS-GOODALE OVERBURDEN	446	0.3	12/18/2004	103.22	3155.78	
CBM02-8FG	FLOWERS-GOODALE COAL	480	0.5	12/18/2004	102.80	3157.20	
CBM02-8KC	KNOBLOCH COAL BED	208	1.0	12/18/2004	160.33	3100.67	
CBM02-8SS	KNOBLOCH COAL UNDERBURDEN	224	10.0	12/18/2004	160.45	3099.55	
CBM03-10AC	ANDERSON COAL	560	0.3	12/1/2004	531.22	3598.78	
CBM03-10SS	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	462	1.0	12/1/2004	372.48	3757.52	
CBM03-11AC	ANDERSON COAL	211	1.0	12/16/2004	153.95	3796.05	
CBM03-11CC	CANYON COAL	438	1.5	12/16/2004	382.20	3567.80	
CBM03-11DC	DIETZ COAL	271	0.2	12/16/2004	227.61	3722.39	
CBM03-12COC	COOK COAL	351	3.0	12/16/2004	166.42	3548.58	

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)	Static water level (altitude ft)	Comments
CBM03-13OC	OTTER COAL	500	1.5	12/16/2004	334.15	3596.85	
DH 75-102	ANDERSON-DIETZ 1 COALS COMBINED	154	6.0	12/16/2004	20.84	3794.16	
FC-01	ANDERSON COAL	133	0.0	12/16/2004	129.21	3605.79	
FC-02	DIETZ COAL	260		12/16/2004	244.02	3490.98	
HC-01	ALLUVIUM	20	17.0	12/16/2004	11.38	3445.62	
HC-24	CANYON COAL OVERBURDEN	150	7.1	12/16/2004	50.48	3449.52	
HWC 86-13	ALLUVIUM	53	3.9	9/24/2004	13.16	3618.34	
HWC 86-15	ALLUVIUM	63	30.0	9/16/2004	16.66	3669.84	
HWC-01	CANYON COAL	232	7.5	12/16/2004	87.80	3442.20	
HWC-29B	ANDERSON COAL	92		12/16/2004	46.54	3573.46	
HWC-37	ALLUVIUM	32		12/16/2004	12.23	3565.77	
HWC-39	ALLUVIUM	39		12/16/2004	26.65	3564.35	
HWC-86-2	ALLUVIUM	50		12/16/2004	20.79	3440.71	
HWC-86-5	ALLUVIUM	33		12/16/2004	15.97	3440.53	
HWCQ-1	ALLUVIUM	20		9/10/2004	12.52	3328.48	
HWCQ-2	ALLUVIUM	19		9/10/2004	12.48	3328.52	
IB-2	KNOBLOCH COAL UNDERBURDEN	245		12/18/2004	119.93	3071.66	
MK-4	KNOBLOCH COAL	188		10/26/2004	119.67	3075.64	
NM-4	NANCE COAL	294		10/26/2004	120.41	3074.90	
OC-13	KNOBLOCH COAL			7/23/2004	19.38	3212.12	
OC-28	KNOBLOCH COAL			6/13/2004	68.35	3102.65	
PKS-1179	DIETZ 2 COAL	282	5.0	12/15/2004	177.70	3280.30	
PKS-2061	ANDERSON-DIETZ 1 COALS COMBINED	244	3.0	12/15/2004			Mined out
PKS-3198	ANDERSON COAL	112		12/15/2004	87.17	3352.83	
PKS-3199	DIETZ COAL	165	20.0	12/16/2004	120.35	3318.65	
PKS-3200	DIETZ 2 COAL	242	20.0	12/16/2004	169.81	3268.19	
PKS-3201	CANYON COAL	390	50.0	12/16/2004	91.30	3346.70	
PKS-3202	ALLUVIUM	60	5.0	12/16/2004	42.31	3395.69	
PKS-3203	CANYON COAL	201		5/20/2005	120.87	3380.13	
PKS-3204	ANDERSON-DIETZ 1 CLINKER AND COAL	82	0.0	12/15/2004	73.30	3426.70	
RBC-1	ALLUVIUM	27		12/15/2004	11.63	3848.37	
RBC-2	ALLUVIUM	17		12/15/2004	8.20	3843.80	

