2011 Annual Coalbed-Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

Montana Bureau of Mines and Geology Open-File Report 614

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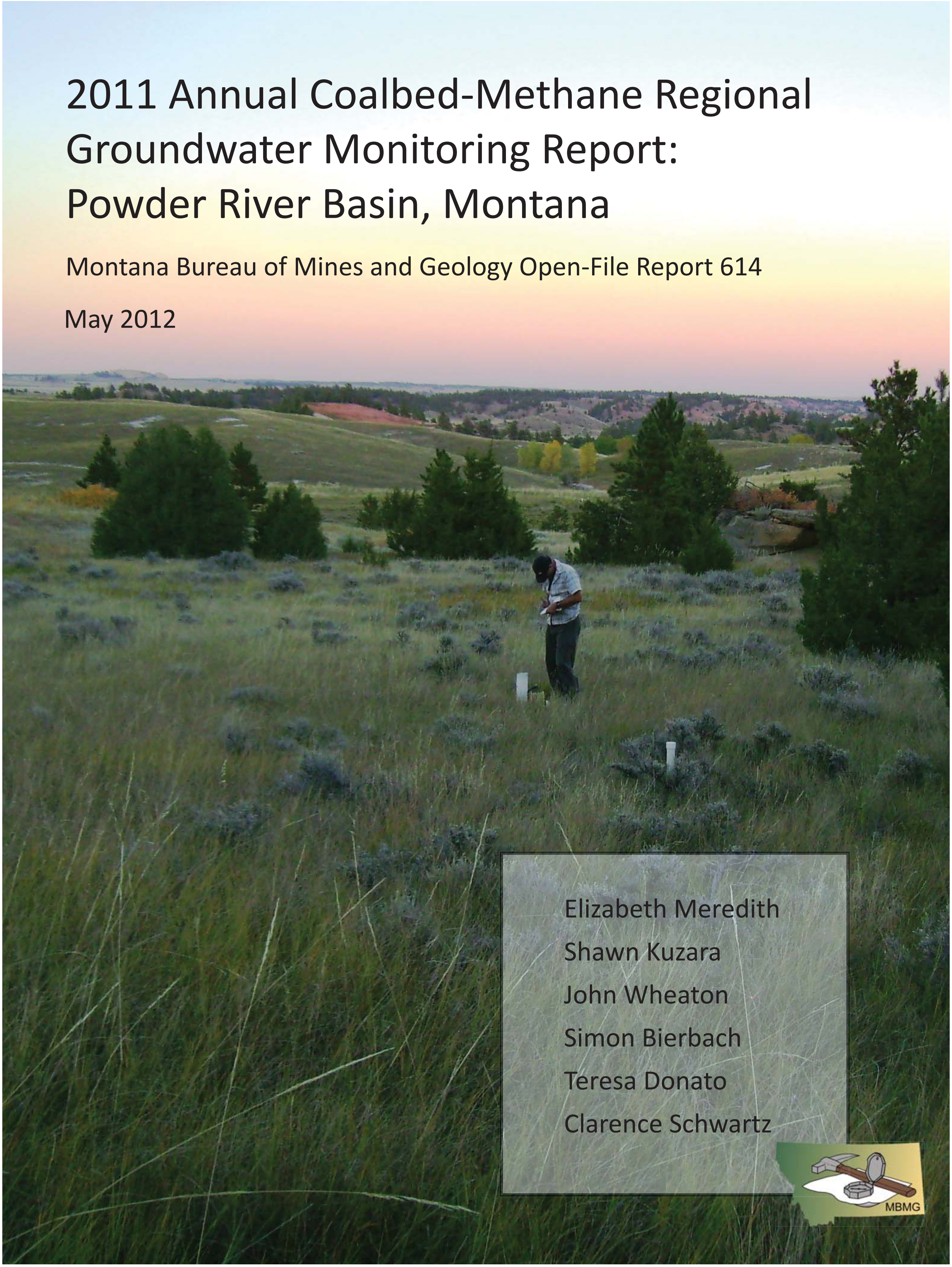

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EXECUTIVE SUMMARY

This report presents groundwater data collected through September 2011 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 2011. This annual report is presented on the water year, which is October through September. This is the ninth 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 present 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 had 750 CBM wells that produced methane, water, or both during 2011. This is 74 fewer wells than in 2010. A total of 7.14 million mscf (1 mscf = 1000 standard cubic feet) of CBM was produced in Montana during 2011, 91 percent of which came from the CX field. The other 9 percent of the methane was produced from the Dietz, Coal Creek, and Waddle Creek fields.

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 50, and total dissolved solids concentrations between 1,000 and 2,500 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 2011, the Montana Bureau of Mines and Geology (MBMG) regularly measured water levels in the network of monitoring wells throughout much of the Powder River Basin in Montana, with a focus on areas with current CBM activity or areas expected to have high CBM potential. Fidelity Exploration and Production Company (Fidelity) and Summit Gas Resources (Summit; formerly Pinnacle Gas Resources, Inc.) also provided water-level measurements in monitoring wells and during 24-hour shut-in tests of selected wells. Fidelity reported 309 water-level measurements from 65 wells; the majority of the wells were completed in the Anderson/Dietz coal zone. The Decker coal mine reported 21 water levels from 9 wells. The Spring Creek coal mine reported 75 water-level measurements from 22 wells. Summit supplied 38 water-level measurements from as many wells: 6 from the Anderson/Dietz coal zone, 2 from the Canyon coal, 8 from the Cook coal, 17 from the Wall coal, and 5 from the Flowers–Goodale coal. These water levels were combined to help create plates 2, 3, 4, and 5. The Anderson/Dietz and Canyon coalbeds are primarily used in discussions in this report because of the greater density and coverage of monitoring wells completed in those coalbeds. Hydrostatic heads in the Dietz coal have been lowered 200 feet or more within areas of production. The potentiometric surface in the Canyon coal has been lowered more than 600 feet. After 12 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 production area boundary. These distances are somewhat less than originally predicted in the Montana CBM environmental impact statement (U.S. Department of the Interior, Bureau of Land Management, 2003). The radius of the 20-foot drawdown contour will increase if the duration and magnitude of CBM production increases; however, these increases became less over time and these radii have not noticeably changed since 2004 (Wheaton and others, 2005).

Initial computer modeling efforts and reviews of monitoring data from nearby coal mines, conducted near the beginning of CBM production in Montana, projected drawdown of 20 feet would eventually reach as far as 4 miles beyond the edges of large production fields. The amount of 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). After more than 10 years of production, the 20-foot drawdown contour generally does not extend beyond 2 miles outside the CBM fields. Faults tend to act as barriers to groundwater flow, and drawdown has not been observed to migrate across fault planes where measured in monitoring wells; however, recent computer modeling of the Ash Creek mine area shows that the hydraulic conductivity of faults can vary significantly along their length from impermeable to permeable. This may be particularly true on scissor faults. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, but it is anticipated that decades will be needed before water levels recover to near pre-production. The extent of drawdown and rates of recovery will mainly be determined by the rate, intensity, and continuity of CBM development; site-specific aquifer characteristics, including the extent of faulting and proximity to recharge areas; and other significant groundwater withdrawals in the area, such as coal mining. 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 indicate that baseline water levels will be reached in approximately 30 years; however, that projection is based on recovery rates in fields where there is still some CBM production. Recovery rates may increase as more CBM wells are taken out of production.

Projections are important for evaluating potential future impacts. However, long-term monitoring is necessary to test the accuracy of computer models and determine the actual magnitude and duration of impacts. Monitoring data and interpretations are key to making informed development decisions and to determining the causes of observed changes in groundwater availability.

List of Abbreviations

above mean sea level (amsl); barrels (bbls); coalbed methane (CBM); gallons per minute (gpm); million cubic feet (MMCF); Montana Board of Oil and Gas Conservation (MBOGC); Montana Bureau of Mines and Geology (MBMG); Million British Thermal Units (MMBtu); Montana Groundwater 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 Department of the Interior, Bureau of Land Management (BLM); United States Geological Survey (USGS); Wyoming Oil and Gas Conservation Commission (WOGCC).

INTRODUCTION

In the Powder River Basin coalbed methane (CBM) is produced through the biogenic breakdown of coal by microbes, and held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping groundwater from coal seams allows methane to desorb and be collected. CBM production groundwater is typically pumped at a rate and scale that reduces water pressure (head) to a few feet above the top of the produced coalbed over large areas. Since these coal seams are also important aquifers, 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. There are also concerns regarding the management of the water to potential and impacts to surface-water quality and soils from water management practices. The drawdown (reduction of hydrostatic pressure) in coal aquifers that results from coalbed-methane production will reduce yields from wells and discharge rates of springs that obtain their water from the developed coal seams. Due to concern regarding the magnitude, geographic extent, and duration of this drawdown, the Montana regional monitoring program was established.

The benefits to Montana from CBM production include tax revenue, increased employment, secondary economic effects on local economies, and potential royalty payments to landowners (Blend, 2002). To date, th3e CBM industry has contributed over $45 million dollars to the state of Montana through taxes and royalties (table 1; written commun., Mike Keller, Fidelity and Terry Webster, Summit, March 2011). Revenues, taxes, and royalties depend upon gas prices; the spot Henry Hub price of natural gas has varied greatly in dollars per MMBtu (million British Thermal Units). It reached a peak in 2005 of over $15/MMBtu and currently stands just below $3.50/MMBtu (www.energystox.com).

Table 1. Taxes and royalties paid to the state of Montana from CBM production companies by year.

1999	2000	2001	2002	2003	2004	2005
$7,472	$588,676	$2,061,469	$2,029,626	$2,531,687	$4,071,391	$7,738,367
2006	2007	2008	2009	2010	2011	
$5,896,658	$5,482,386	$8,429,811	$3,221,266	$3,212,740	*pending*	

This annual report presents groundwater data and interpretations from within the northern portion of the PRB, mainly in Montana. This is the ninth 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 and lack of impacts, to record groundwater recovery, and to provide data and interpretations for use in environmental and permitting decisions. Additional background is presented in Wheaton and Donato (2004). Annual reports present data by water year (October 2010 through September 2011).

This annual 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 areas affected by CBM production. The area covered by the Montana regional CBM groundwater monitoring network is shown in figure 1 and plate 1.

All hydrogeologic monitoring data collected under the Montana regional CBM groundwater monitoring program (including the data presented in this report) are available from the Montana Bureau of Mines and Geology (MBMG) Groundwater Information Center (GWIC) database. 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 (free). 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 buttons. 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 from their webpage (http://www.bogc.dnrc.mt.gov/default.asp), and the Wyoming Oil and Gas Conservation Commission (WOGCC) webpage (http://wogcc.state.wy.us/).

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 in detail (townships 57N and 58N). This covers a distance of about 9 miles south from the state line (plate 1).

