2008 Water Year Annual Coalbed Methane Regional Ground-Water Monitoring Report: Powder River Basin, Montana

MBMG OPEN FILE REPORT 578

Elizabeth Meredith
John Wheaton
Shawn Kuzara
Teresa Donato

Montana Bureau of Mines and Geology

Supported by:
U.S. Bureau of Land Management
Big Horn Conservation District
U.S. Department of Agriculture Forest Service
Montana Department of Natural Resources and Conservation

2008

Table of Contents

Figures

Tables

Plates

Appendices

Abstract

This report presents ground-water data collected through September 2008 from within the northern portion of the Powder River Basin and brief discussions of those data with an emphasis on data collected during water year 2008. This is the first year the report is presented on the water year, October 2007 through September 2008 and will be referred to as the 2008 data. This is the sixth 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 with factual data, and to provide data and interpretations to aid environmental analyses and permitting decisions. Detailed discussions of the regional ground-water systems were presented in the first annual report (Wheaton and Donato, 2004). The current network consists of a combination of pre-existing monitoring wells installed during the late 1970s and early 1980s in response to actual and potential coal mining, and recently installed monitoring wells specific to CBM impacts, domestic wells, stock wells, and springs.

Methane (natural gas) production from coalbeds is a potentially important industry in Montana, potentially providing 1.5% of tax revenue. The first commercial production of CBM in Montana in April, 1999 was from the CX field near Decker. This field is operated by Fidelity Exploration and Production Company (Plate 1). Several CBM fields are now producing in Montana and include a total of 907 wells, which produced methane, water, or both during 2008. A total of 14.0 million mcf (1 mcf [also called mscf] = 1,000 standard cubic feet) of CBM was produced in Montana during 2008, 91 percent of which came from the CX field (down from 96% last year). The other 9% of the methane was produced from the Dietz field (6.8% up from 2.7% last year) and Coal Creek field (1.6% up from 1.1% last year). A newly producing field, Waddle Creek, has one well which produced 27,837 mcf in 2008. Unlike last year there was no production from wildcat wells in 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 has raised 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. Sodium adsorption ratios (SAR) are generally between 40 and 60, and total dissolved solids concentrations between 1,000 and 2,000 mg/L. Sulfate concentrations in production water are very low. This production water is typically of acceptable quality for domestic and livestock use; however, its high SAR makes it undesirable for direct application to soils.

During 2008, the Montana Bureau of Mines and Geology (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 Exploration and Production Company 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 feet or more within areas of production. Locally, hydrostatic pressure in the Canyon coal has been lowered more than 600 feet. The first reported water or gas production in Montana occurred during April, 1999 in the CX field. After 9 years of CBM production, the 20-foot 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, 2003). The radius of the 20-foot 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 feet 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 feet was predicted to reach as far as 5 to 10 miles beyond production fields after 20 years (Wheaton and Metesh, 2002). Other observations to date support faults tending to act as barriers to ground-water flow and drawdown not migrating across fault planes. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, but it may take decades for hydrostatic pressures to return to the original levels. The extent of drawdown and rates of recovery will mainly be determined by the rate, intensity, 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 monitoring 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 feet. After 5 to 7 years, recovery in these four wells has now reached 73 to 82% of baseline levels. Recovery trends are similar to those presented in the MT environmental impact statement (U. S. Bureau of Land Management, 2003).

Projections based upon ground-water modeling 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 117 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.

List of abbreviations

above mean sea level (amsl); barrels (bbls); coalbed methane (CBM); gallons per minute (GPM); thousand cubic feet (MCF); Montana Board of Oil and Gas Conservation (MBOGC); Montana Bureau of Mines and Geology (MBMG); Montana Ground-Water Information Center (GWIC); Powder River Basin (PRB); sodium adsorption ratio (SAR); specific storage (Ss); specific yield (Sy); storativity (S); total dissolved solids (TDS); Tritium Units (TU); United States Bureau of Land Management (U.S. BLM); United States Geological Survey (USGS); Wyoming Oil and Gas Conservation Commission (WOGCC)

Introduction

Coalbed methane (CBM) 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 has raised 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.

The reduction of hydrostatic pressure in coal aquifers during coalbed-methane production may affect yield from wells and discharge rates of springs that 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.

Modern streams in the Montana PRB have formed valleys that cut through the entire coal-bearing Tongue River Member of the Fort Union Formation. 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 additional methane migrates to the lower pressure of the well bore.

Coalbed methane production is a potentially important industry in Montana. The benefits from CBM production include tax revenue, increased employment, secondary economic effects on local economies, and potential royalty payments to landowners. The spot price of natural gas varies greatly by dollars per MMBtu. It reached a peak in 2005 of over $15 and peaked again in the summer of 2008 at $13.50. Currently prices are under $6 and have reached lows of less than $2 in 1999 and in late 2001 – early 2002 (Blend, 2002; www.energystox.com).

This report presents ground-water data and interpretations from within the northern portion of the Powder River Basin (PRB) undergoing CBM development. This is the sixth year in which the Montana regional 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). This and future reports released each year will present data collected in the water year (October through September).

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 Bureau of Mines and Geology 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 907 CBM wells produced water, gas, or both in Montana during 2008, an increase of 44 wells since 2007. Fidelity Exploration and 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 772 wells actively producing gas or water or both during 2008. 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 2008, 31 wells are listed as producing water, methane, or both in the Coal Creek field and 103 wells are listed as producing in the Dietz field.

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 Montana - Wyoming state line 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 (1,732 active wells during 2008) in Wyoming is adjacent to the CX field in Montana. The Hanging Woman Creek field (281 active wells during 2008) is near the center of the PRB along the state line. The Powder River area (an informal name used in this report) is on the eastern edge of the PRB in Wyoming and included 634 active wells during 2008 (Plate 1).

Hydrogeologic data were collected by MBMG at 234 wells, 15 springs, and 2 streams during 2008. 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). Collected data are stored in GWIC. No new monitoring wells were installed in 2008. 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 2008 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 with the support of the Big Horn Conservation District. 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 the town of Ashland (Figure 1 and Plate 1). This is the Montana portion of the PRB believed to have high or medium 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 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 average high temperature is 89ºF in July and August and the average low temperature is 32 ºF in December and January (Western Regional Climate Center, 2008).

Geologic setting

The PRB is a structural and hydrogeologic 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 currently being produced from outside this zone.

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 nearest the basin axis (Lopez, 2006). East of the axis, ground-water recharge generally occurs along outcrop areas and natural flow is generally toward the west and north, eventually discharging along outcrops or seeping into deeper aquifers. 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.

Table 1. Correlation of nomenclature used by the MBMG, USGS, coal mine companies, and CBM companies in the Powder River Basin of Montana.

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 & 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

Hydrogeologic setting

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; generally in confined aquifers. 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^-.

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 discharge to springs and to streams 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. 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.

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.

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 11.75 inches, based on records from 1970 through the end of water year 2008 (Western Regional Climate Center, 2008). During 2008, Moorhead received 15.19 inches of precipitation, which is 29% 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 water availability in possible recharge areas.

Aquifer characteristics

The ability of an aquifer to store and release water is determined by its storativity (S), which is a combination of two distinct components: specific yield (S_y) and specific storage (S_s). Specific yield is the volume of water that can be drained from the pore spaces per unit volume of material. Specific storage is the volume of water released from a unit volume of aquifer per unit change in pressure head. 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. For any given aquifer, specific yield is several orders of magnitude greater than specific storage (Fetter, 1994). Within unconfined 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 coalbeds in the PRB) specific storage, not specific yield, is the primary means of 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 cubic feet of water would be released by completely draining 1 cubic foot 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 cubic feet of water from 1 cubic foot of material. The two examples of water released are basically comparable, as each represents a 1-foot change in water level. The difference in the quantities of water released is a function of how the water is released. Removal of water during CBM production typically reduces the hydrostatic pressure (S_s) rather than draining the pores (S_y).

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 were 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 demonstrate that this fault limits ground-water flow. However, long term monitoring at other sites have demonstrated that fault systems can also allow slow leaking across the fault. These different boundary conditions are possibly due to fault offset thickness. If the offset is less than the thickness of the coal seam, the aquifer may still be hydrologically connected. If the offset is greater than then thickness of the coalbed, the aquifer may encounter a no-flow boundary.

Ground-water chemistry

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 periodically 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 147 samples collected from monitoring wells completed in coal aquifers in southeastern Montana. In cases where more than one water quality measurement was reported, only the most recent sample was chosen for inclusion in the statistical analysis. Summary statistics for individual coals are presented in Table 2. The number of samples from individual coals ranged from 1 to 26. The variability of pH within coals is very low but between coals is significant, ranging from 7.44 (Rosebud) to 8.23 (Anderson-Dietz 1,2). However, within individual coalbeds TDS, SAR, sodium, bicarbonate, and sulfate concentrations varied greatly. In one half the monitored coalbeds the lowest sulfate measurements were below detection, however overall high sulfate concentrations were found in Rosebud, Flowers-Goodale and Dietz 1 coals. The Rosebud and Flowers-Goodale are not sources of CBM. Low sulfate concentrations in coalbed water indicate reducing conditions and can be an important tool for CBM exploration (Van Voast, 2003).

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

Coalbed (# of samples)	pH			TDS (mg/L)			SAR		
	Ave (std dev)	Max	Min	Ave (std dev)	Max	Min	Median	Max	Min
Anderson (23)	8.01 (0.38)	8.70	7.10	2530 (1748)	8802	1027	42.0	56.3	11.1
Anderson-Dietz 1 (7)	8.02 (0.34)	8.27	7.35	1560 (600)	2766	1008	37.9	65.1	1.8
Anderson-Dietz 1, 2 (10)	8.23 (0.30)	8.71	7.76	1479 (620)	3020	832	49.7	79.2	28.2
Dietz (12)	8.20 (0.48)	9.14	7.49	1591 (706)	3037	671	25.6	54.2	2.9
Dietz 1 (2)	8.06 (0.06)	8.10	8.02	2494 (153)	2602	2385	78.5	80.1	76.8
Dietz 1, 2 (10)	8.39 (0.39)	8.80	7.70	966 (350)	1596	393	37.7	51.2	0.5
Dietz 2 (11)	8.10 (0.51)	9.03	7.30	1921 (1566)	6057	890	14.4	67.9	4.3
Canyon (12)	8.19 (0.47)	9.36	7.69	1366 (268)	1778	888	41.6	67.7	7.3
Knobloch (4)	7.86 (0.43)	8.22	7.24	1832 (618)	2498	1017	44.6	68.3	2.3
Lower Knobloch (2)	8.33 (0.21)	8.48	8.18	902 (340)	1143	662	28.4	38.9	17.8
Mckay (26)	7.58 (0.37)	8.52	7.00	1980 (1037)	3812	473	2.0	32.0	0.3
Rosebud (20)	7.44 (0.50)	8.37	6.26	2645 (1217)	5104	1155	1.7	32.2	0.6
Smith (3)	8.20 (0.04)	8.23	8.16	1351 (304)	1695	1121	43.1	52.7	38.3
Flowers-Goodale (1)	9.01			1321			82.4		
Wall (1)	8.66			896			68.7		

Coalbed (# of samples)	Sodium (mg/L)			Bicarbonate (mg/L)			Sulfate (mg/L)		
	Ave (std dev)	Max	Min	Ave (std dev)	Max	Min	Ave (std dev)	Max	Min
Anderson (23)	815 (323)	1660	416	1397 (379)	2141	694	1056 (1410)	5590	BD
Anderson-Dietz 1 (7)	426 (345)	1025	106	938 (645)	1835	321	588 (372)	1004	BD
Anderson-Dietz 1, 2 (10)	584 (226)	1126	339	1285 (368)	2000	902	243 (330)	997	BD
Dietz (12)	505 (280)	1058	139	957 (428)	1790	300	499 (407)	1151	1.1
Dietz 1 (2)	959 (66)	1005	912	1851 (250)	2028	1674	557 (41)	586	528
Dietz 1, 2 (10)	365 (189)	608	20	846 (335)	1258	312	144 (181)	502	BD
Dietz 2 (11)	516 (193)	806	248	1081 (467)	2016	441	823 (1384)	4050	BD
Canyon (12)	547 (138)	780	330	1253 (431)	1943	517	204 (281)	646	BD
Knobloch (4)	578 (362)	1028	181	1353 (784)	2498	716	448 (408)	863	10.9
Lower Knobloch (2)	340 (92)	405	275	747 (52)	784	710	147 (203)	290	3
Mckay (26)	203 (162)	688	13	571 (179)	987	172	1092 (711)	2400	30.2
Rosebud (20)	176 (118)	495	56	690 (175)	1089	351	1540 (870)	3283	457
Smith (3)	573 (114)	705	498	1470 (416)	1923	1106	19.9	19.9	BD
Flowers-Goodale (1)	520			767			297		
Wall (1)	394			923			<2.5		

BD indicates lowest readings were below detection

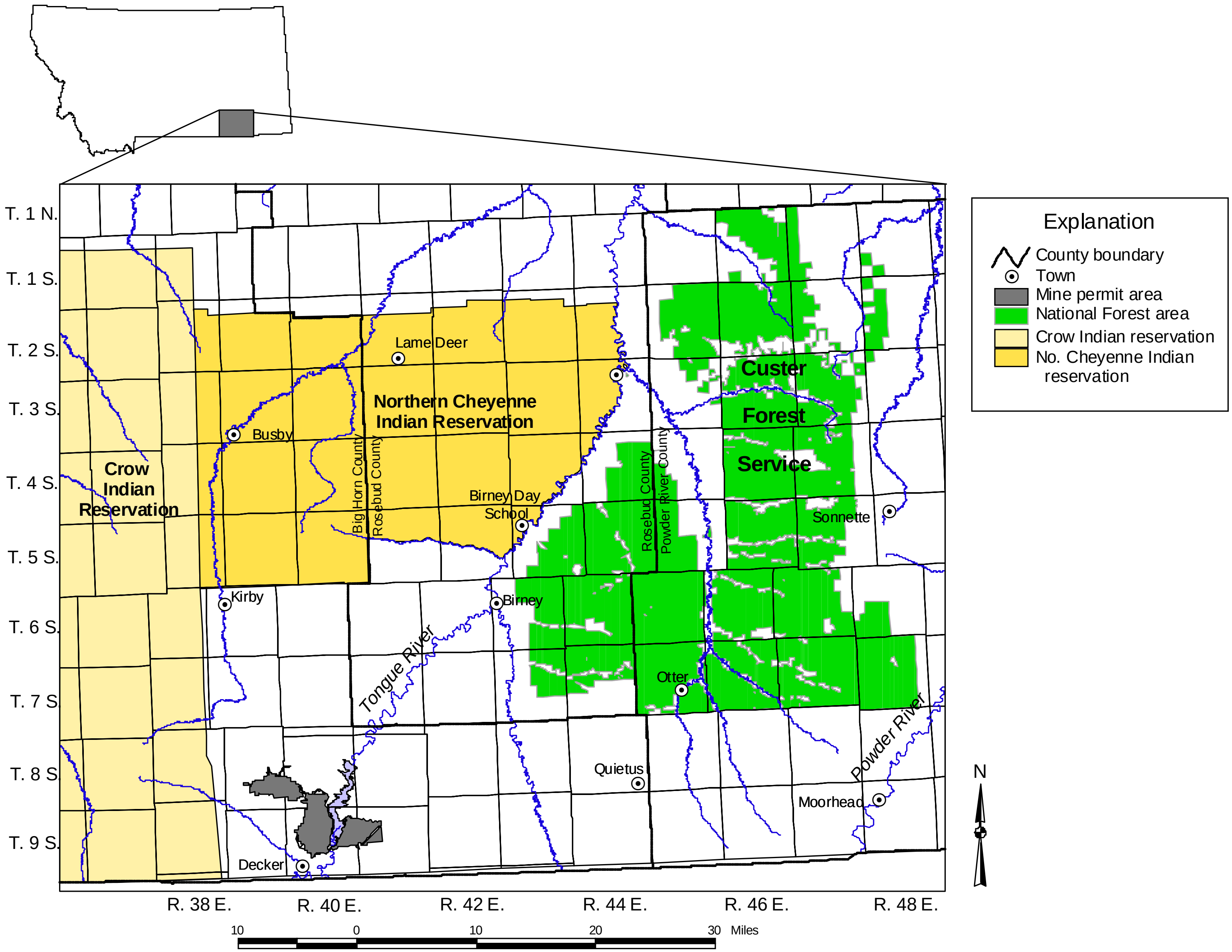


Figure 1. Location of study area.

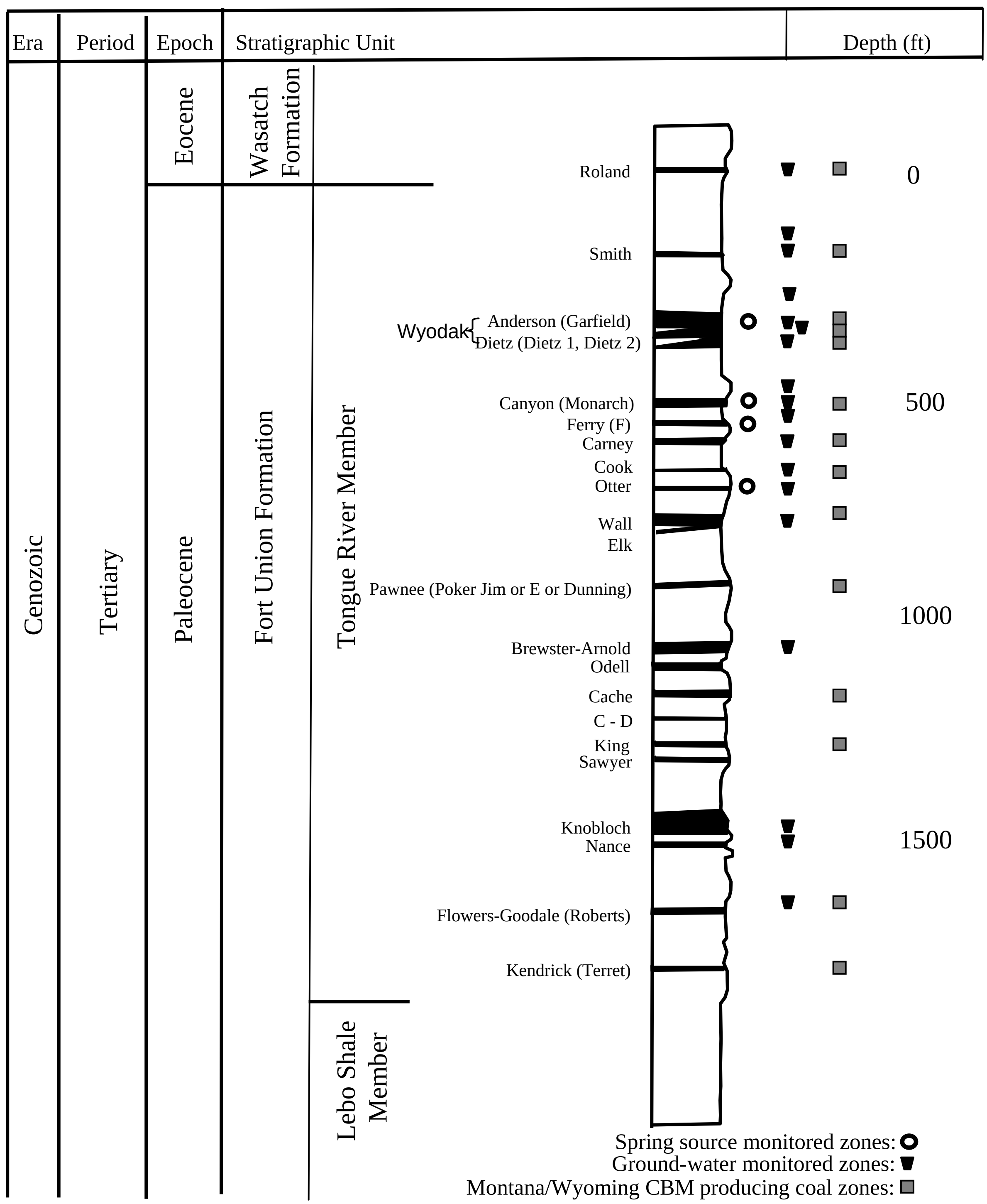


Figure 2. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation in southeastern Montana. The general relative positions of selected coal beds are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line 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).

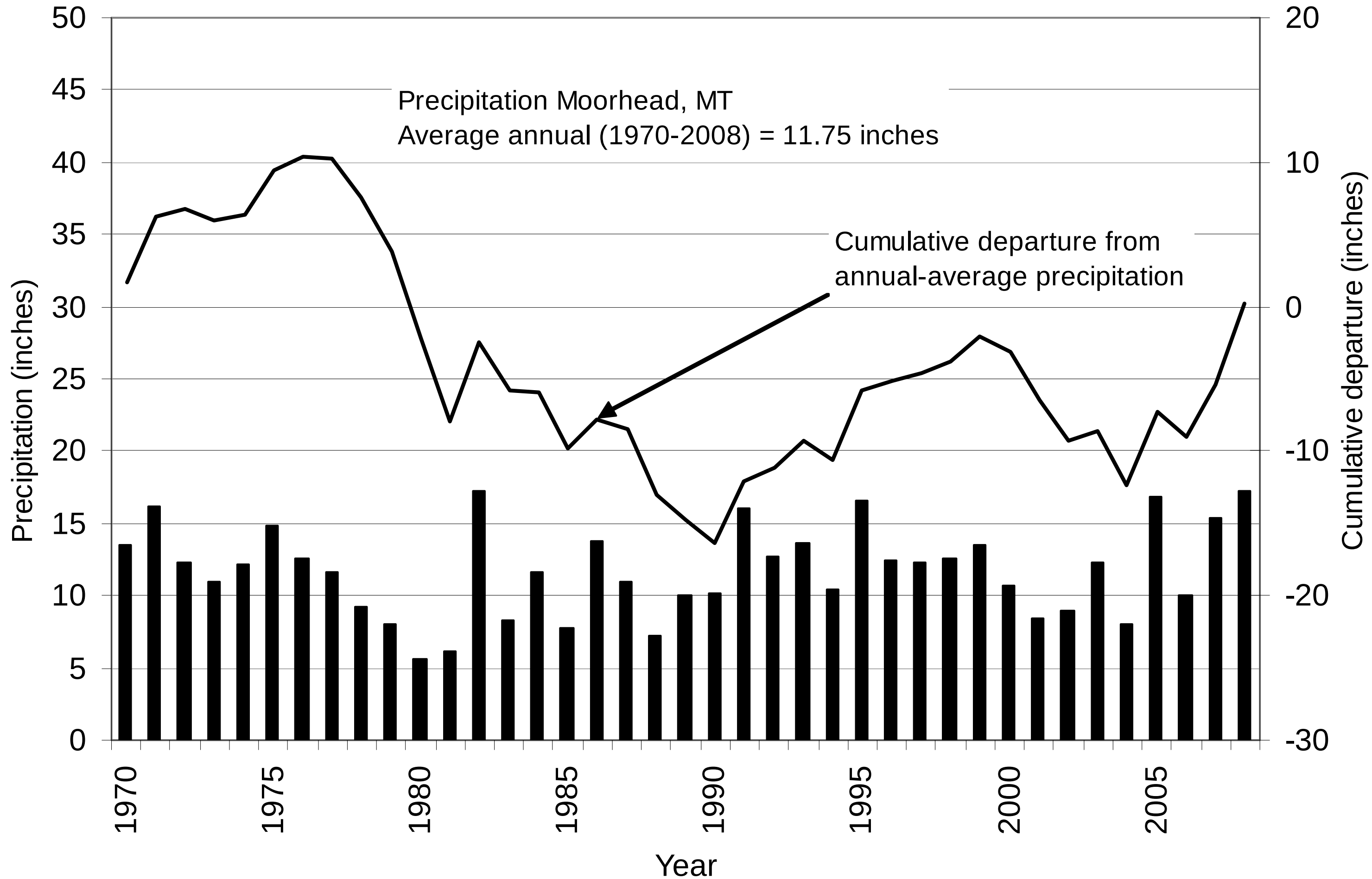


Figure 3. Annual precipitation (bar graph) at Moorhead MT. Cumulative departure from average precipitation provides a perspective on the long-term moisture trends that may effect ground-water recharge.

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 and Canyon coal beds, as interpreted from the available data, are shown on Plates 2 and 3, respectively. Near the outcrop areas, topography exerts a strong control on flow patterns. Ground-water flows generally from south to north with recharge occurring in Montana 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. Ground-water discharges to outcrops, producing springs, 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 CBM 03-12, data from 1974 through 2008 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 trends. At site CBM 03-11, the Anderson and Dietz 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 also reflects baseline conditions.

Monitoring site CBM 02-8 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 natural discharge to nearby outcrops in Coal Creek and along the Tongue River (Figure 6). Water levels in wells completed in the underlying Flowers-Goodale coal and overburden are higher than those measured in the Knobloch overburden and coal. The upward gradient suggests that this is near a discharge area for the Flowers-Goodale units. Flowing wells near Birney, including the town water-supply well, also reflect this upward gradient. These deep wells flow at ground surface due to the high hydrostatic pressure at depth and the relatively low land surface near the Tongue River. Well CBM 02-8DS is completed in the "D" channel sandstone overlying the Flowers-Goodale coal. This channel sandstone has been identified as a possible location for re-injecting CBM produced water (Lopez and Heath, 2007). Yield from this well, measured during drilling, is approximately 35 gpm.

At monitoring site CBM 02-1, 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 cycle, 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). Several landowners have flowing wells in this area, owing to this upward gradient. The shallow sandstone (WO-3) is directly discharging to the Otter Creek alluvium that provides baseflow for the creek. The deeper units (WO-1 and WO-2) are likely confined, and therefore are flowing towards their outcrop/subcrop areas.

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 in a cooperative effort between the Northern Cheyenne Nation and the USGS. Monitoring wells NC02-1 through NC02-6 (GWIC ID numbers 223238, 223240, 223242, 223243, 223236, and 223237; USGS ID numbers 05S40E31BDCC01, 05S42E14ADDC02, 05S41E17ADBD01, 05S40E13ADAB01, 05S42E16CCAB01, and 05S41E14BDCD01) monitor the water levels of the Wall, Flowers-Goodale, Pawnee, Wall, and Knobloch (2) coal beds respectively. These wells are monitored periodically and as of the last measurements, 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 the bedrock aquifer will discharge into the alluvium where the two units are in contact (Figures 8, 9, and 10). Based on the upward hydrologic gradient at this site, the Otter Creek alluvium receives discharge from bedrock aquifers. Recharge to the alluvium also occurs as precipitation infiltrates locally and possibly by loss from Otter Creek during periods of high flow. Alluvial water levels at this site vary seasonally. Otter Creek appears to transition between a gaining and 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 also vary with precipitation trends. The geologic cross section (Figure 11) crosses Rosebud Creek and a tributary. As shown in Figure 11, ground-water flows toward, and provides baseflow to, Rosebud Creek (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 the highest levels occurring during late winter and early spring and the 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 closer look at RBC-2 (Figure 12C) illustrates the effects of transpiration from the nearby alfalfa field on ground-water levels. The summer months are typically periods of high transpiration as grasses use large amounts of water during the daylight hours and very little at night. As air temperatures increase in the morning, plant 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. This diurnal cycling causes the high frequency oscillations in water levels from June to the end of August. The over-all downward trend of the water table in August, 2008 indicates transpiration exceeds recharge rates during this hot, dry time. However, the abundant rainfall that fell in June, 2008 resulted in recharge rates matching transpiration, therefore a downward trend is not seen in early summer. The diurnal cycling of the water table abruptly ends in late July or early August most likely because alfalfa has been harvested.

Detailed precipitation data for the Rosebud Creek site (Figure 12C) (Rosebud Meteorological Station data available on the MBMG GWIC website), illustrates how quickly alluvial ground-water levels respond to precipitation events. A precipitation event of 2.04 inches of rainfall in a 38 hour period between May 21st and May 23rd resulted in an almost immediate rise in ground-water levels of almost one foot. Previous events at this site indicated a 6- to 18-hour lag between precipitation and water level rises; however the delay may have been minimized by previous rain events that resulted in saturated soil conditions.

Water-quality samples were collected in September 2007 and June 2008 from one alluvial well (RBC-2) outside areas of potential coalbed-methane influence (appendix C). This well is completed in alluvium of Rosebud Creek. Concentrations of TDS ranged from 553 to 575 mg/L and SAR values ranged from 0.80 to 0.86. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate. The data are available on GWIC.

Spring and stream flow and water quality

Flow rates and specific conductivity data were collected at 15 springs and one stream within the project area during 2008. These springs and stream are located outside the current area of potential CBM impacts. The locations of monitored springs and the stream are shown on Plate 1, site data are in appendix B, and water chemistry in appendix C. Data collected from these sites during 2008 are available in the GWIC database. Springs are discharge points for ground-water flow systems. Local recharge occurs on ridge tops and hillsides adjacent to springs. 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 or at higher elevations, features such as at the base of clinker zones on ridges, the spring is assumed to be local in origin. 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.

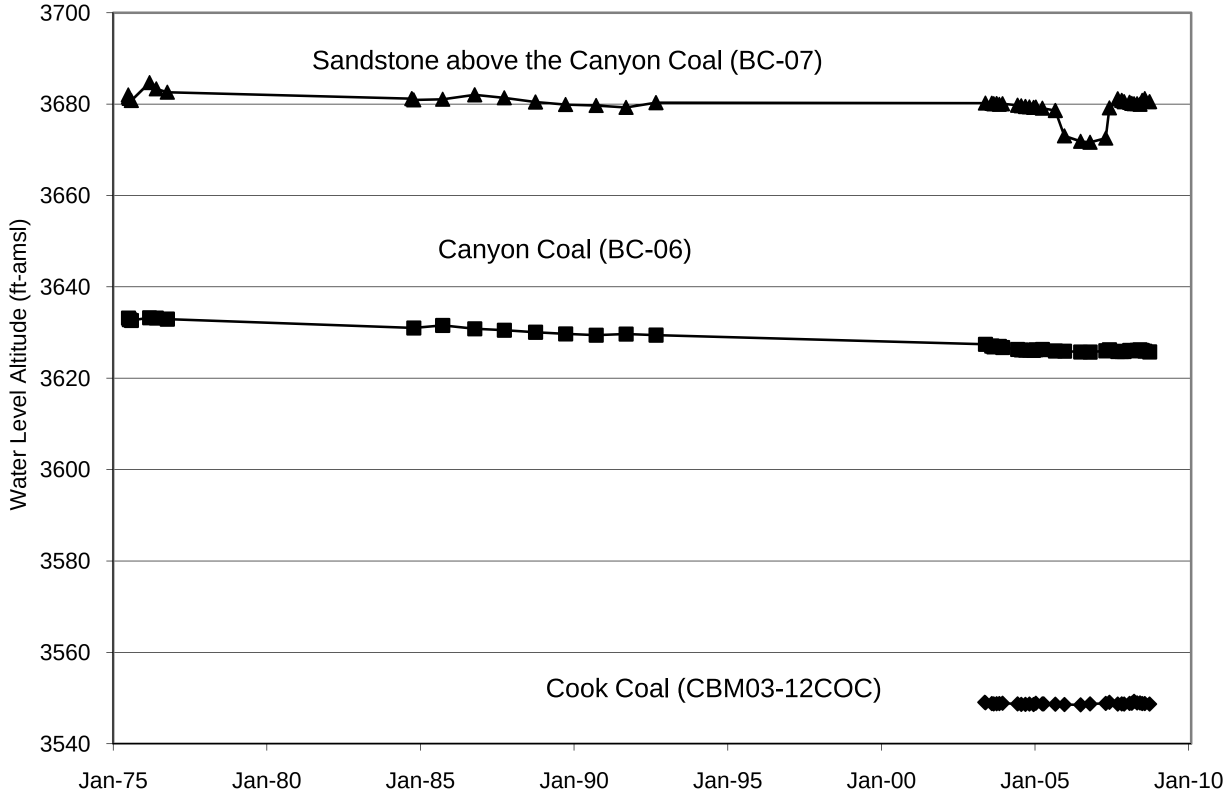
In the southern portion of the Custer National Forest Ashland Ranger District, along Otter Creek, Alkali Spring discharges at rates of between 0.5 and 1.2 gpm. The discharge rate at this spring shows some seasonal influence (Figure 13A). Evidence suggests that Alkali Spring is a mixture of regional and local flow systems. Evidence for regional flow systems includes a tritium analysis in 2007 that indicated a tritium-dead (old) system. However the seasonally dependent discharge rate and seasonally dependent water quality indicate a local source of water (Fig. 13B). Based on stratigraphic relationships and the regional nature of the spring, it appears that the Otter coal supplies some of the water to this spring (Wheaton et al., 2008).

In contrast, the North Fork Spring, in the southeastern portion of the Ashland Ranger District, is located in a topographically high area. The North Fork Spring shows moderate seasonal influence in discharge rates which are typically 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, located east of the town of Ashland along U.S. Highway 212, probably receives a combination of regional flow and local recharge. This spring is associated with the Ferry coalbed and average discharge at this spring is 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 90^{o} v-notch weir with a stage recorder. During winter months the creek freezes and there is no flow. The maximum flow rates over the period of record was 1,100 gpm during March, 2007 (snow melt) and 1,000 gpm in June, 2007 (flood event) (Figure 16). Typical summer flows are generally less than 150 gpm. Flow in East Fork Hanging Woman Creek responds quickly to precipitation events, and is sensitive to antecedent soil-moisture conditions and available storage capacity in upstream constructed reservoirs. Heavy rain events in spring 2007 resulted in a large increase in surface flow in the creek, however, the 3.28 inches of rain over the period of May 22-24, 2008 (measured at the Poker Jim meteorological station located near the headwater area for the creek) did not result in similar increases because of the lack of antecedent soil moisture and low stage conditions in up stream reservoirs.

Water-quality samples were collected in September or October 2007 and May 2008 from two springs (Three Mile Spring, Alkali Spring) and one creek (East Fork Hanging Woman Creek Weir) outside areas of coalbed-methane production (Appendix C). Three Mile Spring is located near a clinker recharge area and the water from it had a TDS concentration of 310 mg/L and SAR value of 0.8. Alkali Spring flows from a coal bed with regional influence and had TDS concentrations of 1833 and 2081 mg/L and SAR values of 9.3 and 9.8. Water from the East Fork Hanging Woman Creek Weir had TDS concentrations of 986 and 315 mg/L with SAR values of 2.3 and 0.9. One of the springs and the creek are within the Custer National Forest, Ashland Ranger District. The other spring is located in the Post Creek watershed, a tributary to the Tongue River.



