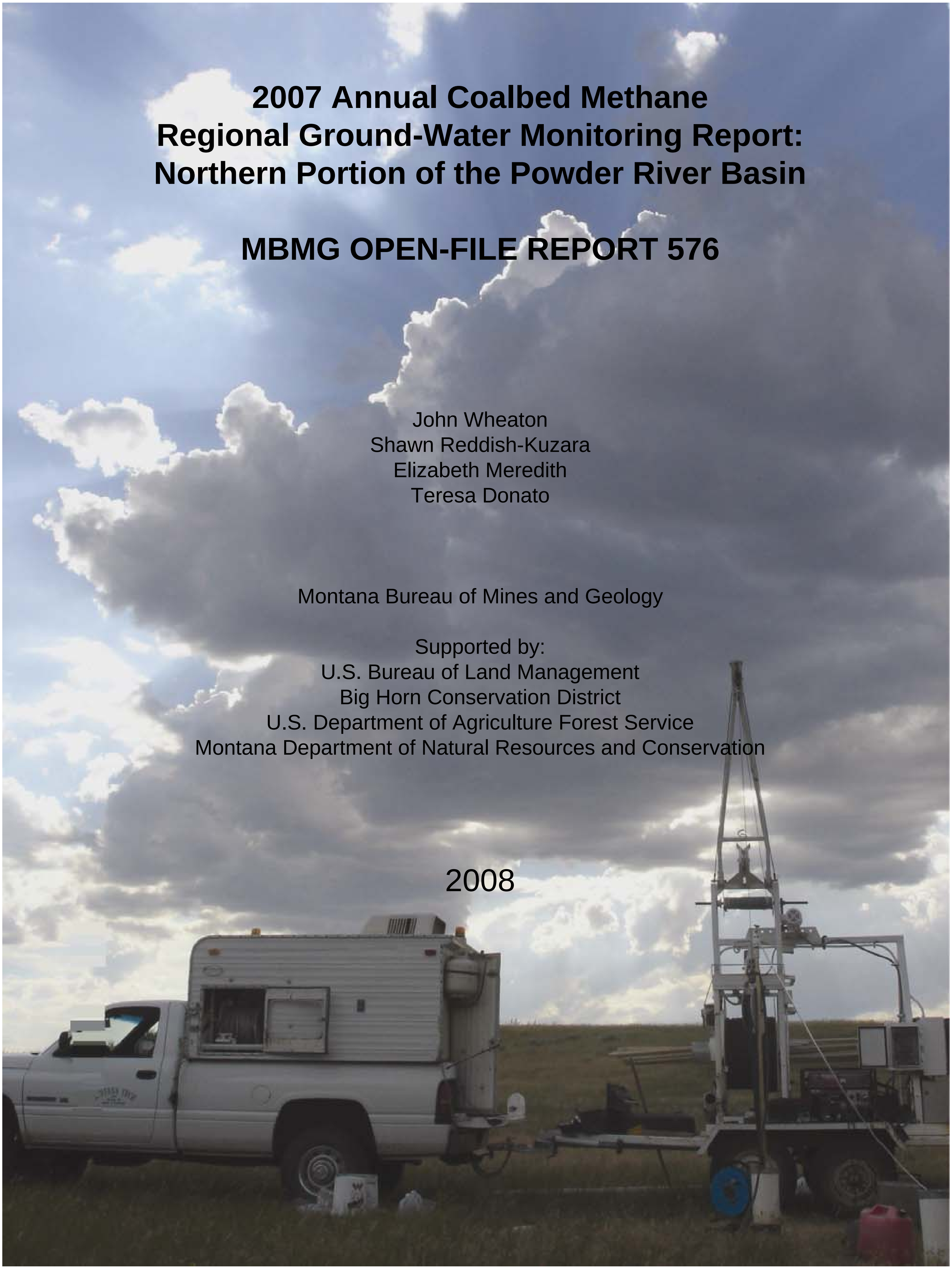

2007 Annual Coalbed Methane Regional Ground-Water Monitoring Report: Northern Portion of the Powder River Basin

MBMG OPEN-FILE REPORT 576

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Abstract

This report presents ground-water data collected from within the northern portion of the Powder River Basin up to and including 2007 and brief discussions of those data, with emphasis on data collected during 2007. This is the fifth year in which the 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 help replace rumors and projections with factual data, and to provide data and interpretations to aid environmental analyses and permitting decisions. The Montana Bureau of Mines and Geology (MBMG) collects data at a network that consists of monitoring wells installed during the late 1970s and early 1980s in response to actual and potential coal mining, monitoring wells specifically installed to monitor CBM impacts, domestic wells, stock wells, and springs. In addition to the data collected by MBMG, Fidelity Exploration & Production Company (Fidelity) provided data from shut-in tests of CBM wells that are included in this report.

Methane (natural gas) production from coalbeds is a potentially important industry in Montana. The first commercial production of CBM in Montana was from the CX field near Decker. This field is operated by Fidelity Exploration & Production Company and CBM production began in April, 1999 (Plate 1). Several CBM fields are now producing in Montana and include a total of 863 wells which produced methane, water, or both during 2007. A total of 13.1 million mcf (1 mcf = 1000 standard cubic feet) of CBM was produced in Montana during 2007, 96% of which came from the CX field. The other 4% of the methane was produced from the Dietz (2.7%) and Coal Creek (1.1%) fields and in wildcat wells in both Big Horn and Powder River counties (Plate 1).

Coalbed methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping ground-water from coal aquifers allows methane to desorb. Ground water is typically pumped at a rate and scale that reduces water pressure (head) to a few feet above the top of each coal seam over large areas. The extraction and subsequent management of CBM production water raises concerns about potential loss of stock and domestic water supplies due to ground-water drawdown, and impacts to surface-water quality and soils from water management practices.

Methane-producing coalbeds in the Powder River Basin of Montana contain water that is dominated by ions of sodium and bicarbonate. In CBM production areas, sodium adsorption ratios (SAR) are between 34 and 57, and total dissolved solids concentrations are between 875 and 1,525 mg/L. Sulfate concentrations in production water are very low. This production water is typically of acceptable quality for domestic and livestock use; however, the high SAR in Montana presents challenges when it is used for irrigation.

During 2007, MBMG regularly measured water levels in the network of monitoring wells covering much of the Powder River Basin in Montana, with a focus on areas predicted to have high CBM potential. Fidelity also measured water levels in newly completed wells and during 24-hour shut-in tests of selected wells, and provided those data to be included in this report. The Dietz and Canyon coalbeds are used in discussions in this report because of the greater density and coverage

of monitoring wells completed in those beds. Hydrostatic heads in the Dietz coal have been lowered as much as 150 ft or more within areas of production. Hydrostatic pressure in the Canyon coal has been lowered more than 600 ft. Access to Dietz wells with greater drawdown is not possible due to the safety hazard presented by venting gas. Data provided by Fidelity were used to define the maximum drawdown in the Canyon coal. The first reported water or gas production in Montana occurred during April, 1999 in the CX field. After nearly 9 years of CBM production, the 20-ft drawdown contours for both the Dietz and Canyon coals extend about 1.0 to 1.5 miles beyond the edges of the CX field. These distances are similar to, but somewhat less than originally predicted in the Montana CBM environmental impact statement (U.S. Bureau of Land Management, BLM/MT/PL-03/005, 2003). The radius of the 20-ft drawdown contour is expected to increase as the duration of production increases; however, little change in this radius can be discerned since 2004 (Wheaton and others, 2005). Projections based on computer modeling and reviews of current data from mines, show drawdown of 20 ft is expected to eventually reach as far as 4 miles beyond the edges of large production fields. Drawdown decreases at greater distances, and drawdown of 10 ft was predicted to reach as far as 5 to 10 miles beyond production fields after 20 years (Wheaton and Metesh, 2002). Faults tend to act as barriers to ground-water flow and drawdown does not migrate across fault planes where measured in monitoring wells. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, 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, including the extent of faulting and proximity to recharge areas. Since 2004, recovery due to discontinuation or reduction in CBM production has been measured at four wells near the Montana–Wyoming state line in the far western part of the study area. Drawdown in these wells ranged from 19 to 152 ft. After 4.5 years, recovery in these four wells has now reached 71 to 87% of baseline levels.

Projections are important for evaluating potential future impacts. However, inventories of existing resources and long-term monitoring are necessary to test the accuracy of these models and determine the actual magnitude and duration of impacts. After 105 months of CBM production it continues to be apparent that these monitoring data and interpretations are key to making informed development decisions and for determining the true causes of observed changes in ground-water availability.

Introduction

This report presents ground-water data and interpretations from within the northern portion of the Powder River Basin (PRB) collected through calendar year 2007. This is the fifth year in which the Montana regional coalbed-methane (CBM) ground-water monitoring network has been active. This program was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to quantify ground-water impacts or lack of impacts, to record 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). Beginning in 2008, reporting periods will be from October 1 through September 30 of each year and reports are expected to be released during the winter months.

This report includes: (1) a description of ground-water conditions outside of CBM production areas, which provides an overview of normal variations, helps improve our understanding of the ground-water regime in southeastern Montana, and provides water quality information for planning CBM projects; and (2) a description of ground-water conditions within and near CBM fields that show actual impacts from CBM production. The area covered by the CBM regional ground-water monitoring network is shown in Figure 1 and Plate 1.

All hydrogeologic monitoring data collected under the CBM regional monitoring program (including the data presented in this report) 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. 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.

Methane-production data and produced-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/), and the Wyoming Oil and Gas Conservation Commission (WOGCC) web page (http://wogcc.state.wy.us/).

A total of 863 CBM wells produced water, gas, or both in Montana during 2007, an increase of 38 wells since 2006. Fidelity Exploration & Production (Fidelity) has been producing from the CX field near Decker, Montana (Plate 1) since April 1999. Based on data from the MBOGC web page, the CX field now includes 838 wells, 729 wells of which are listed as actively producing gas or water during 2007. During 2007 Fidelity expanded the area of development within the CX field to the east, bringing new areas into production. Pinnacle Gas Resources, Inc. (Pinnacle) began production in the Coal Creek field during April 2005 and in the Dietz field during January 2006. During 2007, 36 wells are listed as producing water, methane, or both in the Coal Creek field and 96 wells are listed as producing in the Dietz field.

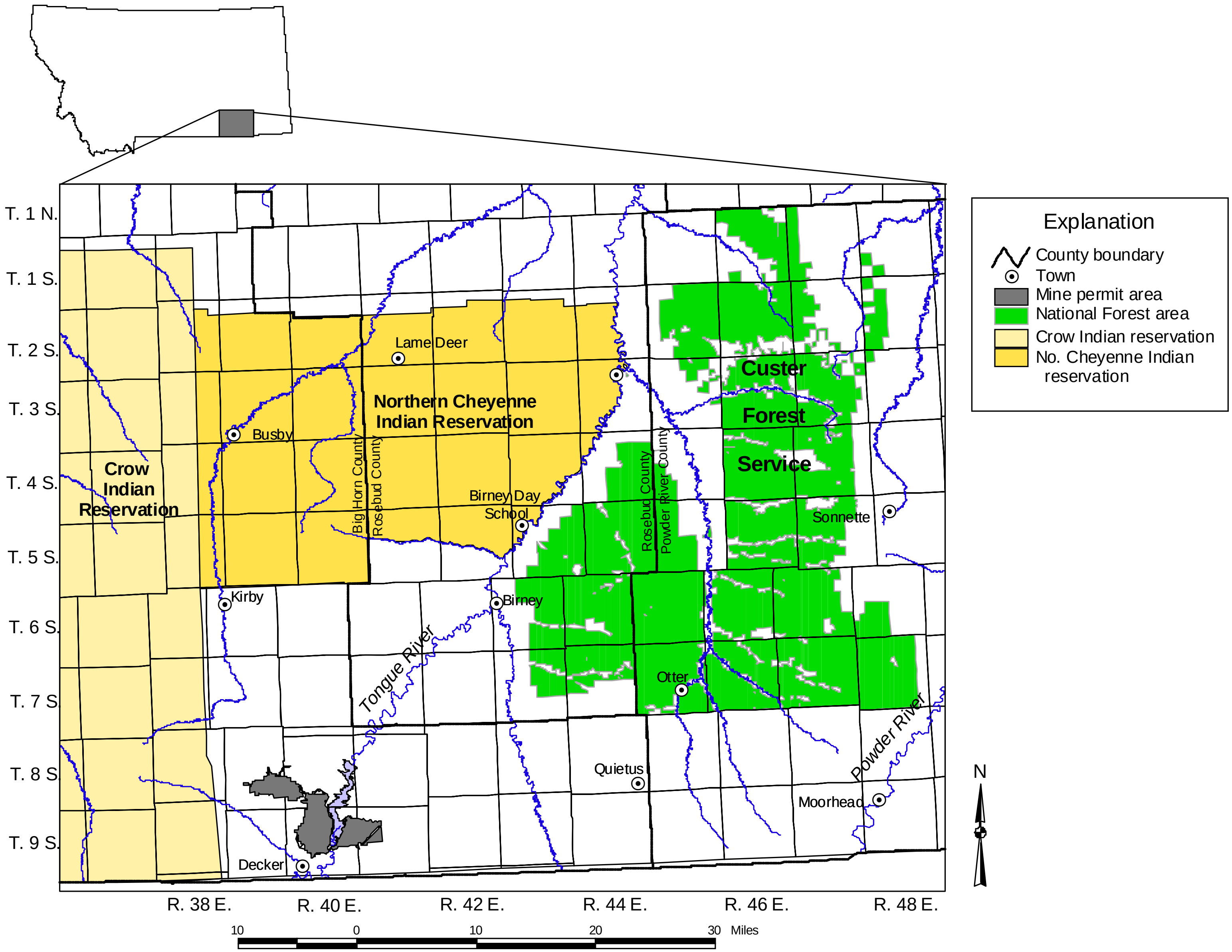


Figure 1. Location of study area.

Coalbed methane is produced in many fields in the Wyoming portion of the PRB. For the purposes of this report, only that activity in the two townships nearest the northern Wyoming border is considered (townships 57N and 58N). This covers a distance of about 9 miles from the state line (Plate 1). The Prairie Dog Creek field (3,115 active wells during 2007) in Wyoming is adjacent to the CX field in Montana. The Hanging Woman Creek field (561 active wells during 2007) is near the center of the PRB along the state line. The Powder River area (as named in this report) is on the eastern edge of the PRB in Wyoming and included 982 active wells during 2007 (Plate 1).

Hydrogeologic data were collected by MBMG at 204 wells, 13 springs, and 2 streams during 2007. Of those monitored sites, 14 wells, 9 springs, and 1 stream are located within the boundary of the Ashland Ranger District of the Custer National Forest. Six monitoring wells, located on the Northern Cheyenne Reservation, are monitored by tribal employees and the United States Geological Survey (USGS). When received, data are added to GWIC. No new monitor wells were installed in 2007. Descriptions of all wells included in the regular monitoring program and the most recent data are listed in appendix A. Site descriptions for monitored springs and the most recent flow data are listed in appendix B. Water-quality data collected during 2007 are listed in appendix C. All data were entered in and are available electronically from GWIC (http://mbmggwic.mtech.edu/). The locations of all monitoring sites are shown in Plate 1.

Acknowledgments

The landowners and coalbed-methane producers who are allowing monitoring access are gratefully acknowledged 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, and the Montana Department of Natural Resources and Conservation. The USDA Forest Service previously provided 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 hydrogeology work. The statewide Ground-Water Assessment Program, operated by the Montana Bureau of Mines and Geology (MBMG), monitors several wells and springs in the Powder River Basin, and those data are incorporated in this work. Mr. Clay Schwartz, of MBMG in Billings, monitors these wells and provides additional assistance to the regional program. Data are also collected by the Northern Cheyenne Indian Tribe with assistance from the United States Geological Survey. Technical discussions and reviews by Mr. Andrew Bobst (U.S. BLM) continue to be invaluable.

Location, description, and general hydrogeology of the area

The study area is that part of the PRB 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 (Figure 1 and Plate 1). This is the Montana portion of the PRB believed to have the highest potential for CBM development (VanVoast and Thale, 2001). Methane production data and locations are included for that portion of the PRB in Wyoming that is adjacent to the Montana–Wyoming state line (townships 57N and 58N).

The PRB is a structural and hydrologic basin in southeast Montana and northeast Wyoming. Exposed formations include the Tertiary Fort Union Formation and overlying Wasatch Formation. 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 coalbeds in the Tongue River Member are the primary targets for CBM development in Montana. The geologic and structural relationships above the Lebo Shale are shown in the cross section on Plate 1. The cross section is based on Montana Bureau of Mines and Geology (MBMG) monitoring wells and published well logs and correlations (Culbertson, 1987; Culbertson and Klett, 1979a,b; Lopez, 2006; McLellan, 1991; McLellan and others, 1990). Generally, the 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). However, methane is being produced in overlying and underlying coalbeds.

A generalized stratigraphic column showing relative stratigraphic positions of the major coalbeds is presented in Figure 2. Not all coal seams shown in Figure 2 are present across the entire basin. The coal from the Anderson and Dietz coalbeds are mined near Decker. Ground-water monitoring wells are completed in numerous coalbeds as well as the overlying and underlying sandstone units. Lithologic units on Figure 2 are marked to indicate intervals that are monitored as part of the regional network, intervals that are the source units for monitored springs, and the coal units that are presently producing CBM in Montana or Wyoming. Several sets of nomenclature are used for coalbeds in the Decker, Montana area. Table 1 shows the correlations between several different naming conventions.

The axis of the PRB in Montana coincides roughly with the Tongue River. Geologic dip is toward the west on the eastern side of the axis and toward the east on the western side. The base of the Tongue River Member is deepest in the central part of the study area nearer the basin axis (Lopez, 2006). East of the axis, ground-water recharge generally occurs along outcrop areas and flow is generally toward the west and north, eventually discharging along outcrops. West of the basin axis, recharge occurs in the topographically high areas in Wyoming and on the Crow Indian Reservation. Ground water flows to the east, toward the Tongue River. Near the Tongue River Reservoir it is interrupted by coal mines and coalbed-methane production.

Three distinct ground-water flow systems are present in the Powder River Basin: (1) local bedrock flow systems; (2) regional bedrock flow systems; and (3) local alluvial flow systems. As used in this report, the terms local and regional bedrock flow systems do not refer to specific geologic units but rather are used to describe changing ground-water conditions with respect to depth and position along flow paths. Where there are sufficient water-level data to support detailed potentiometric mapping, local flow systems demonstrate topographic control of flow direction, whereas regional systems flow toward and then follow the northward trend of the basin axis. Water quality also distinguishes the flow systems, with local ground-water chemistry typically dominated by Ca^{2+}, Mg^{2+} and SO_4^{2-} and regional systems dominated by Na^+ and HCO_3^-. Tritium (^3H) is another tool for distinguishing between local and regional flow systems. In general, a local flow system is dominated by young, recently recharged ground water, which will have tritium values

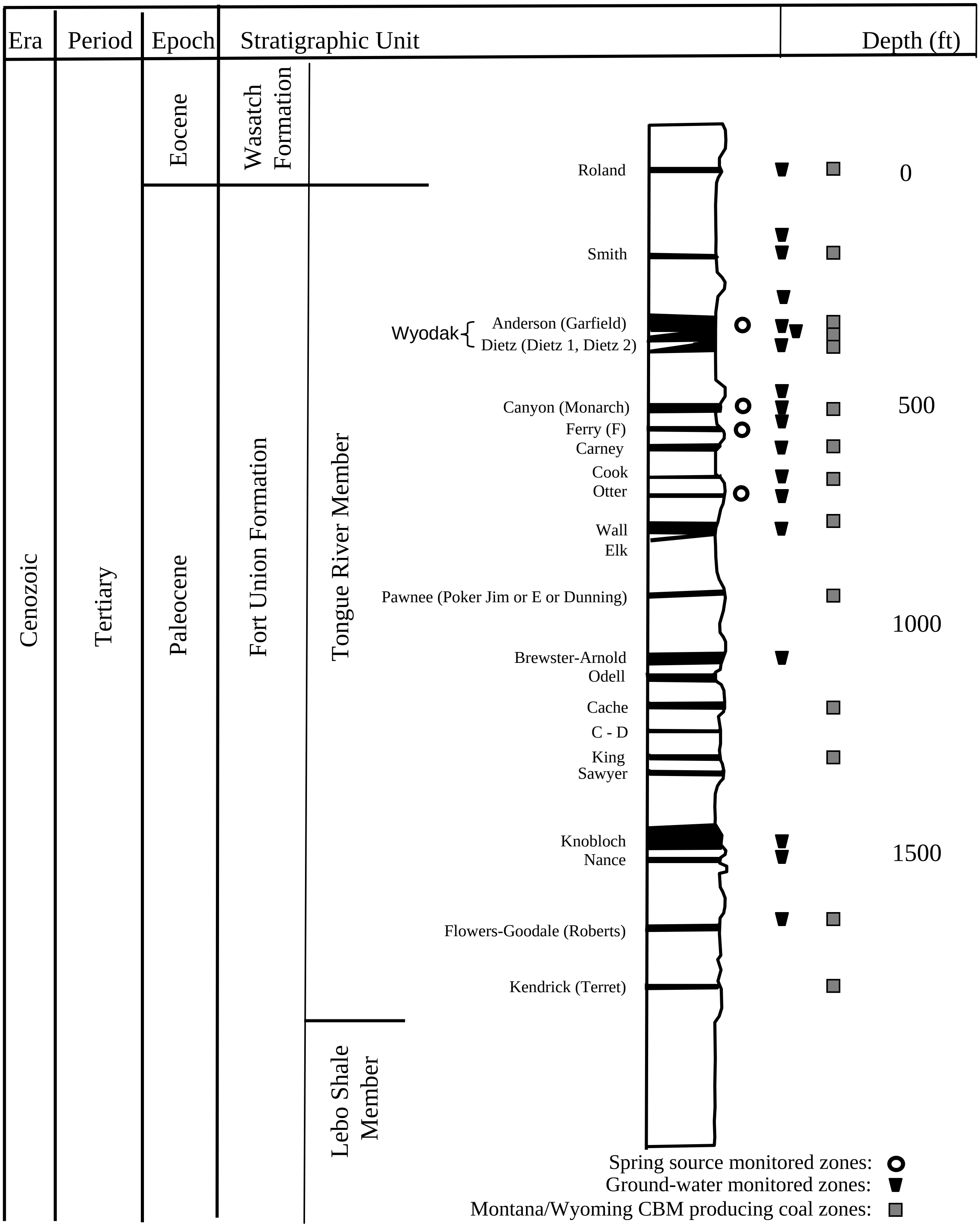


Figure 2. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation in southeastern Montana. The general relative positions of selected coal beds are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Most coals do not exist across the entire area and the interburden thickness varies considerably. The indicated depths are only approximations. Sources: Culbertson, 1987; Fort Union Coal Assessment Team, 1999; Law and others, 1979; Matson and Blumer, 1973; McLellan, 1991; McLellan and Beiwick, 1988; McLellan and others, 1990; and various U. S. Geological Survey coal resource maps prepared by the Colorado School of Mines Research Institute (1979a,b,c,d,e,f,g).

similar to modern precipitation. In contrast, a regional flow system is a longer flow path and will therefore be dominated by water which recharged the aquifer some time in the past. The tritium values of ground water in a regional flow system will reflect the tritium present in the precipitation at the time of recharge less any radioactive decay which occurred (see tritium discussion).

Recharge occurs as precipitation on clinker-capped ridges, outcrops and, in a few locations, stream-flow infiltration into underlying crop areas. Near recharge areas the local bedrock flow systems follow topography. These local flow systems either discharge to alluvial aquifers, form springs at bedrock outcrops, or seep vertically into deeper regional flow systems. Some seepage between aquifers occurs, however, it is limited due to the low permeability of the numerous shale layers. Aquifers that are local flow systems near recharge areas will be part of the regional flow system if they continue a sufficient distance and to great enough depth. The transition is gradual and not correlated with a specific length of flow path or depth.

The regional bedrock flow systems are recharged near the perimeter of the PRB in areas where aquifers crop out and by vertical leakage from the overlying local flow systems. Regionally, ground water flows from Wyoming northward into Montana and towards the Yellowstone River; discharging as springs, to streams, to alluvium, or leaves the PRB as deep ground-water flow. Hundreds of springs originating in the Tongue River Member have been inventoried and mapped in the project area (Kennelly and Donato, 2001; Donato and Wheaton, 2004a, b; and Wheaton and others, 2008). The Tongue River Member is a shale-dominated unit, with relatively thin permeable layers (coal, sandstones, and fractured carbonaceous shale). This stratigraphic setting produces spring discharge from both local and regional ground-water flow systems; and demonstrates the general lack of vertical migration between units. An unknown, but likely significant, percentage of the ground water in the Tongue River Member aquifers discharges at springs and to streams well above the base of the unit.

The coal-bearing Tongue River Member is bounded on the bottom by the Lebo Shale aquitard (Figure 2 and Plate 1). Due to the low vertical permeability of the Lebo Shale, most ground-water that is remaining in lower units of the Tongue River Member at its contact with the Lebo Shale is forced to discharge to springs and streams along the contact between the two units, which is south of the Yellowstone River. A smaller proportion probably seeps vertically into the underlying Tullock Member. Contact springs at the base of the Tongue River Member add baseflow to streams and support springs. In terms of coalbed-methane development, the Lebo Shale effectively limits the potential for impacts from reduced hydrostatic pressure and management of produced water to only those units lying stratigraphically above this aquitard.

Table 1. Correlation of nomenclature used by the MBMG, USGS, coal mine companies, and CBM companies 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 Exploration and Production Company	Pinnacle Gas Resources
Roland	Roland		Roland	Roland	
Smith	Smith		Smith	Smith	Smith
Anderson	Anderson / D1	D1 Upper		D1	Anderson
Dietz 1	D2 Upper	D1 Lower	Anderson-Dietz	D2	D2
Dietz 2	D2 Lower / D3	D2		D3	D3
Canyon	Monarch / Canyon	Canyon / D3	Canyon	Monarch	Canyon
Carney	Carney	D4	D4	Carney	Cook
Cook	Cook				
Wall	Wall	D6	D6	Wall	Wall
					Brewster-Arnold
King	King			King	King
Knobloch	Knobloch	Knobloch	Knobloch	Knobloch	Knobloch
Flowers-Goodale	Flowers-Goodale			Roberts	Flowers-Goodale

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 1959-A

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. Water level differences between aquifers can suggest downward gradients (hydraulic head is lower in wells in deep aquifers than those in shallower aquifers) or upward gradients (hydraulic head is higher in wells in deeper aquifers than those in shallower aquifers). Most areas in the PRB show downward gradients. Areas of recharge have strong downward gradients, while upward gradients indicate proximity to discharge areas.

The ability of an aquifer to store and release water is determined by its storativity (S). Storativity is a combination of two distinct components: specific yield (S_y) and specific storage (S_s). Specific yield is a measure of the volume of water that can be drained from the pore spaces per unit volume of material. Water stored or released due to specific storage results from changes in pressure within the aquifer, which causes the aquifer's mineral skeleton and the water itself to expand and contract. Specific storage is the volume of water released from a unit volume of aquifer per unit change in pressure head. Specific yield is several orders of magnitude greater than specific storage for a given aquifer (Fetter, 1994). Within unconfined, or water table, aquifers the primary means of water release to wells is from specific yield as pore spaces are dewatered, while the effects of specific storage are negligible. Within confined aquifers (such as most areas of coalbeds in the PRB) specific storage, not pore drainage, is the primary means of ground-water release.

Davis (1984) reported values of specific yield for unconfined coal aquifers in the PRB on the order of 0.003 to 0.03, based on effective porosity measurements. For these values, between

0.003 and 0.03 ft^3 of water would be released by completely draining 1 ft^3 of a coalbed aquifer. Typical values for specific storage for a confined coalbed aquifer are much less, on the order of 0.00006 (Wheaton and Metesh, 2002). In this case, reducing the hydrostatic pressure of a confined coalbed by 1 foot would release 0.00006 ft^3 of water from a unit volume (1 ft^3 of material). The two examples of water released are basically comparable, as each represents a 1 ft change in water level within 1 ft^3 of the aquifer. The difference in the quantities of water released is a function of how the water is released. When the water level in an unconfined aquifer is lowered, the pore spaces are drained. When the water level in a confined aquifer is lowered, the confining pressure is reduced, which releases water due to the expansion of the aquifer's matrix and the water. Removal of water during CBM production typically reduces the hydrostatic pressure rather than draining the pores.

The reduction of hydrostatic pressure in coal aquifers during coalbed-methane production may affect yield from wells and discharge rates of springs, which obtain their water from the developed coal seams. The magnitude, geographic extent, and duration of this drawdown are primary focuses of the regional monitoring program. Coalbeds in the PRB are generally separated from other aquifers by shale units. Due to these confining shale units, in most areas water-level drawdown in response to CBM production is expected to be limited to the coal aquifers and not migrate vertically to impact overlying or underlying aquifers. At a few selected locations, overburden and underburden aquifers are monitored and generally verify this concept. In southeastern Montana, faults in the Fort Union Formation are typically no-flow boundaries 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). These wells continue to be monitored, and they continue to demonstrate that this fault is a no-flow boundary.

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 PRB, coalbed methane exists only in reduced (oxygen poor) zones where the water quality is characterized by high concentrations of Na^+ and HCO_3^- and low concentrations of Ca^{2+}, Mg^{2+} and SO_4^{2-} (Van Voast, 2003). Ground-water quality in coal seams is not expected to change in response to CBM production. Infiltration of produced water may, however, cause changes in shallow ground-water quality. To document possible changes, water-quality data are collected in shallow aquifers.

Water-quality samples are collected from monitoring wells as part of the regional ground-water monitoring program and have been collected during previous projects in southeastern Montana. Water-quality data are available in GWIC for 60 samples from monitoring wells completed in coal aquifers where CBM development is both probable in the future and currently occurring in southeastern Montana. The samples chosen for statistical analyses from the data set of coal-aquifer water quality samples were from those wells within the area of likely CBM development and which had bicarbonate comprising at least 90% of the anions in meq/L. Additionally, only the most recent water-quality sample was chosen for inclusion in the statistical analysis where more than one water-quality measurement was reported. Summary statistics for these data are presented in table 2. Based on this analysis, CBM production water in Montana has a median TDS concentration of 1,311 mg/L and a median sodium adsorption ratio (SAR) value of 46.

Low sulfate concentrations in coalbed water indicate reducing conditions and can be an important tool for CBM exploration (Van Voast, 2003). The median sulfate value for the samples included in this summary is 3 mg/L, though samples with concentrations as high as 78 mg/L were included in the selected data set.

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

	SC (umhos/cm^2)	pH	TDS (mg/L)	SAR	Sulfate (mg/L)
Median	2,073	8.10	1,311	46	3
Standard Deviation	565	0.36	366	13	21
Minimum	1,082	7.56	666	4	0
Maximum	3,123	9.36	2,020	103	78

Count is 60; sample dates span June 1972 to August 2007.
SC refers to Specific Conductance, TDS refers to Total Dissolved Solids, and SAR refers to Sodium Adsorption Ratio.

The PRB area is semi-arid, receiving on average less than 15 inches of precipitation per year, based on data from Fort Howes, Badger Peak, Bradshaw Creek, and Moorhead stations (Plate 1). Typically, in the PRB, May and June are the wettest months and November through March the driest. The annual average high temperature is in the low 60ºF range with July and August being the warmest. Annual average low temperature is about 30ºF; December and January are the coolest months (Western Regional Climate Center, 2008).

Aquifers are recharged by precipitation and shallow ground-water levels reflect both short- and long-term precipitation patterns. Precipitation data for the Moorhead station in the southeast part of the study area along the Powder River, near the Montana–Wyoming state line, indicate average total annual precipitation is 11.49 inches, based on records from 1958 through 2007 (Western Regional Climate Center, 2008). During 2007, Moorhead received 15.41 inches of precipitation, which is 34 percent above normal (Figure 3). Long-term precipitation 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 in Figure 3). 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.

Modern streams in the Montana PRB have formed valleys that cut through the entire coal-bearing Tongue River Member. Coal seams exposed along valley walls allow ground-water seepage to form springs and allow methane to naturally leak to the atmosphere. Ground-water monitoring wells completed in a coalbed occasionally release methane under static water-level conditions. It is interpreted that these wells are completed in an area of the coalbed where methane adsorption sites are saturated and free methane is either held in a structural or sedimentary trap or is migrating.

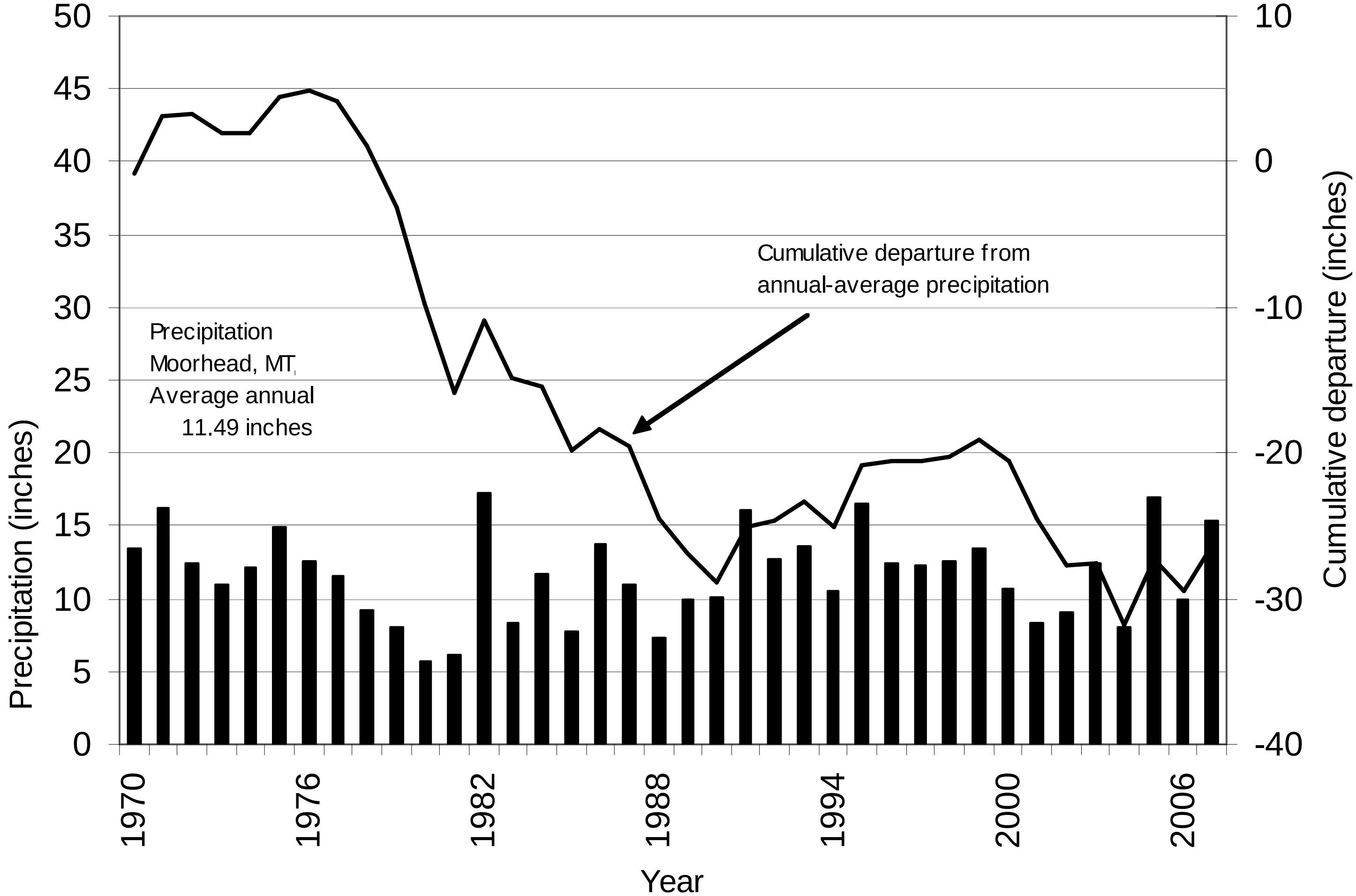


Figure 3. Annual precipitation (bar graph) at Moorhead MT. Cumulative departure from average precipitation provides a perspective on the long-term moisture trends that may effect ground-water recharge.

Ground-water conditions outside of potential coalbed-methane influence

Bedrock aquifer water levels and water quality

Ground-water levels (the potentiometric surface) and inferred ground-water flow directions in the Dietz coal seam, as interpreted from the available data, are shown on Plate 2. Near the outcrop areas, topography exerts a strong control on flow patterns. Ground water generally flows towards the basin axis which, in Montana roughly follows the Tongue River, and from south to north. Recharge in Montana occurs along the western outcrop areas in the Wolf Mountains and in the east near the Powder River. Other regional bedrock aquifers in the Tongue River Member should have similar flow patterns relative to their outcrops.

The potentiometric surface and ground-water flow directions interpreted from the data available for the Canyon coal are shown on Plate 3. Recharge occurs along the western and eastern flanks of the Powder River Basin in Montana, and ground water flows from Wyoming into Montana. Groundwater discharges to outcrop areas along stream channels and to CBM wells.

Hydrographs and geologic cross sections for selected monitoring sites that are outside of potential coalbed-methane impacts are presented in figures 4 through 12. At monitoring site CBM03-12, data from 1974 through 2007 from an overburden sandstone and the Canyon coal indicate a downward gradient (Figure 4). These wells are located in the eastern part of the study area near Bear Creek, and show no response to CBM production. They do, however, show a decline in water levels that is likely related to the long-term precipitation trend (Figure 3). At site CBM03-11, the Anderson, Dietz, and Canyon coals also show a downward gradient (Figure 5). This site is in the south-central portion of the monitoring area, near the Anderson coal outcrop, and reflects background conditions.

Monitoring site CBM02-8 is west of the Tongue River near the outcrop of the Knobloch coal, where 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 (Figure 6). 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. The upward gradient suggests that this is a discharge area for the Flowers-Goodale units. Flowing wells near Birney, including the town water supply well, also reflect this upward gradient. 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. Well CBM02-8DS is completed in channel sandstone overlying the Flowers-Goodale, also known as the “D” sandstone that has been identified as a possible location for re-injecting CBM produced water (Lopez and Heath, 2007). Yield from this well was measured during drilling at approximately 35 gpm.

