2009 Annual Coalbed Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

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Elizabeth Meredith
John Wheaton
Shawn Kuzara
Teresa Donato
Simon Bierbach
Clarence Schwartz

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Table of Contents

Figures

Tables

Plates

Appendices

Abstract

This report presents groundwater data collected through September 2009 from within the northern portion of the Powder River Basin and a brief discussion of all monitoring data with an emphasis on data collected during 2009. This annual report is presented on the water year, which is October through September. Data collected during the water year will be referred to as the 2009 data. This is the seventh year in which the Montana coalbed-methane (CBM) regional groundwater 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 groundwater impacts and recovery, to help replace rumors with factual data, and to provide data and interpretations to aid environmental analyses and permitting decisions. The current monitoring 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, recently installed monitoring wells specific to CBM impacts, domestic wells, stock wells, and springs.

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. Montana currently has 885 CBM wells that produced methane, water, or both during 2009. A total of 12.6 million mcf (1 mcf = 1000 standard cubic feet) of CBM was produced in Montana during 2009, 90 percent of which came from the CX field. The other 10 percent of the methane was produced from the Dietz, Coal Creek, Waddle Creek and Coal Coulee fields. New fields Waddle Creek and Coal Coulee each have one producing well.

Coalbed methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping groundwater from coal aquifers allows methane to desorb. Groundwater 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 groundwater 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 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 2009, 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 with current CBM activity or areas predicted to have high CBM potential. Fidelity Exploration and Production Company (Fidelity) and Pinnacle Gas Resources, Inc. (Pinnacle) also provided water levels measured in monitoring wells and during 24-hour shut-in tests of selected CMB wells. Fidelity supplied 158 water levels from 58 wells measured by Decker (20 water levels) and Spring Creek (87 water levels) Coal Mines in addition to themselves. Pinnacle supplied 53 water levels from as

many wells. Whenever possible, these water levels were used in addition to MBMG measured water levels to create plates 2, 3, 4, and 5. Limitations on use of the Pinnacle data include lack of certainty in positive identification of the producing zone and availability of baseline data. Many of the production wells have multiple completions per well creating distinct coal identification problems. 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 coalbeds. Measured hydrostatic heads in the Dietz coal have been lowered as much as 150 feet or more within areas of CBM production. Access to some Dietz wells is not possible due to the safety hazard presented by venting gas; however, in areas of active CBM production, the Dietz is likely to have drawdown in excess of 150 feet. Hydrostatic pressure in the Canyon coal has been lowered more than 600 feet. Data provided by Fidelity were used to define the maximum drawdown in the Canyon coal. After 10 years of CBM production, the 20-foot drawdown contours for both the Dietz and Canyon coals extend approximately 1.0 to 1.5 miles beyond the boundary of the CX field. These distances, while similar, are somewhat less than originally predicted in the Montana CBM environmental impact statement (U.S. Bureau of Land Management, BLM/MT/PL-03/005, 2003). The radius of the 20-foot drawdown contour would be expected to increase if the rate and duration of production increases; however, there has been little change in this radius since 2004 (Wheaton and others, 2005). Drawdown decreases with distance from the producing fields, 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). Faults tend to act as barriers to groundwater flow and drawdown migration across fault planes has not been observed in monitoring wells. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, but it may take decades for them to return to the original levels. The extent of drawdown and rates of recovery will mainly be determined by the rate, 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 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. Estimates based on current rates of recovery, baseline water levels will be reached in approximately 30 years; however, recovery rates may increase as more CBM wells are taken out of production.

Projections are important for evaluating potential future impacts. However, inventories of existing resources and long-term monitoring are necessary to test the accuracy of these models and determine the actual magnitude and duration of impacts. After 126 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 groundwater availability.

List of abbreviations

above mean sea level (amsl); barrels (bbls); coalbed methane (CBM); environmental impact statement (EIS); gallons per minute (GPM); million 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 groundwater from coal aquifers allows methane to desorb. Groundwater 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 groundwater 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 portion of the Powder River Basin (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 groundwater seepage to form springs and allow methane to naturally leak to the atmosphere. Groundwater 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. The end of September 2009 prices were near their historical low at approximately $2.40 (Blend, 2002; www.energystox.com).

This report presents groundwater data and interpretations from within the northern portion of the PRB undergoing CBM development. This is the seventh year in which the Montana regional CBM groundwater 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 groundwater impacts or lack of impacts, to record groundwater recovery, and to provide data and interpretations for use in environmental and permitting decisions. Additional background information is presented in Wheaton and Donato (2004). This and future reports released each year will present data collected in the prior water year (October through September).

This report includes: (1) a description of groundwater conditions outside of CBM production areas, which provides an overview of normal variations, helps improve our understanding of the groundwater regime in southeastern Montana, and provides water-quality information for planning CBM projects; and (2) a description of groundwater conditions within and near CBM fields that show actual impacts from CBM production. The area covered by the CBM regional groundwater 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) directly and through their 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 885 CBM wells produced water, gas, or both in Montana during 2009, a decrease of 22 wells since 2008. 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 757 wells actively producing gas or water or both during 2009. 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 2009, 30 wells are listed as producing water, methane, or both in the Coal Creek field and 96 wells are listed as producing in the Dietz field.

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 (1,348 active wells during 2009) in Wyoming is adjacent to the CX field in Montana. The Hanging Woman Creek field (213 active wells during 2009) 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 554 active wells during 2009 (Plate 1).

Hydrogeologic data were collected by MBMG at 198 wells, 15 springs, and 2 streams during 2009. Of those monitored sites, 16 wells, 10 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. Three new monitoring wells were installed in 2009: GC09-KC,-TC, and -FG. These three wells, completed in the Knobloch, the Terret and Flowers-Goodale coals, were drilled and installed by the USGS along Gate Creek near the Tongue River. 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 2009 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 provides 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 and Mr. Simon Bierbach, of MBMG in Billings, monitor these wells and provide 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 the BLM, USFS and MBMG 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 near the town of Ashland (Figure 1 and Plate 1). This is the Montana portion of the PRB believed to have high to 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 is classified as a semi-arid climate because it receives, on average, less than 15 inches of precipitation per year based on data from Fort Howes, Badger Peak, Bradshaw Creek, and Moorhead meteorological 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, 2009).

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. Groundwater monitoring wells are completed in numerous coalbeds as well as the overlying and underlying sandstone units.

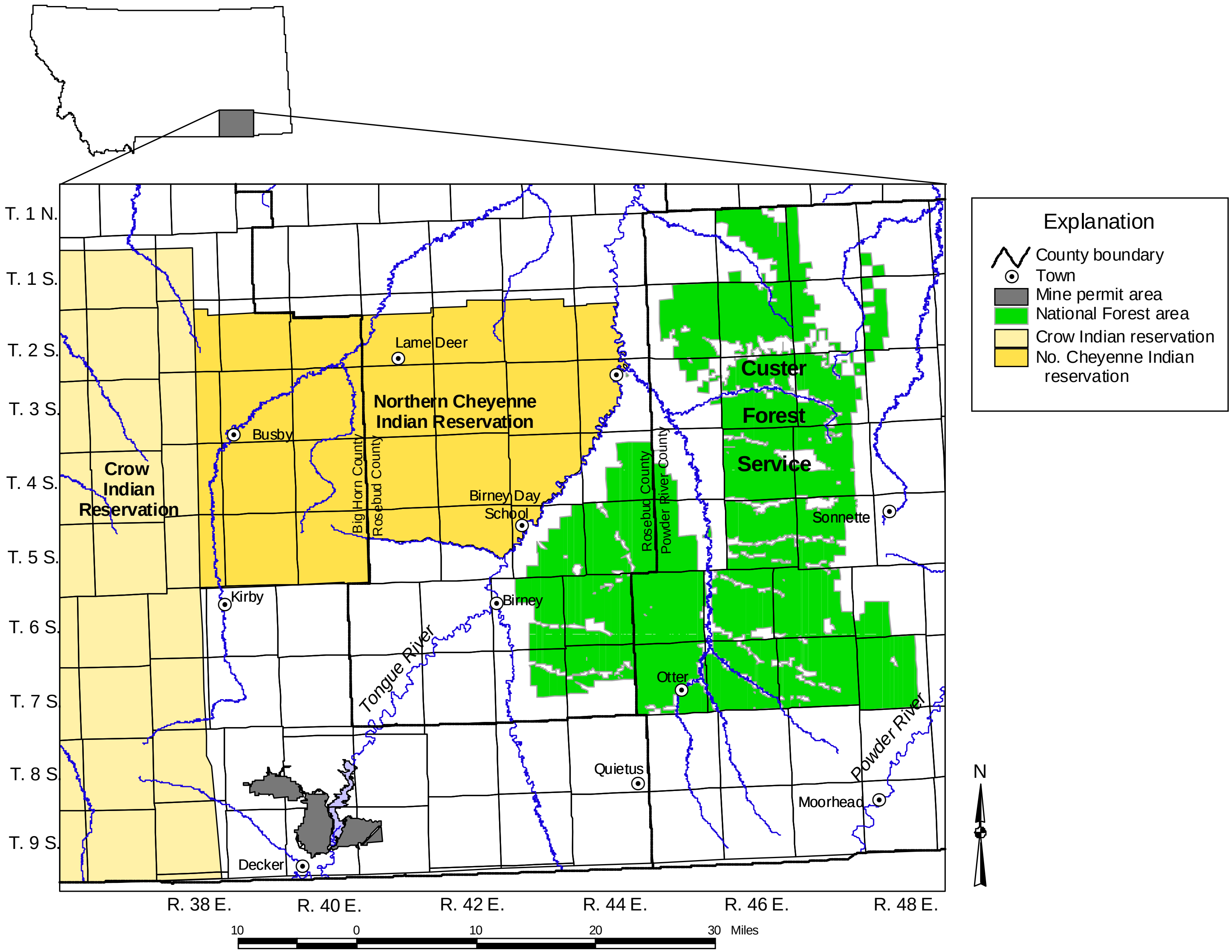


Figure 1. Location of study area.

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. 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. Coal nomenclature varies by agency. 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, groundwater 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. Groundwater 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

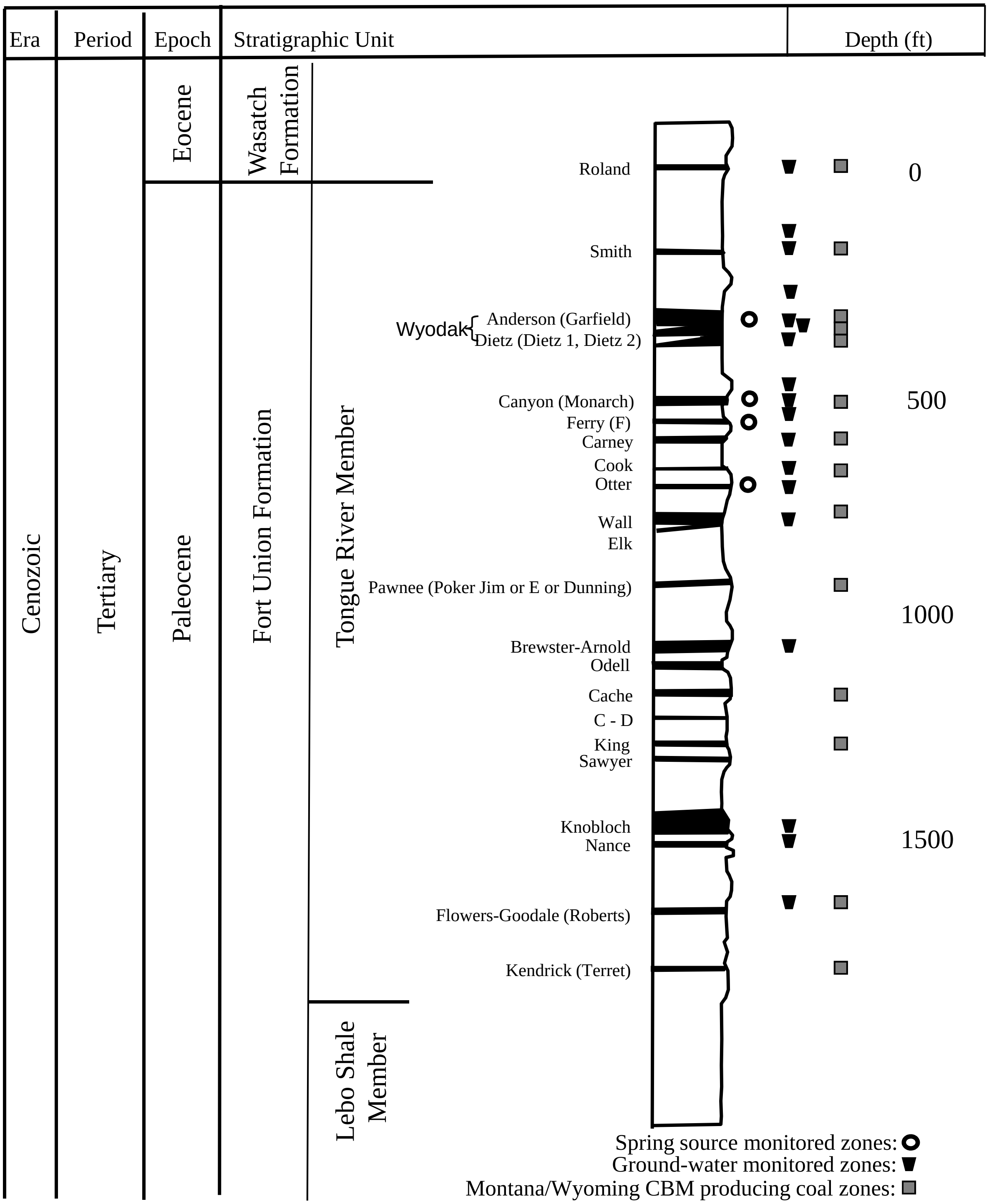


Figure 2. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation in southeastern Montana. The general relative positions of selected coal beds are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line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

Hydrogeologic setting

Three distinct groundwater 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 groundwater 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 these are confined aquifers. Water quality also distinguishes the flow systems, with local groundwater 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 and outcrops and, in a few locations, stream-flow infiltration. 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, seepage 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 definition is not precise and the transition is gradual: 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, groundwater flows from Wyoming northward into Montana and towards the Yellowstone River. Groundwater in regional flow systems will either leave the PRB as deep groundwater flow or discharge as springs, to streams, or to alluvium. 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 groundwater flow systems; and demonstrates the general lack of vertical migration between units. An unknown, but likely significant, percentage of the groundwater 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 groundwater 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. There may be some vertical seepage into the underlying Tullock Member. Contact springs at the base of the Tongue River Member add baseflow to streams. It is likely in terms of coalbed-methane development, that 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.

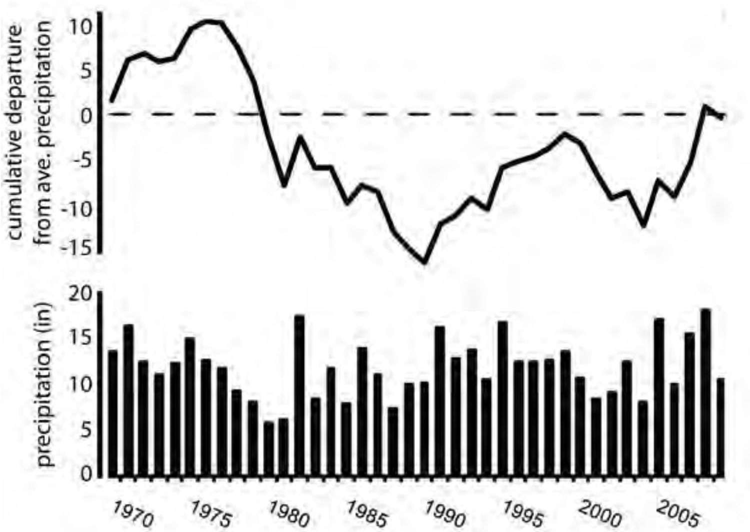


Figure 3. Annual precipitation (bar graph) at Moorehead MT. Cumulative departure from average precipitation (line graph) provides a perspective o the long-term moisture trends that may effect groundwater recharge.

Aquifers are recharged by precipitation and shallow groundwater 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 11.74 inches, based on records from 1970 through the end of water year 2009 (Western Regional Climate Center, 2008). During the water year 2009, Moorhead received 12.13 inches of precipitation, which is very close to the average annual precipitation (Figure 3). Long-term precipitation trends that may affect groundwater 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, water-level drawdown in response to CBM production, in most areas, 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 groundwater 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 the thickness of the coalbed, the aquifer may encounter a no-flow boundary.

Groundwater chemistry

Groundwater quality in the Powder River Basin has been extensively documented. The general chemical characteristics of groundwater 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). Groundwater quality in coal seams is not expected to change in response to CBM production. Infiltration of produced water may, however, cause changes in shallow groundwater 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 groundwater 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

Groundwater conditions currently outside of potential coalbed methane influence

Bedrock-aquifer water levels and water quality

Groundwater levels (the potentiometric surface) and inferred groundwater 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. Groundwater flows generally from south to north with some 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. Groundwater discharges to outcrops, producing springs, and to CBM wells.

Three new wells were installed by the USGS in cooperation with the BLM and the MBMG along Gate Creek in Township 5S, Range 43E, Section 2. These wells are completed in the Flowers-Goodale, Knobloch, and Terret coals. These wells will be monitored quarterly, initially, until their characteristics determine whether more or less frequent monitoring is required.

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 2009 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, Dietz, and Canyon coals also show a downward gradient (Figure 5). This site is in the south-central portion of the monitoring area, near the Anderson coal outcrop, and 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 has a slight seasonal pattern but 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 groundwater discharge zone (Figures 8, 9, and 10). Several landowners have flowing wells in this area, owing to the elevated hydrostatic pressure. 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 (2), Flowers-Goodale, Pawnee, Wall, and Knobloch (2) coal beds. 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 the WO site. 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 groundwater level.

Water levels in Rosebud Creek alluvium also vary with precipitation trends. The geologic cross section shown in Figure 11 crosses Rosebud Creek and a tributary. As shown in Figure 11, groundwater 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, groundwater levels, and surface-water flow (Figure 12). Groundwater 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: http://waterdata.usgs.gov/mt/nwis/uv?06295113. Stream flows correlate well with precipitation events.

The Rosebud alluvial groundwater levels show typical diurnal cycles. The summer months are typically periods of high transpiration as alfalfa, grasses, shrubs, and trees 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 groundwater level recovers. This diurnal cycling causes the high frequency oscillations in water levels from June to the end of August. The overall downward trend of the water table during the growing season indicates transpiration exceeds recharge rates during this hot, dry time.

Detailed precipitation data for the Rosebud Creek site (Figure 12B; Rosebud Meteorological Station data available on the MBMG GWIC website), illustrates how quickly alluvial groundwater levels respond to precipitation events. Increased in-stream flow as this site usually lag behind heavy rain events by 6- to 18-hours. This spring was unusual in that there was consistent, but not heavy, precipitation. This resulted in stream flows that did not reach flood stage.

Water-quality samples were collected in November 2008 and June 2009 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 were 566 and 563 mg/L and SAR values were both 0.8. 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 2009. 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 2009 are available in the GWIC database. Springs are discharge points for groundwater 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 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 gpm. The discharge rate at this spring shows some seasonal influence (Figure 13). 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 (Meredith and others, 2008) indicate a local source of water. 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 with the singular exception of 1.2 gpm measured in May, 2009 (Figure 14). This spring is associated with an isolated portion of the Canyon coal and likely represents local groundwater 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 1.70 gpm, showing moderate seasonal variations (Figure 15). There has been an overall increase in flow rate since monitoring began in 2003. This may be caused by long-term precipitation patterns.

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 measurable 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 Fall 2008 and Spring 2009 from five springs (Three Mile Spring, Alkali Spring, and Chipmunk Spring outside the current area influenced by CBM production and Upper and Lower Anderson Springs within the current CBM producing area) and one creek (East Fork Hanging Woman Creek Weir) outside current areas influenced of CBM production (Appendix C). Three Mile Spring is located near a clinker recharge area and the water has the lowest TDS and SAR values of all measured springs (326 mg/L and 1.0, respectively). Of the measured springs, only Alkali Spring had the sodium-bicarbonate dominated water quality necessary for coalbed methane generation. However, this spring also had high levels of sulfate, which is not found in water associated with CBM. The Otter coal, from which Alkali spring originates, is therefore unlikely to have CBM in this location.

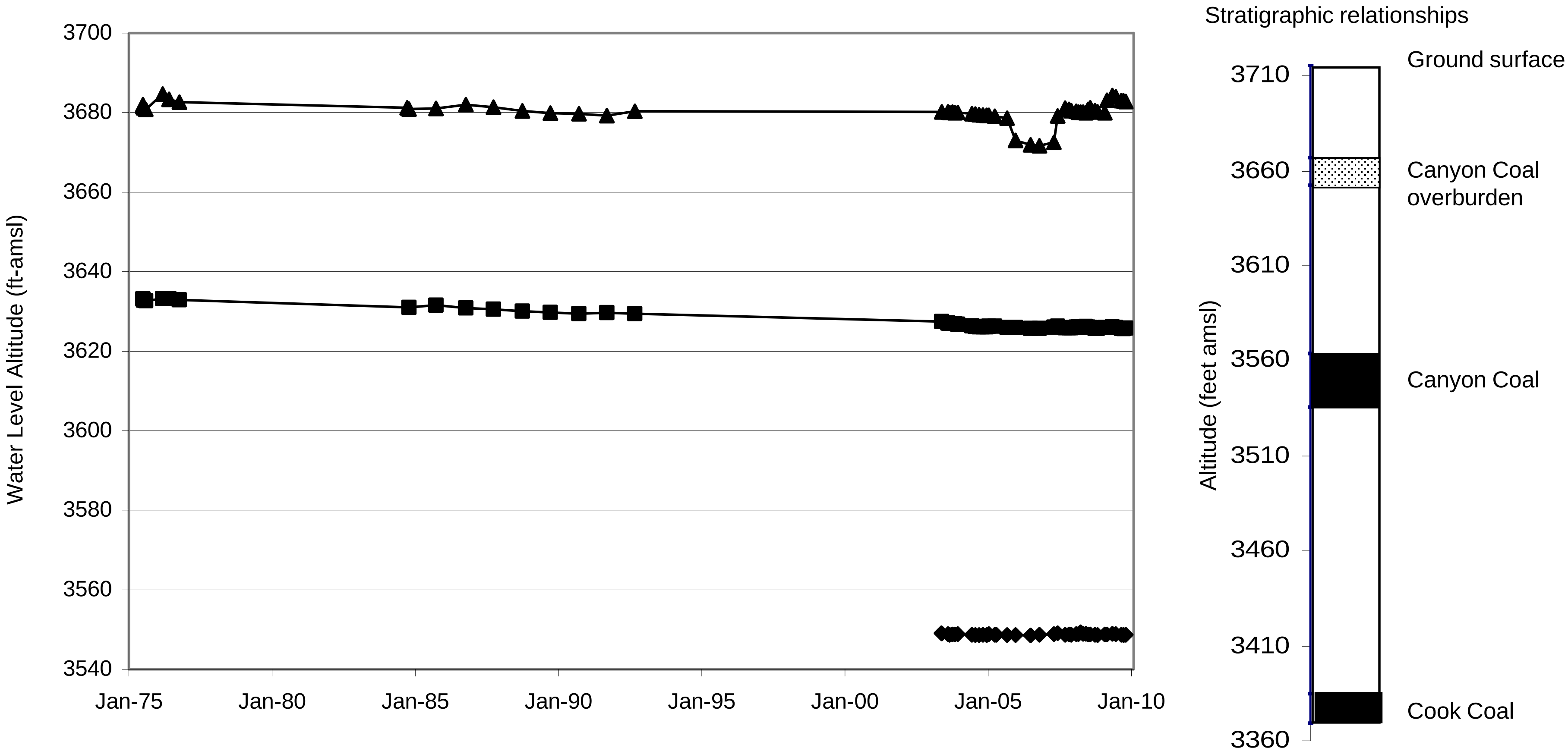


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07), and Canyon coal (BC-06), likely relates to precipitation patterns shown on Figure 2. The short period of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence. In addition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

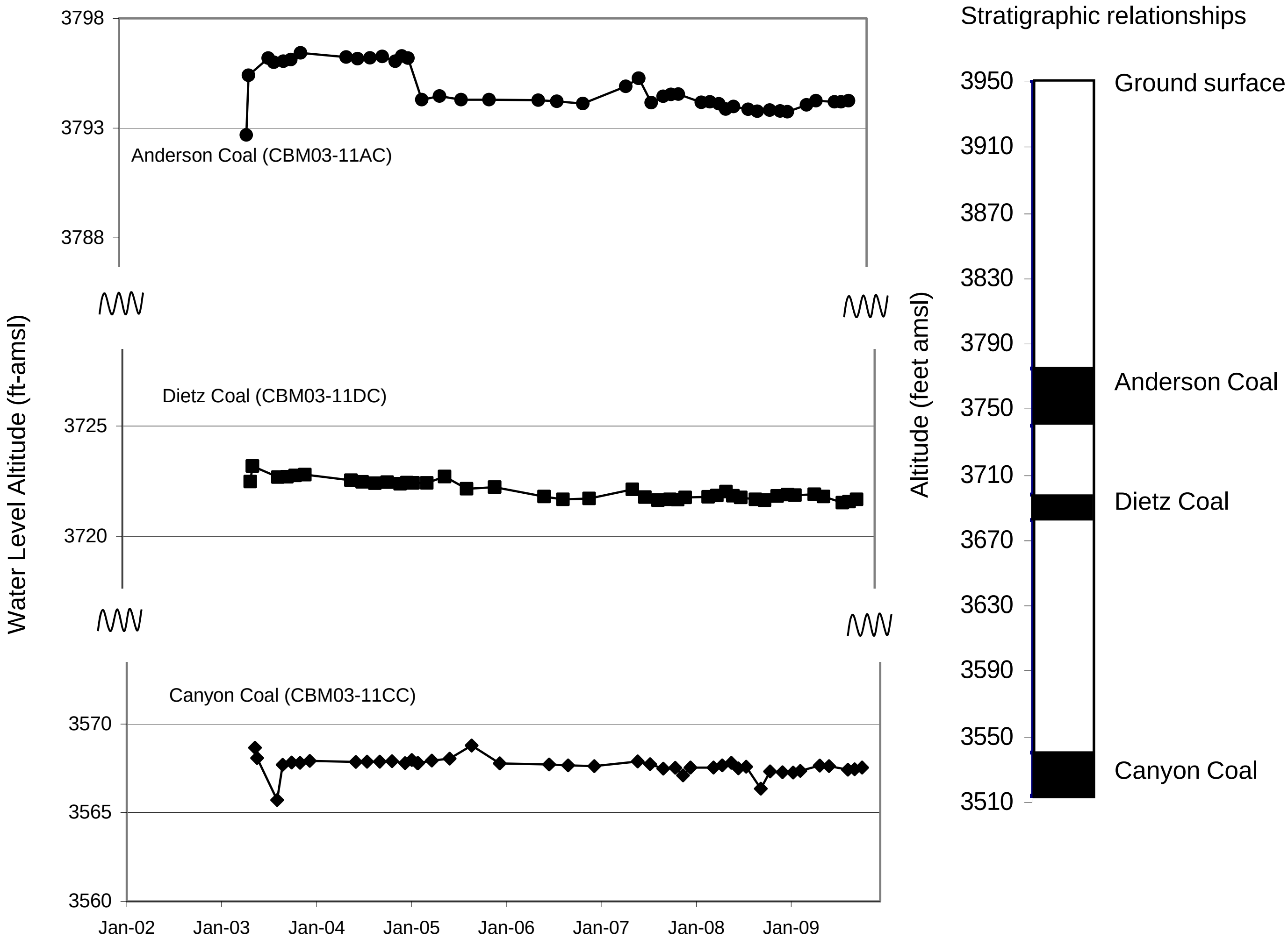


Figure 5 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

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

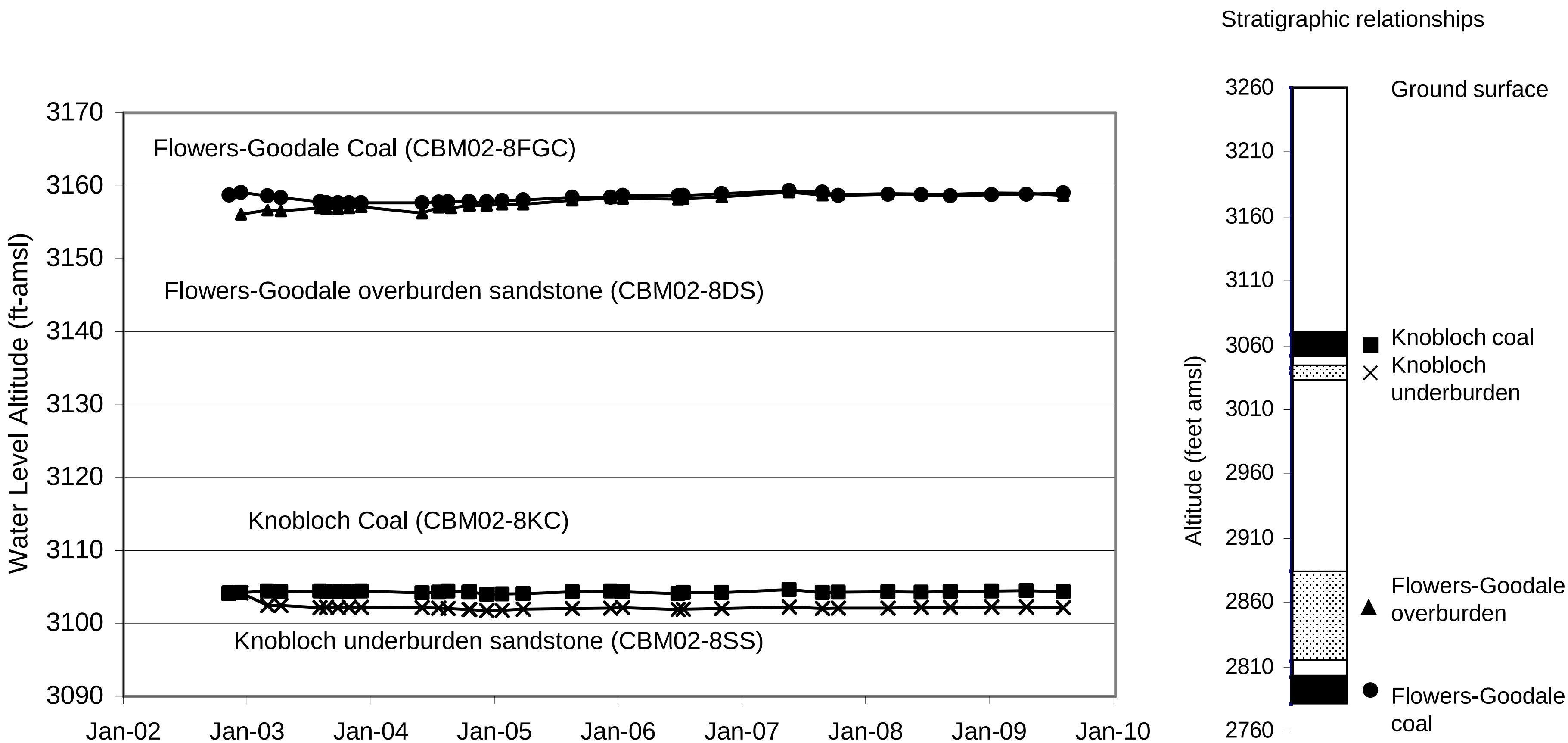


Figure 6. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site.