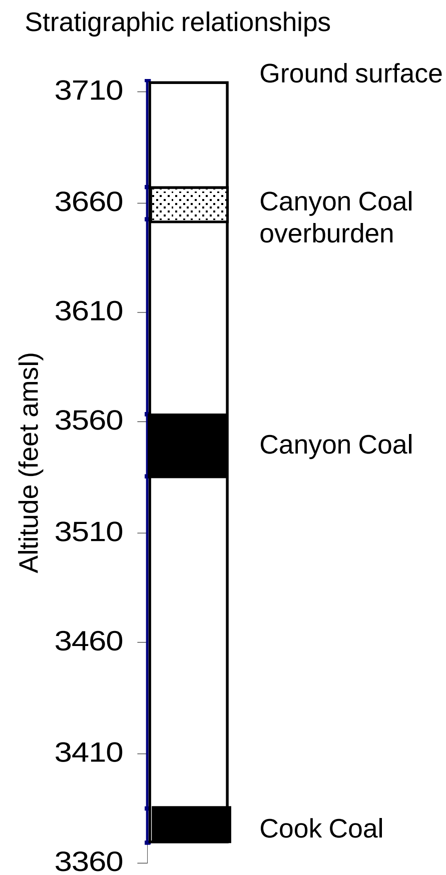


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07), and Canyon coal (BC-06), likely relates to precipitation patterns shown on Figure 2. The short period of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence. In addition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

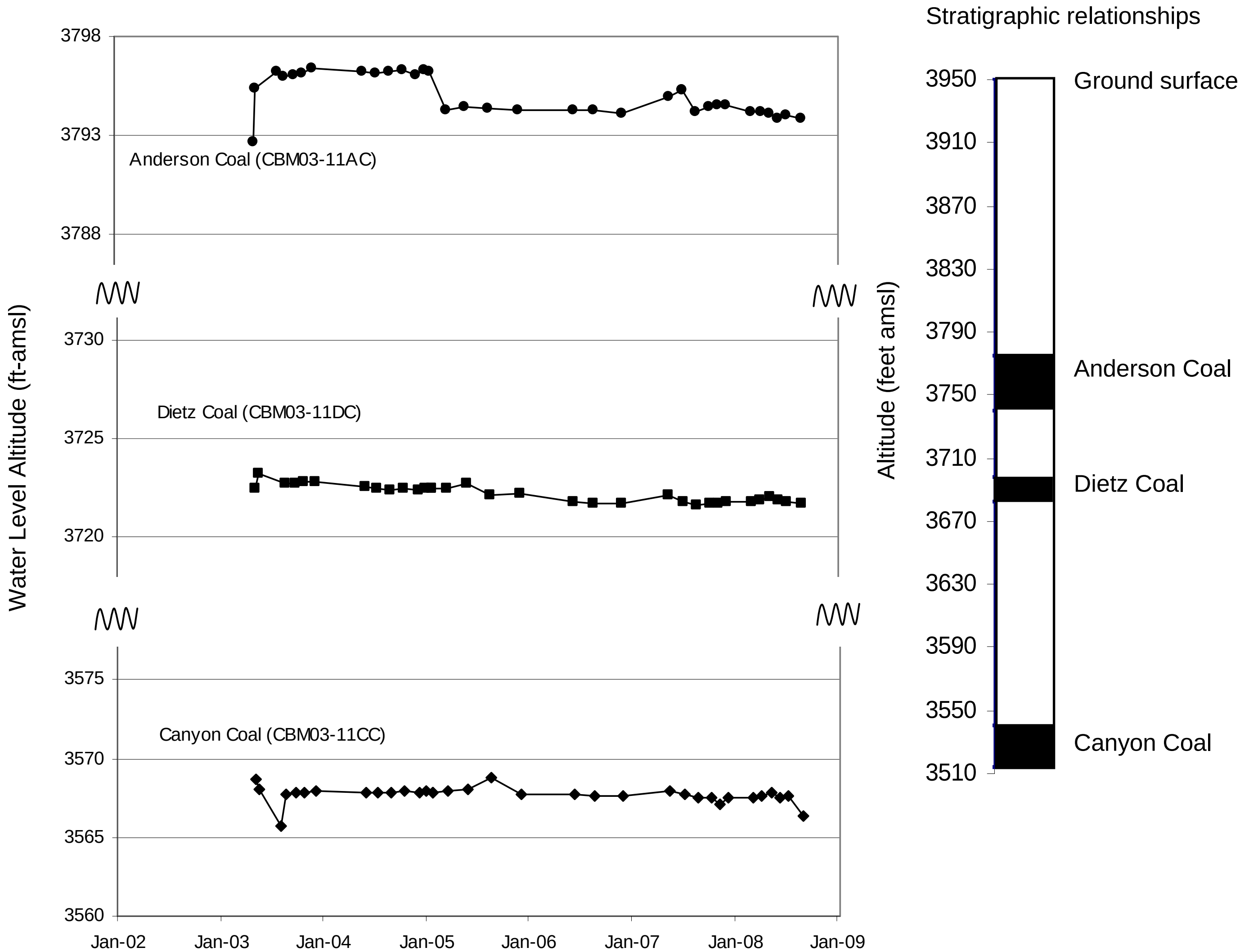


Figure 5 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

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

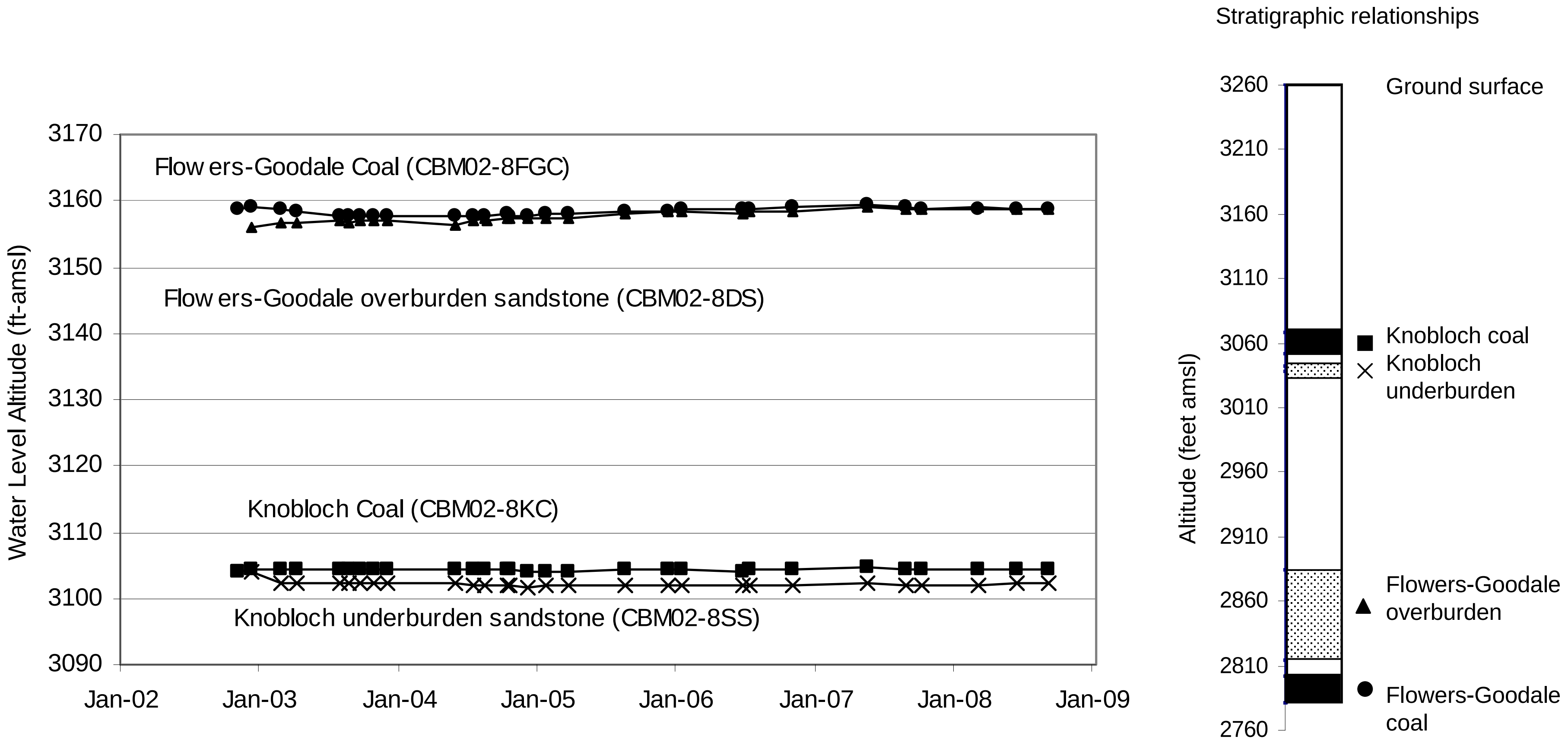


Figure 6. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site.

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

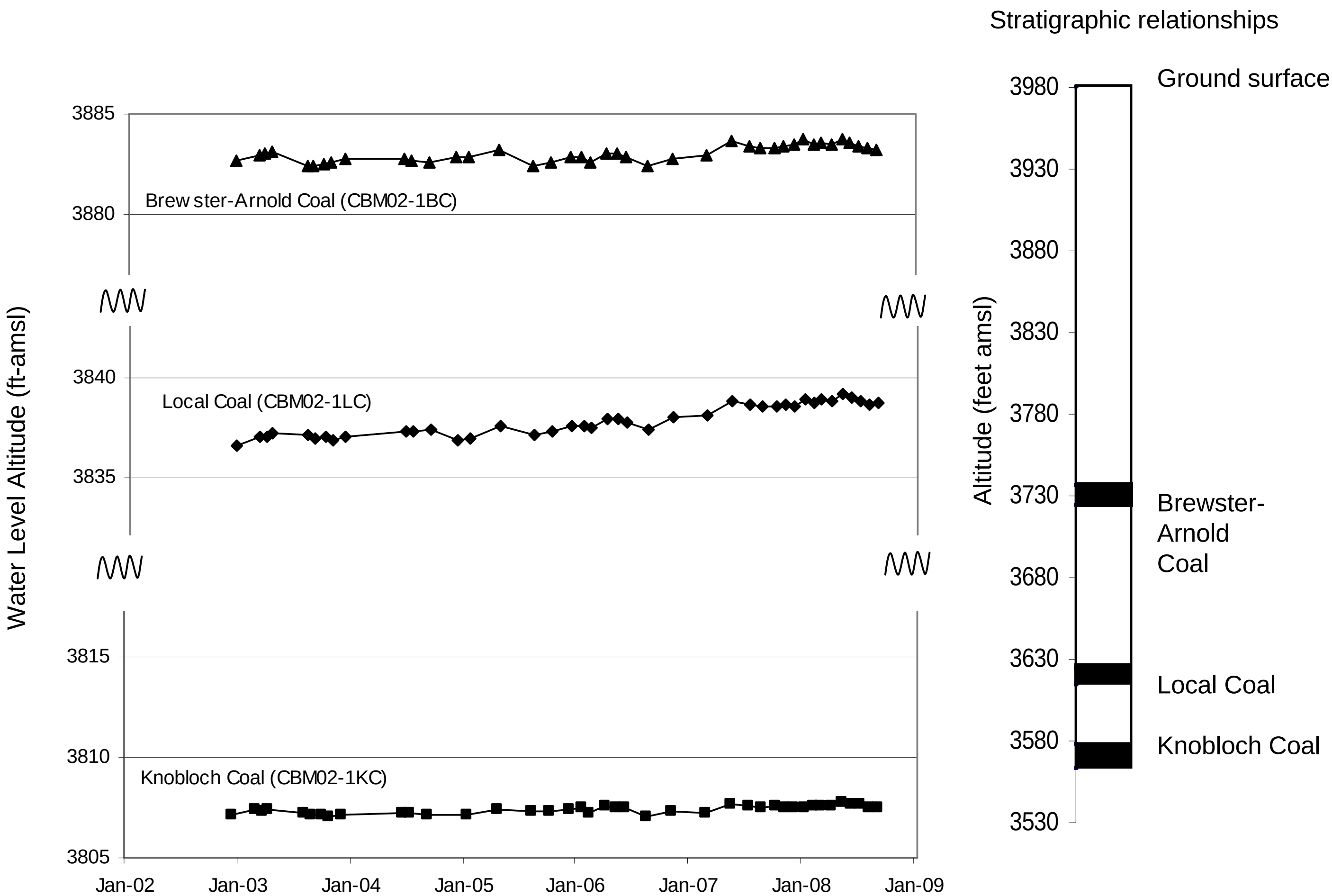


Figure 7. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site.

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

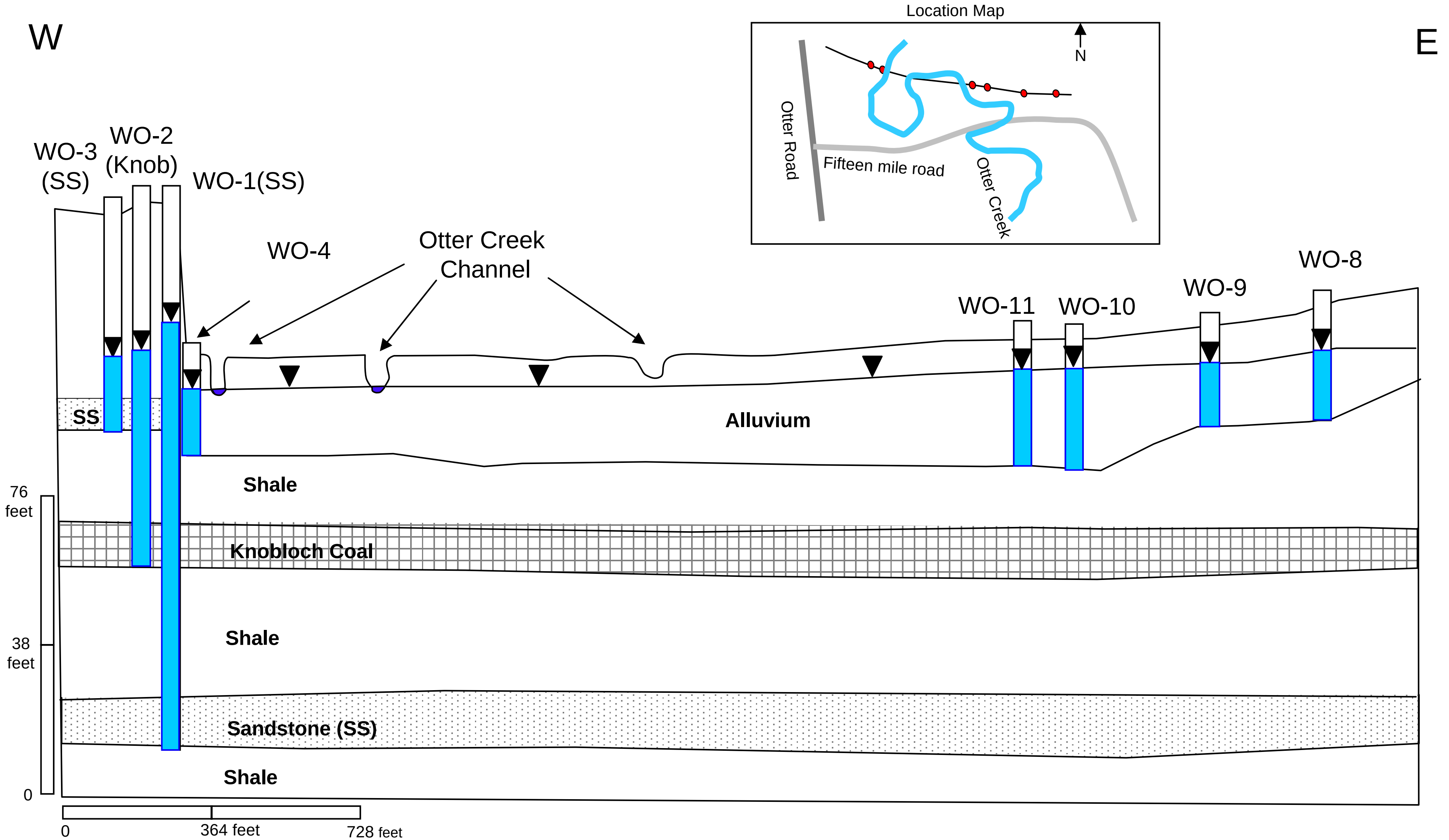


Figure 8. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower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

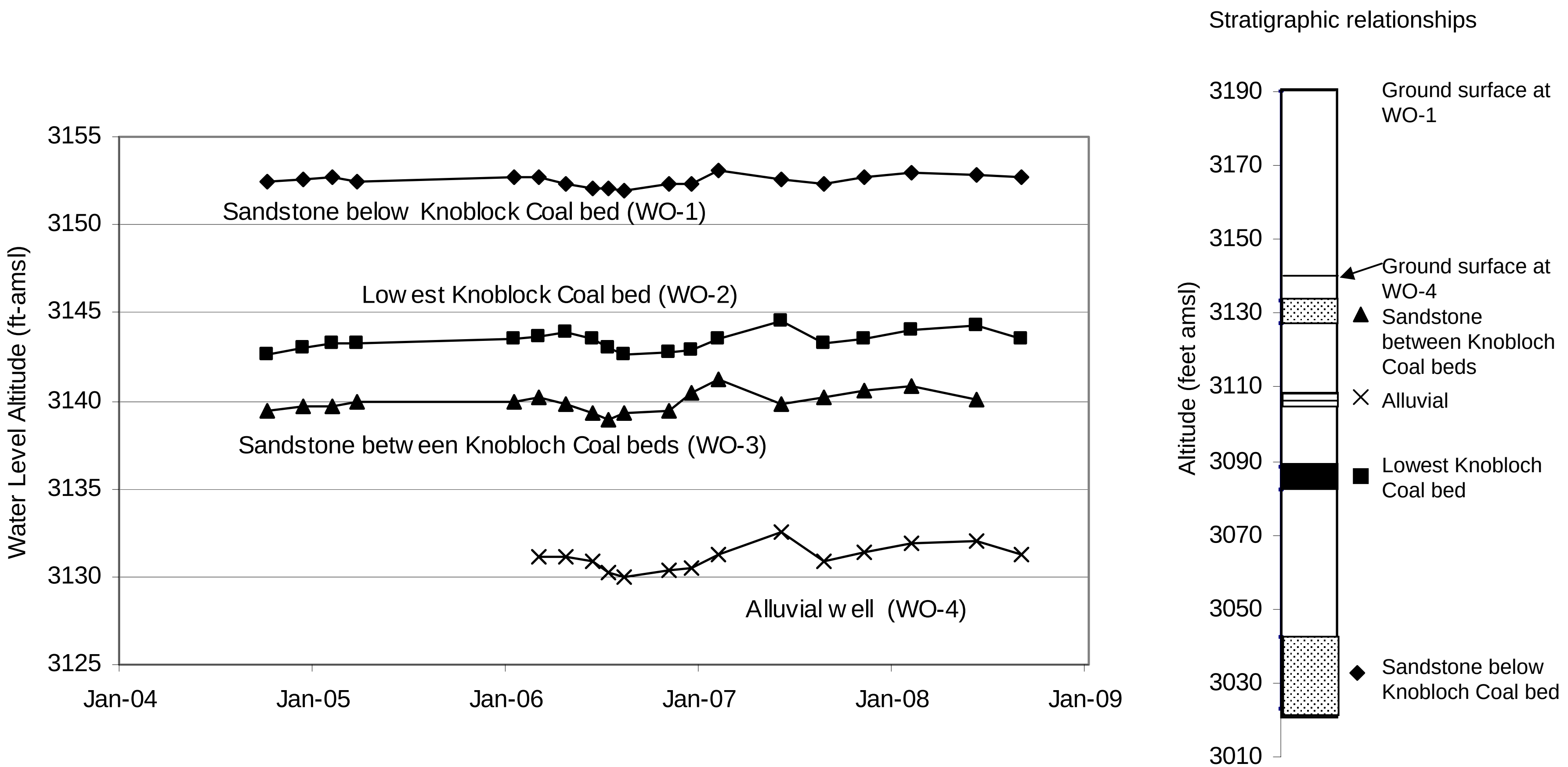


Figure 9. Bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. The alluvial well appears to show the general seasonal water year cycle.

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

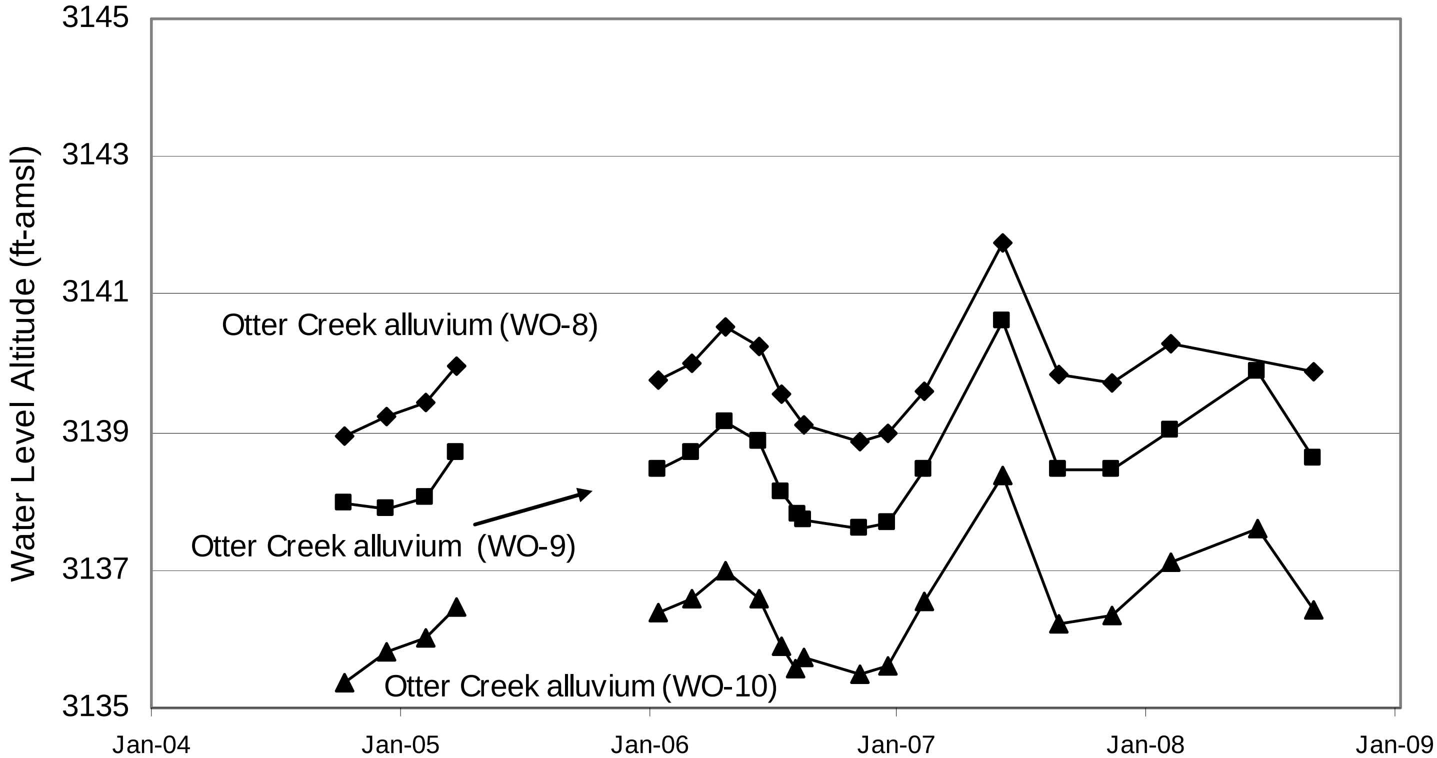


Figure 10. Water-level trends in the alluvium at the Otter Creek site probably relate to weather patterns. The alluvial aquifer appears to receive recharge from the bedrock aquifers in the area, based on the upward vertical gradient.

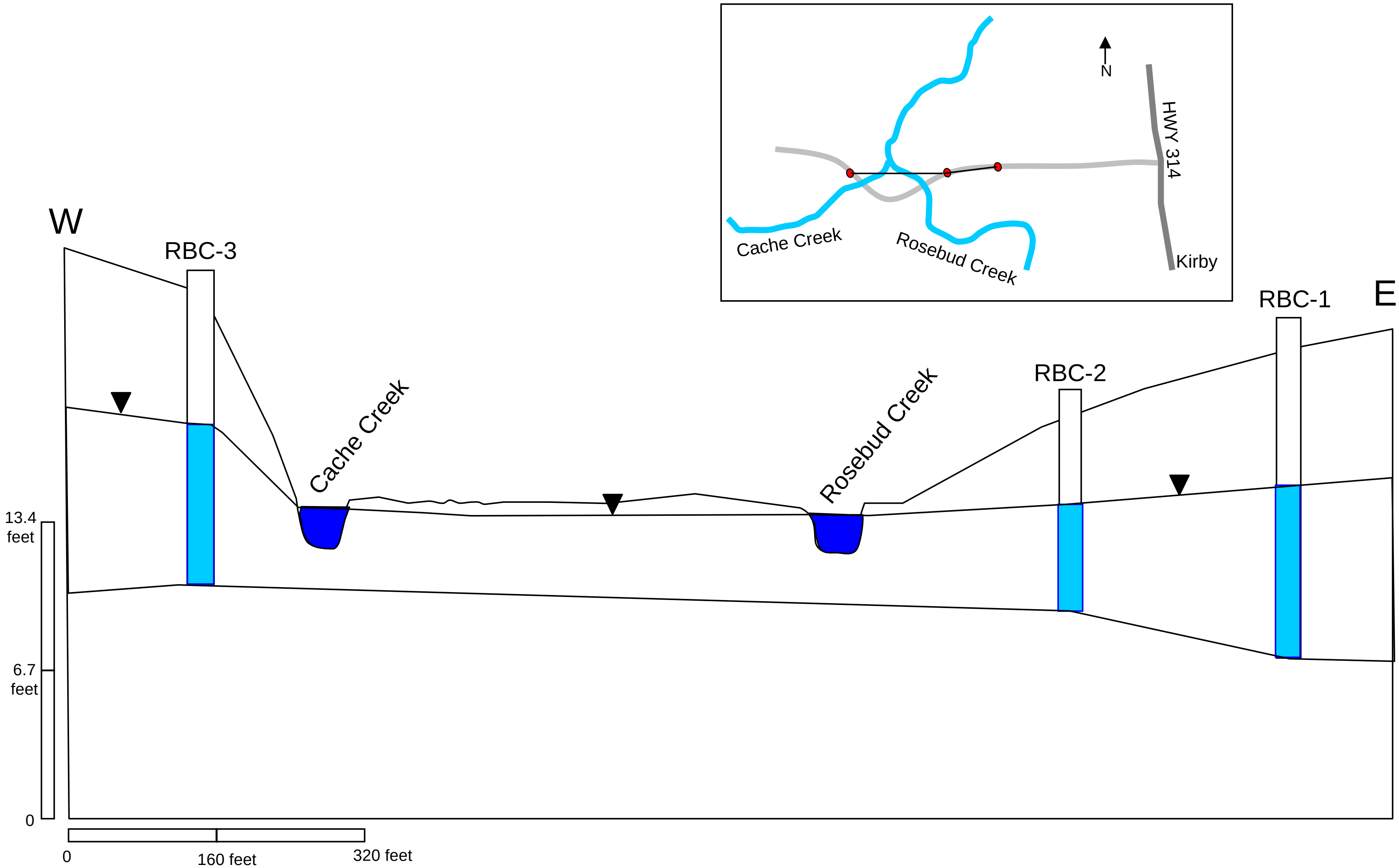


Figure 11. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The water levels at RBC-2 shows a correlation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

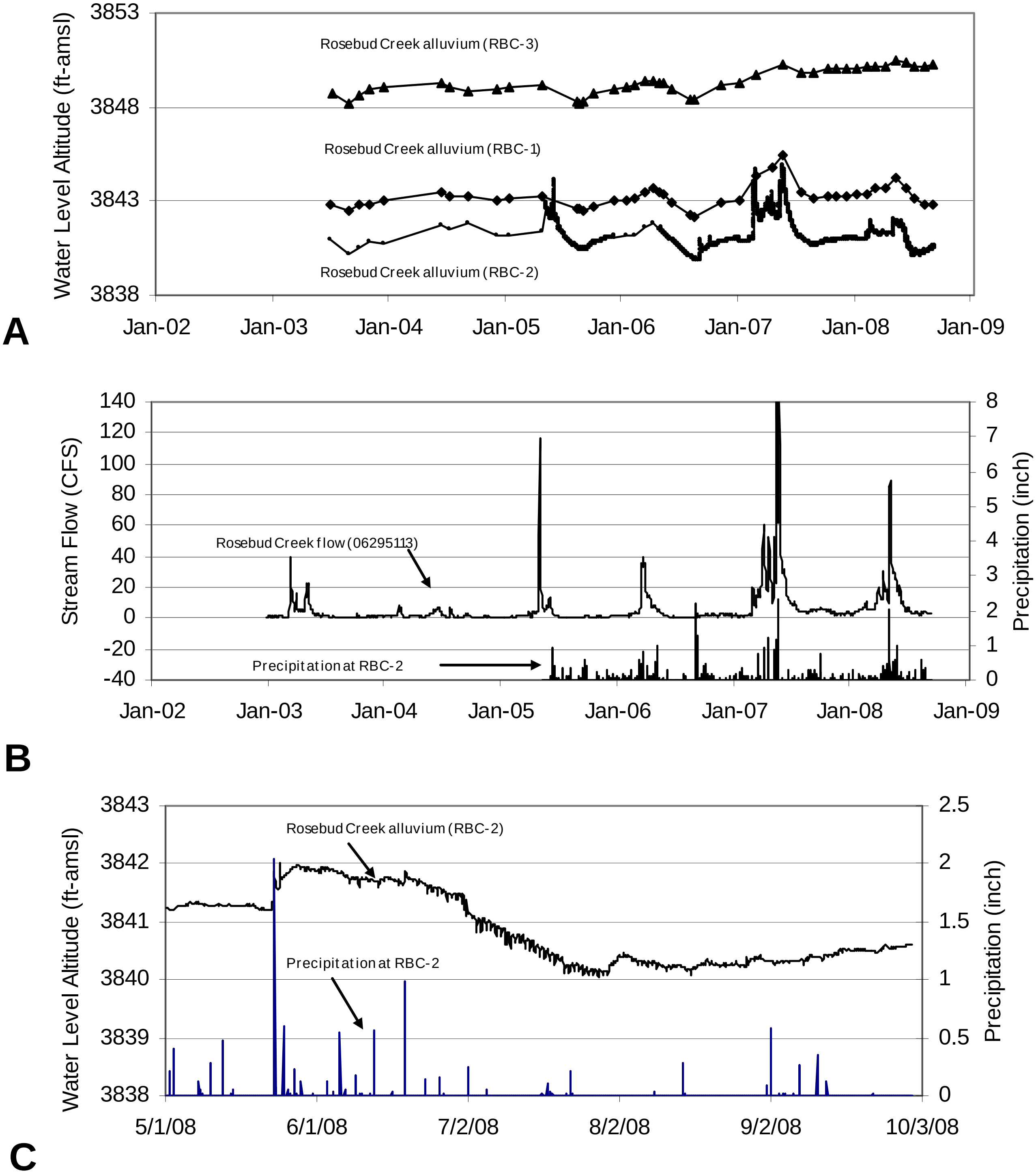


Figure 12. A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. B) Rosebud Creek stream flow follows precipitation trends. C) The alluvial ground-water system responds quickly to precipitation events. A precipitation event on May 23, 2008 of over 2 inches caused the ground-water level to increase by approximately 1 foot in RBC-2. The overall decline in water level is due to transpiration by a nearby alfalfa field. Note that the X axis on C is reduced to a shorter time scale.

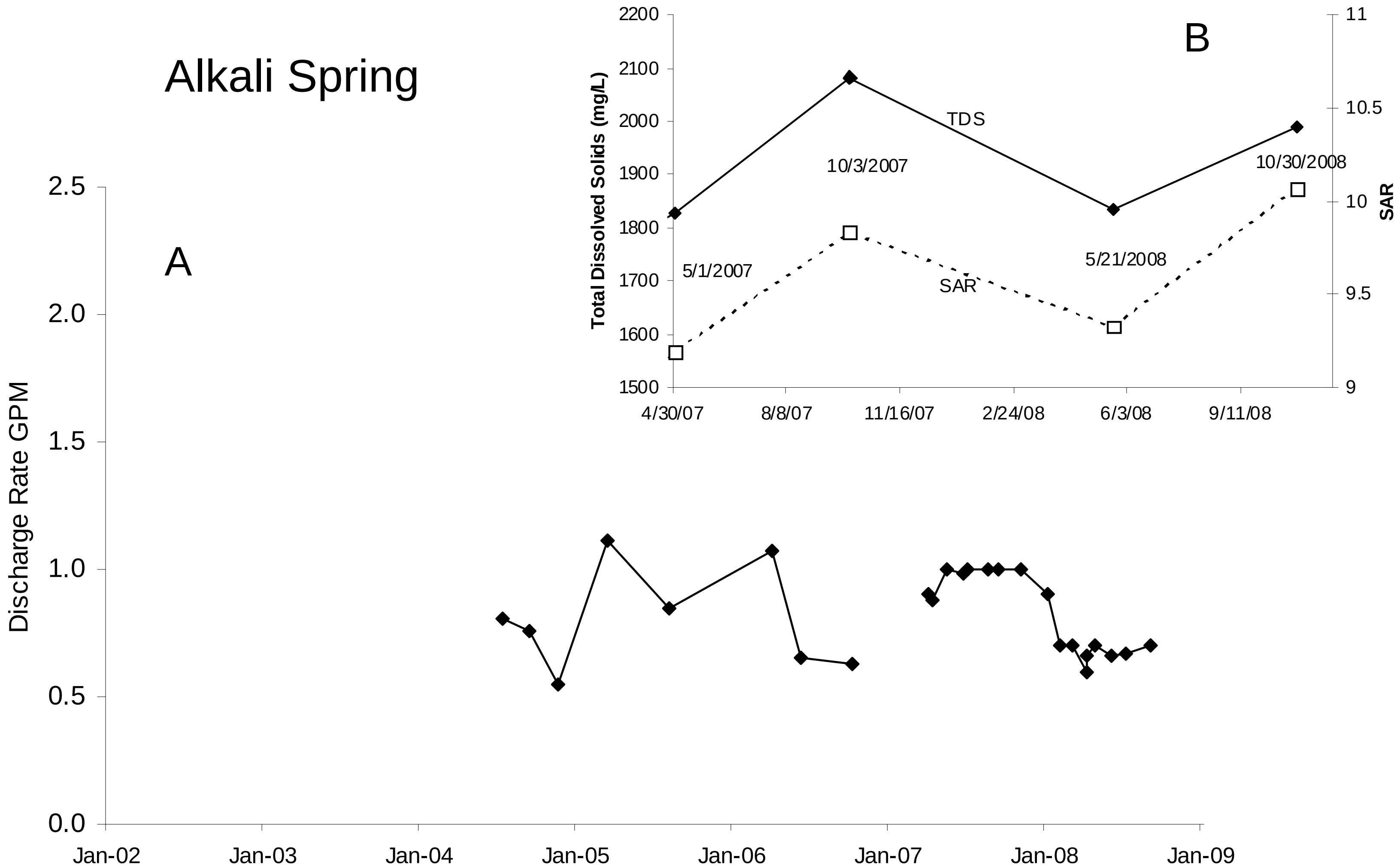


Figure 13. The Alkali Spring (GWIC M:197452) appears to be a combination of local and regional recharge associated with the Cook Coal aquifer. A) The spring has an average discharge rate of about 0.82 gpm. B) Water quality is seasonally dependent indicating a source of local recharge.