Appendix B. Site details and water-level data ground-water monitoring wells

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)	Static water level (altitude ft)	Comments
RBC-3	ALLUVIUM	25		12/15/2004	10.85	3839.15	
UOP-09	CANYON COAL	262	0.8	12/16/2004	154.52	3774.48	
UOP-10	CANYON COAL OVERBURDEN	207	4.4	12/16/2004	141.84	3788.16	
WL-2	KNOBLOCH COAL	199		12/18/2004	119.93	3067.67	
WO-1	KNOBLOCH COAL UNDERBURDEN	172	8.0	12/17/2004	38.68	3152.82	
WO-10	ALLUVIUM	41		10/13/2004	9.62	3135.38	
WO-11	ALLUVIUM	39		10/13/2004	9.74	3135.26	
WO-13	ALLUVIUM	68	10.0	12/17/2004	9.24	3010.76	
WO-14	ALLUVIUM			10/18/2004	8.38	3001.62	
WO-15	ALLUVIUM	63	12.0	12/17/2004	9.29	3012.71	
WO-16	ALLUVIUM	61	3.7	12/17/2004	23.66	3016.34	
WO-2	LOWER KNOBLOCH COAL	112	19.0	12/17/2004	46.59	3142.91	
WO-3	KNOBLOCH OVERBURDEN	66	17.8	12/17/2004	48.03	3139.47	
WO-5	KNOBLOCH COAL UNDERBURDEN	192	20.4	10/13/2004	17.32	3142.68	
WO-6	LOWER KNOBLOCH COAL	82	7.0	10/13/2004	25.12	3134.88	
WO-7	ALLUVIUM	40	29.0	10/13/2004	27.09	3132.91	
WO-8	ALLUVIUM	33	12.0	10/13/2004	16.06	3138.94	
WO-9	ALLUVIUM	45	21.8	10/13/2004	12.03	3137.97	
WR-17A	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	88		12/14/2004	27.82	3546.08	
WR-17B	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	160		12/14/2004	77.69	3497.01	
WR-18	ANDERSON-DIETZ 1 COALS COMBINED	381	10.0	12/14/2004			Gas, water lower than 300 ft
WR-19	DIETZ 1 AND 2 COALS COMBINED	305	20.0	12/14/2004	139.48	3695.92	
WR-20	ANDERSON COAL	166	15.0	12/14/2004	114.97	3720.33	
WR-21	DIETZ 1 AND 2 COALS COMBINED	206	4.0	12/14/2004	57.69	3832.31	
WR-22	DIETZ 1 AND 2 COALS COMBINED	357	10.0	12/14/2004			Sealed, blowing gas
WR-23	DIETZ 1 AND 2 COALS COMBINED	322	6.0	12/14/2004	84.14	3875.86	
WR-24	CANYON COAL	146		12/14/2004	33.26	3743.94	
WR-27	ANDERSON-DIETZ 1 AND 2 COALSD	363	25.0	12/14/2004	193.74	3478.26	
WR-29R	ANDERSON-DIETZ 1 CLINKER AND COAL	72		12/15/2004	48.62	3412.38	
WR-30	DIETZ 1 AND 2 COALS COMBINED	428	5.0	12/14/2004	201.10	3693.50	
WR-31	ANDERSON COAL	316	2.0	12/14/2004	183.49	3711.71	
WR-33	ANDERSON-DIETZ 1 CLINKER AND COAL	165		12/14/2004	52.99	3679.31	