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

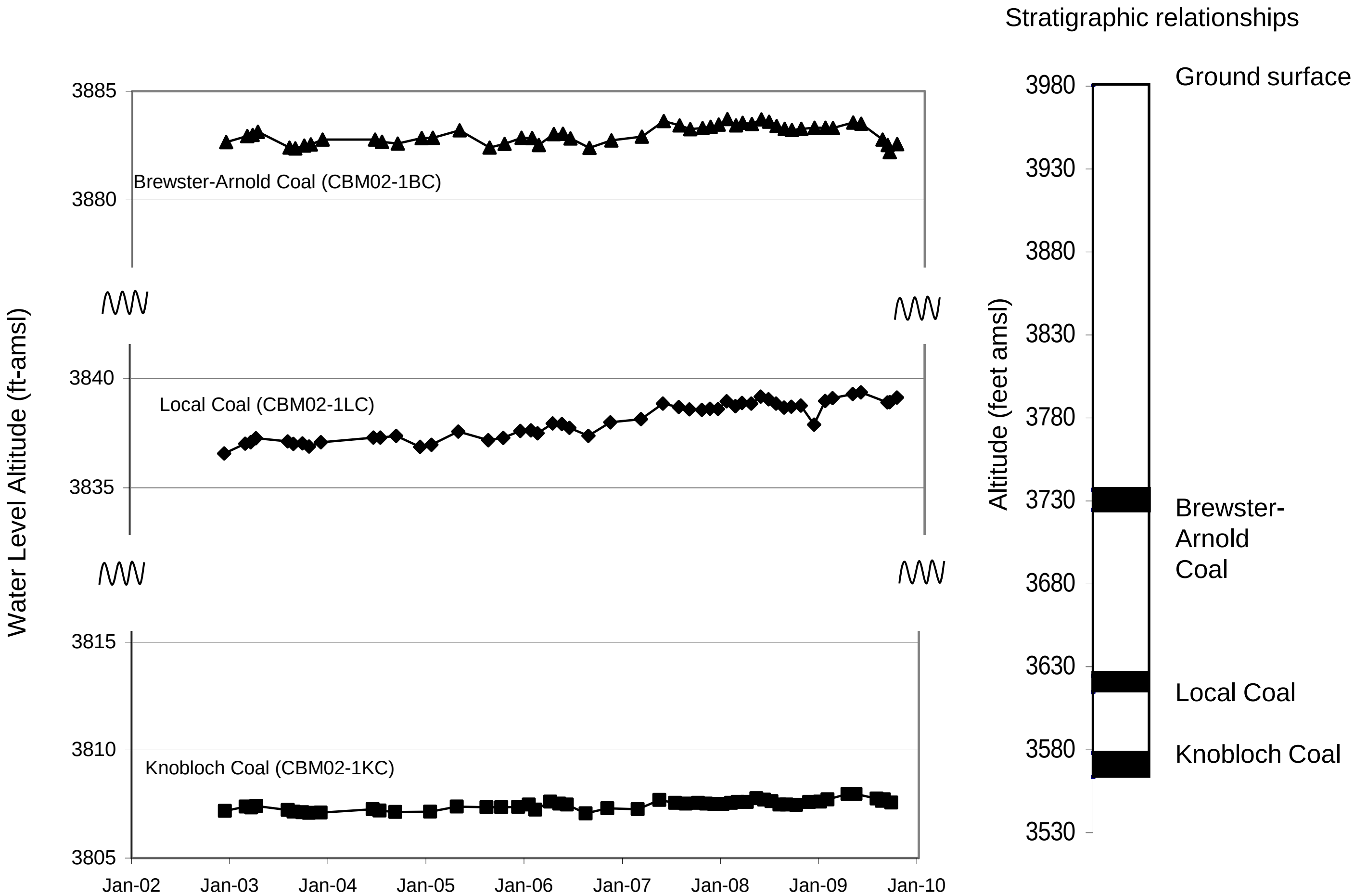


Figure 7. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site.

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

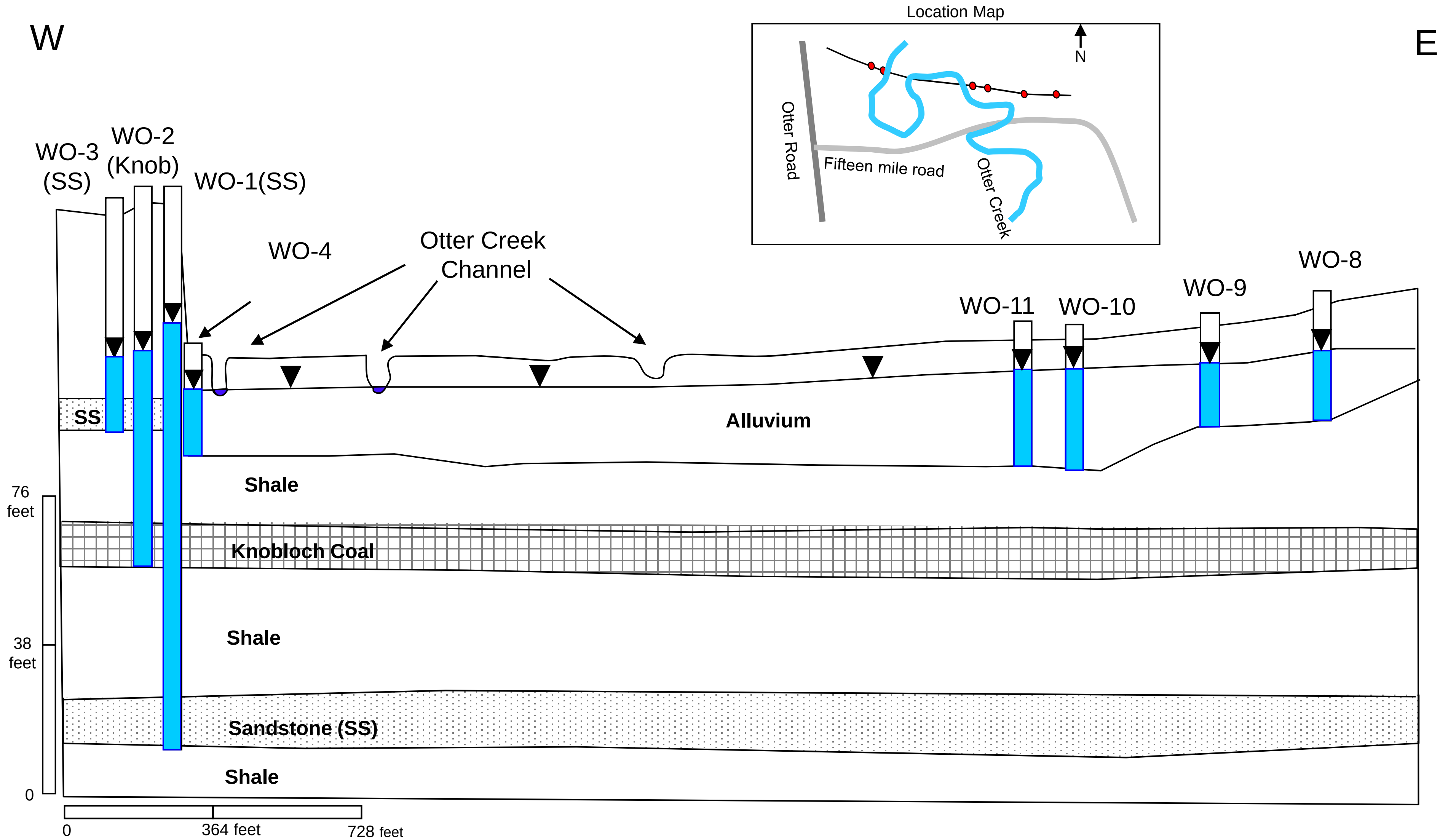


Figure 8. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower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

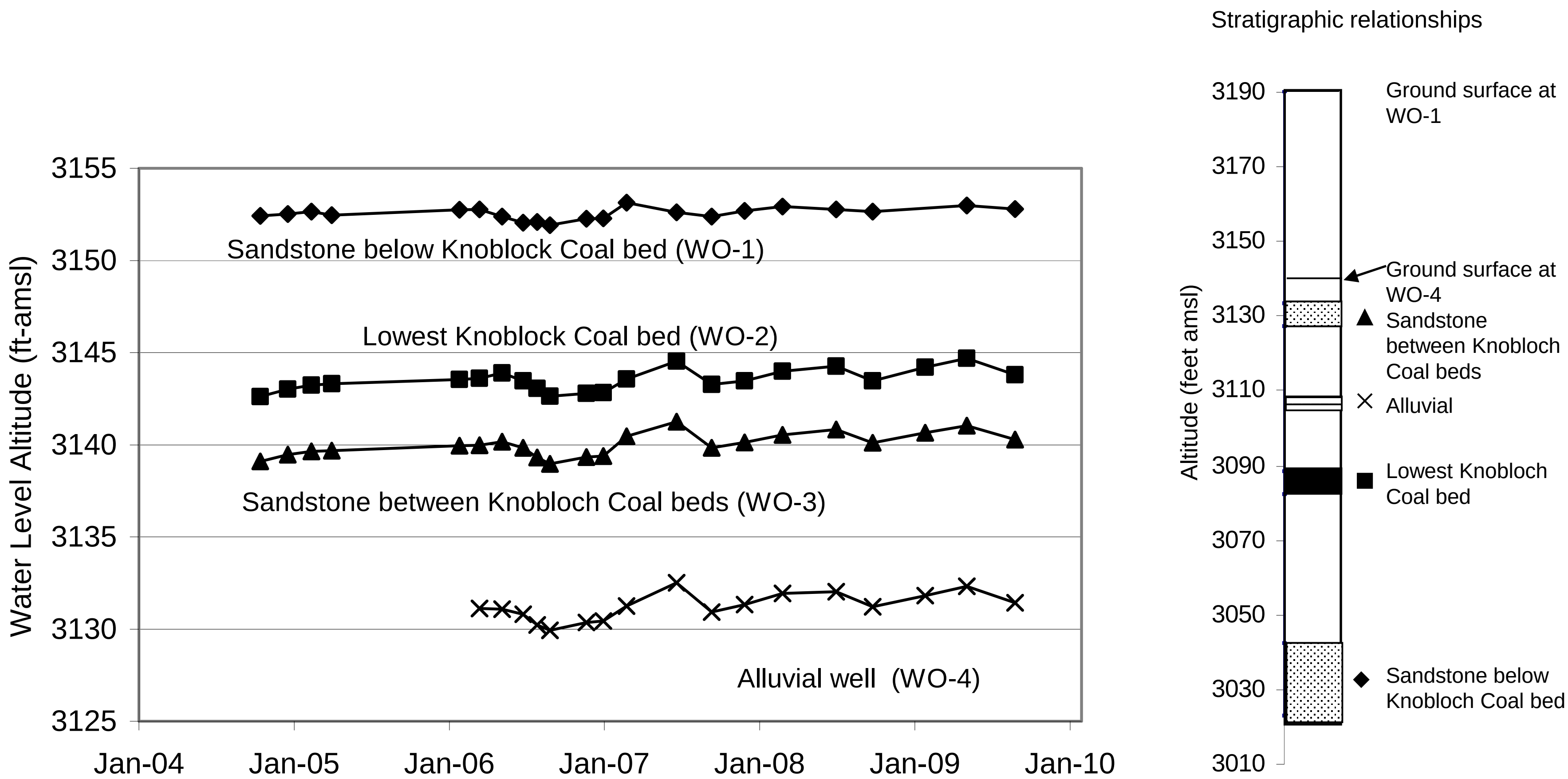


Figure 9. Bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. The alluvial well appears to show the general seasonal water year cycle.

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

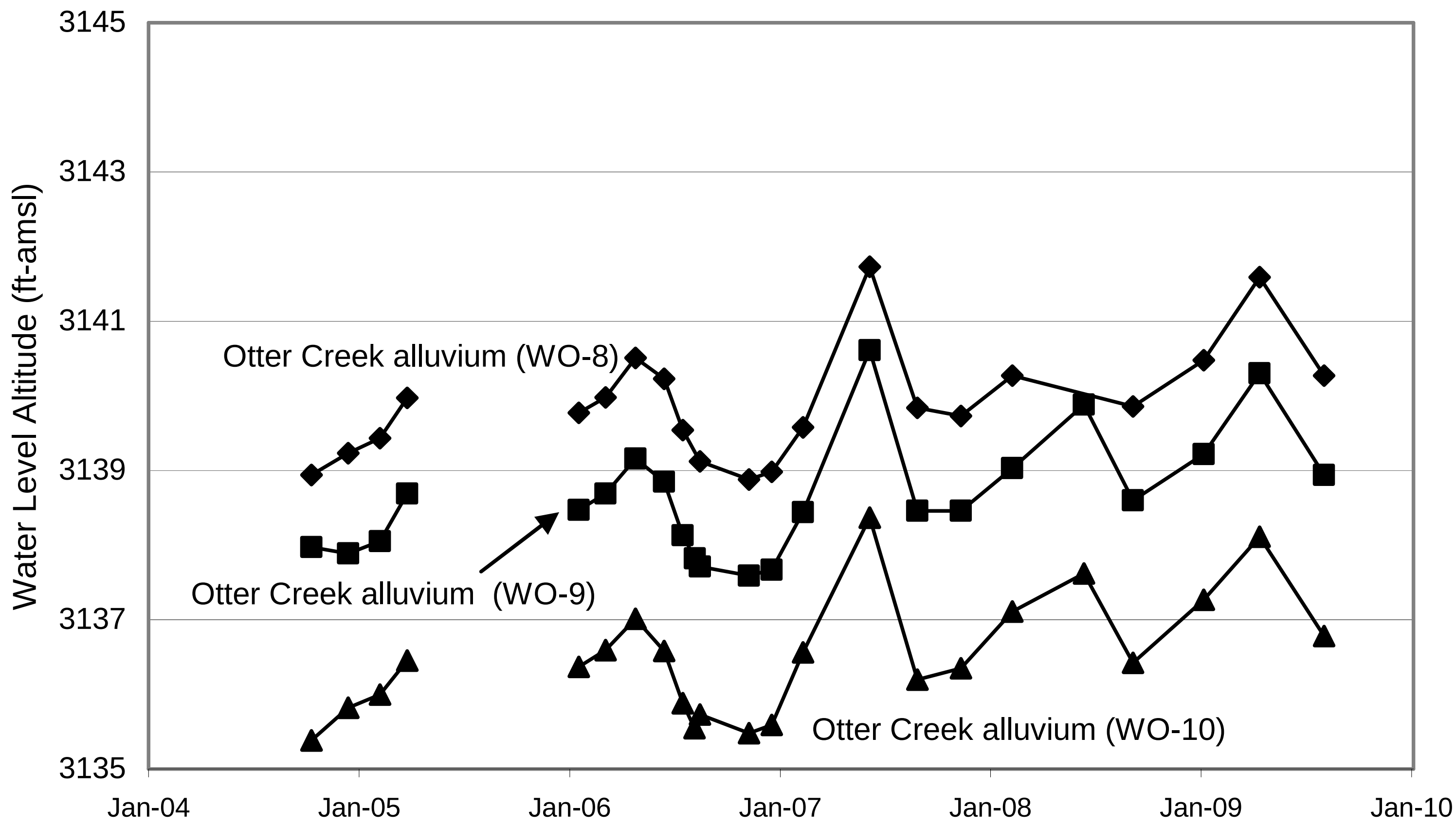


Figure 10. Water-level trends in the alluvium at the Otter Creek site probably relate to weather patterns. The alluvial aquifer appears to receive recharge from the bedrock aquifers in the area, based on the upward vertical gradient.

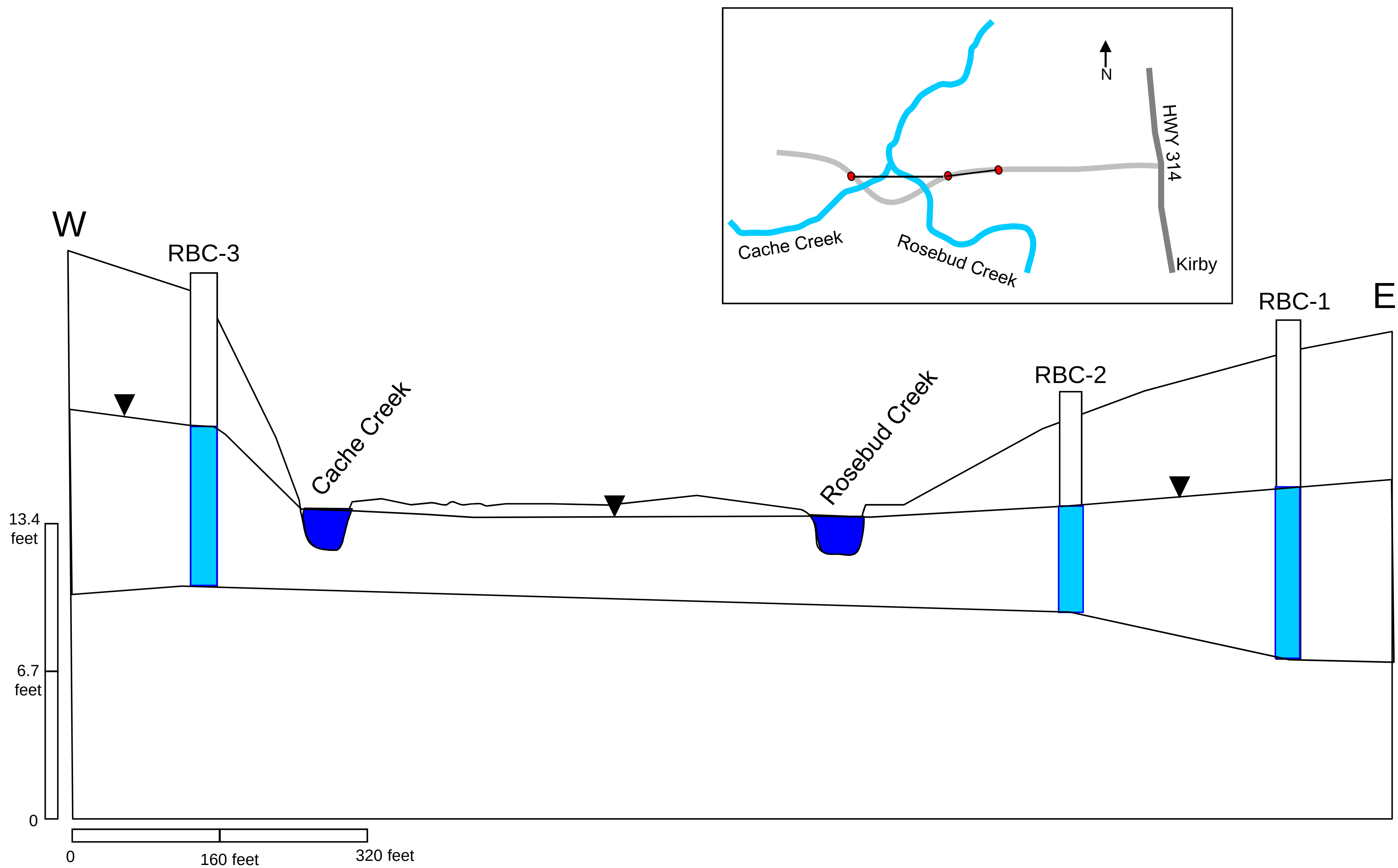
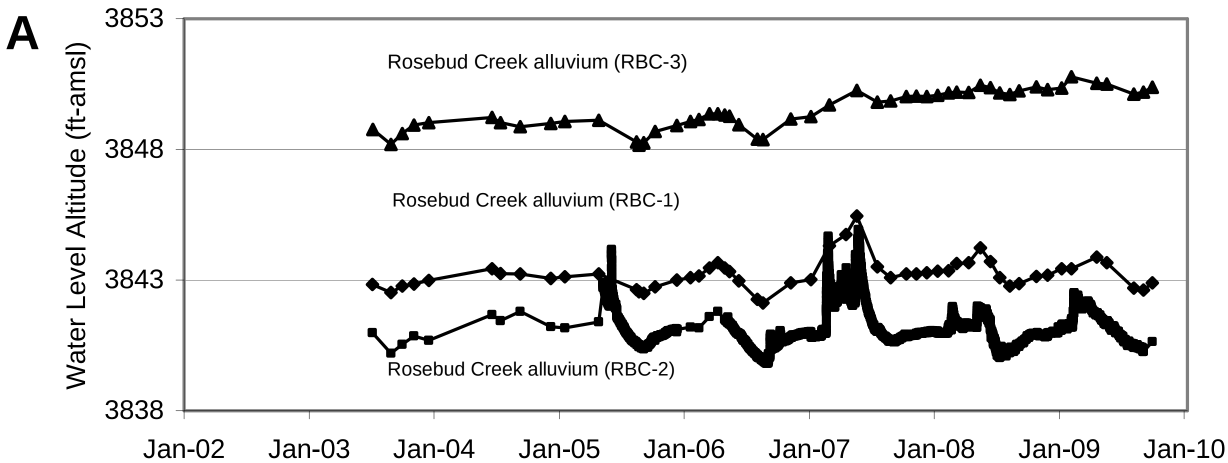


Figure 11. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The water levels at RBC-2 shows a correlation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



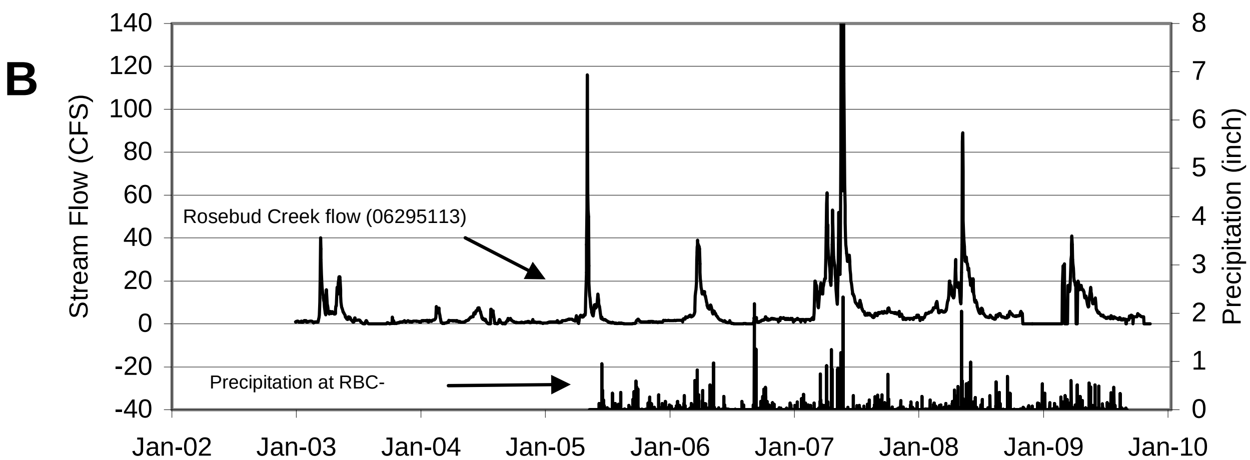


Figure 12. A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. B) Rosebud Creek stream flow follows precipitation trends.

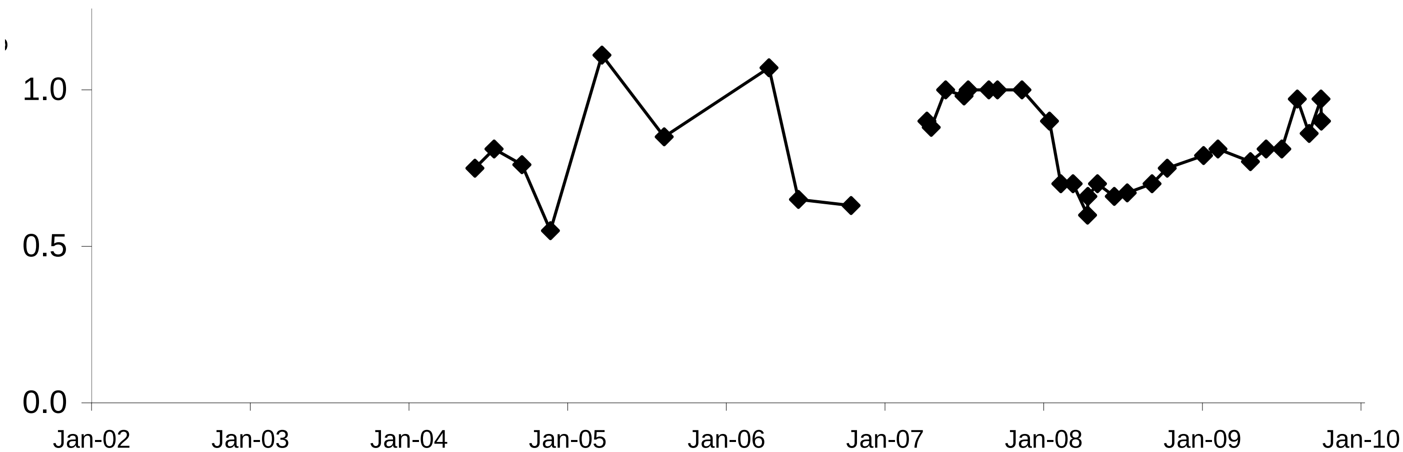


Figure 13. Alkali Spring appears to be a combination of local and regional recharge associated with the Cook coal aquifer. The average discharge rate is 0.82 gpm.

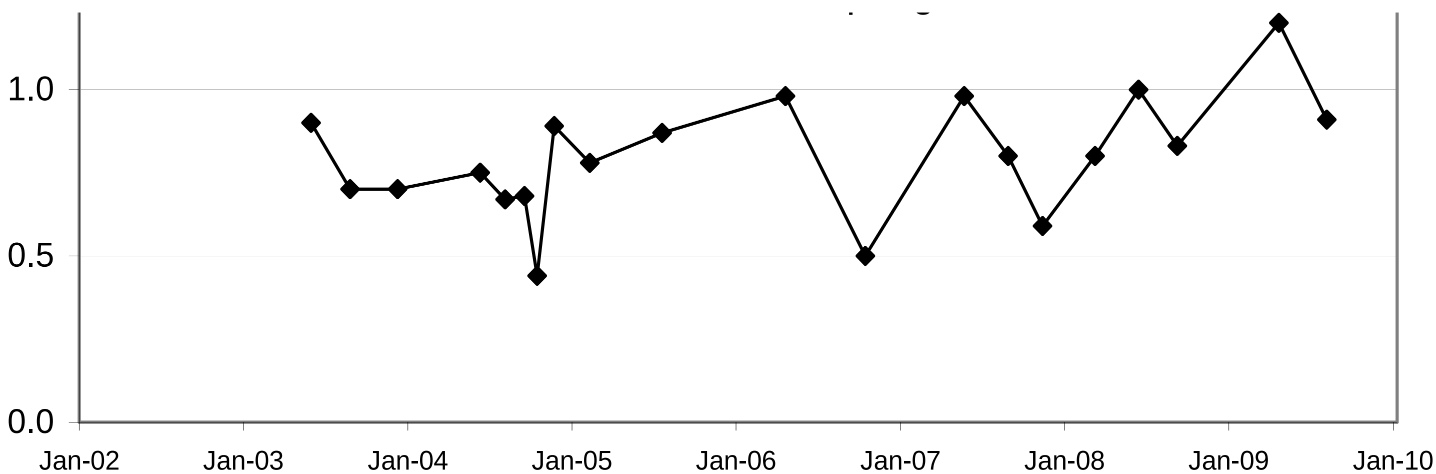


Figure 14. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.77 gpm.

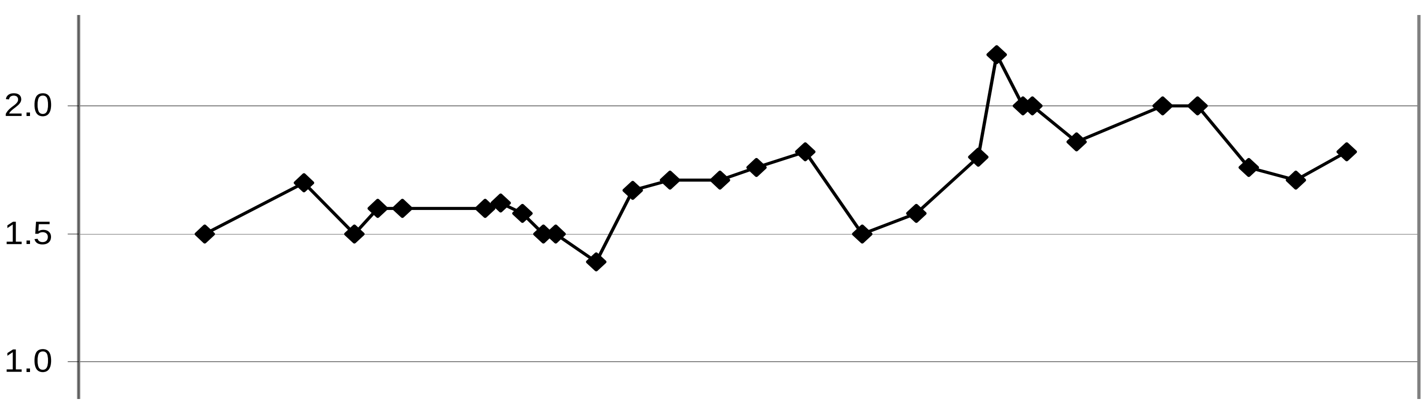


Figure 15. Lemonade Spring appears to be locally recharged by the Canyon and Ferry coal aquifers. The average discharge rate is 1.69 gpm.

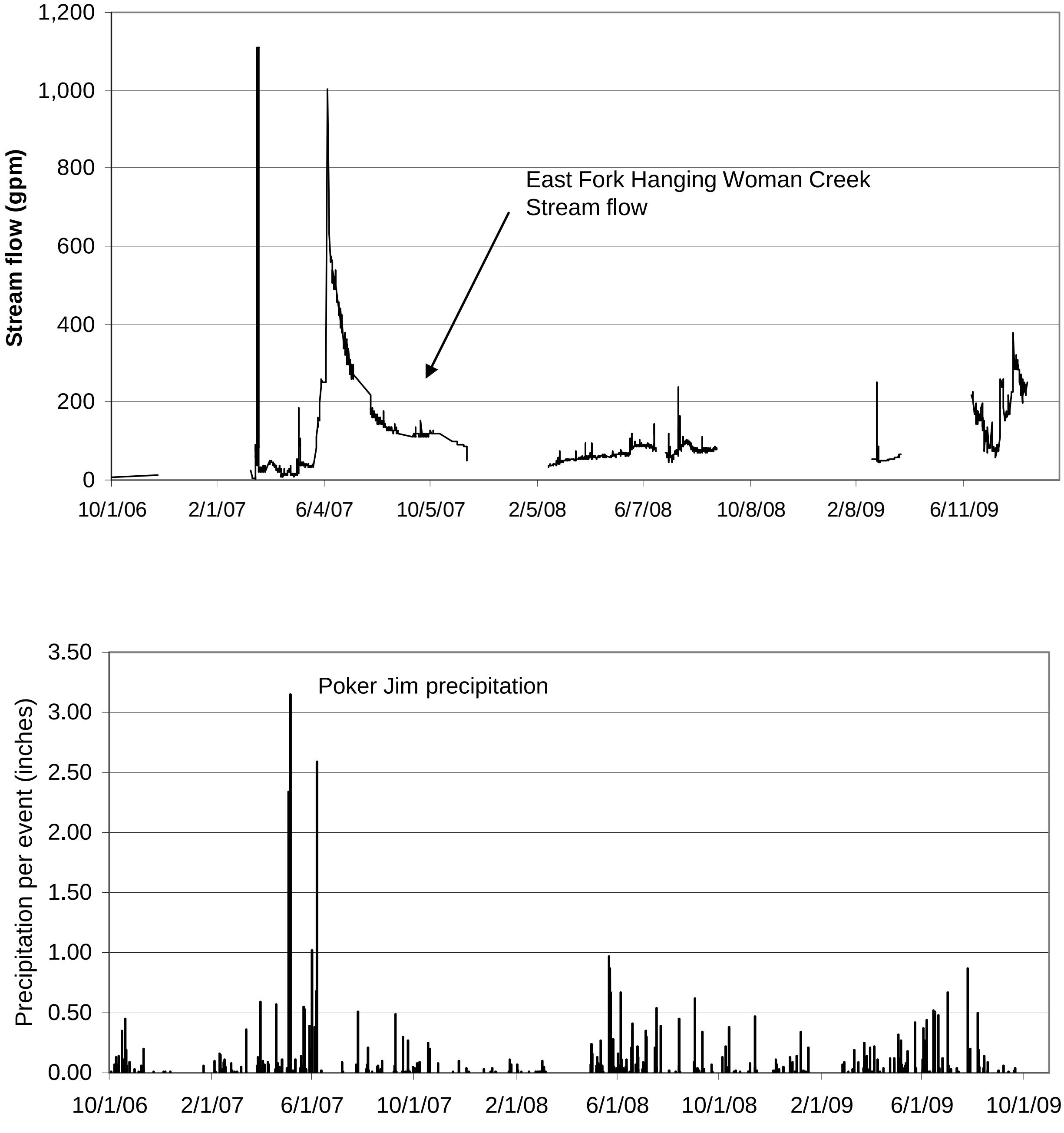


Figure 16. Stream flow at the East Fork Hanging Woman Creek weir correlates with precipitation events recorded at the Poker Jim meteorological station. Precipitation is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous precipitation with no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

Groundwater 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. Coalbed methane permitted wells are summarized by county and field in Table 3. A total of 1,706 coalbed methane wells have been permitted in Montana as of November 11, 2009. Of these wells, 357 are shut-in, abandoned, or plugged and abandoned (P&A on Table 3), 741 are producing and the rest are either permitted, spud (begin drilling operation), or expired. Counties experiencing CBM production or permitting for CBM production include Big Horn, Powder River, Carbon, Custer, Gallatin and Rosebud; however, Gallatin, Custer, and Carbon did not have any wells listed as actively producing.