Hydrogeologic data were collected by the MBMG at 215 wells, 13 springs, and 2 streams during the 2011 water year. Of those monitored sites, 17 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). Fidelity and Summit also contributed their 2011 water-level monitoring data to this report. 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 2011 are listed in appendix C. All data are available electronically from GWIC (http://mbmggwic.mtech.edu/). The locations of all monitoring sites are shown on plate 1.

Acknowledgments

The landowners and coalbed-methane producers who allow 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. Department of the Interior, Bureau of Land Management (BLM). The USDA Forest Service provides funding in support of monitoring on the Ashland Ranger District on the Custer National Forest. The Montana Department of Natural Resources and Conservation, and the Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal and coalbed methane hydrogeologic work. The Coalbed Methane Protection Program has supported the publication of this report and other informational fliers for CBM education. The statewide Ground-Water Assessment Program, operated by the MBMG, monitors several wells and springs in the Powder River Basin, and those data are incorporated in this work. Technical discussions and reviews by the BLM, USFS, and cooperating groups 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 (fig. 1 and plate 1). This is the Montana portion of the PRB believed to have high to medium potential for CBM development (Van Voast 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).

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; however, the Wasatch tends to be more coarse grained. 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 MBMG monitoring wells and published well logs and correlations (Culbertson, 1987; Culbertson and Klett, 1979a,b; Lopez, 2006; McLellan, 1991; McLellan and others, 1990). A discussion of general Fort Union Formation coal geology and nomenclature, including a summary of coal aquifer aqueous geochemistry, can be found in appendix D.

Hydrogeologic Setting

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 can 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.

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 generally toward the Yellowstone River. Groundwater in the regional flow system will either leave the PRB as deep groundwater flow, or will discharge as springs, to streams, or to alluvium. Hundreds of springs originating in the Tongue River Member of the Fort Union Formation have been inventoried and mapped in the project area (Kennelly and Donato, 2001; Donato and Wheaton, 2004a,b; Wheaton and others, 2008).

Water levels in shallow aquifers respond to seasonal variations in precipitation. Deeper aquifers show small, if any, measurable seasonal changes in water level except for long periods of low or high precipitation.

Aquifers are dependent on precipitation for recharge, and shallow groundwater levels reflect both short- and long-term precipitation patterns. Precipitation data from from 1970 through the end of 2011 from the Moorhead weather 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 12.0 inches (Western Regional Climate Center, 2010). During the water year 2011, Moorhead received 17.75 inches of precipitation, which is 5.75 inches higher than the average annual precipitation (fig. 2). Long-term precipitation trends that may affect groundwater levels are illustrated by the departure from average. The early 2000s marked a period of average-to-low precipitation, while precipitation has generally been above average from 2005 to 2011.

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 areal extent of drawdown (Van Voast and Reiten, 1988). A series of monitoring wells were installed south of the East Decker mine in the early 1970s 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 has demonstrated that some fault systems allow for slow leaking across the fault.

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 collected semi-annually in some shallow aquifers.

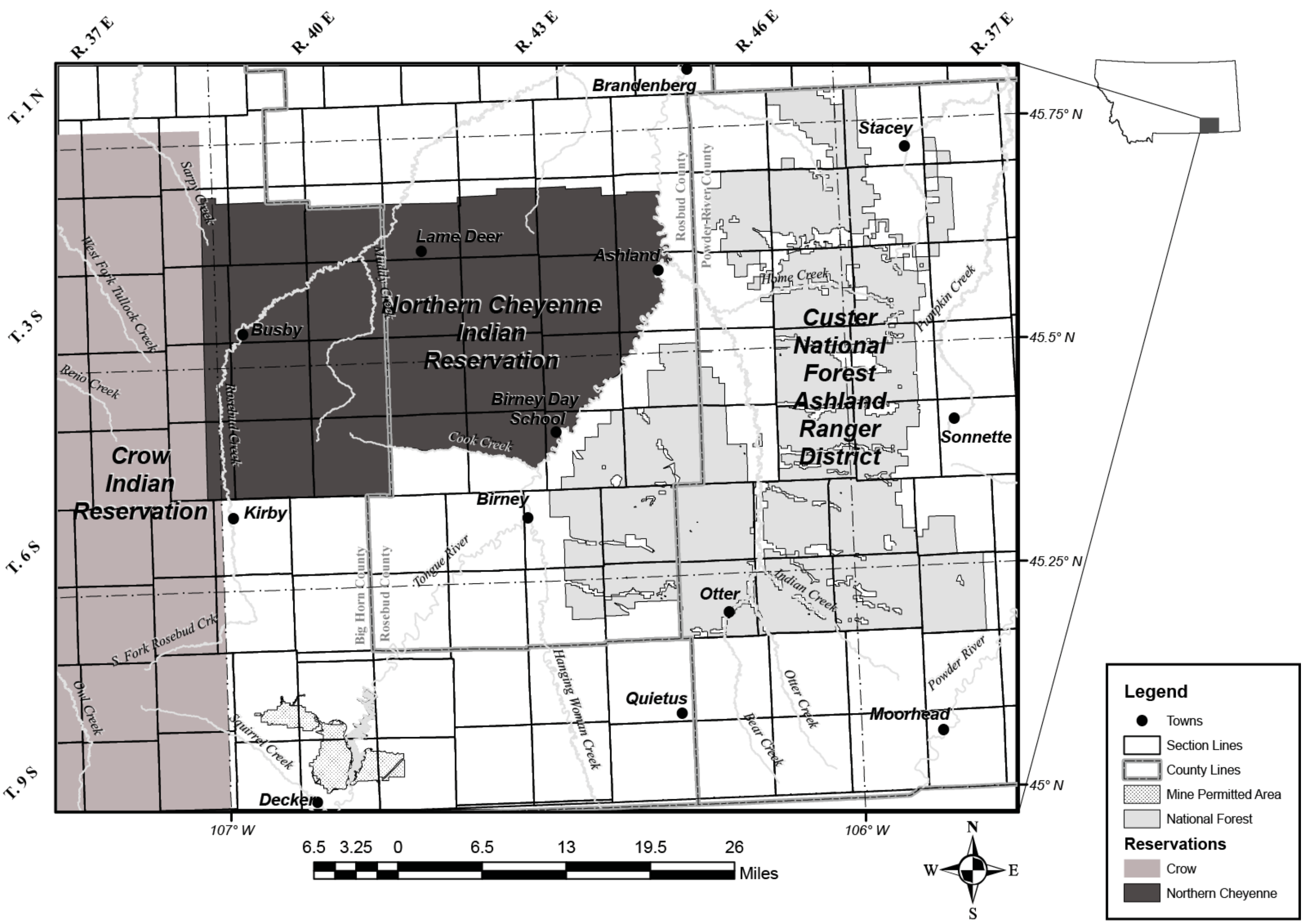


Figure 1. The Montana regional CBM monitoring network covers the area considered to have medium to high potential for CBM development in the PRB. This area extends from the Wolf Mountains in the west to the Powder River in the east, and from the MT–WY state line north to Ashland.

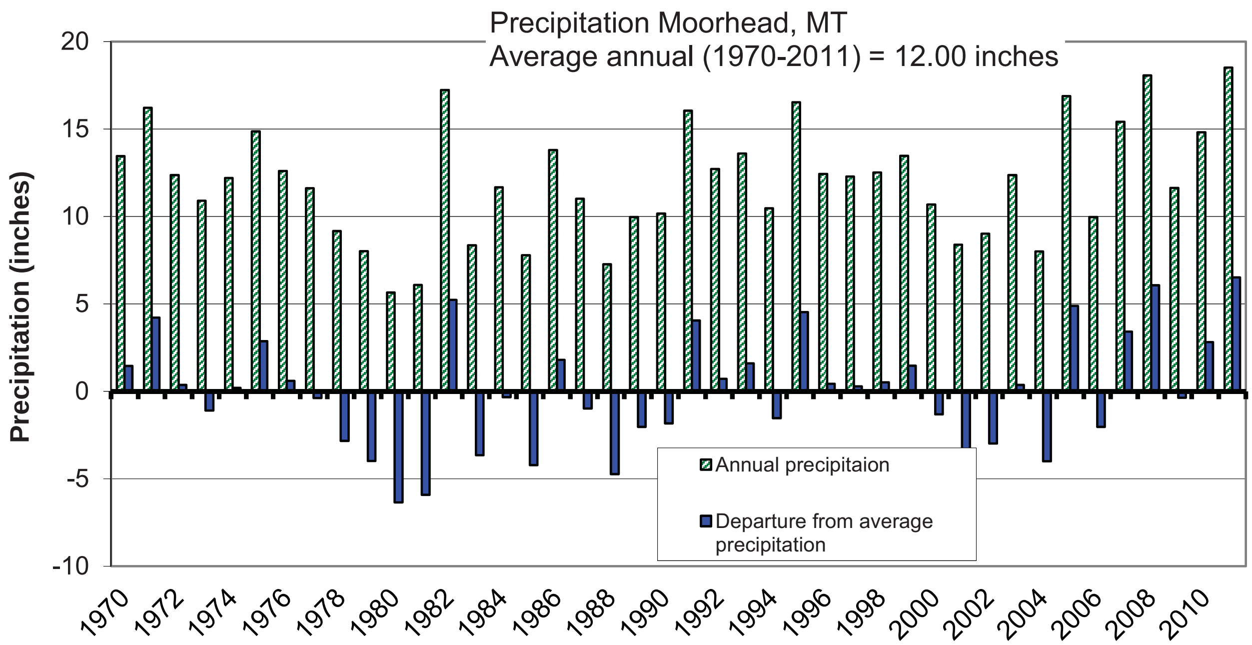


Figure 2. Annual precipitation (striped bar graph) at Moorhead, MT. Departure from average precipitation (solid bar graph) provides a perspective on the long-term moisture trends that may affect groundwater recharge.

GROUNDWATER CONDITIONS OUTSIDE OF CURRENT CBM INFLUENCE

Bedrock- and Alluvial-Aquifer Water Levels and Water Quality

Groundwater levels (the potentiometric surface) and inferred groundwater flow directions in the Dietz and Canyon coalbeds, as interpreted from the available data, are shown in 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 at outcrop springs, domestic wells, stock wells, and CBM wells and seeps into deeper bedrock and/or deep groundwater flow paths. Baseline data presented in previous CBM annual reports (i.e., MBMG Open-File Report 600) can be found in appendix E unless significant or otherwise interesting changes occurred in the current water year.

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 Tribe and the USGS. Monitoring wells NC02-1 through NC02-6 (GWIC IDs 223238, 223240, 223242, 223243, 223236, and 223237; USGS IDs 05S40E31BDCC01, 05S42E14ADDC02, 05S41E17ADBD01, 05S40E13ADAB01, 05S42E16CCAB01, and 05S41E14BDCD01) monitor the water levels of the Wall (2), Flowers–Goodale, Pawnee, and Knobloch (2) coalbeds. 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 MBMG GWIC website and the USGS NWIS website (http://nwis.waterdata.usgs.gov/).