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)	Static water level (altitude ft)	Comments
WR-34	ANDERSON-DIETZ 1 AND 2 COALSD	522		12/14/2004	208.51	3563.59	
WR-38	DIETZ 1 AND 2 COALS COMBINED	286	3.8	12/14/2004	88.91	3603.99	
WR-39	ANDERSON-DIETZ 1 AND 2 COALSD	312		12/14/2004	124.54	3541.46	
WR-41	ALLUVIUM	40	1.0	12/14/2004	17.31	3625.36	
WR-42	ALLUVIUM	66	30.0	12/14/2004	10.60	3626.10	
WR-44	ALLUVIUM	64	30.0	12/14/2004	10.96	3625.94	
WR-45	ALLUVIUM	64	30.0	12/14/2004	11.17	3627.03	
WR-48	ANDERSON COAL	167		12/14/2004	49.93	3643.87	
WR-52A	ALLUVIUM	57	80.0	12/14/2004	9.90	3510.10	
WR-52B	ALLUVIUM	55	59.7	12/14/2004	5.59	3513.24	
WR-52C	ALLUVIUM	62	20.0	12/14/2004	19.09	3510.91	
WR-52D	ALLUVIUM	40	1.0	12/14/2004	22.67	3506.63	
WR-53	ANDERSON-DIETZ 1 AND 2 COALSD	384	20.0	6/18/2004			Water level is below 300 feet
WR-53A	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	187		12/14/2004	110.80	3497.10	
WR-54	ANDERSON-DIETZ 1 AND 2 COALSD	384	20.0	6/18/2004			Water level is below 300 feet
WR-54A	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	211	1.0	12/14/2004	128.02	3503.18	
WR-55	ANDERSON-DIETZ 1 AND 2 COALSD	288	15.0	6/18/2004	246.98	3344.22	
WR-55A	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	72		12/14/2004	44.24	3546.86	
WR-58	ALLUVIUM	55	21.0	12/14/2004	19.87	3611.42	
WR-58A	ALLUVIUM	24	8.0	12/14/2004	19.85	3611.50	
WR-58C	ALLUVIUM	23	2.0	12/14/2004	2.56	3630.00	
WR-58D	ALLUVIUM	27	15.0	12/14/2004	20.17	3607.24	
WRE-01	ALLUVIUM	80		12/16/2004	39.21	3418.19	
WRE-02	ALLUVIUM	79		12/16/2004	38.73	3418.07	
WRE-09	DIETZ 2 COAL	232		12/16/2004	210.19	3300.51	
WRE-10	DIETZ COAL	183		12/16/2004	172.22	3346.28	
WRE-11	ANDERSON COAL	127		12/16/2004	95.50	3413.40	
WRE-12	ANDERSON COAL	172		12/15/2004	119.24	3343.96	
WRE-13	DIETZ COAL	206		12/15/2004	127.69	3334.91	
WRE-16	ANDERSON COAL	458		12/15/2004	70.07	3480.43	
WRE-17	ANDERSON-DIETZ 1 AND 2 OVERBUDEN	250		12/15/2004	69.18	3492.72	
WRE-18	ANDERSON COAL	445		12/15/2004	125.92	3447.18	

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)	Static water level (altitude ft)	Comments
WRE-19	ANDERSON COAL	140		12/16/2004	106.52	3413.78	
WRE-20	ANDERSON COAL	120		12/16/2004	105.33	3414.07	
WRE-24	DIETZ COAL	154	20.0	12/16/2004	68.77	3483.33	
WRE-25	ANDERSON COAL	115		12/16/2004	63.51	3485.89	
WRE-26	ALLUVIUM	35		12/16/2004	11.49	3466.81	
WRE-27	ANDERSON COAL	77	0.5	12/16/2004	48.54	3475.26	
WRE-28	DIETZ COAL	153		12/16/2004	66.31	3458.89	
WRE-29	DIETZ 2 COAL	217		12/16/2004	130.35	3392.95	
WRN-10	DIETZ 2 COAL	79	3.4	12/15/2004	30.83	3402.47	
WRN-11	ANDERSON-DIETZ 1 CLINKER AND COAL	50		12/15/2004	38.01	3398.79	

Appendix C. Site details and flow data for monitoring springs.