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

County	Field or POD (Operators)	Well Status	Mar. 2008	Oct. 2008	Nov. 2009
Big Horn	**Coal Creek** (Pinnacle Gas Resources, Inc.)	Permit to Drill	7	6	4
		Expired Permit	0	0	2
		Spudded	2	1	0
		Producing	13	26	23
		Shut In	49	35	39
	CX (Fidelity Exploration & Production Co., Pinnacle Gas Resources, Inc., Powers Energy, Inc.)	Permit to Drill	27	44	3
		Expired Permit	228	226	280
		Expired, Not Released	3	25	8
		Spudded	17	0	6
		Producing	741	705	676
		Shut In	77	129	172
		Temporarily Abandoned	2	8	9
		Abandoned - Unapproved	29	29	29
		P&A - Approved	2	2	2
	Deer Creek Fee POD (Pinnacle Gas Resources, Inc.)	Permit to Drill	32	21	10
		Expired Permit	0	0	11
		Expired, Not Released	0	11	11
		Shut In	1	1	1
	Dietz (Pinnacle Gas Resources, Inc.)	Permitted Injection Well	1	1	1
		Expired Permit	0	0	35
		Expired, Not Released	42	42	7
		Spudded	1	0	0
		Producing	96	92	36
		Shut In	10	5	61
	Forks Ranch - State (Pinnacle Gas Resources, Inc.)	Permit to Drill	n/a	16	8
		Expired Permit	n/a	0	5
		Expired, Not Released	n/a	0	2
		Shut In	n/a	0	1
	Waddle Creek - State (Quaneco, LLC)	Permit to Drill	n/a	16	16
	Wildcat Big Horn (Petroleum Development Corp. of New Mexico, Yates Petroleum Corporation, Fidelity Exploration & Production Co., Powder River Gas, LLC, Pinnacle Gas Resources, Inc., St. Mary Land & Exploration Company, Pennaco Energy, Inc.)	Permit to Drill	0	1	1
		Expired Permit	36	36	36
		Expired, Not Released	2	2	2
		Spudded	2	2	0
		Producing	2	2	3
		Shut In	19	25	26
		Temporarily Abandoned	1	1	1
		Water Well, Released	0	1	1
Carbon	**Wildcat Carbon** (Florentine Exploration & Production, Inc.)	Expired Permit	1	1	1
		P&A - Approved	3	2	2
Custer	**Wildcat Custer** (Powder River Gas, LLC)	Producing	1	1	0
		P&A - Approved	0	0	1
Gallatin	**Wildcat Gallatin** (Huber, J.M., Corporation)	Expired, Not Released	1	1	0
		Expired Permit	0	0	1
Powder River	**Castle Rock** (Powder River Gas, LLC)	Permit to Drill	121	0	0
		Expired Permit	7	128	128
		Shut In	6	0	0
		P&A - Approved	1	0	0
	Wildcat Powder River (Powder River Gas, LLC, Pennaco Energy, Inc., Rocky Mountain Gas, Inc., Pinnacle Gas Resources, Inc.)	Permit to Drill	1	0	0
		Expired Permit	25	26	26
		Producing	1	1	1
		Shut In	3	9	8
		P&A - Approved	1	2	3
Rosebud	**Wildcat Rosebud, N** (Yates Petroleum Corporation, Fidelity Exploration & Production Co., Pinnacle Gas Resources, Inc.)	Expired Permit	1	1	1
		Spudded	1	2	0
		Permit to Drill	1	0	2
		Producing	0	0	2
		Shut In	1	1	2

Produced-water data for 2009 were retrieved for Montana (MBOGC, 2009) and Wyoming (WOGCC, 2009) and are summarized in Table 4. A total of 885 wells produced methane and/or water in Montana during 2009 (this number differs from the Table 3 either because producers have not updated the well status or because of the time difference between the data downloads of October 1st and November 11th). These wells produced a total of 35.6 million barrels (bbls) of water (4,591 acre-feet). This is the least amount of produced water since 2007. In Wyoming during 2009, 105 million barrels of water (13,477 acre-feet) were produced from the 2,115 wells in the two townships nearest Montana (57N and 58N). Similar to Montana, this is the least amount of water produced since 2007. The total amount of water co-produced with CBM in the Powder River Basin in *all* of Wyoming from October 2008 to September 2009 was approximately 605 million bbls or 77,940 acre-feet.

Table 4. Annual summary for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2009.

	Field	Well Count	Gas (MCF) 2009	Annual+ total water production in **Bbls *1,000** (acre-feet)		
				2009	2008	2007
Montana	Coal Creek	30	272,338	2,055 (265)	1,782 (230)	2,389 (308)
	CX	757	11,371,337	31,625 (4,176)	35,414 (4,565)	34,686 (4,471)
	Dietz	96	914,330	1,790 (231)	2,837 (366)	2,159 (278)
	Waddle Creek	1	39,556	151 (20)	89 (11)	0 (0)
	Coal Coulee	1	190	0 (0)	0 (0)	0 (0)
	Combined	**885**	**12,597,751**	**35,621 (4,591)**	**40,121 (5,171)**	**39,234 (5,057)**
Wyoming	Prairie Dog Creek	1,348	40,858,672	45,052 (5,807)	56,947 (7,340)	51,259 (6,607)
	Hanging Woman Creek	213	3,620,648	19,269 (2,484)	24,589 (3,169)	22,342 (2,880)
	Near Powder River	554	10,264,190	40,233 (5,186)	45,396 (5,851)	38,187 (4,922)
	Combined	**2,115**	**54,743,510**	**104,554 (13,477)**	**126,932 (16,361)**	**111,788 (14,409)**

Montana source: MBOGC web page (http://bogc.dnrc.mt.gov/default.asp)

Wyoming source: WOGCC web page (http://wogcc.state.wy.us/)

+Totals reflect production during the water year for 2008, 2009 and calandar year 2007

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 125 months (the longest producing well) of available production reports. The monthly average water-production rates for 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 hydrologic response. Similarly, the average values for normalized months over 118 are not believed to be indicative of typical CBM well production because less than 25 wells have been producing 118 months or longer (see Figure 18).

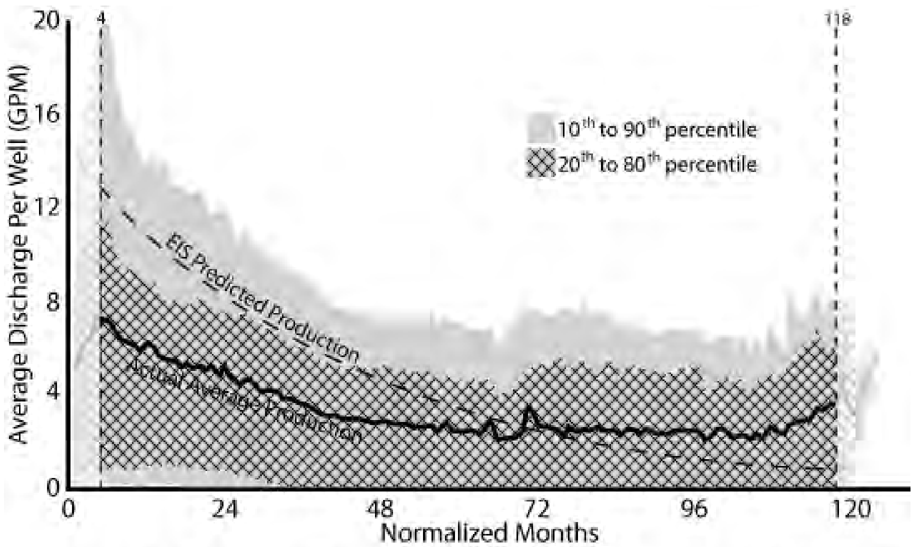


Figure 17. Normalized CBM produced water in gallons per minute in the Montana portion of the Powder River Basin (data from the MT BOGC web site). The actual production (solid line) falls below the EIS predicted production (dashed line: $y = 14.661\ e^{(-0.0242x)}$; U.S. BLM, 2003) for the first 6 years of production. Trends from 1 to 4 months and over 118 months are not considered to be representative of hydrogeologic responses to CBM production.

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 anticipated 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.

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 (Figure 18). After 35 months of production, the gas produced slowly decreases throughout the life of the well. The range of production in wells varies greatly as illustrated by the 90th

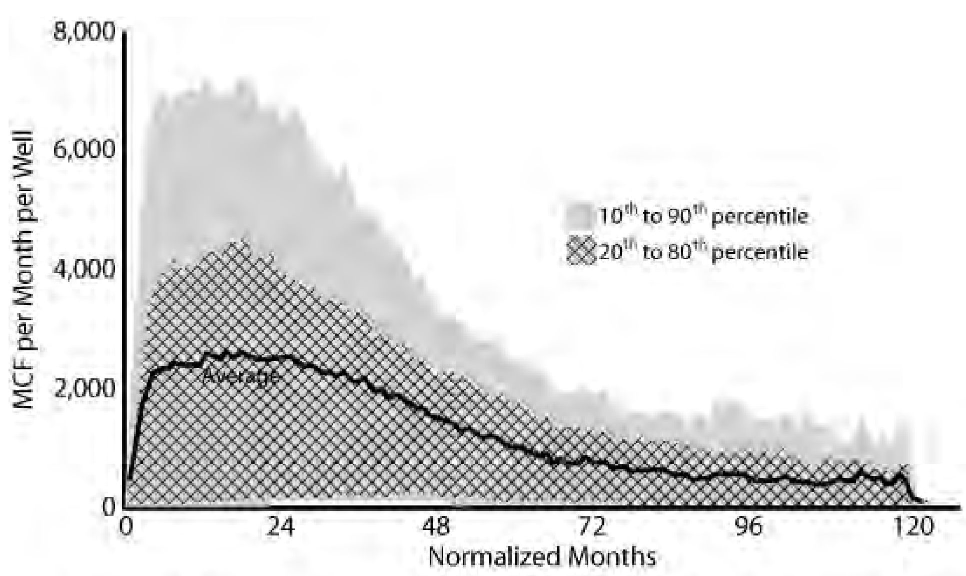


Figure 18. Normalized gas production (MCF) per month for individual CBM wells in the Montana portion of the Powder River Basin (data from MT BOGC web site). Solid line represents the average gas production per well per month.

percentile of production; however, the 80th and 90th average percentiles also follow the same pattern of production. (See also Appendix D for maps comparing water and gas production by location.)

One-hundred, ninety-five CBM wells in Montana have been dormant for at least the last six months (March through September 2009). These wells have either been permanently shut-in or have been temporarily taken out of production. The number of months each of the wells produced either water or gas is presented on Figure 19. The majority of wells produced for 1 to 4 years before being shut-off either temporarily or permanently. A significant number of wells produced for less than 6 months, which may be related to exploration or field development issues. With this limited dataset that does not show a clear bimodal population, it is not possible to determine CBM well life at this time.

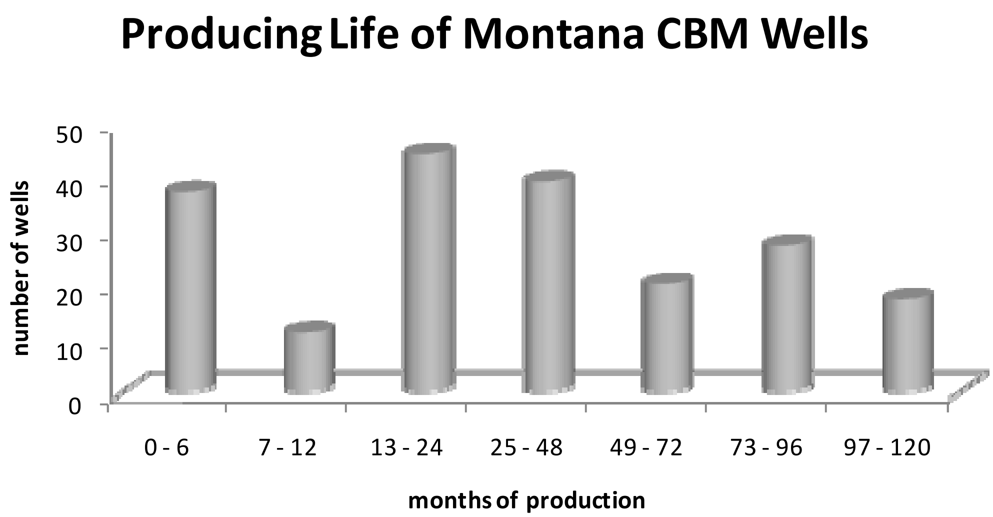


Figure 19. CBM wells are taken out of production for many reasons. This histogram shows the production life of 195 wells in Montana that have not produced water or gas for the last six months (since March 2009).

Total water and gas production since the initiation of CBM production in April, 1999 is presented on Figure 20A. Water production has climbed more steeply than gas production since 2006; this may be due to the large number of new wells coming on-line in 2006 (Figure 20B). The dashed line on Figure 20A represents the water that would have been produced if the rate of water production used in the EIS had been correct. Early production was similar to that predicted by the EIS, however later production was significantly less than predicted. The rate of water production per month decreases in the years immediately following years where few new wells were installed (e.g. 2003). When wells are taken off-line the water production quickly reflects this drop. As the price of methane drops, more wells are taken out of production, such as since mid-2008. The stable gas production rate and the dropping water production rate indicates that the wells being taken out of production produce relatively more water than gas, such as new wells or older wells (Figure 20B).

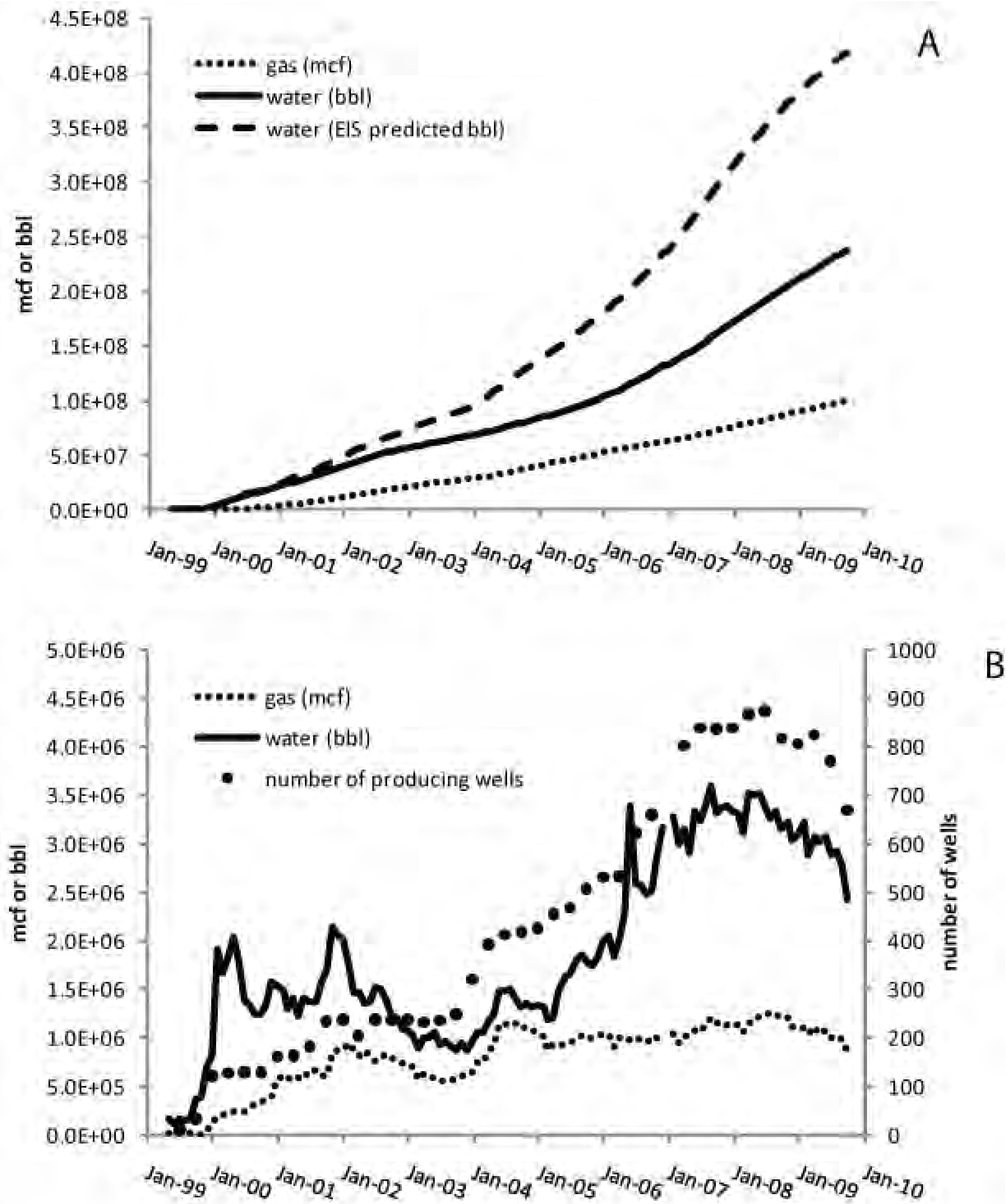


Figure 20A. Total water and gas produced in Montana since CBM production began in the spring of 1999. The dashed line indicates the amount of water that was predicted to be produced based on the EIS rate and the actual number of wells and months produced. **Figure 20B.** Monthly totals of water and gas produced from Montana CBM wells and total number of CBM wells. Water production decreases when few new wells are installed and drops quickly when the number of producing wells decrease.

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 2009, a total of 757 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 total water production for the year was 31.6 million barrels (4,176 acre-feet). Along the western edge of the Fidelity project area near the Montana–Wyoming state line some wells are no longer being used (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. Groundwater 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. Groundwater 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 groundwater levels in the coal seams.

The potentiometric surface for the Dietz coal aquifer 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. This distance has been stable for approximately the last 3 years. 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 near-baseline conditions in 1998. Between 2001 and 2003 groundwater 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 March 2003, the water levels have recovered to within 29

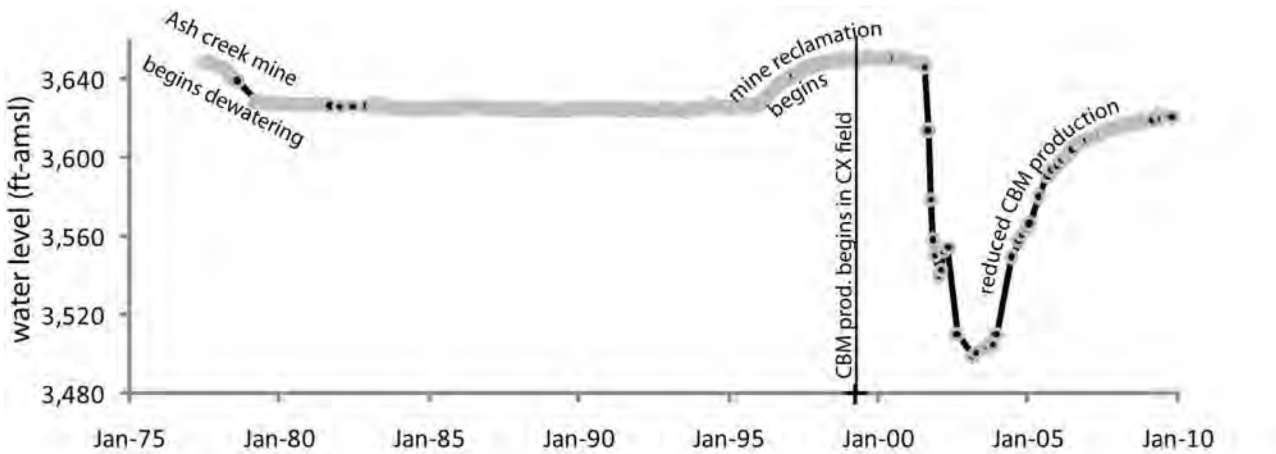


Figure 21. Water levels in the combined Anderson-Dietz coal (WR-34) in the Youngs Creek area respond to both coal mining and coalbed methane production. Water levels began recovering in 2003 in response to CBM production decreases in this portion of the CX field.

feet of baseline conditions. This represents 81 percent recovery during a period of 6.5 years. This recovery appears to be due to a reduction in the pumping rates and the number of producing CBM wells in this area.

Groundwater 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 19 feet of baseline conditions, or a water-level recovery of about 76 percent. 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 a similar response but from opposite direction 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 lowest recorded water level was 161 feet below baseline in May 2006. Since then, the water level has risen and fallen and is currently138 feet below baseline. Since February 2009 the downward trend of the water level has stopped. 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

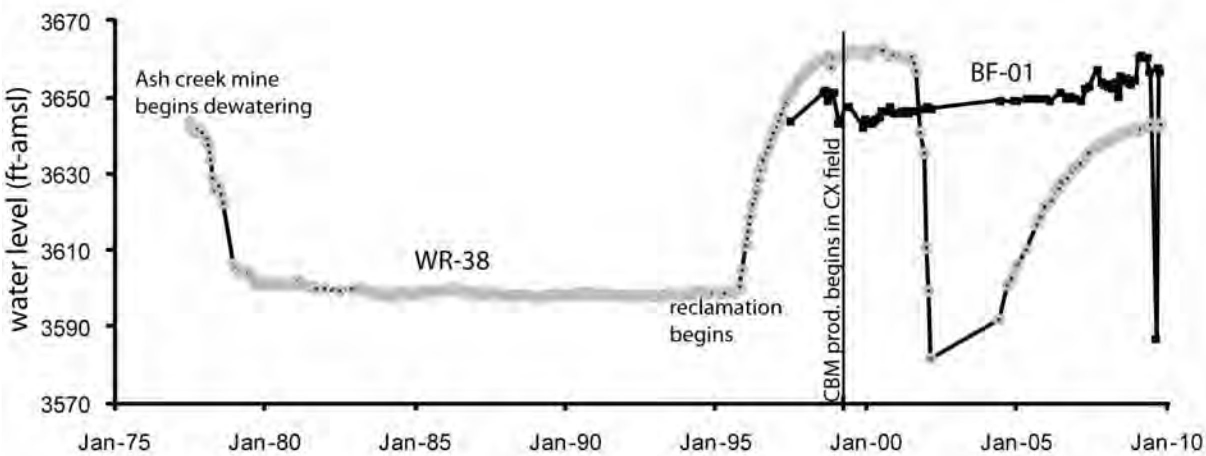


Figure 22. Water levels in the Dietz coal (well WR-38) decreased by 80 feet in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to lowered water levels. This illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses to drawdown. Please note: August 2009 water level in BF-01 is a pumping level.

other and there may be some communication between them. Reduced pressure from coal mining may have migrated around the end of the fault or the reduced pressure from CBM production from the Anderson coal has lowered the pressure in overlying aquifers.

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 15.9 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 above 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 3.9 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. Most likely due to reduced CBM activity in the area, water levels in three coal aquifers (WRE-12, WRE-13, PKS-1179) have shown recovery since September 2008. 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, but is most likely simply a function of the greater head available for drawdown in the deeper 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 3,414 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 average stage during the water year 2009 was 3422, which is higher than the historical average because goals for reservoir storage have increased recently. This creates a greater gradient between the head of the reservoir, which is increasing, and the Dietz coal, which is decreasing due to CBM production, and will most likely result in more water seeping into the coal from the 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 (8 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 7 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 28) including one sampling during summer 2009. The TDS concentration increased from 2,567 mg/L in 1991 to 3,668 mg/L in 2009 and the SAR decreased from 42.5 in 1991 to 24.3 in 2009 (with intervening years having lower values). 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.

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. Farther downstream, in the CBM production area (WR-52D), the water levels in the alluvium were stable until 2000 when levels increased by approximately four 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 November 2008 and June 2009 (appendix C). The TDS concentrations increased from 5,714 mg/L in June 1991 to 6,715 mg/L in June 2009, an increase of 17 percent; the cause of these changes is unknown at this time (See Section Water-Quality Trends in Watersheds). The SAR value increased from 5.6 to 6.2 over the same time period. The water chemistry is dominated by sodium, magnesium, and sulfate.

Water-quality samples were collected from alluvial monitoring well WA-2 near Birney Day Village in December, 2008 and June, 2009 (appendix C). This well is down-gradient from CBM activities on the Tongue River. The TDS concentration has dropped from 1,764 mg/L in August, 2008 to 1,722 mg/L in June, 2009. The SAR value was 21.7 in both of the samples collected this water year. Since August, 2006 the SAR of the water has fluctuated; however, the rise seen last water year has not proven to be a trend (Meredith and others, 2009). The water chemistry is dominated by sodium and bicarbonate.

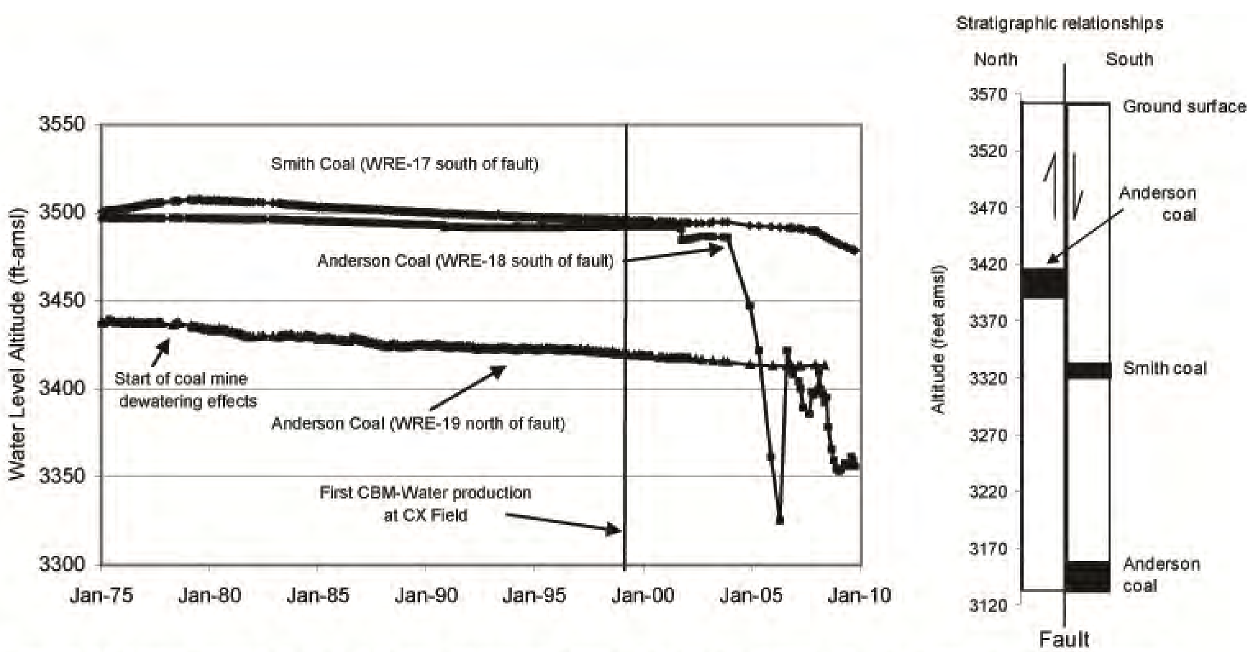


Figure 23. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured south of the fault at WRE 17 (Smith coal) since the mid 1980's. The pressure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

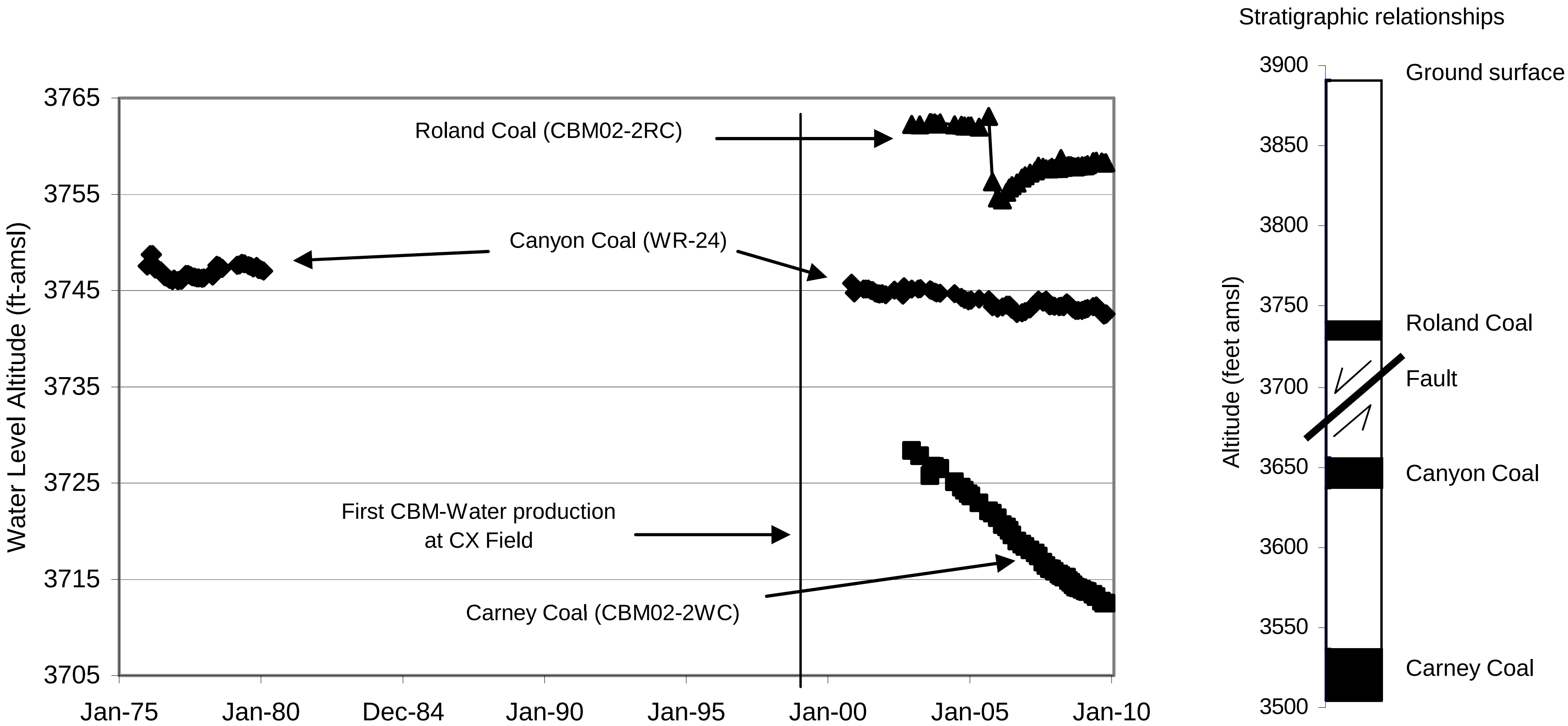


Figure 24. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM related drawdown since its installation. 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.