Monitoring site CBM02-1 is near the town of Kirby just to the east of Rosebud Creek (fig. 3). During the previous 7 years of monitoring at this site, the water levels in the Brewster–Arnold coal and the local coal showed subtle responses to seasonal precipitation patterns, whereas the Knobloch showed very little fluctuation in water level. However, after the unusually high precipitation this spring (2011), all aquifers showed a response to the recharge event. The low storage that generally typifies deep coal aquifers causes the water-level response in the Knobloch to be greater than in the shallower coals.

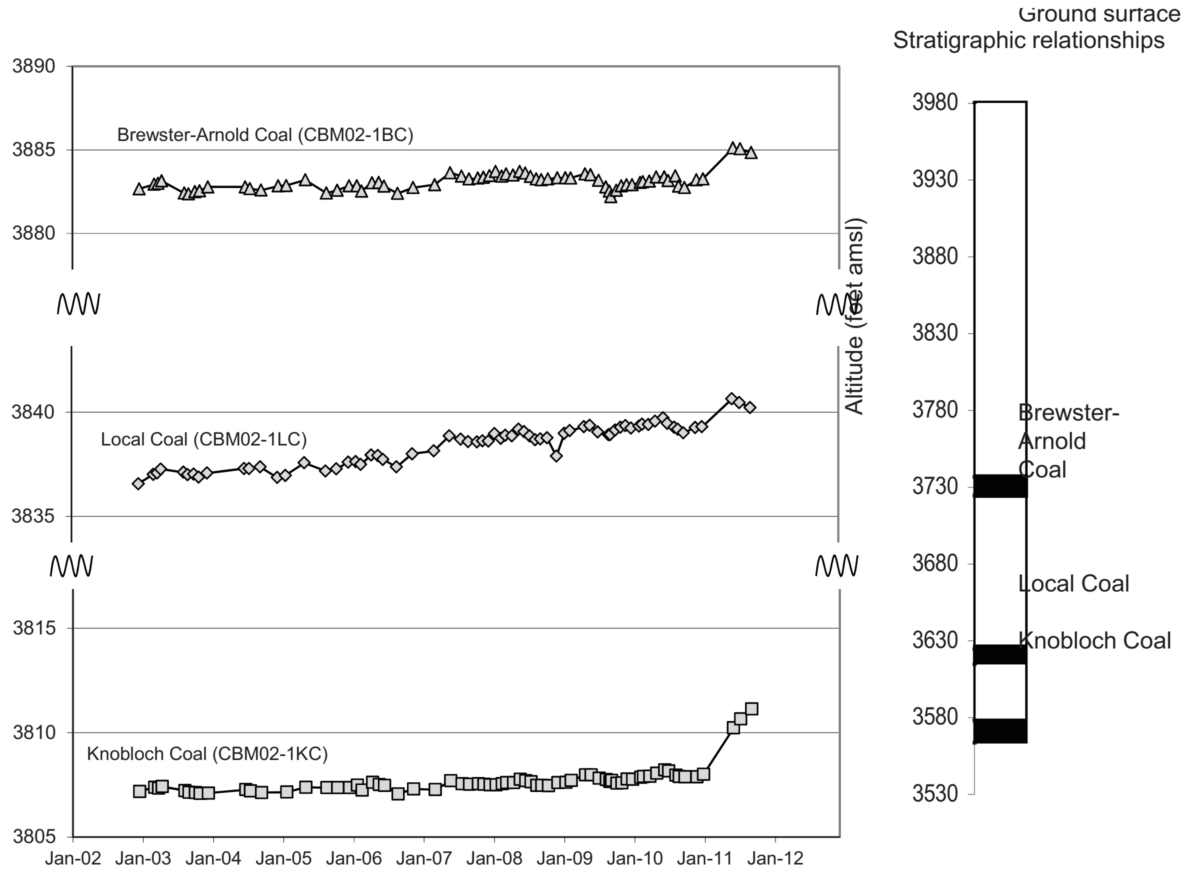


Figure 3. A downward hydrostatic gradient is evident between theBrewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site. This monitoring site is near the town of Kirby, just east of Rosebud creek. Water-level data from the Brewster-Arnold coal and the local coal demonstrate a slight annual cycle with the lowest levels in late summer or early fall, indicating a relationship with precipitation patterns. The deeper Knobloch coal does not typically reflect a seasonal pattern and is most likely part of the regional flow network; however, particularly high precipitation in 2011 caused water levels to rise in all 3 wells.

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

At monitoring site WO, along Otter Creek, the alluvial water levels are responsive to local, recent precipitation (fig. 4). During the heavy spring rains this year, the water level in the alluvium rose uniformly across the valley; despite the dramatic increase in water levels, the direction of water discharge toward the creek did not change. Otter Creek appears to transition between a gaining and losing stream in this area; the exact location along the stream depends on the seasonal alluvial groundwater level.

Water levels in Rosebud Creek alluvium also vary with precipitation trends. Data, particularly those from the continuous recorders at the site, show the relationships between meteorological conditions, groundwater levels, and surface-water flow (fig. 5). Detailed precipitation data for the Rosebud Creek site (fig. 5B) illustrate how quickly alluvial groundwater levels respond to precipitation events. Increased in-stream flow at this site usually lags behind heavy rain events by 6 to 18 hours. Despite the heavy rains and flood-stage conditions, groundwater levels were only slightly higher than previously recorded high conditions.

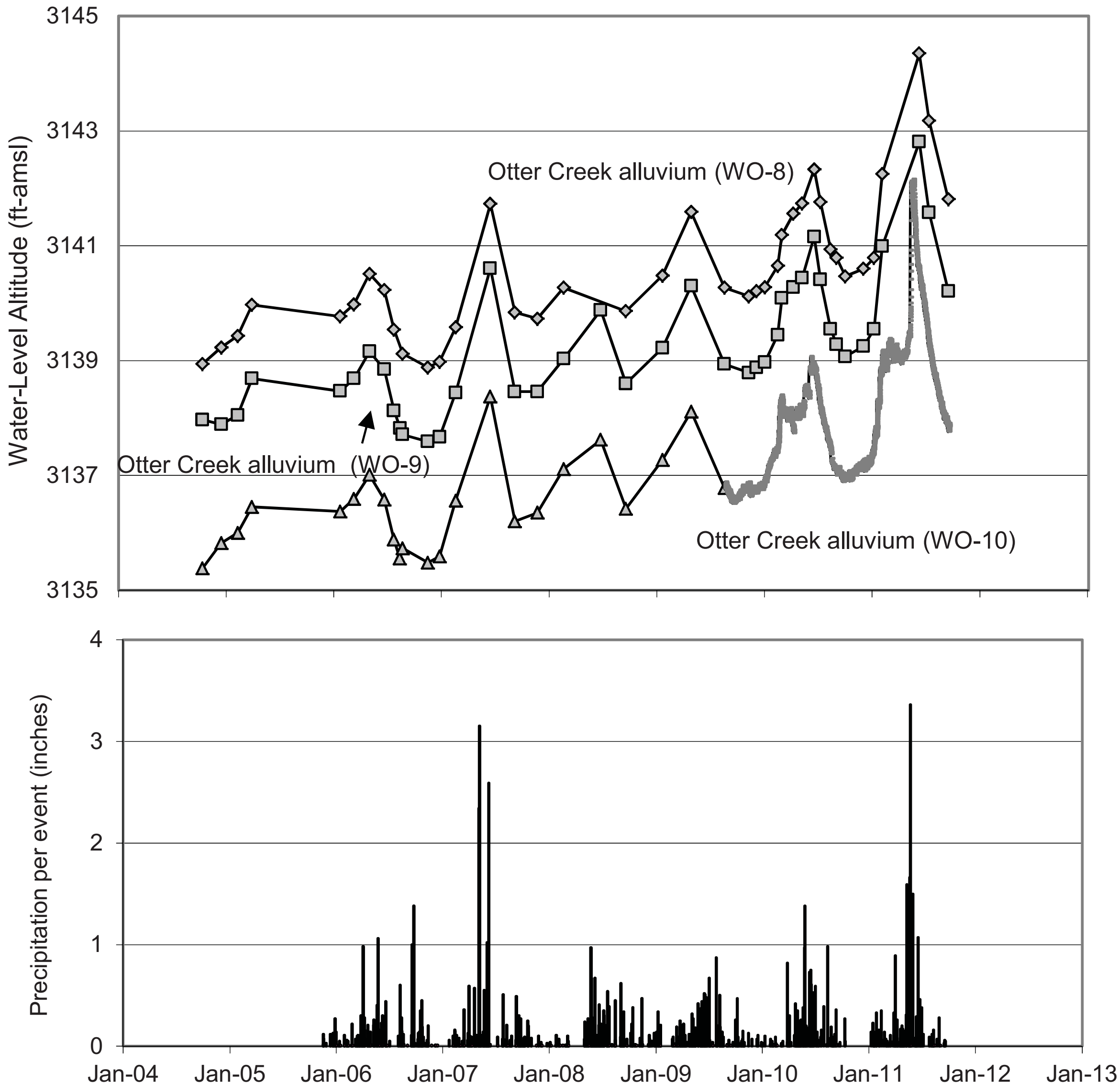


Figure 4. Water-level trends in the alluvium at the Otter Creek site closely follow the precipitation at Poker Jim weather station (shown as the total rain in inches per event in the lower graph).

Water-quality samples were collected in September 2010 and June 2011 from one alluvial well (RBC-2) outside areas of potential coalbed-methane influence (appendix C). This well is completed in alluvium of Rosebud Creek. Similar to previous years, concentrations of TDS were 560 and 593 mg/L and SAR values were 0.9 and 0.8, respectively. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate. The data are available on GWIC.