GWIC ID	Site name	Latitude	Longitude	Township	Range	Section	Tract	County
204994	DEVAULT SPRING	45.75250	-106.05900	01S	46E	16	BADC	POWDER RIVER
199600	UNNAMED SPRING	45.66380	-105.99660	02S	46E	13	BACD	POWDER RIVER
198777	EAST FORK SPRING	45.63370	-105.99100	02S	46E	25	ACBA	POWDER RIVER
198819	BIDWELL SPRING NORTH PIPE	45.64040	-105.96280	02S	47E	19	CCCC	POWDER RIVER
198811	FRARY SPRING	45.59050	-105.96310	03S	47E	7	AADC	POWDER RIVER
198766	LEMONADE SPRING	45.54550	-105.92550	03S	47E	28	ACAA	POWDER RIVER
199589	USDA FS - ROCK JOB SPRING	45.34207	-106.19877	06S	45E	3	DADD	POWDER RIVER
205004	HAGEN 2 SPRING	45.34500	-106.26880	06S	45E	6	ACDC	POWDER RIVER
211316	LOWER FIRST CREEK SPRING	45.30890	-106.18160	06S	45E	14	DDCD	ROSEBUD
7909	COW CREEK 1 SPRING	45.30790	-106.25010	06S	45E	20	ABBC	ROSEBUD
197395	UNNAMED SPRING	45.29530	-106.18500	06S	45E	23	DCDC	POWDER RIVER
199568	HEDUM SPRING	45.28230	-106.07100	06S	46E	26	CDBA	POWDER RIVER
204951	PIPER DRAW SPRING	45.29900	-106.01120	06S	47E	19	DACD	POWDER RIVER
205011	JOE ANDERSON SPRING	45.27150	-105.95470	06S	47E	34	CABA	POWDER RIVER
205010	NORTH FORK SPRING	45.29960	-105.87360	06S	48E	20	BDCA	POWDER RIVER
199573	WILLOW SPRING	45.28310	-105.88790	06S	48E	30	DBBA	POWDER RIVER
204954	STOCKER DRAW SPRING	45.20900	-106.39490	07S	44E	19	CDCC	ROSEBUD
205049	CHIPMUNK SPRING	45.21200	-106.36110	07S	44E	21	CCBB	ROSEBUD
197452	UNNAMED SPRING	45.19140	-106.15010	07S	46E	31	BACD	POWDER RIVER
199576	UNNAMED SPRING	45.26120	-105.92070	07S	47E	3	AACD	POWDER RIVER
205041	SCHOOL HOUSE SPRING	45.19440	-106.00810	07S	47E	32	BABA	POWDER RIVER
205034	USDA FS - WATER GAP SPRING	45.2299	-105.8594	07S	48E	17	AADB	POWDER RIVER
197868	WOLF DEN SPRING	45.19270	-105.86750	07S	48E	29	DBCC	POWDER RIVER
198326	HOME SPRING	45.0423	-106.61400	09S	42E	20	BDAD	BIG HORN

Appendix C. Site details and flow data for monitoring springs.

GWIC ID	Spring source lithology	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Spring yield (gpm)	Spring yield date
204994	COLLUVIUM	KNOBLOCH	LOCAL	3250	0.30	9/1/04
199600		CANYON/FERRY	LOCAL	3520	1.03	11/29/04
198777		CANYON/FERRY	LOCAL	3890	0.32	11/29/04
198819		CANYON/FERRY	LOCAL	3895	0.51	11/29/04
198811		CANYON/FERRY	LOCAL	3680	3.16	11/29/04
198766		CANYON/FERRY	LOCAL	3635	1.50	11/17/04
199589	SANDSTONE	CANYON	LOCAL	3770	0.59	11/29/04
205004	CLINKER	ANDERSON/DIETZ	LOCAL	3830	0.62	11/29/04
211316	COAL AND SANDSTONE	PAWNEE	REGIONAL	3480	0.45	10/20/04
7909	CLINKER	ANDERSON/DIETZ	LOCAL	3940	10.00	10/14/04
197395	SANDSTONE	COOK	LOCAL	3490	4.00	11/29/04
199568	SANDSTONE	COOK	LOCAL	3680	0.71	11/30/04
204951	SANDSTONE	CANYON	LOCAL	3775	1.13	11/30/04
205011		ANDERSON/DIETZ	LOCAL	4030	3.75	10/23/04
205010		CANYON	LOCAL	3950	0.44	10/23/04
199573	SANDSTONE	CANYON	LOCAL	3910	0.53	10/23/04
204954	SANDSTONE	ANDERSON/DIETZ	LOCAL	3715		
205049	SANDSTONE	ANDERSON/DIETZ	LOCAL	3640		
197452	COAL	COOK	REGIONAL	3470	0.76	9/25/04
199576	COAL	ANDERSON/DIETZ	LOCAL	4100	1.20	6/17/04
205041	SANDSTONE	CANYON	LOCAL	3695	1.00	10/20/04
205034	COLLUVIUM	KNOBLOCH	REGIONAL	3600	0.68	7/21/04
197868	CLINKER	CANYON	REGIONAL	3730	0.70	7/31/04
198326	GRAVEL AND COAL	ROLAND	LOCAL	3810	0.25	9/23/04

Appendix D. Ground-water quality data collected during 2004.