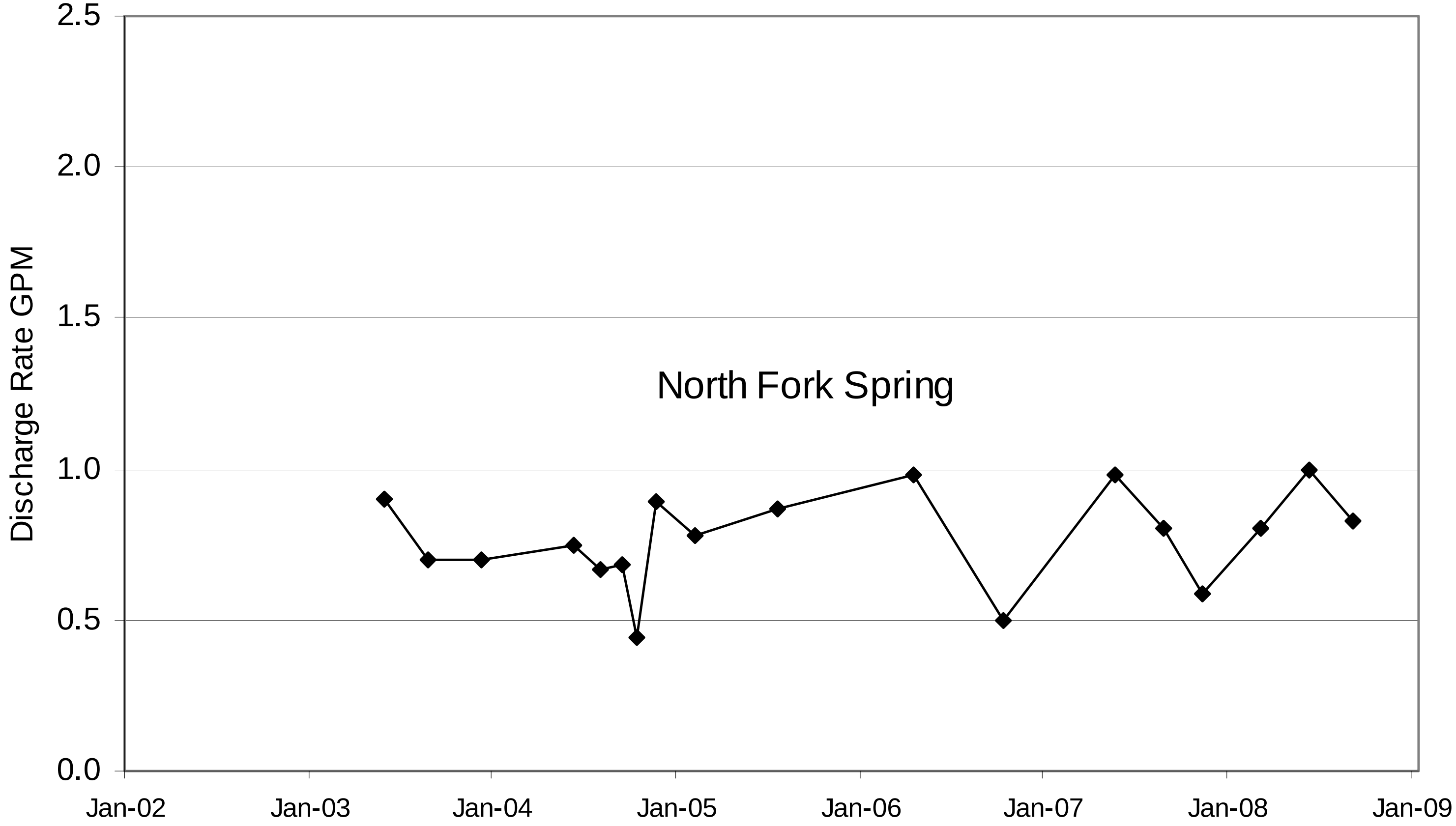


Figure 14. The North Fork spring (GWIC M: 205010) appears to be locally recharged by the Canyon Coal aquifer. The spring discharges less than 1 gpm at an average of 0.77 gpm.

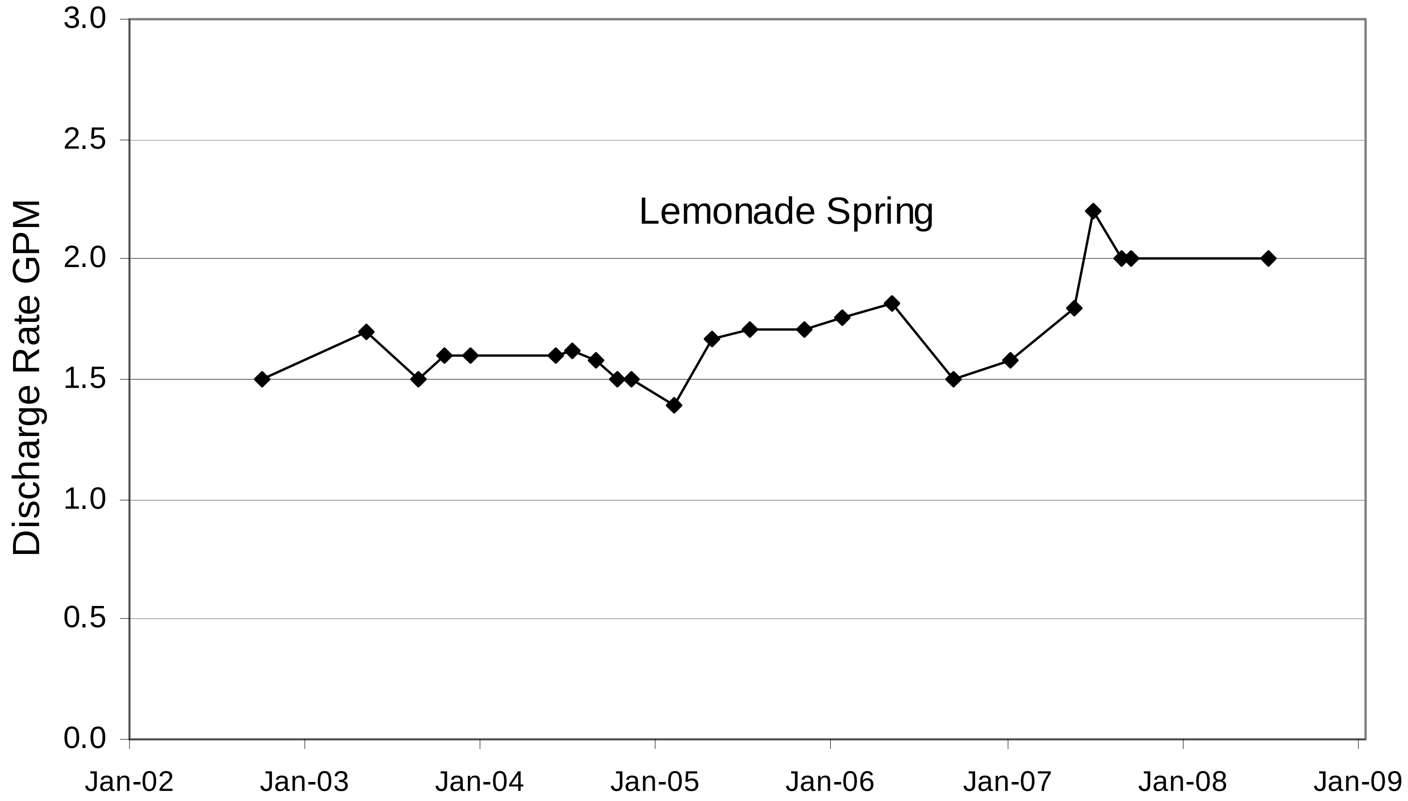


Figure 15. Lemonade Spring (GWIC M:198766) appears to be locally recharged by the Canyon and Ferry coal beds. The spring has an average discharge rate of 1.69 gpm.

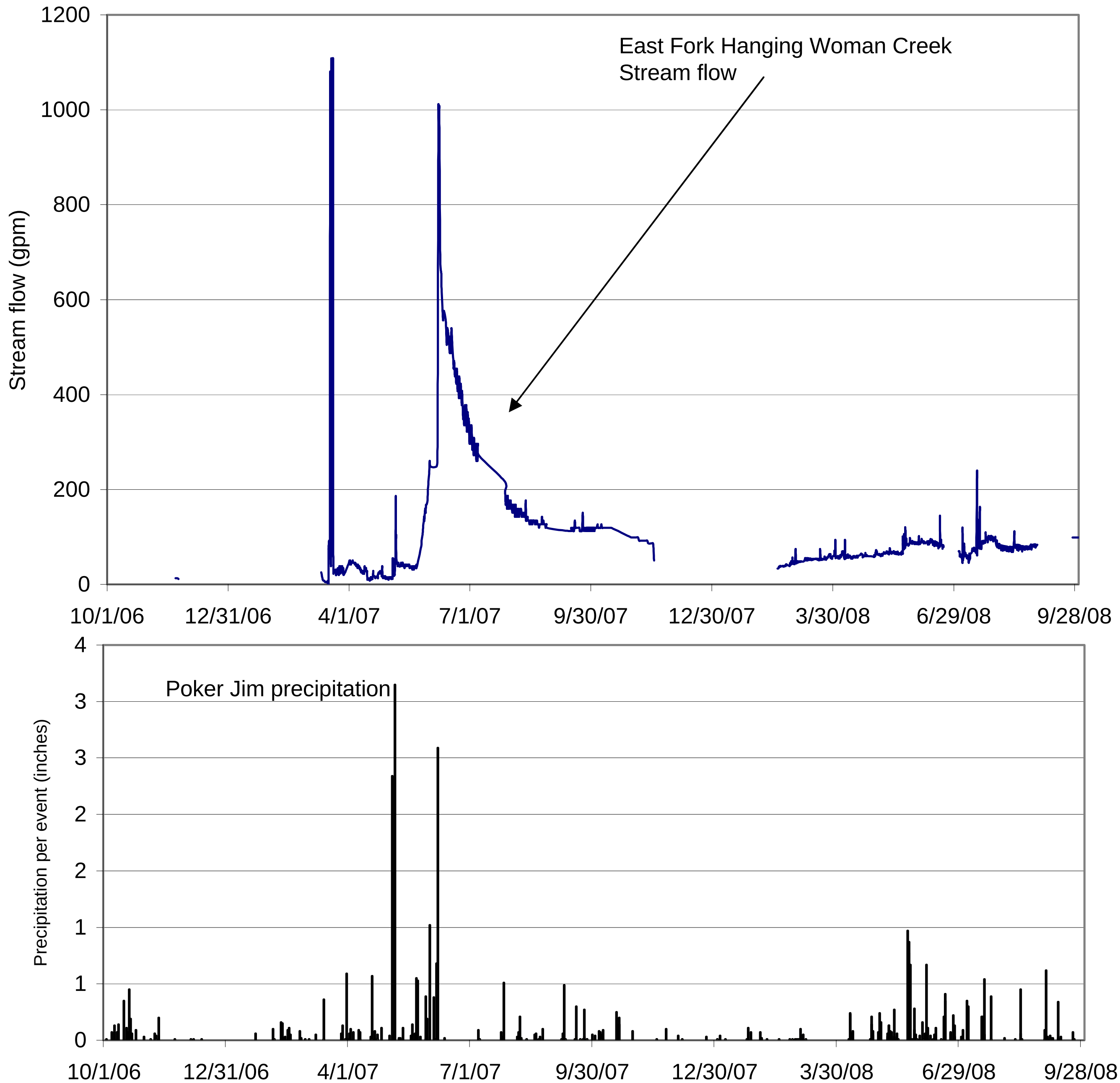


Figure 16. Stream flow at the East Fork Hanging Woman Creek weir correlates with precipitation events recorded at the Poker Jim meteorological station. Precipitation is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation.

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

Contiguous areas of wells classified as producing CBM on the MBOGC web page cover an area of approximately 50 square miles (Plate 1). 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. A total of 1,686 coalbed methane wells have been permitted in Montana as of October 1, 2008, 249 of which are shut-in, abandoned, or plugged and abandoned (P&A on Table 3), 109 are permitted or spud, 499 are expired permits, and 827 are listed as producing. Counties experiencing CBM production or permitting for CBM production include Big Horn, Powder River, Carbon, Custer, Gallatin and Rosebud; however, only Big Horn, Powder River and Custer Counties had wells listed on MBOGC web page as actively producing.

Table 3. Summary of Montana Board of Oil and Gas Conservation Listings of Coalbed Methane Permitted Wells by County, October 1, 2008

County	Field or POD	Total # of Permitted Wells	Operators	Well Status	# of Wells
Big Horn	Coal Creek	68	Pinnacle Gas Resources, Inc.	Permit to Drill	6
				Spudded	1
				Producing	26
				Shut In	35
	CX	1168	Fidelity Exploration & Production Co.	Permit to Drill	44
			Pinnacle Gas Resources, Inc.	Expired Permit	226
			Powers Energy Inc.	Expired, Not Released	25
				Producing	705
				Shut In	129
				Temporarily Abandoned	8
				Abandoned - Unapproved	29
				P&A - Approved	2
	Deer Creek Fee POD	33	Pinnacle Gas Resources, Inc.	Permit to Drill	21
				Expired, Not Released	11
				Shut In	1
	Dietz	140	Pinnacle Gas Resources, Inc.	Permitted Injection Well	1
				Expired, Not Released	42
				Producing	92
				Shut In	5
	Forks Ranch - State	16	Pinnacle Gas Resources, Inc.	Permit to Drill	16
	Waddle Creek - State	16	St. Mary Land & Exploration Company	Permit to Drill	16
	Wildcat Big Horn	70	Petroleum Development Corp. of New Mexi	Permit to Drill	1
			Yates Petroleum Corporation	Expired Permit	36
			Fidelity Exploration & Production Co.	Expired, Not Released	2
			Powder River Gas, LLC	Spudded	2
			Pinnacle Gas Resources, Inc.	Producing	2
			St. Mary Land & Exploration Company	Shut In	25
			Pennaco Energy, Inc.	Temporarily Abandoned	1
				Water Well, Released	1
Carbon	Wildcat Carbon	3	Florentine Exploration & Production, Inc.	Expired Permit	1
				P&A - Approved	2
Custer	Wildcat Custer	1	Powder River Gas, LLC	Producing	1
Gallatin	Wildcat Gallatin	1	Huber, J.M., Corporation	Expired, Not Released	1
Powder River	Castle Rock	128	Powder River Gas, LLC	Expired Permit	128
	Wildcat Powder River	38	Powder River Gas, LLC	Expired Permit	26
			Pennaco Energy, Inc.	Producing	1
			Rocky Mountain Gas, Inc.	Shut In	9
			Pinnacle Gas Resources, Inc.	P&A - Approved	2
Rosebud	Wildcat Rosebud, N	4	Yates Petroleum Corporation	Expired Permit	1
			Fidelity Exploration & Production Co.	Spudded	2
			Pinnacle Gas Resources, Inc.	Shut In	1

Source: Montana Board of Oil and Gas Conservation on-line database: http://bogc.dnrc.mt.gov/ accessed 10/1/2008

Total number of producing wells on 10/1/08: 827

Produced-water data for 2008 were retrieved for Montana (MBOGC, 2008) and Wyoming (WOGCC, 2008) and are summarized in Table 4. A total of 907 wells produced methane and/or water in Montana during 2008. These wells produced a total of 40 million barrels (bbls) of water (5,156 acre feet). The average annual water discharge rates for individual wells in Montana ranged from 2.8 to 9.2 gpm. The overall water-discharge rates for wells in Montana averaged 3.9 gpm. In Wyoming during 2008, 127 million barrels of water (16,370 acre feet) were produced from the 2,647 wells in the two townships nearest Montana (57N and 58N). The average annual water discharge rate for individual wells ranged from 2.6 to 7.0 gpm and the overall average discharge rate in Wyoming was 3.8 gpm. The total amount of water co-produced with CBM in the Powder River Basin in *all* of Wyoming and Montana in from October 2007 to September 2008 was approximately 930 million bbls or 120,000 acre-feet.

Table 4. Annual summary statistics for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2008.

			Annual total water production			Average Annual Water Discharge Rate	
	Field	Well Count	Bbls	acre-feet	Change from 2007	per well (gpm)	Field total (gpm)
Montana	Coal Creek	31	1.78E+06	230	-6.1E+05	7.3	142
Montana	CX	772	3.54E+07	4,565	7.3E+05	4.0	2,830
Montana	Dietz	103	2.84E+06	366	6.8E+05	2.8	227
Montana	Waddle Creek	1	8.88E+04	11	8.9E+04	9.2	9
Montana	**Statewide**	**907**	**4.0E+07**	**5,171**	**1.1E+06**	**3.9**	**3,206**
Wyoming	Prairie Dog Creek	1,732	5.69E+07	7,340	5.7E+06	2.6	4,551
Wyoming	Hanging Woman Creek	281	2.46E+07	3,169	2.2E+06	7.0	1,965
Wyoming	Near Powder River	634	4.54E+07	5,851	7.2E+06	5.7	3,628
Wyoming	**Combined**	**2,647**	**1.27E+08**	**16,361**	**1.5E+07**	**3.8**	**10,143**

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, 2008, p. 4–12) and the technical hydrogeology report associated with that analysis (ALL Consulting, 2001) included an estimation of the average water production rates per CBM well. The trendline for the estimated water production rate for individual wells is shown as a dashed line on Figure 17. This trend is re-evaluated here based on 117 months (9 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 hydrogeologic response. Similarly, the average values for normalized months over 113 are not believed to be indicative of typical CBM well production because only 1 to 6 wells have been producing 113 months or longer. The amount of water initially produced, on average, from each CBM well is less than was expected (Figure 17). However, predicted water production rates are between the 80th and 90th percentile of actual production until normalized month 40, at which time the predicted production falls within the 80th

percentile of actual production. The predicted and observed rates become similar around normalized month 70. After 70 months, the actual rate of CBM water production levels out and exceeds the estimated rate. The area between the anticipated and actual production lines in Figure 17 prior to month 70 represents the amount of water that was anticipated, but never produced. 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. The difference between the anticipated and actual production after month 70 represents the water produced in excess of the predicted production. 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 increases sharply in the well's first 5 months and then is relatively stable from 5 to 35 months of production. After 35 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 90th percentile of production; however, the 80th and 90th average percentiles also follow the same pattern of production. Total water and gas production since the initiation of CBM production in April, 1999 is presented on Figure 19A. 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 red line on Figure 19A represents the water that would have been produced assuming the rate of water production used in the EIS and the actual number of wells and producing months. Early production was similar to that predicted by the EIS, however later production was significantly less than predicted. Water production decreases in the years immediately following years where few new wells were installed (e.g. 2003; Figure 19B).

The ratio of water-to-gas production (in bbls/mcf) is a potentially useful metric and may help identify wells that produce a large amount of water for relatively little gas. This test may be straightforward; however, some wells may individually have high water-to-gas ratios but in fact be decreasing the water pressure in the coal bed, thus allowing other wells to produce gas. The ratios presented in Figure 20 were calculated by dividing the monthly water production in barrels by the amount of gas produced in million cubic feet for each well. The median, 80th and 90th percentiles are presented in Figure 20 normalized by months of production. For those wells that produced water and no reported 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 80th and 90th percentiles to be presented on the same axis as the median values. The 90th percentile approaches 12,000 barrels per mcf gas in the most extreme case. 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 the 80th percentile so is therefore not truly representative of CBM water to gas production. This figure illustrates that low water-to-gas ratios are typically maintained until about the 85th 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.

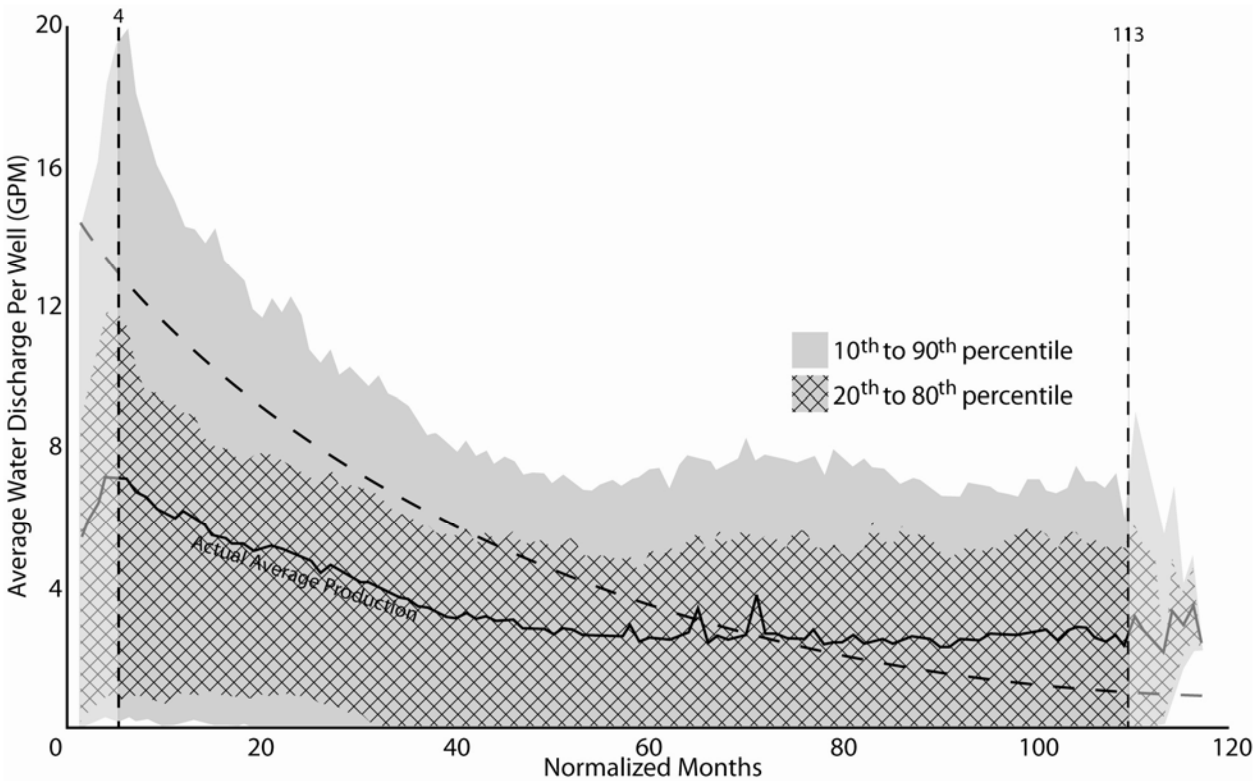


Figure 17. Normalized CBM produced water in gallons per minute in the Montana portion of the Powder River Basin (data from MT BOGC web site). The solid line represents the average production rate, the light grey field represents the range of data within the 10^{th} to 90^{th} percentile, the hatched area represents the range of data within the 20^{th} to 80^{th} percentile. The dashed line is the EIS predicted production per well Y=14.661e-0.0242x (from U.S. BLM, 2003). Trends from 1 to 4 months and 113 to 117 months are not considered to be representative of hydrogeologic responses to CBM production and are most likely related to operational activities and the low number of wells represented by these data.

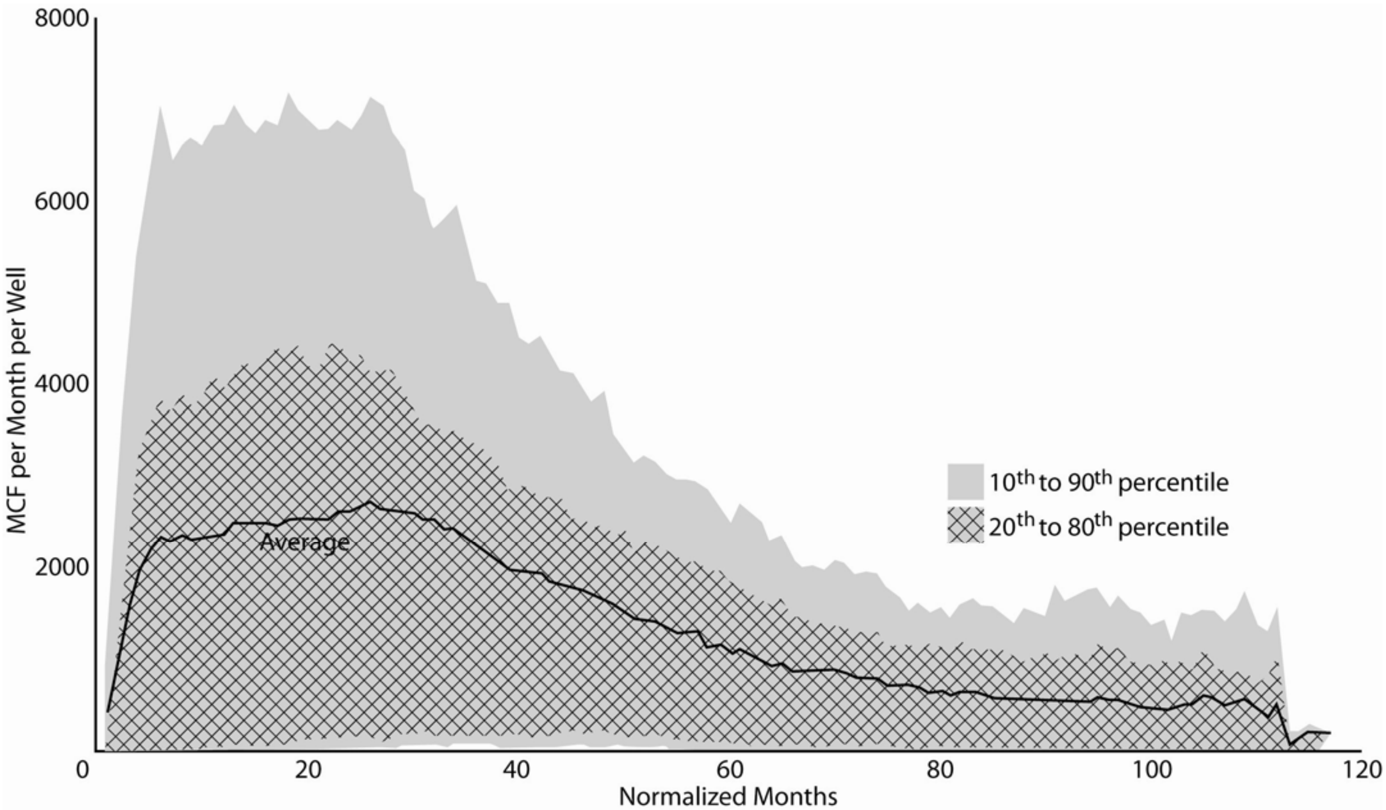


Figure 18. Normalized gas production in MCF per month per well for the Montana portion of the Powder River Basin (data from MT BOGC web site). Solid line represents the average MCF produced, the light grey field represents the data that falls within the 10^{th} to 90^{th} percentile, the hatched area represents the data that falls within the 20^{th} to 80^{th} percentile.

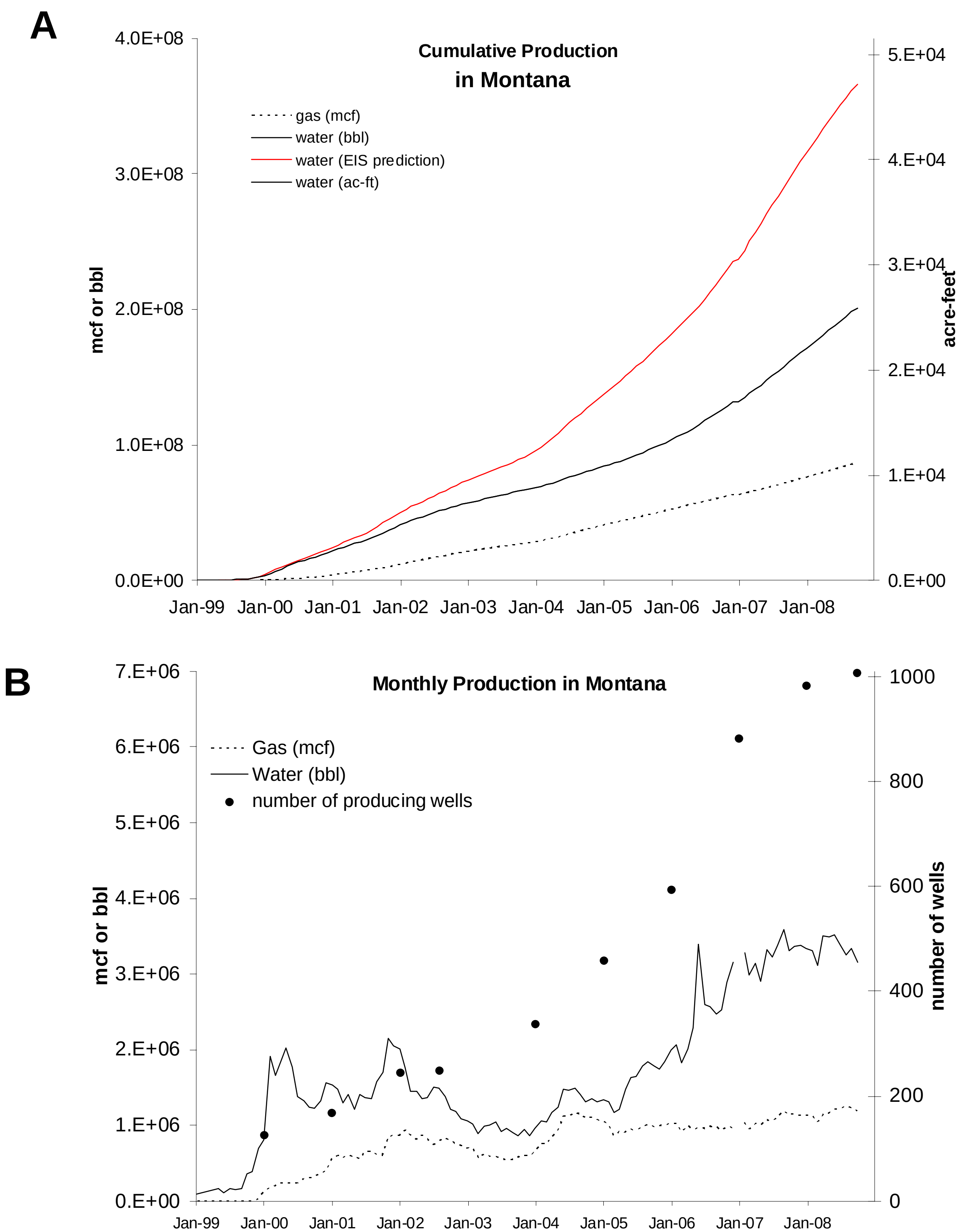


Figure 19A. Total water and gas produced in Montana since CBM production began in the spring of 1999. More new wells cause the rate of water production to increase. The red line indicates the amount of water that was predicted to be produced based on the EIS production rate and the actual number of wells and months produced. **Figure 19B**. Monthly totals of water and gas produced from Montana CBM wells and total number of CBM wells. Water production decreases when few new wells are installed (2003 for example). Gas production lags behind water production because of the dewatering period necessary for gas production.
(Data from MT BOGC on-line database)

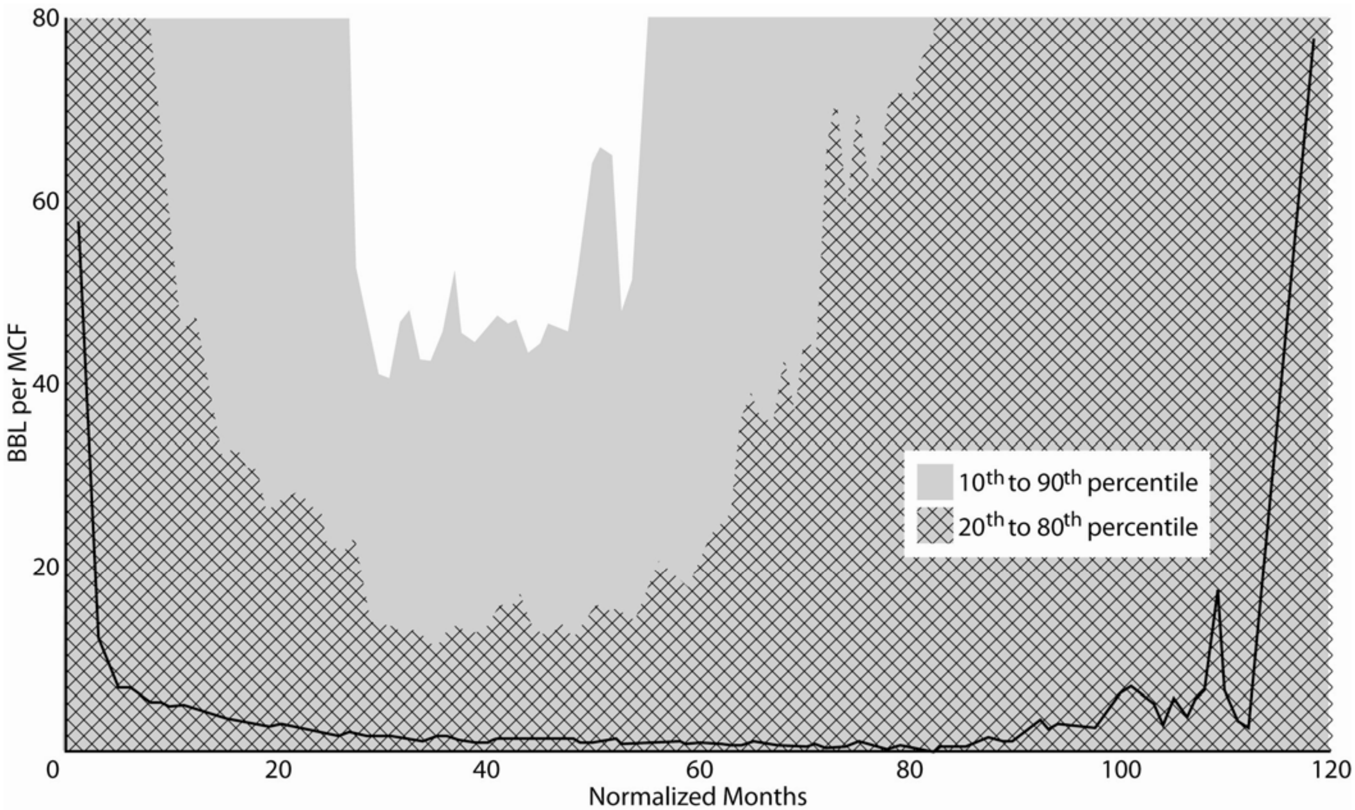


Figure 20. CBM produced water to gas ratio in BBLS/MCF (data from MT BOGC web site). The solid line represents the median ratio. Median, as opposed to mean, values were chosen for display because the few exceptionally high ratios skewed the mean values higher than is representative of most wells (higher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

Montana CBM Fields

CX gas field

Coalbed 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 2008, a total of 772 CBM wells produced either water, gas, or both in the CX field. Production is from the Anderson, Canyon, Carney, Dietz 1, 2, and 3, Monarch, Smith, Wall, King, and Flowers-Goodale coalbeds (Table 4; Figure 2). The average water production rate for all wells over the entire year was 4.0 gpm. The highest water production rate for a single well over a 1-month reporting period was 39.1 gpm. The total water production for the year was 35.4 million barrels (4,563 acre feet). Along the western edge of the Fidelity project area near the Montana–Wyoming state line some wells are no longer being pumped (as indicated by red well symbols on Plate 1) and others are being pumped at a reduced rate as the methane-production rates in this area have declined. Similarly, across the state line in Wyoming, CBM wells are also being shut-in. Water levels should begin to recover as water production rates decrease.

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 feet 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 feet 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). While similar, current measured drawdown is less than expected.

Hydrostatic pressure in the combined Anderson and Dietz coal in well WR-34 near the Ash Creek mine declined about 21 feet between 1977 and 1979 due to mine dewatering (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 feet 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 33 feet of baseline conditions. This represents 79% recovery during a period of 5.5 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 feet 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 21feet of baseline conditions, or a water-level recovery of about 73%. 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 in the Fort Union Formation show that the monitored fault sections in this area are often no-flow boundaries (Van Voast and Hedges, 1975; Van Voast and Reiten, 1988). Dewatering of the East Decker mine pit, which is less than 1 mile north of a monitored fault, has lowered water levels in the Anderson coal (WRE-19), and overburden aquifers for over 25 years on the north side of the fault (Figure 23) but there was no response to mine pit dewatering south of the fault (WRE-18). Current monitoring of CBM-production-related drawdown south of the fault shows an opposite response as water levels in the Anderson coal (WRE-18) south of the fault have been lowered significantly without a similar decrease in water levels north of the fault (WRE-19). WRE-18 has been lowered about 161 feet since 2001, then between May 2006 and February 2008 the water levels rose and fell twice, and has been falling consistently since February 2008. Currently, the water level is 114 feet below baseline. The isolated effects indicate that the fault acts as a barrier to flow within the Anderson coalbed. South of the fault (WRE-17) the Smith coal responds slightly to both coal mining north of the fault and CBM production south of the fault. Due to the offset caused by faulting (Figure 23) the Anderson coal north of the fault and the Smith coal south of the fault are in proximity to each other and there may be some communication between them. Another possibility is that the reduced pressure from mining migrated around the end of the fault.

Near the western edge of the CX field, but across a fault from active CBM wells, water levels in the Carney coal (CBM 02-2WC) have been responding to CBM-related drawdown since the well was installed in 2003. Water levels in this well are now 14.43 feet 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 (CBM 02-2RC) is stratigraphically higher than the CBM production zones, and during 2005 the water level at this well dropped about 8 feet, but began to recover in early 2006 and currently has recovered 3.5 feet. The cause of the water-level changes in the Roland coal is not apparent and is unlikely to be related to CBM development. The type of response is much different than that measured in the other coal aquifers at this site.