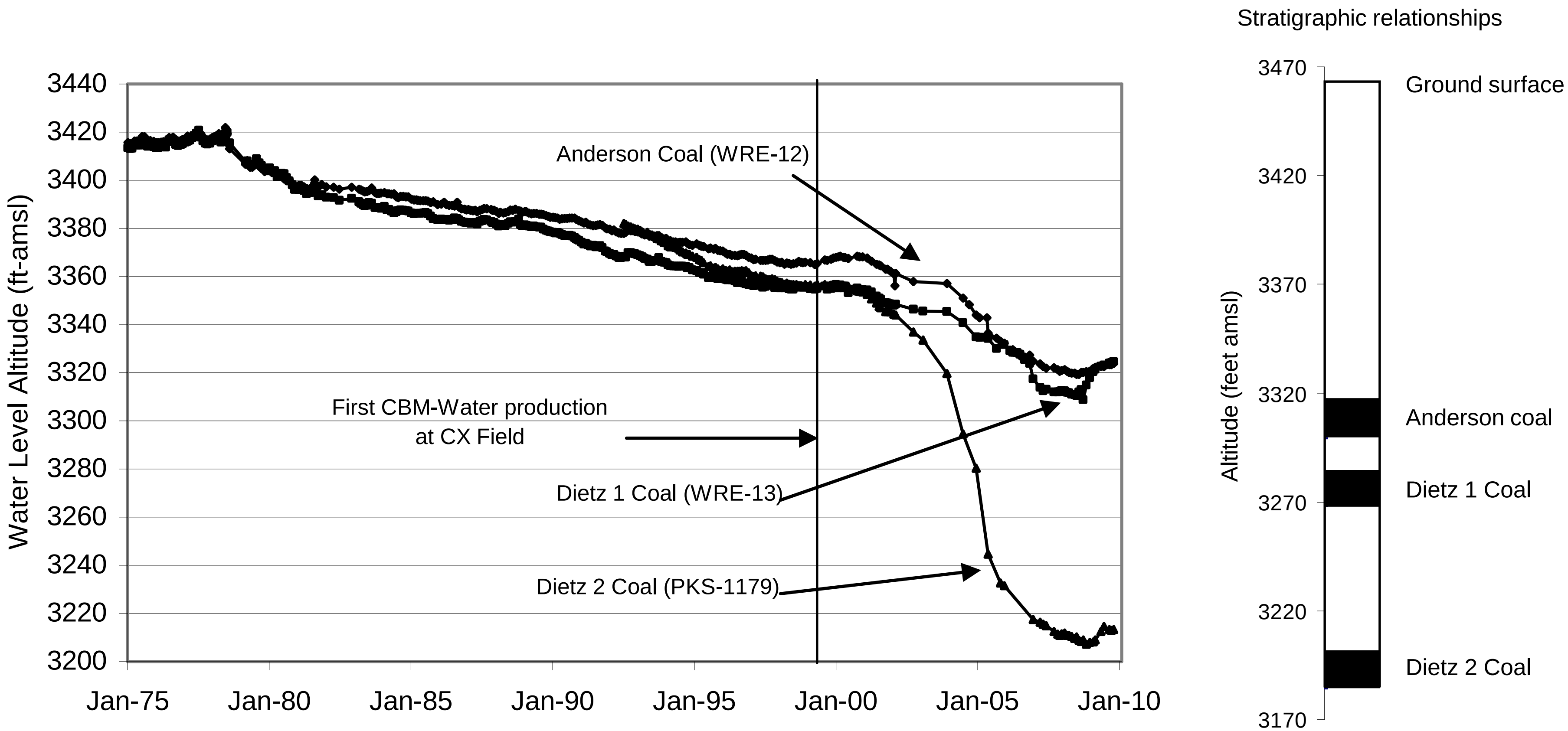


Figure 25. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

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

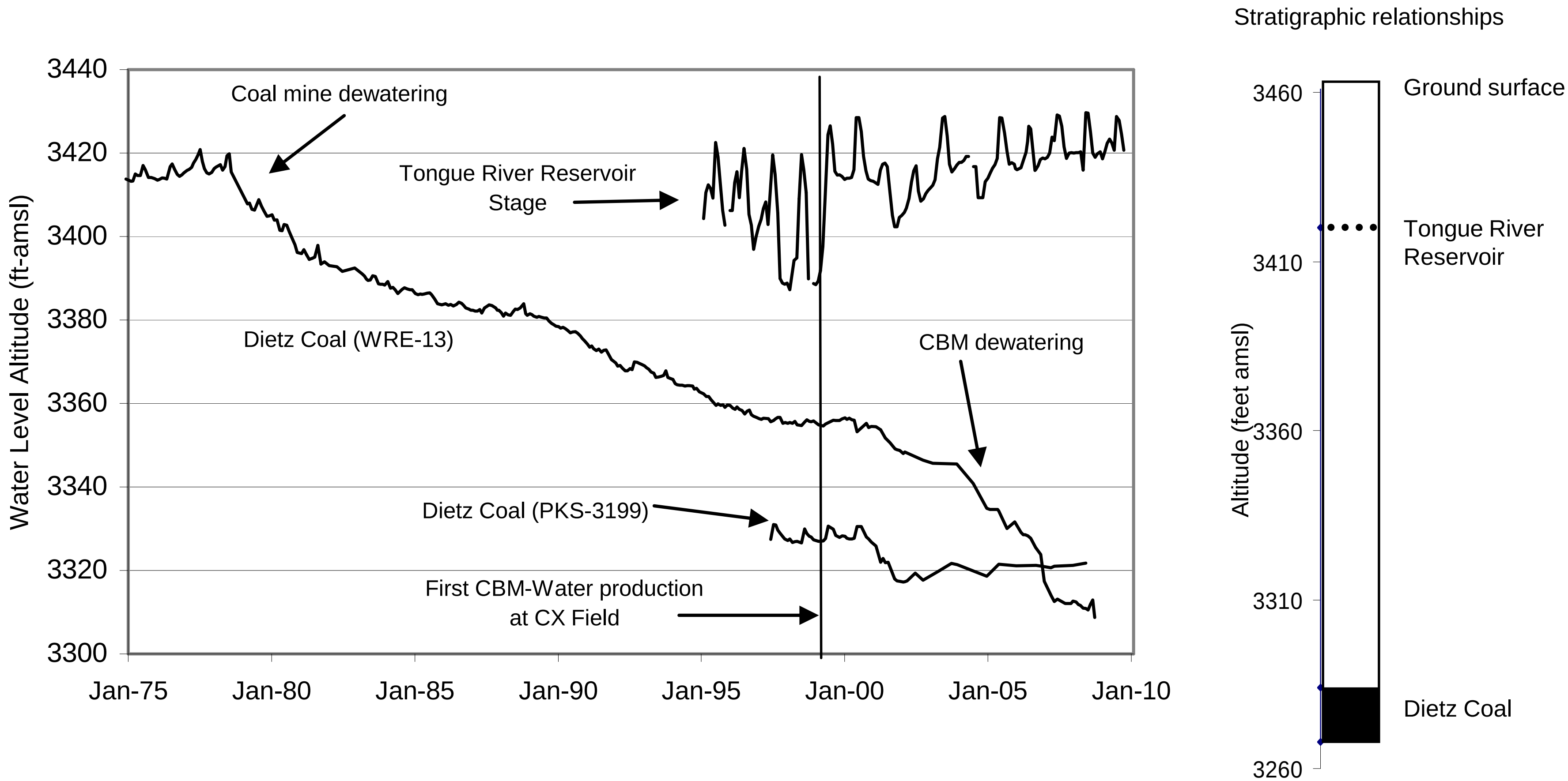


Figure 26. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present. Fluctuations may be related to pressure or water movement.

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

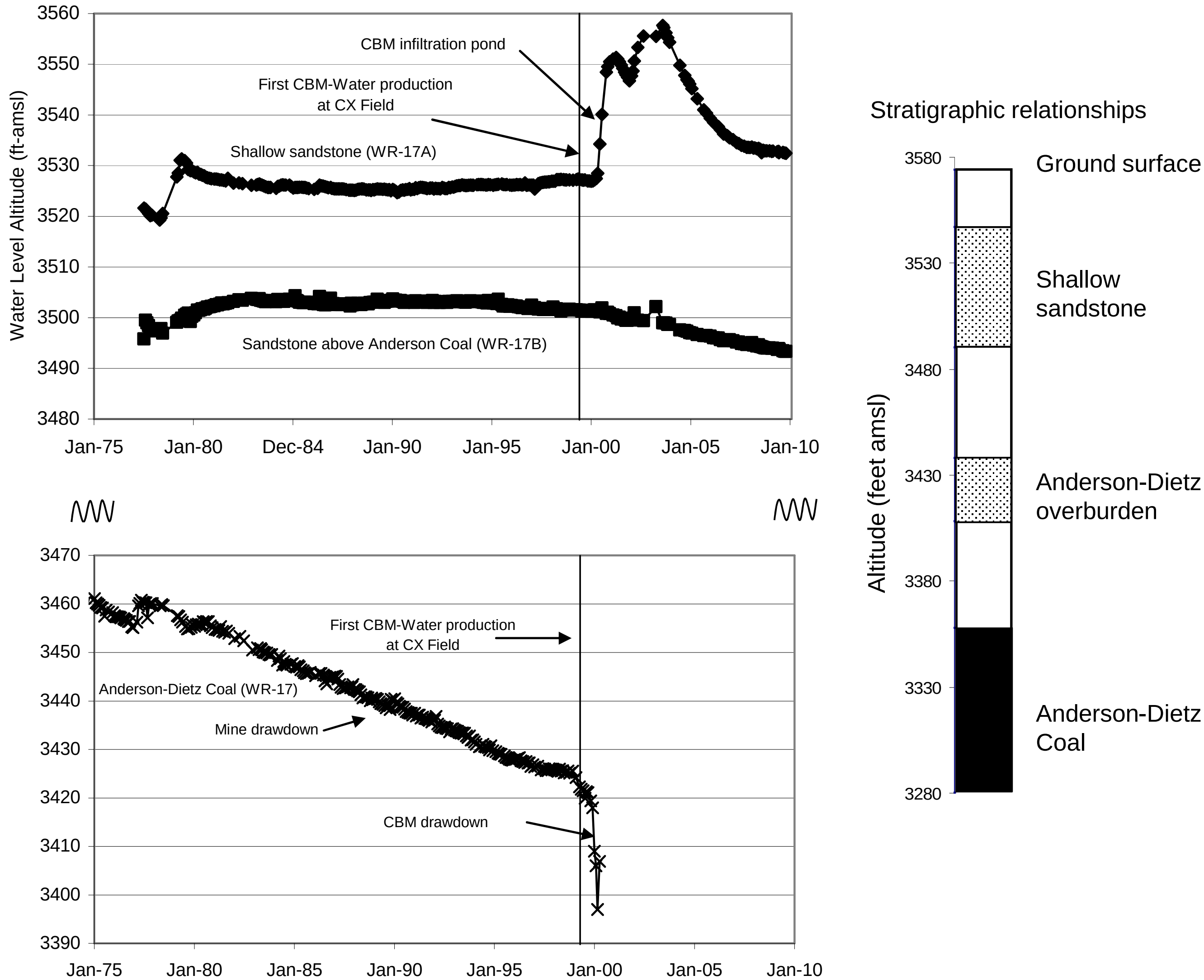


Figure 27. The rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water, therefore the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in 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.

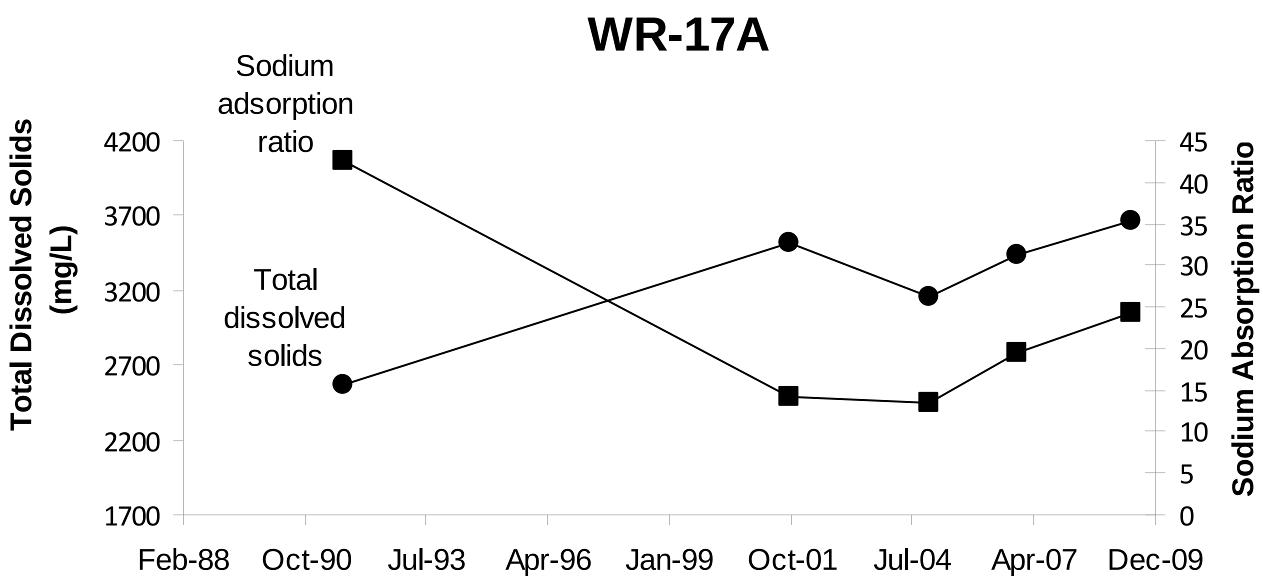


Figure 28. Water quality samples have been collected periodically from WR-17A . As the water level increased at WR-17A (see figure 26) the TDS also increased. At the same time the SAR is decreased due to the dissolution of calcium and magnesium salts.

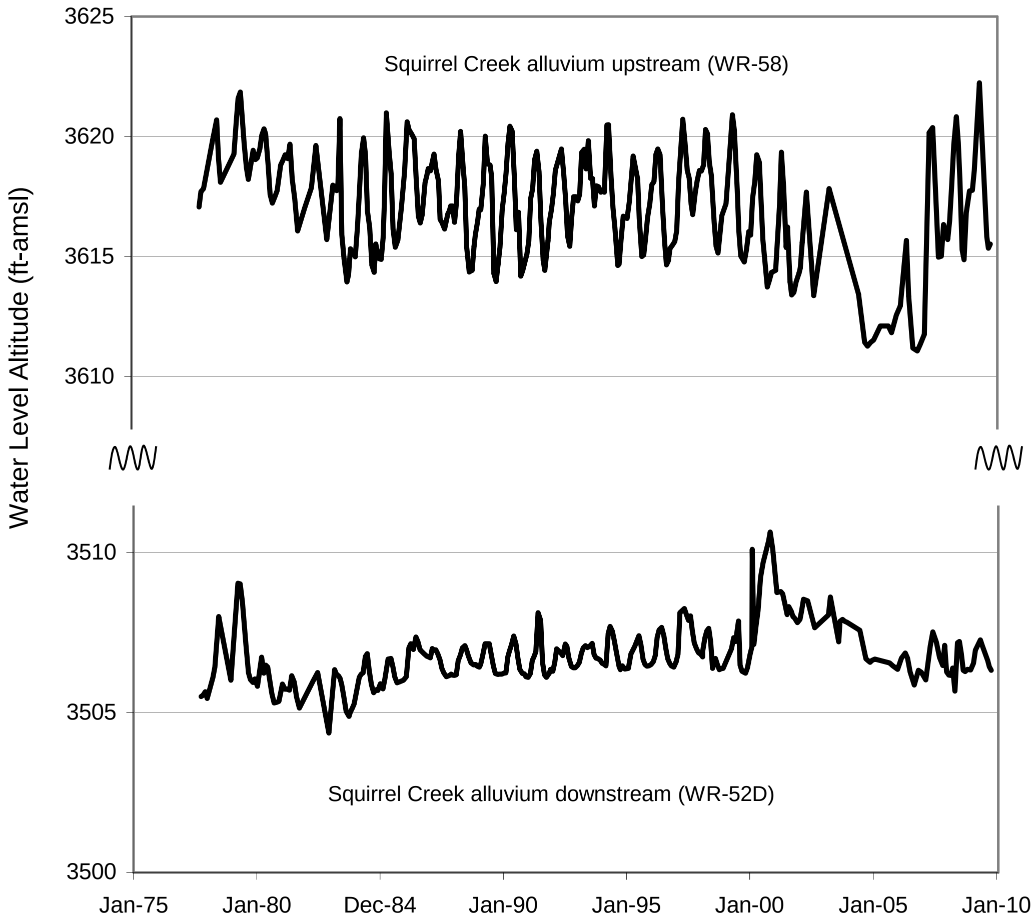


Figure 29. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall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

Coalbed 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 (2009). 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 2009, a total of 30 CBM wells produced water in the Coal Creek field (Table 4). Production was from the Wall and Flowers-Goodale coalbeds (Figure 2). The total water production for the 12-month period was 2,055 million barrels (265 acre-feet).

A total of 96 CBM wells produced water in the Dietz field during 2009 (Plate 1, Table 4). Production is from the Dietz, Canyon, Carney, and Wall coalbeds (Figure 2). The total water production for the 12-month period was 1,790 million barrels (231 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, 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 (no longer shown, see Meredith and others, 2008). It is now believed that this is not a true representation of the water level, but an artifact created by the failing logger. The drop occurred directly before the logger quit and does not appear to represent actual aquifer behavior. 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. The MBMG and BLM have decided to remove this data from the GWIC database. Water levels in the sandstone overburden wells at this site show no response to CBM production (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).

Water-quality samples were collected from Upper and Lower Anderson Springs in June 2009 and from Lower Anderson Spring in October 2008. Water quality is quite different between the two: Upper Anderson had a TDS concentration and SAR value of 4,010 mg/L and 8.6, respectively, in June 2009, while Lower Anderson had TDS and SAR values of 1,515 mg/L and 3.2 in June, 2009. These springs discharge from the Anderson coalbed. 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 (B. Musgrave's property) and was sampled most recently in October 2008 and June 2009 (appendix C). The TDS concentration has a wide variation which could be natural or controlled by dam releases. The upward trend in TDS from September 2006 to October 2008 (747 to 1074 mg/L) was not seen in the most recent sample taken in June 2009 (776 mg/L), which serves to reiterate the importance of regular monitoring. 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.

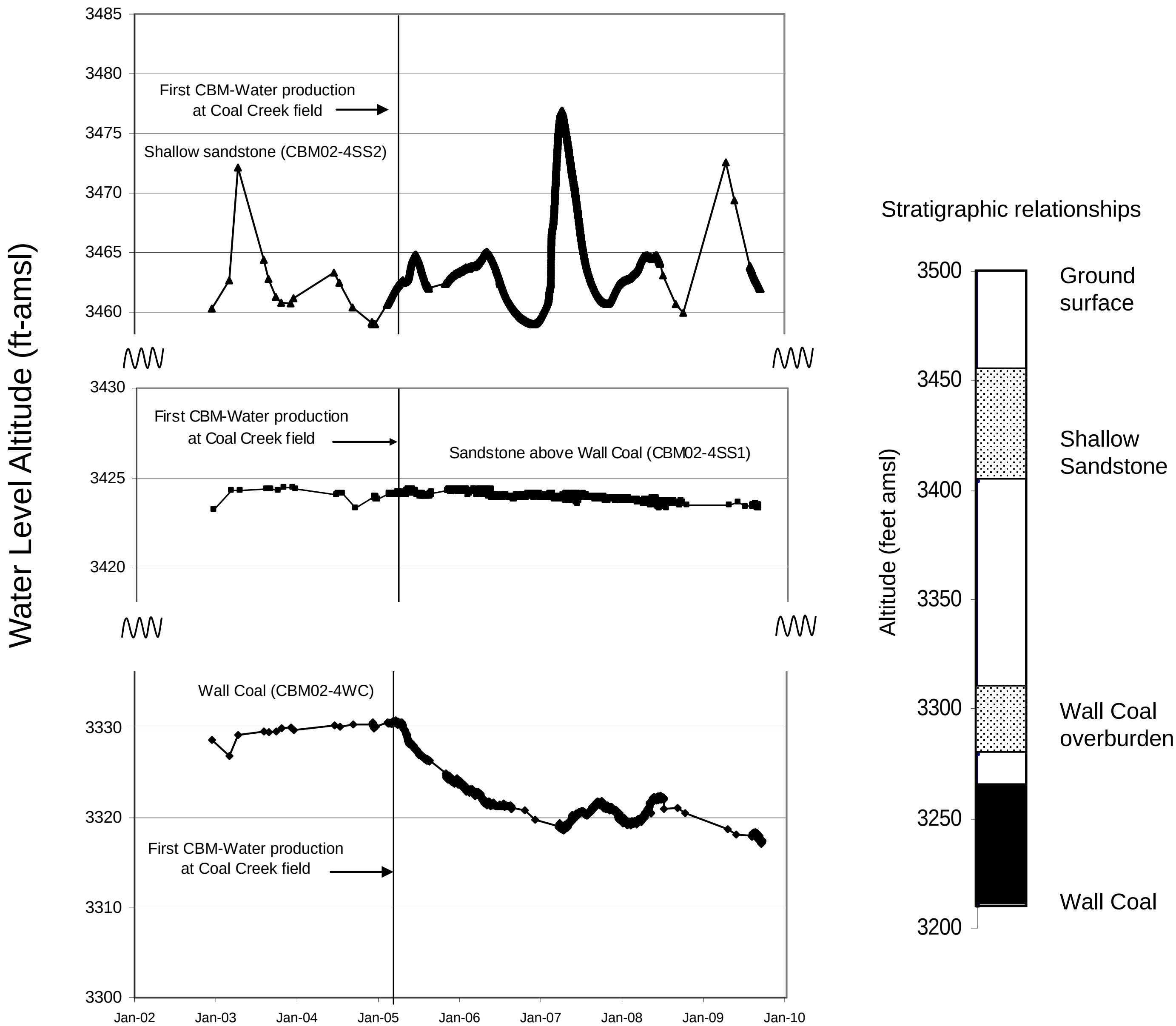


Figure 30. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower sandstone may be.

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

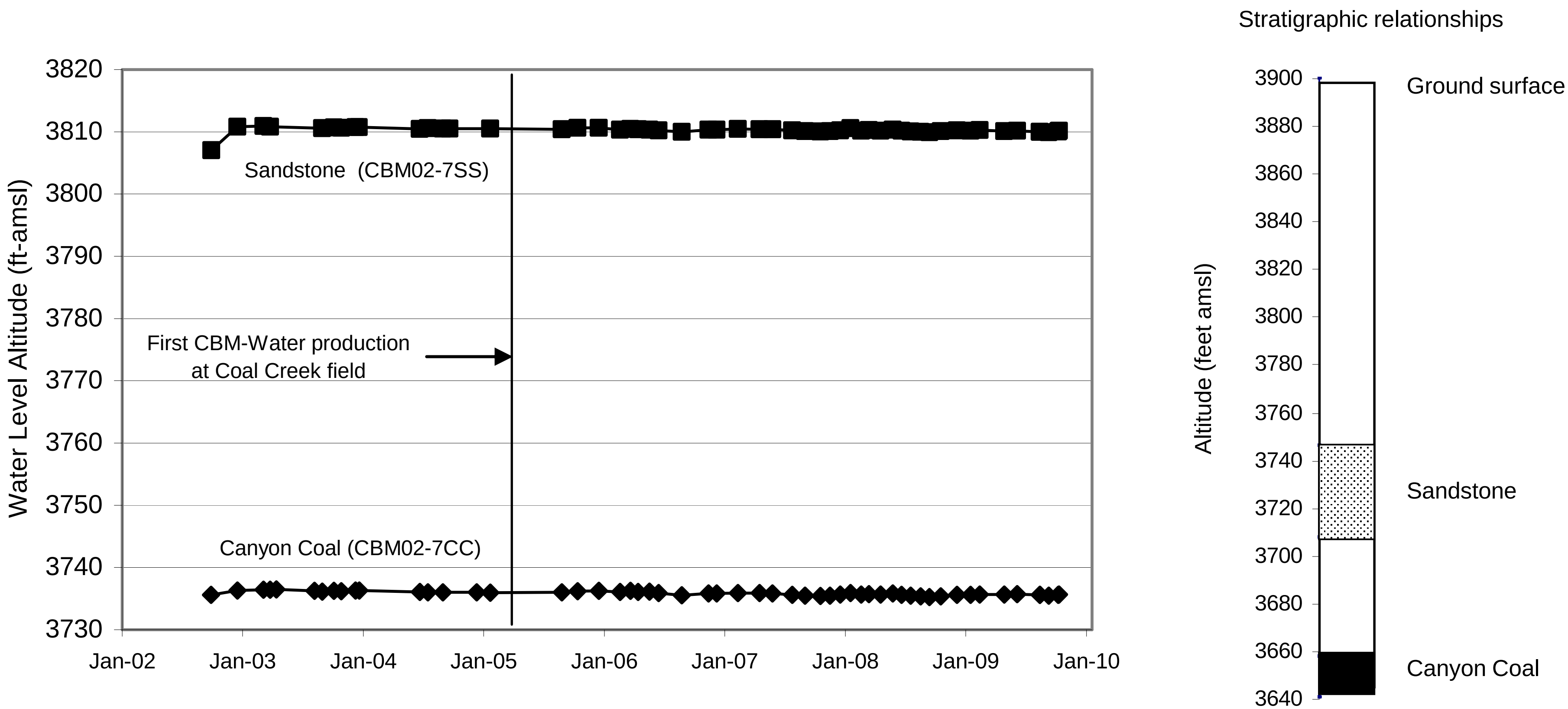


Figure 31. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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 Conservation 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

Coalbed methane water production. The Prairie Dog Creek field is located in Wyoming south of the CX field in Montana. Methane is produced from the Roland, Smith, Anderson, Dietz, Canyon, Carney, Cook, King, and Flowers-Goodale (Roberts) coalbeds (Figure 2). During 2009, a total of 1,348 CBM wells produced methane and/or water in the Prairie Dog Creek field. Cumulative production for the year was 45.0 million barrels (5,807 acre feet; Figure 32). Per-month water production in the field peaked in mid-2002. For the next five years the water production fluctuated between 500 and 600 acre-feet per month; however, since August 2008 the water production has fallen steadily and water production is currently close to 400 acre-feet per month. Gas production rose fairly consistently until early-2008, after which the gas production has fallen slightly. Gas production, however, has not fallen as sharply as water production, most likely because high-water-producing and low-gas-producing wells have been preferentially taken off-line (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

Coalbed 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 2009, a total of 213 CBM wells produced methane and/or water in the Hanging Woman Creek field. The total water production for the 12-month period was 19 million barrels (2,484 acre feet). Water production began to climb in November of 2004 reaching a peak in September of 2007 with 319 acre-feet per month (2.5 million barrels; Figure 32). Since that time, water production has fallen to less than 200 acre-feet per month. Gas production has been low throughout the life of the field.

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 61 feet at this site in response to CBM production (Figure 34). The water level in the Smith coal has also dropped (11 feet); however, the cause of this drop is unclear. Vertical migration of changes in hydrostatic pressure does not seem likely given the short time. The installed data logger 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 feet 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 23 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 from wells HWC 86-13 and HWC 86-15 during November 2008 and June 2009 (appendix C). For the two sampling events, the TDS concentrations in the alluvial water range from 6,644 to 8,662 mg/L and SAR values range from 10.7 to 11.2. The water chemistry in the alluvium is dominated by sodium and sulfate. There is a natural variation of approximately 1000 mg/L in both these wells since sampling began in 1987 (See Section Water-Quality Trends in Watersheds). Water-quality samples were collected on North Fork Waddle Creek at SL-3Q during December 2008 and June 2009 (appendix C). TDS concentrations have not varied much since sampling began in 2005, and during these sampling events were 3,552 and 3,661 mg/L, respectively and SAR values were both 5.1 and 5.3. The water chemistry is dominated by sodium and sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site. Approximately 20 miles down-stream, well HWC86-7 was sampled in November 2008 and June 2009. The TDS was 3,989 mg/L and 3,653 and SAR was 8.6 and 8.1, respectively. Since sampling began in 1987, the TDS has generally increased, but the latest sample collected in June 2009 was less than in November 2008; however, future monitoring will be required to determine if these values represent a trend or natural variation. 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

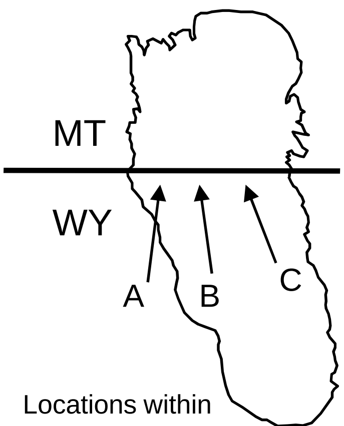
Coalbed methane water production. Near the Powder River (Plate 1), CBM is being produced from the combined Anderson and Dietz (Wyodak), Canyon, Cook, Wall, Pawnee, and Cache coalbeds (Figure 2). During 2009, a total of 554 wells produced methane and/or water in this area. The cumulative production for the 12-month period was 40 million barrels. Water production in the fields near the Powder River increased steadily from January 2004 through July 2008, and peaked at just over 500 acre-feet per month. Current production as of September 2009 is just over 400 acre-feet per month (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. Water level data loggers will be installed in these two Canyon coal monitoring wells.

Alluvial-aquifer water levels and water quality. South of Moorhead, Montana groundwater 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 SL-8-2Q and SL-8-3Q in October 2008 and June 2009 (appendix C). TDS concentrations ranged from 1,971 to 4,231 mg/L and SAR values ranged from 3.2 to 5.8. 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.



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

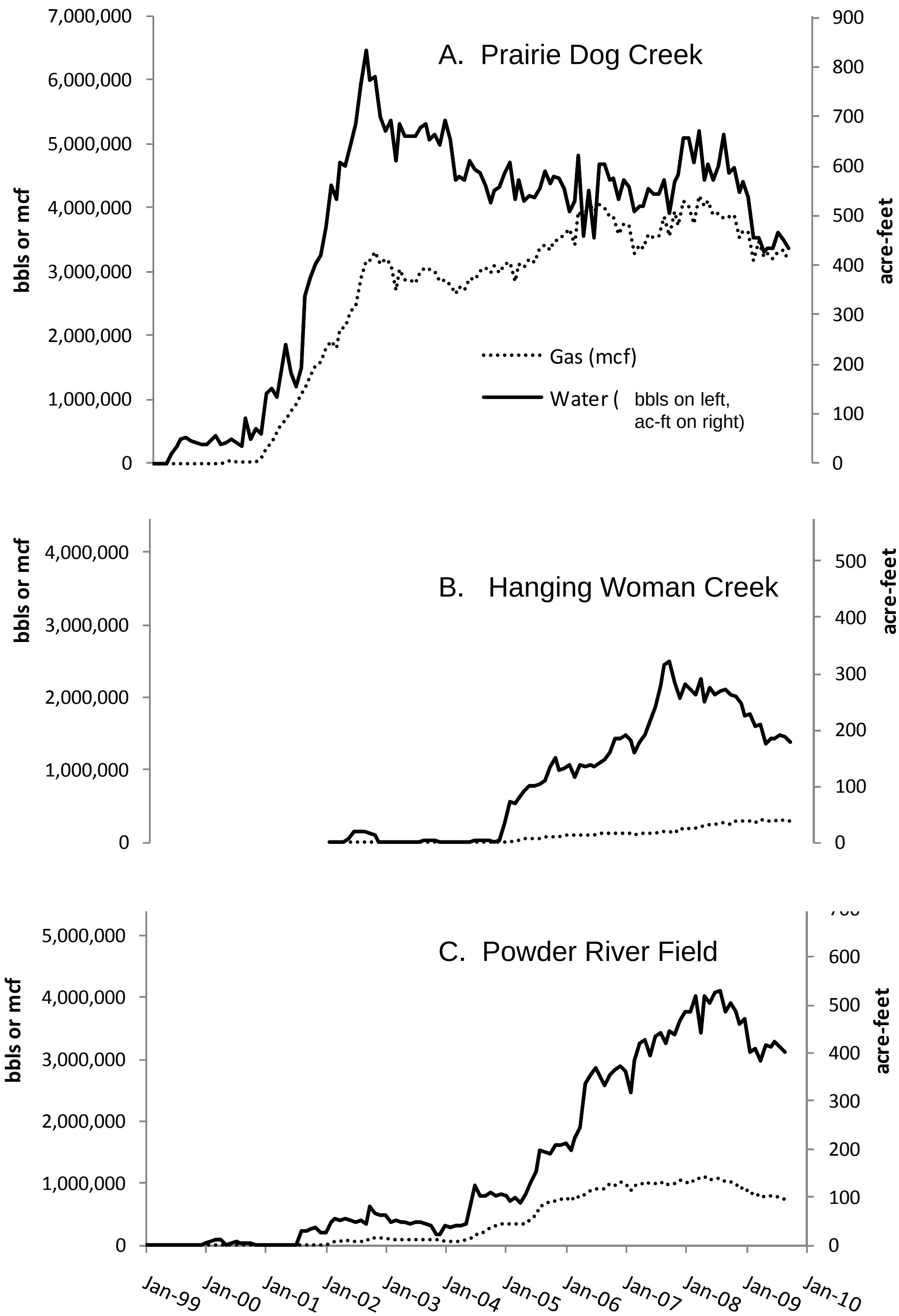


Figure 32. Total water (solid line) and gas (dashed line) produced per month in Wyoming CBM fields. Wyoming development is increasing to the east by the Powder River.

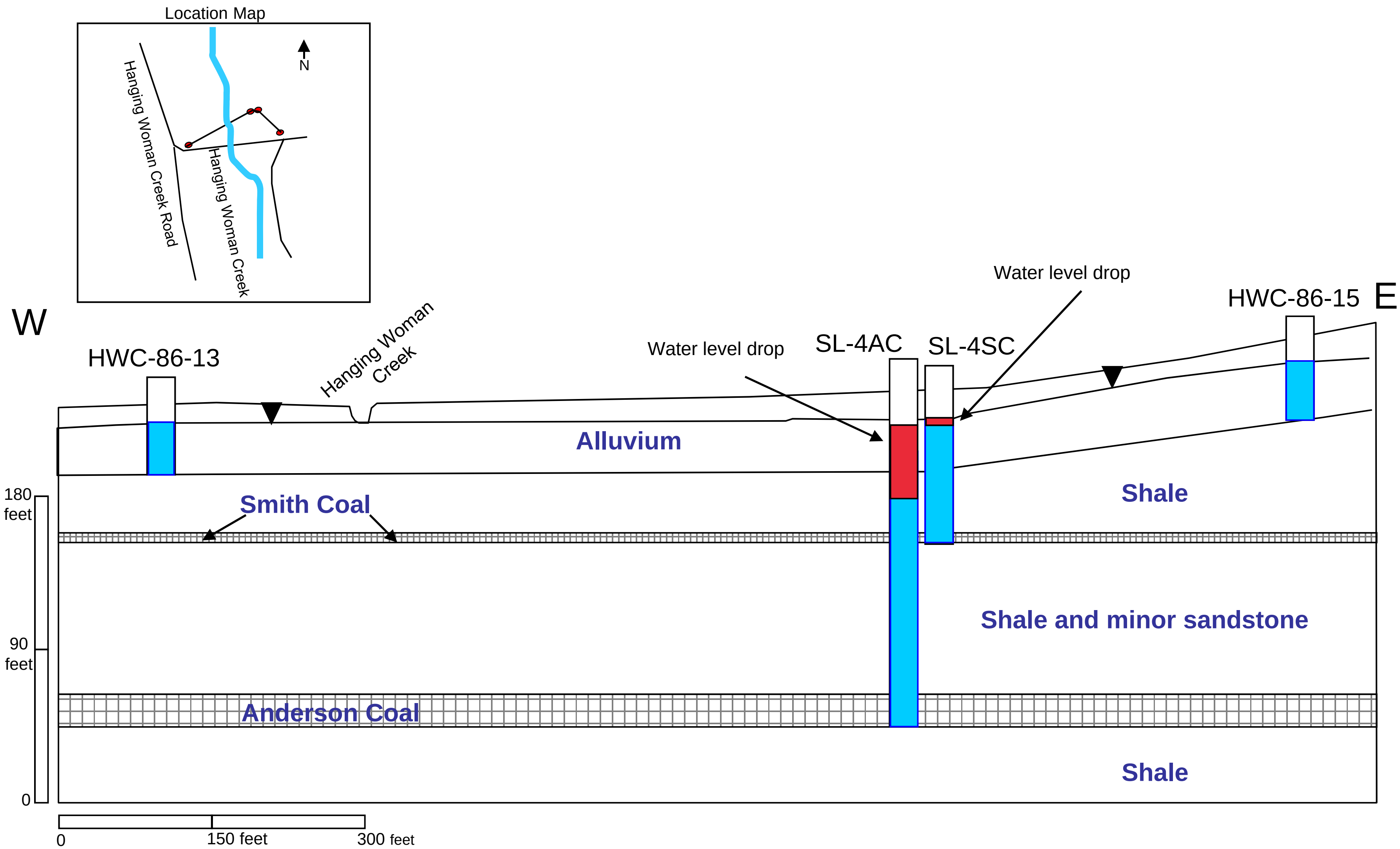


Figure 33. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 61 ft and the Smith has lowered about 11 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.