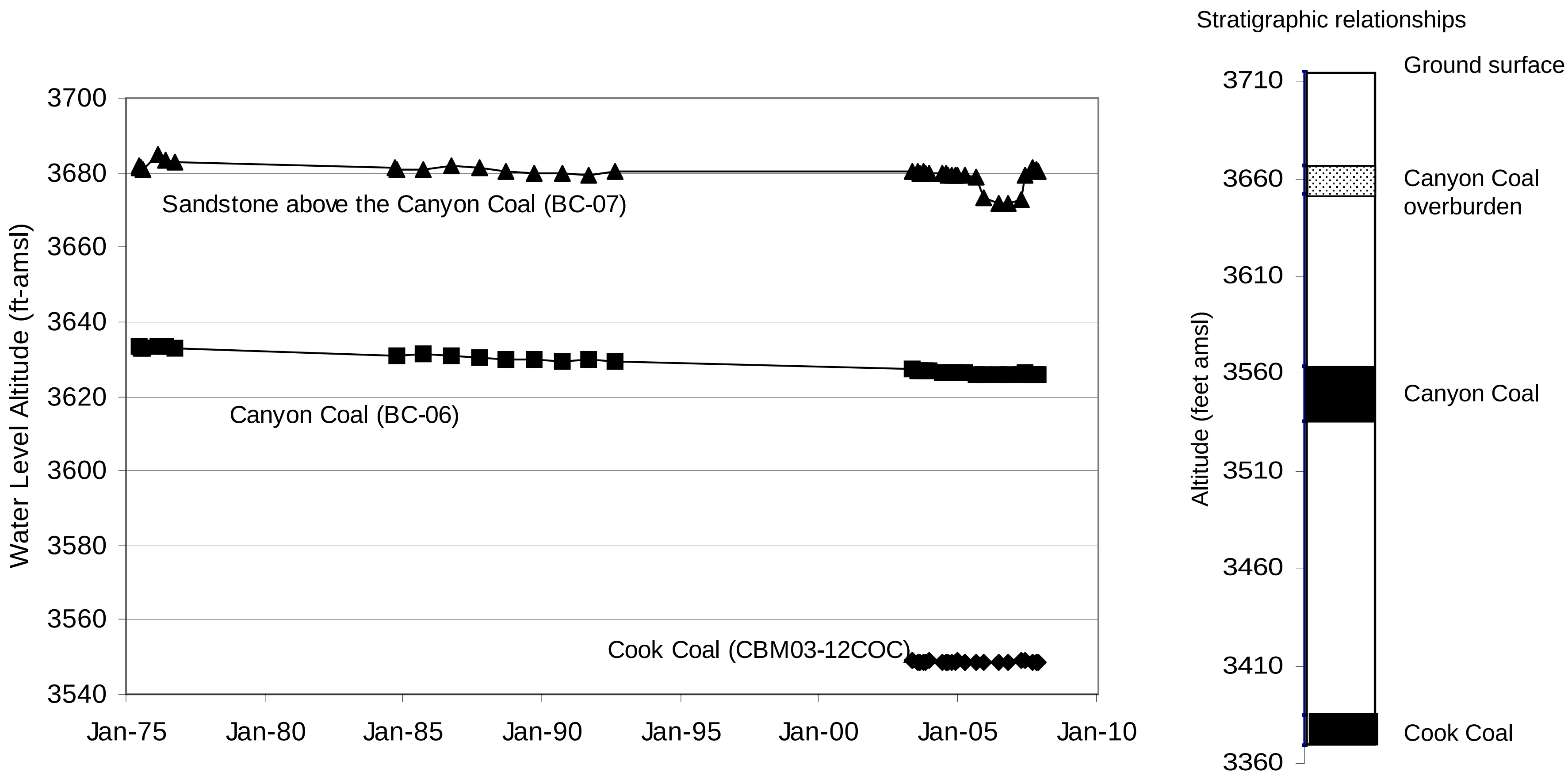


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07), and Canyon coal (BC-06), likely relates to precipitation patterns shown on Figure 2. The short period of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence. In addition to the long-term decrease BC-07 experienced a rapid water level decrease followed by an increase. This water level change is unexplained at this time.

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

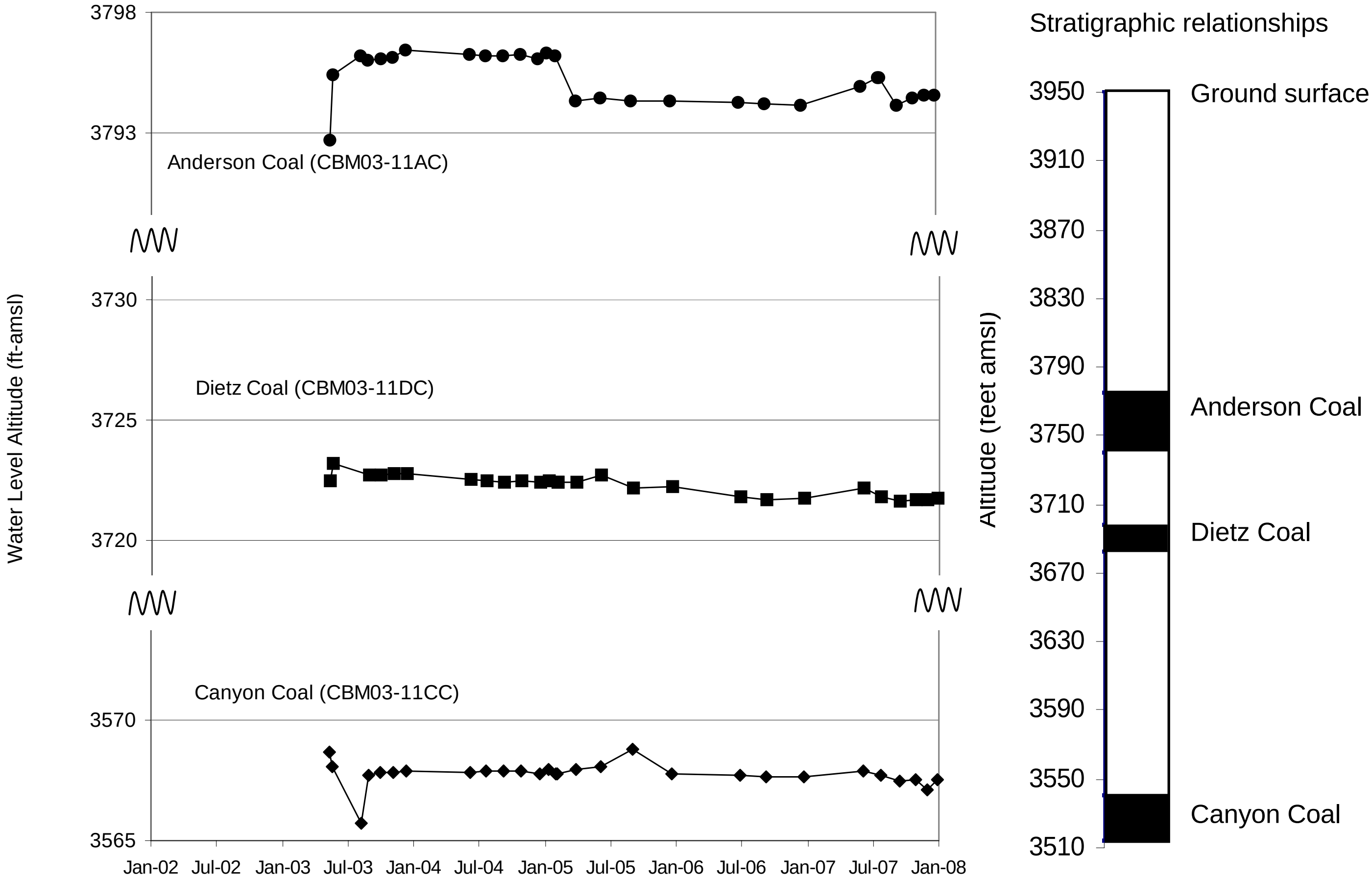


Figure 5 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.
The Y axis scale is broken to show better hydrograph detail.

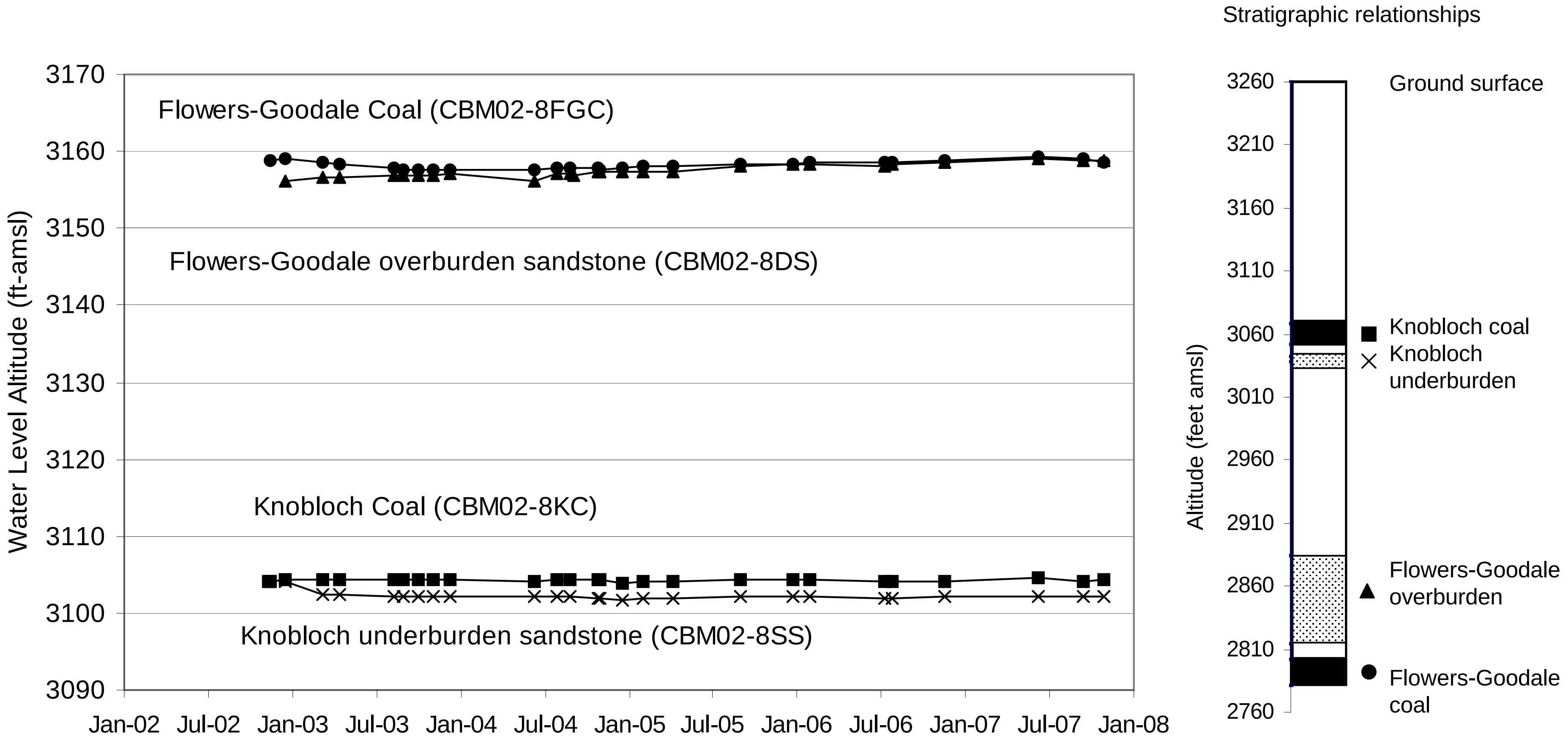


Figure 6. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site.

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

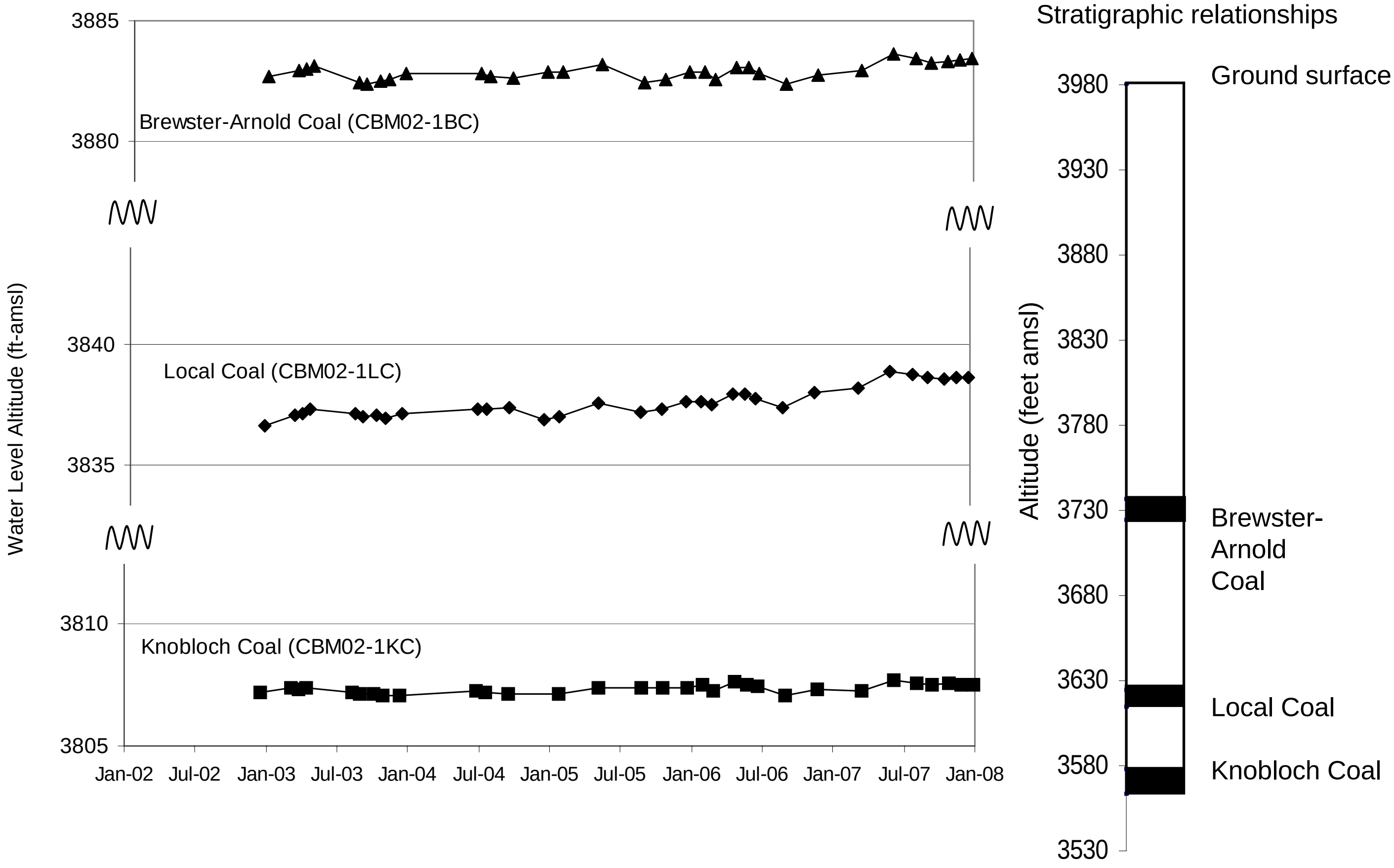


Figure 7. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site.

Note: The vertical scales of the stratigraphic relationship and the hydrograph are different. The Y axis scale is broken to show better hydrograph detail.

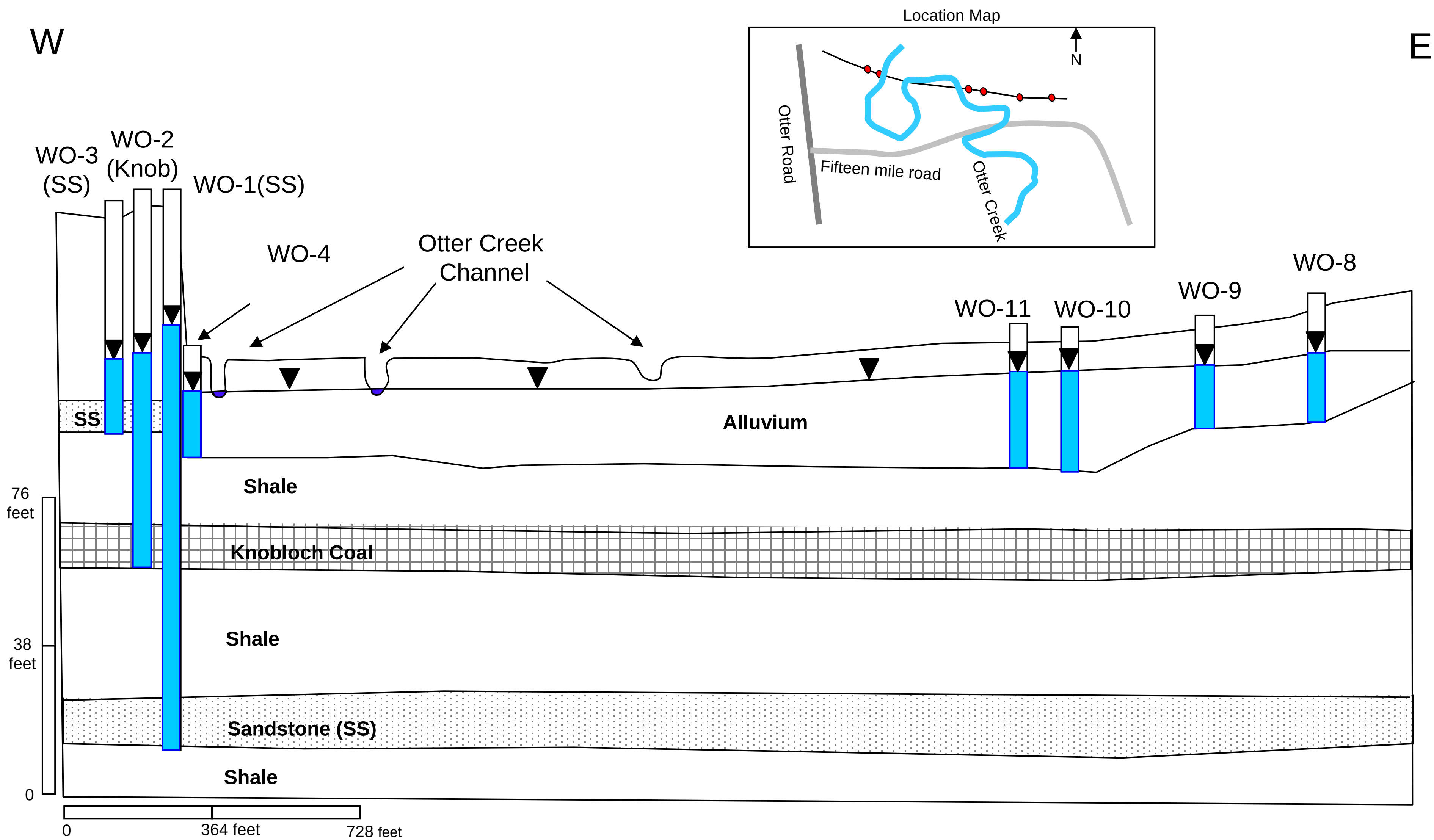


Figure 8. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in February, 2007. Vertical exaggeration is 9.6:1.

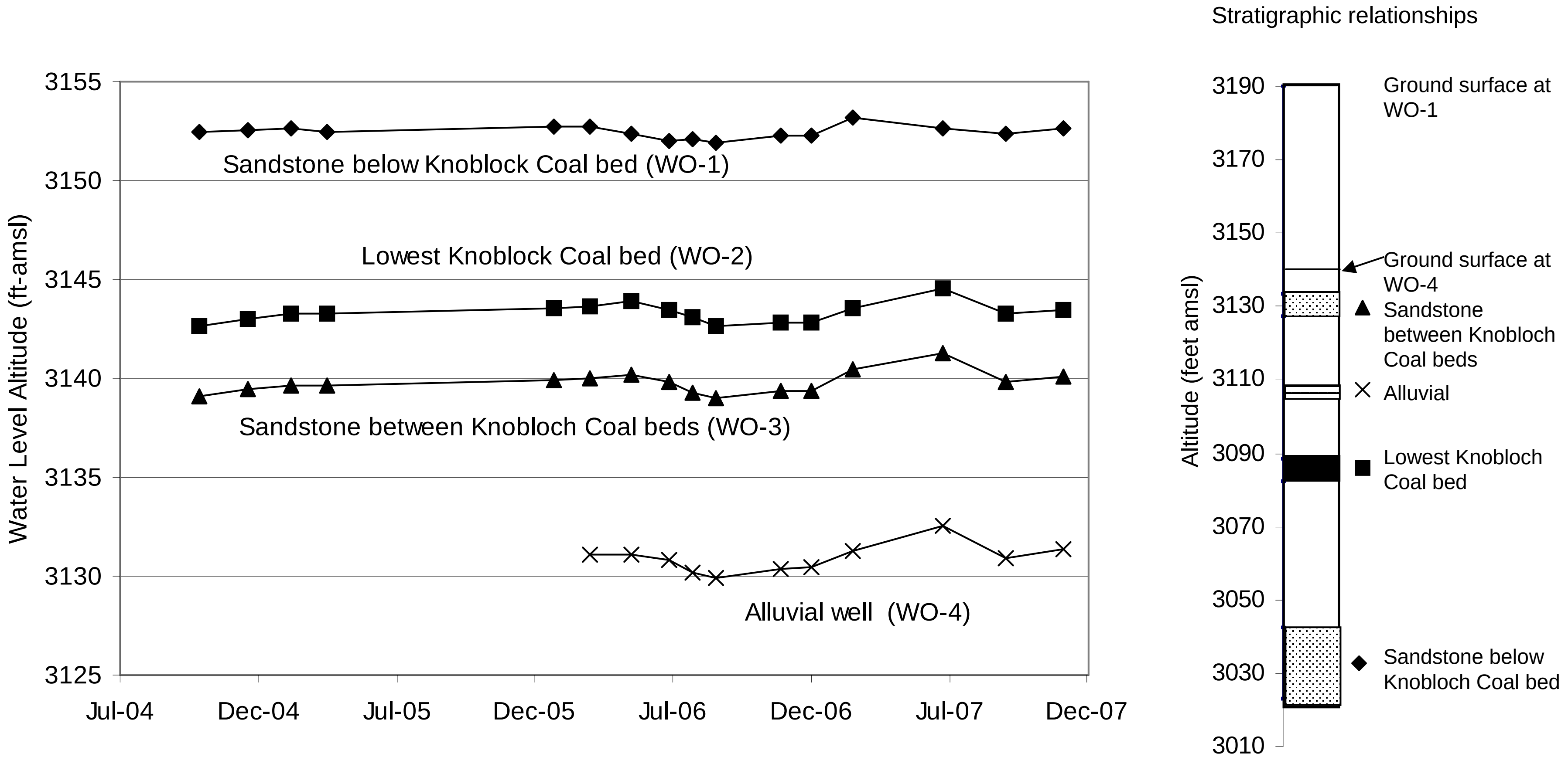


Figure 9. Bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. The alluvial well appears to show the general seasonal water year cycle.

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

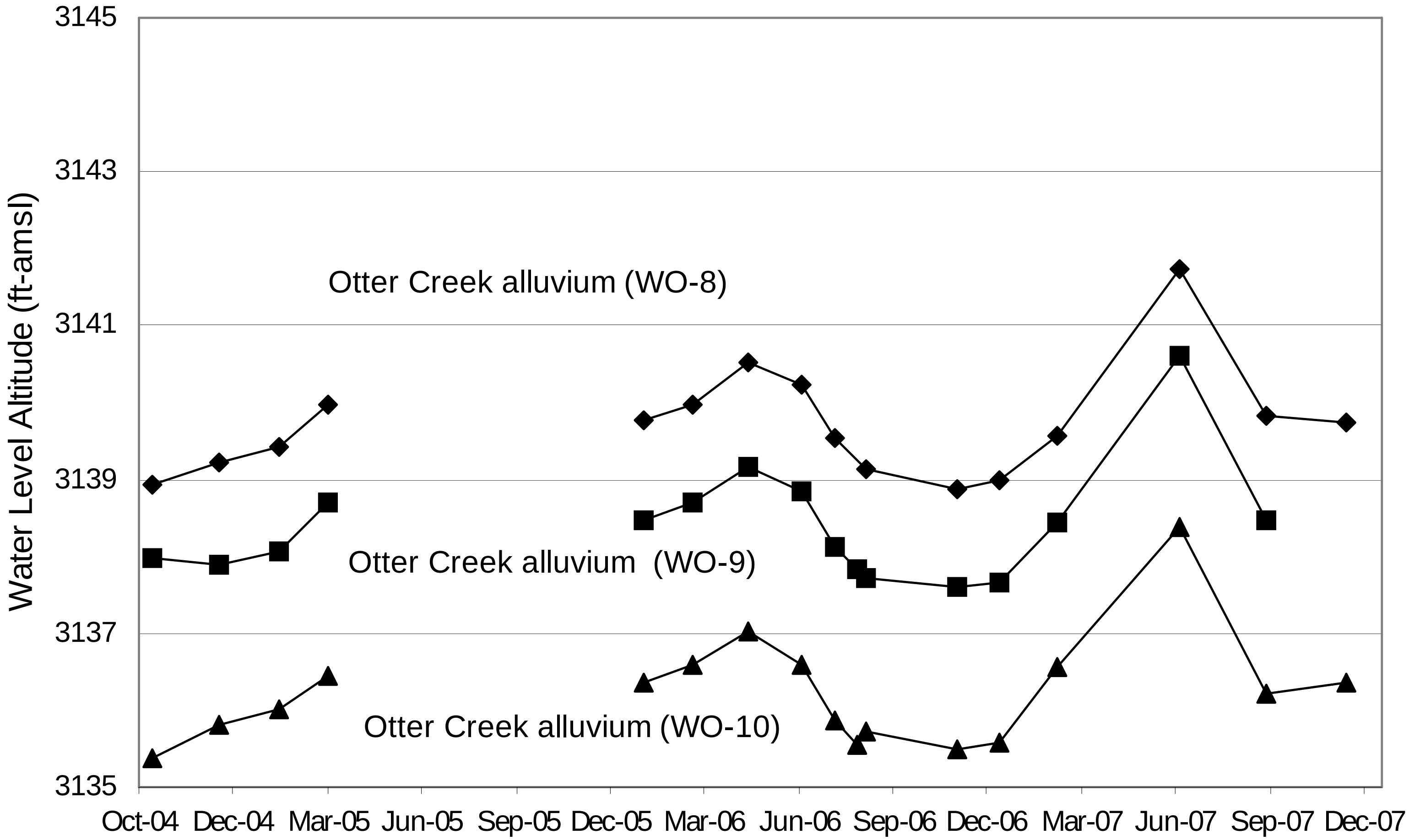


Figure 10. Water-level trends in the alluvium at the Otter Creek site probably relate to weather patterns. The alluvial aquifer appears to receive recharge from the bedrock aquifers in the area, based on the upward vertical gradient.

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 7). Water-level data from the Brewster-Arnold coal and the local coal demonstrate a slight annual trend, with lowest levels in late summer or early fall, indicating a relationship with precipitation patterns. The deeper Knobloch coal does not reflect a seasonal pattern and is most likely part of the regional flow systems.

At monitoring site WO-1, along Otter Creek, an upward vertical gradient exists, indicating proximity to a ground-water discharge zone (figures 8, 9, and 10). There are several flowing wells in this area, owing to this upward gradient. The shallow sandstone (WO-3) is directly discharging to the Otter Creek alluvium, which is providing baseflow for the creek. The deeper units (WO-1 and WO-2) are likely confined, and therefore are flowing towards their outcrop/subcrop areas.

Water-quality samples were collected from two Anderson (CBM03-11AC GWIC ID# 203705, SL-5AC GWIC ID# 219927) and one Canyon (CBM03-11CC GWIC ID# 203708) coalbed wells outside areas of coalbed-methane production in 2007 (appendix C). Concentrations of TDS were 1,219 and 3,409 mg/L and SAR values were 38 and 34 for the Anderson coalbed wells. A TDS concentration of 1,778 mg/L and SAR value of 63 was determined for the Canyon coalbed at this site.

Several monitoring wells on the southern border of the Northern Cheyenne Reservation (Plate 1) are being monitored for influences of CBM production. These wells were installed and are monitored through a cooperative effort by the Northern Cheyenne Nation, the USGS and the BLM. Monitoring wells NC02-1 through NC02-6 monitor the water levels of the Wall, Flowers-Goodale, Pawnee, Wall, and Knobloch (2) coal beds respectively. None of these wells have shown any significant changes in water level since monitoring began in 2002. Water level data for these wells are available on the Montana Bureau of Mines and Geology GWIC web-site and the USGS NWIS website (http://nwis.waterdata.usgs.gov/).

Alluvial aquifer water levels and water quality

Water levels in the Otter Creek alluvium are lower than those in the underlying bedrock aquifers at site WO-8. The upward vertical gradient described above indicates a bedrock aquifer discharge zone (figures 8, 9, and 10). Based on the upward hydrologic gradient at this site, the Otter Creek alluvium receives discharge from bedrock aquifers in this area. Alluvial water levels at this site vary with the seasonal trend. Otter Creek appears to be transitional between a gaining or losing stream in this area depending on the exact location along the stream, and the seasonal alluvial ground-water level.

Water levels in Rosebud Creek alluvium vary with precipitation trends. The geologic cross section, shown in Figure 11, crosses Rosebud Creek and a tributary. As shown in Figure 11, ground water flows toward, and provides baseflow to, Rosebud Creek (i.e., it is a gaining stream). Data, particularly those from the continuous recorders at the site, show the relationships between meteorological conditions, ground-water levels, and surface-water flow (Figure 12). Ground-water levels show typical annual responses with highest levels occurring during the late winter and early spring and lowest levels occurring during late summer and fall (Figure 12a). Flow data in Figure 12b for Rosebud Creek are from the U.S. Geological Survey gauging station near Kirby (station number 06295113) and are available from the website at http://waterdata.usgs.gov/mt/nwis/uv?06295113. Stream flows correlate well with precipitation events.

A comparison of the water-level and air temperature data at the RBC-2 site demonstrate part of the effect of transpiration on water table aquifers (Figure 12c). Diurnal fluctuations in the water table are the result of transpiration from the surrounding alfalfa crop. As air temperatures increase in the morning, plant growth increases and water consumption increases, lowering the water table. In the evening, as the air temperature decreases, plant stress on the water table decreases and the ground-water level recovers. The rate of withdrawal is greater than the rate of recovery, so over the period of the growing season, the water table is lowered. During September the air temperature dropped during a storm event. The transpiration demand decreased and precipitation reaching the water table caused a significant rise in the ground-water level. This event marked the beginning of the fall recharge period. Detailed precipitation data from this site for three fall precipitation events during September and October 2006 (MBMG file data), when compared to continuously-recorded water levels, indicate a 6- to 18-hour lag period between the onset of rainfall and a rise in ground-water levels.

During 2007, water-quality samples were collected in May and September from one alluvial well (RBC-2 GWIC ID# 207066) outside areas of potential coalbed-methane influence (appendix C). These samples were collected near Rosebud Creek. Concentrations of TDS were 561 and 575 mg/L and SAR values were 0.9. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate. The data are available on GWIC.

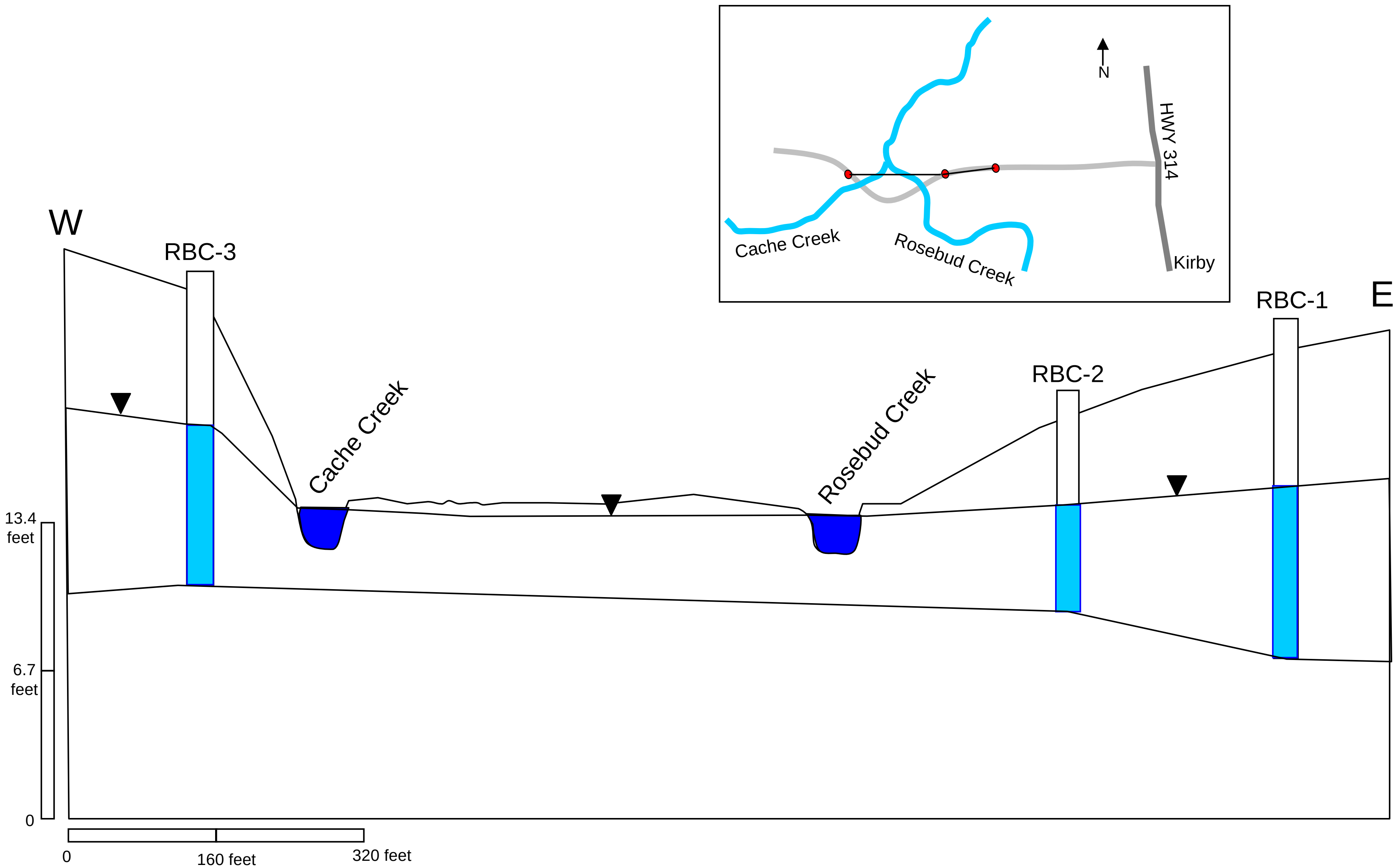


Figure 11. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The water levels at RBC-2 shows a correlation with the diurnal effect from the surrounding alfalfa plants. Water levels for this cross section were taken in January 2007.

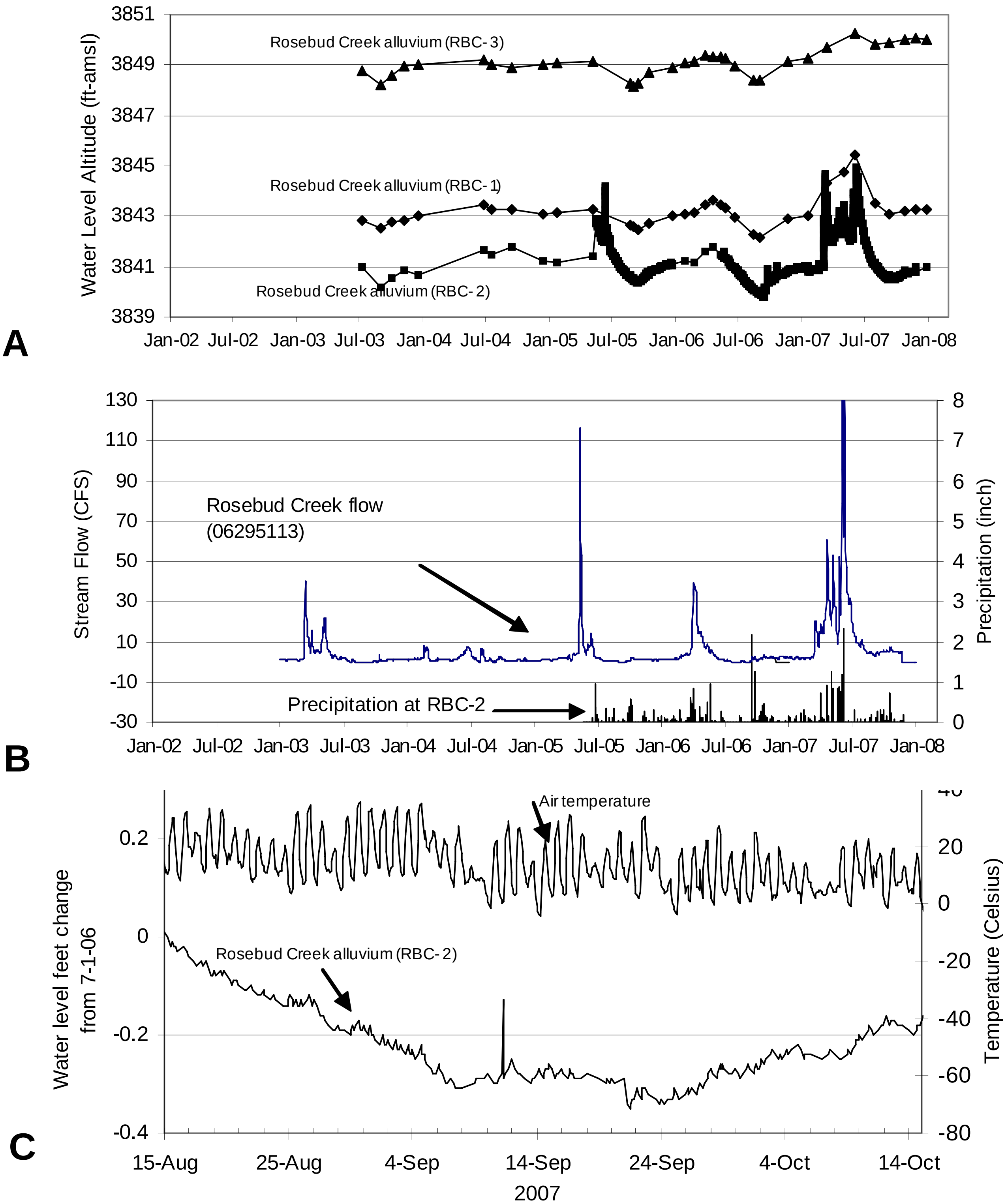


Figure 12. A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. B) Rosebud Creek stream flow follows precipitation trends. C) Diurnal drawdown occurs in the aquifer due to the surrounding alfalfa fields as shown by the correlation between water levels and air temperature. Note that the X axis on C is reduced to a shorter time scale.

Spring and stream flow and water quality

Flow rates and specific conductivity data were collected at 13 springs and one stream within the project area during 2007. All of these springs and the stream are located outside the current area of potential CBM impacts. The locations of monitored springs and stream are shown in Plate 1, site data are in appendix B, and water chemistry in appendix C. Data collected from these sites during 2007 are available in the GWIC database. Springs are discharge points for ground-water flow systems. Local recharge occurs on ridge tops adjacent to springs or along the hillside between the spring and the top of the adjacent ridge. Regional recharge originates at more distant locations such as outcrop areas along the edges of the Powder River Basin and flows beneath valleys between the recharge area and the discharge area. If a spring is topographically isolated from the regional flow systems by a valley, it is assumed to be local in origin. Springs located at higher elevations, such as at the base of clinker zones on ridges, are recharged by local ground-water recharge. Springs located low on hillsides or along the floors of major valleys such as Otter Creek may represent regional flow systems or a combination of local and regional recharge. A survey of springs within the northern PRB showed that most springs probably obtain their water from local flow systems (Wheaton and others, 2008). Springs are identified by a local name or, where absent, the GWIC number is used.

In the southern portion of the Custer National Forest Ashland Ranger District, along Otter Creek, Alkali Spring discharges at an average rate of 0.9 gpm. The discharge rate at this spring shows some seasonal influence (Figure 13). This spring represents either local flow or a mixture of regional and local flow systems. It appears that the Otter coal supplies some of the water to this spring.

The North Fork Spring is in the southeastern portion of the Ashland Ranger District. This spring is located in a topographically high area and shows moderate seasonal influence in discharge rates which are less than 1 gpm (Figure 14). This spring is associated with an isolated portion of the Canyon coal and likely represents local ground-water recharge.

Lemonade Spring is located east of the town of Ashland along U.S. Highway 212. This spring is associated with the Ferry coalbed, and probably receives local recharge. Discharge at this spring averages 1.7 gpm, showing moderate seasonal variations (Figure 15).