Gwic Id	Site Name	Sample	Latitude	Longitude	Location (TRS)	County	State	Site Type	Depth (feet)	Agency
203681	CBM02-4SS1	2005Q0041	45.17980	-106.78030	07S40E36CDDC	ROSEBUD	MT	WELL	221	MBMG
203680	CBM02-4WC	2005Q0042	45.17980	-106.78020	07S40E36CDDC	BIG HORN	MT	WELL	291	MBMG
203695	CBM02-7SS	2005Q0136	45.17990	-106.89060	08S39E01AAAA	BIG HORN	MT	WELL	190.3	MBMG
203700	CBM02-8DS	2005Q0138	45.36870	-106.54700	05S42E28DDAC	ROSEBUD	MT	WELL	446	MBMG
203701	CBM02-8FG	2005Q0295	45.36880	-106.54710	05S42E28DDAC	ROSEBUD	MT	WELL	480.4	MBMG
203697	CBM02-8KC	2005Q0137	45.36890	-106.54730	05S42E28DDAC	ROSEBUD	MT	WELL	208	MBMG
203699	CBM02-8SS	2005Q0135	45.36880	-106.54720	05S42E28DDAC	ROSEBUD	MT	WELL	224	MBMG
123796	WR-17A	2005Q0315	45.02160	-106.86410	09S40E29BBAC	BIG HORN	MT	WELL	88	MBMG
8710	WR-52B	2005Q0316	45.01500	-106.86270	09S40E29CACB	BIG HORN	MT	WELL	55	MBMG
132961	WR-52D	2005Q0317	45.01640	-106.86160	09S40E29CABD	BIG HORN	MT	WELL	40	MBMG
94666	COYOTE WELL	2005Q0034	45.7524	-106.0505	01S46E16AACC	POWDER RIVER	MT	WELL	190	MBMG
183560	NANCE PROPERTIES INC	2005Q0035	45.4387	-106.4205	05S43E04AAAB	ROSEBUD	MT	WELL	20	MBMG
100472	EAST FORK WELL	2005Q0037	45.5935	-106.1642	03S45E10BACB	POWDER RIVER	MT	WELL	193	MBMG
105007	TOOLEY CREEK WELL	2005Q0038	45.2153	-106.2697	07S45E19CAAA	POWDER RIVER	MT	WELL	110	MBMG

Appendix D. Ground-water quality data collected during 2004.

Gwic Id	Sample Date	Water Temperature (c)	Field pH	Field specific conductance	Lab	Lab pH	Lab specific conductance	Procedure	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Sodium absorption ratio
203681	7/29/2004	13.3	8.50	1567	MBMG	8.91	1544	DISSOLVED	3.68	2.03	415	43.1
203680	7/29/2004				MBMG	8.66	1398	DISSOLVED	1.54	0.58	394	68.7
203695	9/3/2004				MBMG	7.82	1290	DISSOLVED	17.9	12.8	273	12.0
203700	9/2/2004	14.2	8.64	1660	MBMG	8.68	1654	DISSOLVED	6.28	3.05	412	33.7
203701	10/28/2004	15.9	8.85	1991	MBMG	9.01	2040	DISSOLVED	2.01	0.611	520	82.4
203697	9/1/2004	39.0	8.40	1670	MBMG	8.22	1674	DISSOLVED	1.52	0.865	426	68.3
203699	9/1/2004	39.0	8.34	1750	MBMG	8.41	1713	DISSOLVED	2.14	0.875	446	64.9
123796	11/18/2004	11.5	7.91	3454	MBMG	8.26	4140	DISSOLVED	46.6	167	871	13.4
8710	11/18/2004	12.6	7.23	6760	MBMG	7.70	6110	DISSOLVED	318	607	809	6.1
132961	11/18/2004	14.5	7.80	3495	MBMG	8.06	3340	DISSOLVED	22.7	115	700	13.2
94666	7/20/2004	12.8	8.81	2010	MBMG	9.04	1928	DISSOLVED	6.93	4.93	467	33.1
183560	7/19/2004	12.9	7.4	890	MBMG	7.95	946	DISSOLVED	78	39.4	51.6	1.2
100472	7/20/2004	15.3	8.54	1680	MBMG	8.82	1643	DISSOLVED	4.27	2.16	416	40.9
105007	7/19/2004	13.2	7.6	2300	MBMG	8.23	2230	DISSOLVED	35.4	37.3	522	14.6

Appendix D. Ground-water quality data collected during 2004.