Near the East Decker mine, coal mining has lowered water levels in the Anderson, Dietz 1, and Dietz 2 coals (Figure 25). The rate of water level drawdown 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 characteristics, or simply a function of the initial water levels in the aquifers.

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 3,430 feet above mean sea level (amsl) (personal communication Kevin Smith, DNRC). Average reservoir stage during this time has been about 3,413 feet amsl, which is higher than the Dietz potentiometric surface and it is likely 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. Ultimately, however, the amount of the increased seepage related to CBM production will be limited by faulting (Plate 2).

The water level in the Anderson coal monitored in the Squirrel Creek watershed (WR-17; Figure 27) was lowered 37 feet by coal mine dewatering and had been lowered 30 feet from CBM production until monitoring ended. 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. Declining water levels (7 feet since the year 2000) in Anderson overburden at this site show either a possible correlation with precipitation patterns or migration of water from CBM production in underlying coalbeds, however this aquifer is separated from the Anderson coal by over 50 feet of shale, siltstone, and coal. The shallow, unconfined aquifer (WR-17A) shows a rapid rise following the start of CBM production. This rise, totaling about 30 feet, 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 water table has returned to within 5.8 feet of 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 (Figure 28A), however none were collected in 2007 or 2008. 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 are flushed from the 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. This well is scheduled to be sampled again in the coming year.

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). The overall trend in water levels in WR-58 from 1999 to 2007 was declining in response to drought conditions, however the water levels have returned to normal in 2008. Farther downstream, in the CBM production area (WR-52D), the water levels in the alluvium were stable until 2000 when levels increased by approximately 4 feet. Since that time water levels have gradually returned to baseline and are currently at their original 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.

Water-quality samples were collected from the Squirrel Creek alluvium WR-59 in September 2007 and June 2008 (appendix C). The TDS concentrations ranged from 6,196 to 6,701 mg/L and the SAR value ranged from 6.1 to 6.4. Since August, 2006 the TDS of water at this site in the Squirrel Creek alluvium has increased from 5,600 to 6,700 mg/L, an increase of 20% (Figure 28B). Future sampling will include additional wells along Squirrel Creek, WR-58,WR-52B, and WR-17A to identify the extent of these changes and the potential source of these changes. The water chemistry is dominated by sodium, magnesium, and sulfate.

A water-quality sample was collected from alluvial monitoring well WA-2 near Birney Day Village in May 2008 (appendix C). The TDS concentration was 1,751 mg/L and the SAR value was 22.9. Since August, 2006 the SAR of the water has risen by 2.5. Further monitoring will be necessary to determine if this is a trend and the source of this potential trend. The water chemistry is dominated by sodium and bicarbonate.

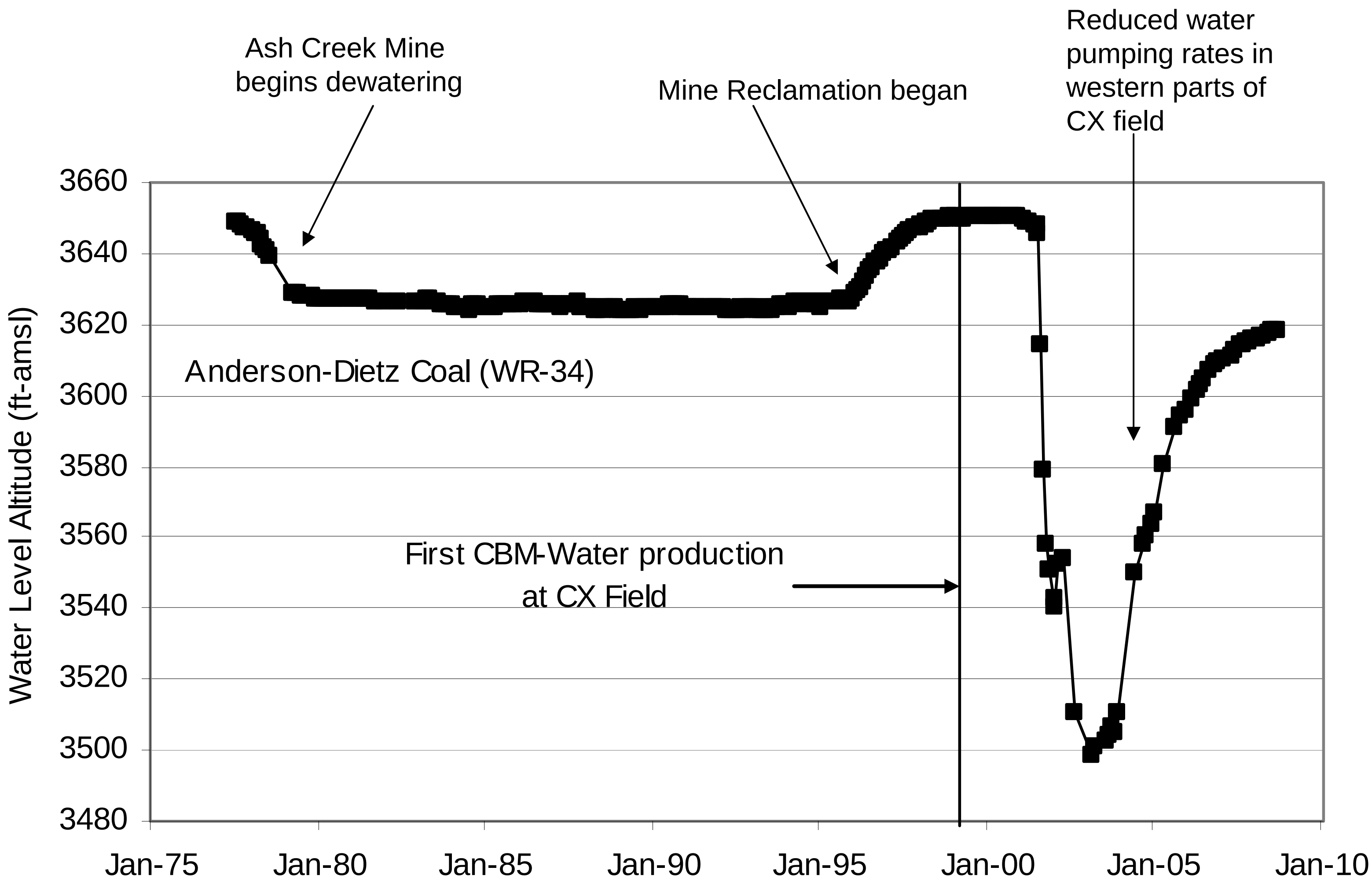


Figure 21. Water levels in the combined Anderson and Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed methane production. The water level recovered starting in 2003 in response to water production decreases in this portion of the CX field.

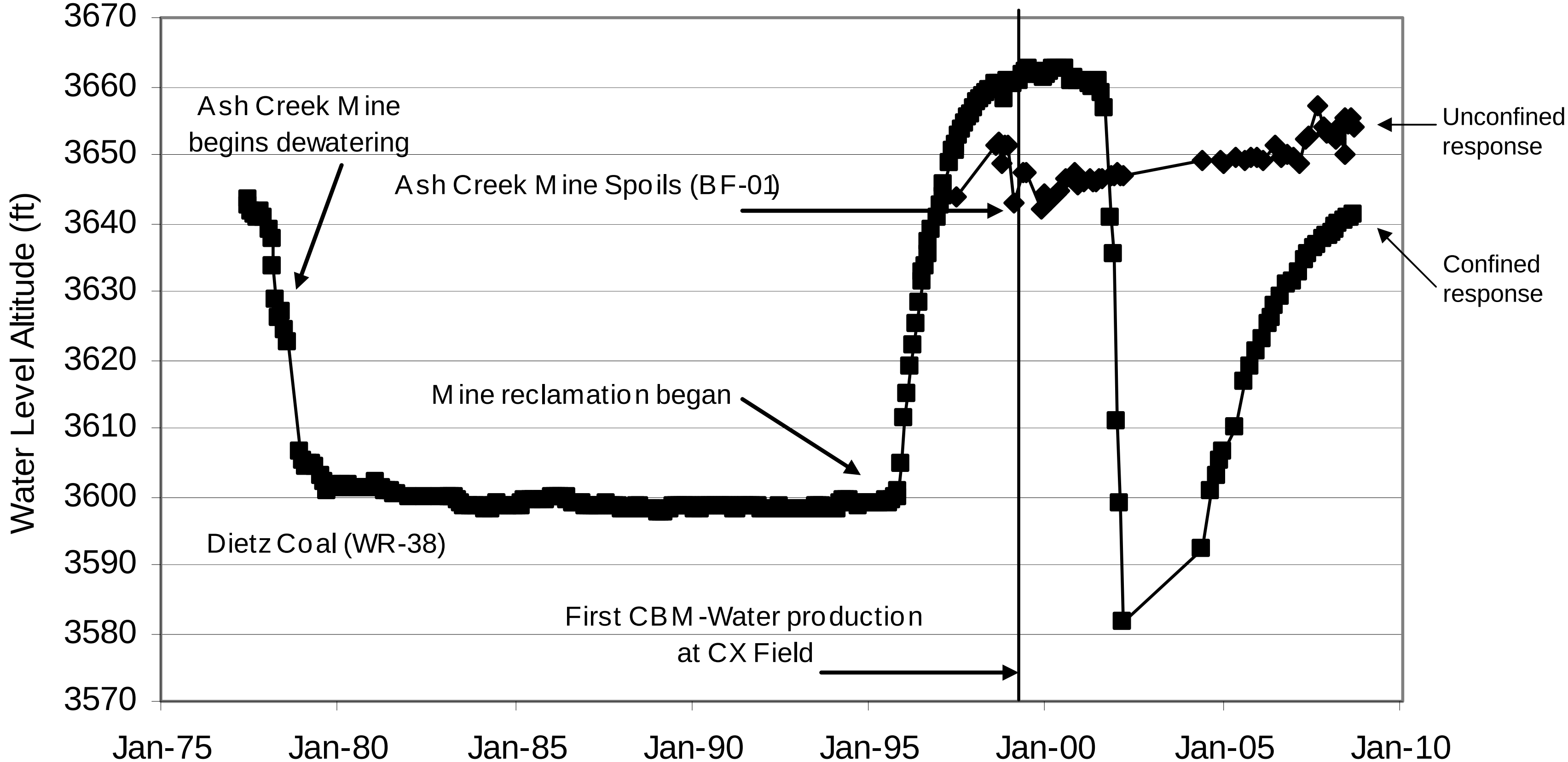


Figure 22. The mine spoils well is being dewatered for CBM production but the water levels show no response to the lowered water levels. However, water levels have decreased by 80 feet in the Dietz Coal in response to the CBM production.

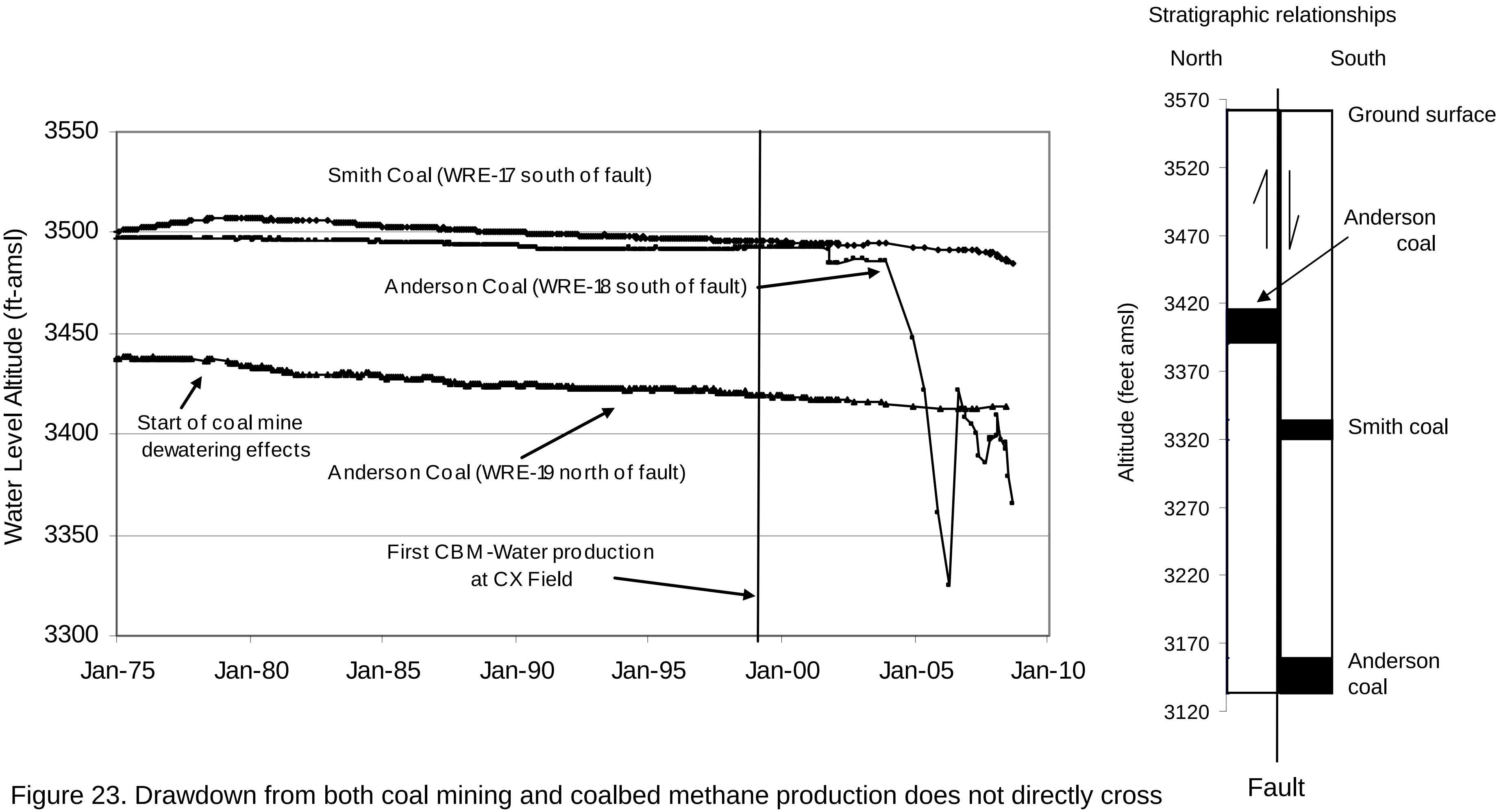


Figure 23. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980's. The pressure reduction has probably migrated around the end of the fault. Coalbed methane production south of the fault is apparent in WRE-18 but not north of the fault in WRE-19.

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

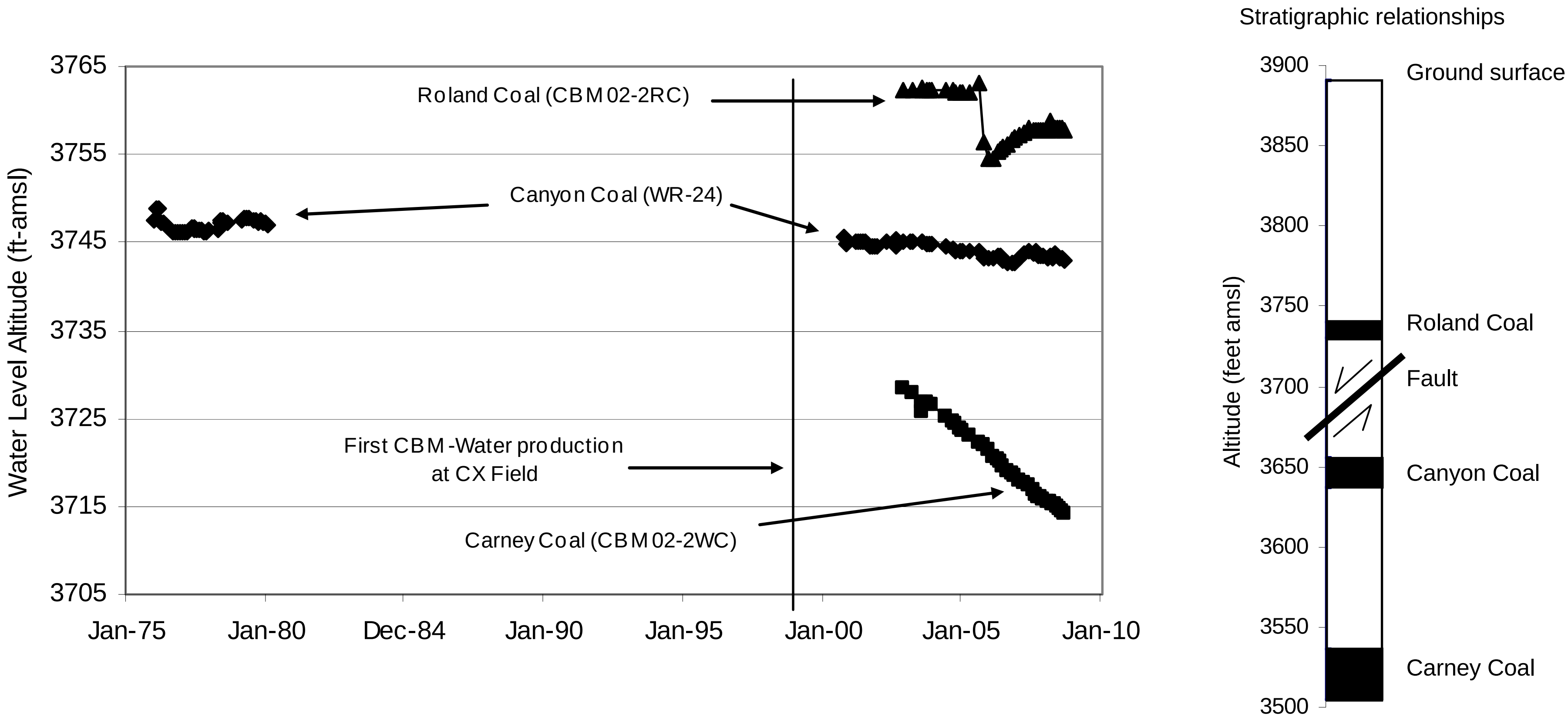


Figure 24. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM related drawdown since its installation. The Roland Coal has not been developed for CBM production and the water-level decline is not apparent at this time but is unlikely to be a response to CBM activities.

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

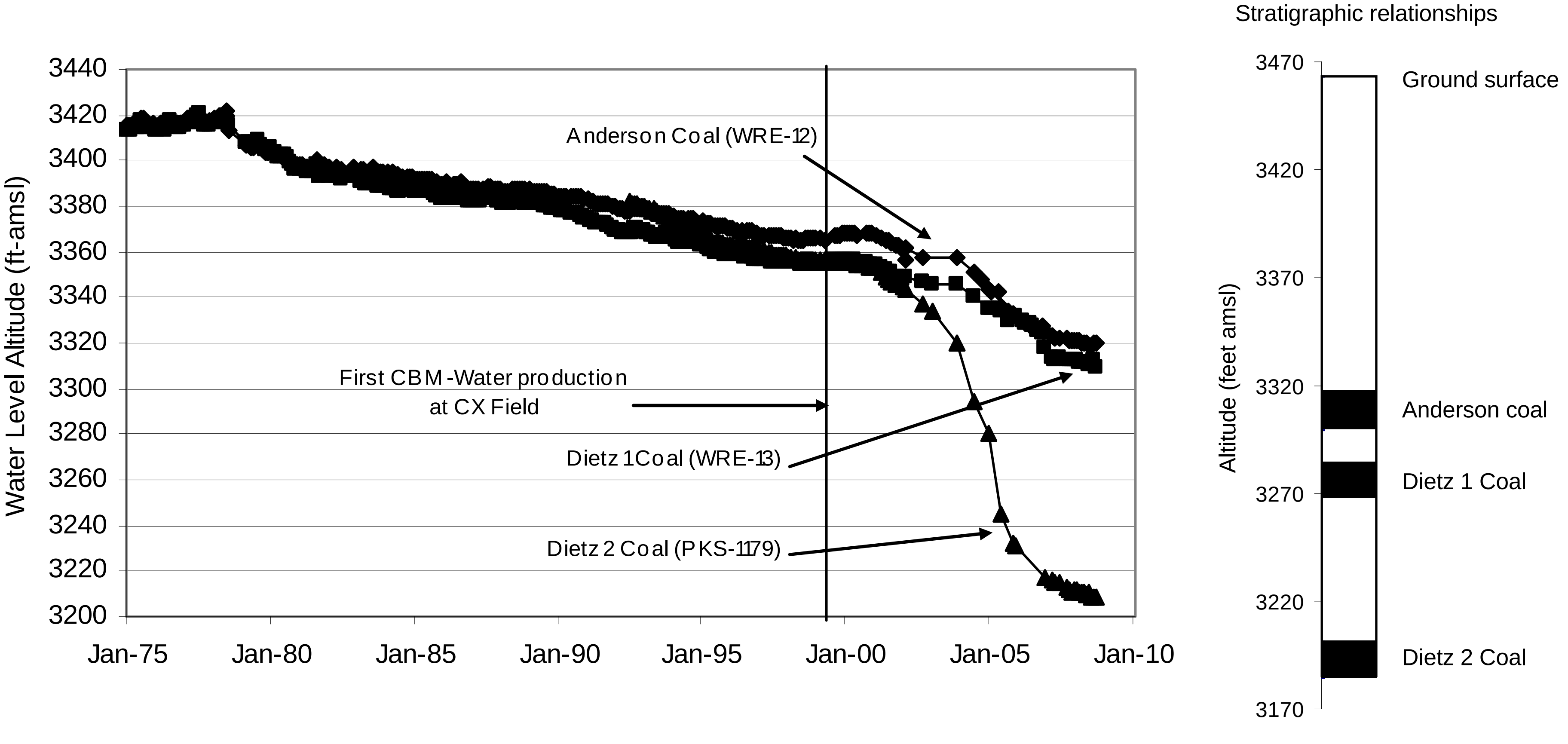


Figure 25. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

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

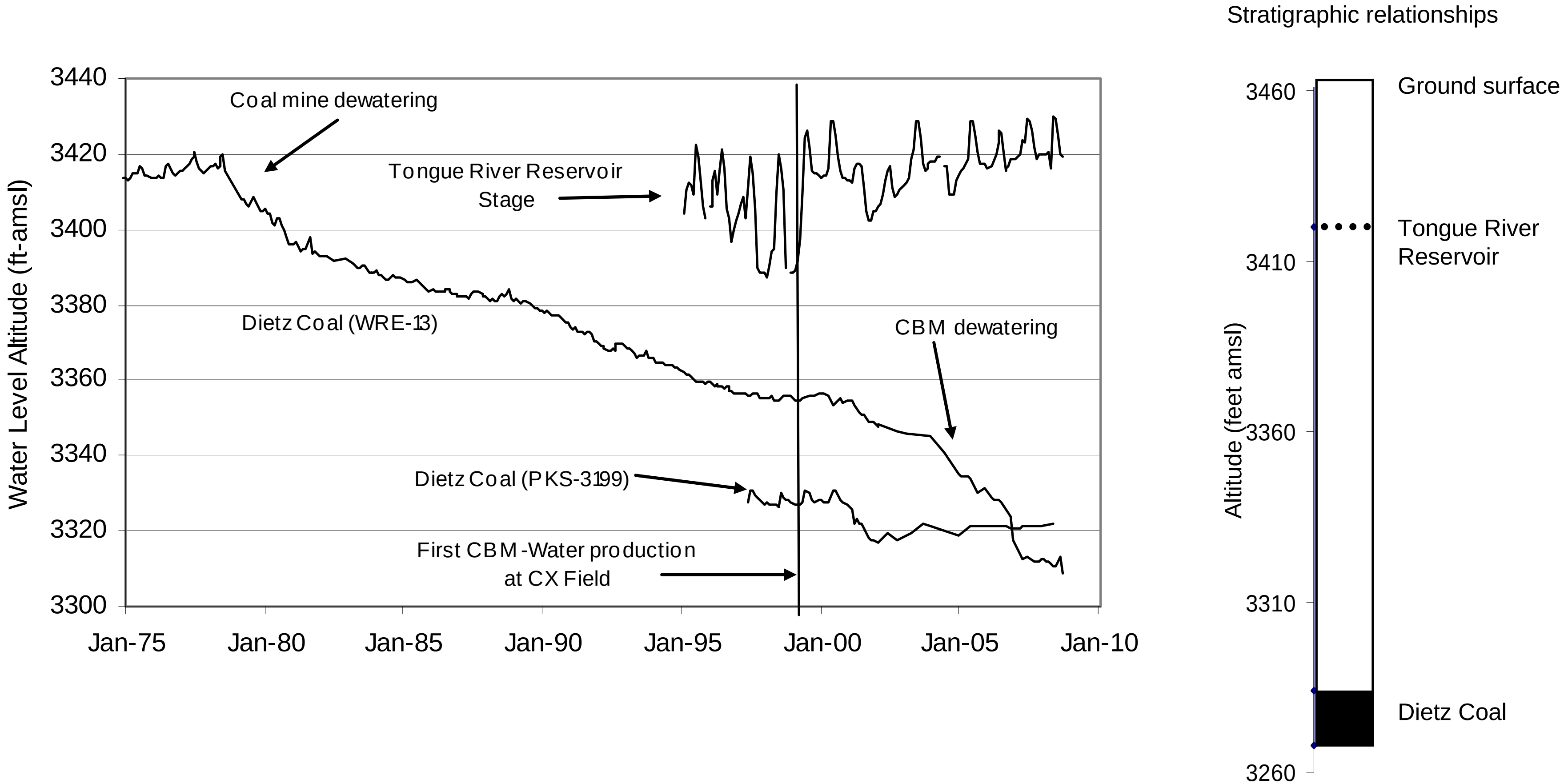


Figure 26. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present.

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

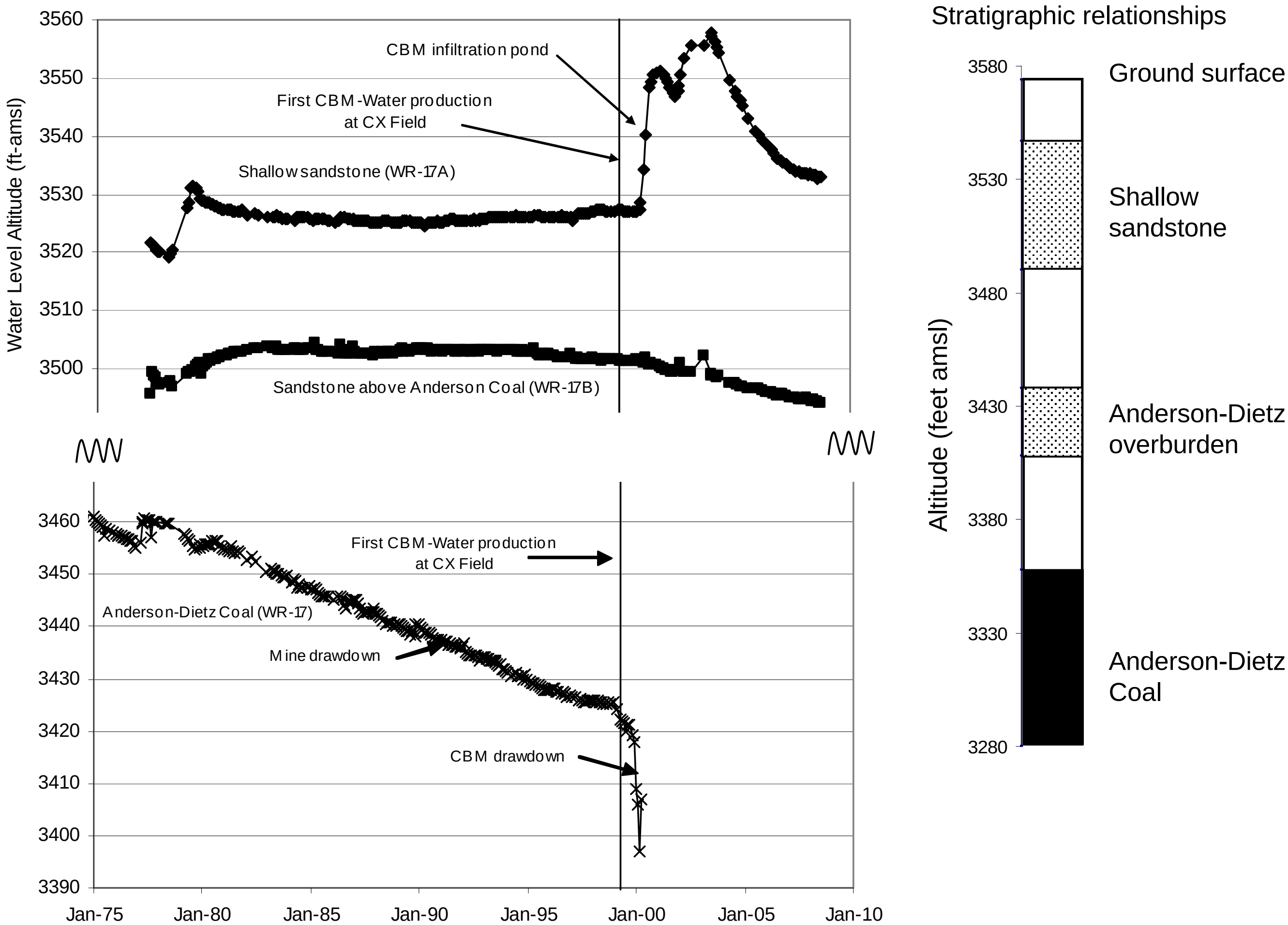
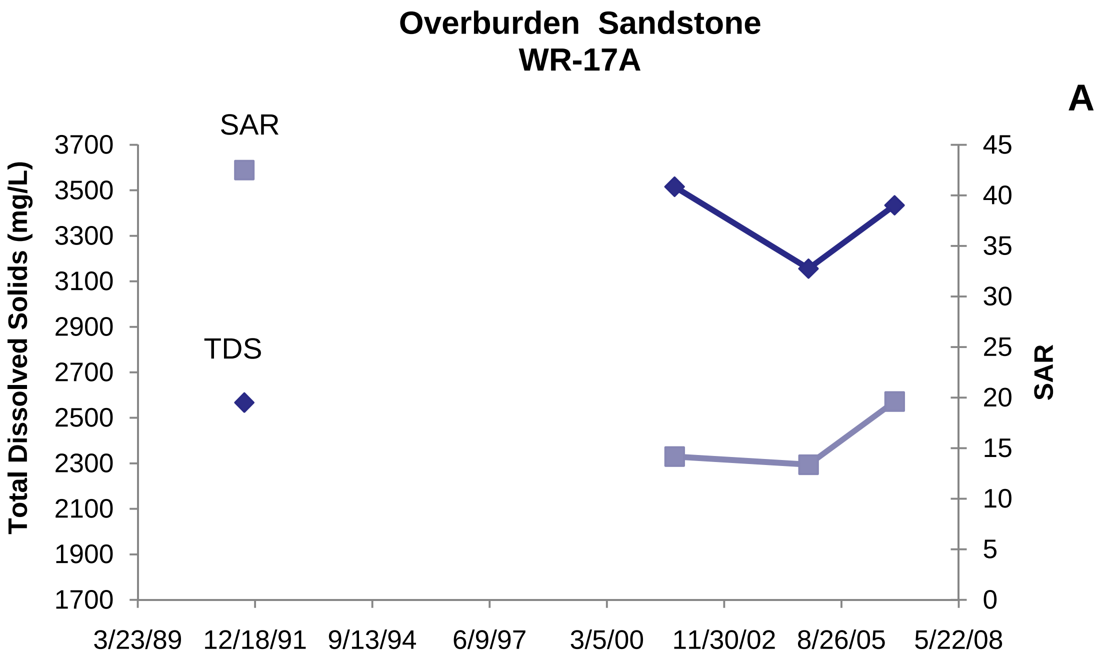


Figure 27. The rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water, therefore the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in the Squirrel Creek area may relate to precipitation patterns or to migration of water drawdown from CBM production in underlying coalbeds. Water levels in the Anderson coal (WR-17) were drawn-down first by coal mining and subsequently by CBM production. Water levels are no longer measured because of the volume of methane gas released from the well.

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



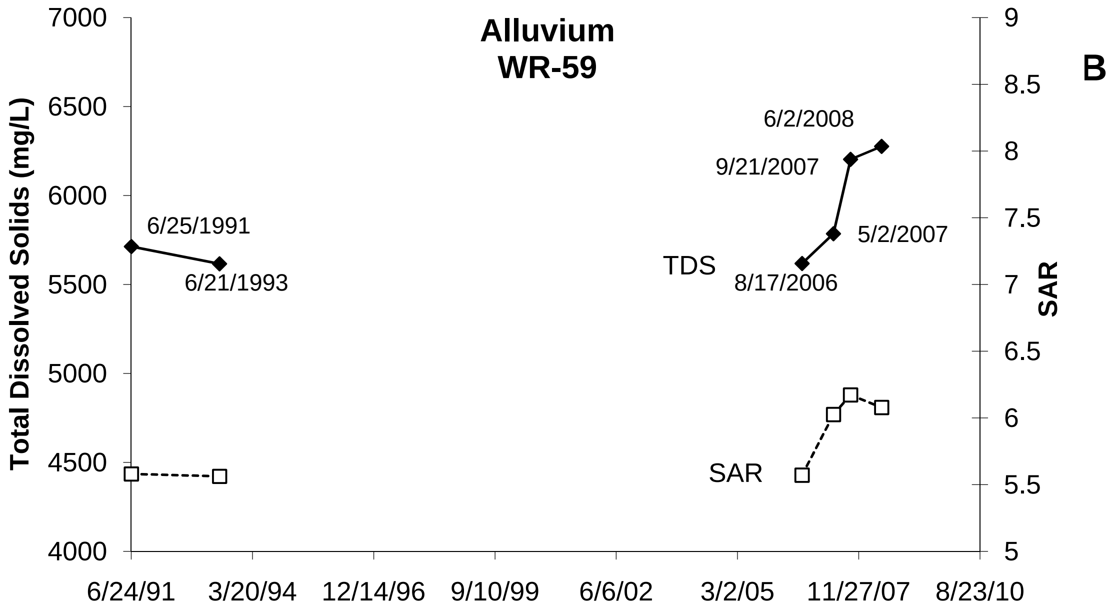


Figure 28. Water quality samples have been collected periodically from WR-17A (A) and WR-59 (B). As the water level increased at WR-17A (see figure 26) the TDS also increased. At the same time the SAR is decreased due to the dissolution of calcium and magnesium salts. TDS and SAR have been increasing in samples collected from well WR-59 (B). Further monitoring will be necessary to determine if a trend exists and the cause of the potential trend.

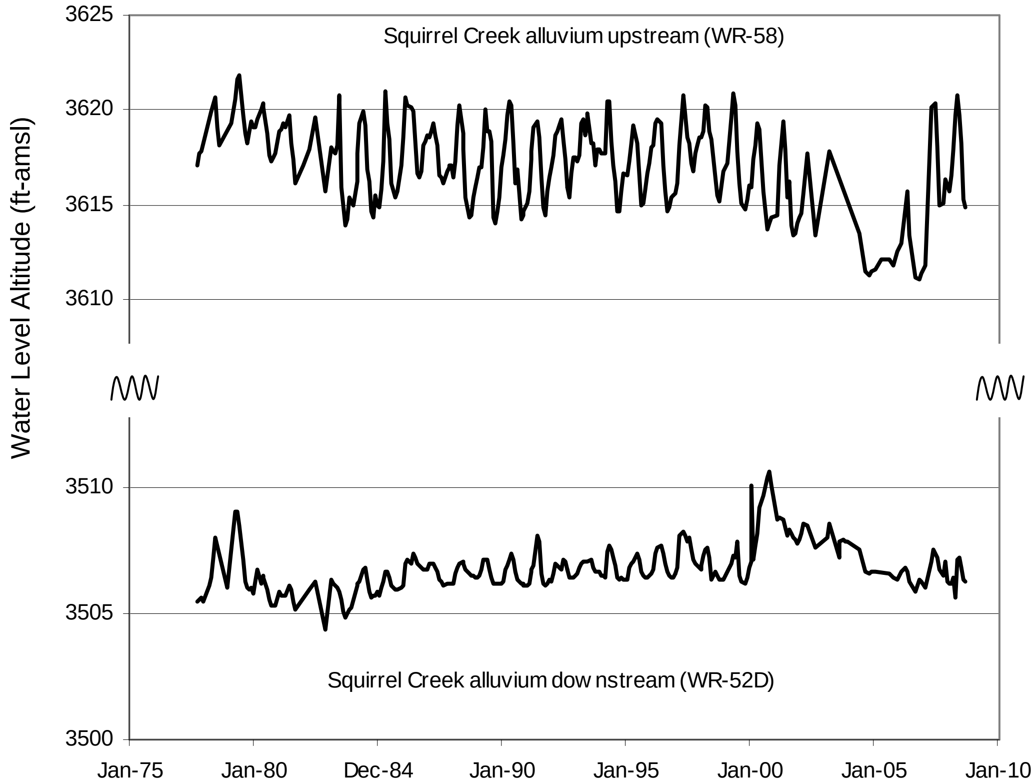


Figure 29. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall 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.