The East Fork Hanging Woman Creek site is located on the Ashland Ranger District boundary, east of Birney. The site consists of a v-notch weir with a stage recorder. Annual average flow measured at the weir during 2007 was 137 gpm. During winter months the creek freezes and there is no flow. The maximum flow rate was 1,000 gpm during June (Figure 16). Flow in East Fork Hanging Woman Creek responds to precipitation events, and is sensitive to antecedent soil-moisture conditions and available storage capacity in upstream reservoirs. Three rainfall events during the spring, 2007, exceeded 2 inches as measured at the Poker Jim meteorological station located near the headwater area for the creek. At the weir, the streamflow increased during the first two events from about 20 gpm to nearly 200 gpm. In response to the third event, the flow increased to 1,000 gpm.

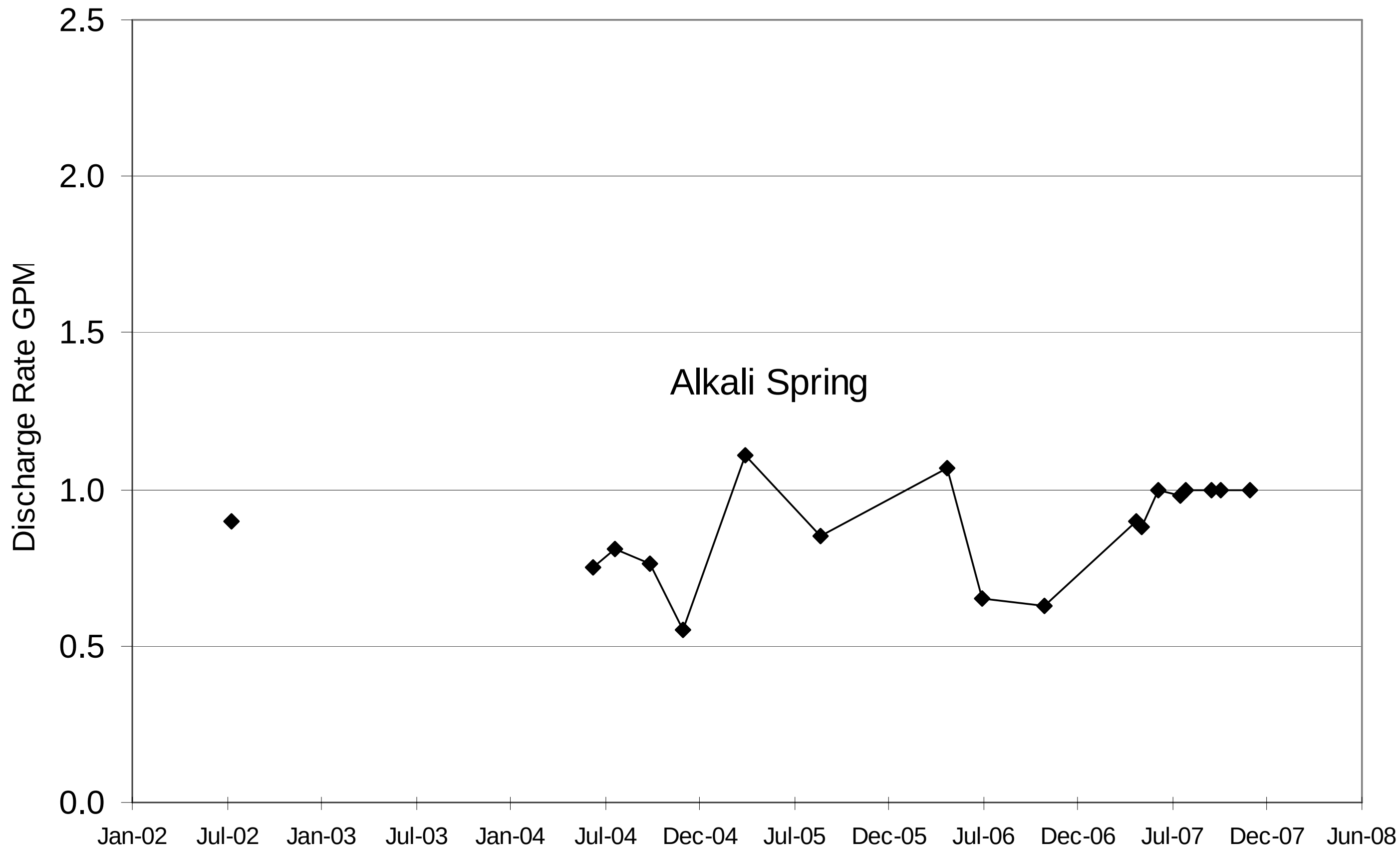


Figure 13. The Alkali Spring (GWIC M:197452) appears to be a combination of local and regional recharge associated with the Cook Coal aquifer. The spring discharges at about 0.9 gpm.

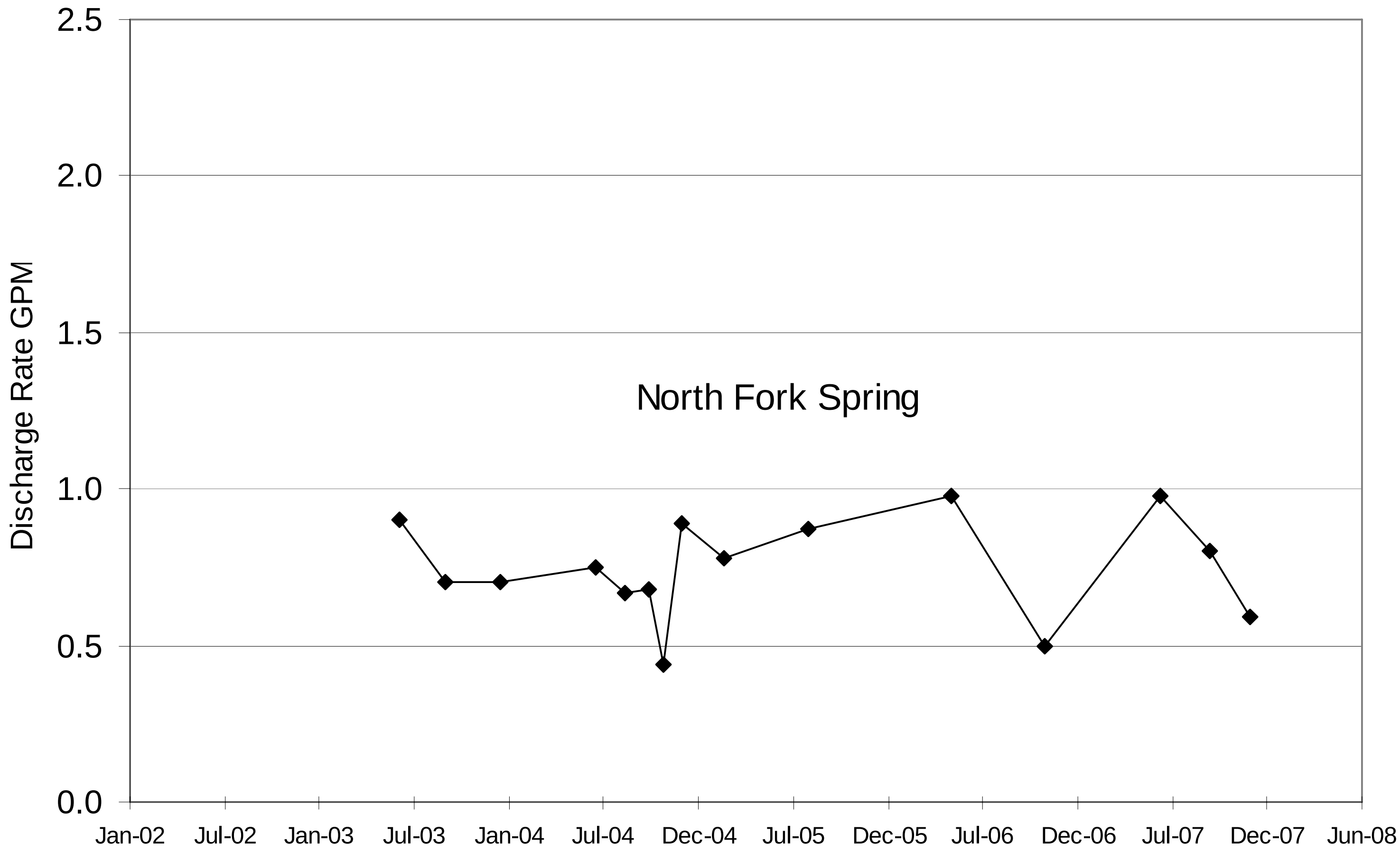


Figure 14. The North Fork spring (GWIC M: 205010) appears to be locally recharged by the Canyon Coal aquifer. The spring discharges less than 1 gpm.

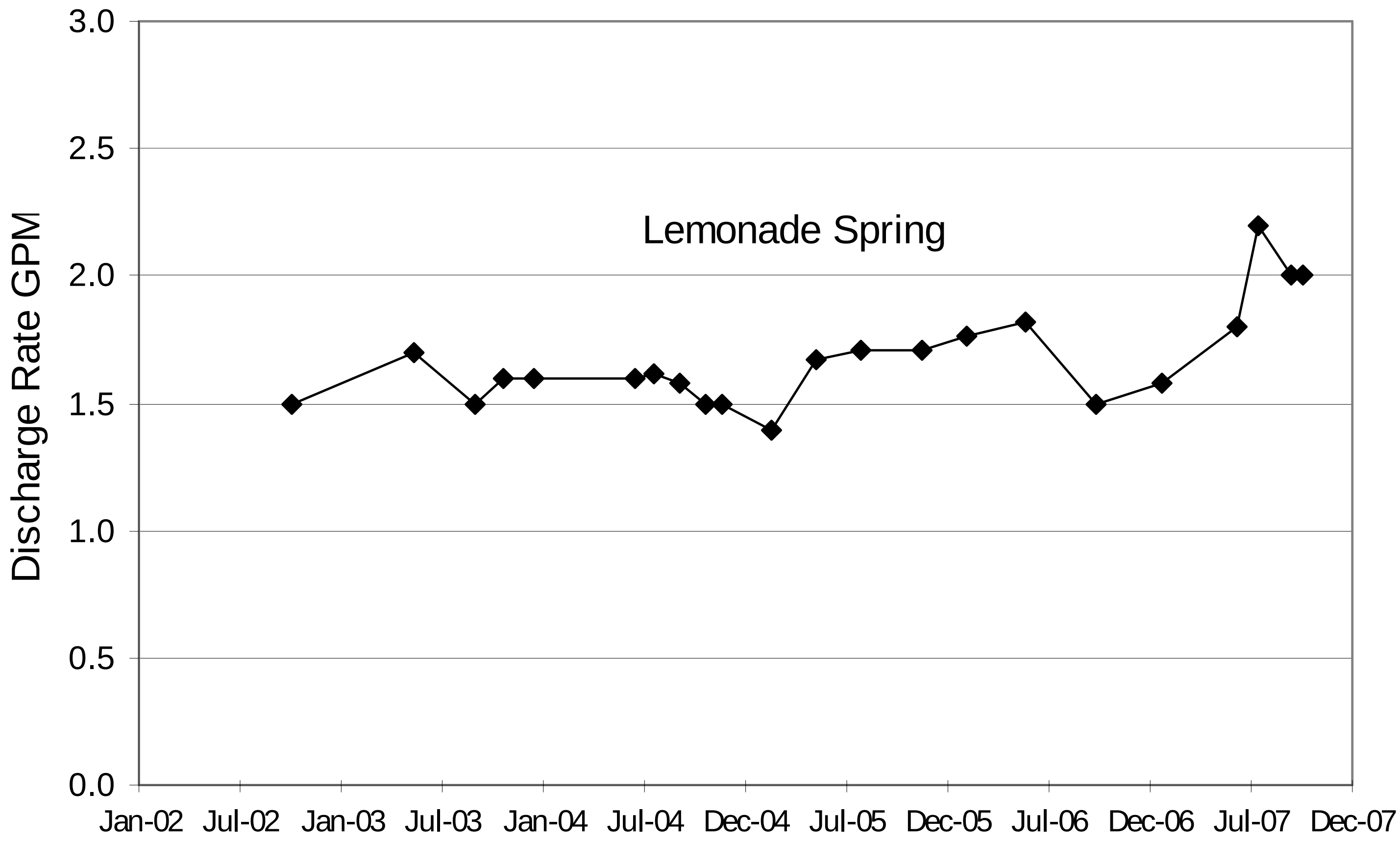


Figure 15. Lemonade Spring (GWIC M:198766) appears to be locally recharged by the Canyon and Ferry coal beds. The spring has an average discharge of 1.7 gpm.

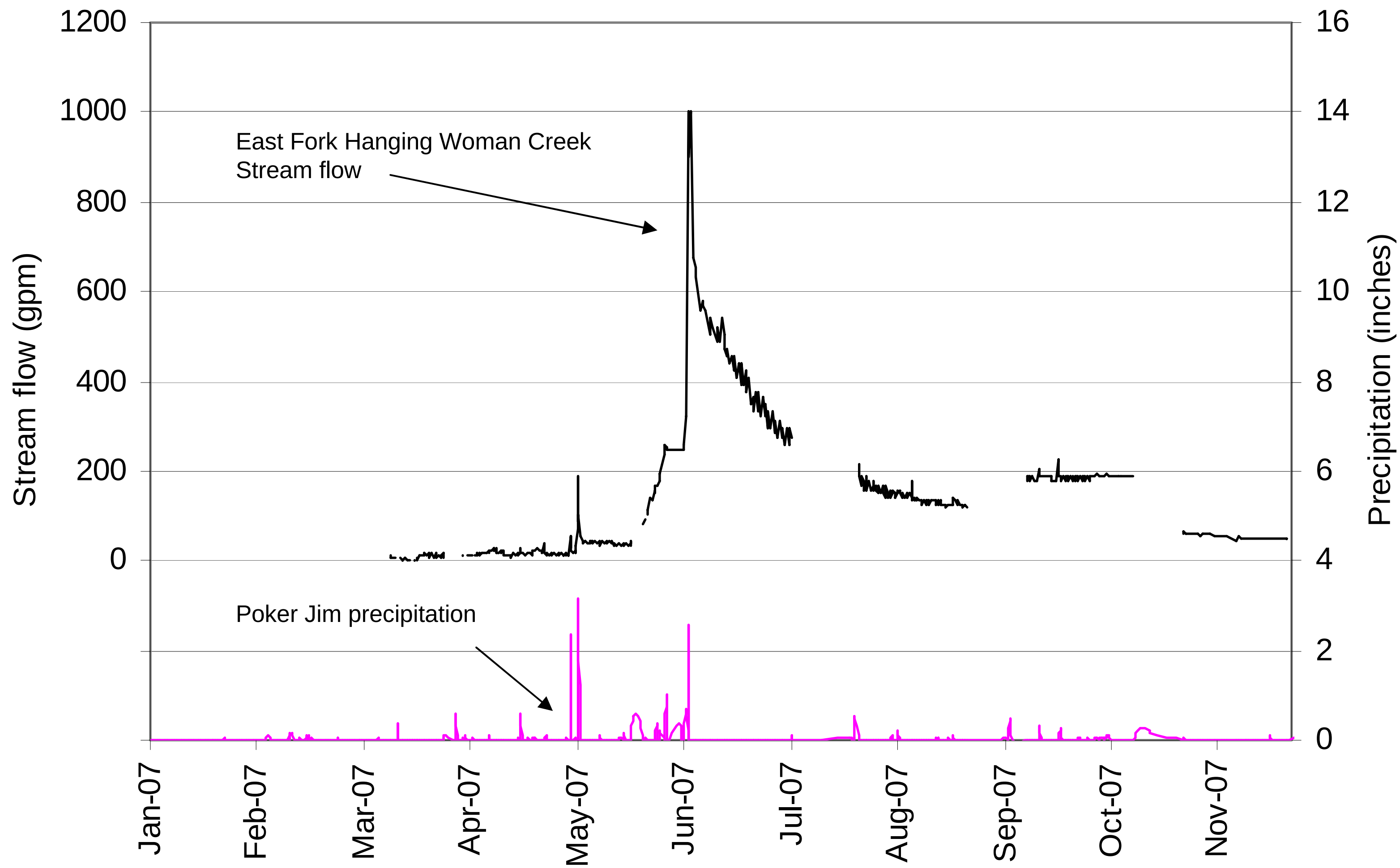


Figure 16. Stream flow at the East Fork Hanging Woman Creek weir correlates with precipitation events recorded at the Poker Jim meteorological station. Precipitation is shown as the total per event.

Water-quality samples were collected from two springs (Three Mile Spring GWIC ID# 228591, Alkali Spring GWIC ID# 197452) and one creek (East Fork Hanging Woman Creek Weir GWIC ID# 223877) outside areas of coalbed-methane production in May, September and October, 2007 (appendix C). Concentrations of TDS for the spring samples ranged from 311 to 2,081 mg/L with SAR values of 0.8 and 9.8 respectively. The creek TDS concentrations were 860 and 1,153 mg/L with SAR values of 2.2 and 2.5. One of the springs and the creek are within the Custer National Forest, Ashland Ranger District. The other spring is located on Post Creek near the Tongue River.

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

Wells classified as producing CBM on the MBOGC web page cover an area of approximately 50 square miles. Roughly one-half of the area is west of the Tongue River and one-half is east of the river. Coal bed methane permitted wells are summarized by county and field in table 3. Counties experiencing CBM production or permitting for CBM production include Big Horn, Powder River, Carbon, Custer, Gallatin and Rosebud. However, as of March 2008, only Big Horn, Powder River and Custer Counties had actively producing wells. At the end of 2007, a total of 1,618 wells have been permitted in Montana, 205 of which are shut-in, abandoned, or plugged and abandoned (P&A on table 4), 213 are permitted or spudded, 346 are expired permits, and 854 are producing. Table 3 indicates 863 producing wells because it reflects the well status as of March 18, 2008.

Table 3. Summary of Montana Board of Oil and Gas Conservation Listings of Coal Bed Methane Permitted Wells by County, March 18, 2008.

County	Field or POD	Total # of Permitted Wells	Operators	Well Status	# of Wells
Big Horn	Coal Creek POD	71	Pinnacle Gas Resources, Inc.	Permit to Drill	7
				Spudded	2
				Producing	13
				Shut In	49
	CX Field	1,126	Fidelity Exploration & Production Co.	Permit to Drill	27
	Deer Creek North POD			Expired Permit	228
	E. Decker Mine POD			Expired, Not Released	3
	Coal Creek POD			Spudded	17
	Badger Hills POD			Producing	741
	Dry Creek POD			Shut In	77
	Pond Creek POD			Temporarily Abandoned	2
				Abandoned - Unapproved	29
				P&A - Approved	2
	Deer Creek Fee POD	33	Pinnacle Gas Resources, Inc.	Permit to Drill	32
				Shut In	1
	Dietz POD	150	Pinnacle Gas Resources, Inc.	Permitted Injection Well	1
				Expired, Not Released	42
				Spudded	1
				Producing	96
				Shut In	10
	Wildcat Big Horn	62	Fidelity Exploration & Production Co.	Expired Permit	36
			Pennaco Energy, Inc.	Expired, Not Released	2
			Petroleum Development Corp. of New Mexico	Spudded	2
			Pinnacle Gas Resources, Inc.	Producing	2
			Powder River Gas, LLC	Shut In	19
			St. Mary Land & Exploration Company	Temporarily Abandoned	1
			Yates Petroleum Corporation		
Powder River	Castle Rock	135	Powder River Gas, LLC	Permit to Drill	121
			Rocky Mountain Gas, Inc.	Expired Permit	7
				Shut In	6
				P&A - Approved	1
	Wildcat Powder River	31	Pennaco Energy, Inc.	Permit to Drill	1
			Powder River Gas, LLC	Expired Permit	25
			Rocky Mountain Gas, Inc.	Producing	1
			Pinnacle Gas Resources, Inc.	Shut In	3
				P&A - Approved	1
Carbon	Wildcat Carbon	4	Florentine Exploration & Production, Inc.	Expired Permit	1
				P&A - Approved	3
Custer	Wildcat Custer	1	Powder River Gas, LLC	Producing	1
Gallatin	Wildcat Gallatin	1	Huber, J.M., Corporation	Expired, Not Released	1
Rosebud	Wildcat Rosebud, N	4	Fidelity Exploration & Production Co.	Permit to Drill	1
			Pinnacle Gas Resources, Inc.	Expired Permit	1
			Yates Petroleum Corporation	Spudded	1
				Shut In	1

Source: Montana Board of Oil and Gas Conservation on-line database: http://bogc.dnrc.mt.gov/default.asp

Produced-water data for 2007 were retrieved for Montana (MBOGC, 2008) and Wyoming (WOGCC, 2008) and are summarized in table 4. A total of 863 wells were producing methane and/or water in Montana during 2007. These wells produced a total of 39 million barrels (bbls) of water. The average annual water discharge rates for individual wells in Montana ranged from 1.7 to 13 gpm. The overall water-discharge rates for wells in Montana averaged 4.0 gpm. In Wyoming during 2007, 110 million bbls of water were produced from the 4,658 wells in the two townships nearest Montana (57N and 58N). The average annual water discharge rate for individual wells ranged from 1.3 to 3.2 gpm and the overall average discharge rate in Wyoming was 1.9 gpm. The total amount of water co-produced with CBM in the Powder River Basin, Wyoming and Montana in 2007 was approximately 85,000 acre-feet. The number of producing wells listed on Table 3 may differ slightly from table 4 due to the fact that the data for table 3 reflects the current state of the wells as of March 18, 2008 whereas table 4 reflects production up through December 2007.

Table 4. Annual summary statistics for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2007.

			Annual total water production			Average Annual Water Discharge	
	Field or POD	Well Count	Bbls	acre-feet	Change from 2006	per well (gpm)	Field total (gpm)
Montana	Coal Creek POD	36	2.39E+06	308	-5.1E+05	8.0	191
	CX	729	3.5E+07	4,471	9.7E+06	4.0	2,772
	Deer Creek Fee POD	1	5.3E+03	1	5.3E+03	1.7	0
	Dietz POD	96	2.16E+06	278	1.6E+06	2.2	173
	Wildcats	1	1.3E+05	17	-1.7E+05	13.0	10
	Combined	**863**	**3.9E+07**	**5,074**	**1.1E+07**	**4.0**	**3,146**
Wyoming	Prairie Dog Creek	3,115	5.1E+07	6,607	1.3E+06	1.3	4,096
	Hanging Woman Creek	561	2.2E+07	2,880	1.2E+07	3.2	1,785
	Near Powder River	982	3.8E+07	4,922	8.2E+06	3.1	3,051
	Combined	**4,658**	**1.1E+08**	**14,409**	**2.2E+07**	**1.9**	**8,933**

Montana source: MBOGC web page (http://bogc.dnrc.mt.gov/default.asp)
Wyoming source: WOGCC web page (http://wogcc.state.wy.us/)

Field total assumes year round production
Wyoming rates assume year round production

Estimated average discharge rates per well are used to predict aquifer drawdown and water-management impacts from CBM development. The Montana CBM environmental impact statement (U.S. Bureau of Land Management, 2003, p. 4–61) and the technical hydrogeology report associated with that analysis (ALL Consulting, 2001) included an estimation of the average water production rates per CBM well based on 20 months of production values in Montana. The trendline for the estimated water production rate is shown as a dashed line on Figure 17. In Montana, the first reported CBM production water was in April, 1999 (Montana Board of Oil and Gas Conservation, 2008). This trend is re-evaluated here based on 105 months (8 years and 9 months) of available production reports. The monthly average water-production rates for all CBM wells in Montana are plotted in gallons per minute against normalized months in Figure 17.

The early production data (normalized months 1 through 4) appear to reflect the effects of infrastructure construction and well development, not typical dewatering. Similarly, the average values for normalized months 103 to 105 are not indicative of typical CBM well production because the trend does not follow hydrogeologic concepts and only 6 wells have been producing 103 months or longer. The amount of water initially produced, on average, from each CBM well is less than was expected (Figure 17). Predicted water production rates are between the 80^{th} and 90^{th} percentile of actual production until normalized month 40, at which time the expected production falls within the 80^{th} percentile. The predicted and observed rates become similar around normalized month 70. After 70 months the actual rate of CBM water production levels out and begins to exceed the estimated rate. The difference between the anticipated and actual production rates reflects that less water was produced than was anticipated. This reduced quantity of CBM production water decreases the amount of water that must be included in water-management plans and decreases the anticipated stress on the aquifers. How well this trend will transfer to other areas of the PRB in Montana is not yet known.

Gas production for an average well in the PRB, normalized by months of production, increases sharply in the well's first 5 months and then slowly increases, peaking in the well's 20^{th} month of production. After 20 months of production, the gas produced slowly decreases throughout the life of the well (Figure 18). The range of production in wells varies greatly as illustrated by the 90^{th} percentile, however, the 80^{th} and 90^{th} percentiles also follow the same pattern of production peaking in the 20^{th} month.

Total water and gas production since the initiation of CBM production in April, 1999 is presented on Figure 19. Water production climbs more steeply than gas production since 2006, but this may be due to a large number of new wells coming on-line at this time.

The ratio of water to gas produced (in bbls/mcf) is a potentially useful metric if it is possible to identify wells that produce a large amount of water for relatively little gas. This test may be straight forward, however some wells may individually have high water-to-gas ratios but in fact be decreasing the water pressure and allowing other wells to produce gas. The ratios presented in Figure 20 were calculated by dividing the water produced in barrels by the amount of gas produced in million cubic feet for each well. The median, 80^{th} and 90^{th} percentiles are presented in Figure 20 normalized by months of production. For those wells which produced all water and no gas, the ratio was calculated by assuming the denominator to be one-half the lowest reported value (0.5 mcf). The variation in water to gas ratio by well is too large for the 80^{th} and 90^{th} percentiles to be presented on the same axis as the median values. The median was chosen for presentation on this figure as opposed to the average because the few extremely large ratios caused the average to be skewed higher than is truly representative of CBM water to gas production. This figure illustrates that low ratios are typically maintained until about the 85^{th} month of production. However, judging a CBM well's efficiency should be done on an individual and field basis after a certain dewatering period has passed.

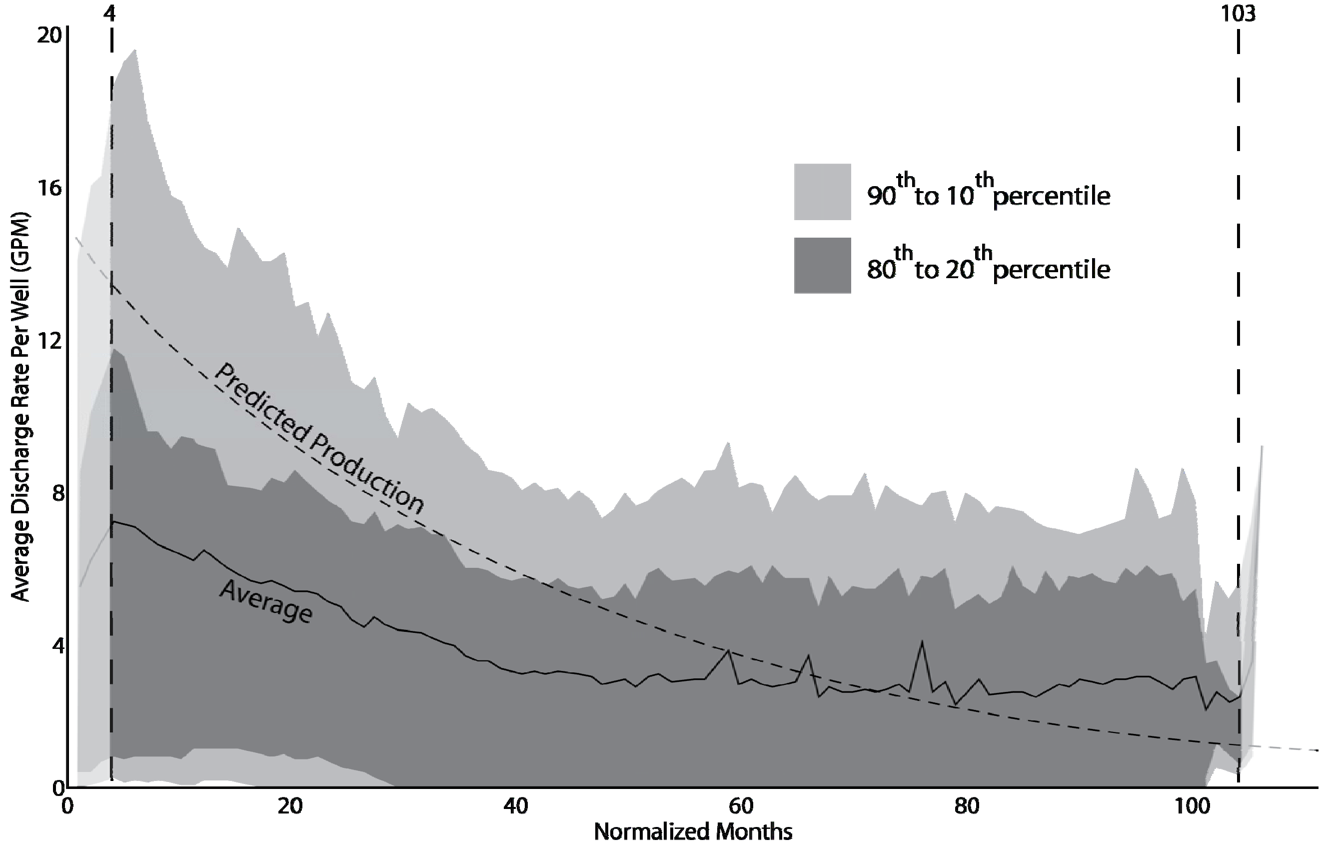


Figure 17. Normalized CBM produced water in gallons per minute in the Montana portion of the Powder River Basin (data from MT BOGC web site). The solid line represents the average production rate, the light grey field represents the range from 10^{th} to 90^{th} percentile, the dark grey field represents the 20^{th} to 80^{th} percentile. The dashed line represents the predicted production per well $Y=14.661e^{-0.0242X}$ (from U.S. BLM, 2003). Trends from one to four months and 103 to 105 months are not considered to be representative of hydrologic responses to CBM production and are most likely related to operational activities.

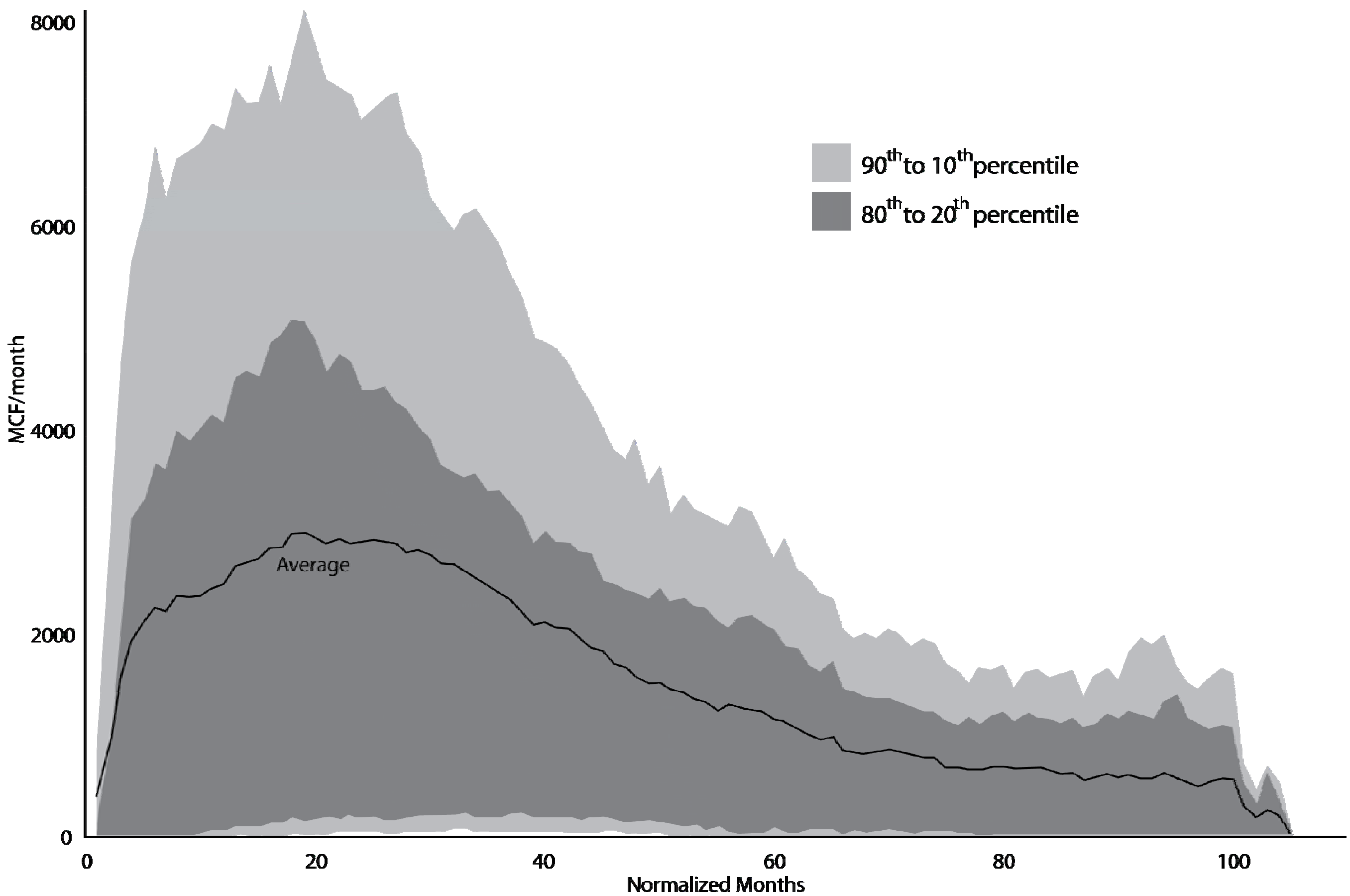
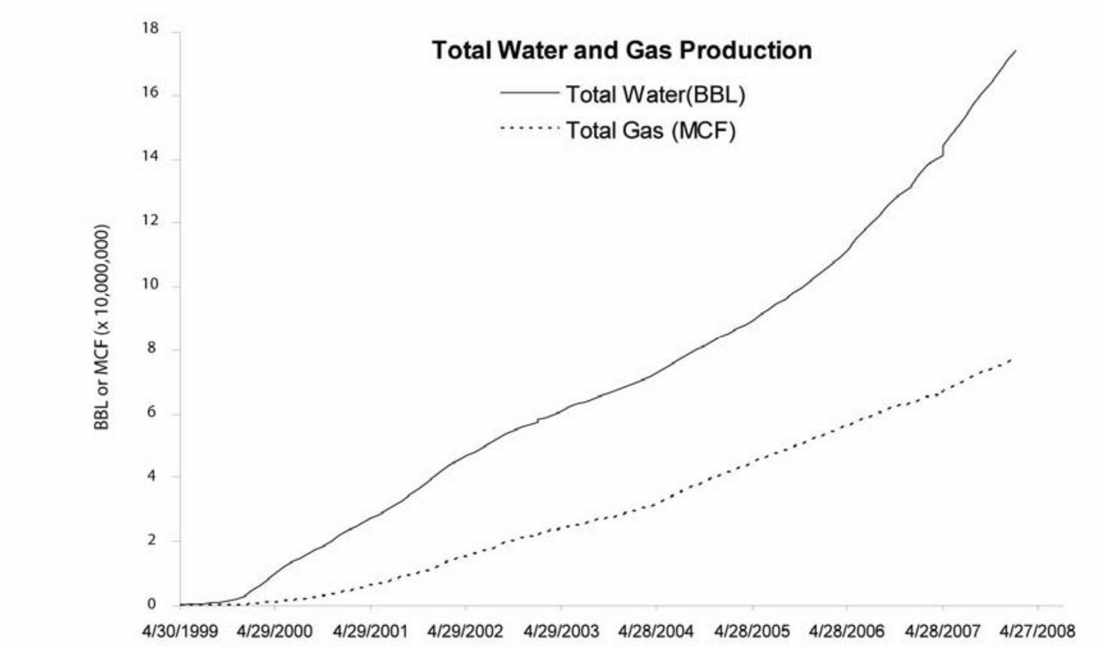


Figure 18. Normalized gas production in MCF per month for the Montana portion of the Power River Basin (data from MT BOGC web site). Solid line represents the average MCF produced, the light grey field represents the 10th to 90th percentile, the dark grey field represents the 20th to 80th percentile.



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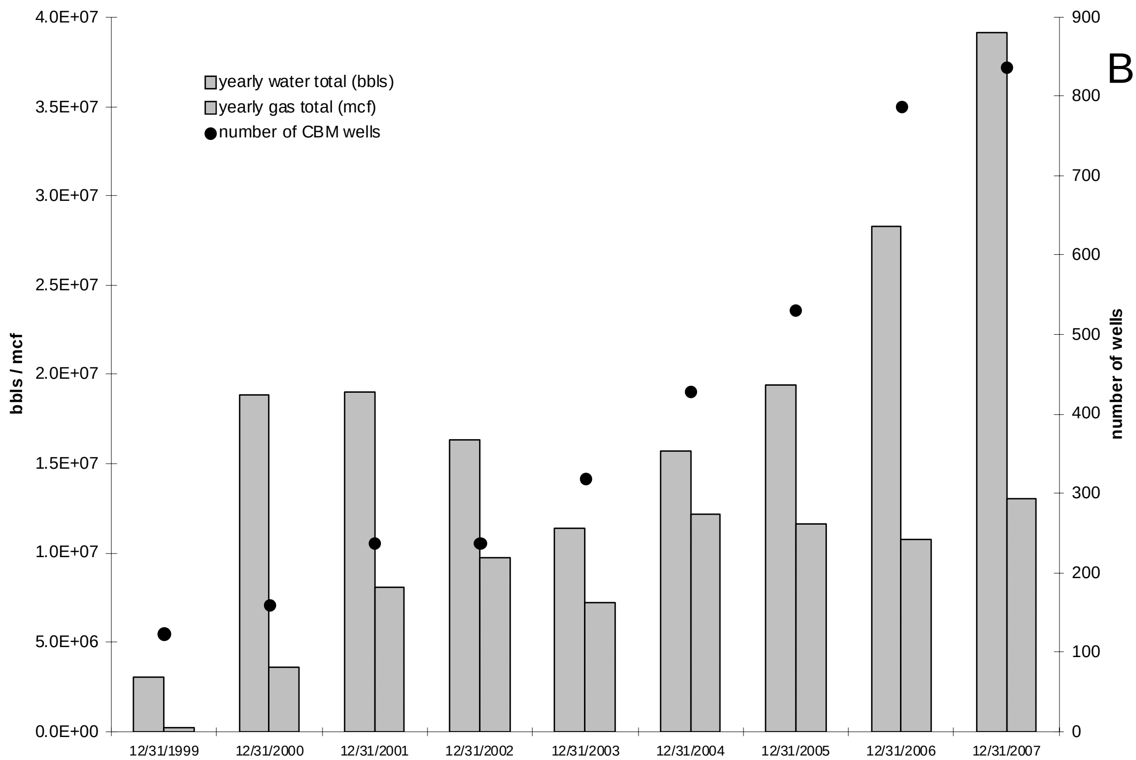


B

Figure 19A. Total water and gas produced since CBM production began in spring 1999 (data from MT BOGC on-line database). Water production climbs faster than gas production since early 2006 most likely due to more new CBM wells coming on-line.

Figure 19B. Yearly totals of water and gas produced from CBM wells (MT BOGC) and total number of CBM wells. Water production decreased when few new wells were installed from 2001 to 2002 but increased substantially with the increased development in 2004-2006. Gas production lags behind the increased number of wells in 2004-2006 because of the dewatering period necessary for gas production.