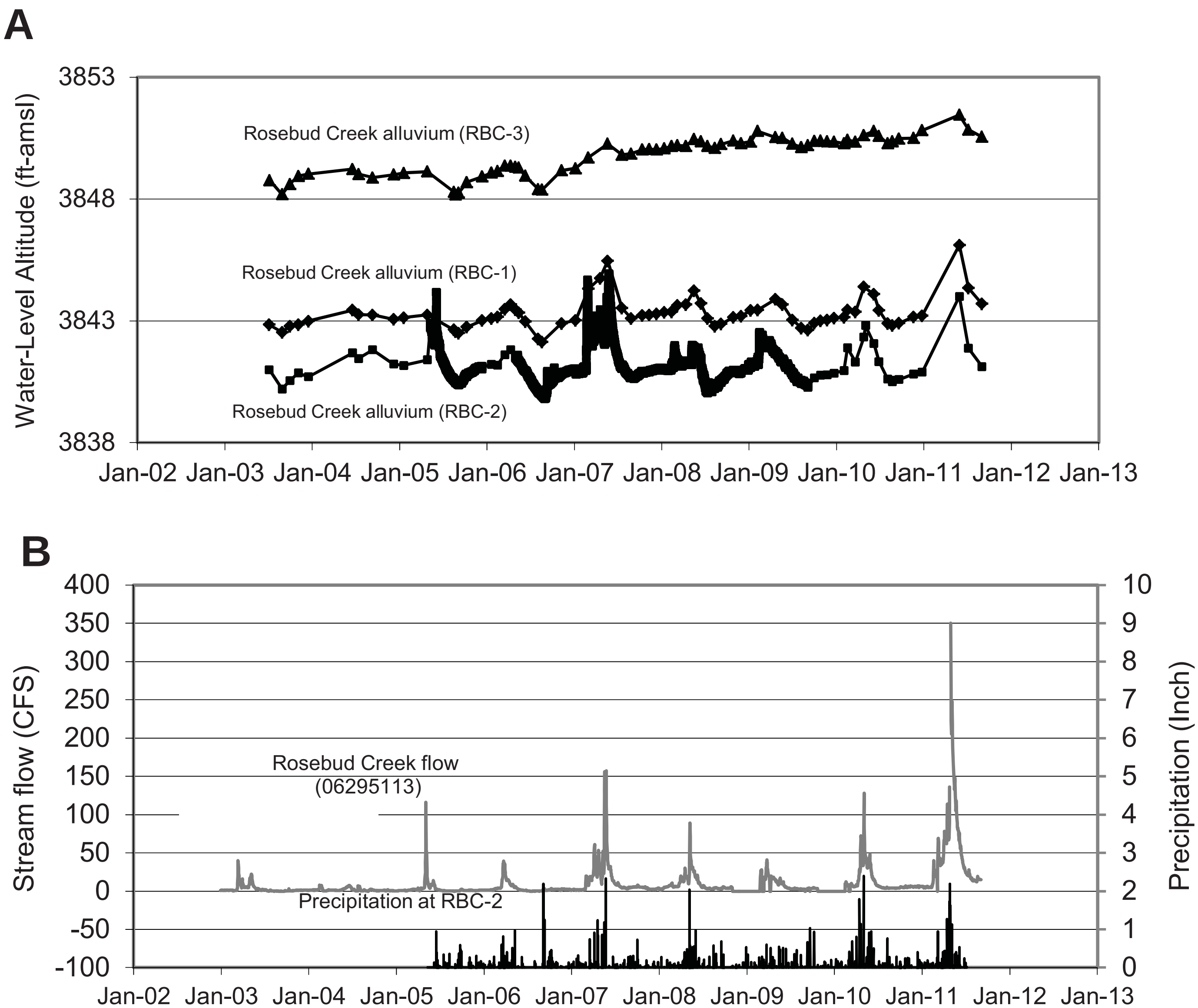


Figure 5. (A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. (B) Rosebud Creek stream flow follows precipitation trends. Precipitation is shown as the total rain in inches per event in the lower graph (flow data from USGS gauging station 06295113 near Kirby). A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation (precipitation data from the Rosebud meteorological station are available on the MBMG GWIC online database).

Spring and Stream Flow and Water Quality

Flow rates and specific conductivity data were collected at 14 springs and two streams within the project area and outside the influence of CBM production during 2011. The locations of monitored springs and the streams are shown on plate 1, site data are in appendix B, and water chemistry data are in appendix C. Data collected from these sites during 2011 are available in the GWIC database.

In the southern portion of the Custer National Forest Ashland Ranger District along Otter Creek, Alkali Spring discharges between 0.5 and 1 gpm. The discharge rate at this spring shows some seasonal influence (fig. 6). 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, 2009) 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 and others, 2008). Because this spring responds to seasonal changes and therefore has a component of local recharge, it is unlikely that CBM activities will impact the flow rate of this spring.

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 the average discharge at this spring is 1.74 gpm, showing moderate seasonal variations (fig. 6). 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 that are typically less than 1 gpm (fig. 6). This spring is associated with an isolated portion of the Canyon coal and likely represents local groundwater recharge.

Water-quality samples were collected in Fall 2010 and Spring 2011 from six springs and one creek: Three Mile Spring, Chipmunk Spring, Joe Anderson Spring, Hagen 2 Spring, and East Fork Hanging Woman Creek are outside the area influenced by CBM production, and Upper and Lower Anderson Springs are within the current CBM producing area (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 (307 mg/L and 0.8 SAR, respectively).

Several springs located in the Ashland Ranger District have flow and field chemistry monitored monthly or quarterly, but do not have a water-quality analysis on record. This year two new spring water-quality sampling sites were added: Joe Anderson Spring and Hagen 2 Spring. Future plans include collecting at least two water-quality samples from every spring that is measured in the Ashland Ranger District.

The East Fork Hanging Woman Creek site is located on the Ashland Ranger District boundary, east of Birney. Monitoring at the site consists of a 90^{o} v-notch weir with a stage recorder. Record-breaking precipitation events were measured this spring at the Poker Jim meteorological station, located near the headwater area for the creek. In April through June 2011, over 15 inches of rain were recorded and a heavy rain event on May 22, 2011 produced 3.4 inches. This created flood-stage conditions that washed out the stage recorder, resulting in lost data.

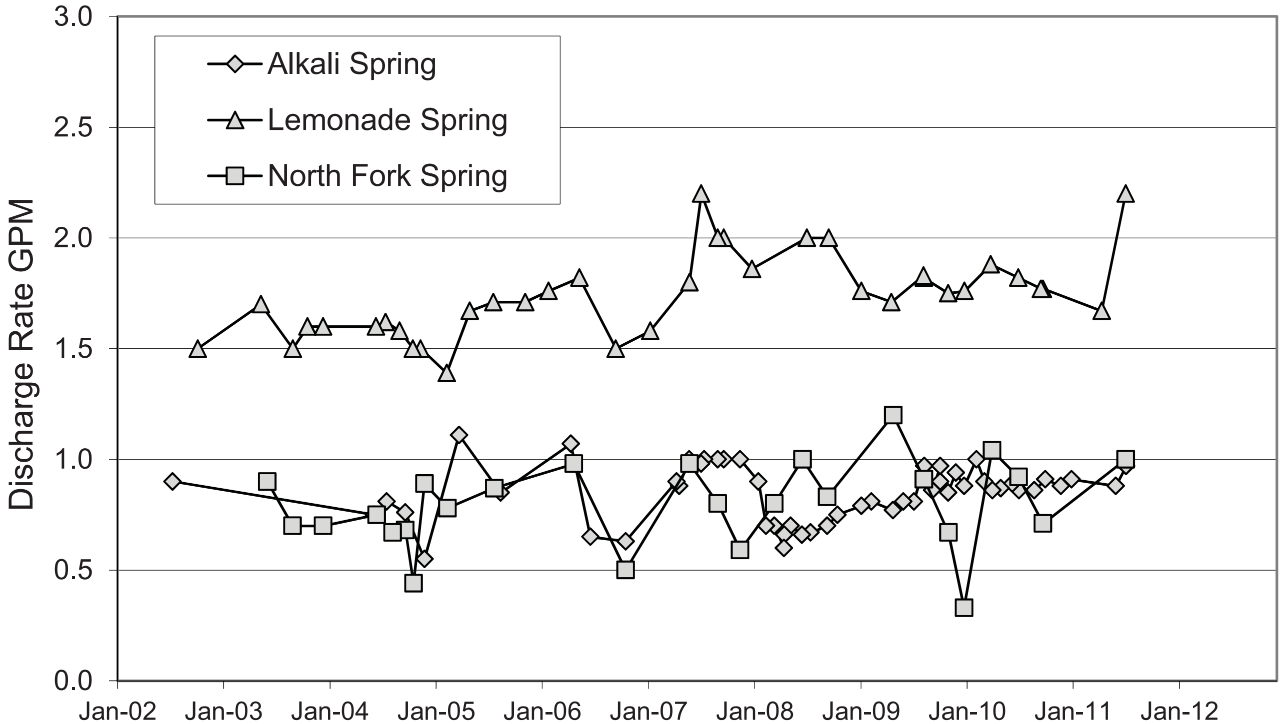


Figure 6. Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.85 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.79 gpm. Lemonade Spring appears to be locally recharged by the Ferry coalbed. The spring has an average discharge rate of 1.74 gpm.

GROUNDWATER CONDITIONS WITHIN AREAS OF CBM INFLUENCE

Contiguous areas of producing CBM wells in Montana cover an area of approximately 50 square miles surrounding the Tongue River Reservoir (plate 1). Roughly one-half of the area is west of the Tongue River and one-half is east of the river.

Produced-water data for 2011 were retrieved for Montana (MBOGC, 2011) and Wyoming (WOGCC, 2011) and are summarized in table 2. A total of 750 wells produced methane and/or water in Montana during 2011 (this number differs from table 3 because table 3 includes all wells that were active in water year 2011). These wells produced a total of 26.9 million barrels (bbls) of water (3,472 acre-feet) in water year 2011. In Wyoming during water year 2011, 73 million barrels of water (9,460 acre-feet) were produced from the 1,574 wells in the two townships nearest Montana (57N and 58N). The total amount of water co-produced with CBM in the Powder River Basin in all of Wyoming during water year 2011 was approximately 488 million bbls or 62,900 acre-feet.

Coalbed-methane-permitted wells are summarized by county and field in table 3. As of October 2011, there were 40 active permits for wells that have not been installed. This is down from 188 in 2008, implying many of these permits were allowed to expire. There are 531 shut-in, abandoned, or plugged and abandoned (P&A on table 3) wells, and 579 producing wells. Since 2010, 129 wells have been taken out of production and are now classified as shut-in or abandoned. Water levels have begun to recover in older fields as a result of these changes (see Montana CBM Fields: Bedrock-aquifer water levels and water quality).

Table 2. Annual summary for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2011.

	Field	Well Count	Gas (MCF) 2011	Annual[1] total water production in **Bbls *1,000** (acre-feet)				
				2011	2010	2009	2008	2007
Montana	Coal Creek	23	188,345	1,848 (238)	2,262 (292)	2,055 (265)	1,782 (230)	2,389 (308)
	CX	656	6,479,807	23,760 (3,062)	29,310 (3,778)	31,625 (4,176)	35,414 (4,565)	34,686 (4,471)
	Dietz	70	443,079	1,239 (160)	1,817 (234)	1,790 (231)	2,837 (366)	2,159 (278)
	Waddle Creek	1	33,689	92.4 (12)	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**750**	**7,144,920**	**26,939 (3,472)**	**33,540 (4,323)**	**35,621 (4,591)**	**40,121 (5,171)**	**39,234 (5,057)**
Wyoming	Prairie Dog Creek	855	23,453,839	29,677 (3,825)	35,938 (4,632)	45,052 (5,807)	56,947 (7,340)	51,259 (6,607)
	Hanging Woman Creek	234	2,768,573	13,309 (1,715)	15,641 (2,016)	19,269 (2,484)	24,589 (3,169)	22,342 (2,880)
	Near Powder River	485	6,139,915	30,412 (3,920)	34,957 (4,506)	40,233 (5,186)	45,396 (5,851)	38,187 (4,922)
	WY Combined	**1,574**	**32,362,327**	**73,398 (9,460)**	**86,535 (11,154)**	**104,554 (13,477)**	**126,932 (16,361)**	**111,788 (14,409)**

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

[1]Totals reflect production during the water year for 2008–2011 and calendar year 2007.