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 2008, a total of 31 CBM wells produced water in the Coal Creek field. Production was from the Wall and Flowers-Goodale coalbeds (Figure 2). The average water production rate for all wells over the 12-month production period was 7.3 gpm (Table 4). The highest water production rate for a single well over a 1-month reporting period was 31.7 gpm. The total water production for the 12-month period was 1.78 million barrels (229 acre feet).

A total of 103 CBM wells produced water in the Dietz field during 2008 (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 2.8 gpm. The highest water production for a single well over 1-month reporting period was 14.4 gpm. The total water production for the 12-month period was 2.84 million barrels (366 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 CBM02-4WC (Plate 1), the water level in the Wall coal was lowered about 12 feet from April 2005 to April 2007 in response to water production in the Coal Creek and Dietz areas (Figure 30). Throughout 2007 the water levels waivered between 3316 and 3322 (feet amsl). In mid 2008 the water level plunged 60 feet to below 3261 feet amsl but had recovered by the end of September 2008. The cause of this rapid decrease event is unexplained at this time. The nearest shut-in CBM wells range from about 1.75 to 2.5 miles from site CBM02-4, while the nearest producing wells are over 4 miles away. Water levels in the sandstone overburden wells show no response to CBM production 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 in water levels due to CBM production has been measured in either the overburden sandstone or Canyon coal at this site (Figure 31).

A water-quality sample was taken from Upper Anderson Spring in May 2008. This spring discharges from the Anderson coalbed. The TDS concentration was 3,756 mg/L, and SAR value was 8.4. No significant water quality changes have occurred from previous samples.

Alluvial aquifer water quality. A domestic well is regularly sampled north of the Tongue River reservoir (Musgrave Bill) and was sampled most recently in October 2007, May 2008, and October 2008 (appendix C). The TDS concentrations ranged from 966 to 1118 mg/L and SAR ranged from 0.2 to 1.8. 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.

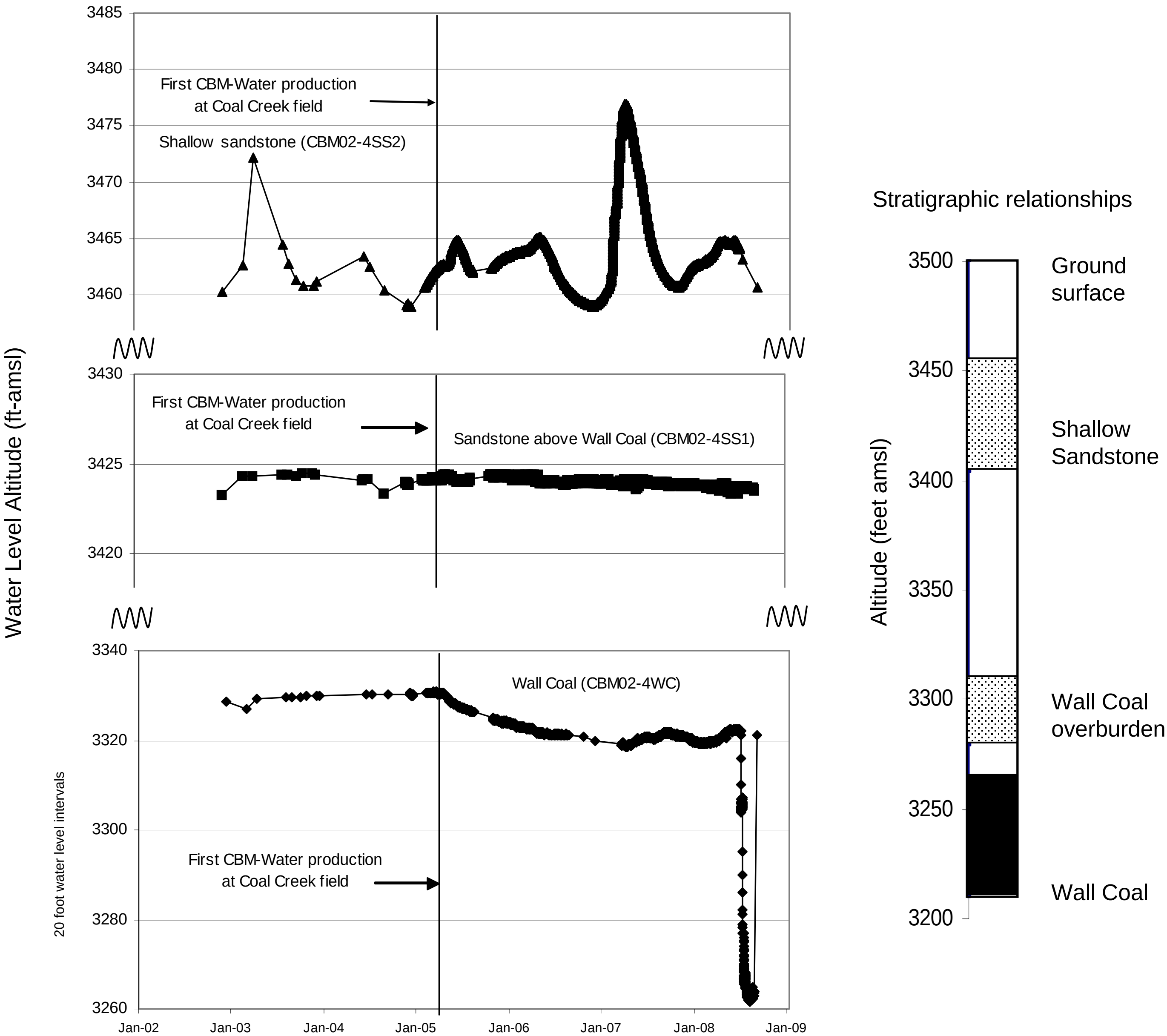


Figure 30. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower sandstone may be. The water level in the Wall Coal aquifer experienced a two month water level drop of 60 ft. The water level has since recovered back to its current water level trend. The cause of this rapid decrease event is unexplained at this time. 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.

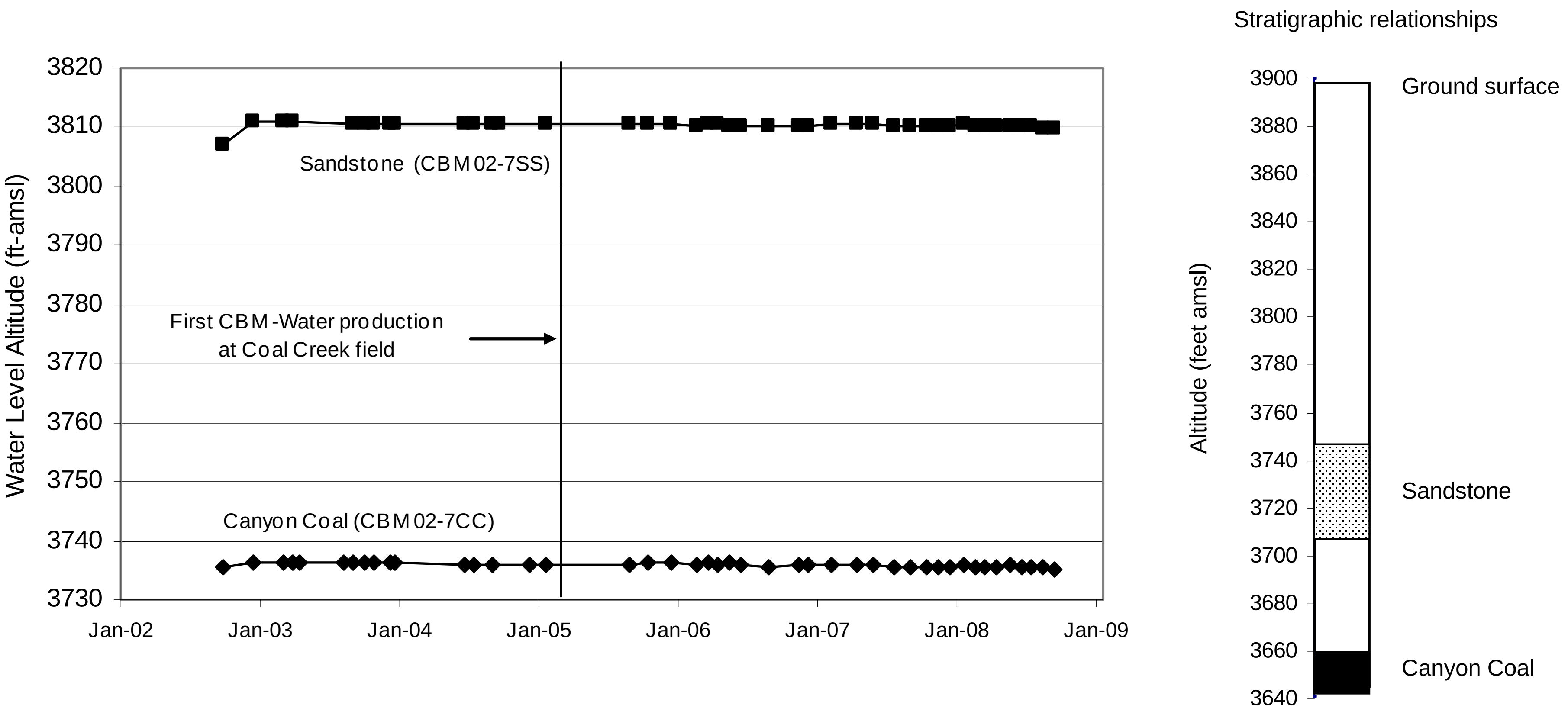


Figure 31. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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 areas 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

Aquifer water levels

Methane water production. The Prairie [illegible] cated in Wyoming south of the CX field in Montana. Methane is produced [illegible] ith, Anderson, Dietz, Canyon, Carney, Cook, King, and Flowers-Goodale (Rob[illegible] e 2). During 2008, a total of 1,732 CBM wells produced methane and/or w[illegible] g Creek field. The average water production per well for the 12-month pe[illegible] d the average producing rate for the field was 4,551 gpm. Cumulative production for the year was 56.9 million barrels (7,335 acre feet). Maximum water was produced in August of 2002 with 832 acre-feet (6.5 million barrels; Figure 32).

Aquifer water levels. Water-level drawdown in Montana that results from CBM 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 2008, a total of 281 CBM wells produced methane and/or water in the Hanging Woman Creek field. The average water production rate per well over the 12-month period was 7.0 gpm. The total water production for the 12-month period was 24 million barrels (3,094 acre feet) at an average cumulative field-discharge rate of 1,965 gpm. Water production began to climb in November of 2004 reaching a peak in September of 2007 with 319 acre-feet (2.5 million barrels; Figure 32).

Bedrock aquifer water levels. 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 33). The water level in the Anderson coal has been lowered about 54 feet at this site in response to CBM production (Figure 34). The water level in the Smith coal has also dropped (13 feet); 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 for half of the year in 2007. It shows high frequency oscillations that do not seem to be related to CBM production. Oscillations are characteristic of pumping in nearby wells completed in the same aquifer, most likely for stock watering or cistern filling (Figure 34 inset). Water-level drawdown, therefore, may be related to domestic use rather than CBM production. This monitoring well is located approximately 150 ft from the Forks Ranch Headquarters well.

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 35). Water levels in the alluvium, sandstone overburden, and Smith are not responding to CBM production. The water level in the Anderson coal has dropped about 18 feet, and water level in the Canyon coal has dropped about 116 feet (Figure 36).

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 37). Alluvial water-level changes at SL-3Q (Figure 38) also appear to be in response to seasonal weather patterns and not to CBM production.

Water-quality samples were collected at HWC 86-13 and HWC 86-15 during May 2008 (appendix C). The TDS concentrations in the alluvial water range from 6,174 to 7,861 mg/L and SAR values range from 11.1 to 11.4. 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). Water-quality samples were collected on North Fork Waddle Creek at SL-3Q during October 2007 and May 2008 (appendix C). The TDS concentrations were 3,579 and 3,387 mg/L, respectively and SAR values were both 5.4. The water chemistry is dominated by sodium sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site. Approximately 20 miles down-stream, a water-quality sample was taken from HWC86-7 during June 2008. The TDS was 3,559 mg/L and SAR was 6.5. Over the last year the TDS has increased and future monitoring will be required to determine if this represents a trend, and what the cause of this potential trend may be. Additional sampling sites between SL-4 and HWC86-7 (either HWC 86-2, HWC 86-5) will be added to help identify the source of increased TDS. Since water quality monitoring sites closer to CBM development have not shown an effect it seems unlikely that these changes are related to CBM development.

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 2008, a total of 634 wells produced methane and/or water in this area. The cumulative production for the 12-month period was 45 million barrels. Average water-production rate per well was 5.7 gpm and the average total production rate for the area was 3,628 gpm. Water production in the fields near the Powder River have increased steadily since January 2004, current production as of September 2008 was 486 acre-feet (3.8 million barrels; Figure 32).

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.

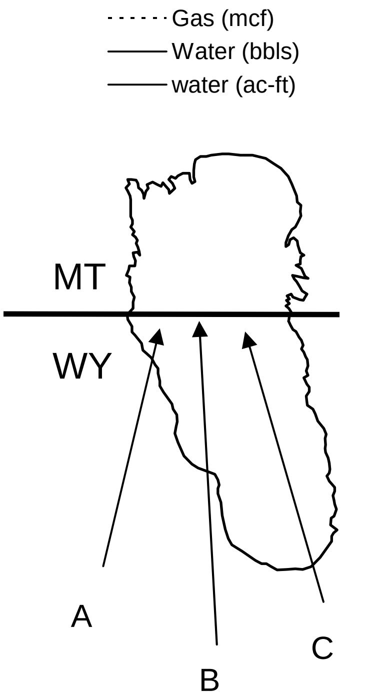
Two monitoring wells at site SL-6 are located 6 miles west of SL-7CC. Well SL-6CC is completed in the Canyon coal and releases gas similar to the conditions described for SL-7CC. For this safety reason, water levels are not currently measured at this well. Well SL-6AC is completed in the Anderson coal and no CBM-related change in water levels have been noted in this well (GWIC data). Water level data loggers will be installed in these 2 Canyon coal monitor wells.

Alluvial aquifer water levels and water quality. South of Moorhead, Montana ground-water flow through the Powder River alluvium is roughly parallel to the river flow (Figures 39 and 40). 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 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 feet 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 wells at SL-8-1Q, SL-8-2Q and SL-8-3Q in October 2007 and from SL-8-2Q and SL-8-3Q in June 2008 (appendix C). TDS concentrations ranged from 2,005 to 3,539 mg/L and SAR values ranged from 3.0 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 39) but no CBM impacts are apparent. There are also insufficient data to identify seasonality trends.

Water Level Recovery in Coal Aquifers

Three monitoring wells completed in the Anderson-Dietz (WR-27, WR-34 and WR-39) coalbed, and one in the Dietz1-Dietz2 (WR-38) coalbed, have shown some recovery in the water levels subsequent to reduced CBM production (Figure 41). These wells are located in the CX CBM field, the first CBM field in Montana that has begun to shut-in wells in the southwest corner (plate 1). Total drawdown during the period of maximum production in the four wells varied between 80 feet (WR-38) and 233 feet (WR-27). Water levels began to recover between October, 2001 and March, 2003. The water levels in the wells have recovered 82, 79, 73 and 77% (WR-27, WR-34, WR-38, and WR-39, respectively) in approximately 5 years. However, due to the variations in CBM pumping rates and the intermixing of producing CBM wells and shut-in CBM wells, the recovery curves are not similar to typical recovery curves. Visual estimations based upon the rate of recovery predict full recovery to baseline conditions in 20 to 30 years, a timeframe similar to that predicted by the EIS.



Locations within the PRB for each area represented by charts A, B, and C.

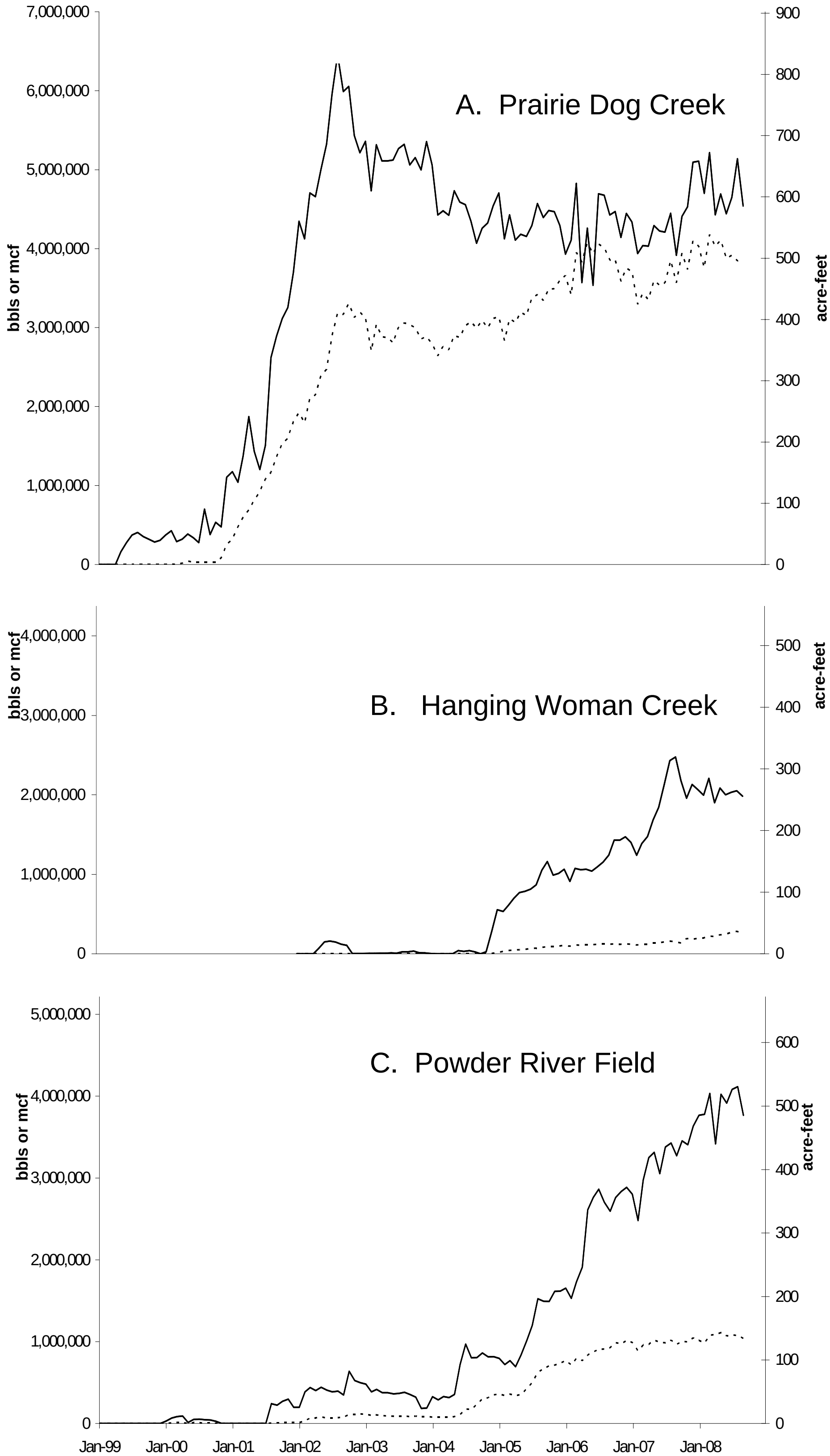


Figure 32. Total water (solid line) and gas (dashed line) produced per month in Wyoming CBM fields. Wyoming development is increasing to the east by the Powder River.

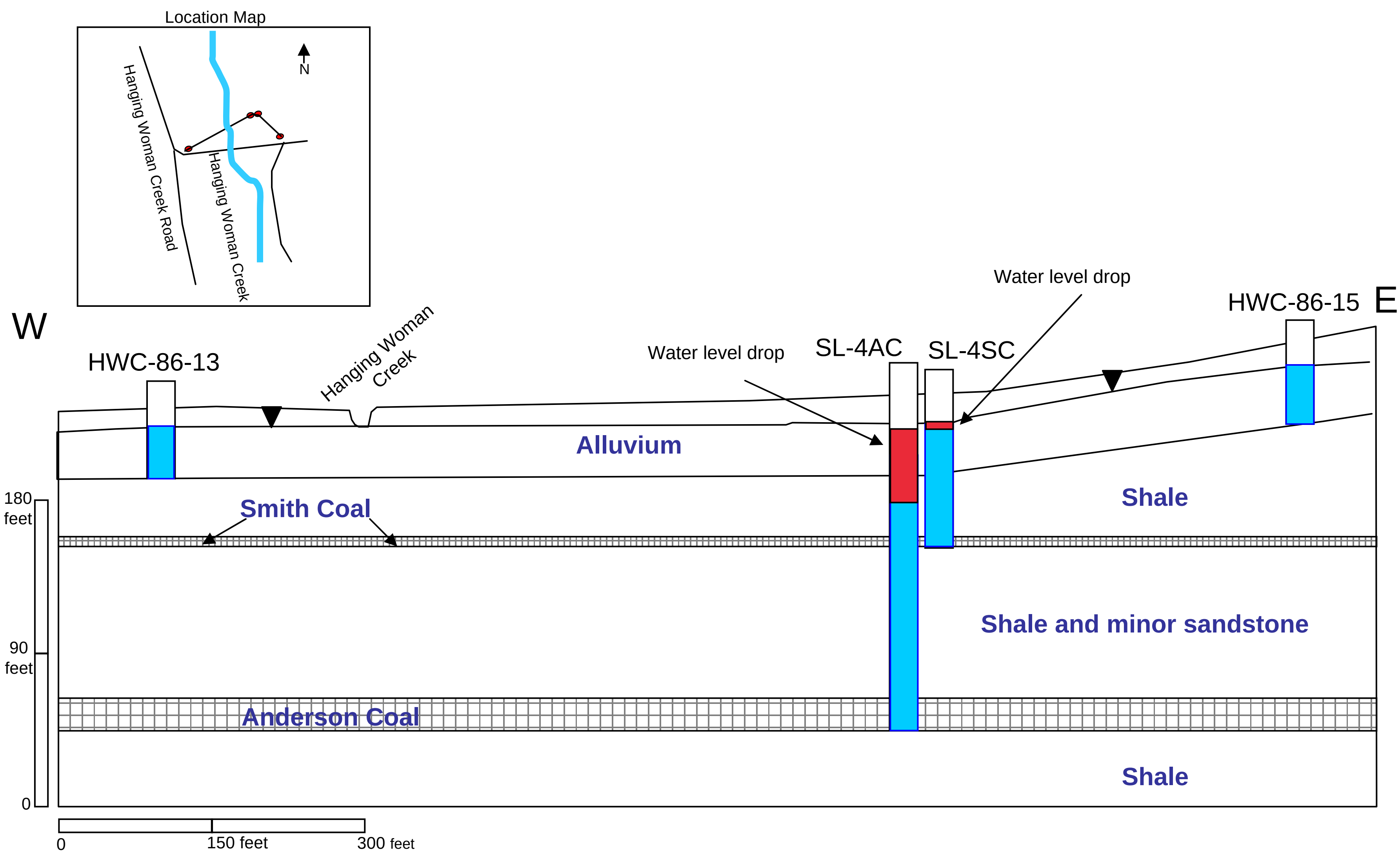


Figure 33. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 54 ft and the Smith has lowered about 13 ft 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.

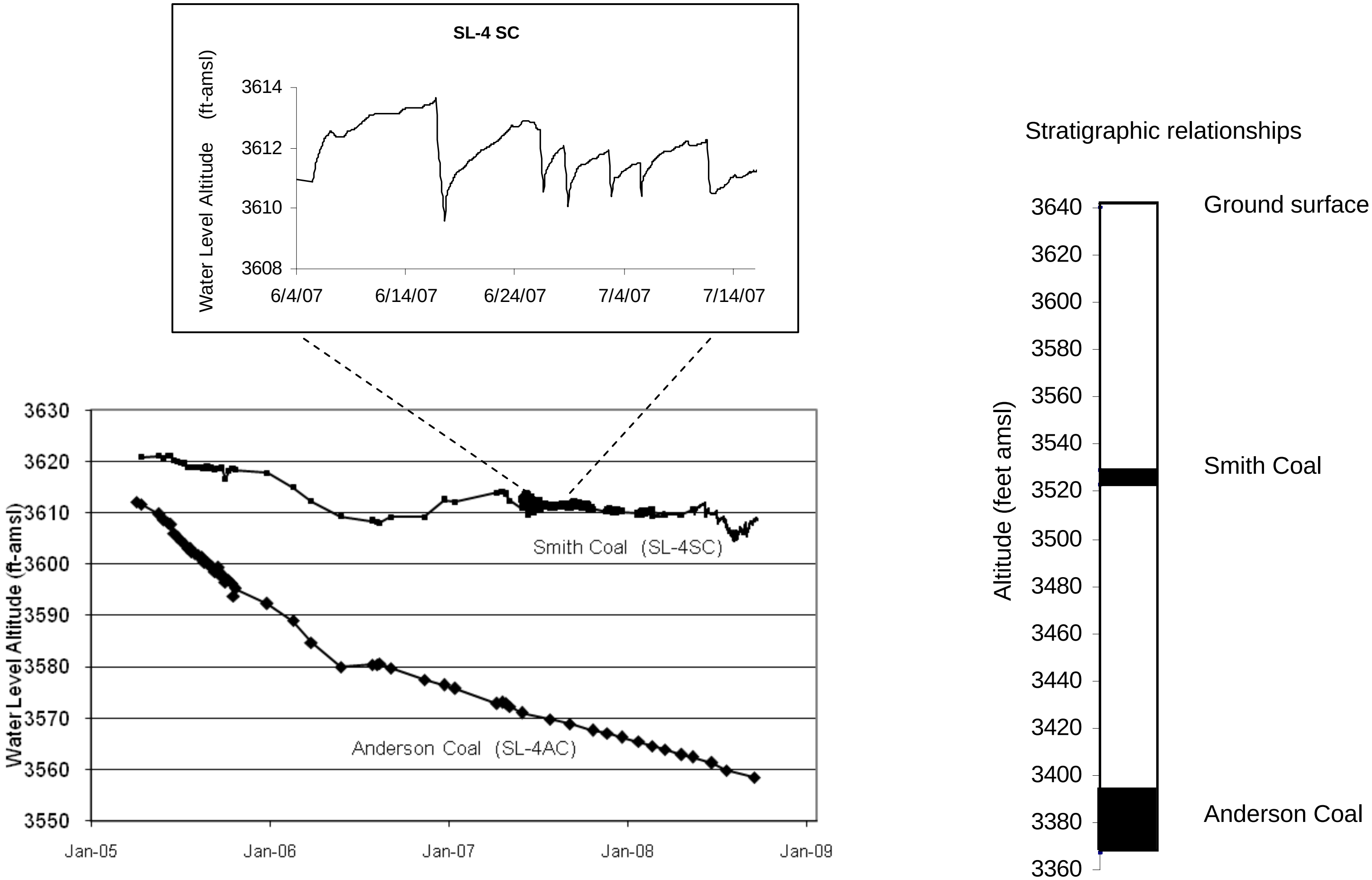


Figure 34. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson Coal appear to have lowered about 54 feet since April 2005 in response to CBM development; however it is unclear if true baseline was obtained prior to impacts occurring. Water levels in the 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. Data-logger data beginning in February 2008 have not been corrected for barometric variations. The Smith Coal well (SL-4SC) shows an aquifer response from the pumping of a private well located about 150 ft from the monitor well (inset graph).

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

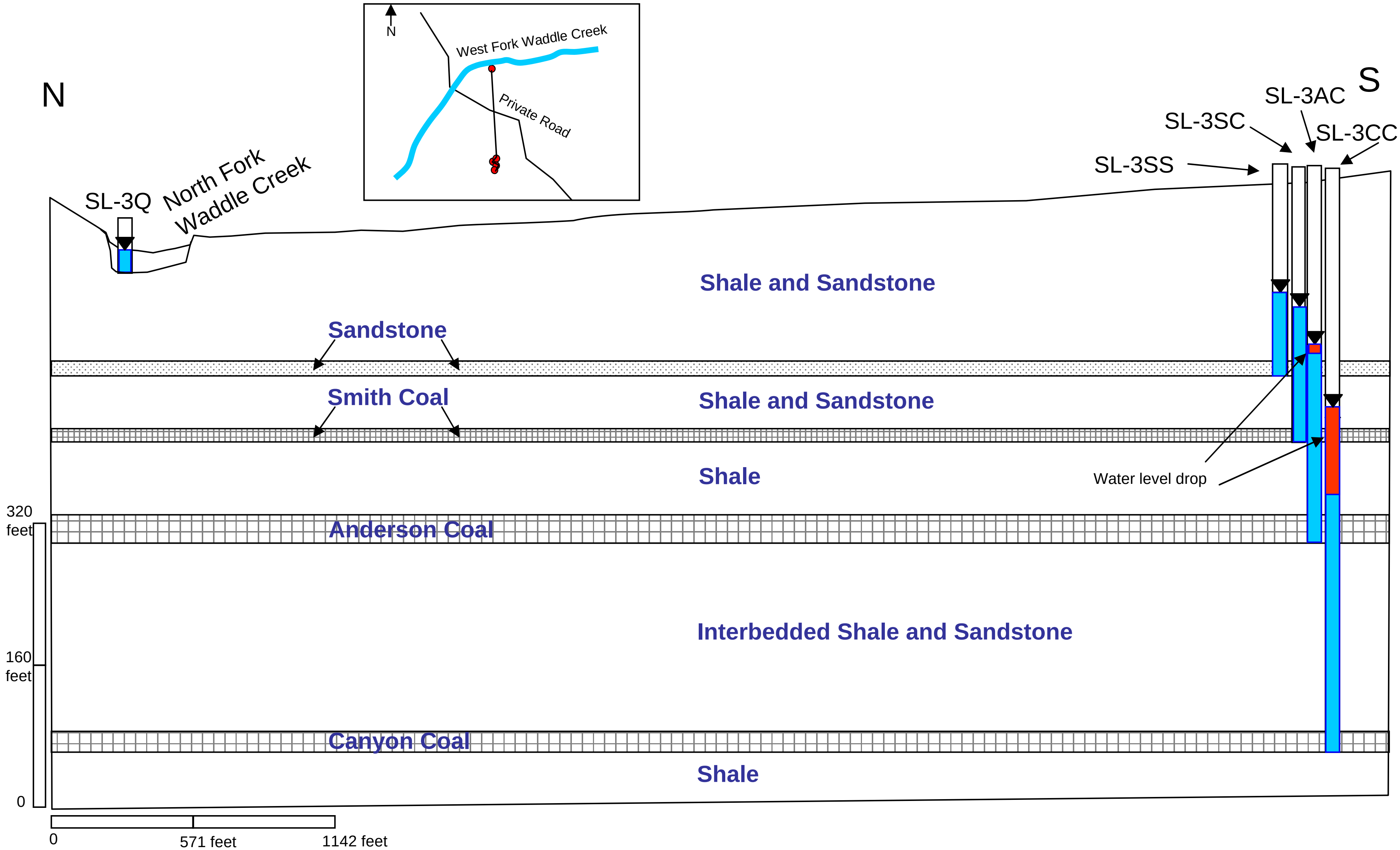


Figure 35. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coal beds located at T9S R42E section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in December 2007. The water level in the Anderson Coal has lowered about 18 feet and the Canyon coal has lowered about 116 feet since well installation. The wells are located roughly 1 mile north from nearest CMB field. Vertical exaggeration is 3.6:1.

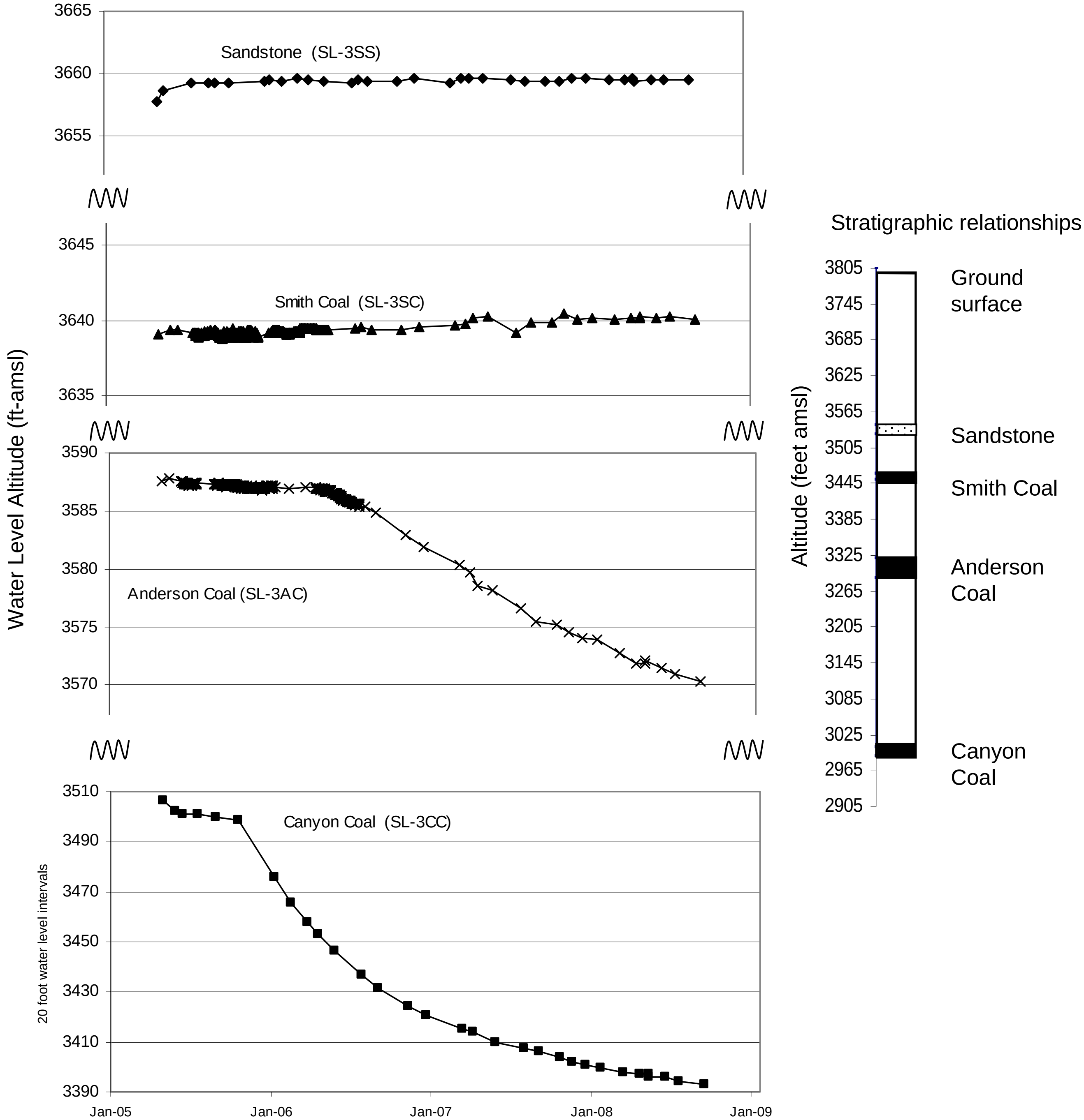


Figure 36. Water levels in the overburden sandstone and Smith coals are not responding to CBM development. However the water level in the Anderson and Canyon Coal have dropped about 18 and 116 feet respectively in response to CBM production.