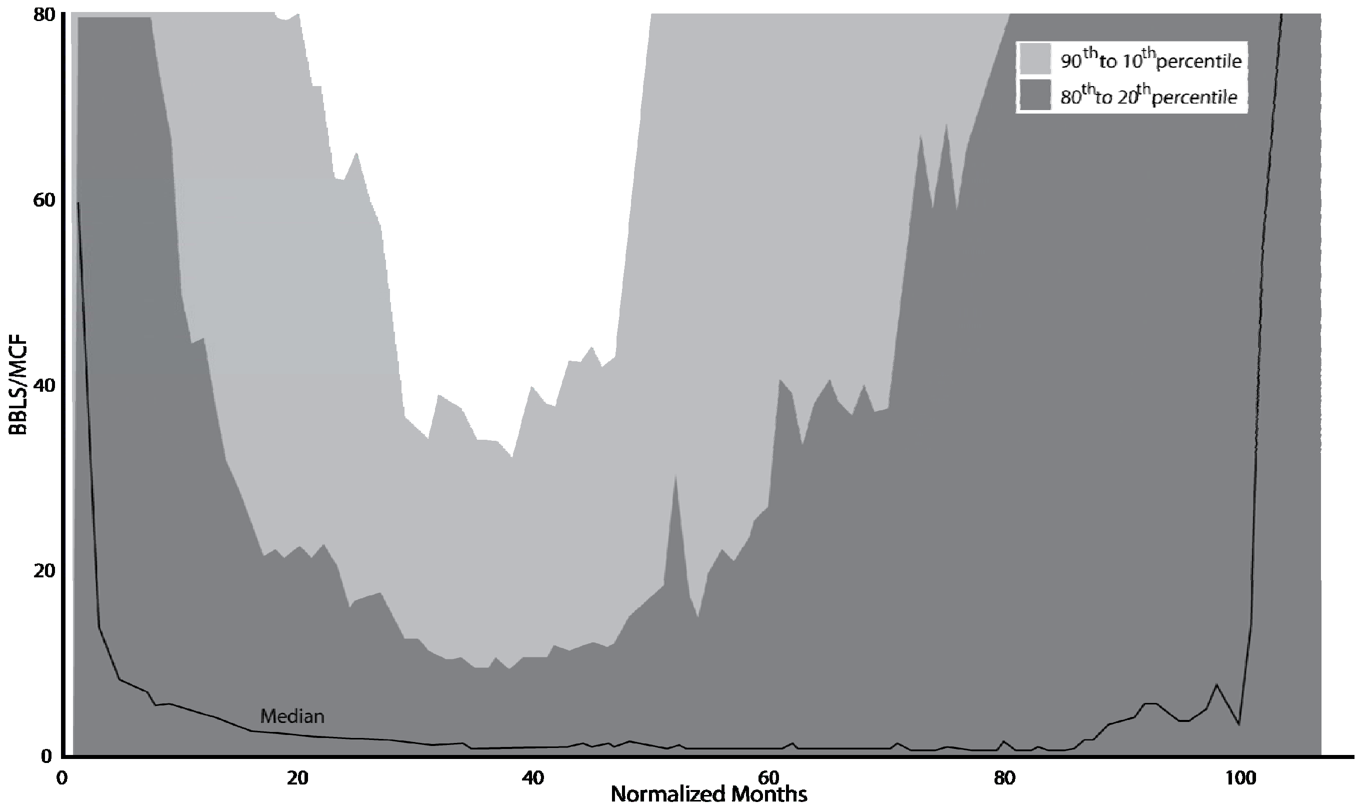


Figure 20. CBM produced water to gas ratio in BBLS/MCF (data from MT BOGC web site). The solid line represents the median ratio. Median as opposed to mean values were chosen for display because the few exceptionally high ratios skewed the mean values higher than is representative (greater than the 90th percentile) of average wells. The light grey field represent the range of values from the 10th to 90th percentiles. The dark grey field represents the range of values between the 20th and 80th percentiles.

Montana CBM Fields

CX gas field

Methane water production. Data from CBM production wells in the CX field (Plate 1) were retrieved from the Montana Board of Oil and Gas Conservation web page (2008). During 2007, a total of 729 CBM wells produced either water, gas, or both in the CX field. Production is from the Smith, Anderson, Dietz, Canyon, Carney, Wall, King, and Flowers-Goodale coalbeds (Figure 2). The average water production rate for all wells over the entire year was 3.0 gpm. The highest water production rate for a single well over a 1-month reporting period was 31.4 gpm. Total monthly water production was least in February with 2.5 million barrels, and highest in August with 3.2 million barrels. The total water production for the year was 35 million bbls or 3,353 acre-feet. Along the western edge of the Fidelity project area near the Montana–Wyoming state line some wells are no longer being pumped and others are being pumped at a reduced rate as the methane-production rates in this area have declined.

Bedrock aquifer water levels and water quality. Ground-water trends in areas of bedrock aquifers that are susceptible to CBM impacts in and adjacent to the CX field are presented in figures 21 through 29. 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.

The potentiometric surface for the Dietz coal is shown in Plate 2, and is based on data provided by the CBM industry and data collected by MBMG as part of the regional monitoring program. Drawdown within the Dietz coal that is interpreted to be specific to CBM production is shown on Plate 4. The locations of active CBM wells at any specific time are not available, so some generalizations are necessary in interpreting Plate 4. It does appear that drawdown of at least 20 ft has reached a typical distance of about 1 mile beyond the active field in most areas and has reached 1.5 miles in some areas. For the Canyon coal, the potentiometric surface is shown on Plate 3 and drawdown related to CBM production is shown on Plate 5. Based on the available data, drawdown within the Canyon coal appears similar to that in the Dietz; 20 feet of drawdown reaches about 1 mile beyond the field boundaries.

Drawdown was expected to reach 20 ft at a distance of 2 miles after 10 years of CBM production (Wheaton and Metesh, 2002) and a maximum distance of 4 to 5 miles if production continued for 20 years in any specific area (U.S. Bureau of Land Management, 2003, p. 4–62). Current measured drawdown is similar to, but less than, expected.

Hydrostatic pressure in the combined Anderson and Dietz coal in well WR-34 near the Ash Creek mine declined about 21 ft between 1977 and 1979 due to mine dewatering (Figure 21). The Ash Creek mine pit reached a maximum size of about 5 acres. Pit dewatering maintained a reduced water level until reclamation and recovery began in 1995. Water levels returned to baseline conditions in 1998. Between 2001 and 2003 ground-water levels at this site were lowered to about 150 ft below baseline conditions by CBM production. The greater magnitude of drawdown at this monitoring well due to CBM development is primarily due to the proximity to the area affected by CBM production. Since 2003, the water levels have recovered to within 36 ft of baseline conditions. This represents 77% recovery during a period of 4.5 years. This recovery appears to be due to a reduction in the pumping rates and the number of producing CBM wells in this area.

Ground-water level responses due to the Ash Creek mine pit dewatering are also evident at well WR-38 (Figure 22). The water level in this well dropped about 80 ft in response to CBM production. In response to decreased pumping from CBM wells in this area, the water levels in WR-38 have now recovered to within 25ft of baseline conditions, or a water-level recovery of about 71%. Well BF-01 is completed in the Ash Creek mine spoils. Although the mine pit created a water-level response in the adjacent coal aquifer, the water level in the spoils has not responded to lowered water levels in the coal due to CBM production. The spoils aquifer is probably unconfined and the lack of a measurable response is not surprising due to the much greater storage capacity of an unconfined system.

Monitoring wells installed to evaluate whether faults in the Fort Union Formation are typically no-flow boundaries (Van Voast and Hedges, 1975; Van Voast and Reiten, 1988) show that dewatering of the mine pit, which is less than 1 mile from the fault, has lowered water levels in the Anderson coal and overburden aquifers for over 25 years on the north side of the fault (Figure 23). Monitoring data indicate mine-pit-related drawdown in the Anderson coal (WRE-19) north of the fault; minor drawdown in the Smith (WRE-17) and no drawdown in the Anderson (WRE-18) coal seams south of the fault. Methane production south of the fault shows the inverse response as water levels in the Anderson coal (WRE-18) south of the fault have been lowered about 159 ft since 2001, then for a 4-month period in 2006 the water level began to rise then began to lower again and rise again in part of 2007. The water levels at WRE-19 north of the fault have not responded to CBM production, indicating that the fault acts as a barrier to flow within the Anderson coalbed.

Near the western edge of the CX field, but across a fault from active CBM wells, water levels in the Carney coal (CBM02-2WC) have been responding to CBM-related drawdown since the well was installed in 2003. Water levels in this well are now 13 ft lower than the first measurement (Figure 24). It appears that the drawdown observed at this site results from migration of drawdown around the edges of a scissor fault. The water level in the Canyon coal (WR-24) at this site has decreased somewhat, which may be a response to CBM production or may be due to long-term precipitation patterns. The Roland coal (CBM02-2RC) is stratigraphically higher than the CBM production zones, and during 2005 the water level at this well dropped about 8 ft, but during 2006 and 2007 the water level has been rising. The cause of the water-level changes in the Roland coal is not apparent. CBM production is unlikely to have had any effect on this unit, and the type of response is much different than that measured in the other coal aquifers at this site.

Near the East Decker mine, water levels have responded to coal mining in the Anderson, Dietz 1, and Dietz 2 coals (Figure 25). Drawdown has increased, particularly in the Dietz 2 coal, in response to CBM production in the area. Research in conjunction with coal mine hydrogeology in Montana has documented greater drawdown in deeper coal beds and it has been speculated that differences in storativity might explain the responses (Van Voast and Reiten, 1988). The difference in responses shown in Figure 25 may be due to aquifer characterisitics, or simply a function of the initial water levels in the aquifers.

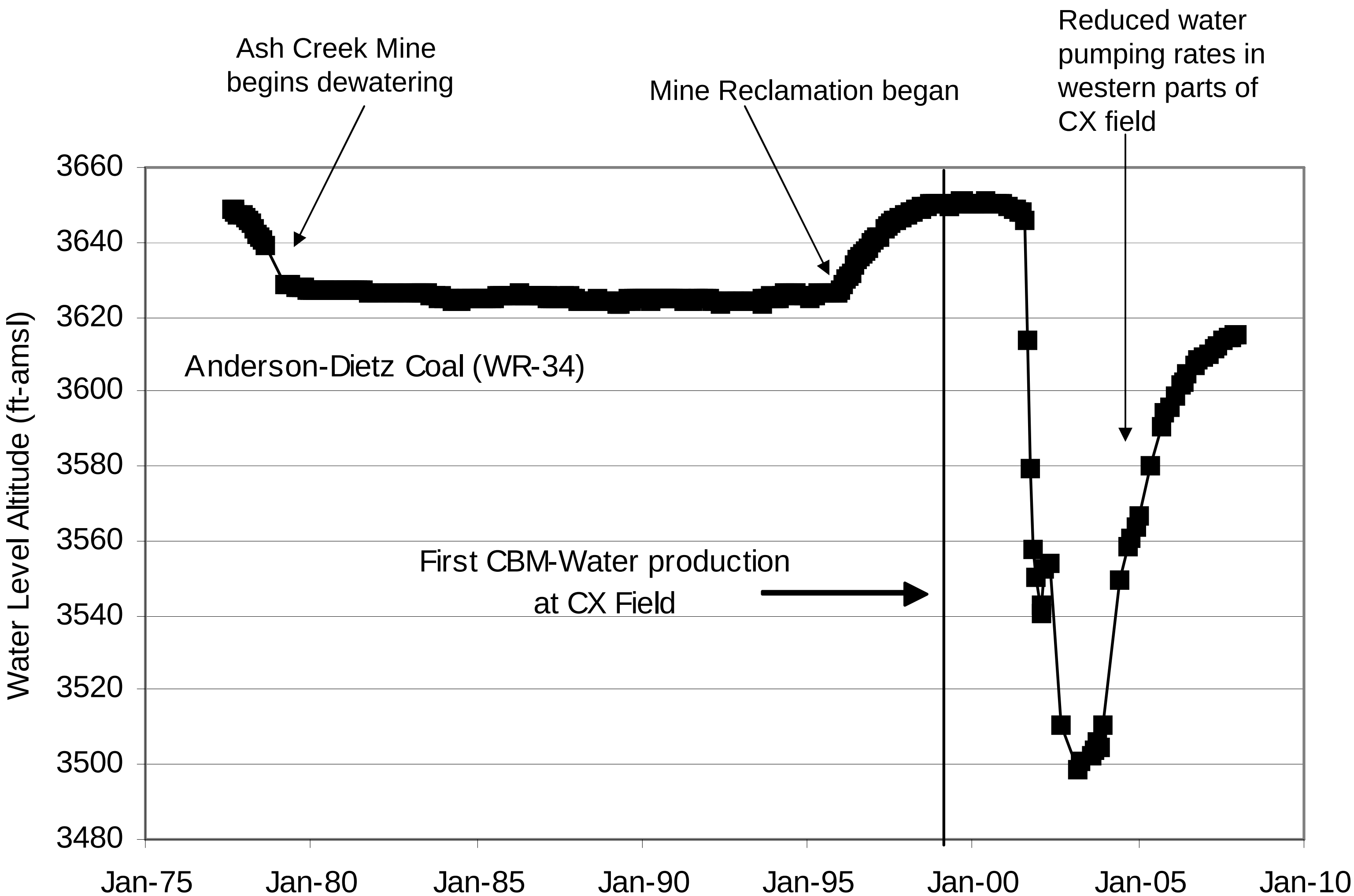


Figure 21. Water levels in the combined Anderson and Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed methane production. The water level recovered starting in 2003 in response to water production decreases in this portion of the CX field.

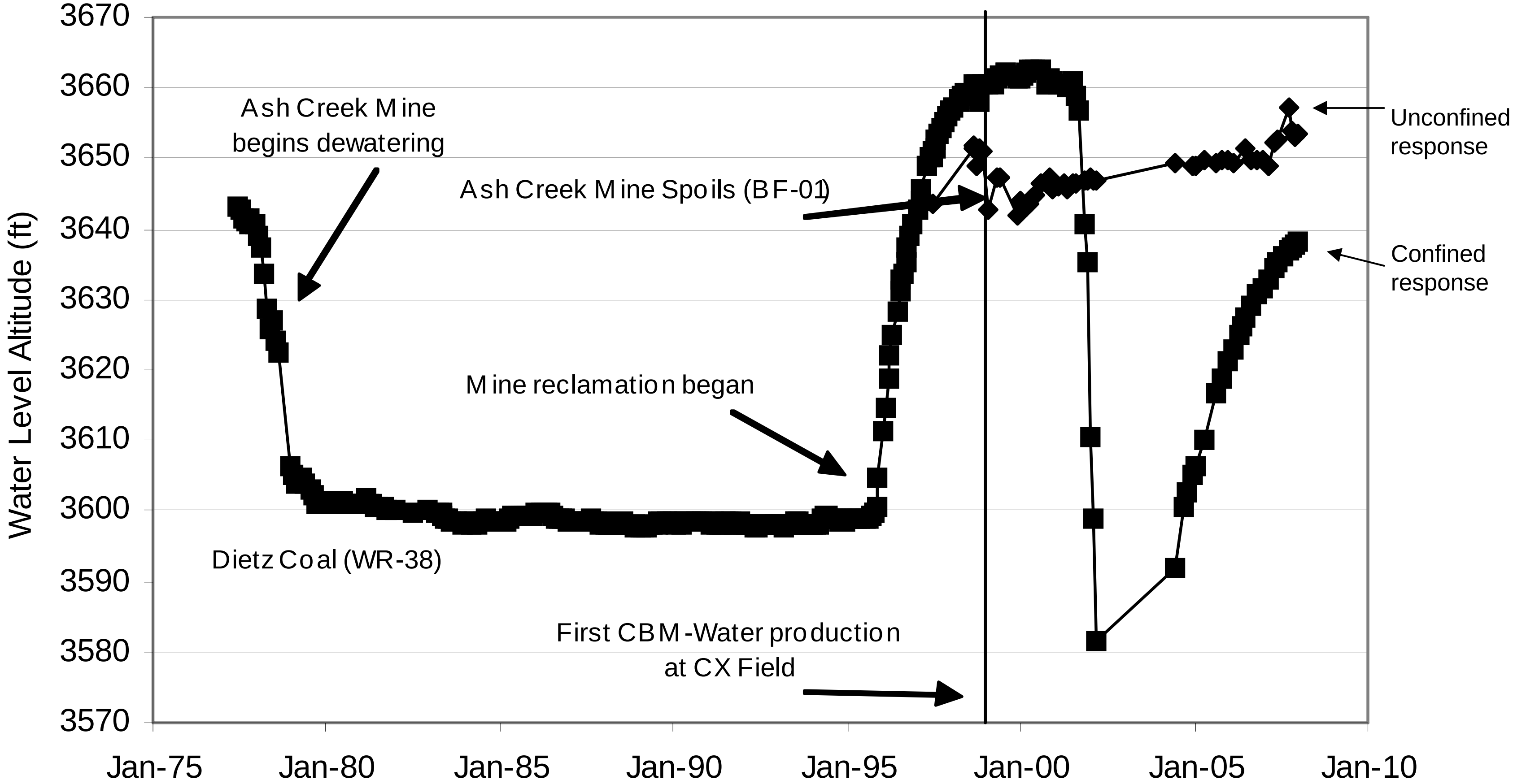
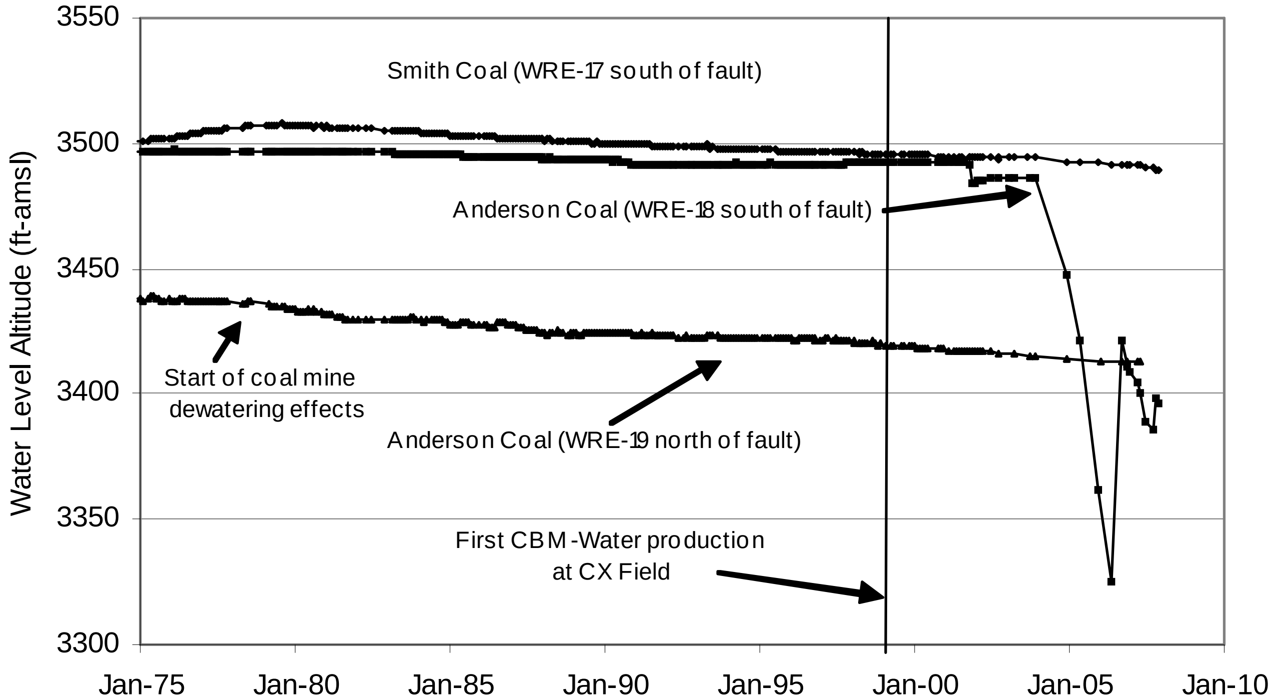


Figure 22. The mine spoils well is being dewatered for CBM production but the water levels show no response to the lowered water levels. However, water levels have decreased by 80 feet in the Dietz Coal in response to the CBM production.



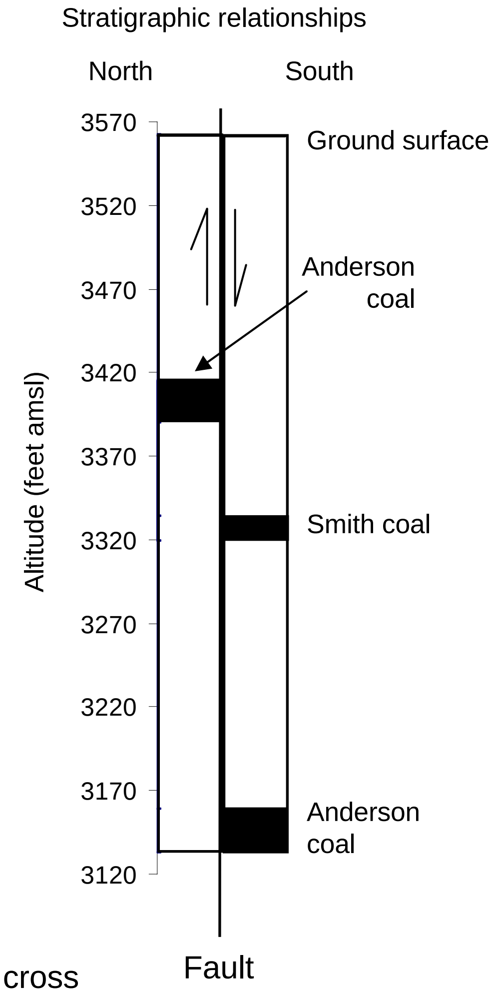


Figure 23. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured at WRE-17 since the mid-1980's. The pressure reduction has probably migrated 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.

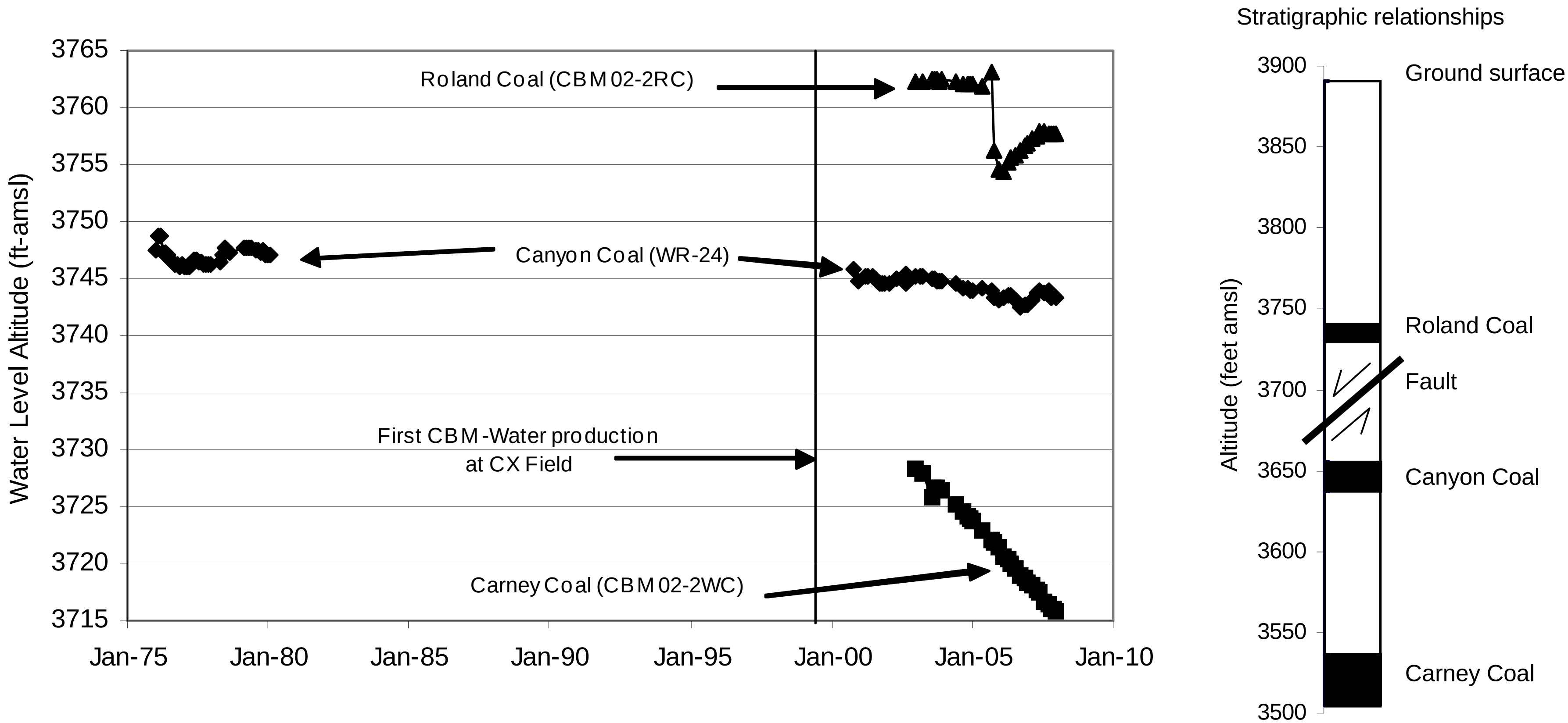


Figure 24. The long-term decrease in water levels in the Canyon Coal is probably related to precipitation patterns. The short period of record for the Carney coal at the CBM02-02 site does not indicate meteorological influence but has responded to CBM related drawdown since its installation. The Roland Coal has not been developed for CBM production and the water-level decline is not likely a response to CBM activities.

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

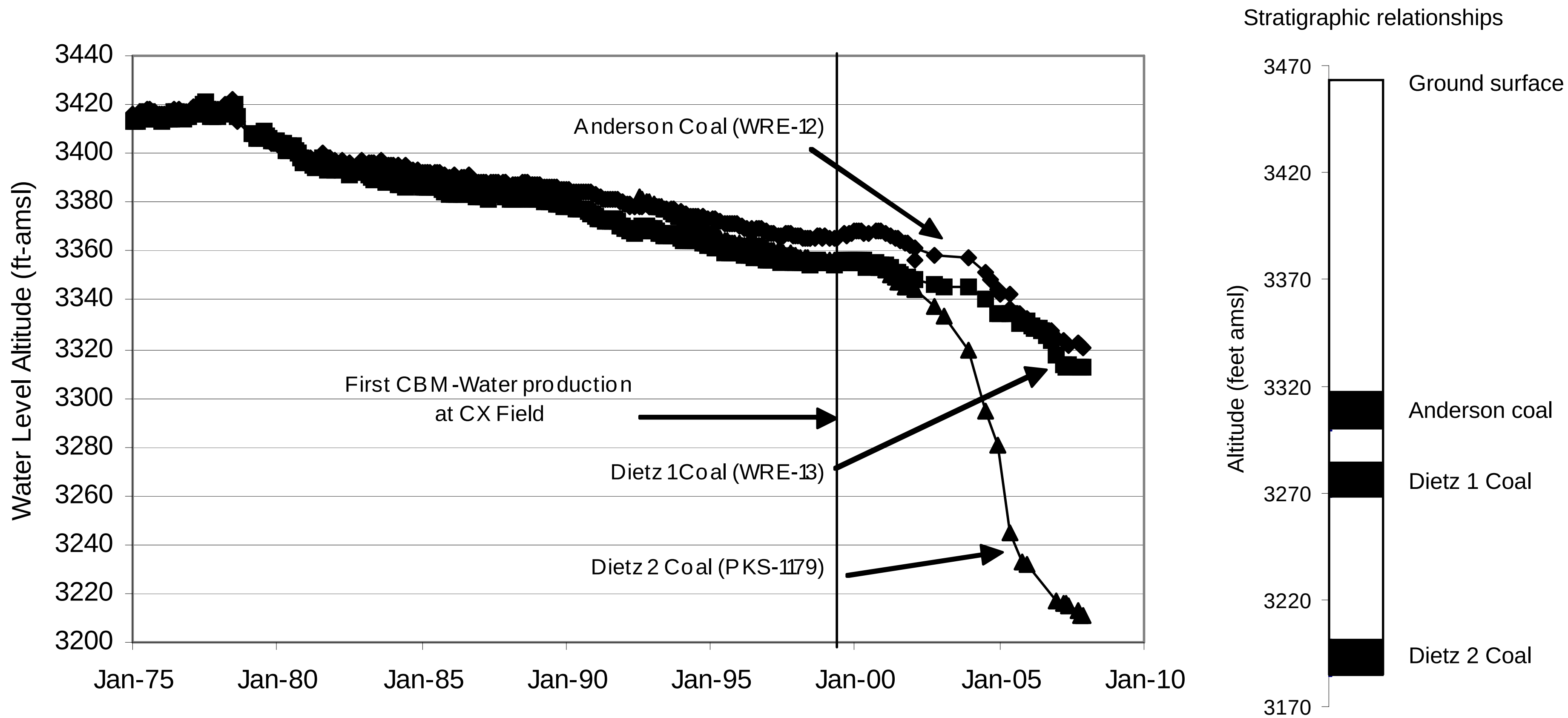


Figure 25. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

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

Changes in stage in the Tongue River Reservoir affect water levels in aquifers that are connected to it such as the Dietz coal, which crops out beneath the reservoir. Water levels in the Dietz coal south of the reservoir show annual responses to the reservoir stage levels, but are more strongly influenced by mining and CBM production (Figure 26). Since January, 1995 the stage in the reservoir has ranged between a low of 3,387 and a high of 3,429 ft above mean sea level (amsl). Average reservoir stage during this time has been about 3,413 ft amsl, which indicates, when compared to the Dietz potentiometric surface, that some water has always seeped from the Tongue River Reservoir to the coal seam. The rate of seepage is likely increasing due to the increasing gradient between the reservoir and the Dietz potentiometric surface. However, the amount of the increased seepage related to CBM production is limited by faulting (Plate 2).

Water levels in Anderson overburden in the Squirrel Creek watershed (Figure 27) show possible correlation with precipitation patterns and no drawdown due to either coal mining or CBM production. The water level in the Anderson coal at this site (WR-17) was lowered 37 ft by coal mine dewatering and about 30 ft by CBM production. Water levels are no longer collected from this Anderson coal well because of the volume of methane that is released when the well is opened. One overburden aquifer (WR-17B) is separated from the Anderson coal by over 50 ft of shale, siltstone, and coal. Water levels at this well do not show noticeable changes in water pressure in response to mine dewatering (which began in 1972). However, a decline of 6 feet since 2000 could relate to CBM water production (which began in 1999). The shallow, water-table aquifer (WR-17A) shows a rapid rise following the start of CBM production. This rise, totaling about 30 ft, is interpreted to be a response to infiltration of CBM production water from an adjacent holding pond. This pond is no longer used to hold CBM production water, and the shallow water table has returned to within 6.5 ft above baseline. The deeper overburden aquifer (WR-17B) at this site shows no response to the holding pond.

Water-quality samples have been collected periodically from WR-17A (QWIC ID#123796; Figure 28). The TDS concentration increased from 2,567 mg/L in 1991 to 3,434 mg/L in 2006 and the SAR decreased from 42.5 in 1991 to 13.4 in 2004 and increased slightly to 19.6 in 2006. The TDS increase and SAR decrease is interpreted to be in response to dissolution of salts along the flow path as water infiltrates from the CBM pond and flows through the underlying material. The introduction of these salts did not change the class of use for this aquifer (Class III). Water quality under this pond is expected to return to baseline values as available salts migrate into the established flow path and are diluted (Wheaton and others, 2007). The length of time needed for the return to baseline to be completed is not yet known. Samples were not collected in 2007.

Alluvial aquifer water levels and water quality. Water levels in the Squirrel Creek alluvium show annual variations that are typical for shallow water table aquifers (Figure 29). Since 1999 the overall trend for alluvial water levels at WR-58 has been to decline slightly in response to drought conditions. Farther downstream, in the CBM production area (WR-52D), the overall water level trend in the alluvium was stable until 2000 when it increased. The water-level trend at WR-52D now appears to be decreasing to approximate baseline levels. This rise and subsequent fall may be in response to CBM production water seepage from nearby infiltration ponds which were in use from 1999 to 2002.

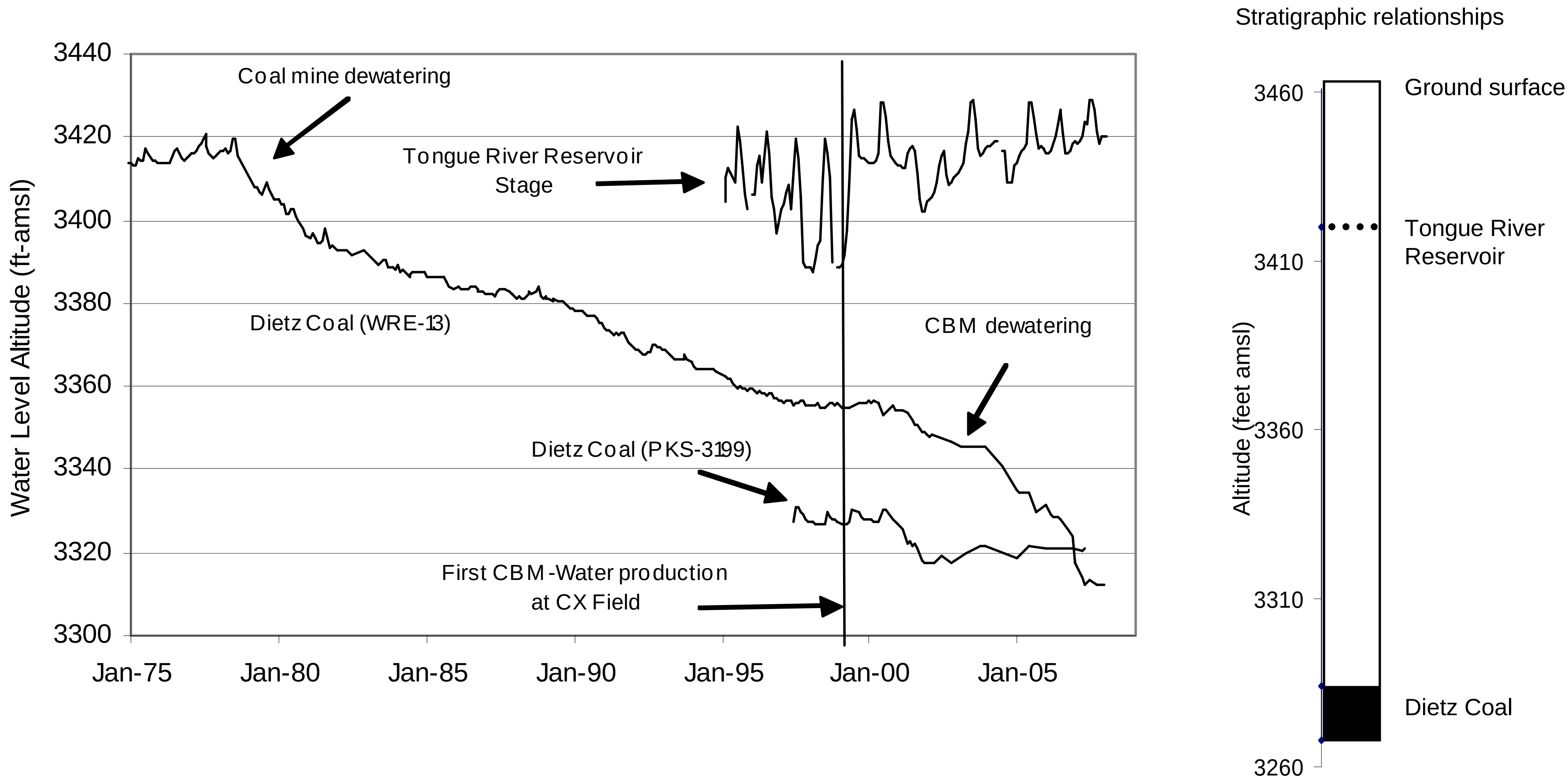


Figure 26. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present.

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

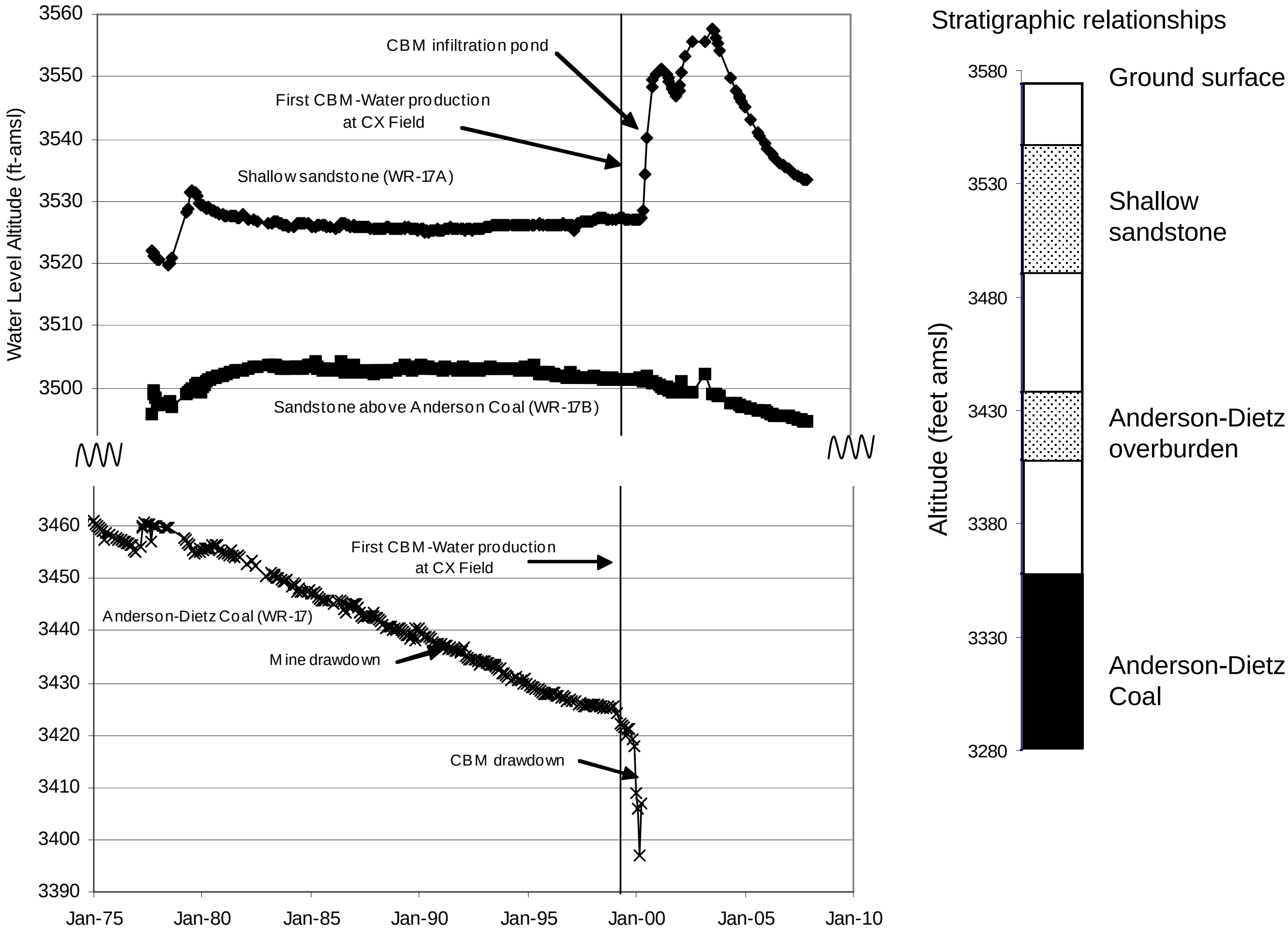


Figure 27. Long-term water-level trends in the Anderson overburden(WR-17A and WR-17B) in the Squirrel Creek area, may relate to precipitation patterns. These wells demonstrate the rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The water level in this aquifer is now dropping as the pond no longer receives water.