Table 3. Summary of Montana Board of Oil and Gas Conservation listings of coalbed methane permitted wells by county and field.

County	Field or POD	Well Status	Mar. 2008	Oct. 2008	Nov. 2009	Nov. 2010	Oct. 2011
Big Horn	Coal Creek	Permit to Drill	7	6	4	5	4
		Expired Permit	0	0	2	2	2
		Spudded	2	1	0	0	1
		Producing	13	26	23	20	14
		Shut In	49	35	39	44	50
	CX	Permit to Drill	27	44	3	0	0
		Expired Permit	228	226	280	288	288
		Expired, Not Released	3	25	8	0	0
		Spudded	17	0	6	0	0
		Producing	741	705	676	623	508
		Shut In	77	129	172	231	346
		Temporarily Abandoned	2	8	9	8	8
		Abandoned - Unapproved	29	29	29	14	0
		P&A - Approved	2	2	2	17	31
	Deer Creek Fee POD	Permit to Drill	32	21	10	10	10
		Expired Permit	0	0	11	22	22
		Expired, Not Released	0	11	11	0	0
		Shut In	1	1	1	1	1
	Dietz	Permitted Injection Well	1	1	1	1	1
		Expired Permit	0	0	35	42	42
		Expired, Not Released	42	42	7	0	0
		Spudded	1	0	0	0	0
		Producing	96	92	36	61	55
		Shut In	10	5	61	45	51
	Fourmile West	Permit to Drill	n/a	n/a	n/a	n/a	1
	Forks Ranch - State	Permit to Drill	n/a	16	8	8	8
		Expired Permit	n/a	0	5	7	7
		Expired, Not Released	n/a	0	2	0	0
		Shut In	n/a	0	1	1	1
	Waddle Creek - State	Permit to Drill	n/a	16	16	16	16
		Producing	n/a	0	0	1	1
	Wildcat Big Horn	Permit to Drill	0	1	1	2	0
		Expired Permit	36	36	36	37	38
		Expired, Not Released	2	2	2	1	1
		Spudded	2	2	0	0	0
		Producing	2	2	3	0	0
		Shut In	19	25	26	21	21
		Temporarily Abandoned	1	1	1	1	1
		Water Well, Released	0	1	1	1	1

Table 3—*Continued.*

Carbon	Wildcat Carbon	Expired Permit	1	1	1	1	1
		P&A - Approved	3	2	2	3	3
Custer	Wildcat Custer	Producing	1	1	0	0	0
		P&A - Approved	0	0	1	1	1
Gallatin	Wildcat Gallatin	Expired, Not Released	1	1	0	0	0
		Expired Permit	0	0	1	1	1
Powder River	Castle Rock	Permit to Drill	121	0	0	0	0
		Expired Permit	7	128	128	128	128
		Shut In	6	0	0	6	6
		P&A - Approved	1	0	0	1	1
	Wildcat Powder River	Permit to Drill	1	0	0	0	0
		Expired Permit	25	26	26	26	26
		Producing	1	1	1	0	0
		Shut In	3	9	8	5	5
		P&A - Approved	1	2	3	1	1
		Water Well, Released	0	0	0	1	1
Rosebud	Hosford	Permit to Drill	n/a	n/a	n/a	1	1
	Kirby, East	Shut In	n/a	n/a	n/a	1	1
	Wildcat Rosebud, N	Expired Permit	1	1	1	1	1
		Spudded	1	2	0	0	0
		Permit to Drill	1	0	2	1	1
		Producing	0	0	2	2	1
		Shut In	1	1	2	1	3

Note. Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ accessed Oct. 3, 2011.

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. Department of the Interior, Bureau of Land Management, 2008) and the technical hydrogeology report associated with that analysis (ALL Consulting, 2001) included an estimation of the average water production rates per CBM well (dashed line, fig. 7). The average water production rate presented here is based on 149 months (the longest producing well) of available production reports (solid line, fig. 7).

Very early and very late production data do not appear to reflect hydrologic responses; rather, the effects of well start-up and lack of statistically significant data (7 wells have produced for 144 months; 1 well has produced for 149 months). The amount of water initially produced, on average, from each CBM well is less than was expected (fig. 7). However, predicted water-production rates are between the 80th and 90th percentile of actual production. The predicted and observed rates are similar at approximately 6 years. Between 6 and 10 years of production, the actual rate of CBM water production levels out and exceeds the anticipated rate. After 10 years the rate of observed water production begins to rise again. This is because wells that have been producing for longer than 10 years are in the older CBM fields in Montana (the CX field) where wells are being shut-in. This means the remaining wells have to produce more water to keep the coal groundwater drawn down. Overall, the Environmental Impact Statement somewhat over-predicted water production. The lesser quantity of CBM water that was produced decreases the amount of water that must be managed and decreases the anticipated stress on the aquifers.

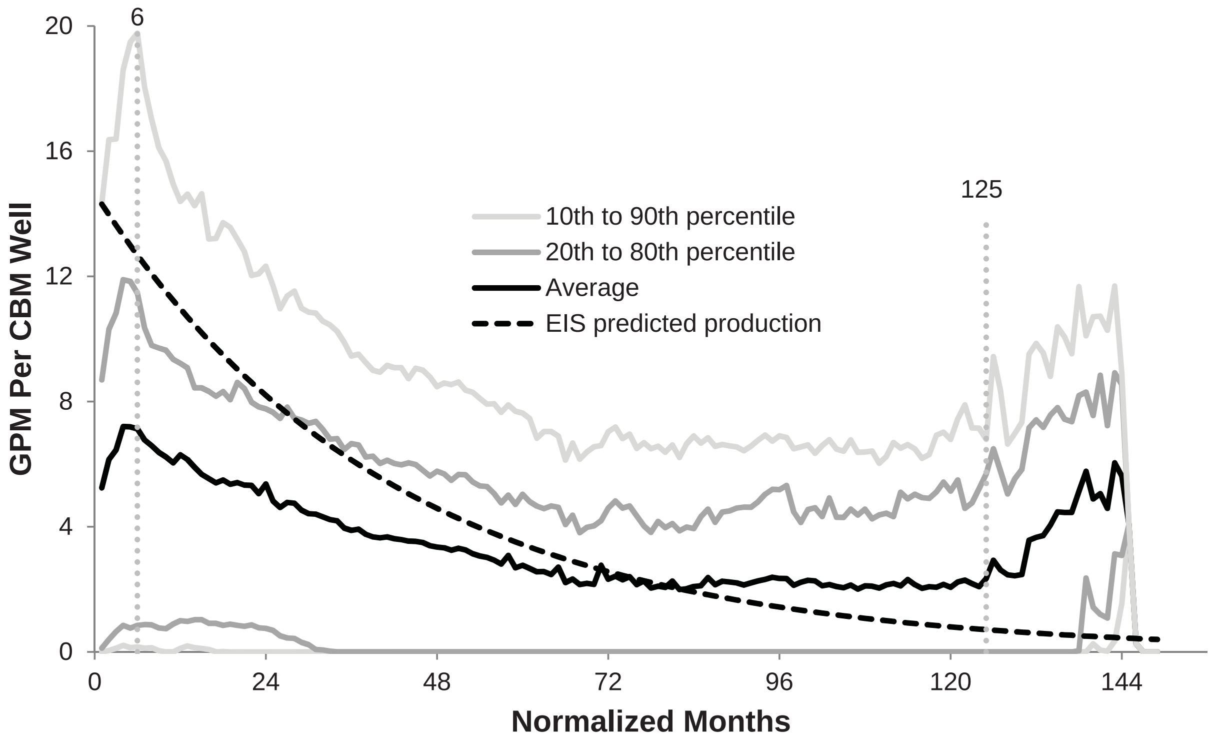


Figure 7. Normalized CBM-produced water in gallons per minute (gpm) in the Montana portion of the Powder River Basin (data from the MT BOGC website). The actual average production (solid black line) falls below the EIS predicted production (dashed line: y=14.661 e^(-0.0242x); US BLM, 2003) for the first 6 years of production. Since most water is produced early, the EIS somewhat over-predicted total water production. Trends from 1 to 6 months and over 125 are not considered to be representative of hydrogeologic responses to CBM production.

Gas production for an average well in the PRB increases sharply in the well's first 5 months of active production and is then relatively stable from 5 to 35 months of production (fig. 8). The peak production for an average well occurs in its second year at around 2,500 MCF/month. 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 10th to 90th percentile of production; however, the 80th and 90th percentile lines also follow the same pattern of production as the average well.

Since mid-2008, wells that produce relatively large amounts of water compared to the amount of gas produced have been shut-in, which causes the slope of the monthly gas production to be more similar to the slope of the monthly water production (fig. 9). The rate of water production per month decreases in the years immediately following years where few new wells were installed (e.g., 2003, 2008). When wells are taken offline the water production quickly reflects this drop (e.g., 2009, 2010). As the price of methane drops, more wells are taken out of production, such as since mid-2008 (fig. 9).

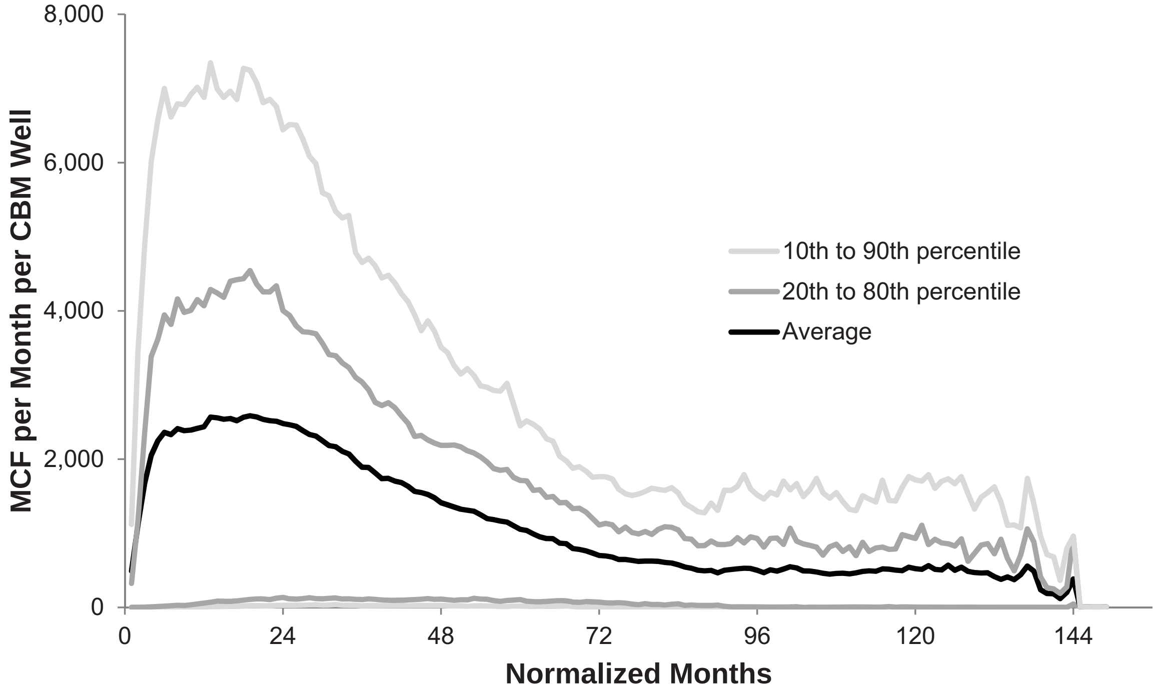


Figure 8. Normalized gas production (MCF) per month for individual CBM wells in the Montana portion of the Powder River Basin (data from MT BOGC web site). The solid black line represents the average gas production per well per month.