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

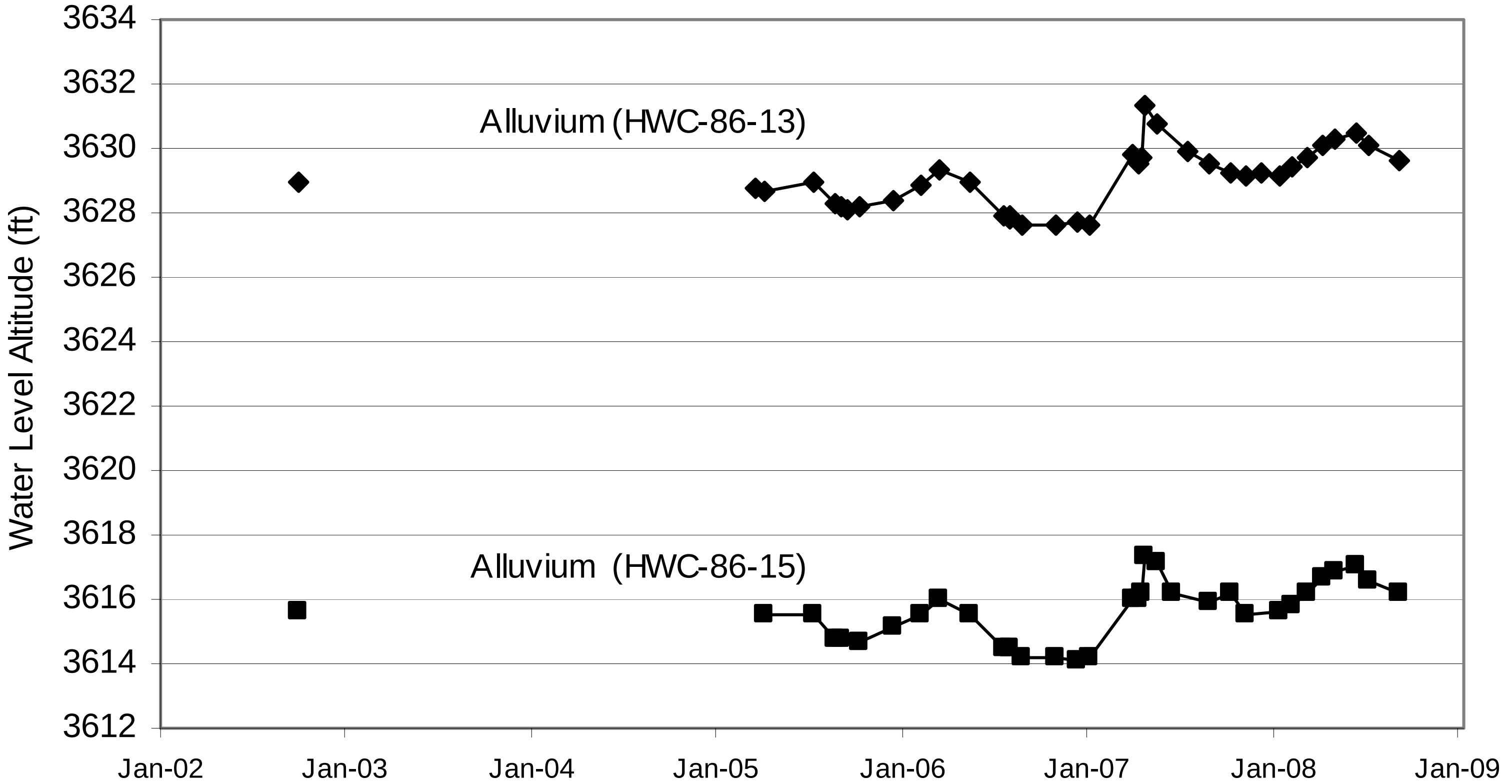


Figure 37. The water level in the Hanging Woman Creek alluvial aquifer near the Montana – Wyoming state line reflects water table response to meteorological pattern. Refer to figure 32 for site location.

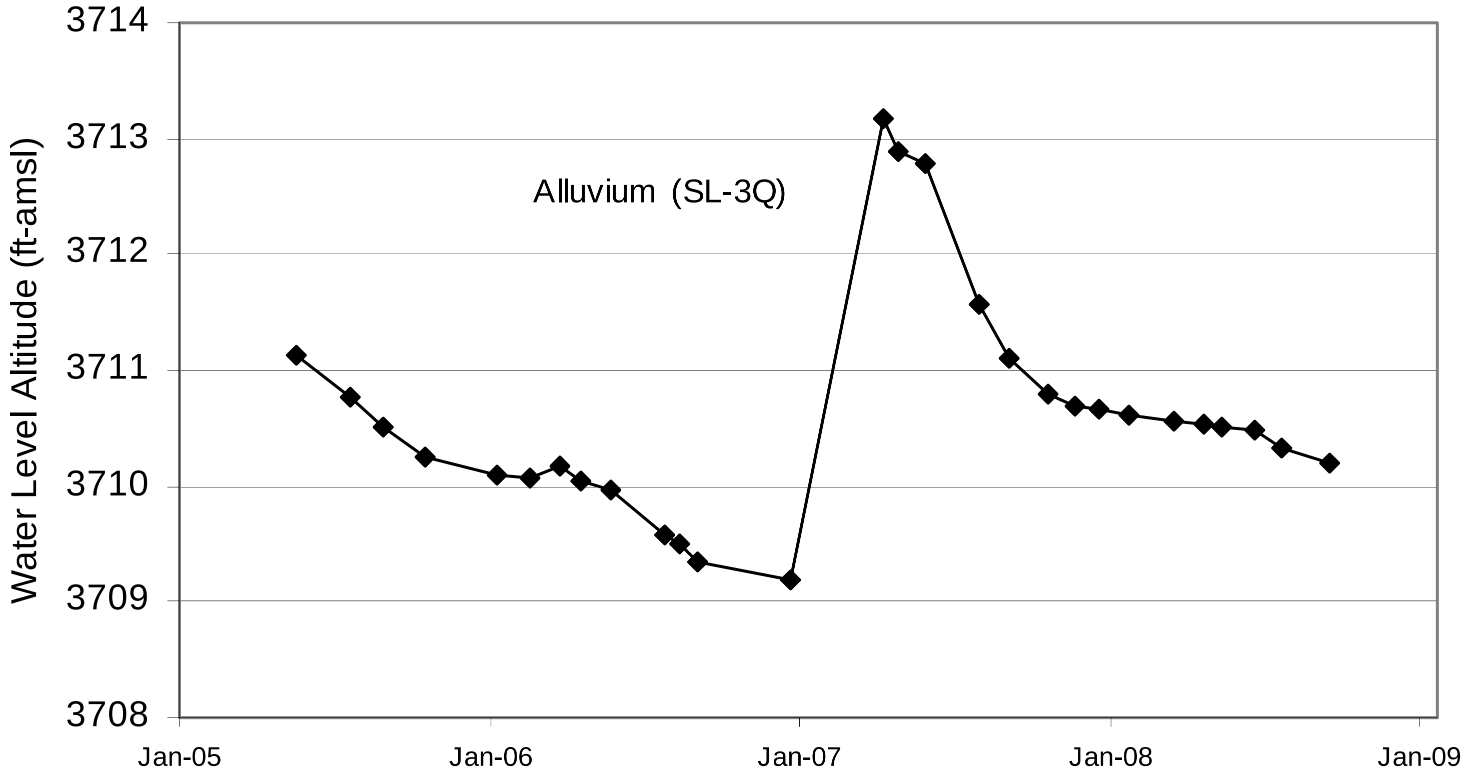


Figure 38. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to figure 34 for site location.

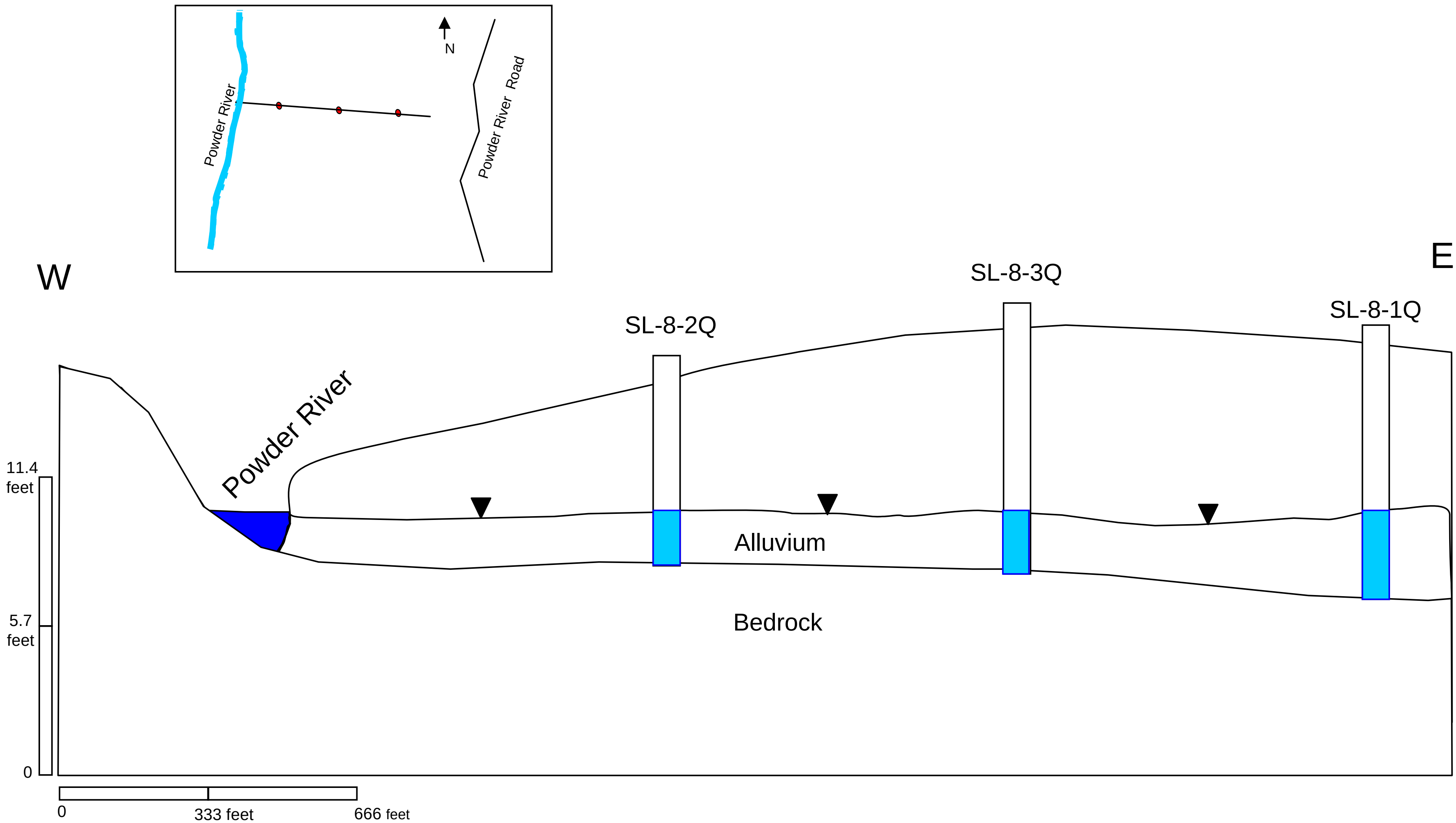


Figure 39. Cross section of alluvial wells south of Moorhead near the Powder River located in T09S R47E section 25. Ground water in the alluvium appear to flow parallel to the river. Water levels for this cross section were taken in January 2007. Vertical exaggeration is 58:1.

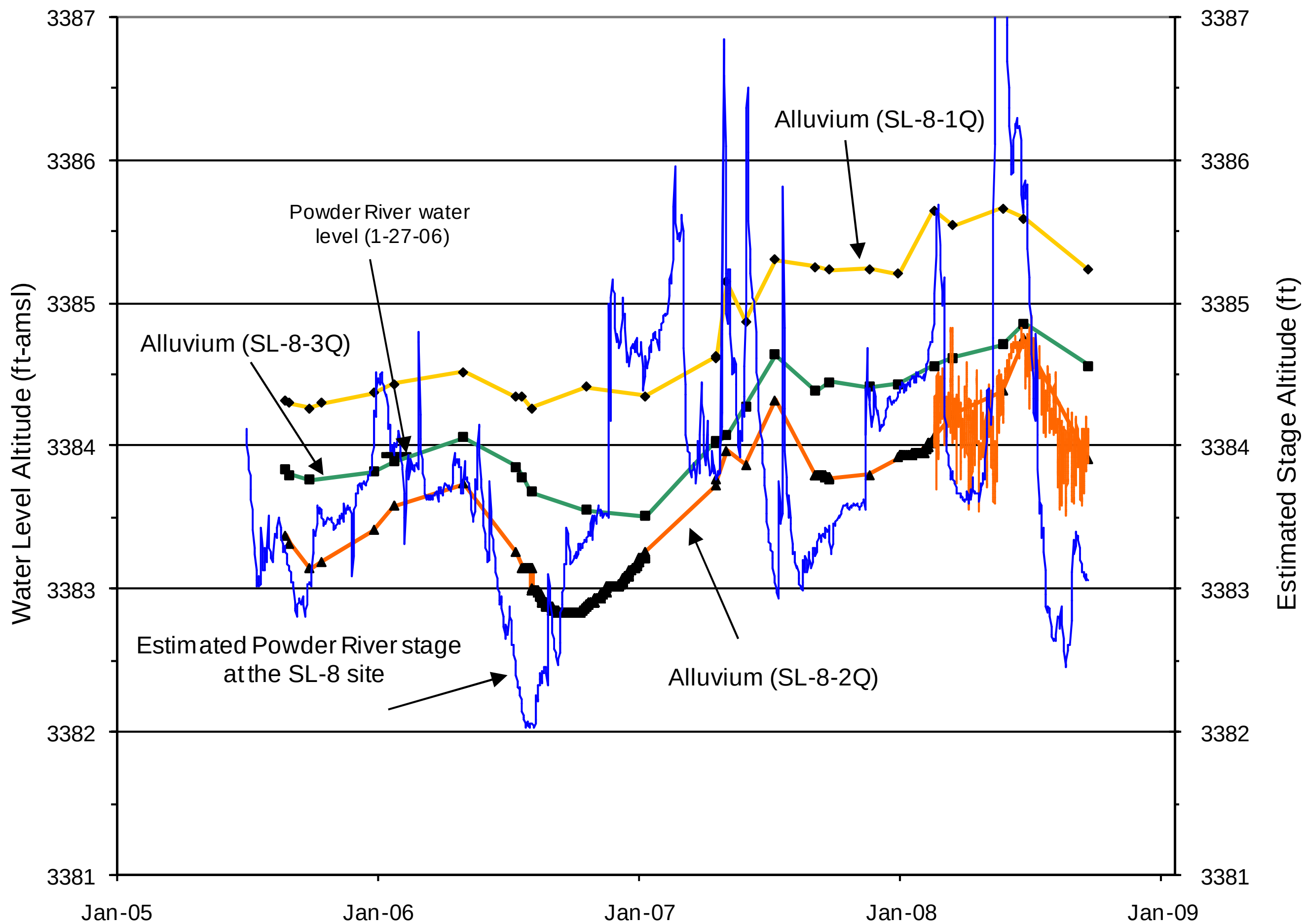


Figure 40. Ground-water flow in the alluvial aquifer at SL-8 is roughly parallel to the Powder River. The ground water-level trends follow river stage trends. The river alternates between gaining (summer) and losing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gaging station (USGS data) and the surveyed river water-level altitude at SL-8 on 1/27/06. Data-logger data beginning in February 2008 have not been corrected for barometric variations.

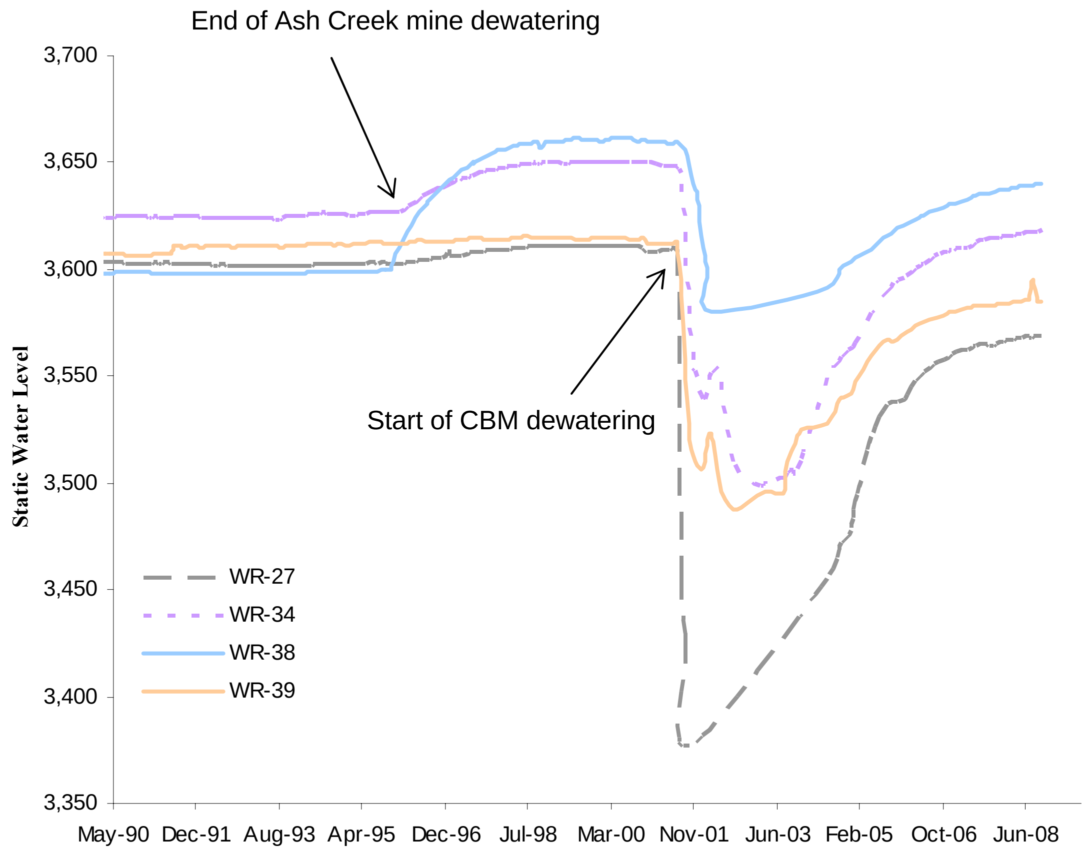


Figure 41. Water level recovery in Dietz coal wells in an area of reduced CBM production. Initial water level recovery is from drawdown from coal mining that occurred prior to CBM development. CBM water level drawdown has recovered 82, 79, 73, and 77% in wells WR-27, -34, -38, and -39, respectively. Water levels have stabilized to a lower level due to remaining CBM wells.

Summary and 2008-2009 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). Depending upon a number of factors, including economic forces and industry priorities, CBM development may expand in those areas within about 12 miles north of the state line and from the Crow Indian Reservation to the Powder River in the next several years. 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 4.0 gpm during 2008 from 772 wells. Within the CX field, ground-water levels have been drawn down by over 200 feet 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 10 years of CBM production, drawdown of up to 20 feet 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 slightly less than those predicted in the Montana CBM environmental impact statement. The EIS predicted 20 feet of drawdown would reach 2 miles after 10 years of CBM production. At the Coal Creek field, 12 feet of drawdown during a period of 24 months has been measured at a distance of 2.5 miles from the nearest producing well. Major faults tend to act as barriers to ground-water flow and drawdown does not migrate across fault planes where measured in monitoring wells. However in cases where faults are not offset at least 10 ft more than the thickness of the coal, they are less likely to act as a barrier. Vertical migration of drawdown tends to be limited by shale layers; however in some cases minor changes in overburden head have been observed.

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 80 to 233 feet. After approximately 5 years, recovery in these four wells is 73 to 82 percent of baseline levels.

Water from production wells is expected to have TDS concentrations generally between 880 mg/L and 1,600 mg/L (Table 2). 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 2008-2009, monitoring sites located within approximately 6 miles of existing or proposed 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 in wells blowing methane, SL-6 and SL-7. Data loggers will also be installed at other sites as warranted. Water-quality samples will be collected semi-annually from selected alluvial sites. Upcoming monitoring will include alluvial sites WR-58, WR-52B, WR-17A, either HWC 86-2 or HWC 86-5, and deep coal wells CBM02-1BC, -1KC, and -1LC. 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.

References

ALL, 2001, Water resources technical report, Montana statewide oil and gas environmental impact statement and amendment of the Powder River and Billings resource management plans: prepared for the U. S. Department of the Interior, Bureau of Land Management, Mile City Field Office, ALL Consulting, Tulsa, OK.

Blend, J. 2002, Important Economic Issues to Address with Coal-bed Methane. Resource Protection and Planning Bureau, Montana Department of Environmental Quality.

Clark, I.D., and Fritz, P., 1997, Environmental Isotopes in Hydrogeology. Lewis Publishers, Boca Raton, Florida.

Colorado School of Mines Research Institute, 1979a, Coal Resource Occurrence and Coal Development Potential Maps of the Bradshaw Creek Quadrangle, Powder River County, Montana, and Campbell County, Wyoming: US Geological Survey, Open-File Report 79-785.

Colorado School of Mines Research Institute, 1979b, Coal Resource Occurrence and Coal Development Potential Maps of the Cook Creek Reservoir Quadrangle Powder River and Rosebud Counties, Montana: US Geological Survey, Open-File Report 79-84.

Colorado School of Mines Research Institute, 1979c, Coal Resource Occurrence and Coal Development Potential Maps of the Hayes Point Quadrangle, Custer and Powder River Counties, Montana: US Geological Survey, Open-File Report 79-13.

Colorado School of Mines Research Institute, 1979d, Coal Resource Occurrence and Coal Development Potential Maps of the Moorhead Quadrangle, Powder River County, Montana, and Campbell County, Wyoming: US Geological Survey, Open-File Report 79-787.

Colorado School of Mines Research Institute, 1979e, Coal Resource Occurrence and Coal Development Potential Maps of the Spring Gulch Quadrangle, Rosebud and Big Horn Counties, Montana: US Geological Survey, Open-File Report 79-778.

Colorado School of Mines Research Institute, 1979f, Coal Resource Occurrence and Coal Development Potential Maps of the Threemile Buttes Quadrangle, Powder River County, Montana: US Geological Survey, Open-File Report 79-100.

Colorado School of Mines Research Institute, 1979g, Coal Resource Occurrence and Coal Development Potential Maps of the Volborg Quadrangle, Custer and Powder River Counties, Montana: US Geological Survey, Open-File Report 79-19.

Culbertson, W.C., 1987, Diagrams showing proposed correlations and nomenclature of Eocene and Paleocene coal beds in the Birney 30' x 60' quadrangle, Big Horn, Rosebud, and Powder River counties, Montana: U.S. Geological Survey Coal Investigations Map C-113.

Culbertson, W.C., and Klett, M.C., 1979a, Geologic map and coal section of the Forks Ranch quadrangle, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1086.

Culbertson, W.C., and Klett, M.C., 1979b, Geologic map and coal sections of the Quietus Quadrangle, Montana: U.S. Geological Survey Miscellaneous Field Studies Map MF-1087.

Davis, R.E., 1984, Geochemistry and geohydrology of the West Decker and Big Sky coal-mining areas, southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report No. 83-4225, 109 p.

Donato, T.A., Wheaton, J.R., 2004a, Spring inventory and other water data, Custer National Forest-Ashland Ranger District, Montana (photos available on CD only), Montana Bureau of Mines and Geology: Open-File Report 493A, 84 p., 1 sheet(s).

Donato, T. A., Wheaton, J. R., 2004b, Spring and well inventory for the Powder River and Tongue River watersheds, southeastern Montana, Montana Bureau of Mines and Geology: Open-File Report 493B, 53 p., 1 sheet(s).

Kennelly P.J., Donato, T., 2001, Hydrologic features of the potential coalbed methane development area of the Powder River Basin, Montana, Montana Bureau of Mines and Geology: Open-File Report 448.

Fort Union Coal Assessment Team, 1999, Resource assessment of selected tertiary coal beds and zones in the Northern Rocky Mountains and Great Plains Region: U.S. Geological Survey Professional Paper 1625-A, 2 CD.

Hedges, R.B., Van Voast, W.A., and McDermott, J.J., 1998, Hydrogeology of the Youngs Creek Squirrel Creek headwaters area, southeastern Montana with special emphasis on Potential Mining Activities 1976: Montana Bureau of Mines and Geology, Butte, MT, Reports of Investigation 4, 24 p., 5 figs, 4 tables, 7 plates.

Law, B.E., Barnum, B.E., and Wollenzien, T.P., 1979, Coal bed correlations in the Tongue River member of the Fort Union formation, Monarch, Wyoming, and Decker, Montana, areas: U.S. Geological Survey Miscellaneous Investigations Series Map I-1128.

Lopez, D.A., 2006, Structure contour map - top of the Lebo Shale/Bearpaw Shale, Powder River Basin, southeastern Montana, Montana Bureau of Mines and Geology: Report of Investigation 16, 3 sheets, 1:250,000.

Lopez, D.A., and Heath L.A., 2007, CBM-produced water disposal by injection, Powder River Basin, Montana: Montana Bureau of Mines and Geology Report of Investigation 17; 37 p., 7 plates.

Mapel, W.J., and Martin, B.K., 1978, Coal Resource Occurrence and Coal Development Potential Maps of the Browns Mountain Quadrangle, Rosebud County, Montana: US Geological Survey, Open-File Report 78-39.

Mapel, W.J., Martin, B.K., and Butler, B.A., 1978a, Coal Resource Occurrence and Coal Development Potential Maps of the Hamilton Draw Quadrangle, Rosebud, Big Horn, and Powder River Counties, Montana: US Geological Survey, Open-File Report 78-640.

Mapel, W.J., Martin, B.K., and Butler, B.A., 1978b, Coal Resource Occurrence and Coal Development Potential Maps of the Lacey Gulch Quadrangle, Rosebud County, Montana: US Geological Survey, Open-File Report 78-37.

Mapel, W.J., Martin, B.K., and Butler, B.A., 1978c, Coal Resource Occurrence and Coal Development Potential Maps of the Poker Jim Butte Quadrangle, Rosebud and Powder River Counties, Montana: US Geological Survey, Open-File Report 78-651.

Mapel, W.J., Martin, B.K., and Butler, B.A., 1978d, Coal Resource Occurrence and Coal Development Potential Maps of the Stroud Creek Quadrangle, Rosebud and Big Horn Counties, Montana: US Geological Survey, Open-File Report 78-38.

Matson, R.E., and Blumer, J.W., 1973, Quality and reserves of strippable coal, selected deposits, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 91, 135 p.

McKay, E.J., Butler, B.A., and Robinson, L.N., 1979, Coal Resource Occurrence And Coal Development Potential Map of The Bear Creek School Quadrangle, Powder River County, Montana: US Geological Survey, Open-File Report 79-106.

McKay, E.J., and Robinson, L.N., 1979, Coal Resource Occurrence and Coal Development Potential Maps of the Fort Howes Quadrangle, Rosebud and Powder River Counties, Montana: US Geological Survey, Open-File Report 79-104.

McLellan, M.W., 1991, Cross section showing the reconstructed stratigraphic framework of Paleocene rocks and coal beds in central Powder River Basin from Decker to Bear Skull Mountain, Montana: U.S. Geological Survey Miscellaneous Investigations Series Map I-1959-E.

McLellan, M.W., and Biewick, L.R.H., 1988, Stratigraphic framework of the Paleocene coal beds in the Broadus 30’ x 60’ quadrangle, Powder River Basin, Montana-Wyoming: U.S. Geological Survey Coal Investigations Map C-119-A.

McLellan, M.W., Biewick, L.H., Molnia, C.L., and Pierce, F.W., 1990, Cross sections showing the reconstructed stratigraphic framework of Paleocene rocks and coal beds in the northern and central Powder River Basin, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series map I-1959-A, 1:500,000.

Montana Board of Oil and Gas Conservation, 2008, On-Line Data: http://bogc.dnrc.mt.gov/default.asp. Accessed January, 2008.

U. S. Bureau of Land Management, 2003, Montana Final statewide oil and gas environmental impact statement and proposed amendment of the Powder River and Billings resource management plans: U. S. Bureau of Land Management, BLM/MT/PL-03/005, 2 vol.

Van Voast, W., 2003, Geochemical signature of formation waters associated with coalbed methane: Pages 667-676, American Association of Petroleum Geologists Bulletin, V 87, No. 4.

Van Voast, W.A., and Hedges, R.B., 1975, Hydrogeologic aspects of existing and proposed strip coal mines near Decker, southeastern Montana: Montana Bureau of Mines and Geology Bulletin 097, 31 p., 12 plates.

Van Voast, W.A., and Reiten, J.C., 1988, Hydrogeologic responses: Twenty years of surface coal mining in southeastern Montana: Montana Bureau of Mines and Geology Memoir 62, 30 p.

Van Voast, W., and Thale, P., 2001, Anderson and Knobloch coal horizons and potential for methane development, Powder River Basin, Montana: Montana Bureau of Mines and Geology: Geologic Map 60, 1:250,000.

Western Regional Climate Center, 2008, Historical Climate Information: http://www.wrcc.dri.edu/summary/Climsmemt.html. Accessed January, 2008.

Wheaton, J.R., Bobst, A.L., and Brinck, E.L., 2007, Considerations for Evaluating Coalbed Methane Infiltration Pond Sites Based on Site Studies in the Powder River Basin of Montana and Wyoming: in Proceedings of the 2007 National Meeting of the American Society of Mining and Reclamation, Gillette WY, June, 2-7, 2007, R.I. Barnhisel (Ed.) 3134 Montavesta Rd., Lexington, KY 40502.

Wheaton, J.R. and Donato, T.A., 2004, Ground-water monitoring program in prospective coalbed-methane areas of southeastern Montana: Year One: Montana Bureau of Mines and Geology Open-File Report 508, 91 p.

Wheaton, J. R., Donato, T. D., Reddish, S. L., and Hammer, L., 2005, 2004 annual coalbed methane regional ground-water monitoring report: Montana portion of the Powder River Basin: Montana Bureau of Mines and Geology Open-File Report 528, 64 p.

Wheaton, J, Donato,T, Reddish, S., and Hammer, L., 2006, 2005 Annual coalbed methane regional ground-water monitoring report: northern portion of the Powder River Basin, Montana Bureau of Mines and Geology: Open File Report 538, 144 p., 4 sheet(s).

Wheaton, J., Gunderson, J., Kuzara, S., Olson, J., and Hammer, L., 2008, Hydrogeology of the Ashland Ranger District, Custer National Forest, southeastern Montana: Montana Bureau of Mines and Geology Open-File Report 570, 124 p., 6 sheets

Wheaton, J.R. and Metesh, J.J., 2002, Potential ground-water drawdown and recovery for coalbed methane development in the Powder River Basin, Montana: Montana Bureau of Mines and Geology Open-File Report 458, 58 p.

Wheaton, J., Reddish-Kuzara, S., Donato, T.A., and Hammer, L., 2007, 2006 Annual coalbed methane regional ground-water monitoring report: Northern portion of the Powder River Basin, Montana Bureau of Mines and Geology: Open-File Report 556, 95 p., 3 sheet(s).

Wheaton, J.J., Reddish-Kuzara, S., Meredith, E., and Donato, T. A., 2008, 2007 Annual coalbed methane regional ground-water monitoring report: Northern portion of the Powder River Basin, Montana Bureau of Mines and Geology: Open-File Report 576, 99 p., 6 sheet(s).

Wyoming Oil and Gas Conservation Commission, 2008, CoalBed: http://wogcc.state.wy.us. Accessed January, 2008.