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

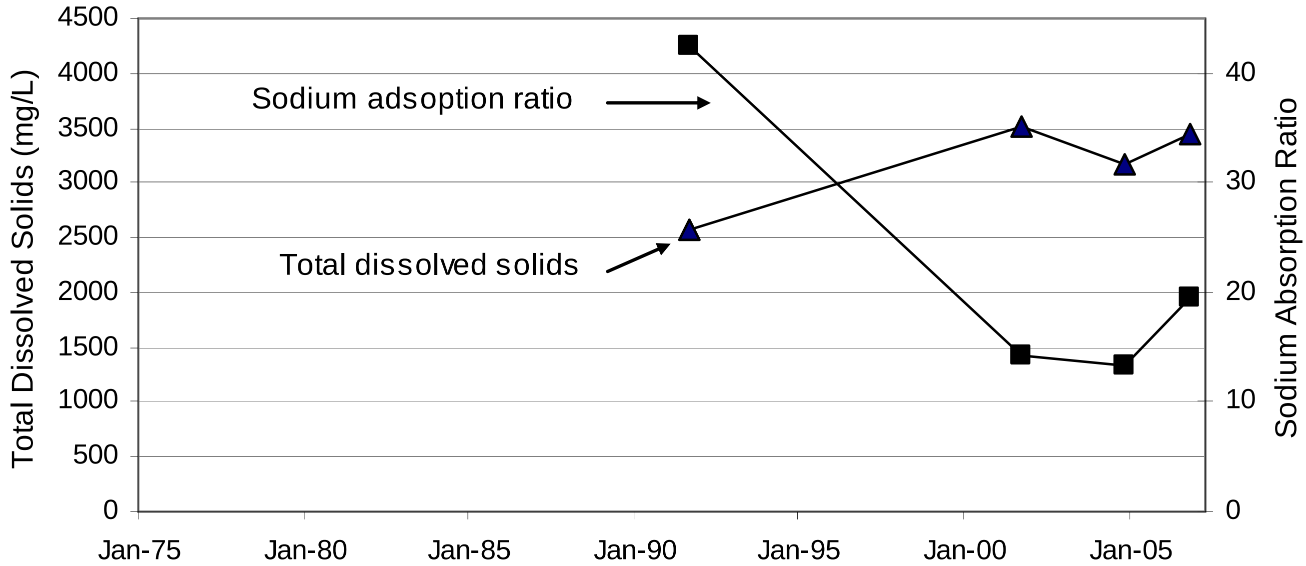


Figure 28. Water quality samples have been collected periodically from WR-17A.
As the water level increased (see figure 26) the TDS also increased.
At the same time the SAR is decreased due to the dissolution of
calcium and magnesium salts.

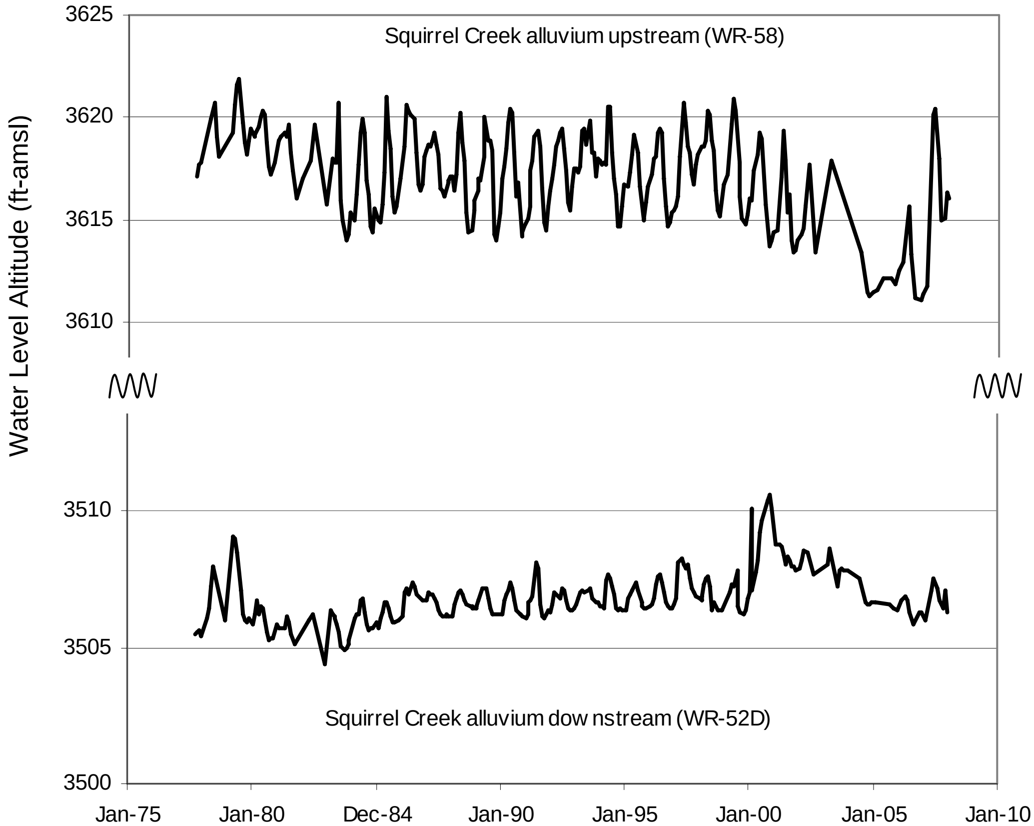


Figure 29. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall during 2004 likely relates to infiltration ponds located in between these sites (WR-52D).

Note: The Y axis scale is broken to show better hydrograph detail.

Water-quality samples were collected from the Squirrel Creek alluvium WR-59 (GWIC ID#122766) in May and September of 2007 (appendix C). The TDS concentrations were 5,778 and 6,196 mg/L respectively and the SAR value ranged from 6.0 to 6.2. There is little difference between these data and data from a previous sample collected in 1993 (GWIC). The water chemistry reflects Squirrel Creek alluvium, which is dominated by sodium, magnesium, and sulfate.

Water-quality samples were also collected at WA-2 near Birney Day Village (GWIC ID#223952) in May and September of 2007 (appendix C). The TDS concentrations were 1,767 and 1,773 mg/L and the SAR value were 21.7 and 22.5. The water chemistry is dominated by sodium bicarbonate.

Coal Creek and Dietz gas fields

Methane water production. Data from CBM production wells in the Coal Creek field and Dietz field (Plate 1) were retrieved from the Montana Board of Oil and Gas Conservation web page (2008). Pinnacle Gas Resources, Inc. first produced water from CBM wells in the Coal Creek field north of the Tongue River Reservoir in April 2005 and from the Dietz field northeast of the reservoir in November 2005. During 2007, a total of 36 CBM wells produced water in the Coal Creek field. Production was from the Wall and Flowers-Goodale (Roberts) coalbeds (Figure 2). The average water production rate for all wells over the 12-month production period was 6.0 gpm (table 3). The highest water production rate for a single well over a 1-month reporting period was 27.2 gpm. Average total field production was least in December with 39.8 thousand barrels and highest in January with 405 thousand barrels. The total water production for the 12-month period was 2.4 million barrels, or 231 acre-feet.

A total of 96 CBM wells produced water in the Dietz field during 2007 (Plate 1). Production is from the Dietz, Canyon, Carney, and Wall coalbeds (Figure 2). The average water production rate for all wells over the 12-month production was 1.7 gpm. The highest water production for a single well over 1-month reporting period was 15.7 gpm. Total monthly water production was least in March with 122 thousand barrels and highest in December with 226 thousand barrels. The total water production for the 12-month period was 2.2 million barrels, or 209 acre-feet.

Bedrock aquifer water levels and water quality. Two miles west of the Tongue River and about 4 miles north of the Tongue River Dam, at site CBM02-4 (Plate 1), the water level in the Wall coal was lowered about 11 ft from April 2005 to December 2006 in response to water production in the Coal Creek and Dietz areas (Figure 30). In early 2007 the water level began to rise then began to lower again. The nearest CBM well is about 2.5 miles from site CBM02-4. Water levels in the sandstone overburden wells show no response at this site (Figure 30). Monitoring well site CBM02-7 is located about 6 miles northwest of the Coal Creek field (Plate 1). No response has been measured in either the overburden sandstone or Canyon coal at this site as well (Figure 31).

Water-quality samples were taken from Upper Anderson Spring (GWIC ID# 228776) and Lower Anderson Spring (GWIC ID# 240578) in August 2007. These springs are discharge points for the Anderson coalbed. The TDS concentrations were 3,820 and 1,553 mg/L and SAR values were 8.1 and 3.0, respectively.

Alluvial aquifer water quality. A domestic well is regularly sampled north of the Tongue River reservoir (Musgrave Bill GWIC ID# 228592) and was sampled most recently in May and October of 2007 (appendix C). The TDS concentrations were 701 and 966 mg/L, respectively and SAR values of 1.2 and 1.8, respectively. The water chemistry is dominated by calcium and bicarbonate. The dominant ions in the water-quality samples do not indicate an influence from CBM production. The data are available on GWIC.

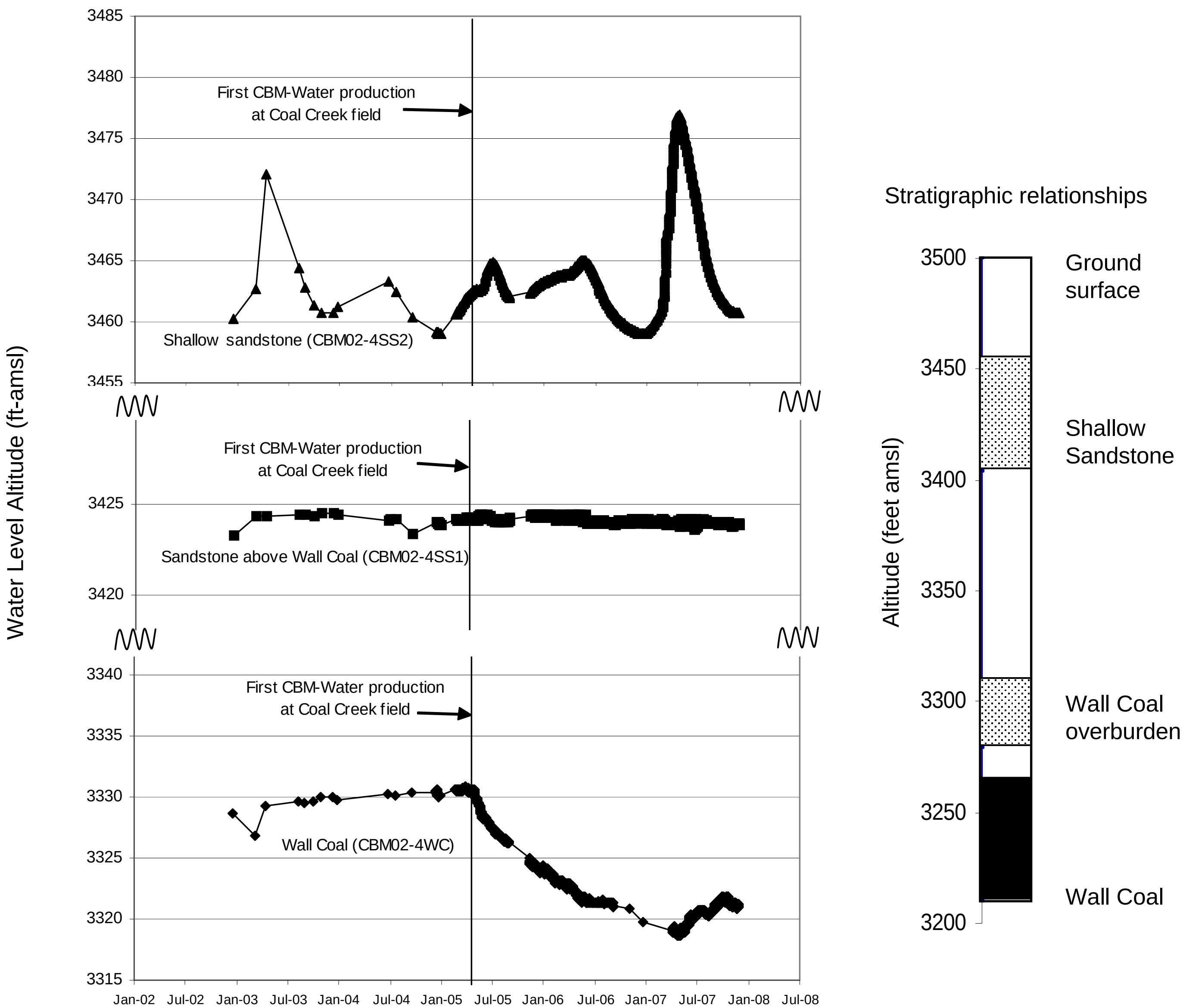


Figure 30. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower sandstone may be. The water level in the Wall Coal aquifer has decreased 11ft in response to CBM development. No CBM effects are seen in the shallower aquifers.

Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.
The Y axis scale is broken to show better hydrograph detail.

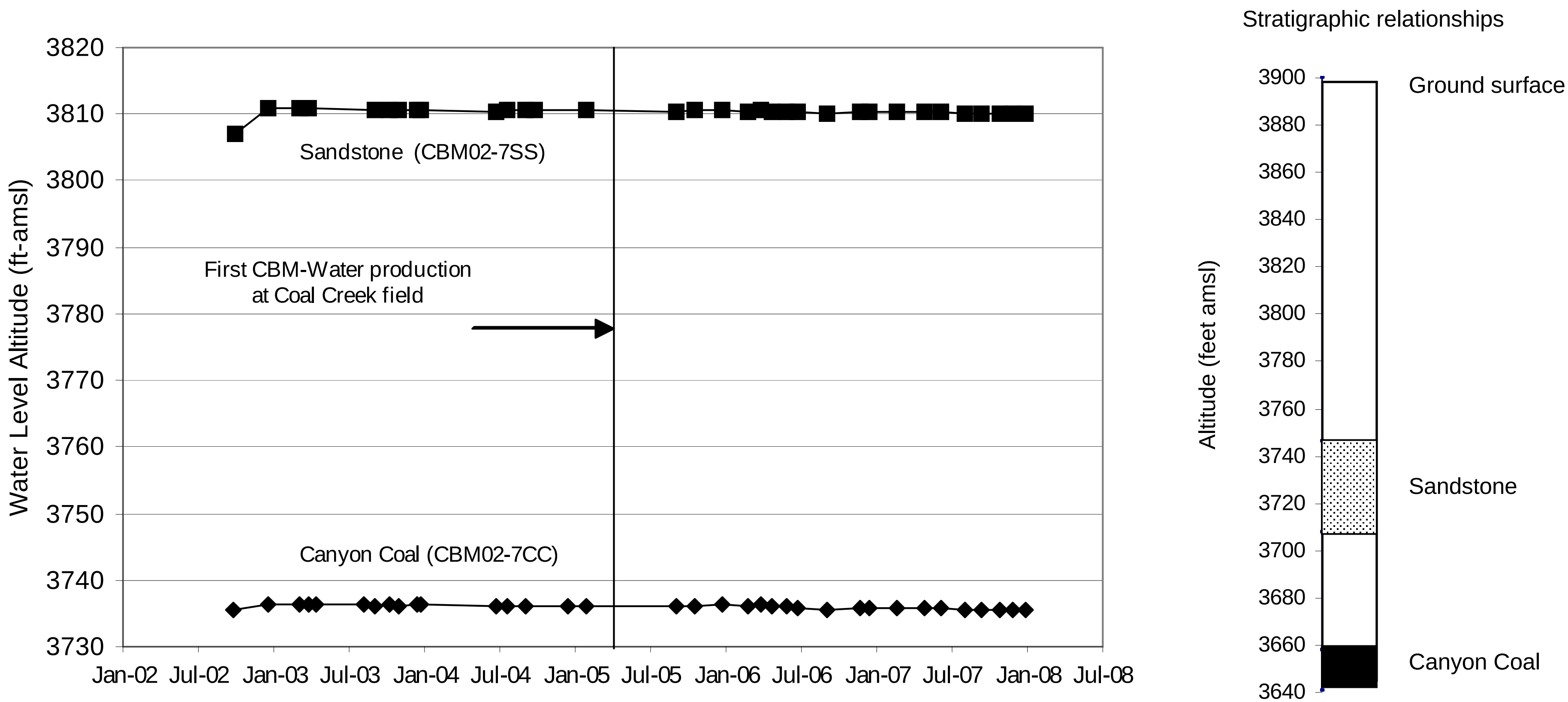


Figure 31. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

Wyoming CBM fields near the Montana border

Data for CBM wells in Wyoming are available from the Wyoming Oil and Gas Commission website (http://wogcc.state.wy.us/). For this report, only those wells located near the Montana–Wyoming state line in townships 57N and 58N were considered (Plate 1). Water production data were downloaded for CBM wells located in these townships. For the purpose of this report the CBM producing area near the state line are referred to as the Prairie Dog and Hanging Woman fields and the area near Powder River (Plate 1).

Prairie Dog Creek gas field

Methane water production. The Prairie Dog Creek field is located in Wyoming south of the CX field in Montana. Methane is produced from the Roland, Smith, Anderson, Dietz, Canyon, Carney, Cook, King, and Flowers-Goodale (Roberts) coalbeds (Figure 2). During 2007, a total of 3,115 CBM wells produced methane and/or water. The average water production per well for the 12-month period was 1.0 gpm, and the average producing rate for the field was 3,072 gpm. Cumulative production for the year was 51 million barrels or 4,955 acre-feet of water.

Aquifer water levels. Water-level drawdown in Montana that results from production in the Prairie Dog Creek field cannot be separated from the drawdown that results from Montana production in the CX field, and therefore is included in the earlier discussion in this report.

Hanging Woman Creek gas field

Methane water production. During November 2004, St. Mary Land and Exploration (St. Mary, previously Nance Petroleum) began pumping water from CBM wells in the Hanging Woman Creek watershed, directly south of the Montana–Wyoming state line (Plate 1). According to data retrieved from the Wyoming Oil and Gas Commission website, St. Mary is producing CBM from the Roland, Anderson, Dietz, Canyon, Cook, Brewster-Arnold, Knobloch, Flowers-Goodale (Roberts), and Kendrick coalbeds (Figure 2). During 2007, a total of 561 CBM wells produced methane and/or water. The average water production rate per well over the 12-month period was 2.4 gpm. The total water production for the 12-month period was 22 million barrels, or 2,160 acre-feet at an average cumulative field-discharge rate of 1,339 gpm.

Bedrock aquifer water levels and water quality. Monitoring well site SL-4 is located about 1 mile north of the nearest CBM well in the Hanging Woman Creek gas field. Monitoring wells at this site are completed in the alluvium, Smith, and Anderson coalbeds (Figure 32). The water level in the Anderson coal has been lowered about 46 ft at this site in response to CBM production (Figure 33). The water level in the Smith coal has also dropped; however, the cause of this drop is unclear. Vertical migration of changes in hydrostatic pressure does not seem likely given the short time. A data logger was installed in this well in 2007; additional monitoring data may help explain the changes in the Smith coal.

Site SL-3 is located 6 miles west of site SL-4 and about 1 mile north of the nearest Wyoming CBM well. Monitoring wells at SL-3 include the alluvium of North Fork Waddle Creek, an overburden sandstone, and Smith, Anderson, and Canyon coals (Figure 34). Water levels in the overburden and Smith are not responding to CBM production. The water level in the Anderson coal has dropped about 13.5 ft, and water level in the Canyon coal has dropped about 103 ft (Figure 35).

A water-quality sample was collected from HWC-01 a Canyon Coal well (GWIC ID#8107) during August of 2007. The TDS concentration was 1,492 and the SAR was 67.7. The water chemistry is dominated by sodium bicarbonate.

Alluvial aquifer water levels and water quality. Based on water-level trends and lithology, the Hanging Woman Creek alluvium near the state line appears to be effectively isolated from the Anderson and Smith coalbeds (figures 33 and 37). Changes in water levels in the alluvium reflect water table response to seasonal weather patterns (Figure 35). Alluvial water-level changes at SL-3Q (Figure 36) also appear to be in response to seasonal weather patterns and not to CBM production, as no change in overburden water levels has been detected.

Water-quality samples were collected at HWC 86-13 (GWIC ID#8888) and HWC 86-15 (GWIC ID#198489) during May and September of 2007 (appendix C). The TDS concentrations in the alluvial water range from 6,314 to 8,170 mg/L and SAR values range from 10.6 to 11.8. The water chemistry in the alluvium is dominated by sodium and sulfate. There is very little difference between these data and data from samples collected at these wells in 1987 (GWIC). A water-quality sample was collected on North Fork Waddle Creek at SL-3Q (GWIC ID#219136) during May and October of 2007 (appendix C). The TDS concentrations were 3,682 and 3,579 mg/L, respectively and SAR values were 5.2 and 5.4, respectively. The water chemistry is dominated by sodium sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site. Water-quality samples were taken from HWC86-7 (GWIC ID#7905) during May and September of 2007. The TDS was 2,990 and 2,914 and SAR was 7.0 and 6.6 respectively. These data are available on GWIC.

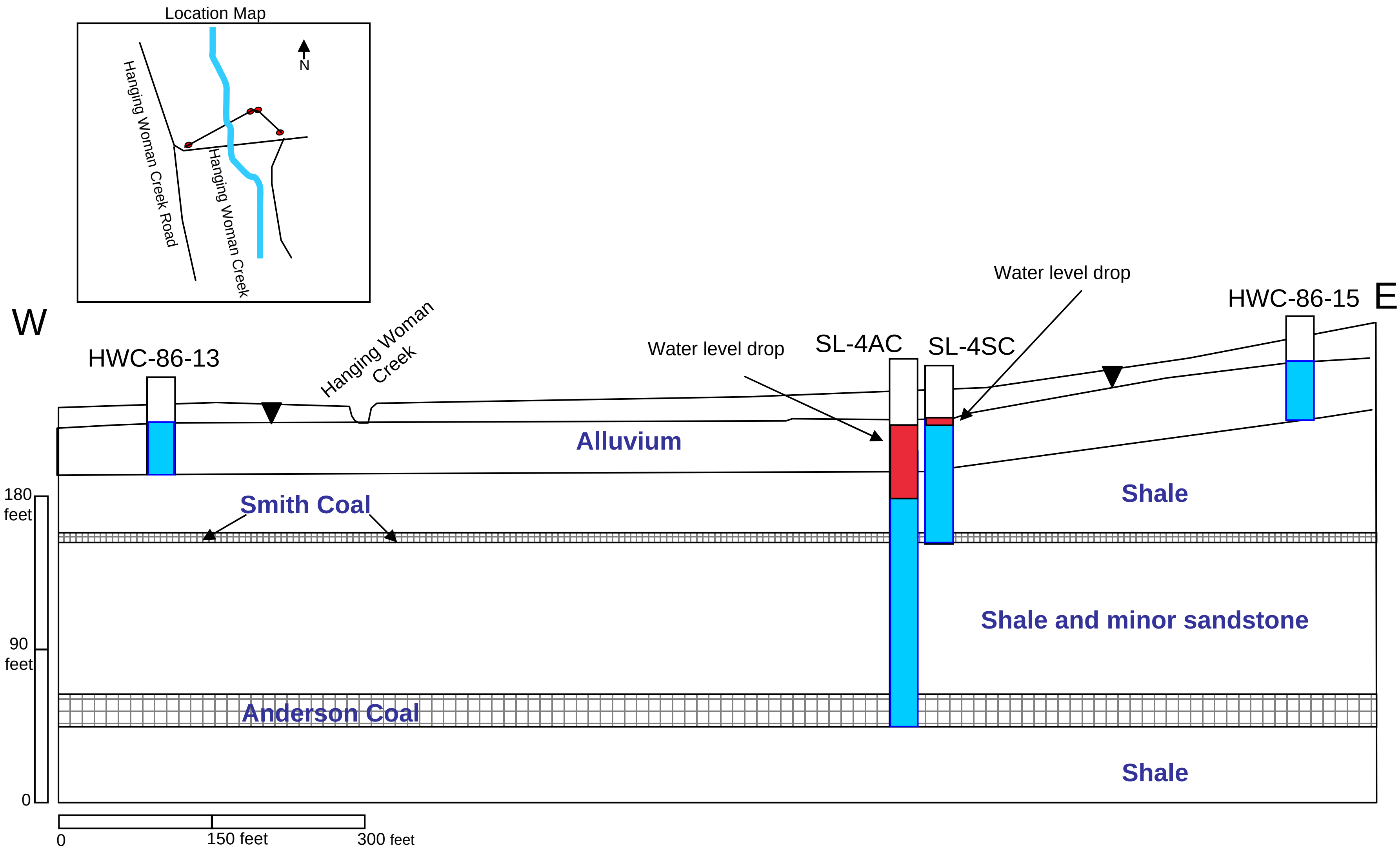


Figure 32. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 46ft and the Smith has lowered about 11ft since well instillation (shown in cross section). These wells are located roughly 1 mile north of the nearest CBM field. Water levels for the cross section were taken in December 2007. Vertical exaggeration is 1.7:1.

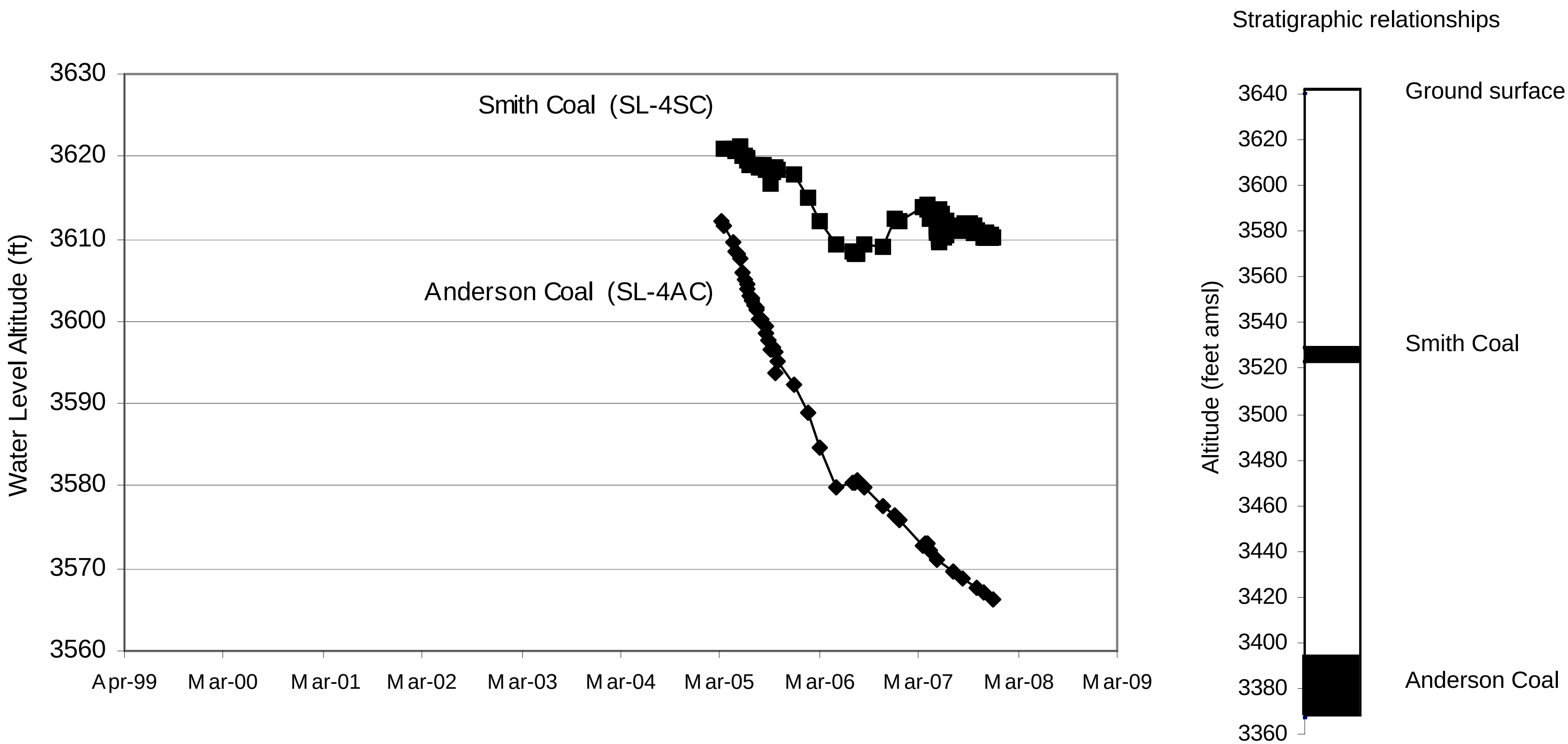


Figure 33. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson Coal appear to have lowered about 46 feet since April 2005 in response to CBM development; however it is unclear if true baseline was obtained prior to impacts occurring. Water levels in the Smith Coal have decreased, but a clear relationship to CBM has not been established. Water production from CBM wells in this field began during November, 2004.

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

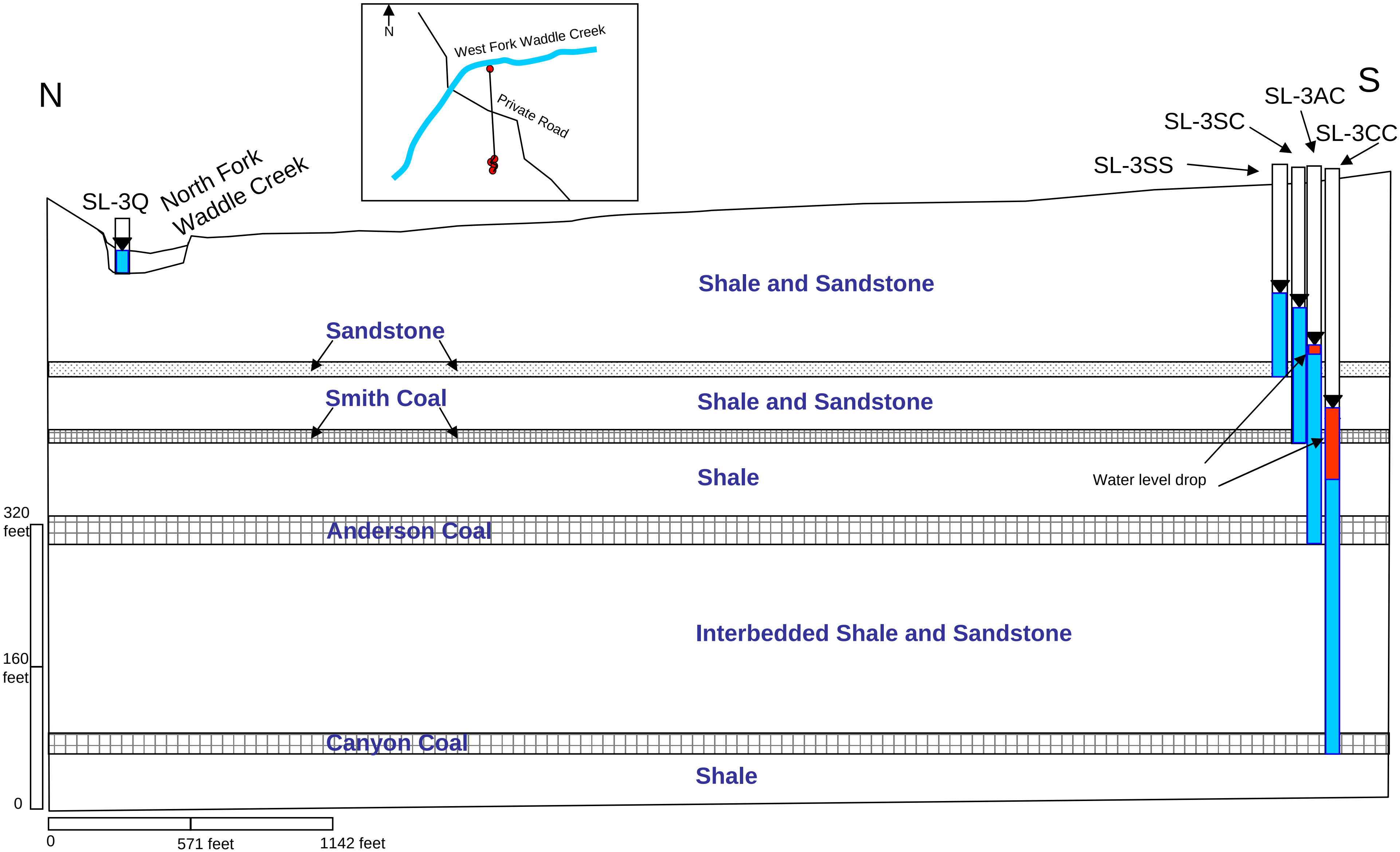


Figure 34. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coal beds located at T9S R42E section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in December 2007. The water level in the Anderson Coal has lowered about 13.5 feet and the Canyon coal has lowered about 101 feet since well installation. The wells are located roughly 1 mile north from nearest CMB field. Vertical exaggeration is 3.6:1.

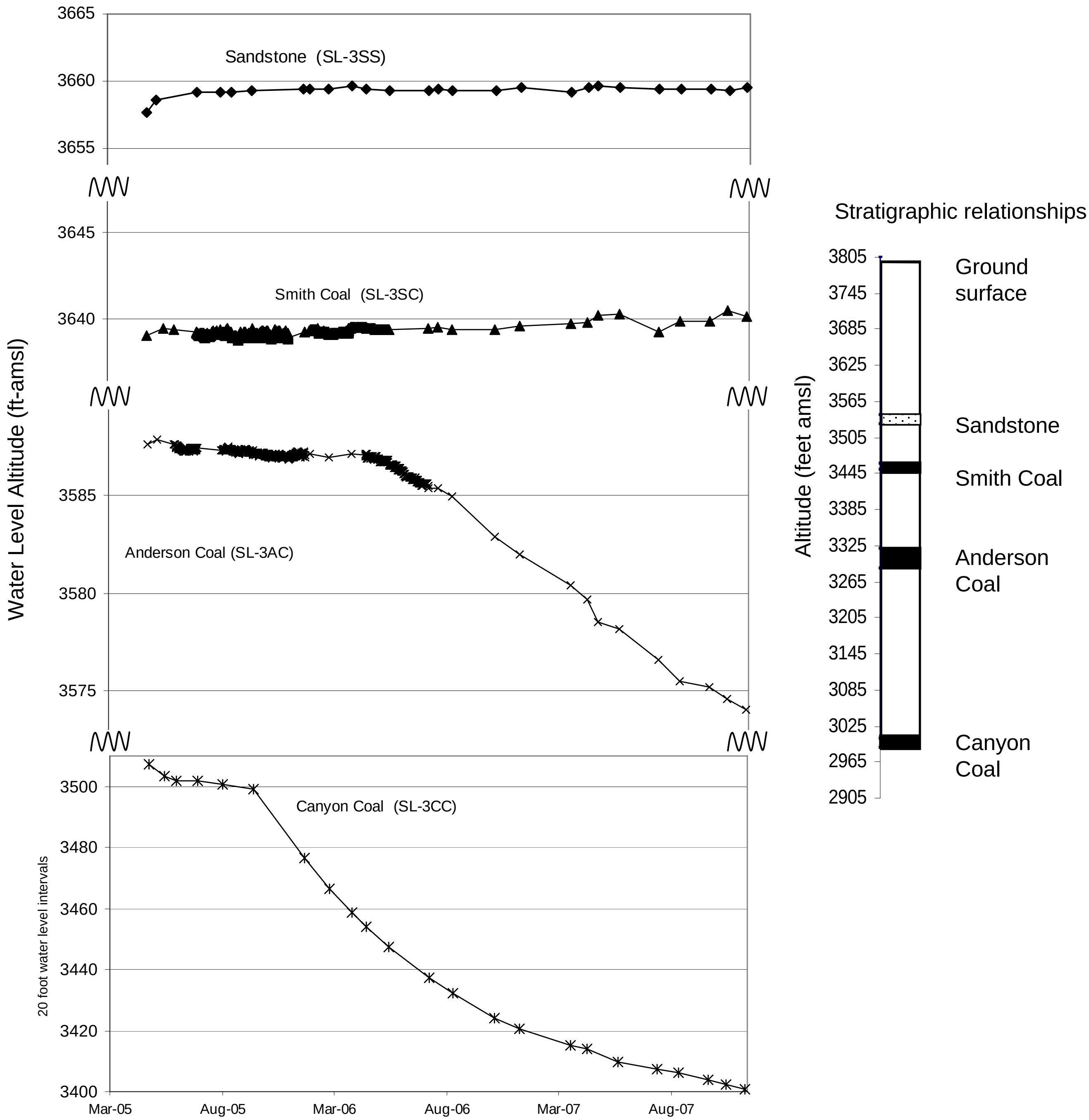


Figure 35. Water levels in the overburden sandstone and Smith coals are not responding to CBM development. However the water level in the Anderson and Canyon Coal have dropped about 13.5 and 103 feet respectively in response to CBM production.

Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.
The Y axis scale is broken to show better hydrograph detail.

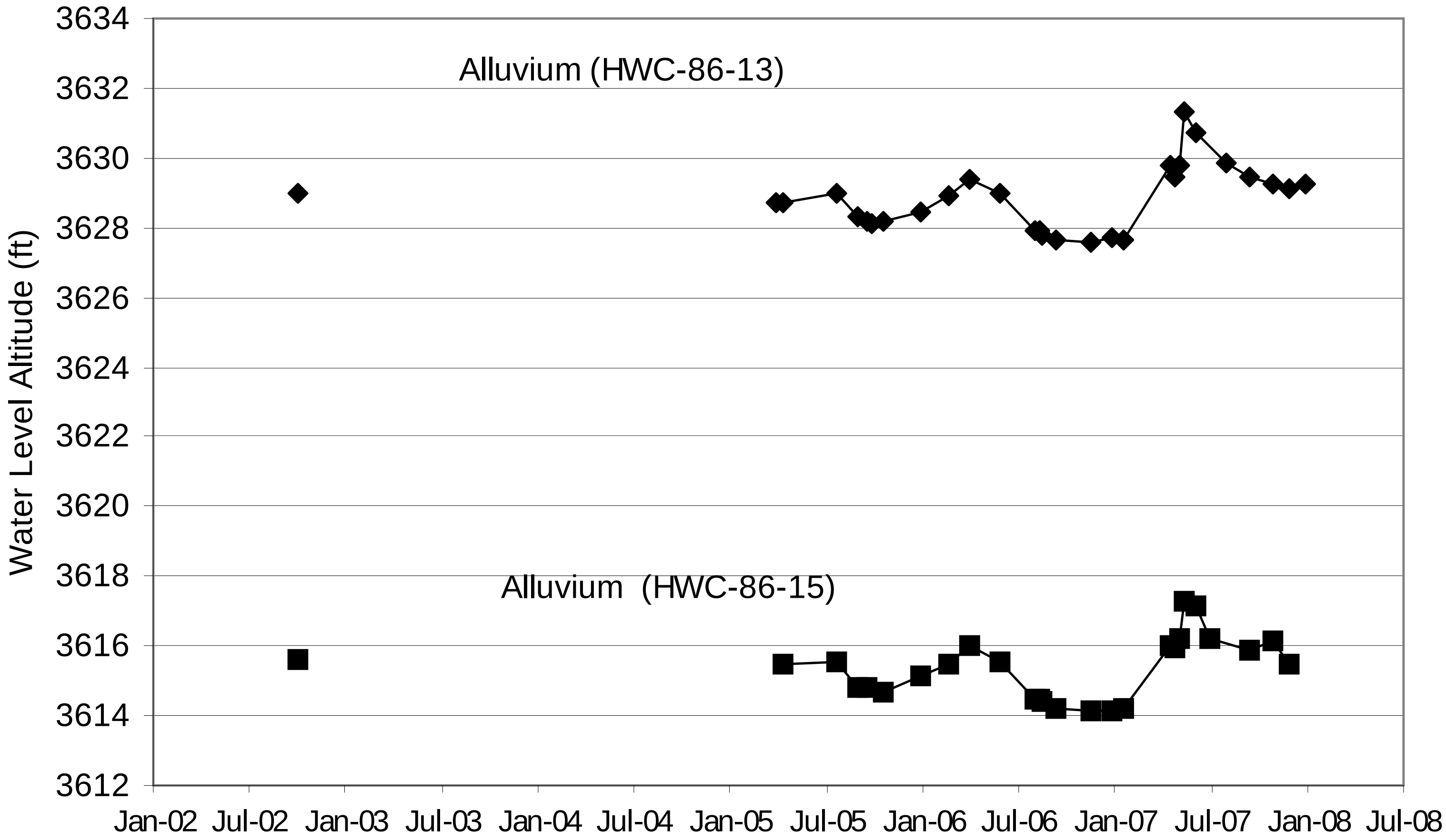


Figure 36. The water level in the Hanging Woman Creek alluvial aquifer near the Montana – Wyoming state line reflects water table response to meteorological pattern.