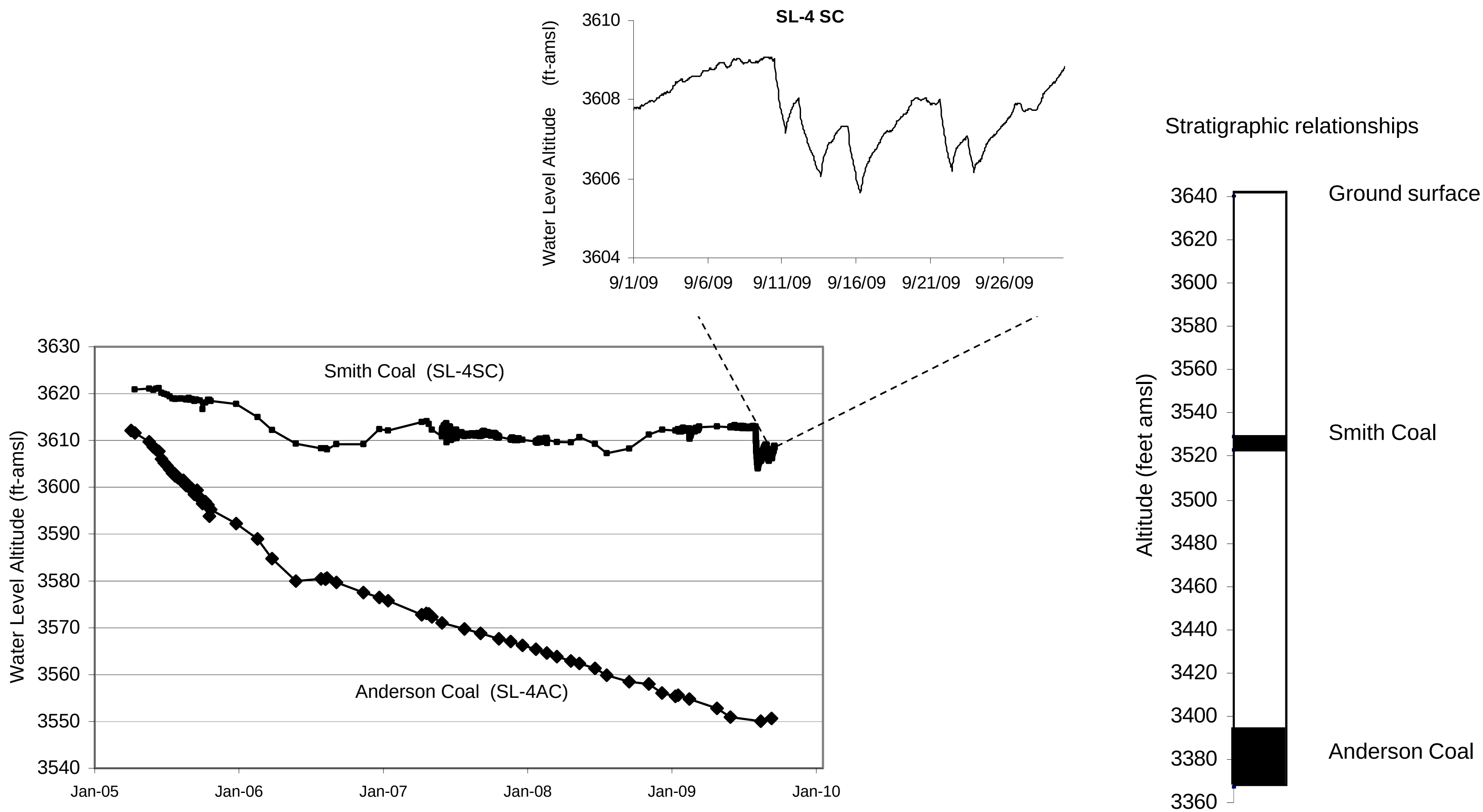


Figure 34. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson Coal appear to have lowered about 61 feet since April 2005 in response to CBM development; however it is unclear if true baseline was obtained prior to impacts occurring. Water levels in the 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. 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.

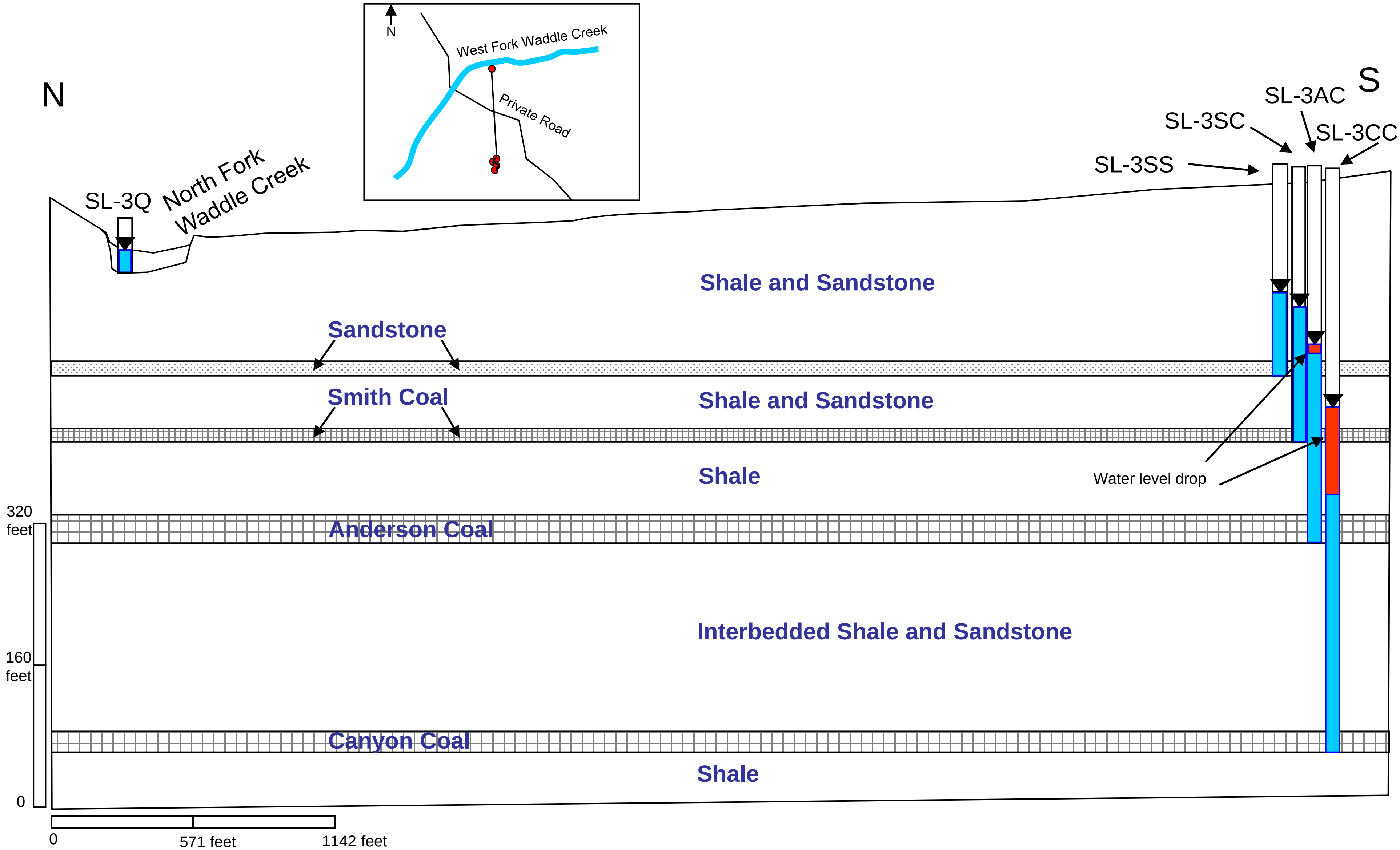


Figure 35. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coal beds located at T9S R42E section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in December 2007. The water level in the Anderson Coal has lowered about 23 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.

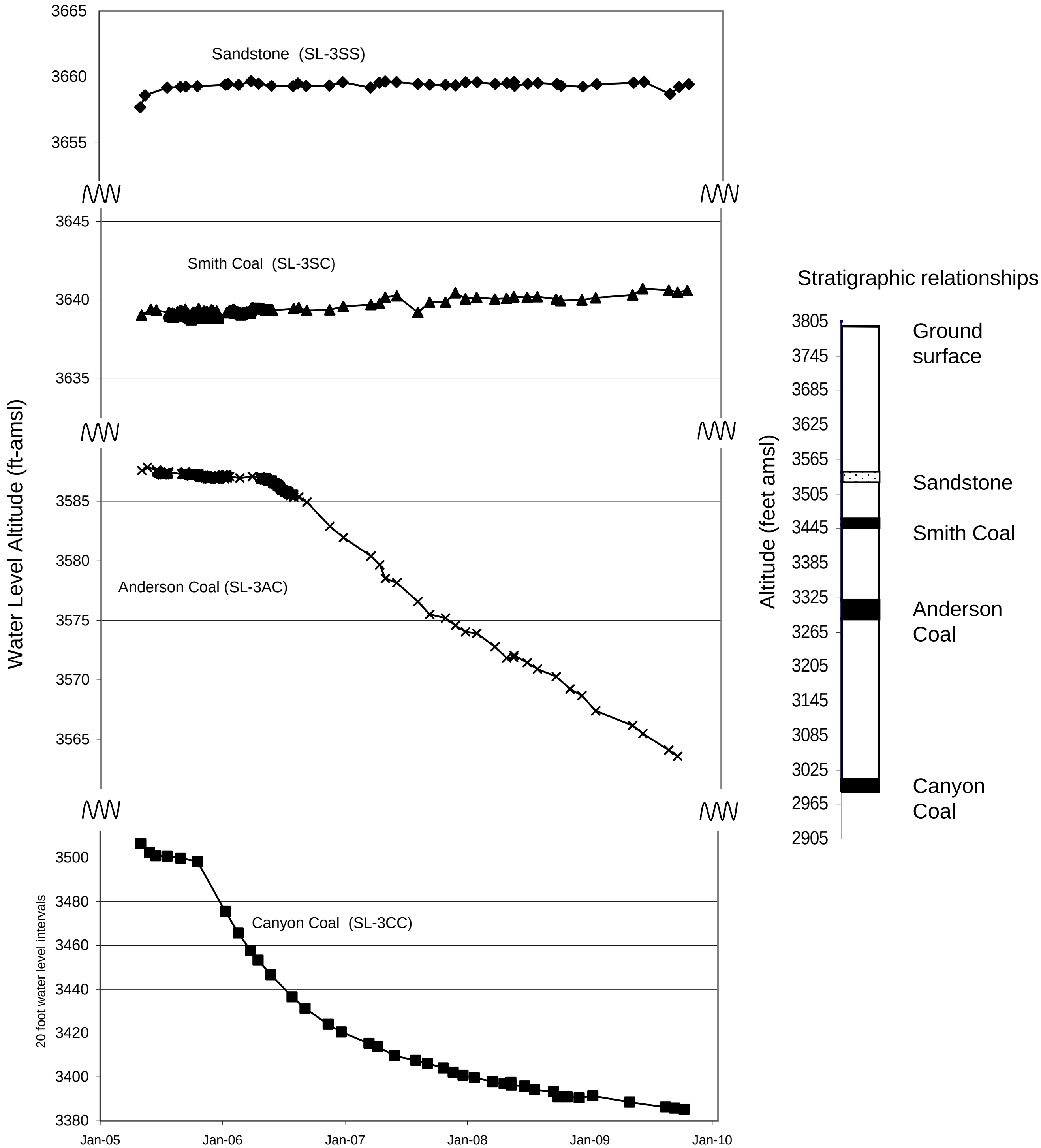


Figure 36. Water levels in the overburden sandstone and Smith coals are not responding to CBM development. However the water level in the Anderson and Canyon Coal have dropped about 23 and 116 feet respectively in response to CBM production.

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

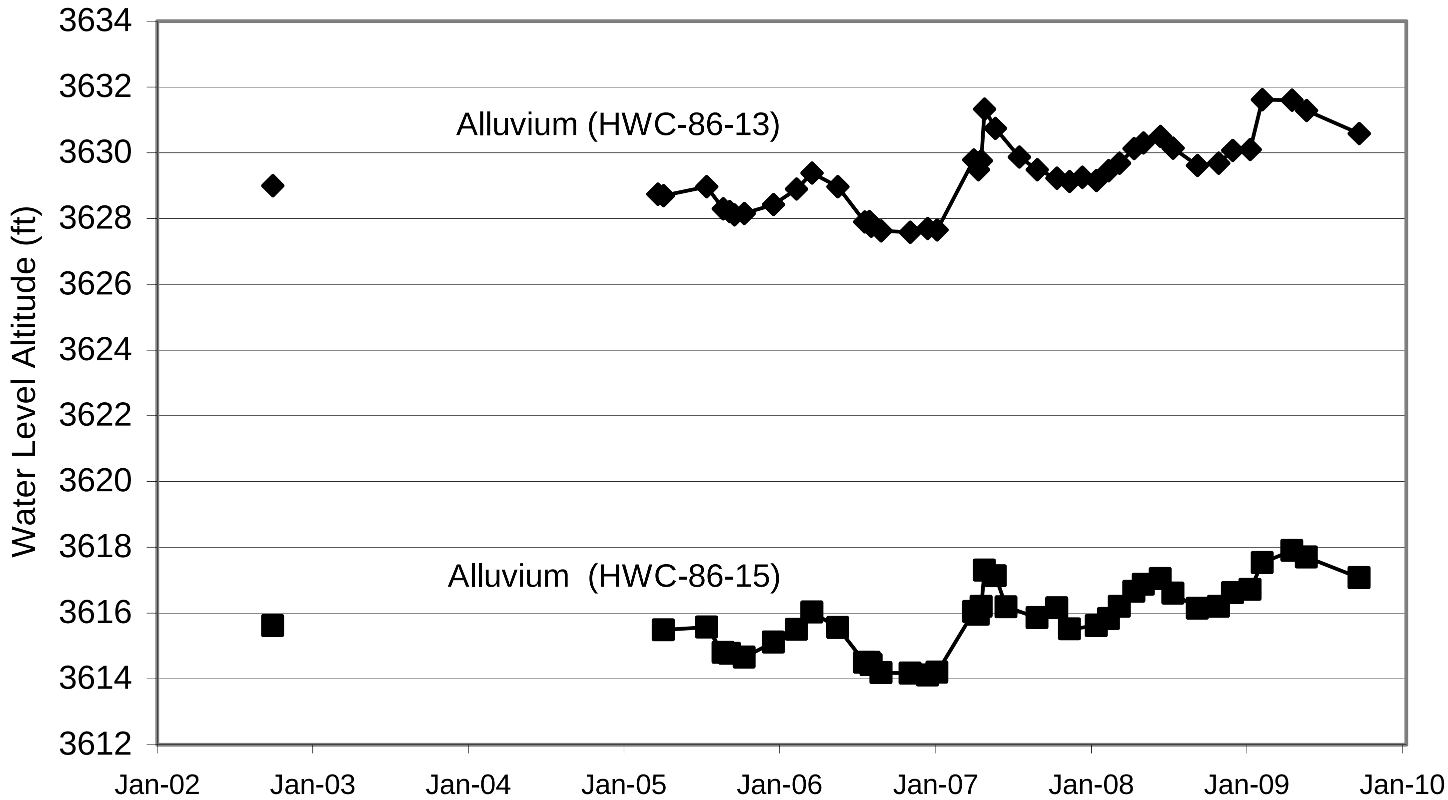


Figure 37. The water level in the Hanging Woman Creek alluvial aquifer near the Montana – Wyoming state line reflects water table response to meteorological pattern. Refer to figure 32 for site location.

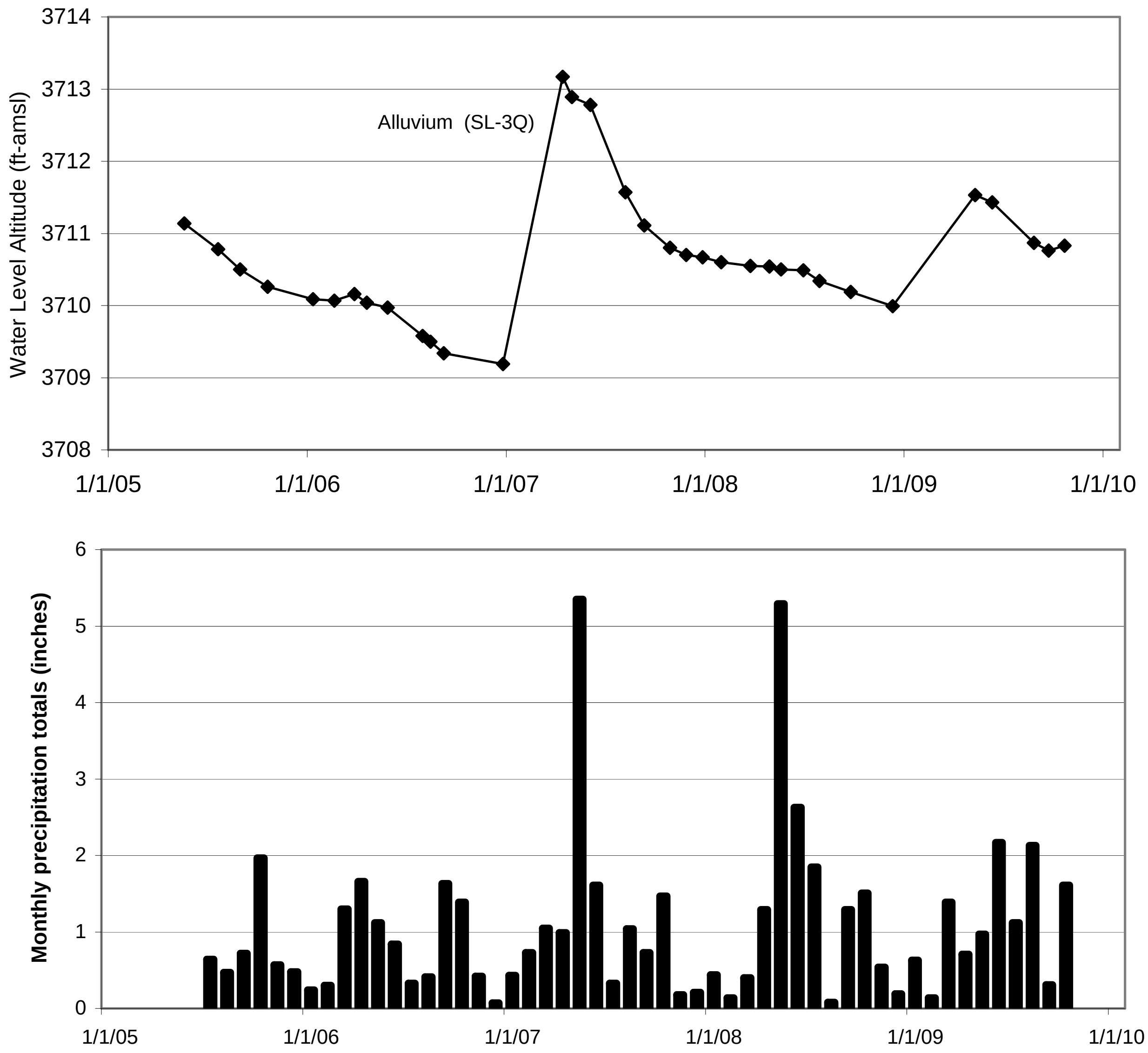


Figure 38. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to figure 34 for site location. Monthly precipitation totals in inches is displayed on the lower graph.

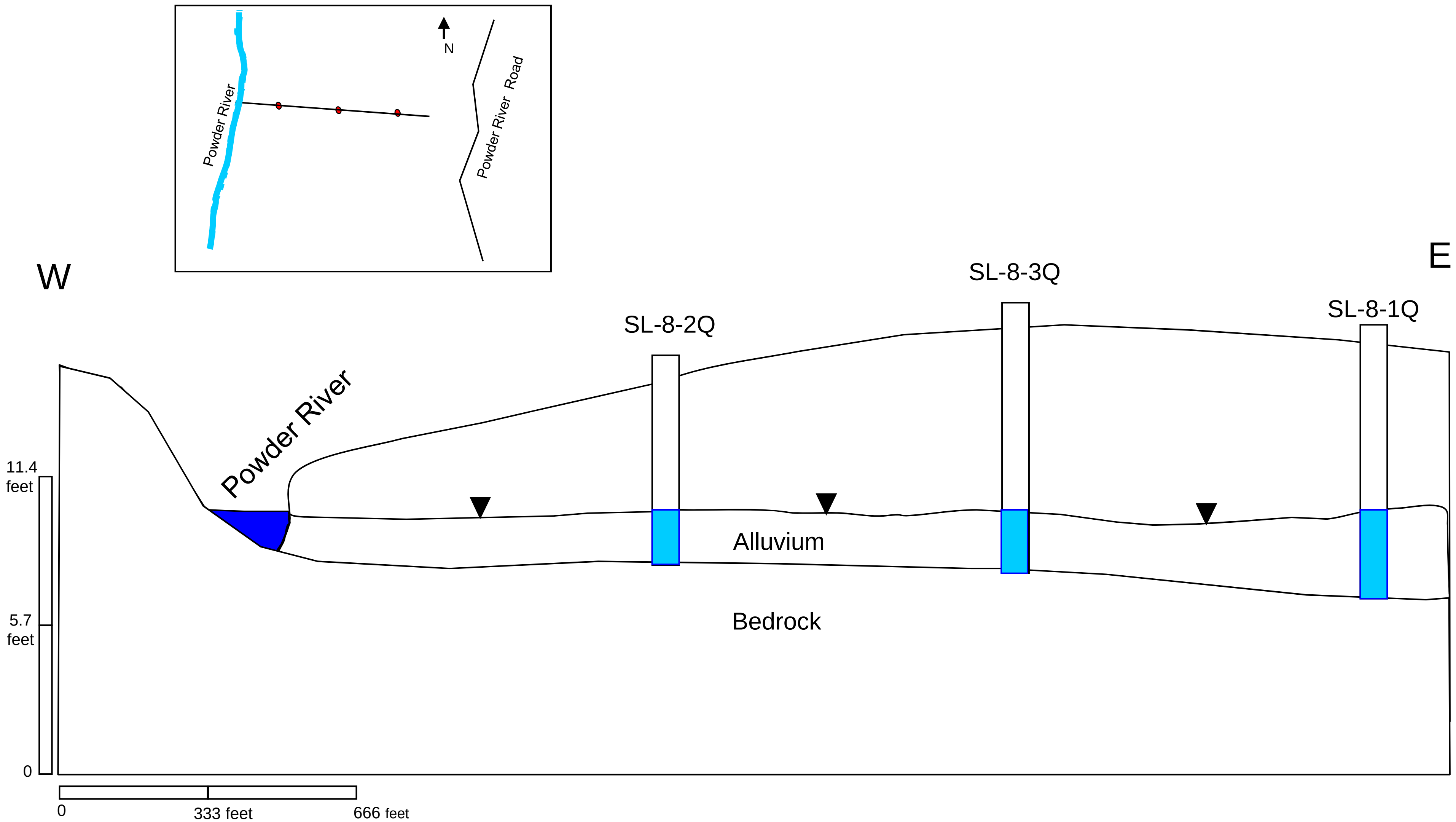


Figure 39. Cross section of alluvial wells south of Moorhead near the Powder River located in T09S R47E section 25. Groundwater in the alluvium appear to flow parallel to the river. Water levels for this cross section were taken in January 2007. Vertical exaggeration is 58:1.

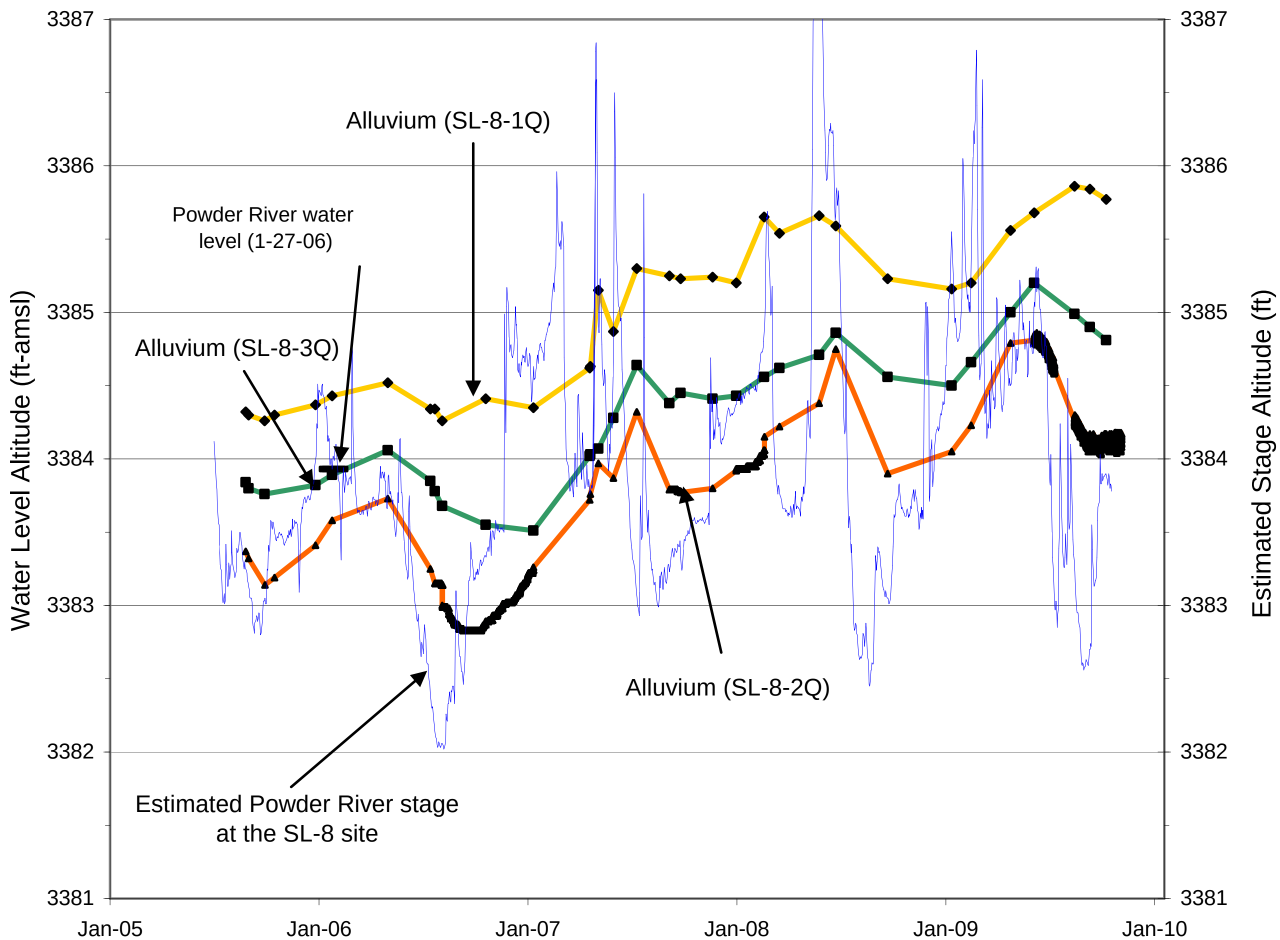


Figure 40. Ground-water flow in the alluvial aquifer at SL-8 is generally toward the Powder River. The ground water-level trends follow river stage trends. The river alternates between gaining (summer) and losing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gaging station (USGS data) and the surveyed river water-level altitude at SL-8 on 1/27/06.

Water-Quality Trends in Watersheds

Several wells were identified in the 2008 Annual Coalbed Methane Regional Groundwater Monitoring Report as showing trends in water quality that may indicate impact from coalbed methane development, but could also simply reflect natural variation. These chemistry changes were taken into account when determining which wells would be included in the semiannual groundwater sampling trips. More wells were incorporated into the sample set that are up-gradient from two of the potentially impacted wells to help identify the extent and, perhaps, cause of the changes. Wells identified as having possible water-quality impacts include:

- Well WR-59 near the confluence of Squirrel Creek and the Tongue River, therefore up-gradient alluvial wells WR-52B and WR-58 were included.
- Well HWC86-7 along Hanging Woman Creek near the confluence with the Tongue River, therefore up-gradient alluvial wells HWC 86-2, HWC 86-13 and HWC 86-15 were included in the sample set.

Squirrel Creek

Groundwater salinity tends to be higher in lower reaches of the in the Squirrel Creek watershed (Figure 41) as opposed to the upper reaches. Higher in the watershed, well WR-58 is over 5 miles from the Tongue River confluence and has had consistently low TDS and SAR values throughout its sample history including samples collected in 1980, 1993 and 2009. In contrast, well WR-59 has had high salinity (over 5,000 mg/L) since sampling began in 1991 – prior to CBM development in the watershed. However, the six samples collected from 2006 through June 2009 have shown progressively higher salinity levels. Historical data from well WR-52B may indicate that this watershed has highly variable salinity. All samples collected from WR-52B show the TDS varies between nearly 5,000 to approximately 6,500 mg/L. The SAR values in the lower Squirrel Creek watershed tend to be between 5 and 7 with the exception of the sample collected in 2001 from WR-52B. This particular sample not only has the highest SAR for all wells in the area, but also has the lowest TDS of the samples collected from this well. Higher SAR and lower TDS can be a fingerprint for CBM impacts; however, all subsequent samples have shown water qualities similar to baseline. At this time evidence does not suggest that the alluvial aquifer these wells monitor is being impacted by CBM development. Further monitoring of wells WR-52B and WR-59 is recommended to ensure the variation in salinity level is natural. In addition, a well farther up-stream, in T08S R39E sec 32 such as well WR-21 (plate 1), may be valuable.

Hanging Woman Creek

Well HWC 86-7, near the confluence of Hanging Woman Creek and the Tongue River, was chosen for further investigation because samples from fall 2007, spring 2008 and fall 2008 showed an upward trend in salinity and a slightly higher SAR in fall 2008. This trend did not represent a large increase in the magnitude of TDS, from approximately 2,900 to 4,000 mg/L, but did represent an increase of approximately 28 percent. This trend was not upheld in the most recent sample collected in spring 2009. Wells along Hanging Woman Creek near the Wyoming state line are also regularly monitored (HWC 86-13 and -15) but have not shown a similar trend. A well in the Hanging Woman Creek alluvium that falls between these two locations (HWC 86-2) was chosen for additional analysis this year.

The general pattern seen in the alluvium of Squirrel Creek is reversed in the Hanging Woman Creek watershed (Figure 42) in that the higher salinities are found higher in the watershed.

The highest salinity of the four wells measured in the watershed in June 2009 was found in well HWC 86-15. While it is located near well HWC 86-13, this well is farther from the creek (see Figure 33) so bedrock inputs may be influencing the water quality. The only CBM development in this watershed occurs up-stream, in Wyoming. The naturally high salinities of the wells near the state line (HWC 86-13 and -15) may mask any influence of CBM in Hanging Woman Creek that is seen down-stream in HWC 86-7. Alternatively, this salinity pattern at HWC 86-7 could be natural variation. Continued sampling of wells HWC 86-2, -7, -13 and -15 is recommended.

Surface Water Quality

Surface water quality was measured by the USGS on Squirrel Creek near Decker Mine periodically from 1975 to 2009. The sample location identification numbers are 450015106511301; 450047106514201; 06306100. Hanging Woman Creek has been sampled periodically by the USGS at the state line and near Birney from 1977 to 2007. The sample identification numbers are 06307540 and 06307570. Identifying patterns in surface water-quality changes is complicated by changes in flow rate, precipitation patterns, and irrigation practices. The USGS has an ongoing project to identify statistically significant changes in water quality that accounts for variables such as this. A publication of their results is expected soon.