Appendix A

Site details, water-level data and water year 2008-2009 monitoring plan for monitoring wells

Appendix A. Site details, water-level data, and 2009 monitoring schedule for ground-water monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
7573	WO-15	-106.1855	45.5186	04S	45E	4	BDDB	Powder River	3022	Alluvium	63	12.0	9/27/2008	10.6	3011.4	Semi-Annual	
7574	WO-16	-106.1861	45.5158	04S	45E	4	CAAC	Powder River	3040	Alluvium	61	3.7	9/27/2008	25.7	3014.3	Semi-Annual	
7589	Newell Pipeline Well	-106.2143	45.4727	04S	45E	19	DADD	Powder River	3290	Tongue River Formation	325	5.0	9/26/2008	310.1	2979.9	Semi-Annual	
7755	77-26	-106.1839	45.4352	05S	45E	4	ABCC	Powder River	3284	Knobloch Coal	217	3.6	9/27/2008	149.1	3134.9	Semi-Annual	
7770	WO-8	-106.1411	45.3922	05S	45E	23	ABCA	Powder River	3155	Alluvium	33	12.0	9/26/2008	16.3	3138.8	Quarterly	
7772	WO-9	-106.1419	45.3925	05S	45E	23	ABCA	Powder River	3150	Alluvium	45	21.8	9/26/2008	12.6	3137.4	Quarterly	
7775	WO-10	-106.1430	45.3925	05S	45E	23	ABCB	Powder River	3145	Alluvium	41		9/26/2008	10.3	3134.8	Quarterly	
7776	WO-5	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Knobloch Underburden	192	20.4	9/26/2008	18.5	3141.5	Quarterly	
7777	WO-6	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Lower Knobloch Coal	82	7.0	9/26/2008	25.4	3134.6	Quarterly	
7778	WO-7	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Alluvium	40	29.0	9/26/2008	27.6	3132.4	Quarterly	
7780	WO-1	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3190	Knobloch Underburden	172	8.0	9/26/2008	38.7	3151.3	Quarterly	
7781	WO-2	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3188	Lower Knobloch Coal	112	19.0	9/26/2008	46.2	3141.8	Quarterly	
7782	WO-3	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3186	Knobloch Overburden	66	17.8	9/26/2008	47.6	3138.4	Quarterly	
7783	WO-4	-106.1486	45.3941	05S	45E	23	BBAA	Powder River	3140	Alluvium	32		9/26/2008	10.2	3129.8	Quarterly	
7903	HWC86-9	-106.5027	45.2966	06S	43E	19	DACD	Rosebud	3170	Alluvium	44		12/18/2008	11.5	3158.5	Monthly	
7905	HWC86-7	-106.5033	45.2958	06S	43E	19	DDBA	Rosebud	3170	Alluvium	71		12/18/2008	10.0	3160.0	Monthly	Semi-Annual
7906	HWC86-8	-106.5030	45.2961	06S	43E	19	DDBA	Rosebud	3170	Alluvium	67		12/18/2008	9.3	3160.8	Monthly	
8074	WR-21	-106.9791	45.0877	08S	39E	32	DBBC	Big Horn	3890	Dietz 1 and Dietz Coals Combined	206	4.0	12/17/2008	58.1	3831.9	Monthly	
8101	HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	Big Horn	3460	Alluvium	50		12/18/2008	20.6	3439.4	Monthly	Annual (or)
8103	HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	Big Horn	3455	Alluvium	33		12/18/2008	15.9	3439.1	Monthly	Annual (or)
8107	HWC-01	-106.4866	45.1338	08S	43E	20	DDDD	Big Horn	3530	Canyon Coal	232	7.5	12/18/2008	90.2	3439.9	Monthly	
8118	HC-24	-106.4747	45.1297	08S	43E	21	BDBB	Big Horn	3500	Canyon Overburden	150	7.1	9/25/2008	52.7	3447.3	Semi-Annual	
8140	FC-01	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Anderson Coal	133	0.0	12/18/2008	132.8	3602.2	Monthly	
8141	FC-02	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Dietz Coal	260		12/18/2008	240.0	3495.0	Monthly	
8191	BC-06	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Coal	188	4.6	10/30/2008	89.1	3625.9	Monthly	
8192	BC-07	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Overburden	66	0.8	10/30/2008	37.2	3677.8	Monthly	
8347	WR-23	-106.9905	45.0922	09S	38E	1	AADC	Big Horn	3960	Dietz 1 and Dietz Coals Combined	322	6.0	12/17/2008	84.2	3875.8	Monthly	
8368	391	-107.0320	45.0413	09S	38E	22	DADC	Big Horn	3987	Dietz 1 and Dietz Coals Combined	175		12/17/2008	61.3	3925.8	Monthly	
8371	388	-107.0205	45.0391	09S	38E	23	CDAD	Big Horn	3975	Dietz Coal	190		12/17/2008	79.0	3896.0	Monthly	
8372	396	-107.0088	45.0491	09S	38E	24	BBBC	Big Horn	3939	Anderson-Dietz 1 and 2 Coals	280	25.0	12/17/2008	56.1	3882.9	Monthly	
8377	394	-107.0075	45.0330	09S	38E	25	BCBA	Big Horn	3909	Dietz Coal	242	5.0	12/17/2008	93.0	3816.0	Monthly	
8379	422	-107.0061	45.0261	09S	38E	25	CBDC	Big Horn	3917	Dietz Coal	187		9/24/2008	123.3	3793.8	Semi-Annual	
8387	395	-107.0618	45.0361	09S	38E	26	ABAB	Big Horn	3900	Dietz Coal	299	15.0	12/17/2008	64.8	3835.2	Monthly	
8412	WR-58	-106.9122	45.0408	09S	39E	14	DDBD	Big Horn	3631	Alluvium	55	21.0	12/17/2008	14.4	3616.9	Monthly	Annual
8413	WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	Big Horn	3627	Alluvium	27	15.0	12/17/2008	14.4	3613.0	Monthly	

Appendix A. Site details, water-level data, and 2009 monitoring schedule for ground-water monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
8417	WR-19	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Dietz 1 and Dietz Coals Combined	305	20.0	12/17/2008	135.7	3699.8	Monthly	
8419	WR-20	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Anderson Coal	166	15.0	12/17/2008	107.4	3727.9	Monthly	
8428	WR-54A	-106.8902	45.0147	09S	39E	25	DADB	Big Horn	3631	Anderson-Dietz 1 and 2 Overburden	211	1.0	12/17/2008	127.7	3503.6	Monthly	
8430	WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	Big Horn	3608	Anderson-Dietz 1 and 2 Overburden	187		12/17/2008	109.7	3498.2	Monthly	
8436	WR-24	-106.9877	45.0202	09S	39E	29	BBDD	Big Horn	3777	Canyon Coal	146		12/17/2008	32.2	3745.0	Monthly	
8441	WR-33	-106.9758	45.0066	09S	39E	32	ACAA	Big Horn	3732	Anderson-Dietz 1 Clinker and Coal	165		12/17/2008	51.6	3680.7	Monthly	
8444	WR-27	-106.9658	45.0008	09S	39E	33	DBBD	Big Horn	3672	Anderson-Dietz 1 and 2 Coals	363	25.0	12/17/2008	75.3	3596.7	Monthly	
8446	WR-45	-106.9538	44.9966	09S	39E	33	DDCC	Big Horn	3638	Alluvium	64	30.0	12/17/2008	10.0	3628.2	Monthly	
8447	WR-44	-106.9522	44.9966	09S	39E	33	DDCD	Big Horn	3637	Alluvium	64	30.0	12/17/2008	9.3	3627.6	Monthly	
8451	WR-42	-106.9502	44.9966	09S	39E	33	DDDD	Big Horn	3637	Alluvium	66	30.0	12/17/2008	10.5	3626.2	Monthly	
8456	WRN-10	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3433	Dietz 2 Coal	79	3.4	12/17/2008	24.4	3409.0	Monthly	
8461	WRN-15	-106.8275	45.0638	09S	40E	9	AADD	Big Horn	3500	Dietz 2 Coal	140		6/4/2008	91.6	3408.3	Monthly	
8471	DS-05A	-106.8338	45.0555	09S	40E	9	DCAB	Big Horn	3506	Dietz 2 Coal	166	5.0	6/4/2008	106.0	3399.5	Monthly	
8500	WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	Big Horn	3511	Dietz 2 Coal	232		6/4/2008	166.1	3344.6	Monthly	
8501	WRE-10	-106.7741	45.0383	09S	40E	13	DCCB	Big Horn	3519	Dietz Coal	183		6/4/2008	148.8	3369.7	Monthly	
8504	WRE-11	-106.7736	45.0383	09S	40E	13	DCCD	Big Horn	3509	Anderson Coal	127		6/4/2008	83.9	3425.0	Monthly	
8574	DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	Big Horn	3430	Dietz 2 Coal	150		6/4/2008	56.1	3374.0	Monthly	
8650	WR-55	-106.8858	45.0300	09S	40E	19		Big Horn	3591	Tongue River Formation	288	15.0	12/17/2008	154.9	3436.3	Monthly	
8651	WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	Big Horn	3591	Anderson-Dietz 1 and 2 Overburden	72		12/17/2008	46.3	3544.8	Monthly	
8687	WRE-12	-106.8038	45.0311	09S	40E	23	BCCD	Big Horn	3463	Anderson Coal	172		12/18/2008	82.7	3380.5	Monthly	
8692	WRE-13	-106.8044	45.0311	09S	40E	23	BCCD	Big Horn	3463	Dietz Coal	206		12/18/2008	88.4	3374.2	Monthly	
8698	WRE-16	-106.7697	45.0352	09S	40E	24	AACB	Big Horn	3551	Anderson Coal	458		12/18/2008	61.4	3489.2	Monthly	
8706	WR-17B	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3575	Anderson-Dietz 1 and 2 Overburden	160		12/17/2008	74.1	3500.6	Monthly	
8708	WR-51	-106.8620	45.0186	09S	40E	29		Big Horn	3541	Tongue River Formation	344	4.4	12/17/2008	120.1	3420.9	Monthly	
8709	WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	Big Horn	3541	Anderson-Dietz 1 and 2 Overburden	187		12/17/2008	55.1	3486.2	Monthly	
8710	WR-52B	-106.8627	45.0147	09S	40E	29	CACB	Big Horn	3519	Alluvium	55	59.7	12/17/2008	12.9	3506.0	Monthly	Annual
8721	WRE-27	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3524	Anderson Coal	77	0.5	12/20/2007	47.2	3476.7	Monthly	
8723	WRE-28	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3525	Dietz Coal	153		12/20/2007	61.9	3463.4	Monthly	
8726	WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	Big Horn	3523	Dietz 2 Coal	217		12/20/2007	110.2	3413.1	Monthly	
8754	CC-1	-106.4646	45.0875	09S	43E	4	ABDD	Big Horn	3520	Alluvium	28	4.2	12/18/2008	14.7	3505.3	Monthly	
8757	CC-4	-106.4659	45.0874	09S	43E	4	ABDD	Big Horn	3511	Alluvium	25	4.8	12/18/2008	7.9	3503.1	Monthly	

Appendix A. Site details, water-level data, and 2009 monitoring schedule for ground-water monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
8758	CC-3	-106.4654	45.0864	09S	43E	4	ACAA	Big Horn	3521	Alluvium	35	4.6	12/18/2008	14.8	3506.2	Monthly	
8777	HWC-38	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3586	Alluvium	41		12/18/2008	19.1	3566.9	Monthly	
8778	HWC-17	-106.4133	45.0570	09S	43E	13	BCAA	Big Horn	3610	Anderson Coal	82	6.9	12/18/2008	52.3	3557.7	Monthly	
8782	HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	Big Horn	3600	Anderson Coal	129	10.0	12/18/2008	31.7	3568.3	Monthly	
8796	HWC-29B	-106.3969	45.0688	09S	44E	7	BBCC	Big Horn	3620	Anderson Coal	92		12/18/2008	45.6	3574.4	Monthly	
8835	AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	Powder River	3965	Dietz Coal	240	1.4	10/30/2008	170.0	3795.0	Monthly	
8846	UOP-09	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3929	Canyon Coal	262	0.8	10/30/2008	158.0	3771.0	Monthly	
8847	UOP-10	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3930	Canyon Overburden	207	4.4	10/30/2008	143.4	3786.6	Monthly	
8863	Fulton George *NO.6	-105.8628	45.0807	09S	48E	5	ACDD	Powder River	3380	Tongue River Formation	410	4.0	10/1/2008	16.8	3363.2	Quarterly	
8888	HWC 86-13	-106.4262	45.0020	10S	43E	2	ABCA	Big Horn	3640	Alluvium	53	3.9	12/18/2008	12.0	3628.0	Monthly	Semi-Annual
94661	Liscom Well	-106.0323	45.7782	01S	46E	3	DBAA	Powder River	3275	Fort Union Formation	135	10.0	10/1/2008	97.7	3177.3	Quarterly	
94666	Coyote Well	-106.0505	45.7524	01S	46E	16	AACC	Powder River	3294	Fort Union Formation	190	5.0	10/1/2008	135.7	3158.3	Quarterly	
100472	East Fork Well	-106.1642	45.5935	03S	45E	10	B	Powder River	3210		193	5.0	10/1/2008	136.6	3073.5	Quarterly	
103155	Padget Creek Pipeline Well	-106.2940	45.3939	05S	44E	22	BBBD	Rosebud	3385	Tongue River Formation	135	10.0	9/26/2008	65.6	3319.4	Quarterly	
105007	Tooley Creek Well	-106.2697	45.2153	07S	45E	19	CAAA	Powder River	3755	Fort Union Formation	110	12.0	9/25/2008	43.6	3711.4	Quarterly	
121669	WRE-18	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3573	Anderson Coal	445		12/18/2008	89.3	3483.9	Monthly	
122766	WR-59	-106.8526	45.0050	09S	40E	32	ACAD	Big Horn	3470	Alluvium	34	10.0	12/17/2008	9.1	3461.0	Monthly	Semi-Annual
122767	WRE-20	-106.7716	45.0369	09S	40E	24	ABAB	Big Horn	3519	Anderson Coal	120		6/4/2008	95.1	3424.3	Monthly	
122769	WR-38	-106.9650	44.9938	37N	63E	23	BBCB	Sheridan	3693	Dietz 1 and Dietz Coals Combined	286	3.8	12/17/2008	78.0	3614.9	Monthly	
122770	WR-39	-106.9555	44.9952	37N	63E	23	ABBC	Sheridan	3666	Anderson-Dietz 1 and 2 Coals	312		12/17/2008	65.4	3600.6	Monthly	
123795	WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	Big Horn	3549	Anderson Coal	115		12/20/2007	62.9	3486.5	Monthly	
123796	WR-17A	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3574	Anderson-Dietz 1 and 2 Overburden	88		12/17/2008	45.5	3528.4	Monthly	Annual
123797	WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	Big Horn	3520	Anderson Coal	140		6/4/2008	96.6	3423.7	Monthly	
123798	WRN-11	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3437	Anderson-Dietz 1 Clinker and Coal	50		12/17/2008	22.8	3414.0	Monthly	
127605	WR-54	-106.8902	45.1470	09S	39E	25		Big Horn	3630	Anderson and Dietz Coal	384	20	12/17/2008	196.6	3433.3	Monthly	
130475	WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	Big Horn	3552	Dietz Coal	154	20.0	12/20/2007	67.9	3484.2	Monthly	
130476	WR-31	-106.9863	45.0163	09S	39E	29	CBAA	Big Horn	3895	Anderson Coal	316	2.0	12/17/2008	184.0	3711.2	Monthly	
132716	WR-48	-106.9650	44.9933	37N	63E	23	BBCB	Sheridan	3694	Anderson Coal	167		12/17/2008	40.3	3653.5	Monthly	
132903	WR-58A	-106.9123	45.0403	09S	39E	14	DDBD	Big Horn	3631	Alluvium	24	8.0	12/17/2008	14.2	3617.1	Monthly	
132907	WR-53	-106.8880	45.0125	09S	39E	25		Big Horn	3607	Anderson and Dietz Coal	384	20.0	12/17/2008	175.1	3432.0	Monthly	
132908	WR-30	-106.9874	45.0165	09S	39E	29	CBAB	Big Horn	3895	Dietz 1 and Dietz Coals Combined	428	5.0	12/17/2008	202.4	3692.2	Monthly	
132909	WR-34	-106.9702	45.0015	09S	39E	33	CBBB	Big Horn	3772	Anderson-Dietz 1 and 2 Coals	522		12/17/2008	152.0	3620.1	Monthly	

Appendix A. Site details, water-level data, and 2009 monitoring schedule for ground-water monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
132910	WRE-02	-106.7756	45.0712	09S	40E	1	DBCC	Big Horn	3457	Alluvium	79		12/20/2007	40.1	3416.7	Monthly	
132958	WRE-21	-106.7730	45.0386	09S	40E	24	ABAB	Big Horn	3529	Anderson Coal	130		6/4/2008	83.9	3445.5	Monthly	
132959	WRE-17	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3562	Anderson-Dietz 1 and 2 Overburden	250		12/18/2008	63.9	3498.0	Monthly	
132960	WR-52C	-106.8629	45.0164	09S	40E	29	CABC	Big Horn	3530	Alluvium	62	20.0	12/17/2008	18.6	3511.5	Monthly	
132961	WR-52D	-106.8616	45.0164	09S	40E	29	CABD	Big Horn	3529	Alluvium	40	1.0	12/17/2008	23.4	3505.9	Monthly	
132973	PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	Big Horn	3458	Dietz 2 Coal	282	5.0	12/18/2008	123.1	3334.9	Monthly	
144969	Pipeline Well 7(PL-1W) LOHOF	-106.3074	45.2354	07S	44E	14	ABD	Rosebud	3850	Tongue River Formation	225	15.0	9/25/2008	142.2	3707.8	Quarterly	
157879	5072B	-106.4904	45.7393	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal	109	2.0	11/18/2008	34.9	3125.1	Quarterly	
157882	5072C	-106.4905	45.7394	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal Overburden	106	0.3	11/18/2008	29.6	3130.4	Quarterly	
157883	5080B	-106.5126	45.7199	01S	42E	26	DCBA	Rosebud	3260	Knobloch Coal	89	1.3	11/18/2008	42.8	3217.2	Quarterly	
157884	5080C	-106.5126	45.7200	01S	42E	26	DCBA	Rosebud	3260	Knobloch Overburden	110	0.3	11/18/2008	36.4	3223.6	Quarterly	
161749	BF-01	-106.9667	44.9897	58N	84W	22	ACCC	Sheridan	3680	Coal Mine Spoils Bank	125		12/17/2008	32.5	3647.5	Monthly	
166351	PKS-3204	-106.8299	45.1067	08S	40E	28	ADA	Big Horn	3500	Anderson-Dietz1 Coalbed	82		12/17/2008	75.3	3424.7	Monthly	
166358	PKS-3203	-106.8302	45.1068	08S	40E	28	ADA	Big Horn	3500	Canyon Coal	201		12/17/2008	111.1	3388.9	Monthly	
166359	PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	Big Horn	3438	Alluvium	60	5.0	6/4/2008	40.8	3397.2	Monthly	
166362	PKS-3201	-106.7971	45.0437	09S	40E	14	CAA	Big Horn	3438	Canyon Coal	390	50.0	6/4/2008	95.6	3342.4	Monthly	
166370	PKS-3200	-106.7969	45.0440	09S	40E	14	CAA	Big Horn	3438	Dietz 2 Coal	242	20.0	6/4/2008	174.4	3263.6	Monthly	
166388	PKS-3199	-106.7966	45.0443	09S	40E	14	CAA	Big Horn	3439	Dietz Coal	165	20.0	6/4/2008	115.6	3323.4	Monthly	
166389	PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	Big Horn	3440	Anderson Coal	112		6/4/2008	87.8	3352.2	Monthly	
166761	WR-29R	-106.8153	45.0465	09S	40E	15	ACCD	Big Horn	3461	Anderson-Dietz 1 Clinker and Coal	72		12/17/2008	46.3	3414.8	Monthly	
183559	Nance IP-11 Bridge	-106.4549	45.4114	05S	43E	8	BCDC	Rosebud	3085	Tongue River Formation	540		9/27/2008	-11.4	3096.4	Quarterly	
183560	Nance Properties INC	-106.4205	45.4387	05S	43E	4	AAAB	Rosebud	3035	Alluvium	20		9/27/2008	12.3	3022.7	Quarterly	
183563	Fulton George	-105.8709	45.0637	09S	48E	8	CABC	Powder River	3360	Alluvium	30	1.0	10/1/2008	19.0	3341.0	Quarterly	
183564	Whitetail Ranger Station	-105.9758	45.6404	02S	47E	19	CDCA	Powder River	4045	Fort Union Formation	60		10/1/2008	42.7	4002.3	Quarterly	
183565	Skinner Gulch Pipeline Well	-105.9171	45.4275	05S	47E	3	BCCD	Powder River	3730	Tongue River Formation	167		10/1/2008	51.6	3678.4	Quarterly	
184222	SH-624	-107.0917	45.0725	09S	38E	7	DADB	Big Horn	4645	Anderson-Dietz1 Coalbed	435		9/24/2008	349.9	4294.8	Quarterly	
184223	625	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Dietz Coal	186		9/24/2008	45.6	4141.0	Quarterly	
184224	625A	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Anderson Coal	91		9/24/2008	55.3	4131.5	Quarterly	
184225	634	-107.0728	45.1422	08S	38E	17	DADD	Big Horn	4481	Dietz Coal	348	12.0	9/24/2008	149.5	4331.0	Semi-Annual	
184226	634A	-107.0883	45.1422	08S	38E	17	DADD	Big Horn	4481	Anderson Coal	159		9/24/2008	115.5	4365.7	Semi-Annual	
186195	WR-41	-106.9498	44.9950	09S	39E	34	CCCC	Big Horn	3643	Alluvium	40	1.0	12/17/2008	17.6	3625.0	Monthly	
189802	HWC-37	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3578	Alluvium	32		12/18/2008	11.3	3566.7	Monthly	
189838	HWC-39	-106.4004	45.0713	09S	43E	12	ADBD	Big Horn	3591	Alluvium	39		12/18/2008	26.0	3565.0	Monthly	

Appendix A. Site details, water-level data, and 2009 monitoring schedule for ground-water monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
190902	HWC-10	-106.4695	45.0444	09S	43E	21	BADA	Big Horn	3610	Dietz Coal	229		12/18/2008	96.9	3513.1	Monthly	
190904	HWC-11 TR-77	-106.4696	45.0444	09S	43E	21	BADA	Big Horn	3615	Anderson Coal	135	8.0	12/18/2008	53.5	3561.5	Monthly	
191139	20-LW	-106.7801	45.3391	06S	40E	1	CDDC	Big Horn	3940	Wall Coal	253	0.2	10/31/2008	90.4	3849.6	Monthly	
191155	22-BA	-106.6954	45.3484	06S	41E	3	BADD	Rosebud	3530	Brewster-Arnold Coal	262	0.4	9/27/2008	106.4	3423.7	Quarterly	
191163	28-W	-106.7292	45.3211	06S	41E	16	BBCC	Rosebud	3715	Wall Coal	144	1.3	10/31/2008	106.2	3608.8	Monthly	
191169	32-LW	-106.7098	45.2955	06S	41E	21	DDDC	Rosebud	3530	Wall Coal	51	0.2	10/31/2008	36.7	3493.3	Monthly	
191634	75-23	-106.2011	45.0966	08S	45E	34	BDBC	Powder River	3780	Canyon Coal	247		10/30/2008	133.2	3646.8	Monthly	
192874	YA-109	-107.0312	45.0407	09S	38E	22	DADC	Big Horn	3830	Alluvium	44		12/17/2008	30.3	3799.8	Monthly	
198464	HWC-7	-106.4093	45.0537	09S	43E	13	DAAA	Big Horn	3624		67		12/18/2008	30.5	3593.5	Monthly	
198465	HWC-6	-106.4093	45.0536	09S	43E	13	CAAA	Big Horn	3595	Dietz Coal	152		12/18/2008	71.0	3524.0	Monthly	
198489	HWC 86-15	-106.4235	45.0025	10S	43E	2	AABC	Big Horn	3630	Alluvium	63	30.0	12/18/2008	15.8	3614.3	Monthly	Semi-Annual
203646	CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3980	Knobloch Coal	417	0.5	12/17/2008	174.1	3806.2	Monthly	Annual
203655	CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3984	Brewster-Arnold Coal	256	5.0	12/17/2008	101.9	3881.9	Monthly	Annual
203658	CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3982	Local Coals	366	2.0	12/17/2008	145.2	3836.6	Monthly	Annual
203669	CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	Big Horn	3792	Carney Coal	290	10.0	12/17/2008	73.6	3718.4	Monthly	
203670	CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	Big Horn	3890	Roland Coal	159	1.0	12/17/2008	132.4	3757.6	Monthly	
203676	CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	Big Horn	3920	Canyon Coal	376	0.3	12/17/2008	303.0	3617.0	Monthly	
203678	CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	Big Horn	3920	Dietz Coal	235	0.1	12/17/2008	186.2	3733.8	Monthly	
203680	CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	Big Horn	3500	Wall Coal	291	0.2	10/29/2008	184.4	3315.7	Monthly	
203681	CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	Rosebud	3500	Wall Coal Overburden	221	5.0	10/29/2008	77.4	3422.6	Monthly	
203690	CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	Big Horn	3500	Canyon Underburden	97	30.0	10/29/2008	36.0	3464.0	Monthly	
203693	CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	Big Horn	3900	Canyon Coal	263	1.5	12/17/2008	165.3	3734.7	Monthly	
203695	CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	Big Horn	3900	Canyon Overburden	190	5.0	12/17/2008	90.6	3809.4	Monthly	
203697	CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	Rosebud	3262	Knobloch Coal	208	1.0	9/27/2008	159.7	3102.6	Quarterly	
203699	CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	Rosebud	3262	Knobloch Underburden	224	10.0	9/27/2008	160.5	3101.7	Quarterly	
203700	CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Overburden	446	0.3	9/27/2008	103.9	3156.6	Quarterly	
203701	CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Coal	480	0.5	9/27/2008	103.2	3157.4	Quarterly	
203703	CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson Coal	560	0.3	12/18/2008	531.5	3598.5	Monthly	
203704	CBM03-10SS	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson-Dietz 1 and 2 Overburden	462	1.0	12/18/2008	372.5	3757.5	Monthly	
203705	CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	Big Horn	3950	Anderson Coal	211	1.0	12/18/2008	155.6	3794.4	Monthly	
203707	CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	Big Horn	3950	Dietz Coal	271	0.2	12/18/2008	229.3	3720.7	Monthly	
203708	CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	Big Horn	3950	Canyon Coal	438	1.5	12/18/2008	383.3	3566.7	Monthly	
203709	CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	Powder River	3715	Cook Coal	351	3.0	10/30/2008	167.7	3547.3	Monthly	
203710	CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	Powder River	3931	Otter Coal	500	1.5	10/30/2008	346.1	3584.9	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
205082	Spring Creek Pipeline Well	-105.9538	45.3883	05S	47E	20	ACAC	Powder River	3630	Tongue River Formation	50		7/2/2008	16.7	3613.3	Quarterly	
207064	RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	Big Horn	3855	Alluvium	27		12/17/2008	13.9	3840.8	Monthly	
207066	RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	Alluvium	17		12/17/2008	10.6	3838.9	Monthly	Semi-Annual
207068	RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	Big Horn	3860	Alluvium	25		12/17/2008	12.6	3847.2	Monthly	
207075	YA-114	-107.0543	45.0461	09S	38E	21	ADBD	Big Horn	4000	Alluvium			9/24/2008	13.2	3986.8	Quarterly	
207076	YA-105	-107.0527	45.0465	09S	38E	21	ACAC	Big Horn	4015	Alluvium			9/24/2008	12.3	4002.7	Quarterly	
207080	TA-100	-107.0090	45.0479	09S	38E	23	BBCC	Big Horn	3900	Alluvium			9/24/2008	15.5	3884.5	Quarterly	
207081	TA-101	-107.0090	45.0482	09S	38E	24	BBCC	Big Horn	3910	Alluvium			9/24/2008	17.4	3892.7	Quarterly	
207083	TA-102	-107.0076	45.0486	09S	38E	24	BBCB	Big Horn	3910	Alluvium			9/24/2008	22.6	3887.5	Quarterly	
207096	IB-2	-106.4372	45.3930	05S	43E	21	BBDB	Rosebud	3192	Knobloch Underburdern	245		9/27/2008	123.3	3068.3	Quarterly	
207097	MK-4	-106.4363	45.3919	05S	43E	21	BBDC	Rosebud	3195	Knobloch Coal	188		9/27/2008	123.2	3072.1	Quarterly	
207098	NM-4	-106.4361	45.3916	05S	43E	21	BCAB	Rosebud	3195	Nance Coal	294		9/27/2008	120.3	3075.0	Quarterly	
207099	WL-2	-106.4358	45.3919	05S	43E	21	BBDC	Rosebud	3188	Knobloch Coal	199		9/27/2008	121.0	3066.6	Quarterly	
207101	OC-28	-106.1928	45.4717	04S	45E	21	CCBD	Powder River	3171	Knobloch Coal			9/27/2008	67.7	3103.3	Semi-Annual	
207143	HC-01	-106.4750	45.1314	08S	43E	21	BBDA	Big Horn	3457	Alluvium	20	17.0	9/25/2008	11.2	3445.8	Semi-Annual	
210094	WO-14	-106.1849	45.5183	04S	45E	4	BDDB	Powder River	3010		66		9/26/2008	8.6	3001.4	Semi-Annual	
214096	HWCQ-2	-106.5009	45.1913	07S	43E	32	AAAA	Rosebud	3340	Alluvium	19		12/18/2008	13.1	3326.9	Monthly	
214097	HWCQ-1	-106.5005	45.1912	07S	43E	32	AAAA	Rosebud	3340	Alluvium	20		12/18/2008	13.1	3326.9	Monthly	
214354	WA-7	-106.4347	45.3933	05S	43E	21	BABC	Rosebud	3179	Alluvium			9/27/2008	54.4	3124.6	Quarterly	
215085	WO-11	-106.1433	45.3927	05S	45E	23	ABCC	Powder River	3145	Alluvium	39		9/26/2008	10.0	3135.0	Quarterly	
219125	SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	Big Horn	3925	Anderson Coal	671		12/18/2008	340.9	3584.1	Monthly	
219136	SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	Big Horn	3725	Alluvium	40	2.0	12/11/2008	15.9	3709.1	Monthly	Semi-Annual
219138	SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	Big Horn	3805	Smith Coal	358	2.0	12/11/2008	167.3	3637.7	Monthly	
219139	SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Anderson Coal	523	2.0	12/11/2008	220.9	3584.1	Monthly	
219140	SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	Big Horn	3805	Canyon Coal	817	0.1	12/11/2008	374.5	3430.5	Monthly	
219141	SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	Big Horn	3640	Smith Coal	120	2.0	12/18/2008	30.5	3609.5	Monthly	
219169	SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	Big Horn	3640	Anderson Coal	279	2.0	12/18/2008	55.9	3584.1	Monthly	
219617	SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Smith Coal Overburden	278	5.0	12/11/2008	147.1	3657.9	Monthly	
219927	SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Anderson Coal	223	1.0	12/18/2008	133.5	3676.5	Monthly	
219929	SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Dietz Coal	322	0.7	12/18/2008	170.3	3639.7	Monthly	
220062	SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	Big Horn	4220	Anderson Coal	492	0.1	12/18/2008	378.9	3841.1	Monthly	
220064	SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	Big Horn	4220	Canyon Coal	685	0.5	12/18/2008	523.2	3696.9	Monthly	
220069	SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	Big Horn	4173	Canyon Coal	515	1.0	9/25/2008	457.3	3715.7	Monthly	
220076	SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	Big Horn	3810	Canyon Coal	431	6.0	12/18/2008	181.0	3629.1	Monthly	
220385	SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	Big Horn	3920	Canyon Coal	1301		12/18/2008	446.6	3473.4	Monthly	
220851	SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	Powder River	3397	Alluvium	19	1.0	10/1/2008	13.4	3383.3	Monthly	
220857	SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	Powder River	3394	Alluvium	14	0.3	10/1/2008	12.4	3381.7	Monthly	Semi-Annual
220859	SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	Powder River	3398	Alluvium	19	1.0	10/1/2008	15.8	3382.6	Monthly	Semi-Annual
223236	USGS 452355106333701	-106.5603	45.3986	05S	42E	16	CCAB	Rosebud	3400		376		8/25/2005	262.7	3137.3		

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Static water level altitude (feet)	2009 SWL monitoring	2009 QW sample collection
223237	USGS 452408106382201	-106.6397	45.4022	05S	41E	14	BDCD	Rosebud	3510		360		8/25/2005	238.4	3271.6		
223238	USGS 452139106504701	-106.8464	45.3608	05S	40E	31	BDCC	Big Horn	4440		681		6/6/2005	619.2	3820.9		
223240	USGS 452411106301601	-106.5044	45.4030	05S	42E	14	ADDC	Rosebud	3220		420		7/16/2007	107.4	3112.6		
223242	USGS 452416106413001	-106.6917	45.4044	05S	41E	17	ADBD	Rosebud	3740		353		3/19/2008	176.9	3563.1		
223243	USGS 452429106435201	-106.7311	45.4080	05S	40E	13	ADAB	Big Horn	3940		380		8/24/2005	200.2	3739.8		
223695	Moorhead Campground Well	-105.8773	45.0542	09S	48E	17	BCBB	Powder River	3400	Pawnee			12/17/2008	4.6	3395.4	Monthly	
223801	SL-5ALQ	-106.2579	45.0129	09S	45E	31	BBA	Powder River	3810	Alluvium	35		12/18/2008	13.3	3796.7	Monthly	
223869	Poker Jim MET	-106.3164	45.3098	06S	44E	23	BBAA	Rosebud	4115							Monthly	
223890	Taylor Creek Pipeline Well	-105.9928	45.2213	07S	47E	21	BBCC	Powder River	3910	Tongue River Formation	150		9/26/2008	123.6	3786.4	Quarterly	
223952	WA-2	-106.4621	45.4020	05S	43E	17	BCDD	Rosebud	3069	Alluvium			12/11/2008	11.5	3057.0	Monthly	Semi-Annual
226919	NC05-1 Near Birney Village	-106.4769	45.4106	05S	43E	7	C	Rosebud	3170		780						
227246	DH 76-102D	-106.1862	45.0798	09S	45E	3	ADCC	Rosebud	3811	Dietz Coal	144		10/30/2008	21.2	3789.8	Monthly	
228124	NC05-2	-106.4772	45.4105	05S	43E	7	CCDC	Rosebud	3170		348						
228592	Musgrave Bill	-106.7319	45.1639	08S	41E	5	ACDB	Big Horn	3335	Alluvium	22		10/29/2008	11.6	3323.4	Monthly	Semi-Annual
231583	RBC-MET	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849							Monthly	
231591	SL-3 MET	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3725							Monthly	

Appendix B

Site details, discharge data and water year 2008-2009 monitoring schedule for monitored springs and streams

Appendix B. Site details, discharge data, and 2009 monitoring schedule for monitored springs and streams.