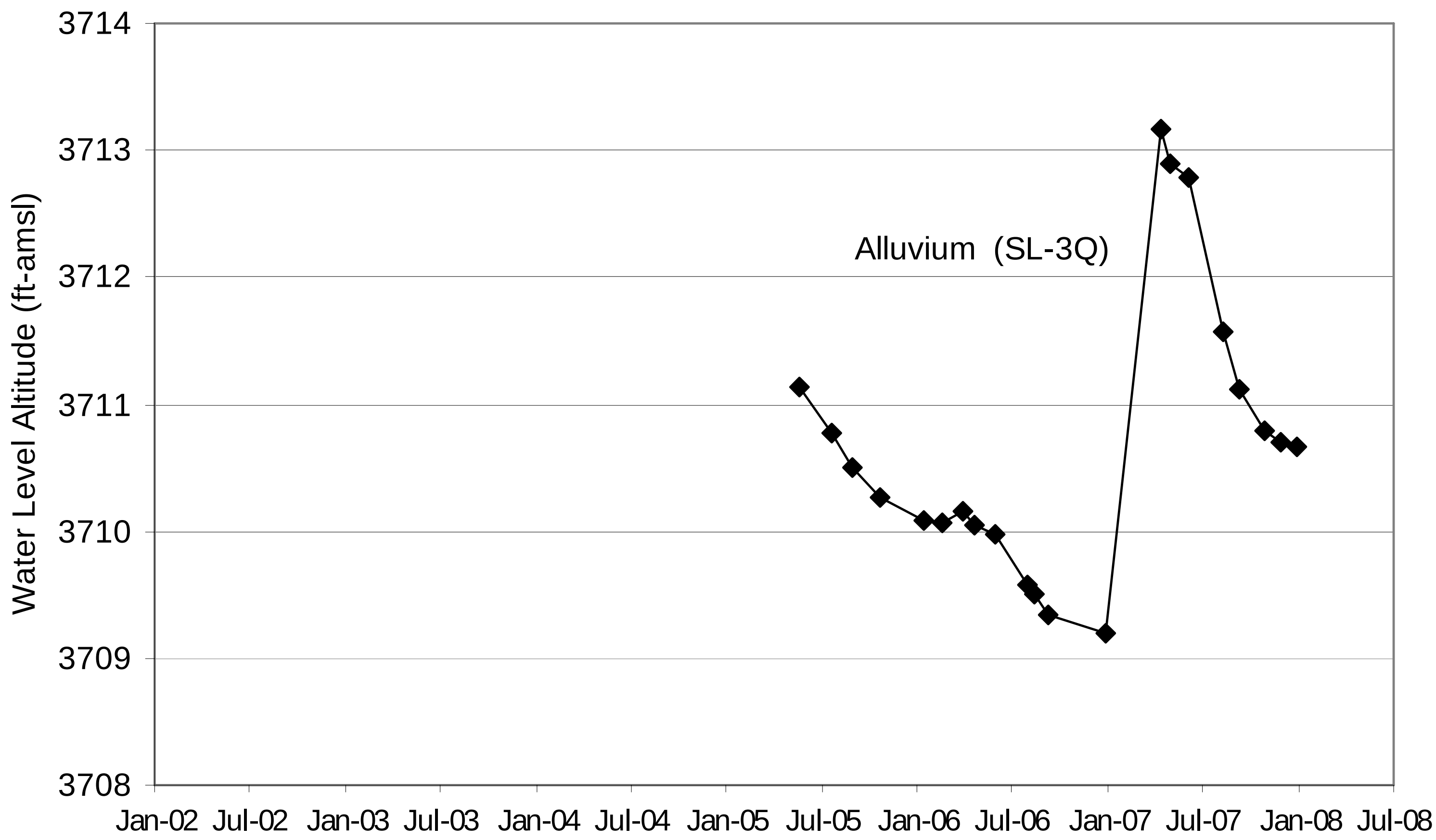


Figure 37. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production.

Gas field near Powder River

Methane water production. Near the Powder River (Plate 1), CBM is being produced from the combined Anderson and Dietz (Wyodak), Canyon, Cook, Wall, Pawnee, and Cache coalbeds (Figure 2). During 2007, a total of 982 wells produced methane and/or water in this area. The cumulative production for the 12-month period was 38 million barrels, or 3,692 acre-feet. Average water-production rate per well was 2.3 gpm and the average total production rate for the area was 2,289 gpm.

Bedrock aquifer water levels. Monitoring well SL-7CC is completed in the Canyon coal and located less than 1 mile north of the state line near the Wyoming CBM production in this area. Water levels are not currently monitored in this well due to the volume of gas released when the well is opened. The free gas release from this well was documented during 2005 and is discussed in the 2005 annual monitoring report (Wheaton and others, 2006). This gas migration was occurring prior to CBM development in this area, so at least some portion of the venting is due to naturally occurring free-phase gas.

Two monitoring wells at site SL-6 are located 6 miles west of SL-7CC. Well SL-6CC is completed in the Canyon coal and releases gas similar to the conditions described for SL-7CC. For this reason, water levels are not currently measured at this well. Well SL-6AC is completed in the Anderson coal and no CBM-related change in water levels have been noted in this well (GWIC data).

Alluvial aquifer water levels and water quality. South of Moorhead, ground-water flow through the Powder River alluvium is roughly parallel to the river flow (figures 38 and 39). This site is located on a large meander of the river, and the river likely loses flow to the alluvium on the up-gradient end of the meander and gains at the lower end. A stock well (GWIC M:221592) at this location is flowing under artesian pressure, indicating an upward gradient with depth. This well is likely producing from a sandstone unit 500 to 586 ft below ground surface (MBMG file date). Water levels in alluvial monitoring wells at this site do not indicate responses to CBM production or CBM water management in Wyoming.

Water-quality samples were collected from three wells at SL-8 in April and October of 2007 (appendix C). Wells SL-8-1Q (GWIC ID#220851), SL-8-2Q (GWIC ID#220857) and SL-8-3Q (GWIC ID#220859) have TDS concentrations ranging from 2,020 to 3,673 mg/L and SAR values ranging from 3.4 to 5.7. The water chemistry is dominated by calcium, sodium, and sulfate. The TDS and SAR values are higher in the well closest to the Powder River (Figure 38) but no CBM impacts are apparent. There are also insufficient data to identify seasonality trends. The data are available on GWIC.

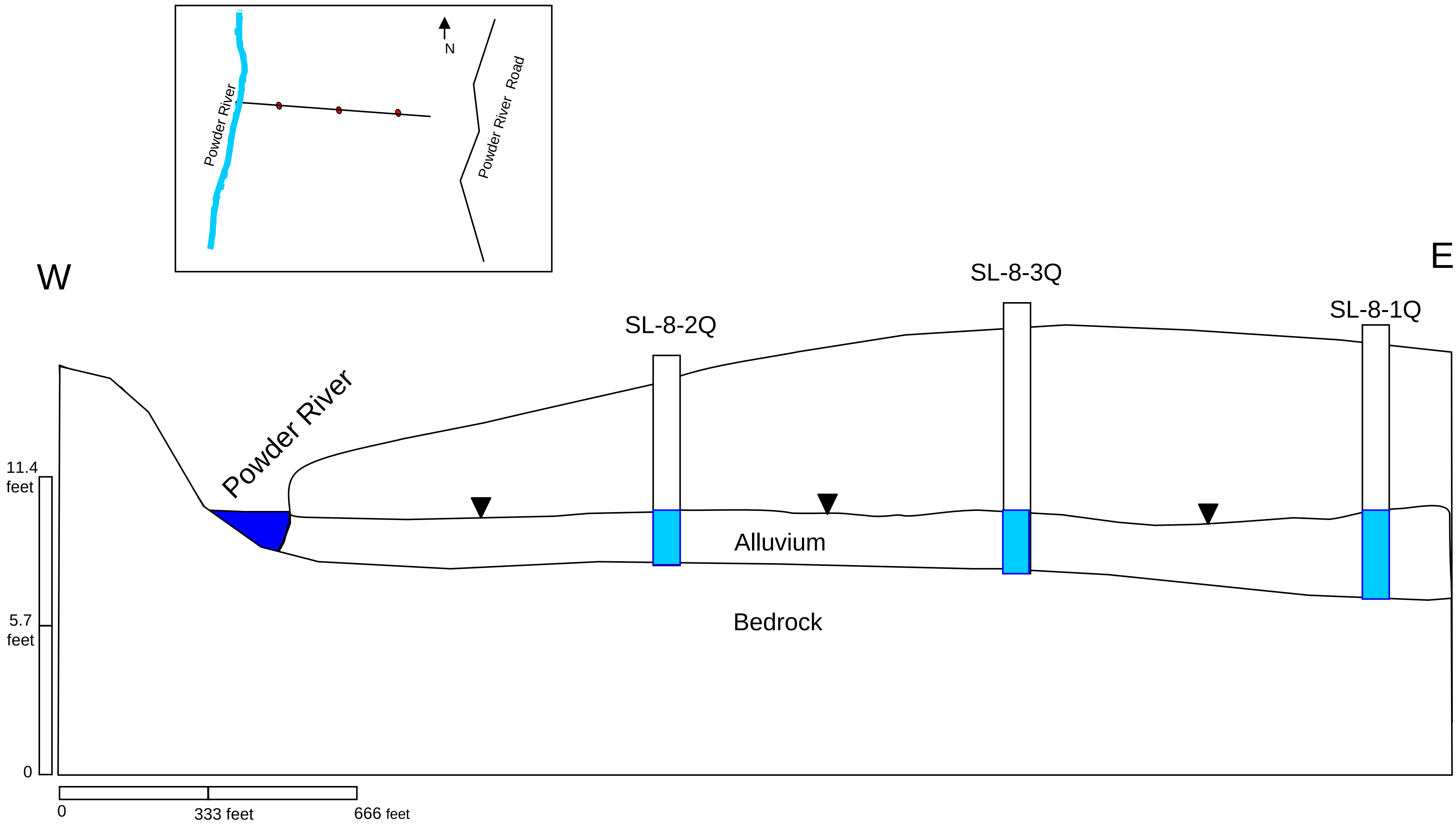


Figure 38. Cross section of alluvial wells south of Moorhead near the Powder River located in T09S R47E section 25. Ground water in the alluvium appear to flow parallel to the river. Water levels for this cross section were taken in January 2007. Vertical exaggeration is 58:1.

Figure 39. Ground-water flow in the alluvial aquifer at SL-8 is roughly parallel to the Powder River. The ground water-level trends follow river stage trends. The river alternates between gaining (summer) and loosing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gaging station (USGS data) and the surveyed river water-level altitude at SL-8 on 1/27/06.

Tritium Analysis

The age of ground water, considered to be the time since the water fell as rain or was last in contact with the atmosphere, can be a useful measurement to determine characteristics of an aquifer. Estimation of the age of water in an aquifer can be done in a number of ways; one common way is through measurement of the tritium concentration of the aquifer water. Tritium is a radioactive isotope of hydrogen that is produced in low levels naturally in the atmosphere and during nuclear power generation. Tritium was also produced in great quantities during nuclear bomb testing prior to The Partial Test Ban Treaty of 1963. The radioactive decay of tritium to helium-3 occurs relatively rapidly with a half life of 12.5 years. Due to this quick decay time, tritium is not present in measureable quantities in water that is over 60 years old. The spike in tritium levels produced during nuclear testing in the 1950s allows the identification of water that originated as meteoric water during that time frame. Tritium is measured in Tritium Units (TU).

As a general rule (Clark and Fritz, 1997):

- Water with no measureable tritium recharged the aquifer prior to 1952.
- Water with intermediate tritium concentrations of 0.8 to 4 TU is most likely a mixture of modern water and older, tritium-dead, water.
- Water with measured 5 to 15 TU is less than 10 years old.
- Water which has TU values of 15 to 30 shows some influence of "bomb" era tritium indicating at least some of the water originated after bomb testing.
- Water with over 30 TU shows a considerable amount of tritium from the 1960s and 1970s.
- Water with over 50 TU most likely recharged the aquifer during the peak of nuclear testing.

Four wells and three springs within the study area were sampled and tritium levels were analyzed (table 5). All monitoring wells and Alkali Spring have non-detectable tritium levels reflecting the long flow path of a regional flow system. These wells are all completed in aquifers that were recharged prior to 1952. However, Three Mile Spring and Upper Anderson Creek Spring have tritium levels which indicate a mixture of older, tritium-dead water, and more modern water.

Local flow systems are dominated by young, recently recharged ground water. Ground water in these systems will have tritium values similar to modern precipitation (5 to 15 TU). Water which shows an intermediate tritium value between 5 and 0, such as Three Mile and Upper Anderson Creek Springs, most likely has some contribution of older water. Three Mile Spring is interpreted to be primarily local flow with a small contribution from older, ground water in a regional flow system. Whereas Upper Anderson Creek may have a significant quantity of older water in addition to a local recharge source. These interpretations are supported by geochemical and physical analyses as well. Springs with primarily local recharge sources are unlikely to be affected by CBM development in deeper aquifers. Tritium is a useful indicator of local versus regional flow regimes, which can help focus monitoring efforts on those springs that may be impacted by CBM development.

Table 5. Tritium from springs and wells in the Montana Powder River Basin						
GWIC ID	Sample Name	Source	Sample Date	^{3}H (TU)	error	average age
197452	USDA Forest Service Alkali Spring	Cook	5/1/2007	<0.8	0.6	greater than 60 years
228591	Three Mile Spring	Clinker	5/2/2007	4	0.7	less than 60 years
228776	Upper Anderson Creek Spring	Canyon	8/1/2007	2.6	0.6	less than 60 years
203705	MBMG Monitoring Well CBM03-11AC	Anderson	7/25/2007	<0.8	0.6	greater than 60 years
203708	MBMG Monitoring Well CBM03-11CC	Canyon	7/24/2007	<0.8	0.6	greater than 60 years
219927	MBMG Monitoring Well SL-5AC	Anderson	7/26/2007	<0.8	0.6	greater than 60 years
8107	MBMG Monitoring Well HWC-01 -O-2 TR-26	Canyon	8/1/2007	<0.8	0.6	greater than 60 years
Measureable tritium can indicate either a true age or a mixture of older and younger water.						

Summary and 2008 monitoring plan

Coalbed-methane production continues in the CX, Coal Creek and Dietz areas in Montana, and near the state line in Wyoming. Projects have been proposed at several additional areas (Plate 1). It appears likely that during the next several years CBM development will expand in those areas within about 12 miles north of the state line and from the Crow Indian Reservation to the Powder River. 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 within the monitored aquifers. 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 in the CX field have been lower than predicted, averaging 3.0 gpm during 2007 from 729 wells. Within the CX field, ground-water levels have been drawn down by over 150 ft in the producing coalbeds. The actual amount of drawdown in some wells cannot be measured due to safety concerns as a result of methane release from monitoring wells. After nearly 9 years of CBM production, drawdown of up to 20 ft has been measured in the coal seams at a distance of roughly 1 to 1.5 miles outside the production areas.

These values have not changed substantially since 2004 (Wheaton and others, 2005). These distances are similar to but somewhat less than predicted in the Montana CBM environmental impact statement. The EIS predicted 20 ft of drawdown would reach 2 miles after 10 years of CBM production. At the Coal Creek field, 12 ft of drawdown during a period of 24 months has been measured at a distance of 2.5 miles from the nearest producing well. Faults tend to act as barriers to ground-water flow and drawdown does not migrate across fault planes where measured in monitoring wells. Vertical migration of drawdown tends to be limited by shale layers.

Water levels will recover after production ceases, but it may take many years 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, including the extent of faults in the Fort Union Formation and proximity to recharge areas. Since 2004, recovery has been measured at four wells near the Montana–Wyoming state line in the far western part of the study area. Drawdown in these wells ranged from 19 to 152 ft. After 4.5 years, recovery in these four wells is 71 to 87 percent of baseline levels.

Water from production wells is expected to have TDS concentrations generally between 875 mg/L and 1,525 mg/L. Data collected during 2006 from coal seams where SO_4 concentrations were low support those values, with the lowest measured TDS being 1,075 mg/L and the highest measured TDS being 2,029 mg/L. Sodium adsorption ratios in methane-bearing coal seams are high, and data collected during 2006 indicate values between 36.8 and 66.3.

Monitoring plans for 2008 are included in appendices A and B and shown on Plate 6. During 2008, monitoring sites located within approximately 6 miles of existing or proposed development (except for the Castle Rock area, which has no current plans for development) will be monitored monthly. Outside of this area monitoring will occur semi-annually or quarterly depending on distance to production and amount of background data collected to date. Meteorological stations currently deployed at SL-3, RBC-2, and near Poker Jim Butte will be maintained. Data loggers will be installed at the gassy SL-6 and SL-7 sites. Data loggers will also be installed at other sites as warranted. Water-quality samples will be collected semi-annually from selected alluvial sites. Monitoring priorities will be adjusted as new areas of production are proposed or developed.

It is anticipated that CBM operators will continue to collect water-level data, and any data provided to MBMG will be incorporated into the future regional monitoring reports. Also, the reporting period for future regional monitoring reports will be shifted to correspond with water years (October through September). Other reports being prepared, such as surface water reports, are based on the water-year period.

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Appendix A

Site details, water-level data and 2008 monitoring plan
for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County	Land-surface altitude (feet)
WO-15	7573	-106.18550	45.51860	04S	45E	4	BDDB	POWDER RIVER	3022.0
WO-16	7574	-106.18610	45.51580	04S	45E	4	CAAC	POWDER RIVER	3040.0
NEWELL PIPELINE WELL	7589	-106.21430	45.47270	04S	45E	19	DADD	POWDER RIVER	3290.0
77-26	7755	-106.18390	45.43520	05S	45E	4	ABCC	POWDER RIVER	3284.0
WO-8	7770	-106.14110	45.39220	05S	45E	23	ABCA	POWDER RIVER	3155.0
WO-9	7772	-106.14190	45.39250	05S	45E	23	ABCA	POWDER RIVER	3150.0
WO-10	7775	-106.14300	45.39250	05S	45E	23	ABCB	POWDER RIVER	3145.0
WO-5	7776	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER	3160.0
WO-6	7777	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER	3160.0
WO-7	7778	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER	3160.0
WO-1	7780	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER	3190.0
WO-2	7781	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER	3188.0
WO-3	7782	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER	3186.0
WO-4	7783	-106.14860	45.39410	05S	45E	23	BBAA	POWDER RIVER	3140.0
HWC86-9	7903	-106.50270	45.29660	06S	43E	19	DACD	ROSEBUD	3170.0
HWC86-7	7905	-106.50330	45.29580	06S	43E	19	DDBA	ROSEBUD	3170.0
HWC86-8	7906	-106.50300	45.29610	06S	43E	19	DDBA	ROSEBUD	3170.0
WR-21	8074	-106.97910	45.08770	08S	39E	32	DBBC	BIG HORN	3890.0
HWC-86-2	8101	-106.48270	45.13500	08S	43E	17	DDCA	BIG HORN	3460.0
HWC-86-5	8103	-106.48220	45.13410	08S	43E	17	DDDC	BIG HORN	3455.0
HWC-01	8107	-106.48660	45.13380	08S	43E	20	DDDD	BIG HORN	3530.0
HC-24	8118	-106.47470	45.12970	08S	43E	21	BDBB	BIG HORN	3500.0
FC-01	8140	-106.51660	45.10250	08S	43E	31	BBDA	BIG HORN	3735.0
FC-02	8141	-106.51660	45.10250	08S	43E	31	BBDA	BIG HORN	3735.0
BC-06	8191	-106.21000	45.13870	08S	45E	16	DBCB	POWDER RIVER	3715.0
BC-07	8192	-106.21000	45.13870	08S	45E	16	DBCB	POWDER RIVER	3715.0
WR-23	8347	-106.99050	45.09220	09S	38E	1	AADC	BIG HORN	3960.0
391	8368	-107.03200	45.04130	09S	38E	22	DADC	BIG HORN	3987.0
388	8371	-107.02050	45.03910	09S	38E	23	CDAD	BIG HORN	3975.0
396	8372	-107.00880	45.04910	09S	38E	24	BBBC	BIG HORN	3939.0
394	8377	-107.00750	45.03300	09S	38E	25	BCBA	BIG HORN	3909.0
422	8379	-107.00610	45.02610	09S	38E	25	CBDC	BIG HORN	3917.0
395	8387	-107.06180	45.03610	09S	38E	26	ABAB	BIG HORN	3900.0
WR-58	8412	-106.91220	45.04080	09S	39E	14	DDBD	BIG HORN	3631.3
WR-58D	8413	-106.91380	45.03940	09S	39E	14	DDCC	BIG HORN	3627.4
WR-19	8417	-106.95050	45.05250	09S	39E	16	AABA	BIG HORN	3835.4
WR-20	8419	-106.95050	45.05250	09S	39E	16	AABA	BIG HORN	3835.3
WR-54A	8428	-106.89020	45.01470	09S	39E	25	DADB	BIG HORN	3631.2
WR-53A	8430	-106.88880	45.01220	09S	39E	25	DDAA	BIG HORN	3607.9
WR-24	8436	-106.98770	45.02020	09S	39E	29	BBDD	BIG HORN	3777.2
WR-33	8441	-106.97580	45.00660	09S	39E	32	ACAA	BIG HORN	3732.3
WR-27	8444	-106.96580	45.00080	09S	39E	33	DBBD	BIG HORN	3672.0
WR-45	8446	-106.95380	44.99660	09S	39E	33	DDCC	BIG HORN	3638.2
WR-44	8447	-106.95220	44.99660	09S	39E	33	DDCD	BIG HORN	3636.9
WR-42	8451	-106.95020	44.99660	09S	39E	33	DDDD	BIG HORN	3636.7
WRN-10	8456	-106.80940	45.07330	09S	40E	3	DABA	BIG HORN	3433.3
WRN-15	8461	-106.82750	45.06380	09S	40E	9	AADD	BIG HORN	3499.8
DS-05A	8471	-106.83380	45.05550	09S	40E	9	DCAB	BIG HORN	3505.5
WRE-09	8500	-106.77410	45.03970	09S	40E	13	DCBC	BIG HORN	3510.7
WRE-10	8501	-106.77410	45.03830	09S	40E	13	DCCB	BIG HORN	3518.5
WRE-11	8504	-106.77360	45.03830	09S	40E	13	DCCD	BIG HORN	3508.9
DS-02A	8574	-106.81660	45.04160	09S	40E	15	DBCC	BIG HORN	3430.0
WR-55A	8651	-106.88630	45.03020	09S	40E	19	CBBD	BIG HORN	3591.1
WRE-12	8687	-106.80380	45.03110	09S	40E	23	BCCD	BIG HORN	3463.2
WRE-13	8692	-106.80440	45.03110	09S	40E	23	BCCD	BIG HORN	3462.6
WRE-16	8698	-106.76970	45.03520	09S	40E	24	AACB	BIG HORN	3550.5
WR-17B	8706	-106.86410	45.02160	09S	40E	29	BBAC	BIG HORN	3574.7
WR-51A	8709	-106.86220	45.01860	09S	40E	29	BDCB	BIG HORN	3541.3
WR-52B	8710	-106.86270	45.01470	09S	40E	29	CACB	BIG HORN	3518.8
WRE-27	8721	-106.73910	45.05860	09S	41E	8	CABC	BIG HORN	3523.8
WRE-28	8723	-106.73910	45.05860	09S	41E	8	CABC	BIG HORN	3525.2
WRE-29	8726	-106.74110	45.05860	09S	41E	8	CBAD	BIG HORN	3523.3
CC-1	8754	-106.46460	45.08750	09S	43E	4	ABDD	BIG HORN	3520.0

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County	Land-surface altitude (feet)
CC-4	8757	-106.46590	45.08740	09S	43E	4	ABDD	BIG HORN	3511.0
CC-3	8758	-106.46540	45.08640	09S	43E	4	ACAA	BIG HORN	3521.0
HWC-38	8777	-106.40170	45.07230	09S	43E	12	ADBB	BIG HORN	3586.0
HWC-17	8778	-106.41330	45.05700	09S	43E	13	BCAA	BIG HORN	3610.0
HWC-15	8782	-106.44680	45.04120	09S	43E	22	ACCA	BIG HORN	3600.0
HWC-29B	8796	-106.39690	45.06880	09S	44E	7	BBCC	BIG HORN	3620.0
AMAX NO. 110	8835	-106.11530	45.06990	09S	46E	8	BACC	POWDER RIVER	3965.0
UOP-09	8846	-106.05780	45.07200	09S	46E	11	BBBA	POWDER RIVER	3929.0
UOP-10	8847	-106.05780	45.07200	09S	46E	11	BBBA	POWDER RIVER	3930.0
FULTON GEORGE *NO.6	8863	-105.86280	45.08070	09S	48E	5	ACDD	POWDER RIVER	3380.0
HWC 86-13	8888	-106.42620	45.00200	10S	43E	2	ABCA	BIG HORN	3640.0
LISCOM WELL	94661	-106.03230	45.77820	01S	46E	3	DBAA	POWDER RIVER	3275.0
COYOTE WELL	94666	-106.05050	45.75240	01S	46E	16	AACC	POWDER RIVER	3294.0
EAST FORK WELL	100472	-106.16420	45.59350	03S	45E	10	B	POWDER RIVER	3210.0
PADGET CREEK PIPELINE WELL	103155	-106.29400	45.39390	05S	44E	22	BBBD	ROSEBUD	3385.0
TOOLEY CREEK WELL	105007	-106.26970	45.21530	07S	45E	19	CAAA	POWDER RIVER	3755.0
WRE-18	121669	-106.76830	45.03470	09S	40E	24	AACD	BIG HORN	3573.1
WR-59	122766	-106.85260	45.00500	09S	40E	32	ACAD	BIG HORN	3470.1
WRE-20	122767	-106.77160	45.03690	09S	40E	24	ABAB	BIG HORN	3519.4
WR-38	122769	-106.96500	44.99380	37N	63E	23	BBCB	SHERIDAN	3692.9
WR-39	122770	-106.95550	44.99520	37N	63E	23	ABBC	SHERIDAN	3666.0
WRE-25	123795	-106.73330	45.06830	09S	41E	5	DCCA	BIG HORN	3549.4
WR-17A	123796	-106.86410	45.02160	09S	40E	29	BBAC	BIG HORN	3573.9
WRE-19	123797	-106.77360	45.03690	09S	40E	24	ABBA	BIG HORN	3520.3
WRN-11	123798	-106.80940	45.07330	09S	40E	3	DABA	BIG HORN	3436.8
WRE-24	130475	-106.73330	45.06880	09S	41E	5	DCCA	BIG HORN	3552.1
WR-31	130476	-106.98630	45.01630	09S	39E	29	CBAA	BIG HORN	3895.2
WR-48	132716	-106.96500	44.99330	37N	63E	23	BBCB	SHERIDAN	3693.8
WR-58A	132903	-106.91230	45.04030	09S	39E	14	DDBD	BIG HORN	3631.4
WR-30	132908	-106.98740	45.01650	09S	39E	29	CBAB	BIG HORN	3894.6
WR-34	132909	-106.97020	45.00150	09S	39E	33	CBBB	BIG HORN	3772.1
WRE-02	132910	-106.77560	45.07120	09S	40E	1	DBCC	BIG HORN	3456.8
WRE-21	132958	-106.77300	45.03860	09S	40E	24	ABAB	BIG HORN	3529.4
WRE-17	132959	-106.76830	45.03470	09S	40E	24	AACD	BIG HORN	3561.9
WR-52C	132960	-106.86290	45.01640	09S	40E	29	CABC	BIG HORN	3530.0
WR-52D	132961	-106.86160	45.01640	09S	40E	29	CABD	BIG HORN	3529.3
PKS-1179	132973	-106.80400	45.03140	09S	40E	23	CBBB	BIG HORN	3458.0
PIPELINE WELL 7(PL-1W) LOHOF	144969	-106.30740	45.23540	07S	44E	14	ABD	ROSEBUD	3850.0
5072B	157879	-106.49040	45.73930	01S	42E	24	ACBB	ROSEBUD	3160.0
5072C	157882	-106.49050	45.73940	01S	42E	24	ACBB	ROSEBUD	3160.0
5080B	157883	-106.51260	45.71990	01S	42E	26	DCBA	ROSEBUD	3260.0
5080C	157884	-106.51260	45.72000	01S	42E	26	DCBA	ROSEBUD	3260.0
BF-01	161749	-106.96670	44.98970	58N	84W	22	ACCC	SHERIDAN	3680.0
PKS-3204	166351	-106.82990	45.10670	08S	40E	28	ADA	BIG HORN	3500.0
PKS-3203	166358	-106.83020	45.10680	08S	40E	28	ADA	BIG HORN	3500.0
PKS-3202	166359	-106.79810	45.04510	09S	40E	14	CAA	BIG HORN	3438.0
PKS-3201	166362	-106.79710	45.04370	09S	40E	14	CAA	BIG HORN	3438.0
PKS-3200	166370	-106.79690	45.04400	09S	40E	14	CAA	BIG HORN	3438.0
PKS-3199	166388	-106.79660	45.04430	09S	40E	14	CAA	BIG HORN	3439.0
PKS-3198	166389	-106.79640	45.04460	09S	40E	14	CAA	BIG HORN	3440.0
WR-29R	166761	-106.81530	45.04650	09S	40E	15	ACCD	BIG HORN	3461.0
NANCE PROPERTIES INC	183560	-106.42050	45.43870	05S	43E	4	AAAB	ROSEBUD	3035.0
FULTON GEORGE	183563	-105.87090	45.06370	09S	48E	8	CABC	POWDER RIVER	3360.0
WHITETAIL RANGER STATION	183564	-105.97580	45.64040	02S	47E	19	CDCA	POWDER RIVER	4045.0
SKINNER GULCH PIPELINE WELL	183565	-105.91710	45.42750	05S	47E	3	BCCD	POWDER RIVER	3730.0
SH-624	184222	-107.09170	45.07250	09S	38E	7	DADB	BIG HORN	4644.7
625	184223	-107.05220	45.11330	08S	38E	28	DADB	BIG HORN	4186.6
625A	184224	-107.05220	45.11330	08S	38E	28	DADB	BIG HORN	4186.7
634	184225	-107.07280	45.14220	08S	38E	17	DADD	BIG HORN	4480.5
634A	184226	-107.08830	45.14220	08S	38E	17	DADD	BIG HORN	4481.2
WR-41	186195	-106.94980	44.99500	09S	39E	34	CCCC	BIG HORN	3642.7
HWC-37	189802	-106.40170	45.07230	09S	43E	12	ADBB	BIG HORN	3578.0
HWC-39	189838	-106.40040	45.07130	09S	43E	12	ADBD	BIG HORN	3591.0

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County	Land-surface altitude (feet)
HWC-10	190902	-106.46950	45.04440	09S	43E	21	BADA	BIG HORN	3610.0
HWC-11 TR-77	190904	-106.46960	45.04440	09S	43E	21	BADA	BIG HORN	3615.0
20-LW	191139	-106.78010	45.33910	06S	40E	1	CDDC	BIG HORN	3940.0
22-BA	191155	-106.69540	45.34840	06S	41E	3	BADD	ROSEBUD	3530.0
28-W	191163	-106.72920	45.32110	06S	41E	16	BBCC	ROSEBUD	3715.0
32-LW	191169	-106.70980	45.29550	06S	41E	21	DDDC	ROSEBUD	3530.0
75-23	191634	-106.20110	45.09660	08S	45E	34	BDBC	POWDER RIVER	3780.0
YA-109	192874	-107.03120	45.04070	09S	38E	22	DADC	BIG HORN	3830.0
HWC-7	198464	-106.40930	45.05370	09S	43E	13	DAAA	BIG HORN	3624.0
HWC-6	198465	-106.40930	45.05360	09S	43E	13	CAAA	BIG HORN	3595.0
HWC 86-15	198489	-106.42350	45.00250	10S	43E	2	AABC	BIG HORN	3630.0
CBM02-1KC	203646	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN	3980.3
CBM02-1BC	203655	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN	3983.9
CBM02-1LC	203658	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN	3981.8
CBM02-2WC	203669	-106.98840	45.02070	09S	39E	29	BBDC	BIG HORN	3792.0
CBM02-2RC	203670	-106.98890	45.01850	09S	39E	29	BCBD	BIG HORN	3890.0
CBM02-3CC	203676	-106.96080	45.13920	08S	39E	16	BAAA	BIG HORN	3920.0
CBM02-3DC	203678	-106.96070	45.13910	08S	39E	16	BAAA	BIG HORN	3920.0
CBM02-4WC	203680	-106.78020	45.17980	07S	40E	36	CDDC	BIG HORN	3500.0
CBM02-4SS1	203681	-106.78030	45.17980	07S	40E	36	CDDC	ROSEBUD	3500.0
CBM02-4SS2	203690	-106.78030	45.17980	07S	40E	36	CDDC	BIG HORN	3500.0
CBM02-7CC	203693	-106.89060	45.18010	08S	39E	1	AAAA	BIG HORN	3900.0
CBM02-7SS	203695	-106.89060	45.17990	08S	39E	1	AAAA	BIG HORN	3900.0
CBM02-8KC	203697	-106.54730	45.36890	05S	42E	28	DDAC	ROSEBUD	3262.3
CBM02-8SS	203699	-106.54720	45.36880	05S	42E	28	DDAC	ROSEBUD	3262.2
CBM02-8DS	203700	-106.54700	45.36870	05S	42E	28	DDAC	ROSEBUD	3260.5
CBM02-8FG	203701	-106.54710	45.36880	05S	42E	28	DDAC	ROSEBUD	3260.6
CBM03-10AC	203703	-106.60450	45.11410	08S	42E	29	ADAD	BIG HORN	4130.0
CBM03-10SS	203704	-106.60450	45.11410	08S	42E	29	ADAD	BIG HORN	4130.0
CBM03-11AC	203705	-106.36320	45.17930	08S	44E	5	BBBB	BIG HORN	3950.0
CBM03-11DC	203707	-106.36410	45.17930	08S	44E	5	BBBB	BIG HORN	3950.0
CBM03-11CC	203708	-106.36470	45.17930	08S	44E	5	BBBB	BIG HORN	3950.0
CBM03-12COC	203709	-106.21210	45.13520	08S	45E	16	DBCB	POWDER RIVER	3715.0
CBM03-13OC	203710	-106.05720	45.07220	09S	46E	11	BBBA	POWDER RIVER	3931.0
SPRING CREEK PIPELINE WELL	205082	-105.95380	45.38830	05S	47E	20	ACAC	POWDER RIVER	3630.0
RBC-1	207064	-106.98360	45.33270	06S	39E	8	CAAA	BIG HORN	3854.7
RBC-2	207066	-106.98440	45.33270	06S	39E	8	CAAA	BIG HORN	3849.4
RBC-3	207068	-106.98680	45.33310	06S	39E	8	BDCD	BIG HORN	3859.9
YA-114	207075	-107.05430	45.04610	09S	38E	21	ADBD	BIG HORN	4000.0
YA-105	207076	-107.05270	45.04650	09S	38E	21	ACAC	BIG HORN	4015.0
TA-100	207080	-107.00900	45.04790	09S	38E	23	BBCC	BIG HORN	3900.0
TA-101	207081	-107.00900	45.04820	09S	38E	24	BBCC	BIG HORN	3910.0
TA-102	207083	-107.00760	45.04860	09S	38E	24	BBCB	BIG HORN	3910.0
IB-2	207096	-106.43720	45.39300	05S	43E	21	BBDB	ROSEBUD	3191.6
MK-4	207097	-106.43630	45.39190	05S	43E	21	BBDC	ROSEBUD	3195.3
NM-4	207098	-106.43610	45.39160	05S	43E	21	BCAB	ROSEBUD	3195.3
WL-2	207099	-106.43580	45.39190	05S	43E	21	BBDC	ROSEBUD	3187.6
OC-28	207101	-106.19280	45.47170	04S	45E	21	CCBD	POWDER RIVER	3171.0
HC-01	207143	-106.47500	45.13140	08S	43E	21	BBDA	BIG HORN	3457.0
WO-14	210094	-106.18490	45.51830	04S	45E	4	BDDB	POWDER RIVER	3010.0
HWCQ-2	214096	-106.50090	45.19130	07S	43E	32	AAAA	ROSEBUD	3340.0
HWCQ-1	214097	-106.50050	45.19120	07S	43E	32	AAAA	ROSEBUD	3340.0
WA-7	214354	-106.43470	45.39330	05S	43E	21	BABC	ROSEBUD	3179.0
WO-11	215085	-106.14330	45.39270	05S	45E	23	ABCC	POWDER RIVER	3145.0
SL-2AC	219125	-106.63580	45.02760	09S	42E	30	BDAC	BIG HORN	3925.0
SL-3Q	219136	-106.53860	45.01610	09S	42E	36	BBAD	BIG HORN	3725.0
SL-3SC	219138	-106.53130	45.00800	09S	42E	36	DBCB	BIG HORN	3805.0
SL-3AC	219139	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN	3805.0
SL-3CC	219140	-106.53130	45.00820	09S	42E	36	DBCB	BIG HORN	3805.0
SL-4SC	219141	-106.42430	45.00310	10S	43E	2	ABAA	BIG HORN	3640.0
SL-4AC	219169	-106.42440	45.00310	10S	43E	2	ABAA	BIG HORN	3640.0
SL-3SS	219617	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN	3805.0
SL-5AC	219927	-106.27140	45.01190	09S	44E	36	ABBD	BIG HORN	3810.0