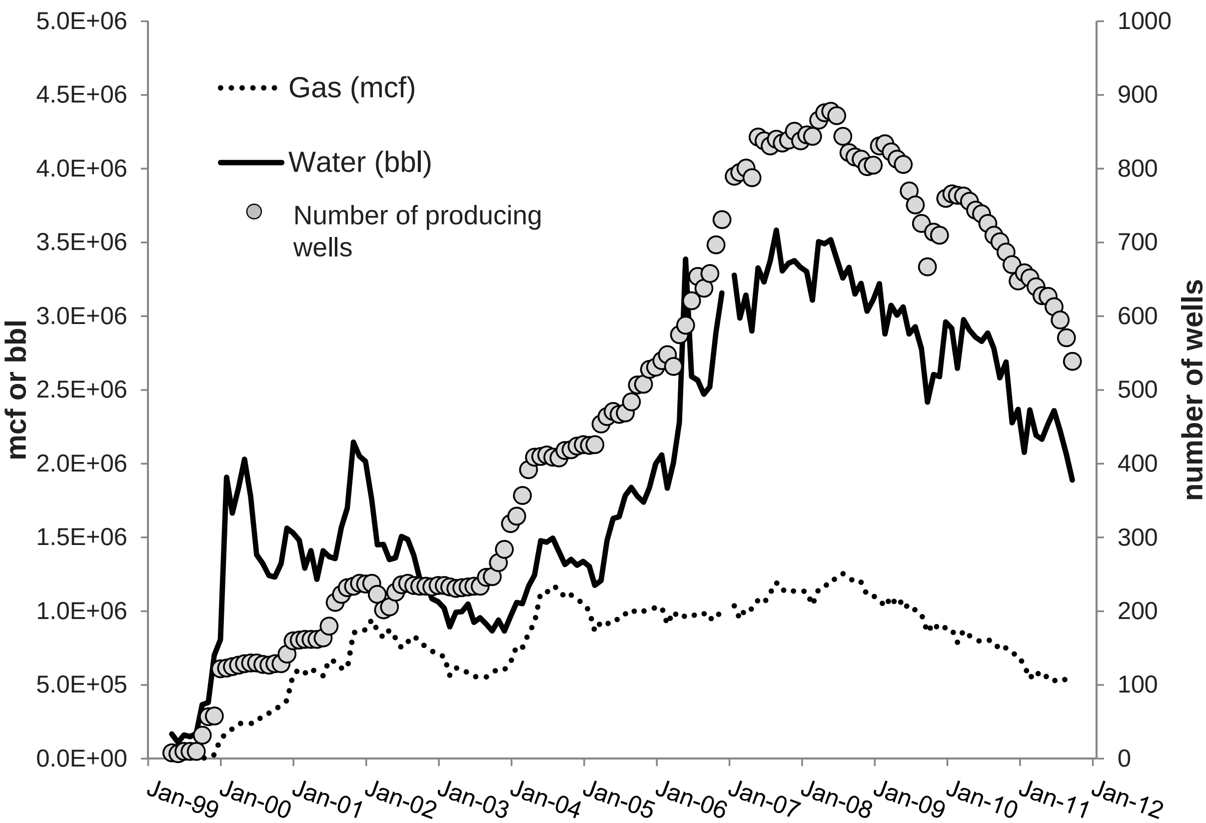


Figure 9. Monthly totals of water and gas produced from Montana CBM wells and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production. The total number of producing wells and the amount of water and gas produced has dropped since March, 2008.

Montana CBM Fields

Coalbed-Methane Water Production

CX gas field. Data from CBM production wells in the CX field (plate 1) were retrieved from the MBOGC webpage (2011). During 2011, a total of 656 CBM wells produced either water, gas, or both in the CX field. Production is from the Smith, Anderson (D1), Dietz 1 (D2), Dietz 2 (D3), Canyon (Monarch), Carney, Wall, King, and Flowers–Goodale coalbeds (table 3; appendix D). The total water production for the year was 23.8 million barrels (3,062 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. CBM wells in Wyoming are also being shut-in. Water levels have begun to recover in areas where CBM water production rates have decreased, as seen in wells WR-27 and WR-38 (fig. 10), among others.

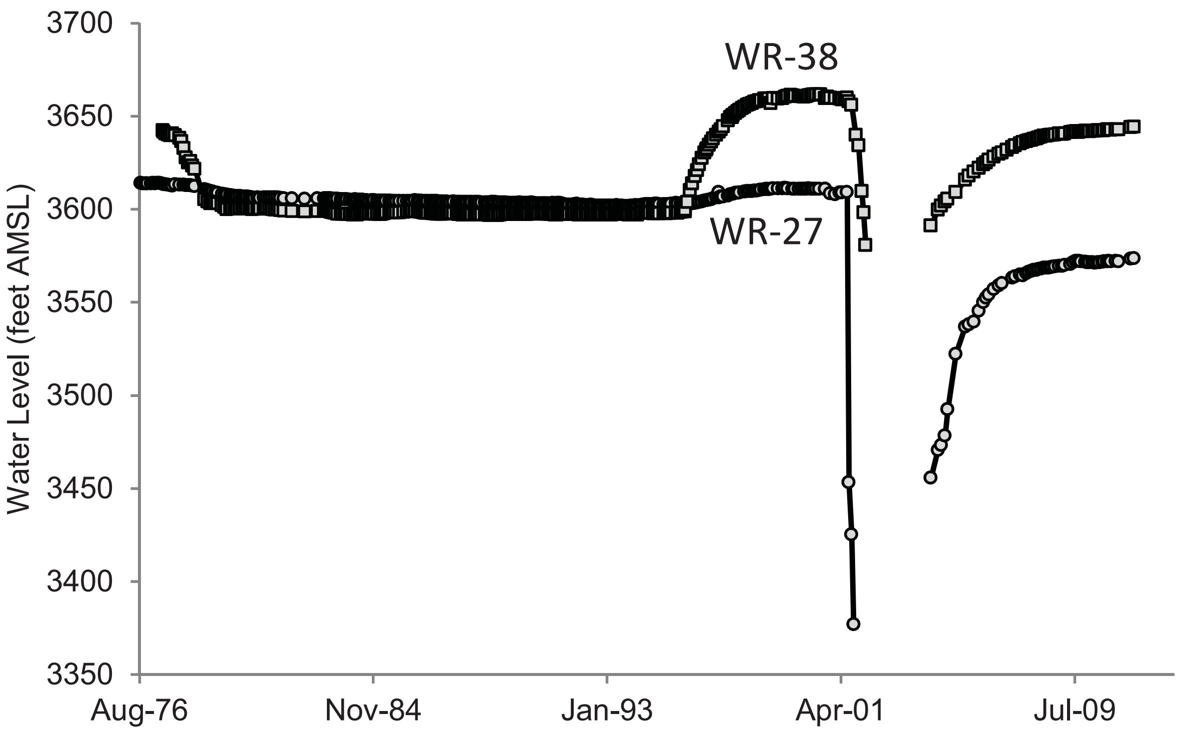


Figure 10. Water levels records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production. The recovery water levels are flattening; however, they still have not reached baseline conditions and this is probably due to other wells still producing nearby.

Coal Creek and Dietz gas fields. Data from CBM production wells in the Coal Creek field and Dietz field (plate 1) were retrieved from the MBOGC webpage (2011). Summit (at the time Pinnacle Gas Resources, Inc.) first produced from CBM wells in the Coal Creek field, northeast of the Tongue River Reservoir, in April 2005 and from the Dietz field, east of the reservoir, in November 2005. During 2011, a total of 23 CBM wells produced water or gas in the Coal Creek field (table 3). Production was from the Wall and Flowers–Goodale coalbeds (appendix D). The total water production for the 12-month period was 1.8 million barrels (238 acre-feet). A total of 70 CBM wells produced water or gas in the Dietz field during 2011 (plate 1, table 3). Production is from the Dietz, Canyon, Carney, and Wall coalbeds (appendix D). The total water production for the 12-month period was 1.2 million barrels (160 acre-feet).

Bedrock-Aquifer Water Levels and Water Quality

In areas susceptible to CBM impacts in and adjacent to the CX field, groundwater levels have responded to a combination of influences from precipitation, coal mining, and CBM production. Both coal mining and CBM production have created large areas of lowered groundwater levels in the coalbeds.

Potentiometric surface maps for the Dietz and Canyon coal aquifers (plates 2 and 3) are based on data collected by the MBMG as part of the regional monitoring program and data provided by the CBM industry and coal mine operators. Drawdown within the Dietz coal that is interpreted to be specific to CBM production (plate 4) shows 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 a maximum of around 1.5 miles in some areas. For the Canyon coal, drawdown appears similar to that in the Dietz; 20 feet of drawdown reaches about 1 mile beyond the field boundaries (plate 5).

Drawdown was predicted 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. Department of the Interior, Bureau of Land Management, 2008). Measured drawdown is somewhat less than predicted. This is primarily due to CBM development rates, shorter production duration, faults isolating drawdown, and lower CBM water production rates than predicted.

Water Levels. 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 (fig. 11). The Ash Creek mine pit reached a maximum size of about 5 acres. Pit dewatering maintained a reduced water level in the area 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 is primarily due to the close proximity to CBM production. Since March 2003, water levels have recovered to within 28 feet of baseline conditions. This represents 82 percent recovery during a period of 8.5 years. Over the past 12 months the water level has recovered over 1.5 feet, a significant increase compared to last year's recovery of only 3 inches. The recovery is due primarily to a reduction in the number of producing CBM wells in this area; 57 more wells were shut-in in the CX field this year, which may have caused the recovery rate to increase. Additionally, an exceptionally wet spring may have caused the recovery rate to increase.