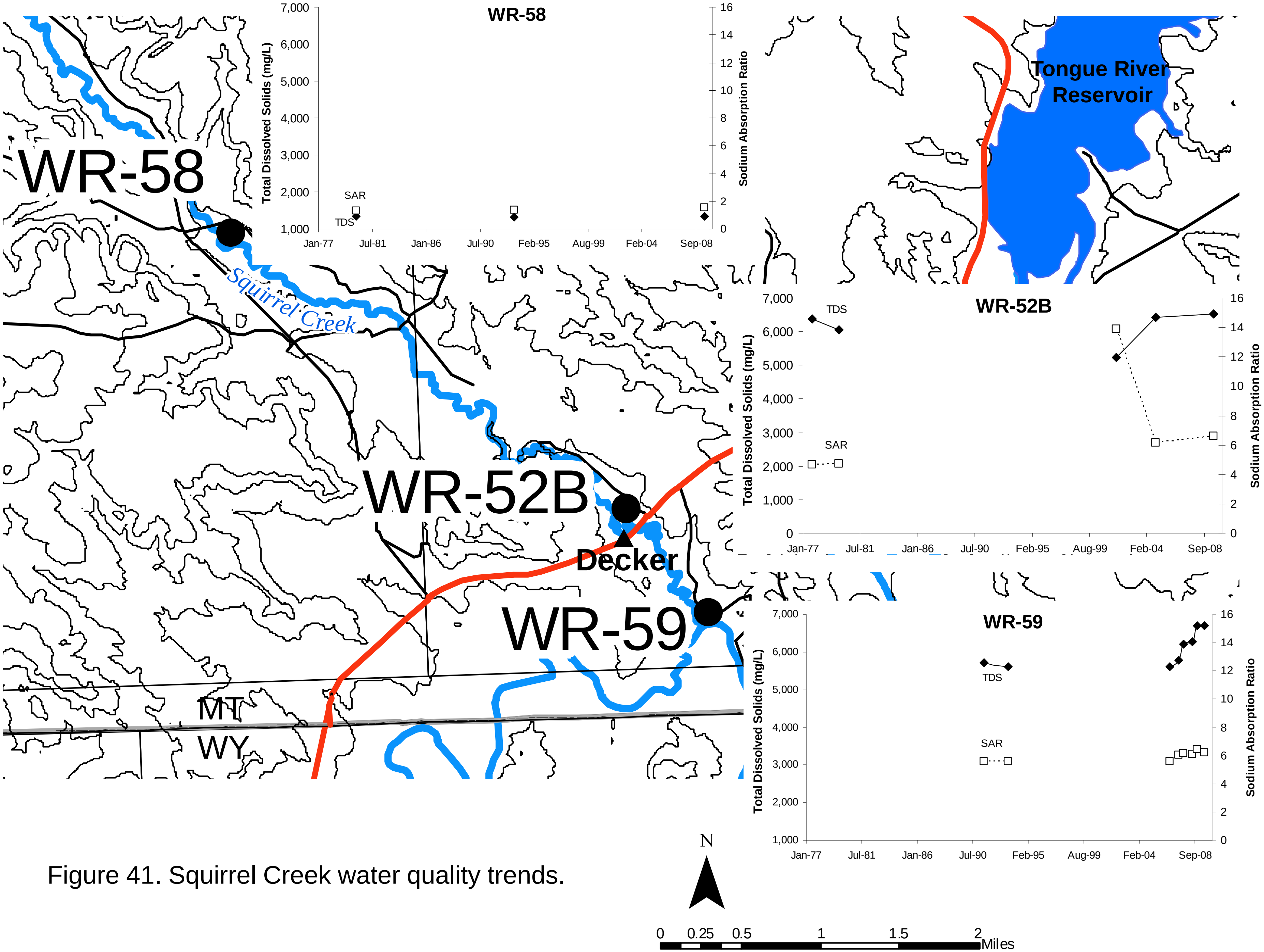


Figure 41. Squirrel Creek water quality trends.

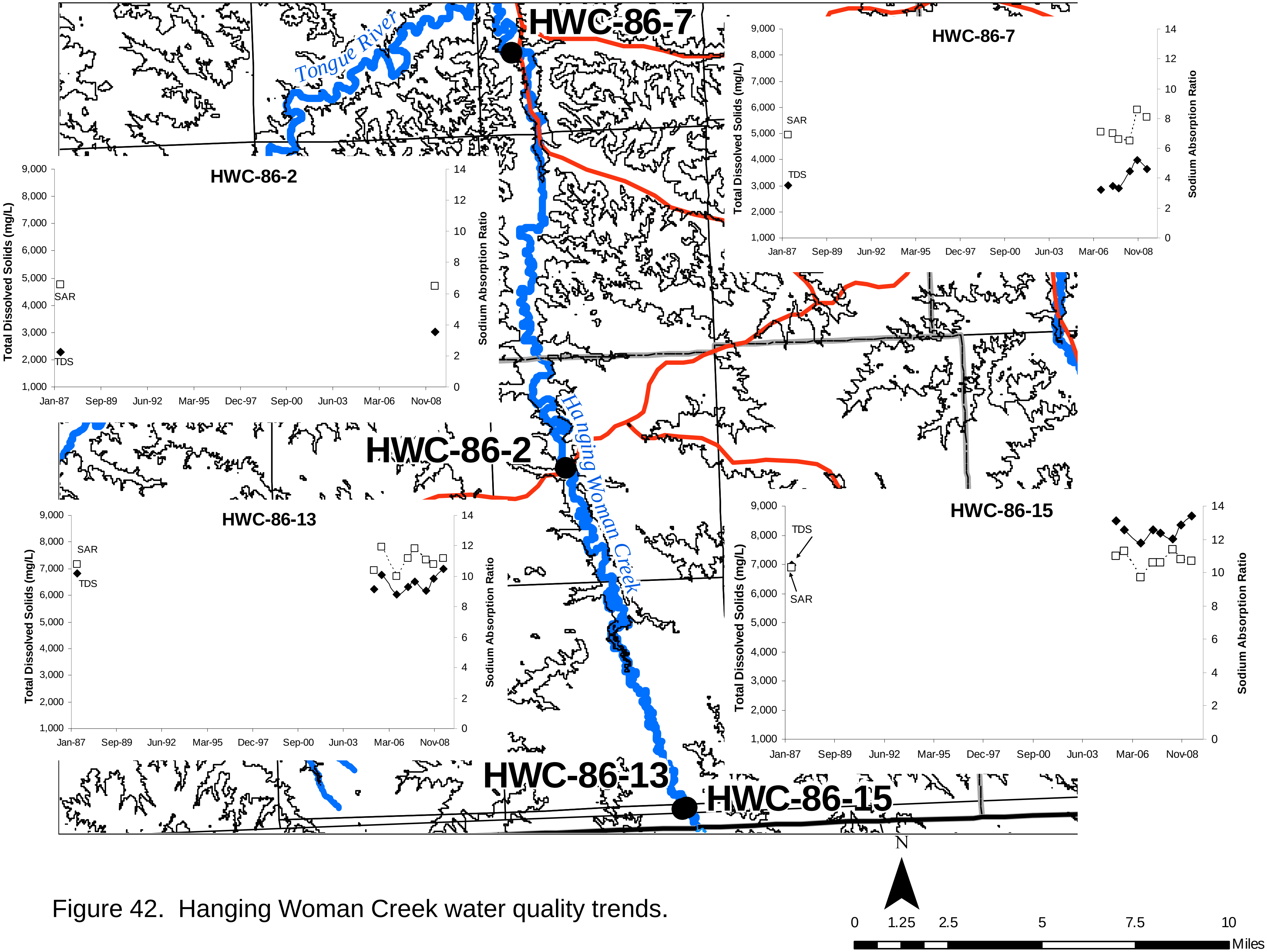


Figure 42. Hanging Woman Creek water quality trends.

Summary and 2009-2010 Monitoring Plan

Coalbed-methane production continues in the CX, Coal Creek and Dietz areas in Montana, and near the state line in Wyoming. CBM development has been proposed in several additional areas (Plate 1). Depending upon a number of factors, including economic forces and industry priorities, CBM development may expand into 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 groundwater monitoring network documents baseline conditions outside production areas, changes to the groundwater systems within the area of influence, and the areal limits of drawdown within the monitored aquifers. Outside the area of influence of CBM production, groundwater conditions reflect normal response to precipitation and the long-term response to coal mining.

Within the CX field, groundwater 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 just over 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 less than those predicted in the Montana CBM environmental impact statement (EIS). The EIS (BLM, 2008) predicted 20 feet of drawdown would reach 2 miles after 10 years of CBM production. Major faults tend to act as barriers to groundwater flow and drawdown migration across fault planes has not been observed in monitoring wells. However in cases where faults are not offset at least 10 feet 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. These changes are less than projected in the EIS.

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.

Water from production wells is expected to have relatively low TDS concentrations generally between 1,000 mg/L and 2,000 mg/L (Table 2) and relatively high sodium adsorption ratios generally between 30 and 40, but have reached near 80 in some samples.

Monitoring plans for 2010 are included in appendices A and B and shown on Plate 6. During the water year 2009-2010, monitoring sites located within approximately 6 miles of existing or proposed development will be monitored monthly. Outside of this area monitoring will occur quarterly or semi-annually depending on distance to production and amount of background data collected to date. Meteorological stations that are currently deployed at SL-3, RBC-2, and near Poker Jim Butte will continue to be maintained. Data loggers will be installed in wells venting 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. 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.

To reflect the increasing CBM development on the eastern edge of the Powder River Basin in Wyoming, monitoring wells will be installed east of the Powder River in Montana during the summer or fall of 2010.

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.

Meredith, E.L., Wheaton, J.W., Kuzara, S.L., and Donato, T., 2008, 2008 Water Year Annual Coalbed Methane Regional Ground-Water Monitoring Report: Powder River Basin, Montana. Montana Bureau of Mines and Geology Open File Report 578, 75 p. 6 sheets.

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, 2009, Historical Climate Information: http://www.wrcc.dri.edu/summary/Climsmemt.html. Accessed December 2009.

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 2009 – 2010 monitoring plan for wells

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
7573	WO-15	-106.1855	45.5186	04S	45E	4	BDDB	Powder River	3022	Alluvium	63	12.0	8/27/2009	10.56	3011.4	Monthly	
7574	WO-16	-106.1861	45.5158	04S	45E	4	CAAC	Powder River	3040	Alluvium	61	3.7	8/27/2009	25.43	3014.6	Monthly	
7589	Newell Pipeline Well	-106.2143	45.4727	04S	45E	19	DADD	Powder River	3290	Tongue River Formation	325	5.0	8/27/2009	307.12	2982.9	Quarterly	
7755	77-26	-106.1839	45.4352	05S	45E	4	ABCC	Powder River	3284	Knobloch Coal	217	3.6	8/27/2009	148.85	3135.2	Quarterly	
7770	WO-8	-106.1411	45.3922	05S	45E	23	ABCA	Powder River	3155	Alluvium	33	12.0	8/27/2009	16.1	3138.9	Monthly	
7772	WO-9	-106.1419	45.3925	05S	45E	23	ABCA	Powder River	3150	Alluvium	45	21.8	8/27/2009	12.46	3137.5	Monthly	
7775	WO-10	-106.1430	45.3925	05S	45E	23	ABCB	Powder River	3145	Alluvium	41		8/27/2009	11.37	3133.6	Monthly	
7776	WO-5	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Knobloch Underburden	192	20.4	8/27/2009	18.43	3141.6	Monthly	
7777	WO-6	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Lower Knobloch Coal	82	7.0	8/27/2009	25.36	3134.6	Monthly	
7778	WO-7	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Alluvium	40	29.0	8/27/2009	27.5	3132.5	Monthly	
7780	WO-1	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3190	Knobloch Underburden	172	8.0	8/27/2009	38.66	3151.3	Monthly	
7781	WO-2	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3188	Lower Knobloch Coal	112	19.0	8/27/2009	46.09	3141.9	Monthly	
7782	WO-3	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3186	Knobloch Overburden	66	17.8	8/27/2009	47.5	3138.5	Monthly	
7783	WO-4	-106.1486	45.3941	05S	45E	23	BBAA	Powder River	3140	Alluvium	32		8/27/2009	10.03	3130.0	Monthly	
7903	HWC86-9	-106.5027	45.2966	06S	43E	19	DACD	Rosebud	3170	Alluvium	44		9/23/2009	11.47	3158.5	Monthly	
7905	HWC86-7	-106.5033	45.2958	06S	43E	19	DDBA	Rosebud	3170	Alluvium	71		9/23/2009	9.97	3160.0	Monthly	Semi-Annual
7906	HWC86-8	-106.5030	45.2961	06S	43E	19	DDBA	Rosebud	3170	Alluvium	67		9/23/2009	9.25	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	9/22/2009	58.12	3831.9	Monthly	
8101	HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	Big Horn	3460	Alluvium	50		9/23/2009	20.48	3439.5	Monthly	
8103	HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	Big Horn	3455	Alluvium	33		9/23/2009	15.85	3439.2	Monthly	
8107	HWC-01	-106.4866	45.1338	08S	43E	20	DDDD	Big Horn	3530	Canyon Coal	232	7.5	10/23/2009	90.44	3439.6	Monthly	
8118	HC-24	-106.4747	45.1297	08S	43E	21	BDBB	Big Horn	3500	Canyon Overburden	150	7.1	8/27/2009	53.02	3447.0	Semi-Annual	
8140	FC-01	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Anderson Coal	133	0.0	9/23/2009	129.03	3606.0	Monthly	
8141	FC-02	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Dietz Coal	260		9/23/2009	243.66	3491.3	Monthly	
8191	BC-06	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Coal	188	4.6	9/24/2009	89.34	3625.7	Monthly	
8192	BC-07	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Overburden	66	0.8	9/24/2009	36.84	3678.2	Monthly	
8347	WR-23	-106.9905	45.0922	09S	38E	1	AADC	Big Horn	3960	Dietz 1 and Dietz Coals Combined	322	6.0	9/22/2009	84.21	3875.8	Monthly	
8368	SH-391	-107.0320	45.0413	09S	38E	22	DADC	Big Horn	3987	Dietz 1 and Dietz Coals Combined	175		9/23/2009	61.52	3925.5	Monthly	
8371	SH-388	-107.0205	45.0391	09S	38E	23	CDAD	Big Horn	3975	Dietz Coal	190		9/23/2009	78.94	3896.1	Monthly	
8372	SH-396	-107.0088	45.0491	09S	38E	24	BBBC	Big Horn	3939	Anderson-Dietz 1 and 2 Coals	280	25.0	9/23/2009	56.21	3882.8	Monthly	
8377	SH-394	-107.0075	45.0330	09S	38E	25	BCBA	Big Horn	3909	Dietz Coal	242	5.0	9/23/2009	92.9	3816.1	Monthly	
8379	SH-422	-107.0061	45.0261	09S	38E	25	CBDC	Big Horn	3917	Dietz Coal	187		8/26/2009	123.25	3793.8	Semi-Annual	
8387	SH-395	-107.0618	45.0361	09S	38E	26	ABAB	Big Horn	3900	Dietz Coal	299	15.0	9/23/2009	64.72	3835.3	Monthly	
8412	WR-58	-106.9122	45.0408	09S	39E	14	DDBD	Big Horn	3631	Alluvium	55	21.0	9/22/2009	14.41	3616.9	Monthly	
8413	WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	Big Horn	3627	Alluvium	27	15.0	9/22/2009	14.01	3613.4	Monthly	
8417	WR-19	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Dietz 1 and Dietz Coals Combined	305	20.0	9/22/2009	135.76	3699.6	Monthly	
8419	WR-20	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Anderson Coal	166	15.0	9/22/2009	107.94	3727.4	Monthly	
8428	WR-54A	-106.8902	45.0147	09S	39E	25	DADB	Big Horn	3631	Anderson-Dietz 1 and 2 Overburden	211	1.0	9/22/2009	127.67	3503.5	Monthly	
8430	WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	Big Horn	3608	Anderson-Dietz 1 and 2 Overburden	187		9/22/2009	109.75	3498.2	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
8436	WR-24	-106.9877	45.0202	09S	39E	29	BBDD	Big Horn	3777	Canyon Coal	146		10/23/2009	32.32	3744.9	Monthly	
8441	WR-33	-106.9758	45.0066	09S	39E	32	ACAA	Big Horn	3732	Anderson-Dietz 1 Clinker and Coal	165		9/23/2009	51.53	3680.8	Monthly	
8444	WR-27	-106.9658	45.0008	09S	39E	33	DBBD	Big Horn	3672	Anderson-Dietz 1 and 2 Coals	363	25.0	9/23/2009	75.82	3596.2	Monthly	
8446	WR-45	-106.9538	44.9966	09S	39E	33	DDCC	Big Horn	3638	Alluvium	64	30.0	9/23/2009	9.92	3628.3	Monthly	
8447	WR-44	-106.9522	44.9966	09S	39E	33	DDCD	Big Horn	3637	Alluvium	64	30.0	9/23/2009	9.29	3627.6	Monthly	
8451	WR-42	-106.9502	44.9966	09S	39E	33	DDDD	Big Horn	3637	Alluvium	66	30.0	9/23/2009	10.3	3626.4	Monthly	
8456	WRN-10	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3433	Dietz 2 Coal	79	3.4	9/22/2009	24.39	3408.9	Monthly	
8461	WRN-15	-106.8275	45.0638	09S	40E	9	AADD	Big Horn	3500	Dietz 2 Coal	140		6/4/2008	91.55	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	3399.5	Monthly	
8500	WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	Big Horn	3511	Dietz 2 Coal	232		6/4/2008	166.14	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	83.86	3425.0	Monthly	
8574	DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	Big Horn	3430	Dietz 2 Coal	150		6/4/2008	56.05	3374.0	Monthly	
8650	WR-55	-106.8858	45.0300	09S	40E	19		Big Horn	3591	Tongue River Formation	288	15.0	9/22/2009	157.1	3434.1	Monthly	
8651	WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	Big Horn	3591	Anderson-Dietz 1 and 2 Overburden	72		9/22/2009	46.31	3544.8	Monthly	
8687	WRE-12	-106.8038	45.0311	09S	40E	23	BCCD	Big Horn	3463	Anderson Coal	172		9/22/2009	83.73	3379.5	Monthly	
8692	WRE-13	-106.8044	45.0311	09S	40E	23	BCCD	Big Horn	3463	Dietz Coal	206		9/22/2009	89.38	3373.2	Monthly	
8698	WRE-16	-106.7697	45.0352	09S	40E	24	AACB	Big Horn	3551	Anderson Coal	458		9/22/2009	61.81	3488.7	Monthly	
8706	WR-17B	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3575	Anderson-Dietz 1 and 2 Overburden	160		9/22/2009	74.41	3500.3	Monthly	
8708	WR-51	-106.8620	45.0186	09S	40E	29		Big Horn	3541	Tongue River Formation	344	4.4	9/22/2009	123.36	3417.6	Monthly	
8709	WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	Big Horn	3541	Anderson-Dietz 1 and 2 Overburden	187		9/22/2009	54.75	3486.6	Monthly	
8710	WR-52B	-106.8627	45.0147	09S	40E	29	CACB	Big Horn	3519	Alluvium	55	59.7	9/22/2009	12.83	3506.0	Monthly	
8721	WRE-27	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3524	Anderson Coal	77	0.5	12/20/2007	47.15	3476.7	Monthly	
8723	WRE-28	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3525	Dietz Coal	153		12/20/2007	61.85	3463.4	Monthly	
8726	WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	Big Horn	3523	Dietz 2 Coal	217		12/20/2007	110.16	3413.1	Monthly	
8754	CC-1	-106.4646	45.0875	09S	43E	4	ABDD	Big Horn	3520	Alluvium	28	4.2	9/22/2009	13.94	3506.1	Monthly	
8757	CC-4	-106.4659	45.0874	09S	43E	4	ABDD	Big Horn	3511	Alluvium	25	4.8	9/22/2009	6.78	3504.2	Monthly	
8758	CC-3	-106.4654	45.0864	09S	43E	4	ACAA	Big Horn	3521	Alluvium	35	4.6	9/22/2009	14.09	3506.9	Monthly	
8777	HWC-38	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3586	Alluvium	41		9/22/2009	18.89	3567.1	Monthly	
8778	HWC-17	-106.4133	45.0570	09S	43E	13	BCAA	Big Horn	3610	Anderson Coal	82	6.9	9/22/2009	51.64	3558.4	Monthly	
8782	HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	Big Horn	3600	Anderson Coal	129	10.0	9/22/2009	32.55	3567.5	Monthly	
8796	HWC-29B	-106.3969	45.0688	09S	44E	7	BBCC	Big Horn	3620	Anderson Coal	92		9/22/2009	45.49	3574.5	Monthly	
8835	AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	Powder River	3965	Dietz Coal	240	1.4	9/24/2009	169.84	3795.2	Monthly	
8846	UOP-09	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3929	Canyon Coal	262	0.8	9/22/2009	157.92	3771.1	Monthly	
8847	UOP-10	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3930	Canyon Overburden	207	4.4	9/22/2009	143.47	3786.5	Monthly	
8863	Fulton George *NO.6	-105.8628	45.0807	09S	48E	5	ACDD	Powder River	3380	Tongue River Formation	410	4.0	10/21/2009	16.84	3363.2	Quarterly	
8888	HWC 86-13	-106.4262	45.0020	10S	43E	2	ABCA	Big Horn	3640	Alluvium	53	3.9	6/10/2009	11.84	3628.2	Monthly	Semi-Annual
94661	Liscom Well	-106.0323	45.7782	01S	46E	3	DBAA	Powder River	3275	Fort Union Formation	135	10.0	10/23/2009	97.65	3177.4	Quarterly	

Appendix A. Site details, water-level data, and 2010 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
94666	Coyote Well	-106.0505	45.7524	01S	46E	16	AACC	Powder River	3294	Fort Union Formation	190	5.0	10/23/2009	135.9	3158.1	Quarterly	
100472	East Fork Well	-106.1642	45.5935	03S	45E	10	B	Powder River	3210		193	5.0	10/14/2009	138.11	3071.9	Quarterly	
103155	Padget Creek Pipeline Well	-106.2940	45.3939	05S	44E	22	BBBD	Rosebud	3385	Tongue River Formation	135	10.0	8/28/2009	65.79	3319.2	Quarterly	
105007	Tooley Creek Well	-106.2697	45.2153	07S	45E	19	CAAA	Powder River	3755	Fort Union Formation	110	12.0	10/22/2009	42.44	3712.6	Quarterly	
121669	WRE-18	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3573	Anderson Coal	445		9/22/2009	91.66	3481.4	Monthly	
122766	WR-59	-106.8526	45.0050	09S	40E	32	ACAD	Big Horn	3470	Alluvium	34	10.0	9/22/2009	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	95.11	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	9/23/2009	77.5	3615.4	Monthly	
122770	WR-39	-106.9555	44.9952	37N	63E	23	ABBC	Sheridan	3666	Anderson-Dietz 1 and 2 Coals	312		9/23/2009	65.75	3600.3	Monthly	
123795	WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	Big Horn	3549	Anderson Coal	115		12/20/2007	62.88	3486.5	Monthly	
123796	WR-17A	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3574	Anderson-Dietz 1 and 2 Overburden	88		9/22/2009	45.44	3528.5	Monthly	
123797	WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	Big Horn	3520	Anderson Coal	140		6/4/2008	96.61	3423.7	Monthly	
123798	WRN-11	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3437	Anderson-Dietz 1 Clinker and Coal	50		9/22/2009	22.95	3413.9	Monthly	
127605	WR-54	-106.8902	45.1470	09S	39E	25		Big Horn	3630	Anderson and Dietz Coal	384	20	9/22/2009	200.06	3429.8	Monthly	
130475	WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	Big Horn	3552	Dietz Coal	154	20.0	12/20/2007	67.89	3484.2	Monthly	
130476	WR-31	-106.9863	45.0163	09S	39E	29	CBAA	Big Horn	3895	Anderson Coal	316	2.0	9/23/2009	183.65	3711.6	Monthly	
132716	WR-48	-106.9650	44.9933	37N	63E	23	BBCB	Sheridan	3694	Anderson Coal	167		9/23/2009	40.19	3653.6	Monthly	
132903	WR-58A	-106.9123	45.0403	09S	39E	14	DDBD	Big Horn	3631	Alluvium	24	8.0	9/22/2009	14.18	3617.2	Monthly	
132907	WR-53	-106.8880	45.0125	09S	39E	25		Big Horn	3607	Anderson and Dietz Coal	384	20.0	9/22/2009	178.51	3428.6	Monthly	
132908	WR-30	-106.9874	45.0165	09S	39E	29	CBAB	Big Horn	3895	Dietz 1 and Dietz Coals Combined	428	5.0	9/23/2009	202.42	3692.2	Monthly	
132909	WR-34	-106.9702	45.0015	09S	39E	33	CBBB	Big Horn	3772	Anderson-Dietz 1 and 2 Coals	522		9/23/2009	151.97	3620.1	Monthly	
132910	WRE-02	-106.7756	45.0712	09S	40E	1	DBCC	Big Horn	3457	Alluvium	79		12/20/2007	40.13	3416.7	Monthly	
132958	WRE-21	-106.7730	45.0386	09S	40E	24	ABAB	Big Horn	3529	Anderson Coal	130		6/4/2008	85.49	3443.9	Monthly	
132959	WRE-17	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3562	Anderson-Dietz 1 and 2 Overburden	250		9/22/2009	64.25	3497.7	Monthly	
132960	WR-52C	-106.8629	45.0164	09S	40E	29	CABC	Big Horn	3530	Alluvium	62	20.0	9/22/2009	18.54	3511.5	Monthly	
132961	WR-52D	-106.8616	45.0164	09S	40E	29	CABD	Big Horn	3529	Alluvium	40	1.0	9/22/2009	23.38	3505.9	Monthly	
132973	PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	Big Horn	3458	Dietz 2 Coal	282	5.0	9/22/2009	128.62	3329.4	Monthly	
144969	Pipeline Well 7(PL-1W) LOHOF	-106.3074	45.2354	07S	44E	14	ABD	Rosebud	3850	Tongue River Formation	225	15.0	8/27/2009	142.7	3707.3	Quarterly	
157879	5072B	-106.4904	45.7393	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal	109	2.0	11/10/2009	34.75	3125.3	Quarterly	
157882	5072C	-106.4905	45.7394	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal Overburden	106	0.3	11/10/2009	29.44	3130.6	Quarterly	
157883	5080B	-106.5126	45.7199	01S	42E	26	DCBA	Rosebud	3260	Knobloch Coal	89	1.3	11/10/2009	42.83	3217.2	Quarterly	
157884	5080C	-106.5126	45.7200	01S	42E	26	DCBA	Rosebud	3260	Knobloch Overburden	110	0.3	11/10/2009	36.32	3223.7	Quarterly	
161749	BF-01	-106.9667	44.9897	58N	84W	22	ACCC	Sheridan	3680	Coal Mine Spoils Bank	125		9/23/2009	32.65	3647.4	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
166351	PKS-3204	-106.8299	45.1067	08S	40E	28	ADA	Big Horn	3500	Anderson-Dietz1 Coalbed	82		9/22/2009	75.23	3424.8	Monthly	
166358	PKS-3203	-106.8302	45.1068	08S	40E	28	ADA	Big Horn	3500	Canyon Coal	201		9/22/2009	112.62	3387.4	Monthly	
166359	PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	Big Horn	3438	Alluvium	60	5.0	6/4/2008	40.84	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	95.62	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	174.38	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	115.62	3323.4	Monthly	
166389	PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	Big Horn	3440	Anderson Coal	112		6/4/2008	87.77	3352.2	Monthly	
166761	WR-29R	-106.8153	45.0465	09S	40E	15	ACCD	Big Horn	3461	Anderson-Dietz 1 Clinker and Coal	72		9/22/2009	46.02	3415.0	Monthly	
183559	Nance IP-11 Bridge	-106.4549	45.4114	05S	43E	8	BCDC	Rosebud	3085	Tongue River Formation	540		10/22/2009	-11.67	3096.7	Quarterly	
183560	Nance Properties INC	-106.4205	45.4387	05S	43E	4	AAAB	Rosebud	3035	Alluvium	20		10/22/2009	12.25	3022.8	Quarterly	
183563	Fulton George	-105.8709	45.0637	09S	48E	8	CABC	Powder River	3360	Alluvium	30	1.0	10/21/2009	18.84	3341.2	Quarterly	
183564	Whitetail Ranger Station	-105.9758	45.6404	02S	47E	19	CDCA	Powder River	4045	Fort Union Formation	60		10/23/2009	42.63	4002.4	Quarterly	
183565	Skinner Gulch Pipeline Well	-105.9171	45.4275	05S	47E	3	BCCD	Powder River	3730	Tongue River Formation	167		10/14/2009	51.62	3678.4	Quarterly	
184222	SH-624	-107.0917	45.0725	09S	38E	7	DADB	Big Horn	4645	Anderson-Dietz1 Coalbed	435		8/26/2009	349.93	4294.8	Quarterly	
184223	SH-625	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Dietz Coal	186		8/26/2009	45.95	4140.7	Quarterly	
184224	SH-625A	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Anderson Coal	91		8/26/2009	54.88	4131.8	Quarterly	
184225	SH-634	-107.0728	45.1422	08S	38E	17	DADD	Big Horn	4481	Dietz Coal	348	12.0	8/26/2009	150.4	4330.1	Semi-Annual	
184226	SH-634A	-107.0883	45.1422	08S	38E	17	DADD	Big Horn	4481	Anderson Coal	159		8/26/2009	115.51	4365.7	Semi-Annual	
186195	WR-41	-106.9498	44.9950	09S	39E	34	CCCC	Big Horn	3643	Alluvium	40	1.0	9/23/2009	17.62	3625.1	Monthly	
189802	HWC-37	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3578	Alluvium	32		9/22/2009	10.88	3567.1	Monthly	
189838	HWC-39	-106.4004	45.0713	09S	43E	12	ADBD	Big Horn	3591	Alluvium	39		9/22/2009	25.87	3565.1	Monthly	
190902	HWC-10	-106.4695	45.0444	09S	43E	21	BADA	Big Horn	3610	Dietz Coal	229		9/22/2009	99.02	3511.0	Monthly	
190904	HWC-11 TR-77	-106.4696	45.0444	09S	43E	21	BADA	Big Horn	3615	Anderson Coal	135	8.0	9/22/2009	51.65	3563.4	Monthly	
191139	20-LW	-106.7801	45.3391	06S	40E	1	CDDC	Big Horn	3940	Wall Coal	253	0.2	9/23/2009	88.93	3851.1	Monthly	
191155	22-BA	-106.6954	45.3484	06S	41E	3	BADD	Rosebud	3530	Brewster-Arnold Coal	262	0.4	8/28/2009	106.59	3423.4	Quarterly	
191163	28-W	-106.7292	45.3211	06S	41E	16	BBCC	Rosebud	3715	Wall Coal	144	1.3	9/23/2009	106.35	3608.7	Monthly	
191169	32-LW	-106.7098	45.2955	06S	41E	21	DDDC	Rosebud	3530	Wall Coal	51	0.2	9/23/2009	36.8	3493.2	Monthly	
191634	75-23	-106.2011	45.0966	08S	45E	34	BDBC	Powder River	3780	Canyon Coal	247		9/24/2009	133.5	3646.5	Monthly	
192874	YA-109	-107.0312	45.0407	09S	38E	22	DADC	Big Horn	3830	Alluvium	44		9/23/2009	31.71	3798.3	Monthly	
198464	HWC-7	-106.4093	45.0537	09S	43E	13	DAAA	Big Horn	3624		67		6/17/2009	30.35	3593.7	Monthly	
198465	HWC-6	-106.4093	45.0536	09S	43E	13	CAAA	Big Horn	3595	Dietz Coal	152		9/22/2009	70.16	3524.8	Monthly	
198489	HWC 86-15	-106.4235	45.0025	10S	43E	2	AABC	Big Horn	3630	Alluvium	63	30.0	6/10/2009	15.58	3614.4	Monthly	Semi-Annual
203646	CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3980	Knobloch Coal	417	0.5	9/23/2009	174.05	3806.3	Monthly	
203655	CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3984	Brewster-Arnold Coal	256	5.0	9/23/2009	101.94	3881.9	Monthly	
203658	CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3982	Local Coals	366	2.0	9/24/2009	145	3836.8	Monthly	
203669	CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	Big Horn	3792	Carney Coal	290	10.0	10/23/2009	74.57	3717.4	Monthly	
203670	CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	Big Horn	3890	Roland Coal	159	1.0	9/23/2009	132.5	3757.5	Monthly	
203676	CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	Big Horn	3920	Canyon Coal	376	0.3	9/22/2009	303.05	3617.0	Monthly	
203678	CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	Big Horn	3920	Dietz Coal	235	0.1	9/22/2009	186.65	3733.4	Monthly	
203680	CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	Big Horn	3500	Wall Coal	291	0.2	9/23/2009	184.35	3315.7	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
203681	CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	Rosebud	3500	Wall Coal Overburden	221	5.0	9/23/2009	77.39	3422.6	Monthly	
203690	CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	Big Horn	3500	Canyon Underburden	97	30.0	9/23/2009	36.04	3464.0	Monthly	
203693	CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	Big Horn	3900	Canyon Coal	263	1.5	10/23/2009	165.34	3734.7	Monthly	
203695	CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	Big Horn	3900	Canyon Overburden	190	5.0	10/23/2009	90.63	3809.4	Monthly	
203697	CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	Rosebud	3262	Knobloch Coal	208	1.0	8/28/2009	159.72	3102.6	Quarterly	
203699	CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	Rosebud	3262	Knobloch Underburden	224	10.0	8/28/2009	160.52	3101.7	Quarterly	
203700	CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Overburden	446	0.3	8/28/2009	103.77	3156.7	Quarterly	
203701	CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Coal	480	0.5	8/28/2009	103.17	3157.5	Quarterly	
203703	CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson Coal	560	0.3	9/22/2009	531.49	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	9/22/2009	372.53	3757.5	Monthly	
203705	CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	Big Horn	3950	Anderson Coal	211	1.0	9/23/2009	155.71	3794.3	Monthly	
203707	CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	Big Horn	3950	Dietz Coal	271	0.2	9/23/2009	229.38	3720.6	Monthly	
203708	CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	Big Horn	3950	Canyon Coal	438	1.5	9/23/2009	383.35	3566.7	Monthly	
203709	CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	Powder River	3715	Cook Coal	351	3.0	9/24/2009	163.71	3551.3	Monthly	
203710	CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	Powder River	3931	Otter Coal	500	1.5	9/22/2009	343.2	3587.8	Monthly	
205082	Spring Creek Pipeline Well	-105.9538	45.3883	05S	47E	20	ACAC	Powder River	3630	Tongue River Formation	50		8/27/2009	16.96	3613.0	Quarterly	
207064	RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	Big Horn	3855	Alluvium	27		9/24/2009	13.86	3840.8	Monthly	
207066	RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	Alluvium	17		9/24/2009	10.68	3838.7	Monthly	Semi-Annual
207068	RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	Big Horn	3860	Alluvium	25		9/24/2009	12.49	3847.4	Monthly	
207075	YA-114	-107.0543	45.0461	09S	38E	21	ADBD	Big Horn	4000	Alluvium			8/26/2009	13.4	3986.6	Quarterly	
207076	YA-105	-107.0527	45.0465	09S	38E	21	ACAC	Big Horn	4015	Alluvium			8/26/2009	12.25	4002.8	Quarterly	
207080	TA-100	-107.0090	45.0479	09S	38E	23	BBCC	Big Horn	3900	Alluvium			9/23/2009	15.23	3884.8	Quarterly	
207081	TA-101	-107.0090	45.0482	09S	38E	24	BBCC	Big Horn	3910	Alluvium			9/23/2009	17.11	3892.9	Quarterly	
207083	TA-102	-107.0076	45.0486	09S	38E	24	BBCB	Big Horn	3910	Alluvium			9/23/2009	22.31	3887.7	Quarterly	
207096	IB-2	-106.4372	45.3930	05S	43E	21	BBDB	Rosebud	3192	Knobloch Underburdern	245		8/28/2009	123.65	3067.9	Quarterly	
207097	MK-4	-106.4363	45.3919	05S	43E	21	BBDC	Rosebud	3195	Knobloch Coal	188		8/28/2009	123.16	3072.2	Quarterly	
207098	NM-4	-106.4361	45.3916	05S	43E	21	BCAB	Rosebud	3195	Nance Coal	294		8/28/2009	120.27	3075.0	Quarterly	
207099	WL-2	-106.4358	45.3919	05S	43E	21	BBDC	Rosebud	3188	Knobloch Coal	199		8/28/2009	121	3066.6	Quarterly	
207101	OC-28	-106.1928	45.4717	04S	45E	21	CCBD	Powder River	3171	Knobloch Coal			8/27/2009	65.77	3105.2	Quarterly	
207143	HC-01	-106.4750	45.1314	08S	43E	21	BBDA	Big Horn	3457	Alluvium	20	17.0	8/27/2009	11.2	3445.8	Semi-Annual	
210094	WO-14	-106.1849	45.5183	04S	45E	4	BDDB	Powder River	3010		66		8/27/2009	8.57	3001.4	Monthly	
214096	HWCQ-2	-106.5009	45.1913	07S	43E	32	AAAA	Rosebud	3340	Alluvium	19		9/23/2009	12.81	3327.2	Monthly	
214097	HWCQ-1	-106.5005	45.1912	07S	43E	32	AAAA	Rosebud	3340	Alluvium	20		9/23/2009	12.83	3327.2	Monthly	
214354	WA-7	-106.4347	45.3933	05S	43E	21	BABC	Rosebud	3179	Alluvium			8/28/2009	54.14	3124.9	Quarterly	
215085	WO-11	-106.1433	45.3927	05S	45E	23	ABCC	Powder River	3145	Alluvium	39		8/27/2009	9.88	3135.1	Monthly	
219125	SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	Big Horn	3925	Anderson Coal	671		9/23/2009	341.49	3583.5	Monthly	
219136	SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	Big Horn	3725	Alluvium	40	2.0	9/23/2009	15.83	3709.2	Monthly	Semi-Annual
219138	SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	Big Horn	3805	Smith Coal	358	2.0	9/23/2009	167.32	3637.7	Monthly	
219139	SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Anderson Coal	523	2.0	9/23/2009	221.08	3583.9	Monthly	
219140	SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	Big Horn	3805	Canyon Coal	817	0.1	9/23/2009	381.41	3423.6	Monthly	
219141	SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	Big Horn	3640	Smith Coal	120	2.0	9/22/2009	30.53	3609.5	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	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)	Ave. static water level altitude (feet)	2010 SWL monitoring	2010 QW sample collection
219169	SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	Big Horn	3640	Anderson Coal	279	2.0	9/22/2009	59.82	3580.2	Monthly	
219617	SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Smith Coal Overburden	278	5.0	9/23/2009	147.14	3657.9	Monthly	
219927	SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Anderson Coal	223	1.0	9/22/2009	133.61	3676.4	Monthly	
219929	SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Dietz Coal	322	0.7	9/22/2009	170.02	3640.0	Monthly	
220062	SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	Big Horn	4220	Anderson Coal	492	0.1	9/22/2009	378.83	3841.2	Monthly	
220064	SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	Big Horn	4220	Canyon Coal	685	0.5	9/22/2009	523.15	3696.9	Monthly	
220069	SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	Big Horn	4173	Canyon Coal	515	1.0	10/22/2009	457.32	3715.7	Monthly	
220076	SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	Big Horn	3810	Canyon Coal	431	6.0	9/22/2009	180.55	3629.5	Monthly	
220385	SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	Big Horn	3920	Canyon Coal	1301		9/23/2009	447.55	3472.5	Monthly	
220851	SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	Powder River	3397	Alluvium	19	1.0	9/22/2009	13.24	3383.5	Monthly	
220857	SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	Powder River	3394	Alluvium	14	0.3	9/22/2009	12.38	3381.7	Monthly	Semi-Annual
220859	SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	Powder River	3398	Alluvium	19	1.0	9/22/2009	15.68	3382.8	Monthly	Semi-Annual
223236	USGS 452355106333701	-106.5603	45.3986	05S	42E	16	CCAB	Rosebud	3400		376		8/25/2005	262.7	3137.3		
223237	USGS 452408106382201	-106.6397	45.4022	05S	41E	14	BDCD	Rosebud	3510		360		8/25/2005	238.37	3271.6		
223238	USGS 452139106504701	-106.8464	45.3608	05S	40E	31	BDCC	Big Horn	4440		681		6/6/2005	619.15	3820.9		
223240	USGS 452411106301601	-106.5044	45.4030	05S	42E	14	ADDC	Rosebud	3220		420		7/16/2007	107.38	3112.6		
223242	USGS 452416106413001	-106.6917	45.4044	05S	41E	17	ADBD	Rosebud	3740		353		3/19/2008	176.94	3563.1		
223243	USGS 452429106435201	-106.7311	45.4080	05S	40E	13	ADAB	Big Horn	3940		380		8/24/2005	200.18	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		9/22/2009	11.66	3798.3	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		8/27/2009	123.16	3786.8	Quarterly	
223952	WA-2	-106.4621	45.4020	05S	43E	17	BCDD	Rosebud	3069	Alluvium			9/23/2009	11.37	3057.1	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		9/24/2009	20.77	3790.2	Monthly	
228592	Musgrave Bill	-106.7319	45.1639	08S	41E	5	ACDB	Big Horn	3335	Alluvium	22		9/23/2009	11.65	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 2009 – 2010 monitoring plan for 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	2010 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	
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	Semi-Annual
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