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County	Land-surface altitude (feet)
SL-5DC	219929	-106.27140	45.01190	09S	44E	36	ABBD	BIG HORN	3810.0
SL-6AC	220062	-106.15140	45.01480	09S	45E	36	ABBB	BIG HORN	4220.0
SL-6CC	220064	-106.15130	45.01480	09S	45E	36	ABBB	BIG HORN	4220.0
SL-7CC	220069	-106.03920	45.01470	09S	46E	36	BBBB	BIG HORN	4173.0
SL-5CC	220076	-106.27150	45.01190	09S	44E	36	ABBD	BIG HORN	3810.0
SL-2CC	220385	-106.63600	45.02730	09S	42E	30	BCBC	BIG HORN	3920.0
SL-8-1Q	220851	-105.89980	45.01760	09S	47E	25	DDDB	POWDER RIVER	3396.7
SL-8-2Q	220857	-105.90520	45.01820	09S	47E	25	DCDB	POWDER RIVER	3394.1
SL-8-3Q	220859	-105.90280	45.01770	09S	47E	25	DDCB	POWDER RIVER	3398.5
USGS 452355106333701	223236	-106.56030	45.39860	05S	42E	16	CCAB	ROSEBUD	3400.0
USGS 452408106382201	223237	-106.84640	45.36080	05S	41E	14	BDCD	ROSEBUD	3510.0
USGS 452139106504701	223238	-106.84640	45.36080	05S	40E	31	BDCC	BIG HORN	4440.0
USGS 452411106301601	223240	-106.50440	45.40300	05S	42E	14	ADDC	ROSEBUD	3220.0
USGS 452416106413001	223242	-106.69170	45.40440	05S	41E	17	ADBD	ROSEBUD	3740.0
USGS 452429106435201	223243	-106.73110	45.40800	05S	40E	13	ADAB	BIG HORN	3940.0
SL-5ALQ	223801	-106.25790	45.01290	09S	45E	31	BBA	POWDER RIVER	3810.0
POKER JIM MET	223869	-106.31640	45.30980	06S	44E	23	BBAA	ROSEBUD	4115.0
TAYLOR CREEK PIPELINE WELL	223890	-105.99280	45.22130	07S	47E	21	BBCC	POWDER RIVER	3910.0
WA-2	223952	-106.46210	45.40200	05S	43E	17	BCDD	ROSEBUD	3068.5
NC05-1 NEAR BIRNEY VILLAGE	226919	-106.47690	45.41060	05S	43E	7	C	ROSEBUD	3170.0
DH 76-102D	227246	-106.18620	45.07980	09S	45E	3	ADCC	ROSEBUD	3811.0
NC05-2	228124	-106.47720	45.41050	05S	43E	7	CCDC	ROSEBUD	3170.0
MUSGRAVE BILL	228592	-106.73194	45.16389	08S	41E	5	ACDB	BIG HORN	3335.0
RBC-MET	231583	-106.98440	45.33270	06S	39E	8	CAAA	BIG HORN	3849.4
SL-3 MET	231591	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN	3725.0
MOORHEAD CAMPGROUND WELL	223695	-105.87730	45.05420	09S	48E	17	BCBB	POWDER RIVER	3400
WR-55	8650	-106.88580	45.03000	09S	40E	19		BIG HORN	3591.2
WR-51	8708	-106.86200	45.01860	09S	40E	29		BIG HORN	3541.0
WR-54	127605	-106.89020	45.14700	09S	39E	25		BIG HORN	3629.9
WR-53	132907	-106.88800	45.01250	09S	39E	25		BIG HORN	3607.1

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)
WO-15	ALLUVIUM	63.0	12.0	1/26/2006	8.53
WO-16	ALLUVIUM	61.0	3.7	1/26/2006	22.74
NEWELL PIPELINE WELL	TONGUE RIVER FORMATION	325.0	5.0		
77-26	KNOBLOCH COAL	216.8	3.6	1/26/2006	145.32
WO-8	ALLUVIUM	33.0	12.0	1/26/2006	15.23
WO-9	ALLUVIUM	45.0	21.8	1/26/2006	11.53
WO-10	ALLUVIUM	41.4		1/26/2006	8.63
WO-5	KNOBLOCH UNDERBURDEN	192.0	20.4	1/26/2006	16.97
WO-6	LOWER KNOBLOCH COAL	82.0	7.0	1/26/2006	24.27
WO-7	ALLUVIUM	40.0	29.0	1/26/2006	26.58
WO-1	KNOBLOCH UNDERBURDEN	172.0	8.0	1/26/2006	37.26
WO-2	LOWER KNOBLOCH COAL	112.0	19.0	1/26/2006	44.46
WO-3	KNOBLOCH OVERBURDEN	66.0	17.8	1/26/2006	46.05
WO-4	ALLUVIUM	31.5		12/31/2006	9.57
HWC86-9	ALLUVIUM	44.0		2/2/2006	10.44
HWC86-7	ALLUVIUM	71.0		2/2/2006	8.98
HWC86-8	ALLUVIUM	67.0		2/2/2006	9.47
WR-21	DIETZ 1 AND DIETZ COALS COMBINED	206.0	4.0	1/13/2006	57.40
HWC-86-2	ALLUVIUM	50.0		12/22/2005	19.62
HWC-86-5	ALLUVIUM	33.0		12/22/2005	14.45
HWC-01	CANYON COAL	232.0	7.5	12/28/2005	87.89
HC-24	CANYON OVERBURDEN	150.0	7.1	10/20/2005	52.72
FC-01	ANDERSON COAL	133.0	0.0	8/31/2005	129.04
FC-02	DIETZ COAL	260.0		8/31/2005	240.63
BC-06	CANYON COAL	188.0	4.6	12/18/2005	89.05
BC-07	CANYON OVERBURDEN	66.0	0.8	12/18/2005	41.96
WR-23	DIETZ 1 AND DIETZ COALS COMBINED	322.0	6.0	1/13/2006	84.04
391	DIETZ 1 AND DIETZ COALS COMBINED	175.0		1/6/2006	61.10
388	DIETZ COAL	190.0		1/6/2006	81.01
396	ANDERSON-DIETZ 1 AND 2 COALS	280.0	25.0	1/13/2006	56.81
394	DIETZ COAL	242.0	5.0	1/6/2006	90.22
422	DIETZ COAL	187.0		1/6/2006	122.12
395	DIETZ COAL	299.0	15.0	1/6/2006	62.38
WR-58	ALLUVIUM	55.0	21.0	12/28/2005	18.73
WR-58D	ALLUVIUM	27.0	15.0	12/28/2005	18.87
WR-19	DIETZ 1 AND DIETZ COALS COMBINED	305.0	20.0	12/28/2005	140.24
WR-20	ANDERSON COAL	166.0	15.0	12/28/2005	115.33
WR-54A	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	211.0	1.0	12/28/2005	127.92
WR-53A	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	187.0		12/28/2005	110.04
WR-24	CANYON COAL	146.0		12/23/2005	34.02
WR-33	ANDERSON-DIETZ 1 CLINKER AND COAL	165.0		12/23/2005	51.92
WR-27	ANDERSON-DIETZ 1 AND 2 COALS	363.0	25.0	12/23/2005	132.51
WR-45	ALLUVIUM	64.0	30.0	10/19/2005	11.30
WR-44	ALLUVIUM	64.0	30.0	10/19/2005	11.05
WR-42	ALLUVIUM	66.0	30.0	10/19/2005	10.76
WRN-10	DIETZ 2 COAL	79.0	3.4	12/10/2005	28.49
WRN-15	DIETZ 2 COAL	140.0		1/5/2006	115.01
DS-05A	DIETZ 2 COAL	166.0	5.0	1/5/2006	136.83
WRE-09	DIETZ 2 COAL	232.0		1/6/2006	213.95
WRE-10	DIETZ COAL	183.0		1/6/2006	173.17
WRE-11	ANDERSON COAL	127.0		1/6/2006	95.51
DS-02A	DIETZ 2 COAL	150.0		1/5/2006	44.37
WR-55A	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	72.0		12/28/2005	45.14
WRE-12	ANDERSON COAL	172.0		12/10/2005	130.92
WRE-13	DIETZ COAL	206.0		12/10/2005	130.93
WRE-16	ANDERSON COAL	458.0		12/10/2005	69.69
WR-17B	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	160.0		12/28/2005	78.37
WR-51A	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	187.0		12/28/2005	30.97
WR-52B	ALLUVIUM	55.0	59.7	12/28/2005	5.69
WRE-27	ANDERSON COAL	77.0	0.5	1/6/2006	48.87
WRE-28	DIETZ COAL	153.0		1/6/2006	66.10
WRE-29	DIETZ 2 COAL	217.0		1/6/2006	129.46
CC-1	ALLUVIUM	28.0	4.2	12/28/2005	14.44

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)
CC-4	ALLUVIUM	25.0	4.8	12/28/2005	-27.36
CC-3	ALLUVIUM	34.5	4.6	12/28/2005	-14.79
HWC-38	ALLUVIUM	40.5		1/13/2006	21.02
HWC-17	ANDERSON COAL	82.0	6.9	1/13/2006	20.89
HWC-15	ANDERSON COAL	129.0	10.0	1/13/2006	12.32
HWC-29B	ANDERSON COAL	92.0		1/13/2006	45.96
AMAX NO. 110	DIETZ COAL	240.0	1.4	1/11/2005	166.66
UOP-09	CANYON COAL	261.5	0.8	1/27/2006	153.27
UOP-10	CANYON OVERBURDEN	207.3	4.4	1/27/2006	141.47
FULTON GEORGE *NO.6	TONGUE RIVER FORMATION	410.0	4.0	1/11/2006	16.19
HWC 86-13	ALLUVIUM	53.0	3.9	12/28/2005	11.58
LISCOM WELL	FORT UNION FORMATION	135.0	10.0	9/27/2005	98.37
COYOTE WELL	FORT UNION FORMATION	190.0	5.0	9/27/2005	134.86
EAST FORK WELL		193.0	5.0	4/1/1961	82.00
PADGET CREEK PIPELINE WELL	TONGUE RIVER FORMATION	135.0	10.0	2/3/2006	74.68
TOOLEY CREEK WELL	FORT UNION FORMATION	110.0	12.0	1/11/2006	37.11
WRE-18	ANDERSON COAL	445.0		12/10/2005	211.79
WR-59	ALLUVIUM	34.0	10.0	12/28/2005	9.42
WRE-20	ANDERSON COAL	120.0		1/6/2006	106.19
WR-38	DIETZ 1 AND DIETZ COALS COMBINED	286.0	3.8	12/23/2005	72.78
WR-39	ANDERSON-DIETZ 1 AND 2 COALS	312.0		10/19/2005	99.65
WRE-25	ANDERSON COAL	114.5		1/6/2006	61.07
WR-17A	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	88.0		12/28/2005	34.56
WRE-19	ANDERSON COAL	140.0		1/6/2006	107.29
WRN-11	ANDERSON-DIETZ 1 CLINKER AND COAL	50.0		12/10/2005	33.94
WRE-24	DIETZ COAL	154.0	20.0	1/6/2006	68.45
WR-31	ANDERSON COAL	316.0	2.0	12/23/2005	182.32
WR-48	ANDERSON COAL	167.0		12/23/2005	46.03
WR-58A	ALLUVIUM	24.0	8.0	12/28/2005	18.73
WR-30	DIETZ 1 AND DIETZ COALS COMBINED	428.0	5.0	12/23/2005	200.47
WR-34	ANDERSON-DIETZ 1 AND 2 COALS	522.0		12/23/2005	176.10
WRE-02	ALLUVIUM	79.0		1/6/2006	35.45
WRE-21	ANDERSON COAL	130.0		1/6/2006	112.71
WRE-17	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	250.0		12/10/2005	69.92
WR-52C	ALLUVIUM	62.0	20.0	12/28/2005	19.21
WR-52D	ALLUVIUM	40.0	1.0	12/28/2005	22.95
PKS-1179	DIETZ 2 COAL	282.0	5.0	12/10/2005	226.42
PIPELINE WELL 7(PL-1W) LOHOF	TONGUE RIVER FORMATION	225.0	15.0	2/3/2006	133.53
5072B	ROSEBUD COAL	109.0	2.0	2/22/2006	35.61
5072C	ROSEBUD COAL OVERBURDEN	106.0	0.3	2/22/2006	29.25
5080B	KNOBLOCH COAL	88.5	1.3	2/22/2006	46.70
5080C	KNOBLOCH OVERBURDEN	110.0	0.3	2/22/2006	35.66
BF-01	COAL MINE SPOILS BANK	125.0		12/23/2005	30.41
PKS-3204	ANDERSON-DIETZ 1 COAL BED	82.0		12/10/2005	73.37
PKS-3203	CANYON COAL	201.0		12/10/2005	121.60
PKS-3202	ALLUVIUM	60.0	5.0	12/28/2005	37.63
PKS-3201	CANYON COAL	390.0	50.0	12/28/2005	159.43
PKS-3200	DIETZ 2 COAL	242.0	20.0	12/28/2005	157.27
PKS-3199	DIETZ COAL	165.0	20.0	12/28/2005	117.89
PKS-3198	ANDERSON COAL	112.0		12/28/2005	82.32
WR-29R	ANDERSON-DIETZ 1 CLINKER AND COAL	72.0		12/10/2005	46.03
NANCE PROPERTIES INC	ALLUVIUM	20.0		1/11/2006	10.24
FULTON GEORGE	ALLUVIUM	30.0	1.0	1/11/2006	19.95
WHITETAIL RANGER STATION	FORT UNION FORMATION	60.0		1/11/2006	41.29
SKINNER GULCH PIPELINE WELL	TONGUE RIVER FORMATION	167.0		1/26/2006	49.50
SH-624	ANDERSON-DIETZ 1 COAL BED	435.1		12/14/2003	348.02
625	DIETZ COAL	186.0		1/13/2006	48.18
625A	ANDERSON COAL	90.6		1/13/2006	54.76
634	DIETZ COAL	348.0	12.0	12/5/2001	156.11
634A	ANDERSON COAL	159.1		12/5/2001	113.81
WR-41	ALLUVIUM	40.0	1.0	10/19/2005	18.09
HWC-37	ALLUVIUM	32.0		1/13/2006	11.51
HWC-39	ALLUVIUM	39.0		1/13/2006	26.82

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)
HWC-10	DIETZ COAL	229.0		12/28/2005	94.87
HWC-11 TR-77	ANDERSON COAL	135.0	8.0	12/28/2005	13.49
20-LW	WALL COAL	253.0	0.2	2/2/2006	93.94
22-BA	BREWSTER-ARNOLD COAL	262.0	0.4	8/30/2005	110.10
28-W	WALL COAL	144.0	1.3	2/2/2006	109.87
32-LW	WALL COAL	51.0	0.2	2/2/2006	37.48
75-23	CANYON COAL	247.0		12/18/2005	130.20
YA-109	ALLUVIUM	43.8		12/23/2005	37.72
HWC-7		67.0		12/28/2006	30.42
HWC-6	DIETZ COAL	151.6		1/13/2006	69.15
HWC 86-15	ALLUVIUM	62.5	30.0	12/28/2005	14.88
CBM02-1KC	KNOBLOCH COAL	417.0	0.5	1/31/2006	172.82
CBM02-1BC	BREWSTER-ARNOLD COAL	255.5	5.0	1/31/2006	101.02
CBM02-1LC	LOCAL COALS	366.0	2.0	1/31/2006	144.13
CBM02-2WC	CARNEY COAL	290.0	10.0	12/23/2005	70.62
CBM02-2RC	ROLAND COAL	159.0	1.0	12/23/2005	135.36
CBM02-3CC	CANYON COAL	376.4	0.3	12/22/2005	301.12
CBM02-3DC	DIETZ COAL	235.0	0.1	12/22/2005	184.69
CBM02-4WC	WALL COAL	291.0	0.2	12/23/2005	175.87
CBM02-4SS1	WALL COAL OVERBURDEN	221.0	5.0	12/23/2005	75.73
CBM02-4SS2	CANYON UNDERBURDEN	96.6	30.0	12/23/2005	36.83
CBM02-7CC	CANYON COAL	263.4	1.5	12/22/2005	163.77
CBM02-7SS	CANYON OVERBURDEN	190.3	5.0	12/22/2005	89.40
CBM02-8KC	KNOBLOCH COAL	208.0	1.0	1/27/2006	157.98
CBM02-8SS	KNOBLOCH UNDERBURDEN	224.0	10.0	1/27/2006	160.06
CBM02-8DS	FLOWERS-GOODALE OVERBURDEN	446.0	0.3	1/27/2006	102.24
CBM02-8FG	FLOWERS-GOODALE COAL	480.4	0.5	1/27/2006	101.96
CBM03-10AC	ANDERSON COAL	560.0	0.3	12/22/2005	531.11
CBM03-10SS	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	462.0	1.0	12/22/2005	372.30
CBM03-11AC	ANDERSON COAL	211.0	1.0	12/18/2005	155.71
CBM03-11DC	DIETZ COAL	271.0	0.2	12/18/2005	227.76
CBM03-11CC	CANYON COAL	438.0	1.5	12/18/2005	382.22
CBM03-12COC	COOK COAL	351.0	3.0	12/18/2005	166.43
CBM03-13OC	OTTER COAL	500.0	1.5	1/27/2006	383.64
SPRING CREEK PIPELINE WELL	TONGUE RIVER FORMATION	50.0		1/26/2006	16.27
RBC-1	ALLUVIUM	26.8		1/31/2006	11.60
RBC-2	ALLUVIUM	16.9		1/31/2006	8.21
RBC-3	ALLUVIUM	24.6		1/31/2006	10.77
YA-114	ALLUVIUM			1/6/2006	13.51
YA-105	ALLUVIUM			1/6/2006	11.14
TA-100	ALLUVIUM			1/13/2006	13.94
TA-101	ALLUVIUM			1/13/2006	15.81
TA-102	ALLUVIUM			1/13/2006	21.09
IB-2	KNOBLOCH UNDERBURDEN	245.0		12/22/2005	119.53
MK-4	KNOBLOCH COAL	188.0		12/22/2005	119.65
NM-4	NANCE COAL	294.0		12/22/2005	120.14
WL-2	KNOBLOCH COAL	199.0		12/22/2005	117.30
OC-28	KNOBLOCH COAL			1/29/2006	68.81
HC-01	ALLUVIUM	19.7	17.0	10/20/2005	11.39
WO-14		66.1		10/18/2004	9.93
HWCQ-2	ALLUVIUM	19.0		2/2/2006	11.83
HWCQ-1	ALLUVIUM	19.5		2/2/2006	11.87
WA-7	ALLUVIUM			12/22/2005	55.15
WO-11	ALLUVIUM	38.5		1/26/2006	8.81
SL-2AC	ANDERSON COAL	671.0		1/6/2006	374.21
SL-3Q	ALLUVIUM	40.0	2.0	1/12/2006	14.91
SL-3SC	SMITH COAL	358.0	2.0	1/20/2006	165.71
SL-3AC	ANDERSON COAL	523.0	2.0	1/20/2006	219.10
SL-3CC	CANYON COAL	817.0	0.1	1/12/2006	329.44
SL-4SC	SMITH COAL	120.4	2.0	12/28/2005	22.28
SL-4AC	ANDERSON COAL	279.0	2.0	12/28/2005	47.73
SL-3SS	SMITH COAL OVERBURDEN	278.0	5.0	1/20/2006	145.54
SL-5AC	ANDERSON COAL	223.0	1.0	1/13/2006	132.11

Site Name	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date	Static water level (feet)
SL-5DC	DIETZ COAL	322.0	0.7	1/13/2006	167.98
SL-6AC	ANDERSON COAL	492.0	0.1	12/9/2005	374.80
SL-6CC	CANYON COAL	685.0	0.5	11/17/2005	521.75
SL-7CC	CANYON COAL	515.0	1.0	10/20/2005	456.92
SL-5CC	CANYON COAL	430.5	6.0	1/13/2006	180.43
SL-2CC	CANYON COAL	1301.0		1/6/2006	470.82
SL-8-1Q	ALLUVIUM	19.0	1.0	1/27/2006	12.27
SL-8-2Q	ALLUVIUM	13.8	0.3	1/27/2006	10.54
SL-8-3Q	ALLUVIUM	19.0	1.0	1/27/2006	14.57
USGS 452355106333701		376.0		8/25/2005	262.69
USGS 452408106382201		360.0		8/25/2005	238.61
USGS 452139106504701		680.5		6/6/2005	624.70
USGS 452411106301601		420.0		6/16/2005	106.90
USGS 452416106413001		353.0		8/24/2005	181.98
USGS 452429106435201		380.0		8/24/2005	200.26
SL-5ALQ	ALLUVIUM	35.0		9/16/2005	14.85
POKER JIM MET					
TAYLOR CREEK PIPELINE WELL	TONGUE RIVER FORMATION	150.0		1/26/2006	122.84
WA-2	ALLUVIUM			10/25/1980	45.20
NC05-1 NEAR BIRNEY VILLAGE		780.0			
DH 76-102D	DIETZ COAL	144.0		10/19/2006	23.98
NC05-2		348.0			
MUSGRAVE BILL	ALLUVIUM	21.5		9/7/2006	5.54
RBC-MET					
SL-3 MET					
MOORHEAD CAMPGROUND WELL	PAWNEE			1/27/2006	
WR-55	TONGUE RIVER FORMATION	288.0	15.0	9/28/1977	127.11
WR-51	TONGUE RIVER FORMATION	344.00	4.4	7/6/1977	76.22
WR-54	ANDERSON AND DIETZ COAL	384	20	9/28/1977	165.15
WR-53	ANDERSON AND DIETZ COAL	384.0	20.0	9/28/1977	142.05

Site Name	Static water level altitude (ft)	Comments	2008 planned SWL monitoring	2008 planned QW sample collection
WO-15	3013.5		SEMI-ANNUAL	
WO-16	3017.3		SEMI-ANNUAL	
NEWELL PIPELINE WELL			SEMI-ANNUAL	
77-26	3138.7		SEMI-ANNUAL	
WO-8	3139.8		QUARTERLY	
WO-9	3138.5		QUARTERLY	
WO-10	3136.4		QUARTERLY	
WO-5	3143.0		QUARTERLY	
WO-6	3135.7		QUARTERLY	
WO-7	3133.4		QUARTERLY	
WO-1	3152.7		QUARTERLY	
WO-2	3143.5		QUARTERLY	
WO-3	3140.0		QUARTERLY	
WO-4	3130.4		QUARTERLY	
HWC86-9	3159.6		MONTHLY	
HWC86-7	3161.0		MONTHLY	SEMI-ANNUAL
HWC86-8	3160.5		MONTHLY	
WR-21	3832.6		MONTHLY	
HWC-86-2	3440.4		MONTHLY	
HWC-86-5	3440.6		MONTHLY	
HWC-01	3442.1		MONTHLY	
HC-24	3447.3		SEMI-ANNUAL	
FC-01	3606.0		MONTHLY	
FC-02	3494.4		MONTHLY	
BC-06	3626.0		MONTHLY	
BC-07	3673.0		MONTHLY	
WR-23	3876.0		MONTHLY	
391	3925.9		MONTHLY	
388	3894.0		MONTHLY	
396	3882.2		MONTHLY	
394	3818.8		MONTHLY	
422	3794.9		SEMI-ANNUAL	
395	3837.6		MONTHLY	
WR-58	3612.6		MONTHLY	
WR-58D	3608.5		MONTHLY	
WR-19	3695.2		MONTHLY	
WR-20	3720.0		MONTHLY	
WR-54A	3503.3		MONTHLY	
WR-53A	3497.9		MONTHLY	
WR-24	3743.2		MONTHLY	
WR-33	3680.4		MONTHLY	
WR-27	3539.5		MONTHLY	
WR-45	3626.9		MONTHLY	
WR-44	3625.9		MONTHLY	
WR-42	3625.9		MONTHLY	
WRN-10	3404.8		MONTHLY	
WRN-15	3384.8		MONTHLY	
DS-05A	3368.7		MONTHLY	
WRE-09	3296.8		MONTHLY	
WRE-10	3345.3		MONTHLY	
WRE-11	3413.4		MONTHLY	
DS-02A	3385.6		MONTHLY	
WR-55A	3546.0		MONTHLY	
WRE-12	3332.3		MONTHLY	
WRE-13	3331.7		MONTHLY	
WRE-16	3480.8		MONTHLY	
WR-17B	3496.3		MONTHLY	
WR-51A	3510.3		MONTHLY	
WR-52B	3513.1		MONTHLY	
WRE-27	3474.9		MONTHLY	
WRE-28	3459.1		MONTHLY	
WRE-29	3393.8		MONTHLY	
CC-1	3505.6		MONTHLY	

Site Name	Static water level altitude (ft)	Comments	2008 planned SWL monitoring	2008 planned QW sample collection
CC-4	3538.4		MONTHLY	
CC-3	3535.8		MONTHLY	
HWC-38	3565.0		MONTHLY	
HWC-17	3589.1		MONTHLY	
HWC-15	3587.7		MONTHLY	
HWC-29B	3574.0		MONTHLY	
AMAX NO. 110	3798.3		MONTHLY	
UOP-09	3775.7		MONTHLY	
UOP-10	3788.5		MONTHLY	
FULTON GEORGE *NO.6	3363.8		QUARTERLY	
HWC 86-13	3628.4		MONTHLY	SEMI-ANNUAL
LISCOM WELL	3176.6		QUARTERLY	
COYOTE WELL	3159.1		QUARTERLY	
EAST FORK WELL	3017.0		QUARTERLY	
PADGET CREEK PIPELINE WELL	3310.3		QUARTERLY	
TOOLEY CREEK WELL	3717.9		QUARTERLY	
WRE-18	3361.3		MONTHLY	
WR-59	3460.7		MONTHLY	SEMI-ANNUAL
WRE-20	3413.2		MONTHLY	
WR-38	3620.1		MONTHLY	
WR-39	3566.4		MONTHLY	
WRE-25	3488.3		MONTHLY	
WR-17A	3539.3		MONTHLY	
WRE-19	3413.0		MONTHLY	
WRN-11	3402.9		MONTHLY	
WRE-24	3483.7		MONTHLY	
WR-31	3712.9		MONTHLY	
WR-48	3647.8		MONTHLY	
WR-58A	3612.6		MONTHLY	
WR-30	3694.1		MONTHLY	
WR-34	3596.0		MONTHLY	
WRE-02	3421.4		MONTHLY	
WRE-21	3416.7		MONTHLY	
WRE-17	3492.0		MONTHLY	
WR-52C	3510.8		MONTHLY	
WR-52D	3506.4		MONTHLY	
PKS-1179	3231.6		MONTHLY	
PIPELINE WELL 7(PL-1W) LOHOF	3716.5		QUARTERLY	
5072B	3124.4		QUARTERLY	
5072C	3130.8		QUARTERLY	
5080B	3213.3		QUARTERLY	
5080C	3224.3		QUARTERLY	
BF-01	3649.6		MONTHLY	
PKS-3204	3426.6		MONTHLY	
PKS-3203	3378.4		MONTHLY	
PKS-3202	3400.4		MONTHLY	
PKS-3201	3278.6		MONTHLY	
PKS-3200	3280.7		MONTHLY	
PKS-3199	3321.1		MONTHLY	
PKS-3198	3357.7		MONTHLY	
WR-29R	3415.0		MONTHLY	
NANCE PROPERTIES INC	3024.8		QUARTERLY	
FULTON GEORGE	3340.1		QUARTERLY	
WHITETAIL RANGER STATION	4003.7		QUARTERLY	
SKINNER GULCH PIPELINE WELL	3680.5		QUARTERLY	
SH-624	4296.7		QUARTERLY	
625	4138.4		QUARTERLY	
625A	4131.9		QUARTERLY	
634	4324.4		SEMI-ANNUAL	
634A	4367.4		SEMI-ANNUAL	
WR-41	3624.6		MONTHLY	
HWC-37	3566.5		MONTHLY	
HWC-39	3564.2		MONTHLY	

Site Name	Static water level altitude (ft)	Comments	2008 planned SWL monitoring	2008 planned QW sample collection
HWC-10	3515.1		MONTHLY	
HWC-11 TR-77	3601.5		MONTHLY	
20-LW	3846.1		MONTHLY	
22-BA	3419.9		QUARTERLY	
28-W	3605.1		MONTHLY	
32-LW	3492.5		MONTHLY	
75-23	3649.8		MONTHLY	
YA-109	3792.3		MONTHLY	
HWC-7	3593.6		MONTHLY	
HWC-6	3525.9		MONTHLY	
HWC 86-15	3615.1		MONTHLY	SEMI-ANNUAL
CBM02-1KC	3807.5		MONTHLY	
CBM02-1BC	3882.8		MONTHLY	
CBM02-1LC	3837.6		MONTHLY	
CBM02-2WC	3721.4		MONTHLY	
CBM02-2RC	3754.6		MONTHLY	
CBM02-3CC	3618.9		MONTHLY	
CBM02-3DC	3735.3		MONTHLY	
CBM02-4WC	3324.1		MONTHLY	
CBM02-4SS1	3424.3		MONTHLY	
CBM02-4SS2	3463.2		MONTHLY	
CBM02-7CC	3736.2		MONTHLY	
CBM02-7SS	3810.6		MONTHLY	
CBM02-8KC	3104.3		QUARTERLY	
CBM02-8SS	3102.1		QUARTERLY	
CBM02-8DS	3158.3		QUARTERLY	
CBM02-8FG	3158.7		QUARTERLY	
CBM03-10AC	3598.9		MONTHLY	
CBM03-10SS	3757.7		MONTHLY	
CBM03-11AC	3794.3		MONTHLY	
CBM03-11DC	3722.2		MONTHLY	
CBM03-11CC	3567.8		MONTHLY	
CBM03-12COC	3548.6		MONTHLY	
CBM03-13OC	3547.4		MONTHLY	
SPRING CREEK PIPELINE WELL	3613.7		QUARTERLY	
RBC-1	3843.1		MONTHLY	
RBC-2	3841.2		MONTHLY	SEMI-ANNUAL
RBC-3	3849.1		MONTHLY	
YA-114	3986.5		QUARTERLY	
YA-105	4003.9		QUARTERLY	
TA-100	3886.1		QUARTERLY	
TA-101	3894.2		QUARTERLY	
TA-102	3888.9		QUARTERLY	
IB-2	3072.1		QUARTERLY	
MK-4	3075.7		QUARTERLY	
NM-4	3075.2		QUARTERLY	
WL-2	3070.3		QUARTERLY	
OC-28	3102.2		SEMI-ANNUAL	
HC-01	3445.6		SEMI-ANNUAL	
WO-14	3000.1		SEMI-ANNUAL	
HWCQ-2	3328.2		QUARTERLY	
HWCQ-1	3328.1		QUARTERLY	
WA-7	3123.8		QUARTERLY	
WO-11	3136.2		QUARTERLY	
SL-2AC	3550.8		MONTHLY	
SL-3Q	3710.1		MONTHLY	SEMI-ANNUAL
SL-3SC	3639.3		MONTHLY	
SL-3AC	3585.9		MONTHLY	
SL-3CC	3475.6		MONTHLY	
SL-4SC	3617.7		MONTHLY	
SL-4AC	3592.3		MONTHLY	
SL-3SS	3659.5		MONTHLY	
SL-5AC	3677.9		MONTHLY	

Site Name	Static water level altitude (ft)	Comments	2008 planned SWL monitoring	2008 planned QW sample collection
SL-5DC	3642.0		MONTHLY	
SL-6AC	3845.2		MONTHLY	
SL-6CC	3698.3	59 PSI SHUT IN	MONTHLY	
SL-7CC	3716.1	16 PSI SHUT IN	MONTHLY	
SL-5CC	3629.6		MONTHLY	
SL-2CC	3449.2		MONTHLY	
SL-8-1Q	3384.4		MONTHLY	
SL-8-2Q	3383.6		MONTHLY	SEMI-ANNUAL
SL-8-3Q	3383.9		MONTHLY	SEMI-ANNUAL
USGS 452355106333701	3137.3			
USGS 452408106382201	3271.4			
USGS 452139106504701	3815.3			
USGS 452411106301601	3113.1			
USGS 452416106413001	3558.0			
USGS 452429106435201	3739.7			
SL-5ALQ	3795.2		MONTHLY	
POKER JIM MET			MONTHLY	
TAYLOR CREEK PIPELINE WELL	3787.2		QUARTERLY	
WA-2	3145.0		MONTHLY	SEMI-ANNUAL
NC05-1 NEAR BIRNEY VILLAGE				
DH 76-102D	3787.0		MONTHLY	
NC05-2				
MUSGRAVE BILL	3321.5		MONTHLY	SEMI-ANNUAL
RBC-MET			MONTHLY	
SL-3 MET			MONTHLY	
MOORHEAD CAMPGROUND WELL		Measure as a spring	MONTHLY	
WR-55	3464.1		MONTHLY	
WR-51	3464.78		MONTHLY	
WR-54	3464.75		MONTHLY	
WR-53	3465.0		MONTHLY	

Appendix B

Site details, discharge data and 2008 monitoring schedule
for monitored wells

Appendix B. Site details, discharge data, and 2008 monitoring schedule for monitored springs.

GWIC ID	Site name	Longitude	Latitude	Township	Range	Section	Tract	County	Spring source lithology
197247	SOUTH FORK HARRIS CREEK SPRING	-106.60530	45.16420	08S	42E	5	DDDB	BIG HORN	
197452	ALKALI SPRING	-106.15010	45.19140	07S	46E	31	BACD	POWDER RIVER	COAL
197607	UPPER FIFTEEN MILE SPRING	-105.93720	45.39200	05S	47E	16	DCDC	POWDER RIVER	COLLUVIUM
198766	LEMONADE SPRING	-105.92550	45.54550	03S	47E	28	ACAA	POWDER RIVER	
199568	HEDUM SPRING	-106.07100	45.28230	06S	46E	26	CDBA	POWDER RIVER	SANDSTONE
199572	DEADMAN SPRING	-105.87430	45.29030	06S	48E	29	BABB	POWDER RIVER	SANDSTONE
205004	HAGEN 2 SPRING	-106.26880	45.34500	06S	45E	6	ACDC	POWDER RIVER	CLINKER
205010	NORTH FORK SPRING	-105.87360	45.29960	06S	48E	20	BDCA	POWDER RIVER	
205011	JOE ANDERSON SPRING	-105.95470	45.27150	06S	47E	34	CABA	POWDER RIVER	
205041	SCHOOL HOUSE SPRING	-106.00810	45.19440	07S	47E	32	BABA	POWDER RIVER	SANDSTONE
205049	CHIPMUNK SPRING	-106.36110	45.21200	07S	44E	21	CCBB	ROSEBUD	SANDSTONE
223687	ROSEBUD CREEK RBC-4	-106.98630	45.33320	06S	39E	8	C	BIG HORN	
223877	EAST FORK HANGING WOMAN CREEK WEIR	-106.40410	45.29090	06S	43E	25	ABDD	ROSEBUD	
228591	THREE MILE SPRING	-106.79584	45.16904	07S	40E	35	BDAC	BIG HORN	
228776	UPPER ANDERSON SPRING	-106.62610	45.11550	08S	42E	30	ADAA	BIG HORN	
240578	LOWER ANDERSON SPRING	-106.69128	45.13732	08S	41E	15	ABBB	BIG HORN	

Appendix B. Site details, discharge data, and 2008 monitoring schedule for monitored springs.