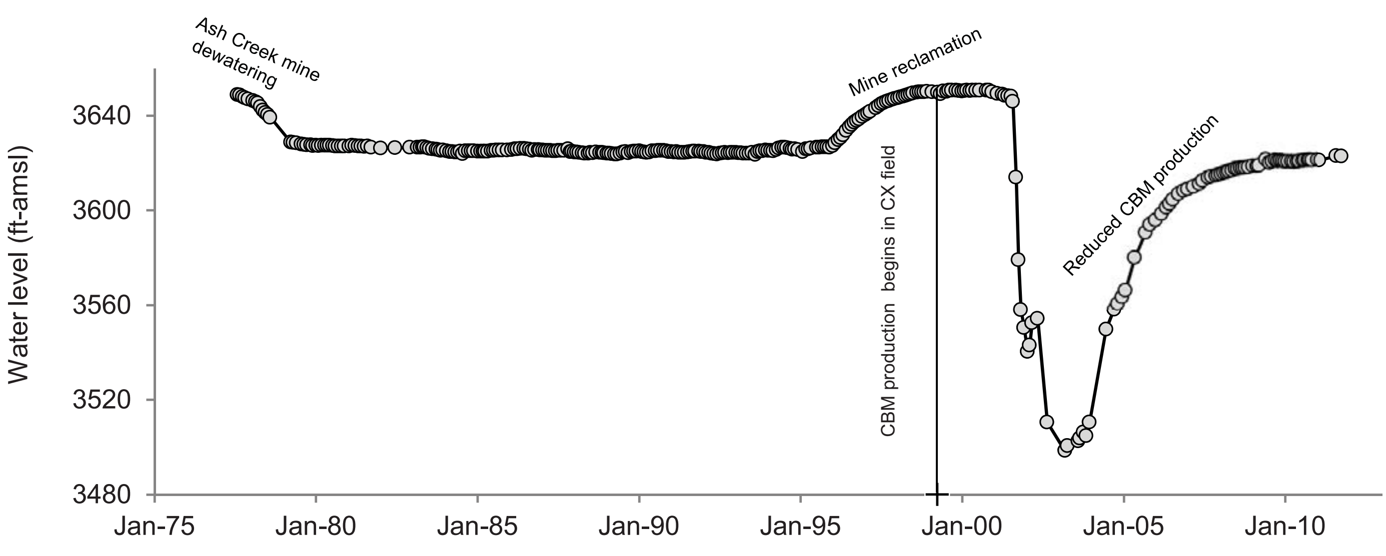


Figure 11. Water levels in the combined Anderson–Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed-methane production. The water level recovered starting in 2003 in response to decreased production in this portion of the CX field.

Groundwater-level responses due to the Ash Creek mine pit dewatering are also evident at well WR-38 (fig. 12). The water level in this well dropped at least 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 16 feet of baseline conditions, or a water-level recovery of about 79 percent. Well BF-01 is completed in the Ash Creek mine spoils. Although the mine pit created a water-level response in the adjacent, confined coal aquifer, the water level in the unconfined spoils did not show a noticeable response to CBM production. The lack of a measurable response is not surprising due to unconfined systems having much greater storativity.

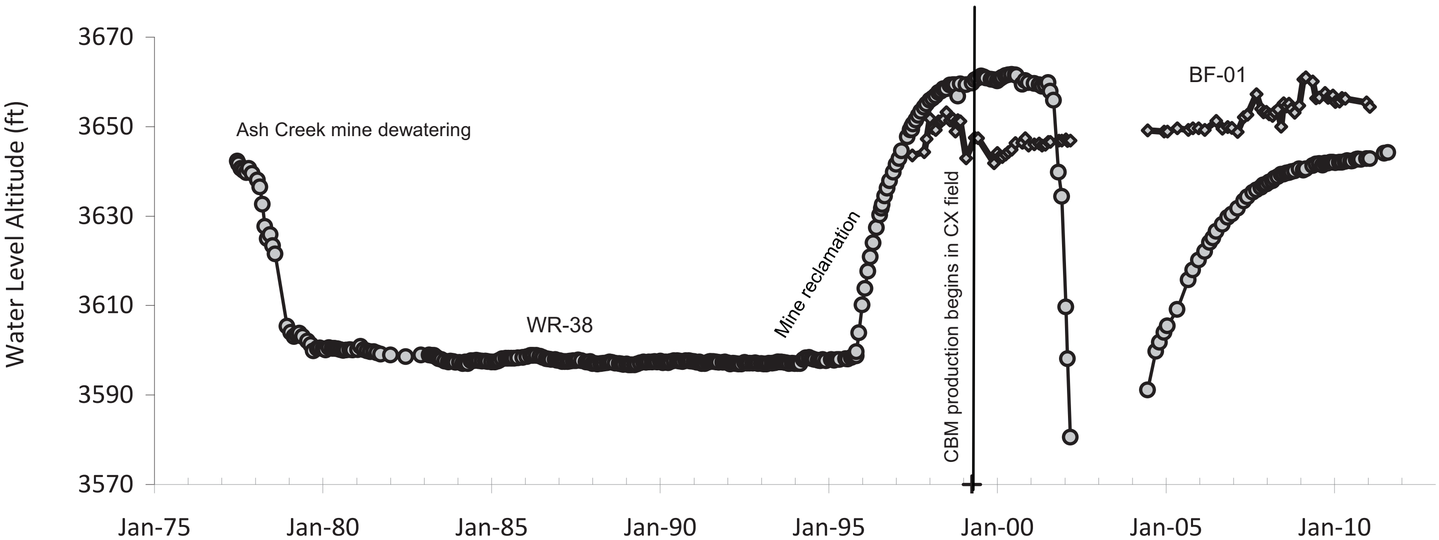


Figure 12. Water levels in the Dietz coal (well WR-38) decreased by at least 80 ft in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping. This illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses to drawdown.

Monitoring wells installed in the Fort Union Formation show that the monitored fault sections in this area are often barriers to flow (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 and overburden aquifers for over 25 years on the north side of the fault, but there was no response to mine pit dewatering south of the fault (fig. 13). Recent monitoring of drawdown related to CBM production south of the fault shows that water levels in the Anderson coal have been lowered significantly without a similar decrease north of the fault. The lowest recorded water levels south of the fault were over 180 feet below baseline. The isolated drawdown effects indicate that the fault acts as a barrier to flow within the Anderson coalbed. South of the fault the Smith coal responds slightly to both coal mining north of the fault and CBM production south of the fault. Reduced pressure from coal mining may have migrated around the end of the fault. Reduced pressure from CBM production may have lowered the pressure in the overlying aquifers, or drawdown from produced coals may have been transmitted to the Smith coal due to variable offset along scissor faults.

Near the western edge of the CX field, but isolated by faults from nearby active CBM wells, water levels in the Carney coal have been responding to CBM-related drawdown since the well was installed in 2003. Water levels in this well are now 18.17 feet lower than the first measurement (fig. 14). It appears that the drawdown observed at this site results from drawdown that is channelized along a SW–NE-trending fault block from CBM wells to the northeast approximately 3.5 miles away on Squirrel Creek. The water level in the Canyon coal at this site has decreased somewhat, which may be a response to CBM production or may be due to long-term precipitation patterns. The water level in the Roland coal, stratigraphically above the CBM production zones and on the other side of the fault, dropped about 8 feet during 2005, began to recover in early 2006, but has not yet reached previous water levels. 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 from that measured in the other coal aquifers at this site.

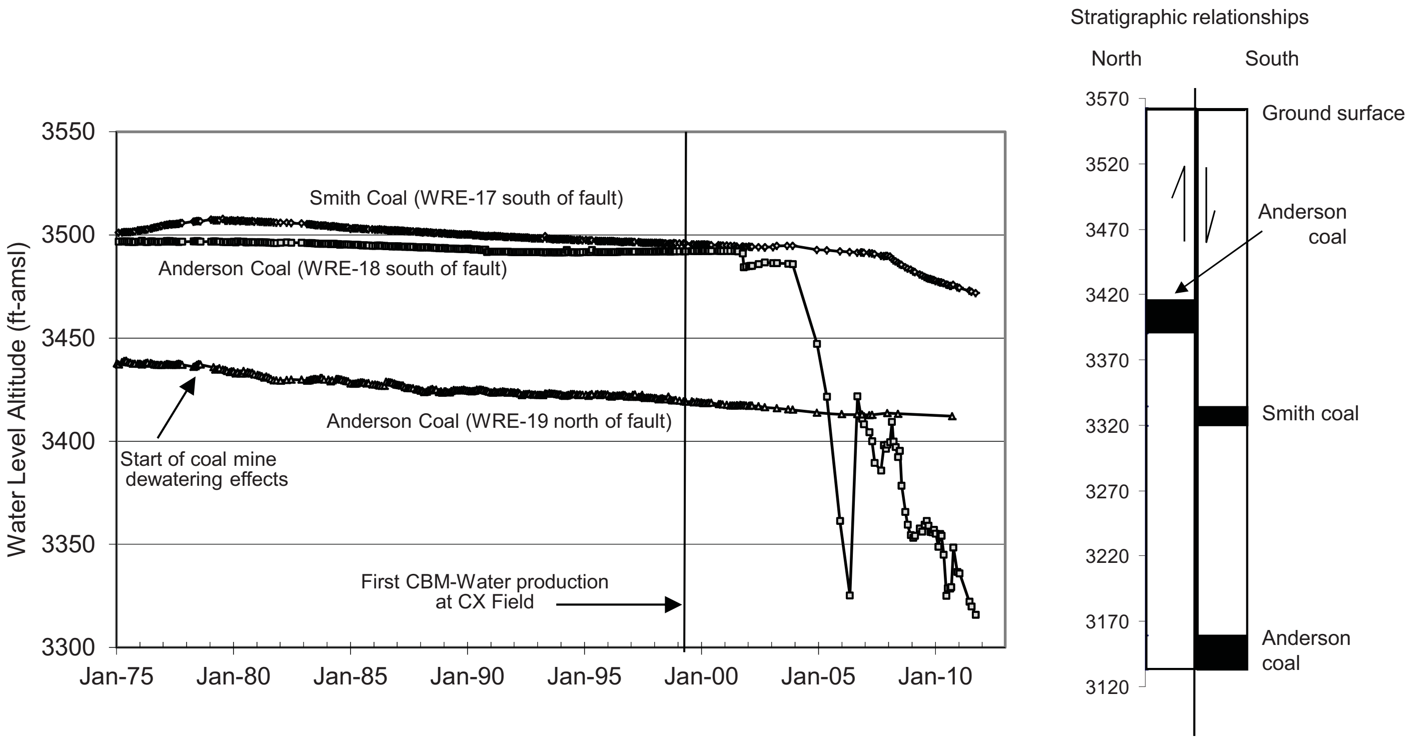


Figure 13. Drawdown from both coal mining and coalbed-methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970s and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980s. The pressure 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.