Groundwater quality data collected during water year 2009

Appendix C. Groundwater quality data collected in the water year 2008-2009

	Gwic Id	Site Name	Sampled in 2009	Latitude	Longitude
Sites outside areas of potential CBM influence	223877	East Fork Hanging Woman Creek Weir	Semi-annual	45.2909	-106.4041
	228591	Three Mile Spring	Semi-annual	45.1690	-106.7958
	197452	Alkali Spring	Last time	45.1914	-106.1501
	207066	Well RBC-2	Semi-annual	45.3327	-106.9844
	205049	Chipmunk Spring	Semi-annual	45.212	-106.3611
	203655	CBM02-1BC	One time	45.3186	-106.9671
Sites within areas of potential CBM influence	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319
	223952	WA-2	Semi-annual	45.4032	-106.4566
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052
	220859	Well SL-8-3Q	Semi-annual	45.0177	-105.9028
	122766	Well WR-59	Semi-annual	45.0050	-106.8526
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261
	240578	Lower Anderson Creek Spring	Semi-annual	45.1373	-106.6913
	8101	HWC-86-2	One time	45.135	-106.4827
	8412	WR-58	One time	45.0408	-106.9122
	8710	WR-52B	One time	45.0147	-106.8627
	123796	WELL WR-17A	One time	45.0216	-106.8641
	223801	SL-5ALQ	One time	45.0129	-106.2579

Appendix C. Groundwater quality data collected in the water year 2008-2009

	Gwic Id	Location (TRS)	County	Site Type	Aquifer	Depth (ft)	Comp Date
Sites outside areas of potential CBM influence	223877	06S 43E 25 ABDD	Rosebud	Stream			
	228591	07S 40E 35 CDDD	Big Horn	Spring	125TGRV		
	197452	07S 46E 31 BACD	Powder River	Spring	125TGRV		
	207066	06S 39E 8 CAAA	Big Horn	Well	110ALVM	16.9	7/9/2003
	205049	07S 44E 21 CCBB	Rosebud	Spring	125TGRV		
	203655	06S 39E 16 DBCA	Big Horn	Well	125BACB	255.5	10/8/2002
Sites within areas of potential CBM influence	228592	08S 41E 5 ACDB	Big Horn	Well	111ALVM	21.5	
	223952	05S 43E 17 BCDD	Rosebud	Well	110ALVM	37.8	8/16/1978
	7905	16S 43E 19 DDBA	Rosebud	Well	110ALVM	71	
	8888	10S 43E 2 ABCA	Big Horn	Well	110ALVM	53	10/8/1986
	198489	10S 43E 2 AABC	Big Horn	Well	110ALVM	62.52	10/8/1986
	219136	09S 42E 36 BBAD	Big Horn	Well	110ALVM	40	4/7/2005
	220857	09S 47E 25 DCDB	Powder River	Well	110ALVM	13.8	8/26/2005
	220859	09S 47E 25 DDCB	Powder River	Well	110ALVM	19	8/26/2005
	122766	09S 40E 32 ACAD	Big Horn	Well	110ALVM	34	8/31/1977
	228776	08S 42E 30 ADAA	Big Horn	Spring	125TGRV		
	240578	08S 41E 15 ABBB	Big Horn	Spring			
	8101	08S 43E 17 DDCA	Big Horn	Well	110ALVM	50	9/29/1986
	8412	09S 39E 14 DDBD	Big Horn	Well	110ALVM	55	8/23/1977
	8710	09S 40E 29 CACB	Big Horn	Well	110ALVM	55	7/14/1977
	123796	09S 40E 29 BBAC	Big Horn	Well	125ADOB	88	6/17/1977
	223801	09S 45E 31 BBA	Powder River	Well	110ALVM	35	

Appendix C. Groundwater quality data collected in the water year 2008-2009

	Gwic Id	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)
Sites outside areas of potential CBM influence	223877	11/13/2008	1067	2.4	9.3	8.09	1424	108	87.2	137	9.43
		6/10/2009 16:50	1037	2.4	11.6	7.83	1430	94.7	85.1	134	10.7
	228591	10/29/2008 16:46	326	1.0		8.07	565	31.8	27.7	30.5	11.9
	197452	10/30/2008 18:10	1990	10.1	9.7	7.81	2620	60.6	103	555	9.07
	207066	11/14/2008	566	0.8	8	8.15	1070	69.3	66.5	40.5	8.72
		6/9/2009 10:28	563	0.8	8	7.86	875	67.7	65.7	40.7	9.31
	205049	6/19/2009 11:14	2980	8.9	12.4	7.89	3510	105	155	617	12
	203655	9/23/2009	Results Pending								
Sites within areas of potential CBM influence	228592	10/29/2008 18:28	1074	0.2	12.2	7.55	1708	170	102	13	6.02
		6/9/2009 12:45	776	1.5	9.9	7.96	1250	98	60.6	78.2	4.89
	223952	12/11/2008 12:16	1746	21.7	10.3	7.76	2510	26.6	27.8	672	6.21
		6/10/2009 18:51	1722	21.7		7.97	2670	25.2	27.1	658	6.88
	7905	11/13/2008	3989	8.6	10.3	7.72	4288	177	242	747	19.2
		6/10/2009 16:05	3653	8.1	9.2	8.1	4070	160	209	657	21.7
	8888	11/14/2008	6644	10.8	10.2	7.36	6480	376	332	1193	8.82
		6/10/2009 12:07	7005	11.2	10.3	7.61	6690	377	326	1234	13.2
	198489	11/14/2008	8359	10.8	10.7	7.79	7890	518	490	1423	9.61
		6/10/2009 10:44	8662	10.7	10.3	7.52	7990	501	472	1396	14
	219136	12/11/2008 14:58	3552	5.1	8.5	7.34	3598	389	215	502	3.19
		6/11/2009 14:29	3661	5.3	9.7	8.05	3970	294	222	497	6.67
	220857	10/1/2008 16:45	4231	5.8	14.1	7.64	4680	518	159	593	4.07
		6/16/2009 13:20	3486	4.7	9	7.79	3630	433	125	434	7.74
	220859	10/1/2008 15:50	1971	3.6		7.58	2450	266	79.6	257	7.35
		6/16/2009 14:00	2039	3.2	9.7	7.72	2670	283	79.2	239	9.41
	122766	11/13/2008	6708	6.4	11.8	7.8	5970	291	595	834	30.3
		6/9/2009 14:31	6715	6.2	9	7.81	6140	286	582	795	32.6
	228776	6/16/2009 20:00	4010	8.6		7.56	4360	153	239	733	14.1
	240578	10/30/2008 10:45	1515	3.2	12.2	7.54	1980	111	137	214	8.85
		6/16/2009 19:15	1585	3.0		7.43	1947	112	133	195	9.46
	8101	6/19/2009 9:53	3022	6.5	11.4	7.83	3480	158	180	505	13.8
	8412	6/9/2009 19:10	1334	1.5	9.8	7.6	1781	109	153	105	11.6
	8710	6/9/2009 15:55	6522	6.6	10.6	7.68	6110	282	543	826	30
	123796	6/18/2009 11:34	3668	24.3	11.5	7.98	4480	42.2	76.1	1142	13.6
	223801	6/17/2009 11:20	4185	9.5	8.9	7.73	4430	205	199	794	7.17

	Gwic Id	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)	Cl (mg/l)	NO3 (mg/l)	F (mg/l)	OPO4 (mg/l)	Ag (ug/l)
Sites outside areas of potential CBM influence	223877	<0.018	<0.003	22.7	558.8	0	417.4	7.56	<0.5 P	1.02	<0.5	<0.57
		0.015	0.005	2.8	539.6	0	433.4	7.99	<0.5 P	1.11	<0.5	<0.20
	228591	<0.004	<0.001	24.5	179.6	0	101.6	7.65	0.769 P	1.05	<0.05	<0.11
	197452	<0.018	<0.003	9.96	1085.8	0	692.5	22.3	<0.5 P	1.55	<1.0	<0.53
	207066	1.09	0.207	28.8	561.6	0	72.9	<5.0	<0.5 P	0.601	<0.5	<0.11
		2.54	0.191	29.2	552.7	0	73.58	<5.0	<0.5 P	0.586	<0.5	<0.04
	205049	0.194	<0.007	14.6	1093.9	0	1505	29.01	0.547 P	1.14	<1.0	<4.42
	203655											
Sites within areas of potential CBM influence	228592	0.076	0.13	22.6	533.9	0	466	31.4	0.672 P	<0.5	<0.5	<0.53
		0.321	0.111	20.2	454.7	0	274.9	14.39	<0.5 P	<0.5	<0.5	<0.20
	223952	<0.017	<0.003	11.1	1501.2	0	201.4	58.7	<0.5 P	2.43	<0.5	<0.56
		0.083	0.014	11.7	1499.4	0	188.8	62.75	<0.5 P	2.37	<1.0	<0.40
	7905	<0.035	0.699	18.7	935.7	0	2321	<50.0	<0.5 P	<2.5	<2.5	<1.14
		0.63	0.744	24.6	1060.2	0	2030	24.8	<0.5 P	<1.0	<1.0	<1.62
	8888	6.01	1.76	10.6	952.8	0	4241	<50.0	<0.5 P	<5.0	<5.0	<1.14
		7.5	2.26	18.1	956.5	0	4550	<50.0	<0.5 P	<5.0	<5.0	<1.62
	198489	8.5	1.86	11.2	878.4	0	5464	<50.0	<0.5 P	<5.0	<5.0	<1.14
		9.4	2.18	18.1	818.6	0	5837	<50.0	<0.5 P	<5.0	<5.0	<1.62
	219136	<0.035	0.379	7.54	486.2	0	2183	8.29	<0.5 P	<1.0	<1.0	<1.13
		1.77	0.59	13.2	447.7	0	2390	10.36	<0.5 P	<1.0	<1.0	<0.40
	220857	1.11	1.283	18.8	653.9	0	2278	332	<0.5 P	<2.5	<2.5	<0.72
		0.187	0.454	19.3	509.5	0	1942	271	2.05 P	<1.0	<1.0	<1.11
	220859	0.024	<0.001	17.2	411.1	0	1014	126	0.656 P	<0.5	<0.5	<036
		0.012	0.017	15.9	390.4	0	1078	140.6	1.38 P	<0.5	<0.5	<0.55
	122766	6.75	0.701	21.2	686.9	0	4584	<25.0	<0.5 P	<2.5	<2.5	<1.14
		7.29	1.01	25.2	708.8	0	4631	<50.0	<0.5 P	<5.0	<5.0	<1.62
	228776	0.78	0.128	11.8	1065.2	0	2329	<25.0	<0.5 P	<2.5	<2.5	<4.42
	240578	<0.004	<0.001	16.7	564.9	0	736.3	9.78	<0.5 P	0.646	<0.5	<0.53
		0.008	<0.001	17.8	705.2	0	755.2	11.98	<0.5 P	0.584	<0.5	<0.55
	8101	0.113	0.039	20	628.3	0	1814	18.83	<0.5 P	<1.0	<1.0	<4.42
	8412	0.093	0.592	24.9	618.5	0	618.7	5.28	<0.5 P	<0.5	<0.5	<0.20
	8710	4.87	1.97	35	724.7	0	4436	<50.0	<0.5 P	<5.0	<5.0	<1.62
	123796	0.152	0.036	10.9	1927.6	0	1398	31.2	20.95 P	<2.5	<2.5	<4.42
	223801	0.115	0.011	12.4	816.2	0	2563	<25.0	1.89 P	<2.5	<2.5	<4.42

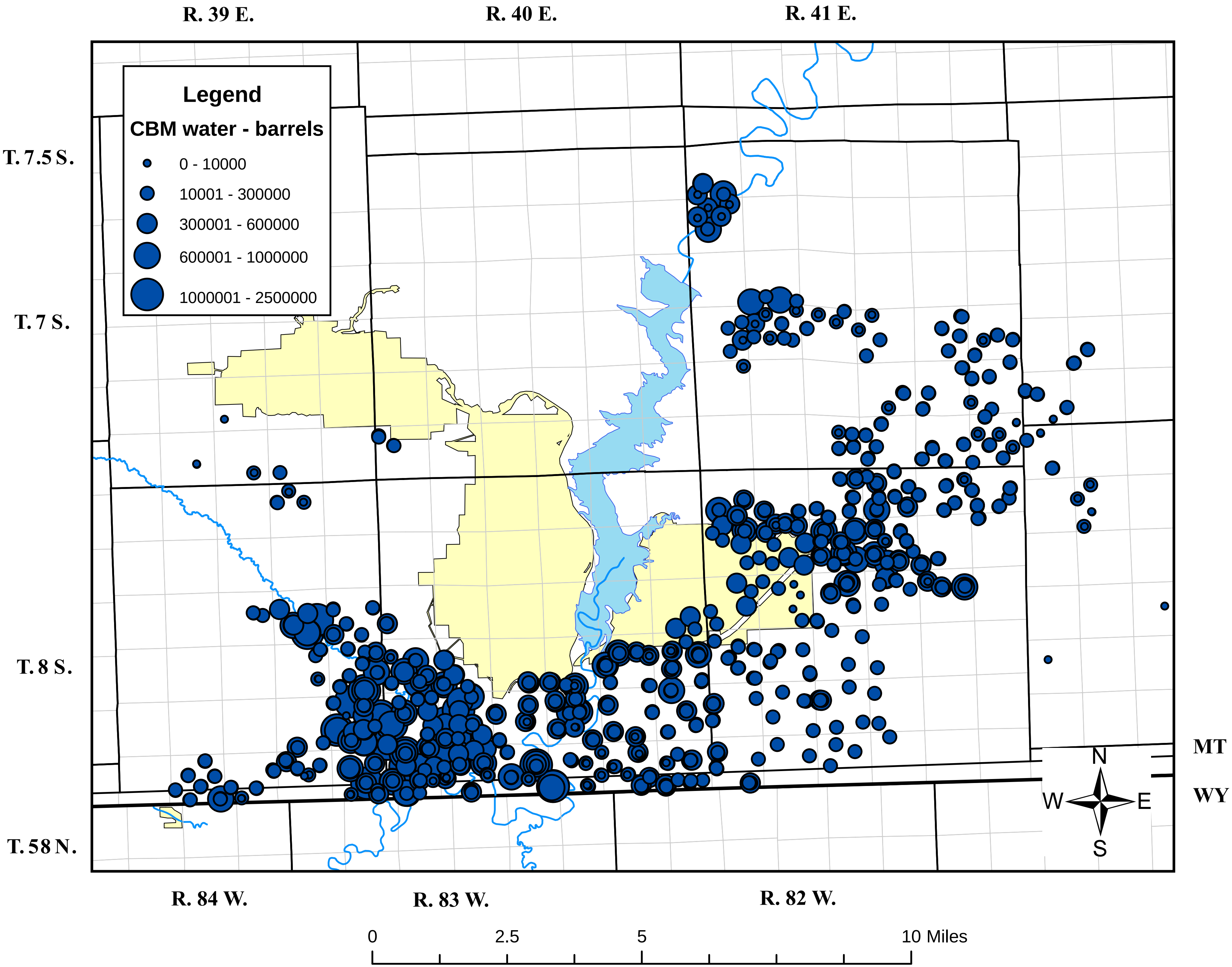
	Gwic Id	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)
Sites outside areas of potential CBM influence	223877	<8.82	<2.34	228	75.7	<1.96	<500	<0.75	<1.38	<0.37	<4.98
		<38.38	0.821	223	66.9	<1.01	<500	<0.25	<0.51	0.391	<2.02
	228591	<5.25	6.75	125	65.7	<0.30	<50	<0.25	<0.08	2.32	<1.98
	197452	<26.3	<2.89	9.57	64.6	<1.48	<2500	<1.25	0.715	<0.61	31.2
	207066	<1.76	2.49	89.4	82.2	<0.39	<500	<0.15	<0.28	1.26	<1.00
		<7.68	2.71	97.2	71.2	<0.20	<500	<0.05	<0.10	<0.04	<0.40
	205049	<16.55	<6.42	348	15.2	<13.24	<1000	4.47	<4.37	<6.63	<7.42
	203655										
Sites within areas of potential CBM influence	228592	<26.3	<2.89	110	72.9	<1.48	<500	<1.25	1.24	<0.61	13.6
		<38.38	0.565	92.5	45	<1.01	<500	<0.25	<0.51	<0.20	<2.02
	223952	<8.73	<2.32	281	25.9	<1.94	<500	<0.74	<1.36	<0.36	<4.94
		<76.76	<1.01	309	26	<2.02	<1000	<0.51	<1.01	0.451	<4.04
	7905	<17.64	<4.68	383	33.1	<3.92	<2500	<1.49	<2.75	<0.73	<9.97
		<307.04	<4.04	351	26.5	<8.08	<1000	<2.02	<4.04	2.32	<16.16
	8888	<17.64	<4.68	237	8.96	<3.92	<5000	<1.49	<2.75	<0.73	<9.97
		<307.04	<4.04	232	8.4	<8.08	<5000	<2.02	<4.04	2.13	<16.16
	198489	<17.6	<4.68	267	7.4	<3.92	<5000	<1.49	<2.75	<0.73	<9.97
		<307.04	<4.04	256	6.96	<8.08	<5000	<2.02	<4.04	<1.62	<16.16
	219136	<17.0	<4.64	95.6	7.83	<3.88	<1000	<1.48	<2.72	<0.72	<9.87
		<76.76	<1.01	109	8.63	<2.02	<1000	<0.51	<1.01	0.479	<4.04
	220857	11.9	2.38	154	28.6	<1.54	<2500	<1.29	2.85	<0.67	<1.99
		7.95	<1.61	113	19.9	<3.31	<1000	<1.12	1.36	<1.66	<1.86
	220859	<4.71	1.63	99.7	22.2	<0.77	<500	<0.64	0.473	<0.33	1.62
		<2.07	0.932	229	18	<1.65	<500	18	<0.56	<0.83	2.08
	122766	<17.64	<4.68	323	19.1	<3.92	<2500	<1.49	<2.75	<0.73	<9.97
		<307.04	<4.04	273	15.8	<8.08	<5000	<2.02	<4.04	2.42	<16.16
	228776	<16.55	<6.42	114	<8.59	<13.24	<2500	<4.47	<4.37	<6.63	<7.42
	240578	<26.3	<2.89	206	19.7	<1.48	<500	<1.25	0.573	<0.61	10
		<2.07	<0.80	229	18.4	<1.65	<500	<0.56	<0.55	<0.83	<0.93
	8101	<16.55	<6.42	315	12.4	<13.24	<1000	<4.47	<4.37	<6.63	<7.42
	8412	<38.38	0.817	189	34.5	<1.01	<500	<0.25	1.15	<0.20	<2.02
	8710	<307.04	<4.04	256	15.1	<8.08	<5000	<2.02	<4.04	<1.62	<16.16
	123796	<16.55	<6.42	<72.13	14.2	<13.24	<2500	<4.47	<4.37	<6.63	<7.42
	223801	<16.55	<6.42	276	<8.59	<13.24	<2500	<4.47	<4.37	<6.63	<7.42

	Gwic Id	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)	U (ug/l)
Sites outside areas of potential CBM influence	223877	61.7	3.72	1.04	<2.60	<0.49	<3.22	<0.55	1601	4.88	<0.34	<3.30
		73.7	4.43	0.815	<0.77	0.246	3.34		1479	4.43	<0.17	6.84
	228591	54.9	7.1	<0.20	<0.11	0.132	3.4	5.58	897	0.9	<0.02	3.29
	197452	726	1.4	<0.98	<0.53	<0.50	<4.56	13.5	1557	31.7	<0.12	3.83
	207066	30.2	3.07	0.488	<0.52	<0.10	<0.64	<0.11	1187	0.769	<0.07	<0.66
		38	2.84	0.163	<0.15	<0.05	<0.10		1114	0.706	<0.03	0.648
	205049	186	<4.64	<7.10	<7.29	<5.41	<8.27	<5.24	2709	14.4	<7.64	7.73
	203655											
Sites within areas of potential CBM influence	228592	21.7	0.9	1.15	<0.53	<0.50	<4.56	0.889	9.16	5.77	<0.12	12.8
		20.1	1.02	0.783	<0.77	<0.24	<0.51		539	2.91	<0.17	6.86
	223952	98.5	<0.58	<0.96	<2.30	<0.48	<3.19	<0.55	1495	<2.28	<0.34	<3.27
		110	<0.40	<1.01	<1.54	<0.48	<1.01	<0.41	1580	2.42	<0.33	<0.23
	7905	124	8.95	3.17	<5.20	<0.98	<6.45	<1.11	3045	25.4	<0.68	<6.61
		143	7.62	<4.04	<6.14	<1.94	<4.04		2736	22.9	<1.33	12.4
	8888	186	1.42	3.89	<5.20	<0.98	<6.45	<1.11	5994	50.8	<0.68	7.1
		210	1.63	4.66	<6.14	<1.94	<4.04		5882	44.3	<1.33	17.9
	198489	226	1.53	4.24	<5.20	1.44	<6.45	<1.11	8.47	67	<0.68	31.8
		245	1.7	5.66	<6.14	<1.94	<4.04		8862	60.8	<1.33	35.5
	219136	136	<1.0	<1.92	<4.60	<0.97	<6.39	<1.09	4640	20.7	<0.67	<6.54
		142	<0.40	<1.01	<1.54	<0.48	<1.01		5313	25.2	<0.33	2.85
	220857	63.8	1.99	3.95	<5.57	<1.10	<3.77	<0.60	3908	28.8	<0.44	35.8
		46.4	2.1	<1.77	<1.82	<1.35	<2.07	<1.31	2819	17.07	<1.91	21.4
	220859	38.2	1.74	1.74	<2.78	<0.55	8.89	<0.30	1778	12.7	<0.22	24.9
		33	2.23	<0.89	<0.91	<0.68	8.45	<0.66	1693	9.77	<0.95	23.4
	122766	119	4.71	2.45	<5.20	<0.98	<6.45	<1.11	6662	51.8	<0.68	22.7
		281	4.08	<4.04	<6.14	<1.94	<4.04		6103	45.7	<1.33	28.8
	228776	295	<4.64	<7.10	<7.29	<5.41	<8.27	<5.24	4672	21.9	<7.64	<6.94
	240578	173.2	<0.48	<0.98	<0.53	<0.50	<4.56	1.54	2704	7.9	<0.12	<0.28
		173	<0.58	<0.89	<0.91	<0.68	<1.03	<0.66	2655	7.18	<0.95	<0.87
	8101	163	<4.64	<7.10	<7.29	<5.41	<8.27	<5.24	2339	17.6	<7.64	16.3
	8412	95.1	3.77	1.28	<0.77	<0.24	<0.51		1732	6.17	<0.17	13.5
	8710	268	5.18	<4.04	<6.14	<1.94	<4.04	<1.66	6359	42.7	<1.33	26.9
	123796	389	<4.64	<7.10	<7.29	<5.41	27.3	<5.24	5084	12.8	<7.64	<6.94
	223801	159	<4.64	<7.10	<7.29	<5.41	10.7	<5.24	2781	23.2	<7.64	33.2

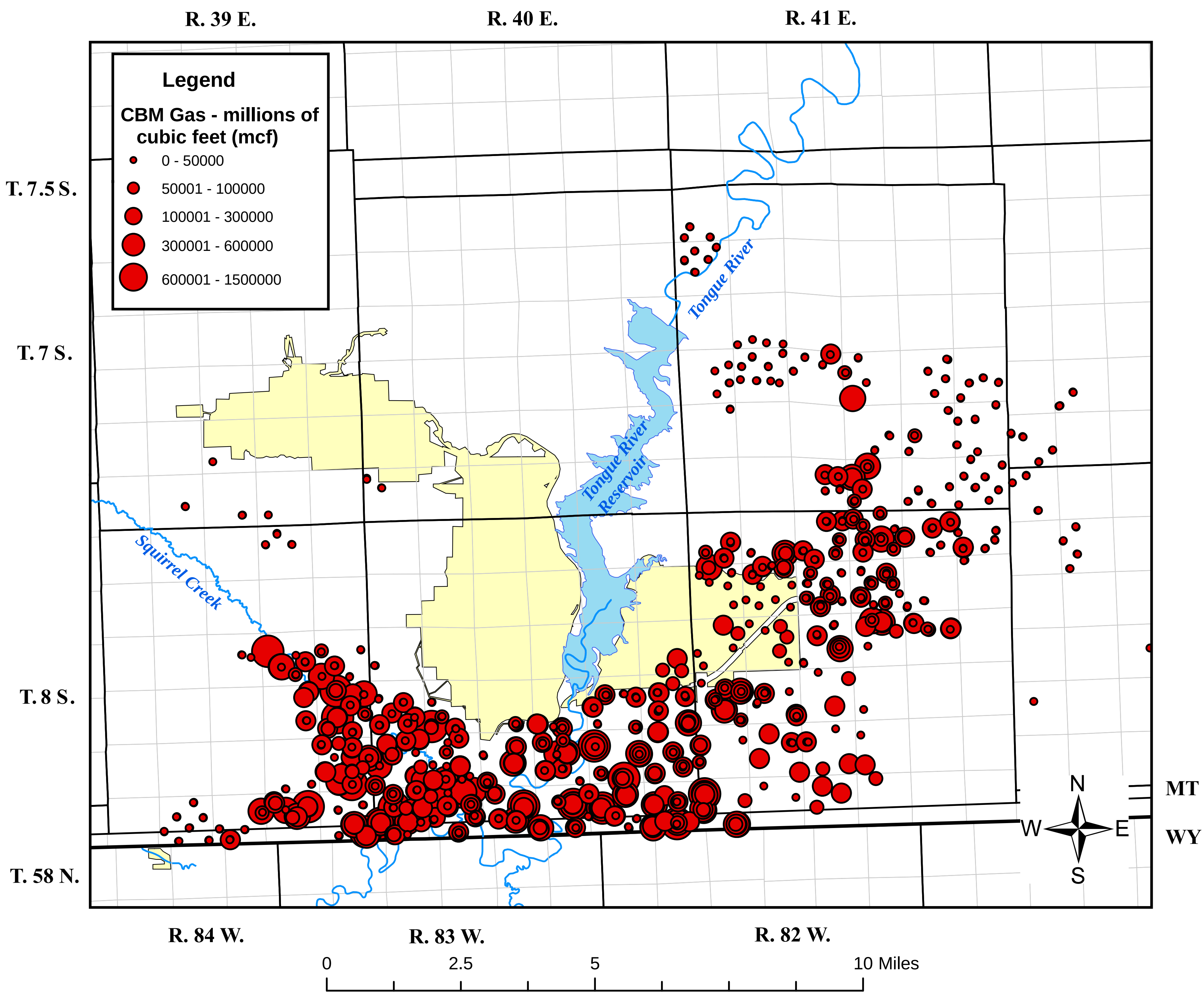
	Gwic Id	V (ug/l)	Zn (ug/l)	Zr (ug/l)
Sites outside areas of potential CBM influence	223877	<8.05	<4.05	<0.24
		1.96	<4.55	<0.152
	228591	37.5	5.88	<0.08
	197452	<0.54	36.3	1.82
	207066	<1.61	1.1	<0.05
		<0.10	2.24	<0.05
	205049	<5.95	<29.51	<3.82
	203655			
Sites within areas of potential CBM influence	228592	<0.54	24.8	<0.41
		0.519	25.9	<0.25
	223952	<7.97	10.1	<0.24
		<1.01	<9.09	<0.51
	7905	<16.10	<8.10	<0.48
		<4.04	<36.36	<2.02
	8888	<16.10	<8.10	<0.48
		<4.04	<36.36	<2.02
	198489	<16.1	<8.10	<8.10
		<4.04	<36.36	<2.02
	219136	<15.9	<8.02	<0.48
		<1.01	<9.09	<0.51
	220857	1.66	<2.69	<1.05
		<1.49	17.06	<0.96
	220859	1.43	<1.35	<0.53
		1.16	<3.69	<0.48
	122766	<16.10	<8.10	<0.48
		<4.04	<36.36	<2.02
	228776	<5.95	<29.51	<3.82
	240578	0.96	19.8	<0.41
		1.11	<3.69	<0.48
	8101	<5.95	<29.51	<3.82
	8412	<0.51	<4.55	<0.25
	8710	<4.04	<36.36	<2.02
	123796	<5.95	<29.51	<3.82
	223801	<5.95	<29.51	<3.82

Appendix D

A comparison of water and gas produced by well location:
Values for water and gas produced are cumulative over the life of the well.
All wells, regardless of production life are represented, and therefore
the values are not necessarily comparable.