GWIC ID	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Spring yield (gpm)	Spring yield date	2008 planned flow monitoring	2008 planned QW sample collection
197247	ANDERSON	REGIONAL	3690	0.6	6/19/2002	MONTHLY	
197452	OTTER	LOCAL	3470	1.1	3/30/2005	MONTHLY	SEMI-ANNUAL
197607	COOK	LOCAL	3805	0.6	1/26/2006	QUARTERLY	
198766	FERRY	LOCAL	3660	1.8	2/3/2006	QUARTERLY	
199568	COOK	LOCAL	3680	0.6	7/30/2005	QUARTERLY	
199572	CANYON	LOCAL	3940	0.6	9/12/2002	QUARTERLY	
205004	ANDERSON/DIETZ	LOCAL	3890	0.6	2/11/2006	QUARTERLY	
205010	CANYON	LOCAL	3960	0.9	7/30/2005	QUARTERLY	
205011	ANDERSON	LOCAL	4050	0.7	7/30/2005	QUARTERLY	
205041	CANYON	LOCAL	3735	0.9	8/21/2005	QUARTERLY	
205049	DIETZ	LOCAL	3670	0.6	10/20/2003	MONTHLY	
223687			3840.95			MONTHLY	
223877	OTTER	REGIONAL & LOCAL	3475	20	11/10/2005	MONTHLY	SEMI-ANNUAL
228591	DIETZ	LOCAL	3620	12.5	6/9/2003	MONTHLY	SEMI-ANNUAL
228776			3920.0	0.06	9/9/2006	MONTHLY	SEMI-ANNUAL
240578	ANDERSON	REGIONAL & LOCAL	3665	0.3	6/18/2002	MONTHLY	SEMI-ANNUAL

Appendix C

Ground-water quality data collected during 2007

Appendix C. Ground-water quality data collected during 2007

	Gwic Id	Site Name	Planned QW sample collection	Aquifer	Latitude	Longitude	Location (TRS)	County
Sites outside areas of potential CBM influence	223877	EAST FORK HANGING WOMAN CREEK WEIR	Semi-annually		45.2909	-106.4041	06S 43E 25ABDD	Rosebud
	228591	THREE MILE SPRING	Semi-annually	125TGRV	45.16904	-106.79584	07S 40E 35CDDD	Big Horn
	207066	WELL RBC-2	Semi-annually	110ALVM	45.3327	-106.9844	06S 39E 8CAAA	Big Horn
	203705	WELL CBM03-11AC		125ANCB	45.1793	-106.3632	08S 44E 5BBBB	Big Horn
	203708	WELL CBM03-11CC		125CNCB	45.1793	-106.3647	08S 44E 5BBBB	Big Horn
	197452	USDA FOREST SERVICE ALKALI SPRING	Semi-annually	125FRUN	45.1914	-106.1501	07S 46E 31BACD	Powder River
	219927	WELL SL-5AC		125ANCB	45.0119	-106.2714	09S 44E 36ABBD	Big Horn
Sites within areas of potential CBM influence	228592	MUSGRAVE BILL ALLUVIAL	Semi-annually	111ALVM	45.16389	-106.731944	08S 41E 5ACDB	Big Horn
	223952	WA-2	Semi-annually	110ALVM	45.403248	-106.456567	05S 43E 17BCDD	Rosebud
	8888	WELL HWC 86-13	Semi-annually	110ALVM	45.002	-106.4262	10S 43E 2ABCA	Big Horn
	198489	WELL HWC 86-15	Semi-annually	110ALVM	45.0025	-106.4235	10S 43E 2AABC	Big Horn
	7905	WELL HWC86-7	Semi-annually	110ALVM	45.2958	-106.5033	06S 43E 19DDBA	Rosebud
	219136	WELL SL-3Q	Semi-annually	110ALVM	45.0161	-106.5386	09S 42E 36BBAD	Big Horn
	220857	WELL SL-8-2Q	Semi-annually	110ALVM	45.0182	-105.9052	09S 47E 25DCDB	Powder River
	220859	WELL SL-8-3Q	Semi-annually	110ALVM	45.0177	-105.9028	09S 47E 25DDCB	Powder River
	123796	WELL WR-17A		125ADOB	45.0216	-106.8641	09S 40E 29BBAC	Big Horn
	122766	WELL WR-59	Semi-annually	110ALVM	45.005	-106.8526	09S 40E 32ACAD	Big Horn
	8107	WELL HWC-01--O-2 TR-26		125CNCB	45.12542	-106.48297	08S 43E 20DDDD	Big Horn
	228776	UPPER ANDERSON CREEK SPRING	Semi-annually	125TGRV	45.1155	-106.6261	08S 42E 30ADAA	Big Horn
	220851	WELL SL-8-1Q		110ALVM	45.0176	-105.8998	19S 47E 25DDDB	Powder River
	240578	LOWER ANDERSON CREEK SPRING		125TGRV	45.13732	-106.69128	08S 41E 15ABBB	Big Horn

Appendix C. Ground-water quality data collected during 2007

	Gwic Id	State	Site Type	Depth (ft)	Sample	Agency	Sample Date	Water Temp (oC)	Lab	Lab pH	Lab SC	Procedure	Calcium (mg/l)	Magnesium (mg/l)
Sites outside areas of potential CBM influence	223877	MT	Stream		2007Q1055	MBMG	5/1/2007	26.9	MBMG	7.06	1256	dissolved	84.3	70.4
					2008Q0180	MBMG	9/21/2007	14.1	MBMG	7.91	1549	dissolved	105	92.7
	228591	MT	Spring		2007Q1053	MBMG	5/2/2007		MBMG	7.32	497	dissolved	30.5	25.7
					2008Q0210	MBMG	10/3/2007	12	MBMG	7.92	552	dissolved	30	25
	207066	MT	Well	16.9	2007Q1048	MBMG	5/3/2007	7.8	MBMG	7.34	1114	dissolved	68.8	65.1
					2008Q0179	MBMG	9/21/2007	9.2	MBMG	7.42	898	dissolved	64.2	66.1
	203705	MT	Well	211	2008Q0056	MBMG	7/25/2007	16.7	MBMG	7.66	4910	dissolved	45.8	31.4
	203708	MT	Well	438	2008Q0054	MBMG	7/24/2007	15.9	MBMG	8.07	2980	dissolved	5.6	3.62
	197452	MT	Spring		2007Q1051	MBMG	5/1/2007	9.6	MBMG	7.67	2650	dissolved	55.8	94.3
					2008Q0209	MBMG	10/3/2007	11.9	MBMG	7.81	2620	dissolved	56	96.2
	219927	MT	Well	223	2008Q0055	MBMG	7/26/2007	15.7	MBMG	7.73	2000	dissolved	6.08	4.16
Sites within areas of potential CBM influence	228592	MT	Well	21.5	2007Q1052	MBMG	5/2/2007	9.5	MBMG	7.3	1033	dissolved	97.6	53.8
					2008Q0212	MBMG	10/3/2007	13.3	MBMG	7.35	1378	dissolved	114	75
	223952	MT	Well	37.8	2007Q1046	MBMG	5/1/2007	9.5	MBMG	7.51	2690	dissolved	24.8	26.4
					2008Q0183	MBMG	9/21/2007	11.9	MBMG	8.03	2820	dissolved	24.6	25.7
	8888	MT	Well	53	2007Q1056	MBMG	5/3/2007	11.3	MBMG	6.96	6290	dissolved	362	309
					2008Q0184	MBMG	9/21/2007	11.7	MBMG	7.16	6650	dissolved	362	314
	198489	MT	Well	62.52	2007Q1047	MBMG	5/3/2007	11.9	MBMG	7.21	7910	dissolved	492	460
					2008Q0182	MBMG	9/21/2007	11.8	MBMG	7.01	8050	dissolved	475	479
	7905	MT	Well	71	2007Q1049	MBMG	5/1/2007	10.8	MBMG	7.28	3490	dissolved	144	185
					2008Q0185	MBMG	9/21/2007	10.2	MBMG	7.36	3740	dissolved	147	192
	219136	MT	Well	40	2007Q1050	MBMG	5/2/2007	10	MBMG	7.25	3940	dissolved	310	235
					2008Q0211	MBMG	10/3/2007	9.5	MBMG	7.5	3970	dissolved	303	221
	220857	MT	Well	13.8	2007Q1045	MBMG	4/25/2007	7.8	MBMG	7.29	4290	dissolved	458	149
					2008Q0213	MBMG	10/2/2007	14.3	MBMG	7.82	3490	dissolved	325	155
	220859	MT	Well	19	2007Q1044	MBMG	4/25/2007	9.7	MBMG	7.38	2560	dissolved	279	80.3
					2008Q0207	MBMG	10/2/2007	12.9	MBMG	7.33	2650	dissolved	283	82.9
	123796	MT	Well	88	2007Q0821	MBMG	11/22/2006	11.6	MBMG	7.62	4590	dissolved	45.2	116
	122766	MT	Well	34	2007Q1054	MBMG	5/2/2007	8.8	MBMG	7.12	5680	dissolved	263	536
					2008Q0181	MBMG	9/21/2007	14.3	MBMG	7.31	6230	dissolved	284	600
	8107	MT	Well	232	2008Q0088	MBMG	8/1/2007	13.8	MBMG	7.78	2420	dissolved	4.2	2.14
	228776	MT	Spring		2008Q0090	MBMG	8/1/2007	17.7	MBMG	7.02	4560	dissolved	153	257
	220851	MT	Well	19	2008Q0208	MBMG	10/2/2007		MBMG	7.53	4050	dissolved	407	139
	240578	MT	Spring		2008Q0089	MBMG	8/1/2007		MBMG	6.98	2070	dissolved	110	131

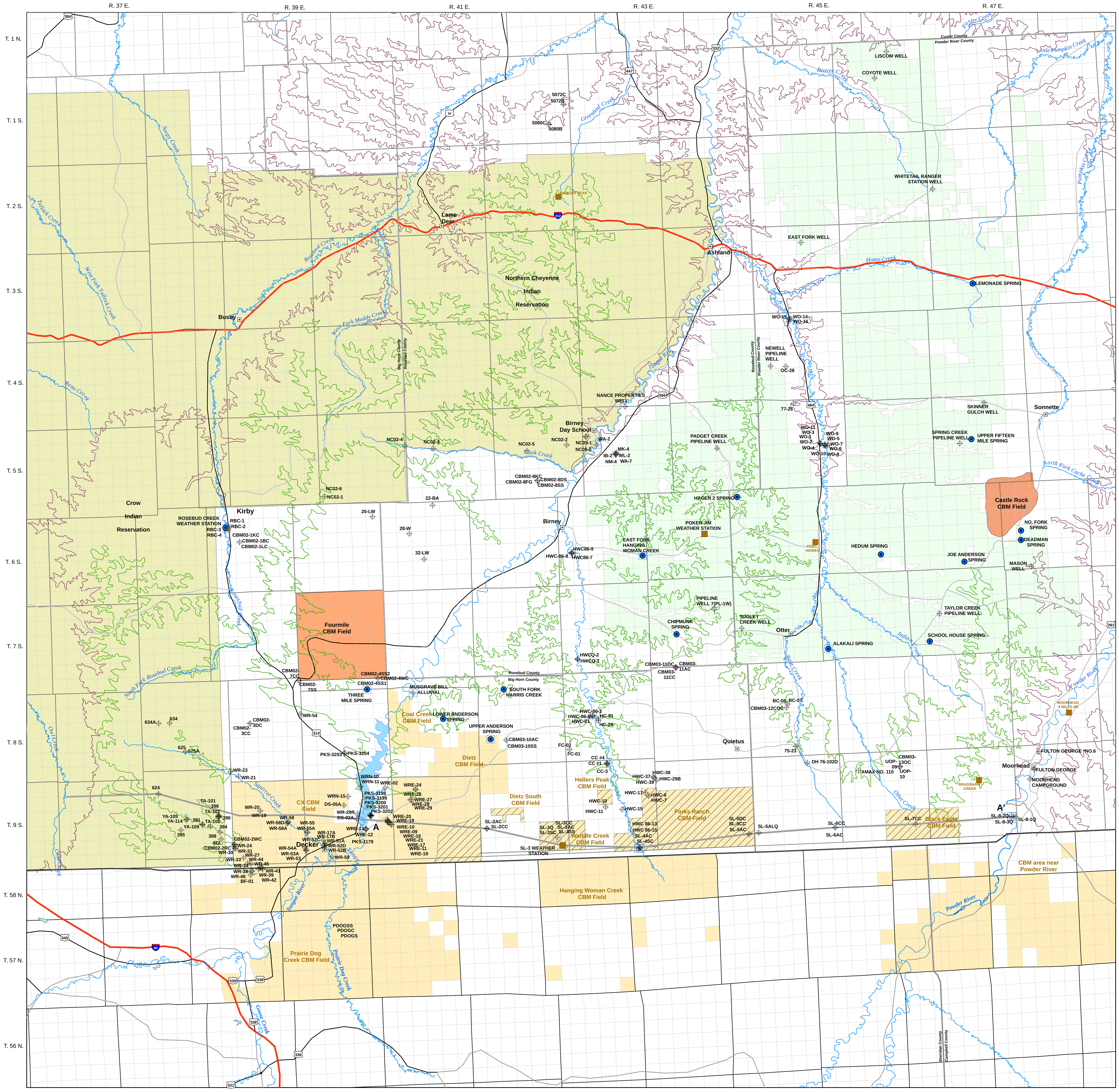
Appendix C. Ground-water quality data collected during 2007

	Gwic Id	Sodium (mg/l)	SAR	Manganese (mg/l)	Silica (mg/l)	Bicarbonate (mg/l)	Carbonate (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Fluoride (mg/l)
Sites outside areas of potential CBM influence	223877	115	2.2	0.061	18.5	433.5	0	335	6	<0.5 P	1.19
		147	2.5	0.002	24.1	614.3	0	460	8.18	<0.5 P	1.53
	228591	28.3	0.9	<0.001	22.1	162.7	0	105	7.22	0.963 P	1
		27.9	0.9	<0.001	23.2	178.9	0	99.9	6.95	0.836 P	0.957
	207066	40.7	0.8	0.227	29.2	517.3	0	83.8	3.72	<0.5 P	0.636
		41.2	0.9	0.205	28.3	552.7	0	87	3.85	<0.05 P	0.71
	203705	1218	33.9	0.054	10.5	1505.5	0	1315	35.5	<0.5 P	<2.5
	203708	780	63.1	<0.005	8.33	1943.1	0	<2.5	16.6	<0.05 P	0.881
	197452	485	9.2	0.02	10.3	1022.4	0	644	21.6	<1.0	1.61
		523	9.8	0.02	9.73	1190.7	0	782	18.3	<1.0 P	1.49
	219927	497	38.0	0.018	8.69	1275.3	0	42	27.6	<0.05 P	1.88
Sites within areas of potential CBM influence	228592	59.8	1.2	0.178	19.2	436.8	0	241	8.64	<0.5 P	0.291
		99.8	1.8	0.142	22.8	595.4	0	341	14	<0.10 P	0.408
	223952	651	21.7	0.016	10.4	1609.6	0	200	57.9	<0.5 P	2.72
		669	22.5	0.016	10.6	1595.8	0	187	54.6	<0.5 P	2.62
	8888	1196	11.1	2.02	14.3	926	0	3953	<50	<5.0 P	<5.0
		1267	11.8	2.22	13.9	1015	0	4027	<50.0	<5.0 P	<5.0
	198489	1366	10.6	2.22	16.5	950.4	0	5339	<50	<5.0 P	<5.0
		1373	10.6	2.13	14.8	888.2	0	5279	<50.0	<5.0 P	<5.0
	7905	542	7.0	0.738	23.2	856.4	0	1632	18.5	<2.5 P	1.03
		518	6.6	0.799	21.2	839.4	0	1600	<25.0	<2.5 P	<2.5
	219136	498	5.2	0.644	10.9	468.5	0	2387	<10	<2.5 P	<1.0
		509	5.4	0.583	10.2	445.3	0	2307	<25.0	<2.5 P	<2.5
	220857	532	5.5	0.189	18.8	430.7	0	1985	310	<2.5 P	<2.5
		435	5.0	1.25	21.3	452.6	0	1755	36.5	<2.5 P	<2.5
	220859	247	3.3	0.687	19.7	375.8	0	1073	121	<1.0 P	<1.0
		284	3.8	0.077	17.4	346.5	0	1082	118	<1.0 P	<1.0
	123796	1095	19.6	0.081	8.36	993.4	0	1641	26.4	32.1 P	<1.00
	122766	741	6.0	0.918	21.3	694.2	0	3836	<25	<5.0 P	<2.5
		800	6.2	0.999	23.8	717.4	0	4096	<50.0	<5.0 P	<5.0
	8107	683	67.6	0.002	8.76	1550.1	0	<2.5	21.9	<0.10 P	3.63
	228776	707	8.1	0.154	9.81	811.3	0	2264	18.1	<1.25 P	1.43
	220851	526	5.7	0.73	22.8	552.7	0	1910	252	<2.5 P	<2.5
	240578	195	3	<0.001	17.8	738.1	0	715	9.65	<0.25 P	1.3

	Gwic Id	Ortho-phosphate (mg/l)	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)
Sites outside areas of potential CBM influence	223877	<0.5	<0.5	4.01	1.71	180	93.9	<0.1	<500	<0.1	0.299	<0.1	0.368	79
		<0.5	<1.0	<2.0	0.748	245	80.6	<0.1	<500	<0.1	0.147	<0.5	0.331	93.4
	228591	<0.05	<5.0	<10	6.12	151	59.1	<1.0	<50	<1.0	<1.0	3.1	<2.0	80.4
		<0.05	<0.5	<2.0	6.89	111	64.5	<0.1	<100	<0.1	<0.1	2.24	1.03	88.6
	207066	<0.05	<0.5	<1.0	2.55	90.6	68.6	<0.1	<50	<0.1	0.141	<0.1	0.255	53.2
		0.333	<1.0	<2.0	2.75	110	80	<0.1	<100	<0.1	<0.1	<0.5	0.206	49.5
	203705	<2.5	<10.0	85.4	<2.0	67.7	14.2	<1.0	<2500	<1.0	<1.0	1.62	<2.0	274
	203708	<0.05	5	50.6	<1.0	90.3	484	<0.5	<50	<0.5	<0.5	<0.5	<1.0	164
	197452	<0.5	<2.5	<5	<1.0	223	10.8	<0.5	<500	<0.5	<0.5	<0.5	<1.0	162
		<1.0	<0.5	<2.0	0.476	180	12.2	<0.1	<1000	<0.1	0.133	<0.1	<0.2	150
	219927	0.172	<5.0	<5.0	<1.0	70.6	234	<0.5	<50	<0.5	<0.5	<0.5	<1.0	63.2
Sites within areas of potential CBM influence	228592	<0.10	<0.5	1.27	0.625	65.1	51.1	<0.1	<100	<0.1	0.151	<0.1	1	21.7
		0.121	<0.5	<2.0	0.783	83	68	<0.1	<200	<0.1	0.274	<0.1	1.66	30.3
	223952	<0.5	<2.5	<5.0	<1.0	299	25.7	<0.5	<500	<0.5	<0.5	<0.5	<1.0	111
		<0.5	<5.0	<10.0	<1.0	293	29.1	<0.5	<500	<0.5	<0.5	<2.5	<1.0	100
	8888	<5.0	<5.0	<10	2.27	210	8.17	<1.0	<5000	<1.0	3.22	<1.0	<2.0	241
		<5.0	<10.0	<20.0	2.69	193	8.19	<1.0	<5000	<1.0	2.83	<5.0	<2.0	225
	198489	<5.0	<5.0	<10	3.16	227	6.77	<1.0	<5000	<1.0	2.87	<1.0	2.92	297
		<5.0	<10.0	<20.0	3.46	211	6.45	<1.0	<5000	<1.0	2.52	<5.0	<2.0	264
	7905	<1.0	<2.5	<5	1.28	288	24.4	<0.5	<1000	<0.5	0.924	<1.0	<1.0	135
		<2.5	<5.0	14.2	1.43	260	27.4	<0.5	<2500	<0.5	0.929	<2.5	<1.0	147
	219136	<1.0	<2.5	<5	<1.0	90.7	8.35	<0.5	<1000	<0.5	0.594	<0.5	<1.0	163
		<2.5	<2.5	<10.0	<1.0	102	8.42	<0.5	<2500	<0.5	0.857	<0.5	1.16	164
	220857	<2.5	<5.0	<10.0	<2.0	97.6	21.7	<1.0	<2500	<1.0	<1.0	<1.0	5.01	60.3
		<2.5	<5.0	<20.0	3.22	152	34.9	<1.0	<2500	<1.0	3.82	<1.0	<2.0	88.5
	220859	<1.0	<2.5	<5	3.11	87.4	23.4	<0.5	<1000	<0.5	1.06	<0.5	<1.0	42.6
		<1.0	<0.5	<2.0	1.75	82.8	29.2	<0.1	<1000	<0.1	0.828	<0.1	2.4	44
	123796	<1.0	<10	<300	<10	<300	<20	<20	<1000	<10	<20	<20	<20	413
	122766	<2.5	<5.0	<10	2.61	265	13.3	<1.0	<2500	<1.0	1.45	<1.0	<2.0	297
		<5.0	<10.0	<20.0	3.58	280	17	<1.0	<5000	<1.0	<1.0	<5.0	<2.0	329
	8107	0.122	<1.0	<1.0	0.738	67.1	474	<0.1	<50	<0.1	<0.1	<0.1	<0.2	138
	228776	<1.25	<10.0	<10.0	<2.0	108	7.34	<1.0	<1250	<1.0	<1.0	<1.0	<2.0	325
	220851	<2.5	<5.0	<20.0	<2.0	160	25.2	<1.0	<2500	<1.0	2.08	<1.0	4.69	69.4
	240578	<0.50	<1.0	3.55	0.328	198	18.2	<0.1	<500	<0.1	0.195	<0.1	1.13	202

	Gwic Id	Molybdenum (ug/l)	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)	TDS
Sites outside areas of potential CBM influence	223877	4.41	0.39	<0.2	0.173	2.91	1397	1.66	<0.1	5.92	2.78	<0.2	0.174	846
		4.12	<0.1	<0.2	<0.1	1.69	1670	1.19	<0.1	7.82	0.965	0.5	<0.1	1144
	228591	<10	<1.0	<2.0	<1.0	<5.0	901	<1.0	<1.0	2.82	41.2	<2.0	<1.0	300
		6.91	0.469	1.19	0.118	3.62	969	1.3	<0.1	3.39	35	0.942	<0.1	302
	207066	2.58	0.145	0.421	<0.1	<0.5	1256	<1.0	<0.1	0.63	<0.1	1.03	<0.1	550
		2.4	<0.1	1.37	<0.1	<0.5	1196	<1.0	<0.1	0.622	<0.1	10.1	<0.1	567
	203705	<10.0	6.86	<2.0	<1.0	<5.0	2660	<10.0	<1.0	<0.50	<1.0	83.9	<1.0	3409
	203708	<5.0	<0.5	<1.0	<0.5	<2.5	551	<5.0	<0.5	<0.25	<0.5	4.53	<0.5	1786
	197452	<5	<0.5	<1.0	<0.5	<2.5	1488	<1	<0.5	0.637	<0.5	<1.0	<0.5	1822
		<1.0	0.762	<0.2	<0.1	0.827	1489	<1.0	327	0.788	<0.1	0.45	0.287	2081
	219927	<5.0	0.635	<1.0	<0.5	<2.5	261	<1.0	<0.5	<0.25	<0.5	1.87	<0.5	1223
Sites within areas of potential CBM influence	228592	<1.0	0.1	<0.2	<0.1	<0.5	613	1.59	<0.1	5.83	0.145	23.5	<0.1	699
		<1.0	2.01	0.246	<0.1	<0.5	778	1.32	23.2	11.4	0.226	31.5	<0.1	964
	223952	<5.0	<0.5	<1.0	<0.5	<2.5	1795	<1	<0.5	<0.25	<0.5	<1.0	<0.5	1775
		<5.0	<0.5	4.04	<0.5	<2.5	1710	<1.0	<0.5	<0.25	<0.5	5.11	<0.5	1769
	8888	<10	3.89	<2.0	<1.0	<5.0	6474	<10	<1.0	15.5	<1.0	8.54	<1.0	6299
		<10.0	1.27	<2.0	<1.0	<5.0	6275	<10.0	<1.0	17.9	<1.0	6.56	<1.0	6494
	198489	<10	3.43	15.4	<1.0	<5.0	8985	<10	<1.0	33.8	<1.0	11.4	<1.0	8151
		<10.0	<1.0	<2.0	<1.0	<5.0	8416	<10.0	<1.0	33.7	<1.0	5.96	<1.0	8067
	7905	7.49	1.74	<1.0	<0.5	<2.5	2504	1.83	<0.5	10.9	<0.5	3.32	<0.5	2974
		7.2	0.761	2.22	<0.5	<2.5	2810	<10.0	<0.5	11.1	<0.5	5.23	<0.5	2899
	219136	<5	<0.5	<1.0	<0.5	<2.5	6140	5.81	<0.5	3.11	<0.5	<1.0	<0.5	3676
		<5.0	5.48	<1.0	<0.5	<2.5	6018	35.2	<0.5	3.25	<0.5	9.37	<0.5	3573
	220857	<10	<1.0	3.4	<1.0	<5.0	3947	<10	<1.0	25.6	<1.0	2.9	<1.0	3668
		<10.0	7.09	<2.0	<1.0	<5.0	3161	28.6	<1.0	17.1	<1.0	21.9	<1.0	2955
	220859	<5	0.688	<1.0	<0.5	<2.5	2155	3.96	3.96	<0.5	<0.5	1.8	<0.5	2009
		3.88	3.66	<0.2	0.336	6.16	2240	14.1	145	33.4	0.905	5.97	<1.0	2041
	123796	<100	<20	<20	<20	30.1	6193	<10	<50	8.65	<50	<20	<20	3429
	122766	<10	1.39	<2.0	<1.0	<5.0	6378	<10	<1.0	26.9	<1.0	4.42	<1.0	5745
		<10.0	<1.0	<2.0	<1.0	<5.0	6857	<10.0	<1.0	27	<1.0	6.53	<1.0	6163
	8107	<1.0	0.304	<0.2	<0.1	1.24	385	<1.0	<0.1	<0.05	<0.1	0.336	0.21	1495
	228776	<10.0	1.09	<2.0	<1.0	<5.0	5573	<10.0	<1.0	2.8	<1.0	2.6	<1.0	3815
	220851	<10.0	6.68	4.34	<1.0	<5.0	3711	30.7	288	36.9	<1.0	12.9	<1.0	3534
	240578	<1.0	1.05	1.73	<0.1	0.597	3027	1.34	<0.1	0.13	0.921	3.49	0.113	1553

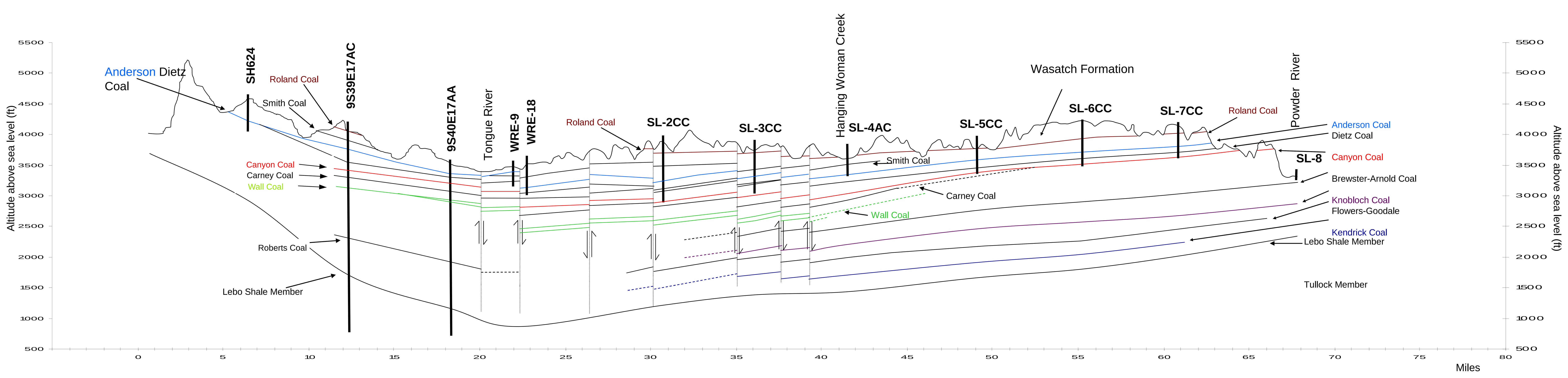
Plate 1. Locations of 2008 monitoring sites, and Anderson and Knobloch coal outcrops.



Explanation

- Monitor wells
- Monitor springs
- Sheduled for semi-annual water sampling
- Anderson coal outcrop
- Knobloch coal outcrop
- CBM field
- CBM field, permitted but not producing
- Potential CBM Field
- Custer National Forest
- Indian reservation lands
- Towns
- Weather station, black border if operated by MBMG
- Local roads
- Secondary roads
- US Route
- County boundary
- Streams
- A - A' Geologic cross-section

0 1.5 3 6 9 12 Miles



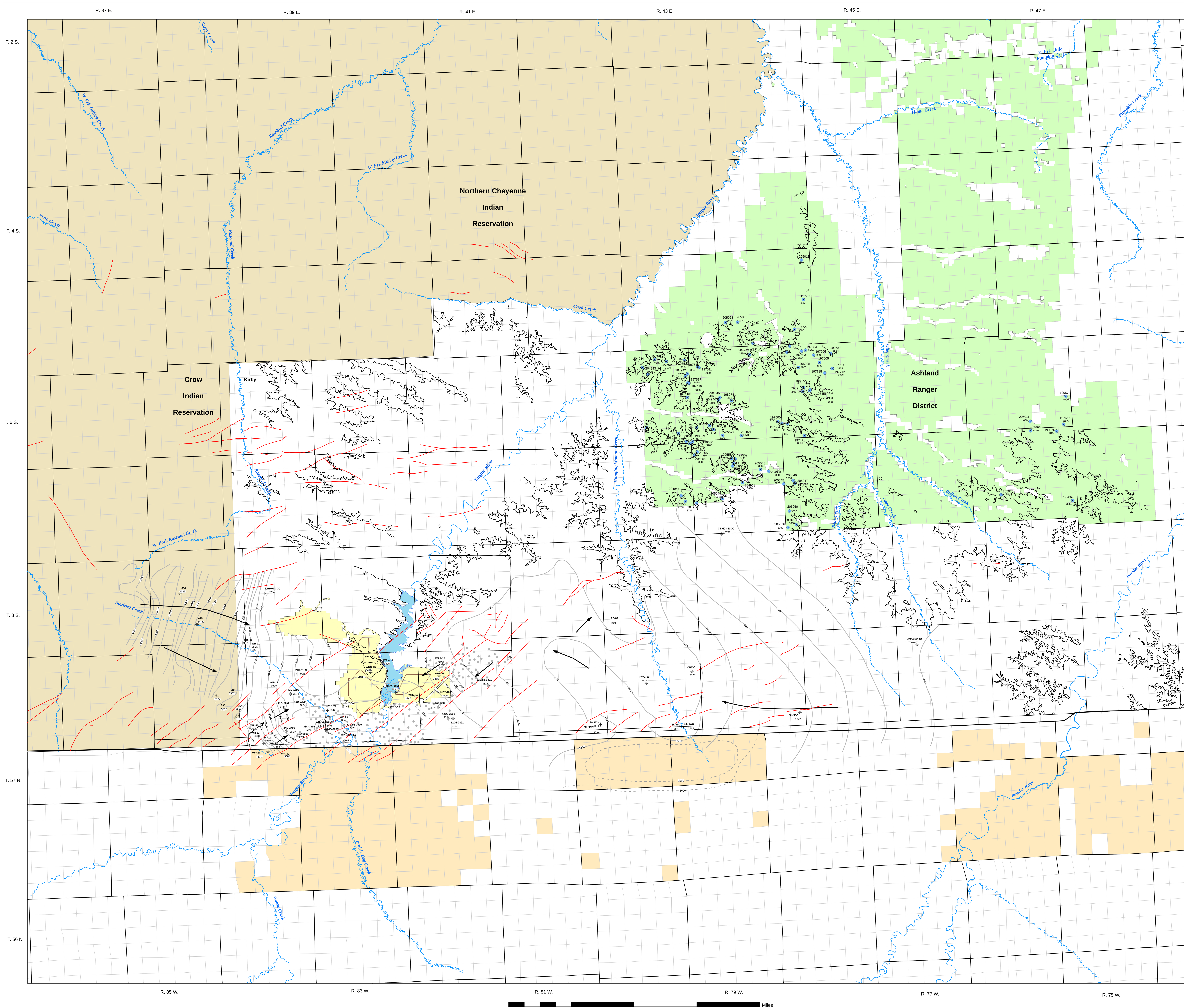


Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2007.

Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, 2008. Squirrel Creek area modified from Hedges and others, 1998), 50-ft contour intervals
- Approximate direction of ground-water flow
- HWC-6 3526 — Monitor well name, water-level attitude for last data in 2007 (ft). Includes MBMG and Fidelity Production Company wells.
- 199587 3920 — Spring with Dietz coal (GWIC identifier number)
- Dietz coal outcrop
- Fault, MBMG geological data, CX coal field area modified using Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- Mine pit boundary, approximate
- CBM production well in the Dietz coal bed with production records during 2007
- CBM production or exploration area in Wyoming (December, 2007)
- Indian Reservation land
- National Forest area, Ashland Ranger District

Map prepared by the MBMG 2008

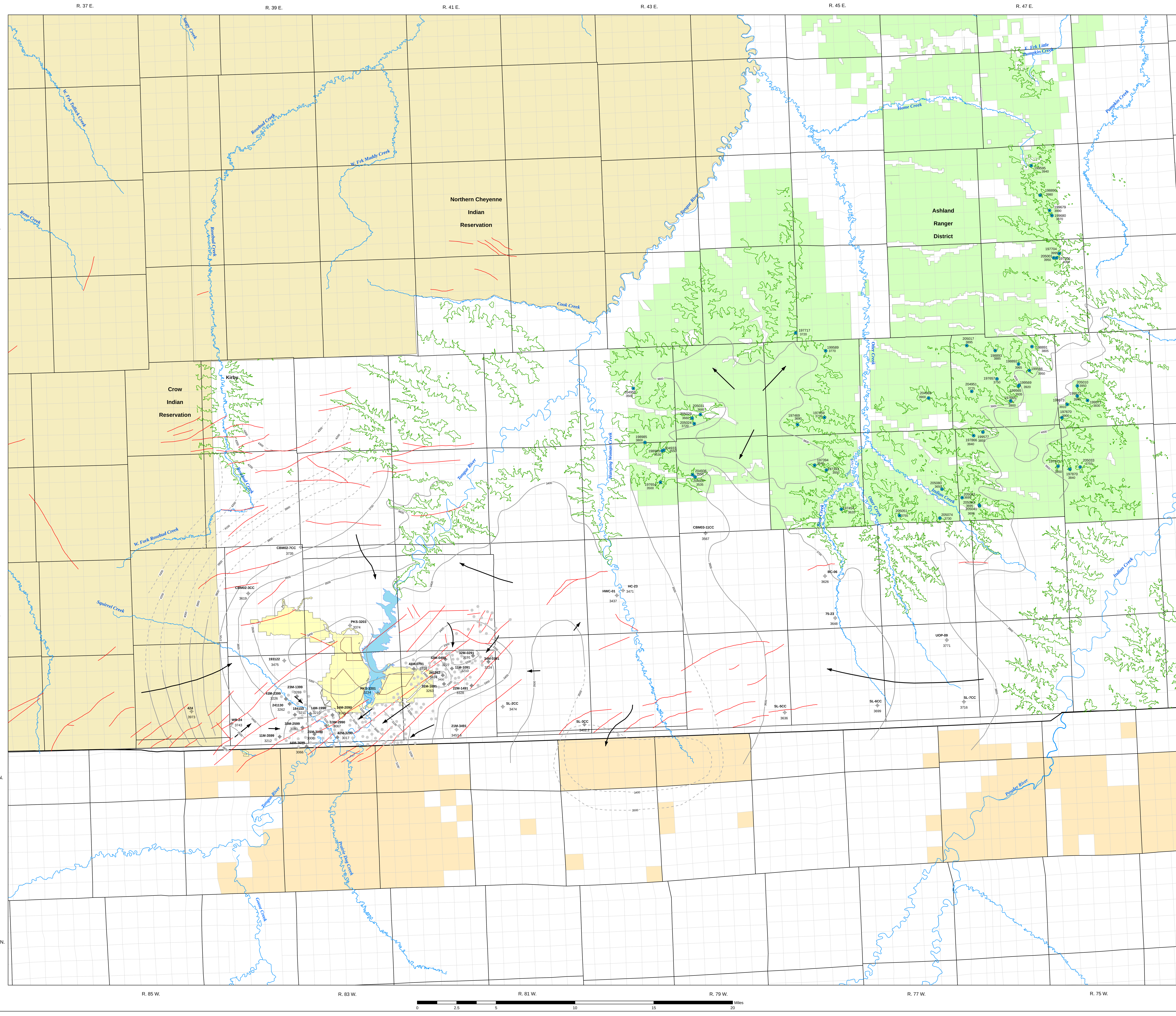


Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2007.

Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, 2008), 100-ft contour intervals
- Approximate direction of ground-water flow
- WR-24 / 3743.5 — Monitor well name, water-level attitude for last data in 2007 (ft). Includes MBMG and Fidelity Production Company wells.
- 199595 / 3940 — Spring with Canyon coal (GWIC identifier number)
- Canyon coal outcrop
- Fault, MBMG geological data, CX coal field area modified using Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- Mine pit boundary, approximate
- CBM production well in the Canyon coal bed in Montana with production records during 2007
- CBM production or exploration area in Wyoming (December, 2007)
- Indian Reservation land
- National Forest area, Ashland Ranger District

Plate 4. Area of CBM-related potentiometric decline for the Dietz coal in the southern portion of the Powder River Basin, Montana

Explanation

Potentiometric decline: dashed where inferred, 50-ft contour intervals, 20-ft line also shown.

Monitor well name, change in water-level for last data in 2007 (ft). Includes MBMG and Fidelity Production Company wells.

Dietz coal outcrop

Dietz coal split line, approximate locations, dashed where inferred. Diagrams show splits.
- A - Anderson Coal
- D - Dietz Coal
- D1 - Dietz 1 Coal
- D2 - Dietz 2 Coal

Fault, MBMG geological data, CX coal field area modified using Fidelity Company data

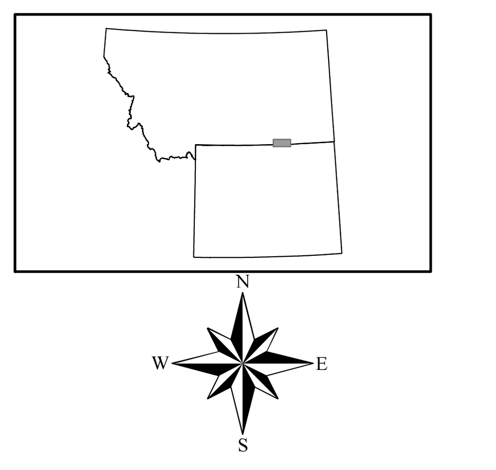
Mine area, includes active, permitted and reclaimed

Mine pit boundary, approximate

CBM production well completed in the Dietz coal (MBOGC records)
- Wells that produced water and/or methane during 2007
- Wells that were listed as shut-in at the end of 2007

CBM production or exploration area in Wyoming (December, 2007)

Indian Reservation land



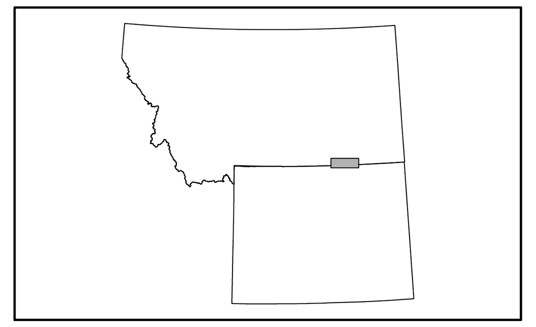
Map prepared by the MBMG

2008

Plate 5. Area of CBM-related potentiometric decline for the Canyon coal in the southern portion of the Powder River Basin, Montana

Explanation

- Potentiometric decline: dashed where inferred, 100-ft contour intervals, 20-ft line also shown.
- WR-24 / 2.3 — Monitor well name, change in water-level for last data in 2007 (ft). Includes MBMG and Fidelity Production Company wells.
- 197717 / 3720 — Spring with Canyon coal (GWIC identifier number)
- Canyon coal outcrop
- Fault, MBMG geological data, CX coal field area modified with Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- Mine pit boundary, approximate
- CBM production well completed in the Dietz coal (MBOGC records)
  - Wells that produced water and/or methane during 2007
  - Wells that were listed as shut-in at the end of 2007
- CBM production or exploration area in Wyoming (December, 2007)
- Indian Reservation land



Map prepared by the MBMG 2008

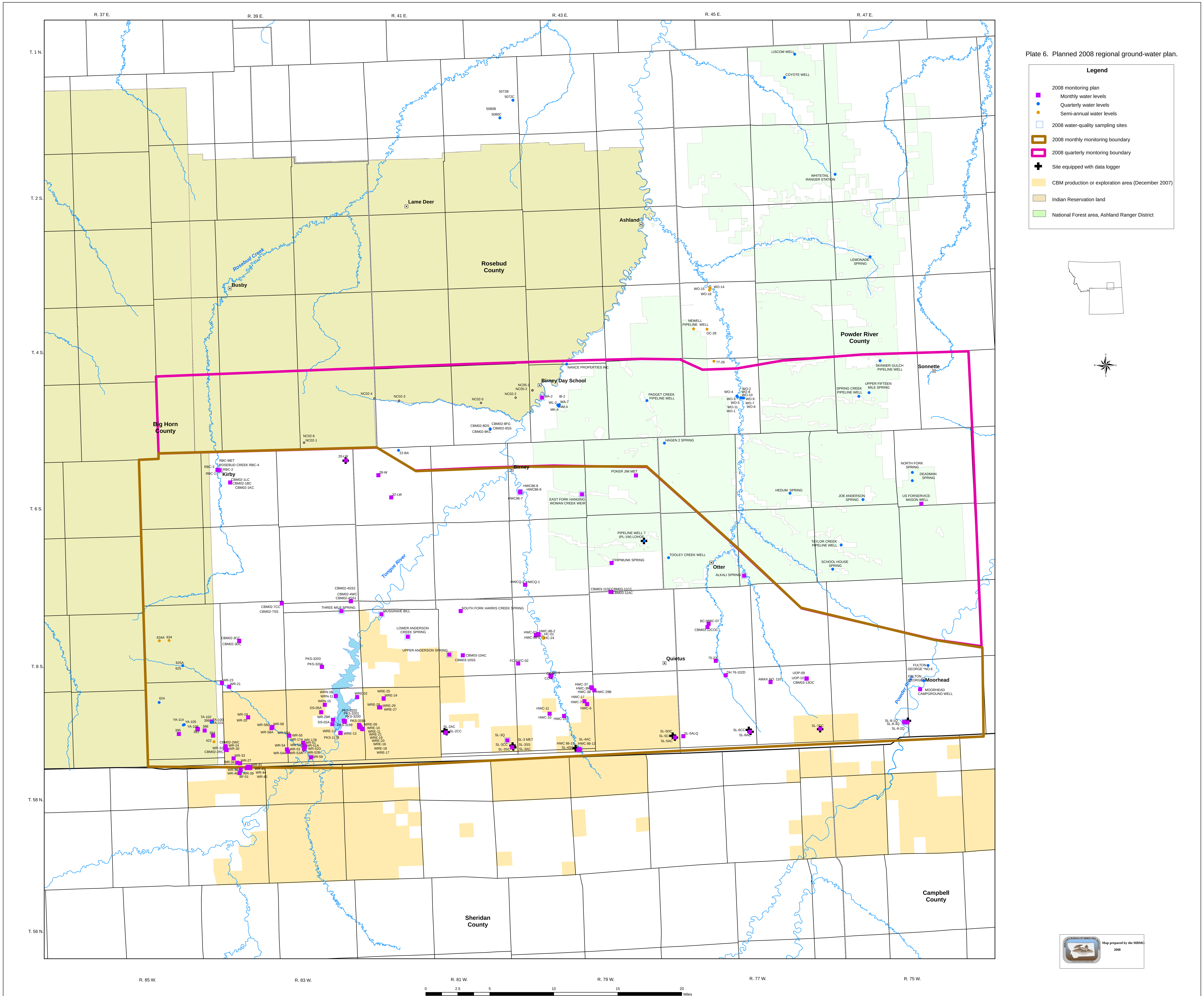


Plate 6. Planned 2008 regional ground-water plan.