GWIC ID	Site name	Longitude	Latitude	Township	Range	Section	Tract	County
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
197607	Upper Fifteen Mile Spring	-105.93720	45.39200	05S	47E	16	DCDC	Powder River
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
199572	Deadman Spring	-105.87430	45.29030	06S	48E	29	BABB	Powder River
205004	Hagen 2 Spring	-106.26880	45.34500	06S	45E	6	ACDC	Powder River
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
205049	Chipmunk Spring	-106.36110	45.21200	07S	44E	21	CCBB	Rosebud
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

GWIC ID	Spring source lithology	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Average spring yield (gpm)	Most recent yield date	2009 planned flow monitoring	2009 planned QW sample collection
197247		Anderson	Regional	3690	1.67	9/26/2008	Monthly	
197452	Coal	Otter	Local	3470	0.82	9/25/2008	Monthly	Semi-Annual
197607	Colluvium	Cook	Local	3805	0.72	9/26/2008	Quarterly	
198766		Ferry	Local	3660	1.70	10/1/2008	Quarterly	
199568	Sandstone	Cook	Local	3680	0.78	9/26/2008	Quarterly	
199572	Sandstone	Canyon	Local	3940	1.05	9/26/2008	Quarterly	
205004	Clinker	Anderson/Dietz	Local	3890	0.79	9/26/2008	Quarterly	
205010		Canyon	Local	3960	0.77	9/26/2008	Quarterly	
205011		Anderson	Local	4050	5.67	9/26/2008	Quarterly	
205041	Sandstone	Canyon	Local	3735	1.27	9/26/2008	Quarterly	
205049	Sandstone	Dietz	Local	3670	0.80	9/25/2008	Monthly	
223687				3841			Monthly	
223877		Otter	Regional & Local	3475	0.14	9/26/2008	Monthly	Semi-Annual
228591		Dietz	Local	3620	3.68	9/25/2008	Monthly	Semi-Annual
228776				3920	0.33	9/26/2008	Monthly	Semi-Annual
240578		Anderson	Regional & Local	3665	0.43	9/26/2008	Monthly	Semi-Annual

Appendix C

Ground-water quality data collected during 2007-2008

Appendix C. Ground-water quality data collected in the water year 2007-2008

	Gwic Id	Site Name	Planned sampling	Latitude	Longitude	Location (TRS)	County	Site Type	Aquifer	Depth (ft)	Comp Date
Sites outside areas of potential CBM influence	223877	East Fork Hanging Woman Creek Weir	Semi-annual	45.2909	-106.4041	06S 43E 25 ABDD	Rosebud	Stream			
	228591	Three Mile Spring	Semi-annual	45.1690	-106.7958	07S 40E 35 CDDD	Big Horn	Spring	125TGRV		
	197452	Alkali Spring	Semi-annual	45.1914	-106.1501	07S 46E 31 BACD	Powder River	Spring	125TGRV		
	207066	Well RBC-2	Semi-annual	45.3327	-106.9844	06S 39E 8 CAAA	Big Horn	Well	110ALVM	16.9	7/9/2003
	157883	Well 5080B		45.7199	-106.5126	01S 42E 26 DCBA	Rosebud	Well	125KNCB	88.5	9/11/1996
	157884	Well 5080C		45.7200	-106.5126	01S 42E 26 DCBA	Rosebud	Well	125KNOB	46	9/11/1996
Sites within areas of potential CBM influence	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319	08S 41E 5 ACDB	Big Horn	Well	111ALVM	21.5	
	223952	WA-2	Semi-annual	45.4032	-106.4566	05S 43E 17 BCDD	Rosebud	Well	110ALVM	37.8	8/16/1978
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S 43E 19 DDBA	Rosebud	Well	110ALVM	71	
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S 43E 2 ABCA	Big Horn	Well	110ALVM	53	10/8/1986
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S 43E 2 AABC	Big Horn	Well	110ALVM	62.52	10/8/1986
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386	09S 42E 36 BBAD	Big Horn	Well	110ALVM	40	4/7/2005
	220851	Well SL-8-1Q		45.0176	-105.8998	09S 47E 25 DDDB	Powder River	Well	110ALVM	19	8/26/2005
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09S 47E 25 DCDB	Powder River	Well	110ALVM	13.8	8/26/2005
	220859	Well SL-8-3Q	Semi-annual	45.0177	-105.9028	09S 47E 25 DDCB	Powder River	Well	110ALVM	19	8/26/2005
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S 40E 32 ACAD	Big Horn	Well	110ALVM	34	8/31/1977
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261	08S 42E 30 ADAA	Big Horn	Spring	125TGRV		

Appendix C. Ground-water quality data collected in the water year 2007-2008

	Gwic Id	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)
Sites outside areas of potential CBM influence	223877	5/21/2008	985.54	2.3	13.9	7.87	1398	97	85.8	129	9.94	<0.005	0.003	16.4	509	0	388
		10/3/2007	315.18	0.914	12.0	7.92	552	30	25	27.9	12.6	<0.005	<0.001	23.2	178.9	0	99.9
	228591	5/20/2008	309.94	0.838	10.7	7.89	530	30.5	25.8	25.9	12	<0.005	<0.001	17.5	183.6	0	99.3
	197452	10/3/2007	2080.9	9.831	11.9	7.81	2620	56	96.2	523	7.92	0.06	0.02	9.73	1190.7	0	782
		5/21/2008	1833.5	9.325	10.1	7.76	2720	57.1	95.5	496	8.89	0.092	0.034	7.38	1030.5	0	639
	207066	6/2/2008	552.84	0.796	7.8	7.47	941	69.6	57.2	37.2	9.84	1.3	0.23	26.9	536	0	83
	157883	6/25/2008	1786.72	2.3	12.8	7.24	2390	201	163	181	8	0.182	0.156	13	716.1	0	863
	157884	6/25/2008	1559.78	1.693	12.8	7.14	2070	161.4	169.1	129.1	7.41	<0.09	0.208	15.5	708.8	0	723
Sites within areas of potential CBM influence	228592	10/3/2007	966.14	1.786	13.3	7.35	1378	114	75	99.8	5.64	0.341	0.142	22.8	595.4	0	341
		5/20/2008	1118.13	1.828	9.9	7.52	1465	139	88.4	112	5.81	0.601	0.247	15.7	582.2	0	441
	223952	5/21/2008	1751.43	22.9	8.6	8.01	2810	25.1	26.9	693	6.93	<0.025	0.014	8.34	1499.4	0	198
	7905	6/2/2008	3559.34	6.545		7.60	4320	182	236	568	23.5	0.457	0.95	20.8	971.1	0	2026
	8888	5/21/2008	6173.72	11.14	11.1	7.19	6710	376	315	1210	12.6	6.15	2.11	10.8	851.6	0	3821
	198489	5/21/2008	7860.66	11.39	12.0	7.43	8090	491	457	1460	13.7	9	2.17	11.7	860.1	0	4992
	219136	10/3/2007	3579.22	5.426	9.5	7.50	3970	303	221	509	6.61	1.93	0.583	10.2	445.3	0	2307
		5/20/2008	3387.37	5.434	9.4	7.32	3730	277	203	488	6.47	1.68	0.537	7.98	491.7	0	2150
	220851	10/2/2007	3539.43	5.743		7.53	4050	407	139	526	9.29	0.075	0.73	22.8	552.7	0	1910
	220857	10/2/2007	2972.17	4.972	14.3	7.82	3490	325	155	435	15.5	3.63	1.25	21.3	452.6	0	1755
		6/3/2008	2793.76	4.112	8.7	7.23	3240	390	116	360	7.15	0.511	1.18	16.8	450.2	0	1476
	220859	10/2/2007	2047.84	3.818	12.9	7.33	2650	283	82.9	284	10.3	<0.005	0.077	17.4	346.5	0	1082
		6/3/2008	2004.63	2.956		8.41	2530	279	78.6	217	9.45	<0.005	0.059	15.1	335	27.6	1095
	122766	6/2/2008	6275.89	6.078	9.9	7.54	6350	279	600	786	30.7	4.52	0.746	18.5	703.9	0	4208
	228776	5/20/2008	3756.4	8.416	10.5	7.35	4490	146	236	707	10.8	0.259	0.115	7.32	897.9	0	2189

	Gwic Id	Cl (mg/l)	NO3 (mg/l)	F (mg/l)	OPO4 (mg/l)	Ag (ug/l)	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)
Sites outside areas of potential CBM influence	223877	7.85	<0.5 P	1.21	<0.10	<2.5	<10.0	<1.0	106	20.9	<0.5	<200	<0.5	<0.5	<0.5	<1.0	79.9	<5.0	<0.5	<1.0
		6.95	0.836 P	0.957	<0.05	<0.5	<2.0	6.89	111	64.5	<0.1	<100	<0.1	<0.1	2.24	1.03	88.6	6.91	0.469	1.19
	228591	6.9	0.815 P	1.04	<0.05	<0.5	<2.0	6.96	187	41.9	<0.1	<100	<0.1	<0.1	1.8	<0.2	83.8	4.55	<0.1	<0.2
	197452	18.3	<1.0 P	1.49	<1.0	<0.5	<2.0	0.476	180	12.2	<0.1	<1000	<0.1	0.133	<0.1	<0.2	150	<1.0	0.762	<0.2
		20.6	<1.0 P	1.45	<0.10	<2.5	<10.0	<1.0	234	7.84	<0.5	<200	<0.5	<0.5	<0.5	<1.0	168	<5.0	<0.5	<1.0
	207066	2.88	<0.05 P	0.738	<0.05	<0.5	<2.0	1.13	46.2	25.7	<0.1	<100	<0.1	<0.1	<0.1	<0.2	55.2	<1.0	<0.1	<0.2
	157883	4.68	<0.5 P	<1.0	<1.0	<0.5	<0.5	<0.5	458	7.08	<0.5	<1000	<0.5	<0.5	<0.5	<0.5	60	<0.5	0.77	<0.5
	157884	4.81	0.46 P	<0.5	<0.5	<0.5	1.76	<0.5	383	7.95	<0.5	<500	<0.5	0.729	<0.5	3.71	51.6	<0.5	1.66	<0.5
Sites within areas of potential CBM influence	228592	14	<0.10 P	0.408	0.121	<0.5	<2.0	0.783	83	68	<0.1	<200	<0.1	0.274	<0.1	1.66	30.3	<1.0	2.01	0.246
		27.8	<0.5 P	0.303	<0.10	<0.5	<2.0	0.532	79.4	45.9	<0.1	<200	<0.1	0.167	<0.1	2.37	26.4	<1.0	<0.1	<0.2
	223952	53.9	<0.5 P	0.585	0.059	<2.5	<10.0	<1.0	284	16.3	<0.5	268	<0.5	<0.5	<0.5	<1.0	116	<5.0	<0.5	<1.0
	7905	22.6	<2.5 P	<1.0	<1.0	<5.0	<20.0	<2.0	143	10.9	<1.0	<1000	<1.0	<1.0	<1.0	<2.0	163	<10.0	1.2	<2.0
	8888	<50.0	<5.0 P	<5.0	<5.0	<5.0	<20.0	2.35	200	5.87	<1.0	<5000	<1.0	2.16	<1.0	3.91	223	<10.0	2.5	5.09
	198489	<125	<5.0 P	<12.5	<12.5	<5.0	<20.0	3.24	214	4.79	<1.0	<12500	<1.0	2.15	<1.0	2.38	264	<10.0	1.37	<2.0
	219136	<25.0	<2.5 P	<2.5	<2.5	<2.5	<10.0	<1.0	102	8.42	<0.5	<2500	<0.5	0.857	<0.5	1.16	164	<5.0	5.48	<1.0
		8.79	<2.5 P	0.867	<0.50	<5.0	<20.0	<2.0	83.7	5.45	<1.0	<1000	<1.0	<1.0	<1.0	<2.0	158	<10.0	<1.0	<2.0
	220851	252	<2.5 P	<2.5	<2.5	<5.0	<20.0	<2.0	160	25.2	<1.0	<2500	<1.0	2.08	<1.0	4.69	69.4	<10.0	6.68	4.34
	220857	36.5	<2.5 P	<2.5	<2.5	<5.0	<20.0	3.22	152	34.9	<1.0	<2500	<1.0	3.82	<1.0	<2.0	88.5	<10.0	7.09	<2.0
		203.8	<2.5 P	<1.0	<1.0	<2.5	50.3	<1.0	39.6	6.74	<0.5	<1000	<0.5	0.767	<0.5	<1.0	46.8	<5.0	<0.5	<1.0
	220859	118	<1.0 P	<1.0	<1.0	<0.5	<2.0	1.75	82.8	29.2	<0.1	<1000	<0.1	0.828	<0.1	2.4	44	3.88	3.66	<0.2
		118	<1.0 P	<1.5	<1.5	<2.5	<10.0	<1.0	35	7.89	<0.5	<1500	<0.5	<0.5	<0.5	<1.0	40.5	<5.0	<0.5	<1.0
	122766	<25.0	<5.0 P	<2.5	<2.5	<5.0	86.3	<2.0	113	4.92	<1.0	<2500	<1.0	<1.0	<1.0	<2.0	313	<10.0	<1.0	<2.0
	228776	17.2	<1.00 P	1	<0.50	<5.0	36.2	<2.0	97	4.63	<1.0	<1000	<1.0	<1.0	<1.0	<2.0	339	<10.0	<1.0	<2.0

Appendix C. Ground-water quality data collected in the water year 2007-2008

	Gwic Id	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)	U (ug/l)	V (ug/l)	Zn (ug/l)	Zr (ug/l)
Sites outside areas of potential CBM influence	223877	<0.5	<2.5	<0.5	1529	2.14	<0.5	2.39	<0.5	2.54	<0.5
		0.118	3.62		969	1.3	<0.1	3.39	35	0.942	<0.1
	228591	<0.1	3.36	<0.1	973	<1.0	<0.1	2.39	37.7	0.428	0.24
	197452	<0.1	0.827		1489	<1.0	327	0.788	<0.1	0.45	0.287
		<0.5	<2.5	<0.5	1564	<5.0	<0.5	0.389	<0.5	23.2	<0.5
	207066	<0.1	<0.5	<0.1	1270	<1.0	<0.1	0.231	<0.1	0.729	0.185
	157883	<0.5	<0.5	<0.5	6803	13	<0.5	<0.5	<0.5	8.87	<0.5
	157884	<0.5	<0.5	0.959	3200	12.3	<0.5	1.64	<0.5	13	<0.5
Sites within areas of potential CBM influence	228592	<0.1	<0.5		778	1.32	23.2	11.4	0.226	31.5	<0.1
		<0.1	<0.5	<0.1	879	2.68	<0.1	11.9	<0.1	30.6	<0.1
	223952	<0.5	<2.5	<0.5	1909	<5.0	<0.5	<0.25	<0.5	3.46	1.86
	7905	<1.0	<5.0	<1.0	3581	<10.0	<1.0	5.84	<1.0	18.8	<1.0
	8888	<1.0	<5.0	<1.0	6520	<10.0	<1.0	15.3	<1.0	12.3	<1.0
	198489	<1.0	<5.0	<1.0	8751	11.2	<1.0	29.3	<1.0	7.96	<1.0
	219136	<0.5	<2.5		6018	35.2	<0.5	3.25	<0.5	9.37	<0.5
		<1.0	<5.0	<1.0	5514	5.21	<1.0	1.84	<1.0	6.23	<1.0
	220851	<1.0	<5.0		3711	30.7	288	36.9	<1.0	12.9	<1.0
	220857	<1.0	<5.0		3161	28.6	<1.0	17.1	<1.0	21.9	<1.0
		<0.5	<2.5	<0.5	3073	6.02	<0.5	7.2	<0.5	34	<0.5
	220859	0.336	6.16		2240	14.1	145	33.4	0.905	5.97	<1.0
		<0.5	2.6	<0.5	2089	5.03	<0.5	12	<0.5	1.6	<0.5
	122766	<1.0	<5.0	<1.0	6993	<10.0	<1.0	11.6	<1.0	3.72	<1.0
	228776	<1.0	<5.0	<1.0	5686	<10.0	<1.0	1.11	<1.0	2.37	<1.0

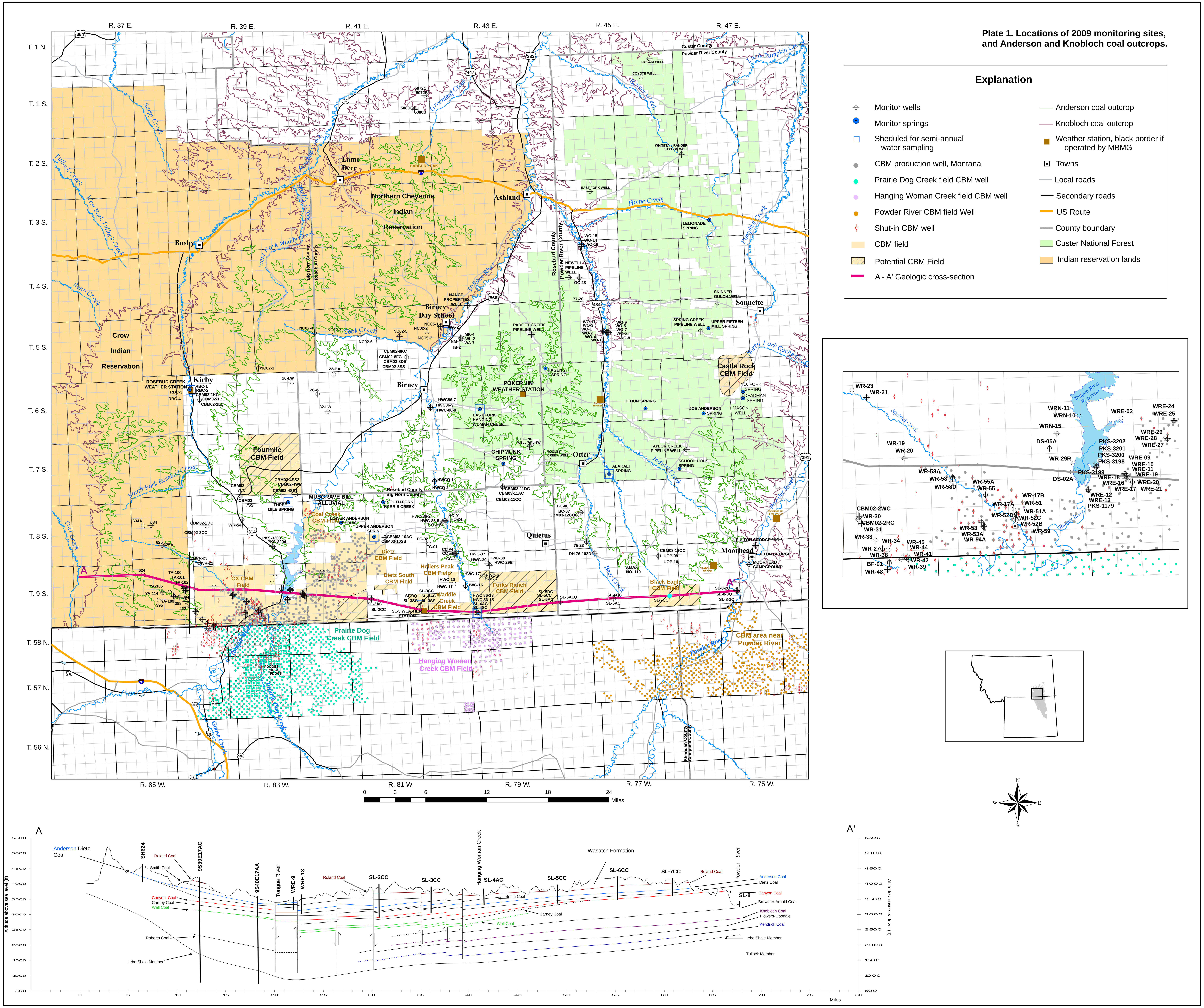
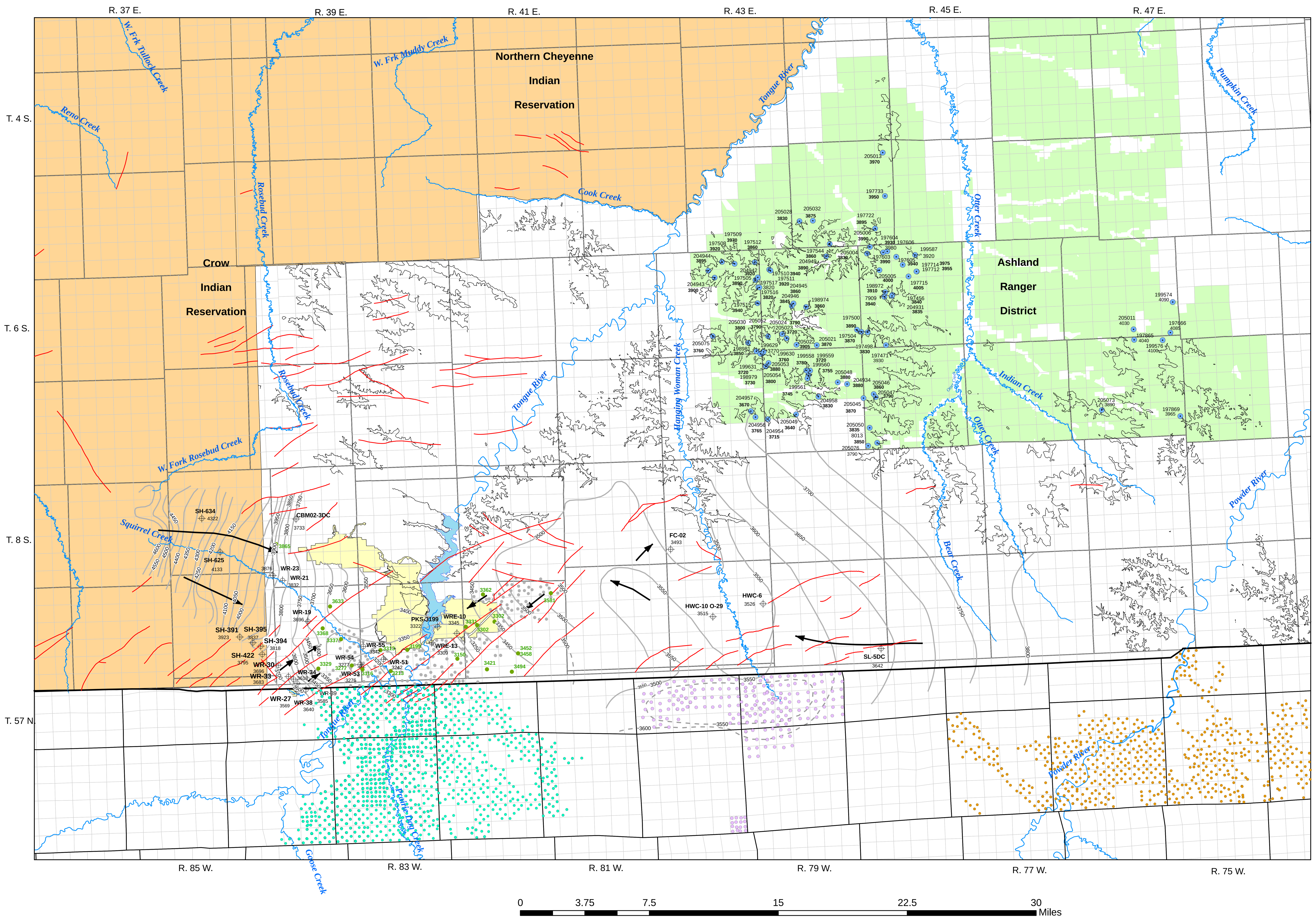


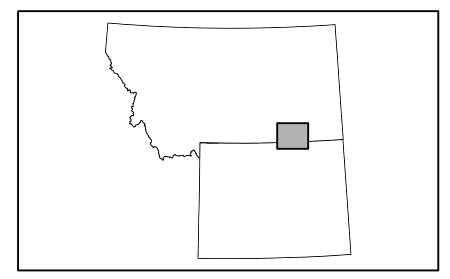
Plate 1. Locations of 2009 monitoring sites, and Anderson and Knobloch coal outcrops.

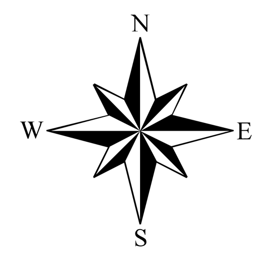
Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2008.



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 — MBMG Monitor well name, water-level altitude (ft) for water year 2008.
- 199587 3920 — Spring with Dietz coal (GWIC identifier number)
- 3452 — Fidelity Production Company wells, water-level altitude (ft)
- Dietz coal outcrop
- Fault, MBMG geological data, CX coal field area modified using Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- CBM production well in the Dietz coal bed with production records during water year 2008.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field well
- Powder River field CBM well
- Indian Reservation land
- National Forest area, Ashland Ranger District





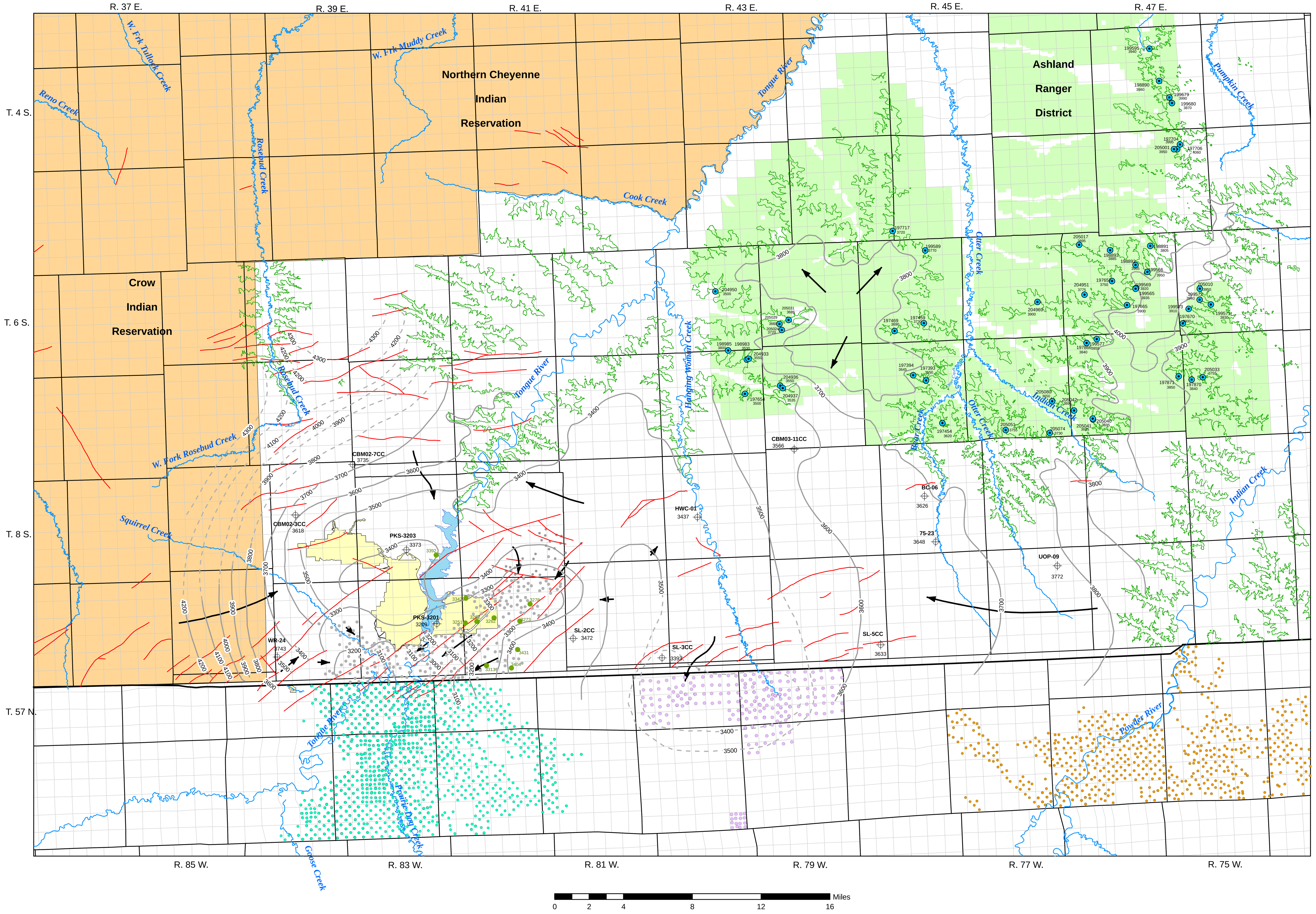
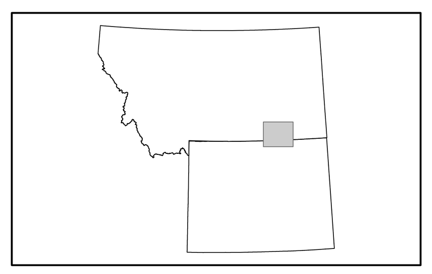


Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2008.

Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, water year 2008), 100-ft contour intervals
- Approximate direction of ground-water flow
- WR-24, 3743 — Monitor well name, water-level altitude (ft) for last data in water year 2008. 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
- CBM production well in the Canyon coal bed in Montana with production records during water year 2008.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field well
- Powder River field CBM well
- Indian Reservation land
- National Forest area, Ashland Ranger District



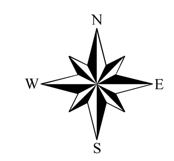
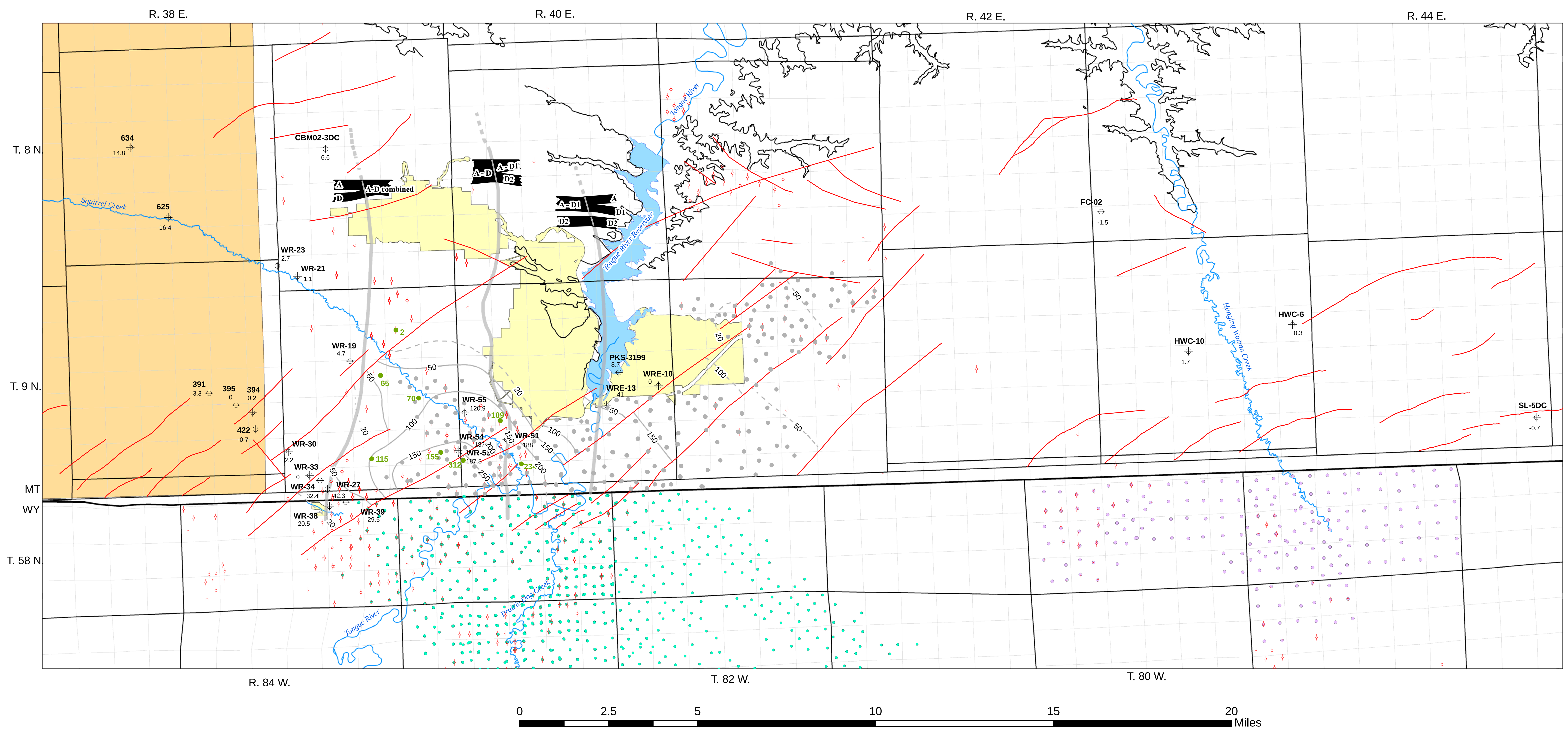


Plate 4. Area of CBM-related potentiometric decline for the Dietz coal in the southern portion of the Powder River Basin, Montana



Explanation

- Potentiometric decline: dashed where inferred, 50-ft contour intervals, 20-ft line also shown.
- WR-34 / 32.4 — MBMG Monitor well name, change in water-level (ft) for last data in water year 2008.
- Fidelity Production Company wells, water-level altitude (ft)
- 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
- CBM production well completed in the Dietz coal that produced water and/or methane during water year 2008.
- CBM production well completed in the Dietz coal that was listed as shut-in at the end of water year 2008.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field well
- Powder River field CBM well
- Indian Reservation land

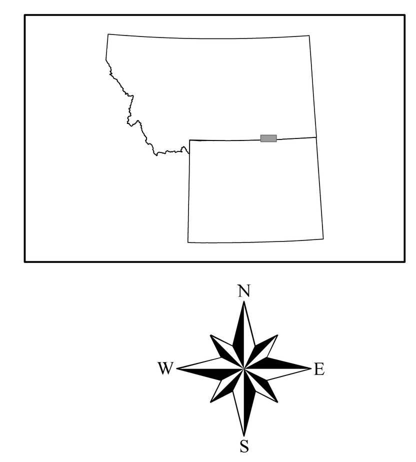
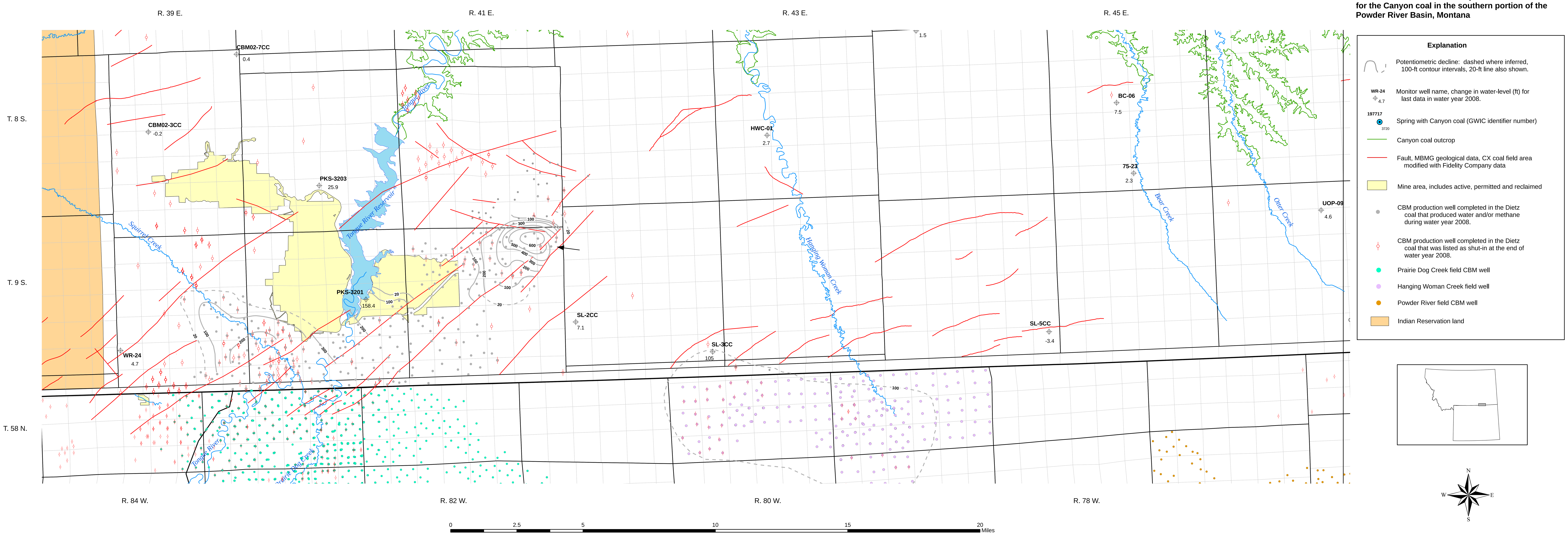


Plate 5. Area of CBM-related potentiometric decline for the Canyon coal in the southern portion of the Powder River Basin, Montana



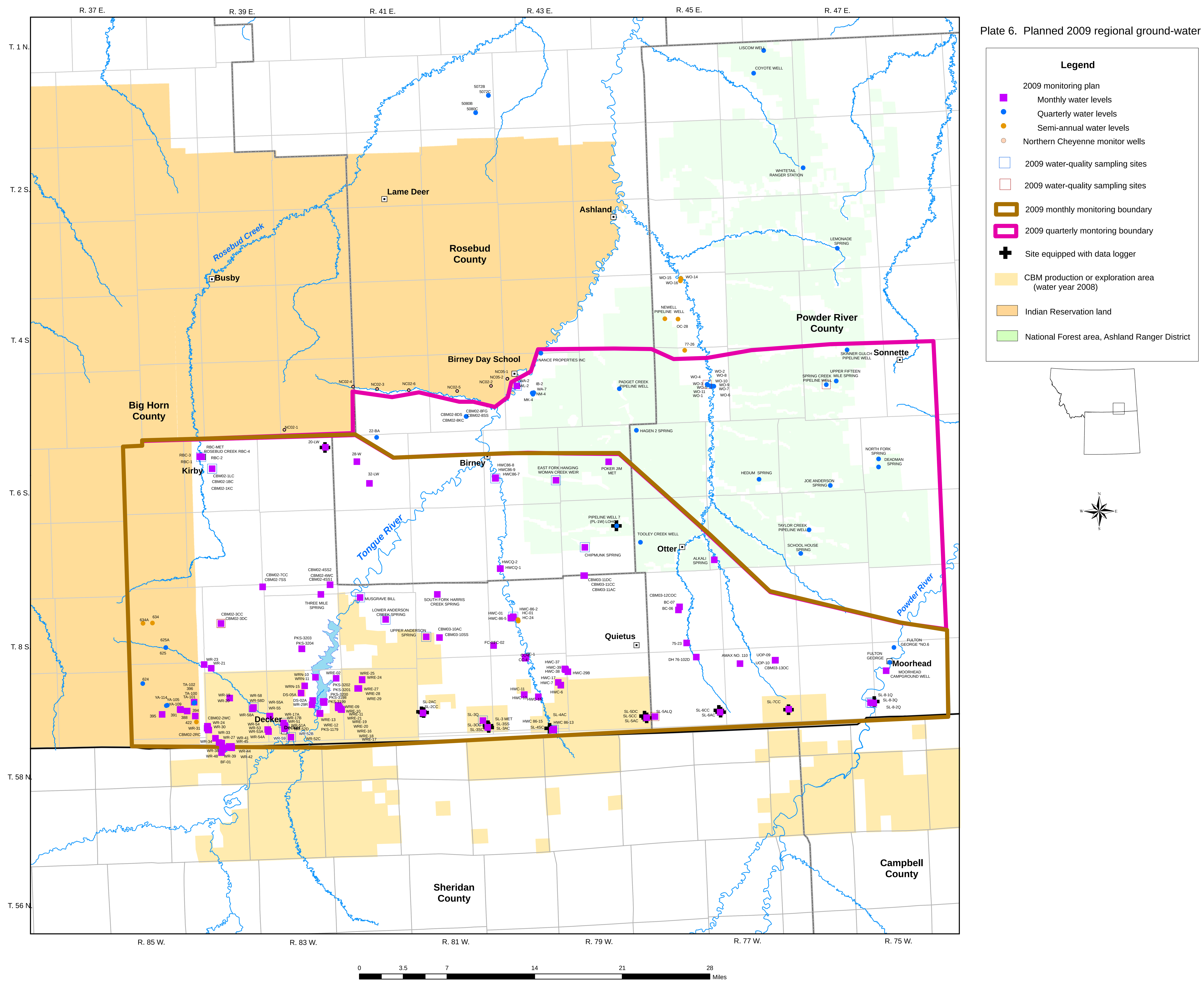


Plate 6. Planned 2009 regional ground-water plan.