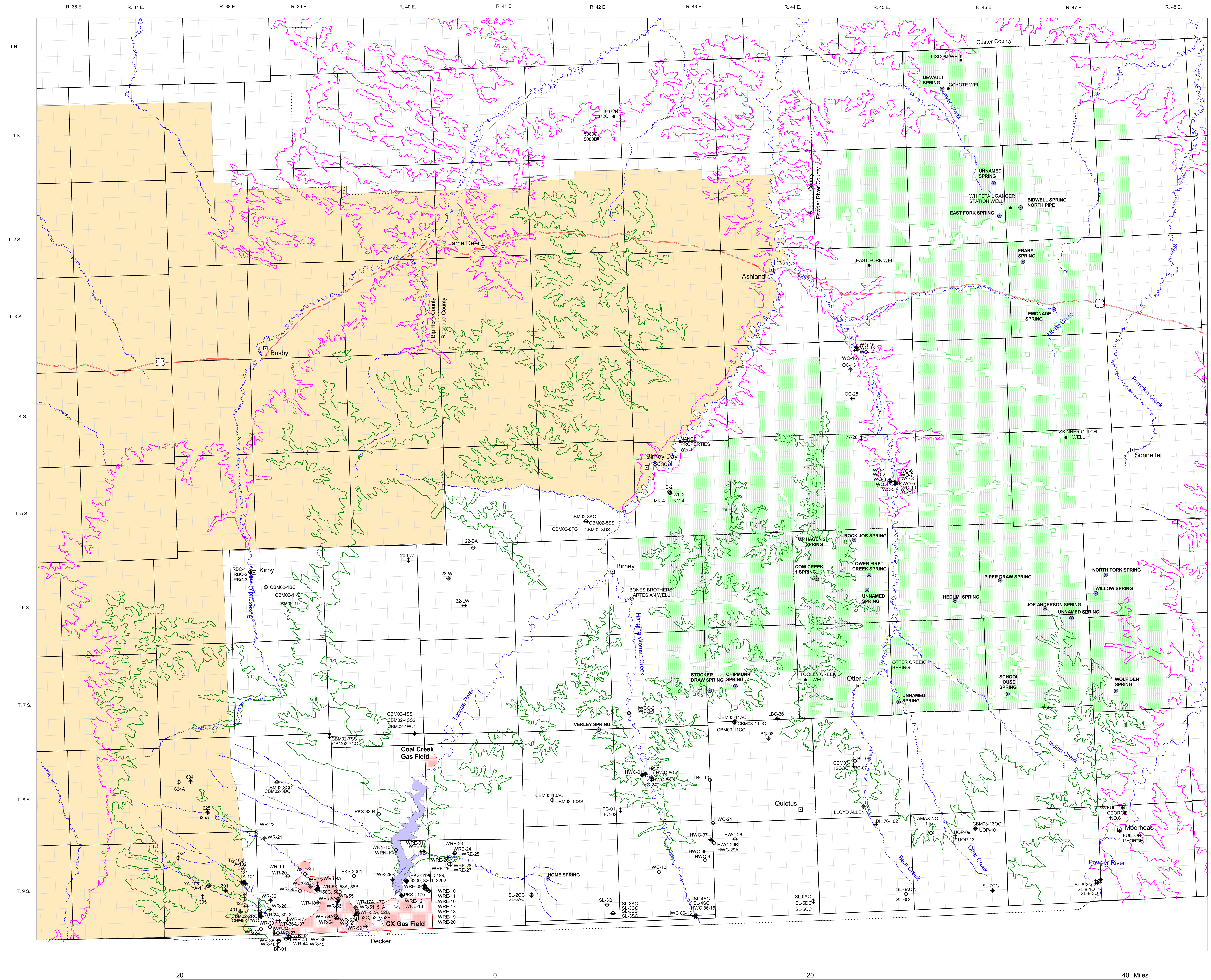
Gwic Id	Potassium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Silica (mg/l)	Bicarbonate (mg/l)	Carbonate (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Flouride (mg/l)	Orthophosphate (mg/l)
203681	3.7	<0.005	0.038	8.43	876.0	38.4	22.2	12.6	<0.05 P	<0.05	1.21
203680	4.09	0.008	0.004	7.48	922.8	25.9	<2.5	7.24	<0.25 P	0.918	<0.05
203695	11.6	0.048	0.038	9.7	478.9	0	268	6.65	<0.25 P	1.26	0.14
203700	6.16	0.347	0.134	9.18	1104.1	55.2	10.5	3.75	<0.50 P	2.3	<0.05
203701	8.14	0.013	0.008	8.59	767.4	49.2	297	53	<0.50 P	4.06	<0.50
203697	2.44	0.07	0.017	7.82	1109.0	0	10.9	9.82	<0.50 P	11.1	0.258
203699	3.28	0.016	0.033	7.54	1276.1	27.6	5.53	10.5	0.501 P	1.01	<0.05
123796	12.8	0.058	0.027	9.71	922.3	0	1572	21.8	30.5 P	<0.25	<0.25
8710	29.4	5.76	2.31	32.1	623.4	0	4307	<25.0	<2.50 P	<2.50	<2.50
132961	12.7	0.122	0.011	15.6	1310.3	0	1064	20.6	3.82 P	0.998	<0.25
94666	2.89	0.01	0.01	5.85	440.0	34.4	554	<5.0	<0.50 P	<0.50	<0.50
183560	10.6	0.031	0.007	20.9	397.3	0	155	7.8	1.92 P	0.192	<0.05
100472	2.11	0.027	0.002	7.64	788.9	36.6	185	8.64	<0.25 P	1.31	<0.10
105007	8.93	0.03	0.04	10.1	832.1	0	588	<5.0	<0.50 P	0.734	<0.50