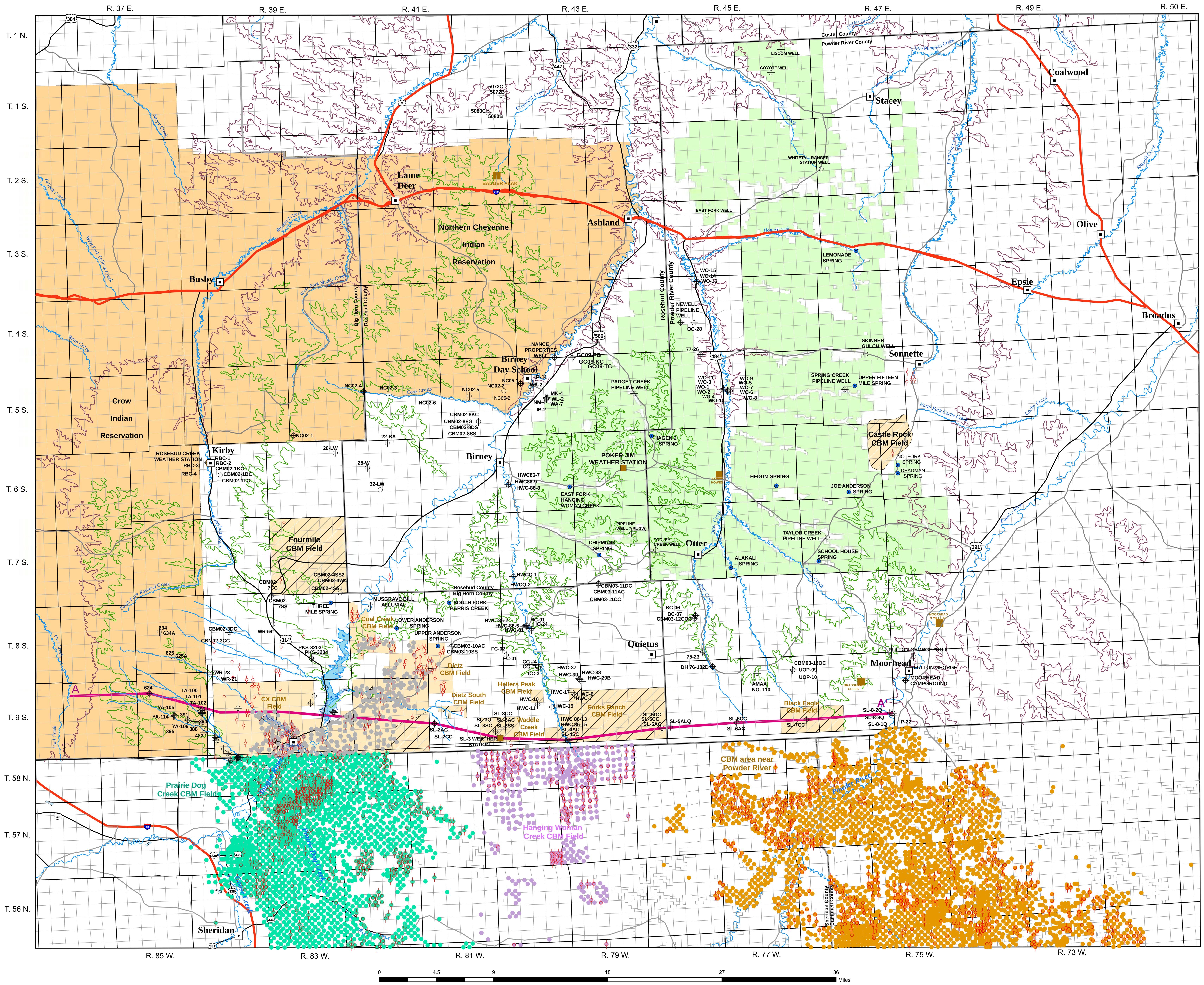


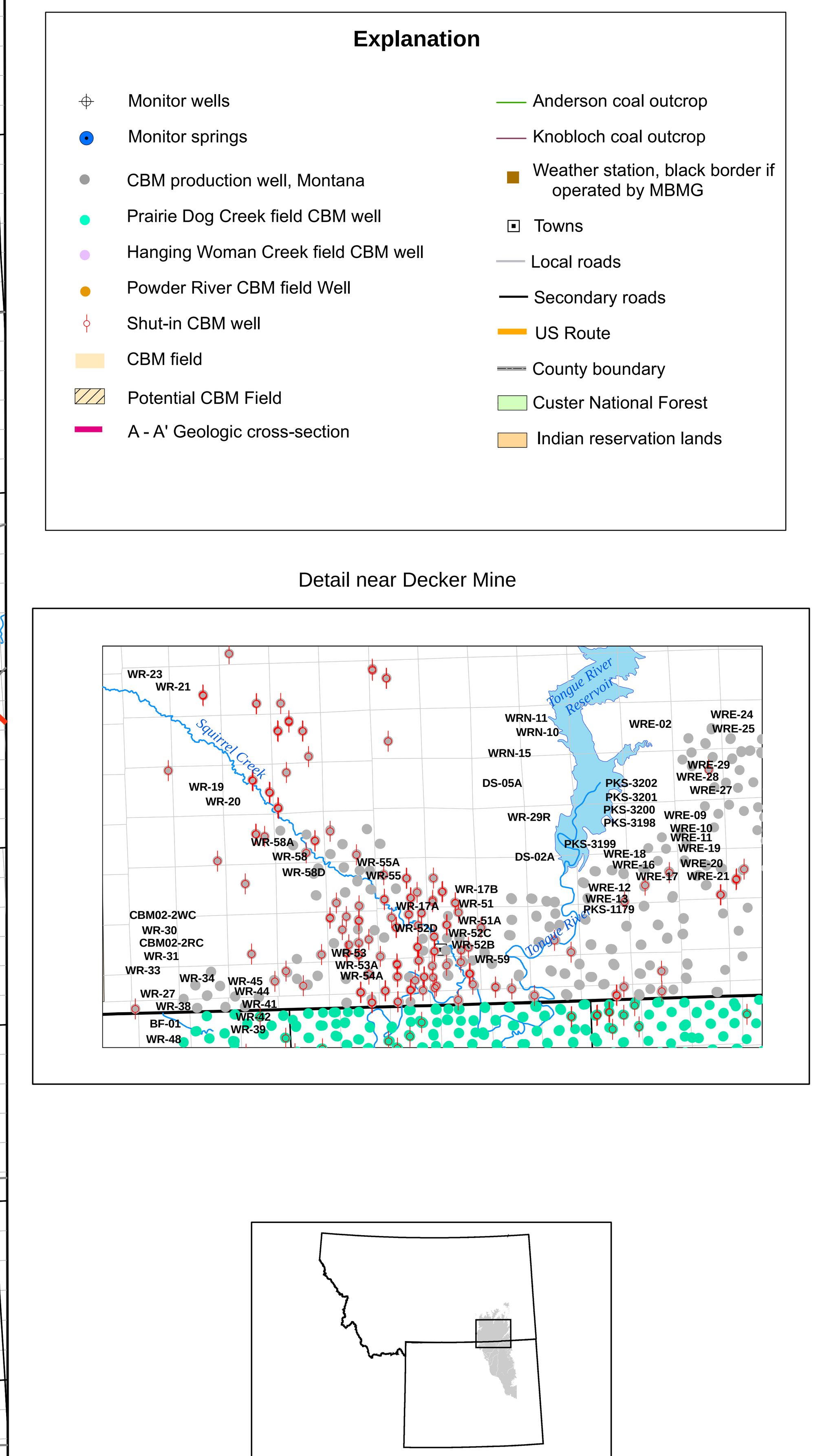
R. 39 E.
R. 40 E.
R. 41 E.
Legend
CBM water - barrels
0 - 10000
10001 - 300000
300001 - 600000
600001 - 1000000
1000001 - 2500000
T. 7.5 S.
T. 7 S.
T. 8 S.
T. 58 N.
MT
WY
N
W
E
S
R. 84 W.
R. 83 W.
R. 82 W.
0
2.5
5
10 Miles



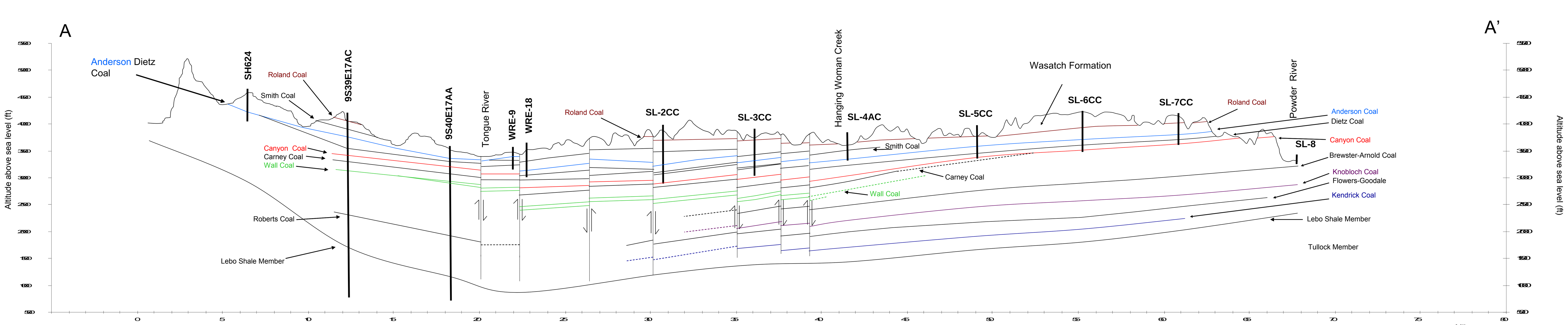
R. 39 E.
R. 40 E.
R. 41 E.
Legend
CBM Gas - millions of cubic feet (mcf)
0 - 50000
50001 - 100000
100001 - 300000
300001 - 600000
600001 - 1500000
T. 7.5 S.
T. 7 S.
T. 8 S.
T. 58 N.
Tongue River
Tongue River Reservoir
Squirrel Creek
MT
WY
N
W
E
S
R. 84 W.
R. 83 W.
R. 82 W.
0
2.5
5
10 Miles

Plate 1. Locations of 2010 monitoring sites, and Anderson and Knobloch coal outcrops.





0 4.5 9 18 27 36 Miles



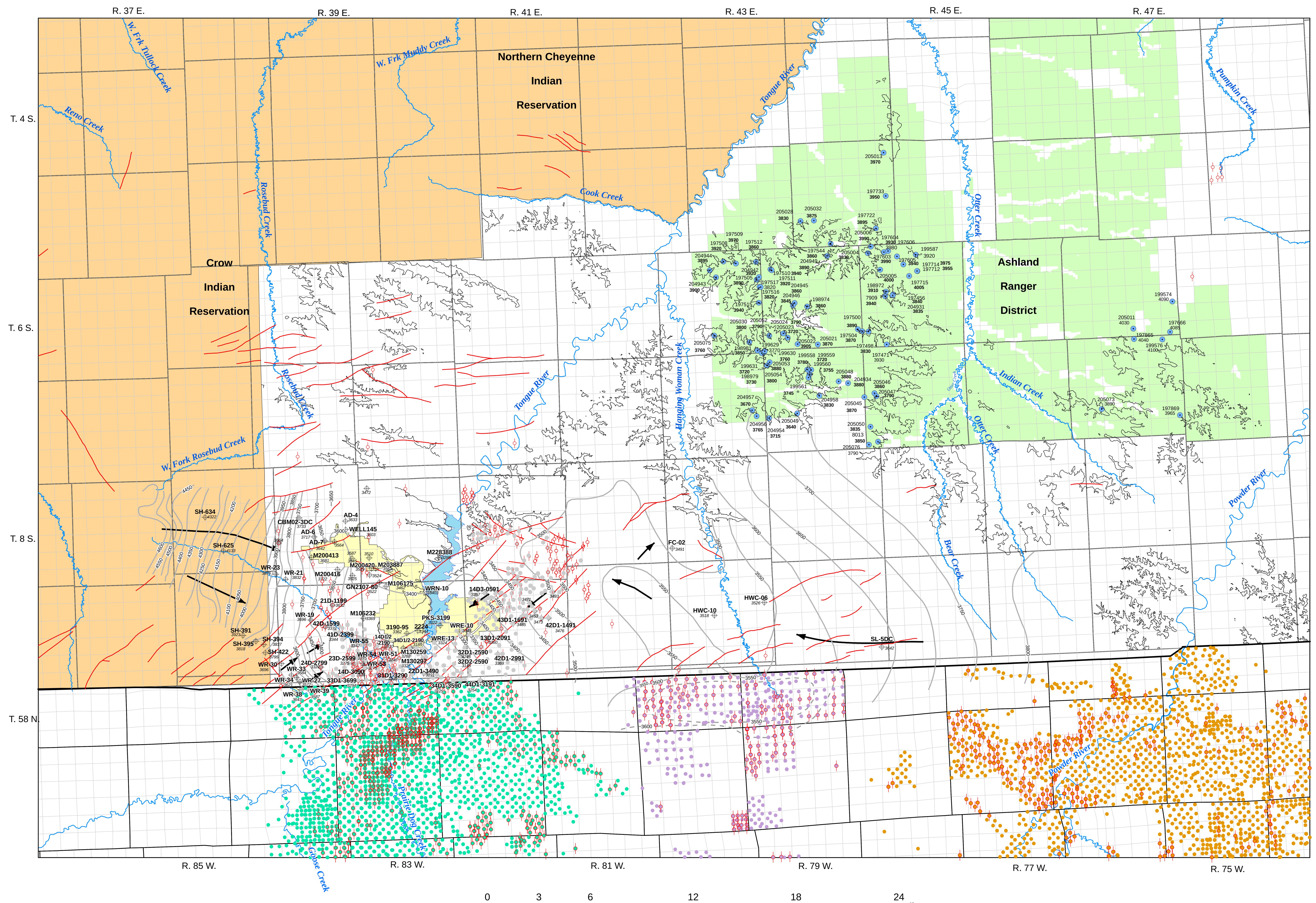


Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2009.

Explanation

Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, 2009. 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 2009.

199587 3920 — Spring with Dietz coal (GWIC identifier number)

Dietz coal outcrop

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

Mine area, includes active, permitted and reclaimed

CBM production well in the Dietz coal bed with production records during water year 2009.

CBM production well was listed as shut-in at the end of water year 2009.

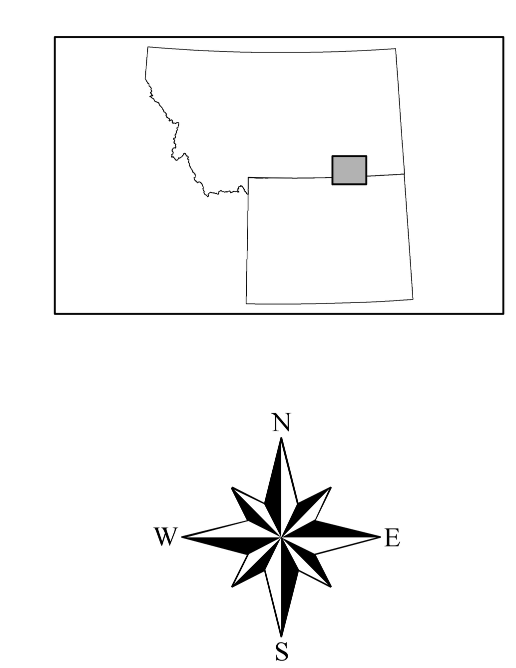
Prairie Dog Creek field CBM well

Hanging Woman Creek field CBM well

Powder River field CBM well

Indian Reservation land

National Forest area, Ashland Ranger District



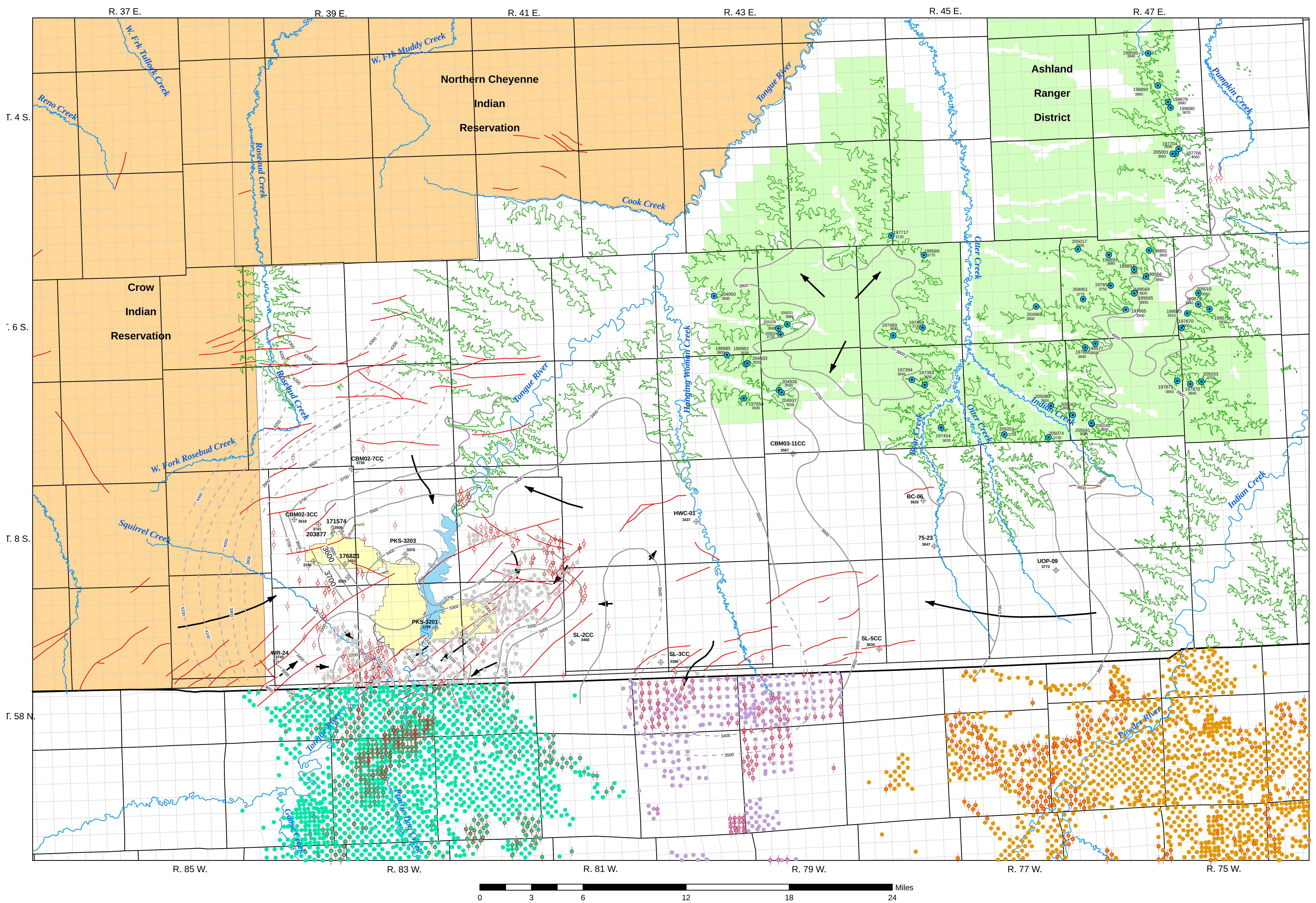
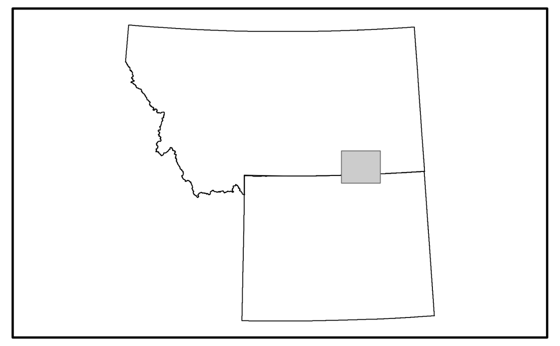


Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2009.

Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, water year 2009), 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 2009.
- 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 Montana with production records during water year 2009.
- CBM production well was listed as shut-in at the end at the end of water year 2009
- Prairie Dog Creek field CBM well
- Hanging Woman Creek CBM field well
- Powder River field CBM well
- Indian Reservation land
- National Forest area, Ashland Ranger District



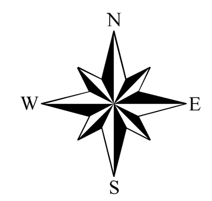
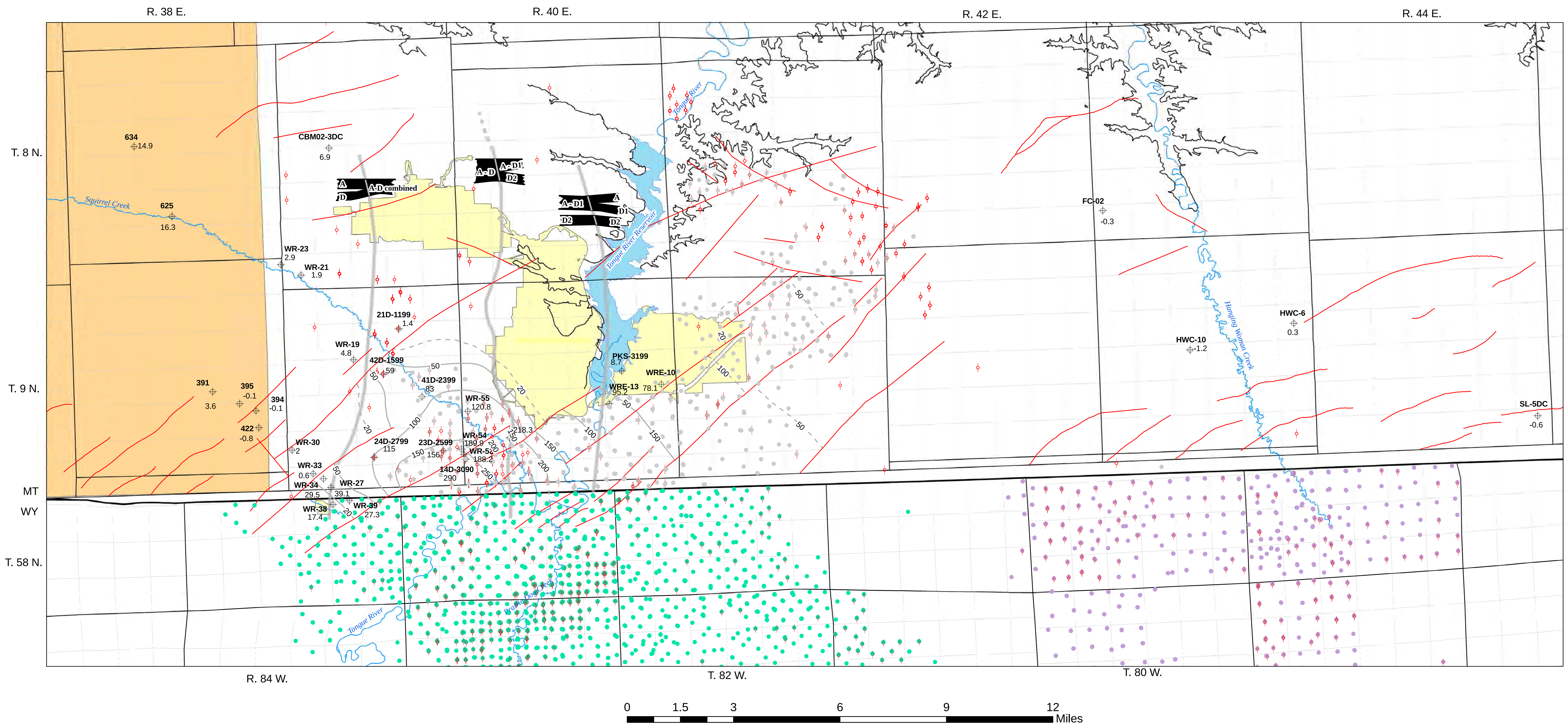
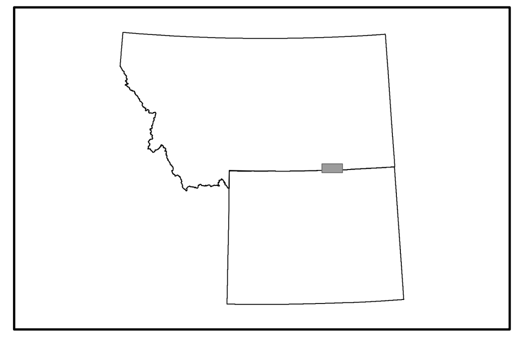
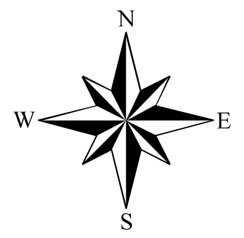


Plate 4. Area of CBM-related potentiometric decline for the Dietz coal in the southern portion of the Powder River Basin, Montana







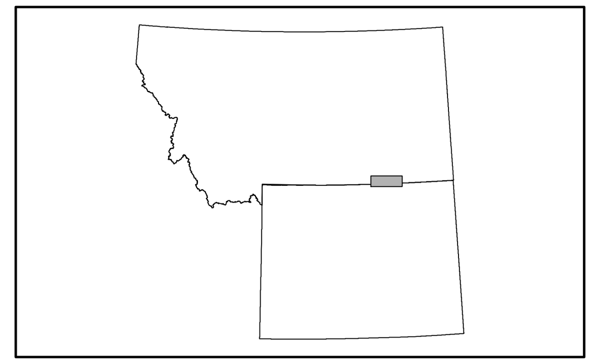
Explanation

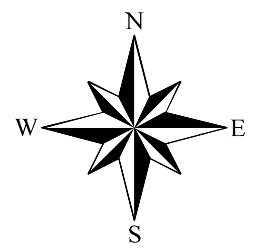
- Potentiometric decline: dashed where inferred, 50-ft contour intervals, 20-ft line also shown.
- WR-34 32.4 — MBMG Monitor well name, change in water-level (ft) for last data in water year 2009.
- Dietz coal outcrop
- Dietz coal split line, approximate locations, dashed where inferred. Diagrams show 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 in Montana that produced water and/or methane during water year 2009.
- CBM production well that was listed as shut-in at the end of water year 2009.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field CBM 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

Explanation

- Potentiometric decline: dashed where inferred, 100-ft contour intervals, 20-ft line also shown.
- WR-24 4.7 — Monitor well name, change in water-level (ft) for last data in water year 2009.
- 197717 3720 — Spring with Canyon coal (GWIC identifier number)
- Canyon coal outcrop
- Fault, MBMG geological data, CX coal field area modified with Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- CBM production well in Montana that produced water and/or methane during water year 2009.
- CBM production well was listed as shut-in at the end of water year 2009.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field CBM well
- Powder River field CBM well
- Indian Reservation land





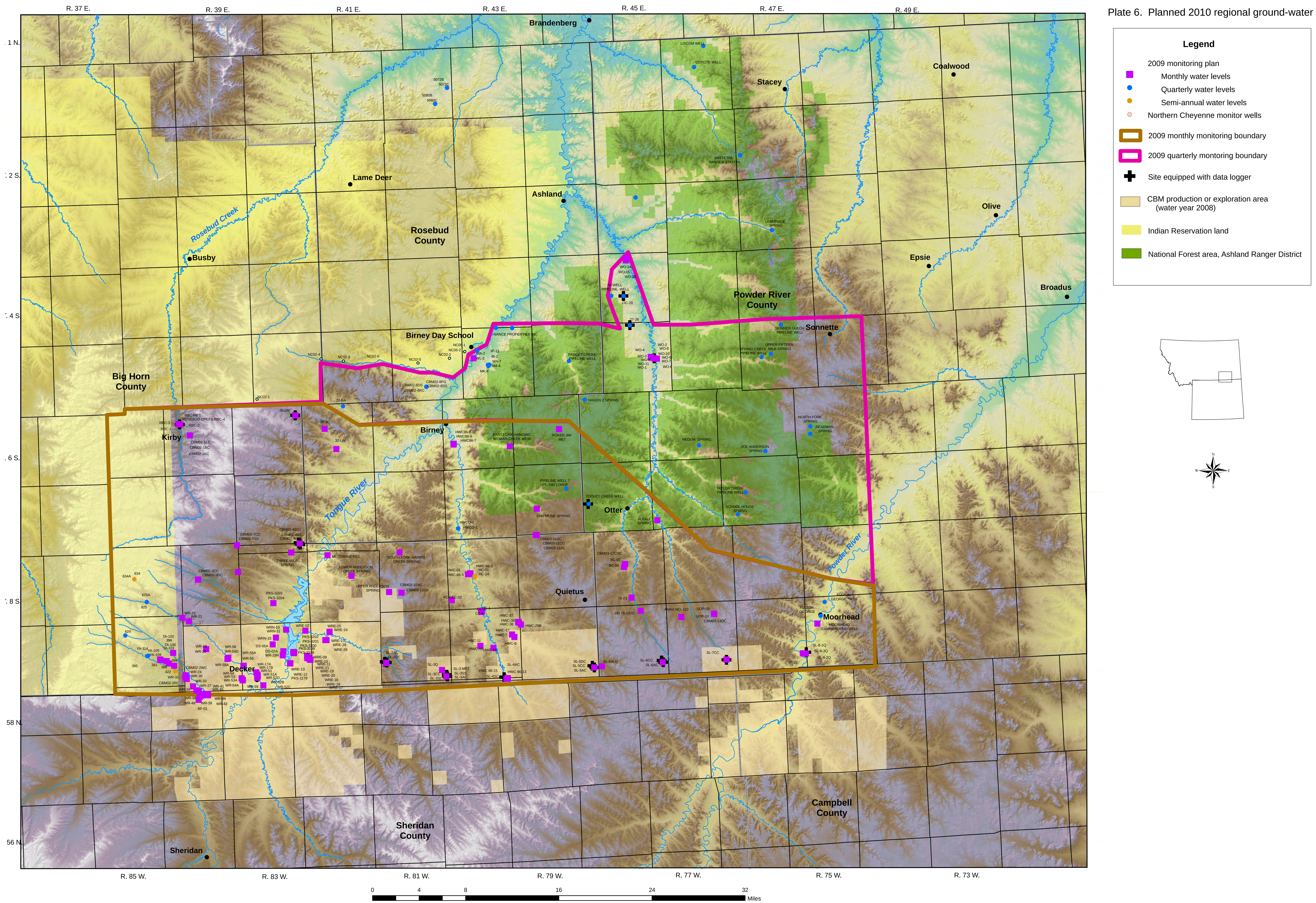


Plate 6. Planned 2010 regional ground-water plan.