Appendix D. Ground-water quality data collected during 2004.

Gwic Id	Silver (ug/l)	Aluminum (ug/l)	Arsenic (ug/l)	Boron (ug/l)	Barium (ug/l)	Beryllium (ug/l)	Bromide (ug/l)	Cadmium (ug/l)	Cobalt (ug/l)	Chromium (ug/l)	Copper (ug/l)	Lithium (ug/l)	Molybdenum (ug/l)
203681	<1	<10	7.39	85.9	87.9	<2	<50	<1	<2	4.21	3.79	151	13.5
203680	<1	11.4	<1	119	192	<2	<50	<1	<2	2.78	3.19	122	<10
203695	<1	<10	12.8	94.9	31	<2	<100	<1	<2	<2	2.22	211	<10
203700	<5	<50	5.72	517	121	<2	<50	<1	<2	<10	<5	84.4	<10
203701	<5	<30	<5	394	35.4	<2	<500	<1	<2	<10	<5	37.5	<10
203697	<5	<30	<5	348	92.2	<2	75	<1	<2	<10	<5	99.8	<10
203699	<5	<30	<10	370	52.8	<2	64	<1	<2	<10	<5	101	<10
123796	<5	<50	<5	<150	<10	<10	<250	<5	<10	21.5	<10	357	<50
8710	<10	<100	<10	<300	<20	<20	<2500	<10	<20	<20	<20	302	<100
132961	<5	<50	<5	510	13.8	<10	<250	<5	<10	15.1	11.6	330	<50
94666	<1	<10	<1	<30	<2	<2	<500	<1	<2	<2	<2	33.4	<10
183560	<1	<10	<1	57.2	49.7	<2	<50	<1	<2	2.83	<2	23.7	<10
100472	<1	<10	3.24	163	23.7	<2	<100	<1	<2	3.64	2.64	32	<10
105007	<5	<30	<5	246	8.88	<2	<500	<1	<2	<10	<5	190	<10

Gwic Id	Nickel (ug/l)	Lead (ug/l)	Antimony (ug/l)	Selenium (ug/l)	Strontium (ug/l)	Titanium (ug/l)	Thallium (ug/l)	Uranium (ug/l)	Vanadium (ug/l)	Zinc (ug/l)	Zirconium (ug/l)	Total Dissolved Solids
203681	4.18	<2	<2	2.15	170	<1	<5	4.15	10.9	31.5	<2	938.9
203680	<2	<2	<2	<1	173	<1	<5	<1	<5	<2	<2	896.4
203695	2.88	<2	<2	3.87	755	1.55	<5	2.39	<5	114	<2	837.2
203700	<2	<10	<10	<5	246	1.87	<25	<3	<10	275	4.6	1053.1
203701	<2	<10	<10	<5	178	<1	<20	<3	<10	<2	<2	1320.7
203697	5.24	<10	<10	<5	143	1.27	<25	<3	<10	15.5	<2	1017.1
203699	3.49	<10	<10	<5	118	<1	<25	<3	<10	<10	2.45	1133.7
123796	<10	<10	<10	26.2	5789	<10	<25	12.1	<25	<10	<10	3185.8
8710	<20	<20	<20	<10	7356	<10	<50	28.8	<50	<20	<20	6417.7
132961	<10	<10	<10	<5	1199	<10	<25	23.7	<25	11.2	<10	2601.0
94666	<2	<2	<2	<1	439	<1	<5	<1	<5	<2	<2	1292.77
183560	7.33	<2	<2	1.12	583	<1	<5	7.89	<5	21.2	<2	561.19
100472	<2	<2	<2	<1	249	<1	<5	<1	<5	3.01	<2	1052.4
105007	<2	<10	<10	<5	1142	<1	20.3	<3	<10	9.28	<2	1612.44

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



Explanation

- Monitor well
- Monitor spring
- GWAAMON monitoring site
- Anderson coalbed outcrop (Van Voast and Thale, 2001)
- Knobloch coalbed outcrop (Van Voast and Thale, 2001
- Forest boundary
- Gas production field
- Reservation lands

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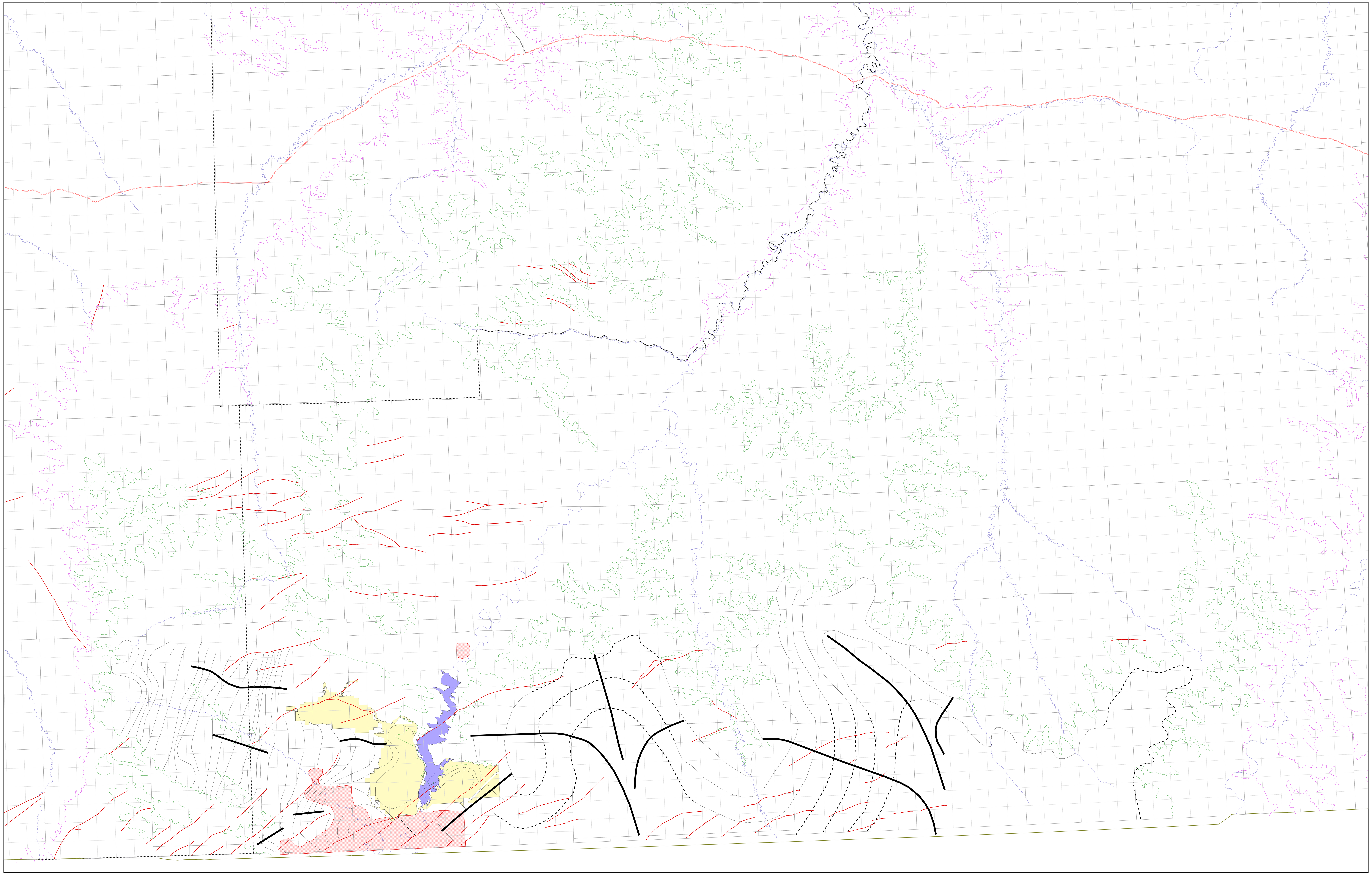

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Plate 3. Area of potentiometric decline for the Dietz coal bed in the CX coalbed methane field.