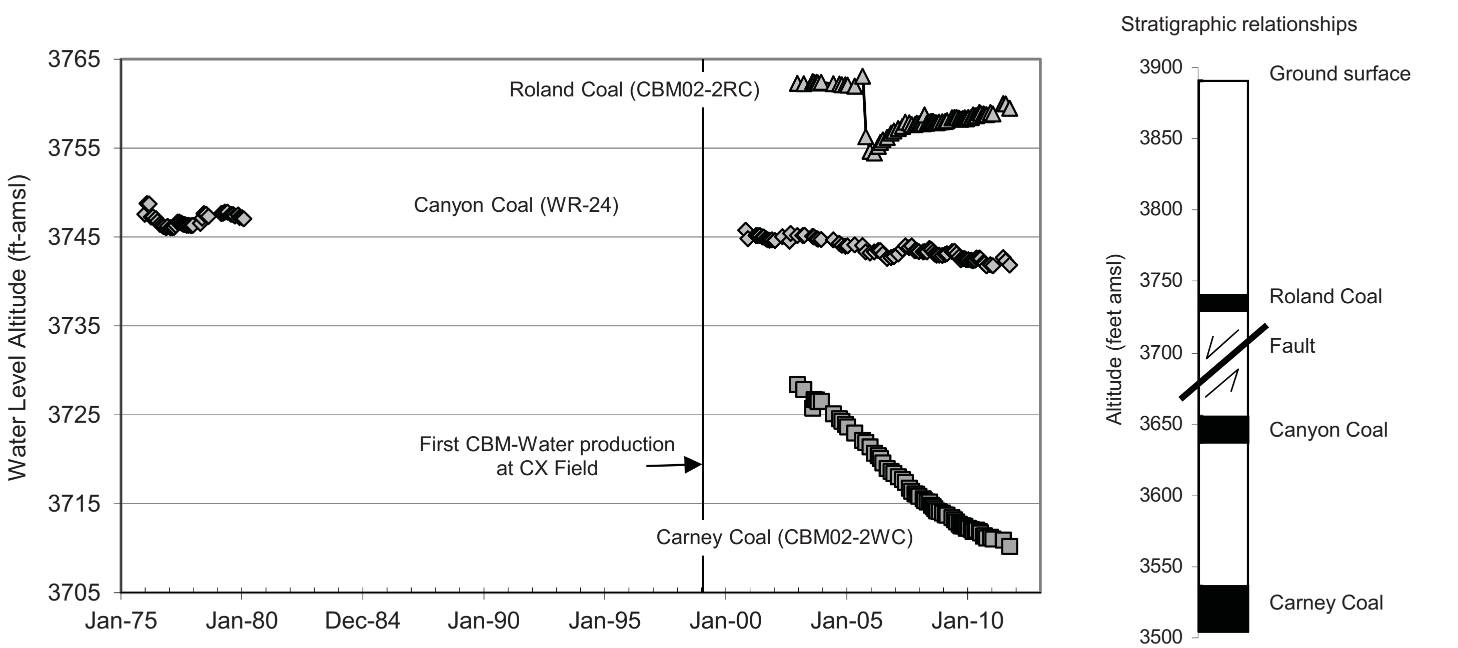


Figure 14. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM-related drawdown since its installation. The Roland Coal has not been developed for CBM production and the cause of 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.

Near the East Decker mine, coal mining and CBM production have lowered water levels in the Anderson, Dietz 1, and Dietz 2 coals (fig. 15). 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 the three coal aquifers recovered slightly in 2008; however, water levels have leveled off in 2011. During CBM production, water levels are lowered to near the top of the aquifer, so deeper coals experience more drawdown than do shallower coals.

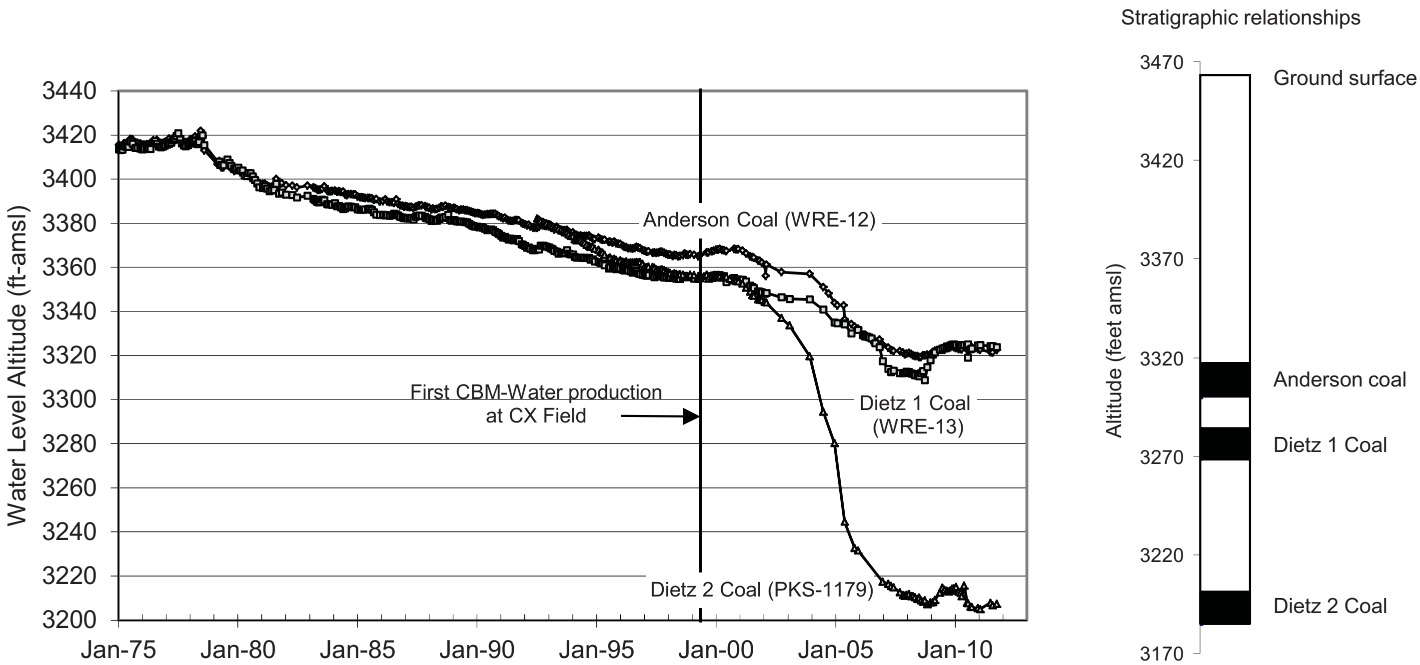


Figure 15. CBM production requires drawdown to near top of the producing zone, for both WRE-12 and WRE-13. Both coal seams have water-level elevations just above the coal seam elevation.

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

Changes in stage in the Tongue River Reservoir affect water levels in aquifers that are in contact with it, such as the Anderson/Dietz coal, which crops out beneath the reservoir. Water levels in the Anderson/Dietz coal south of the reservoir show annual responses to the reservoir stage levels, but the water levels are more strongly influenced by mining and CBM production when these stresses are present (fig. 16). 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) (DNRC, 2011). Average reservoir stage during this time has been about 3,419 feet amsl, which is higher than the Dietz potentiometric surface, and it is likely that some water has always seeped from the Reservoir to the coal seam. The average stage during the water year 2011 was 3,421 feet amsl, which is higher than the historical average because goals for reservoir storage have increased recently. This creates a greater gradient between water levels in the reservoir and water levels in the Anderson/Dietz coal, which are decreasing due to CBM production and coal mining. The combination of these factors will likely result in more water seeping into the coal from the reservoir (plate 2).

The water level in the Anderson coal monitored in the Squirrel Creek watershed (fig. 17) 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 a methane hazard. Declining water levels (8.4 feet since the year 2000) in Anderson overburden at this site show either a possible correlation with precipitation patterns or migration of water due to 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 shows a rapid rise following the start of CBM production. This rise, totaling about 30 feet, is interpreted to be a response to a now unused infiltration pond. Since use of the pond was discontinued, the water table

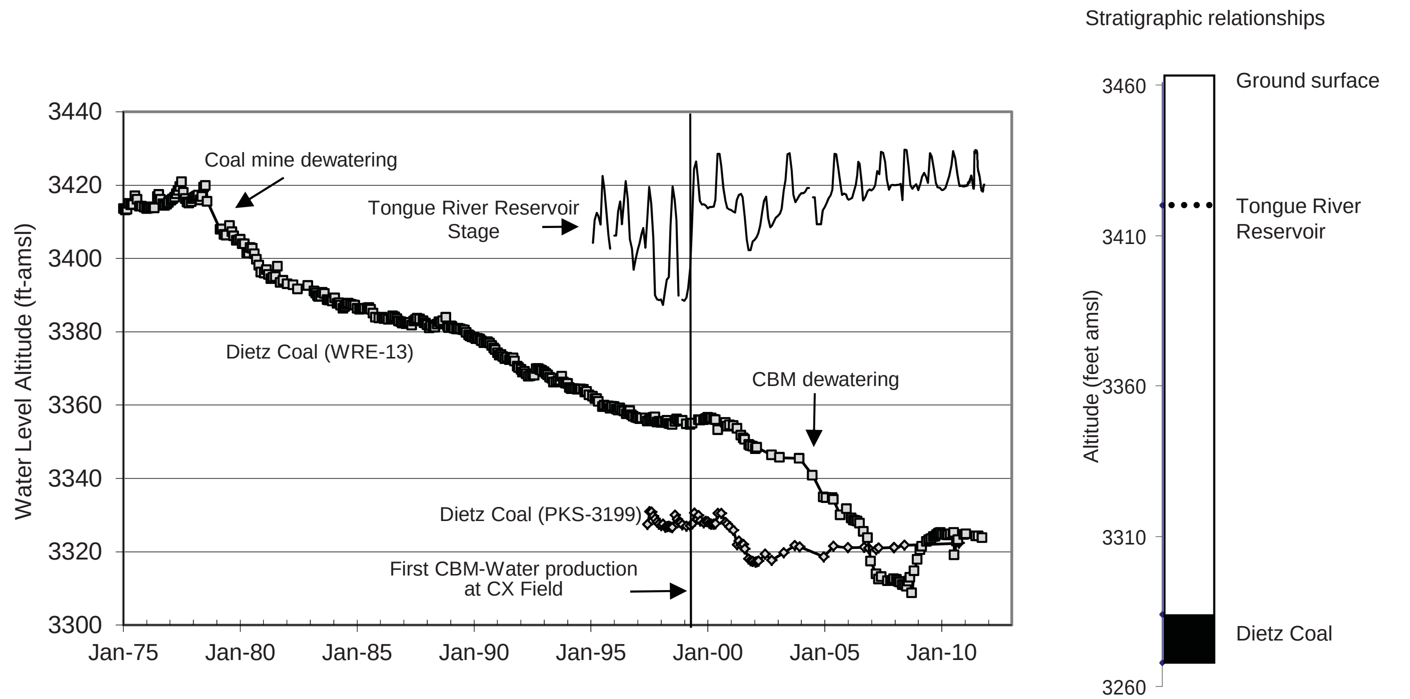


Figure 16. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present.

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

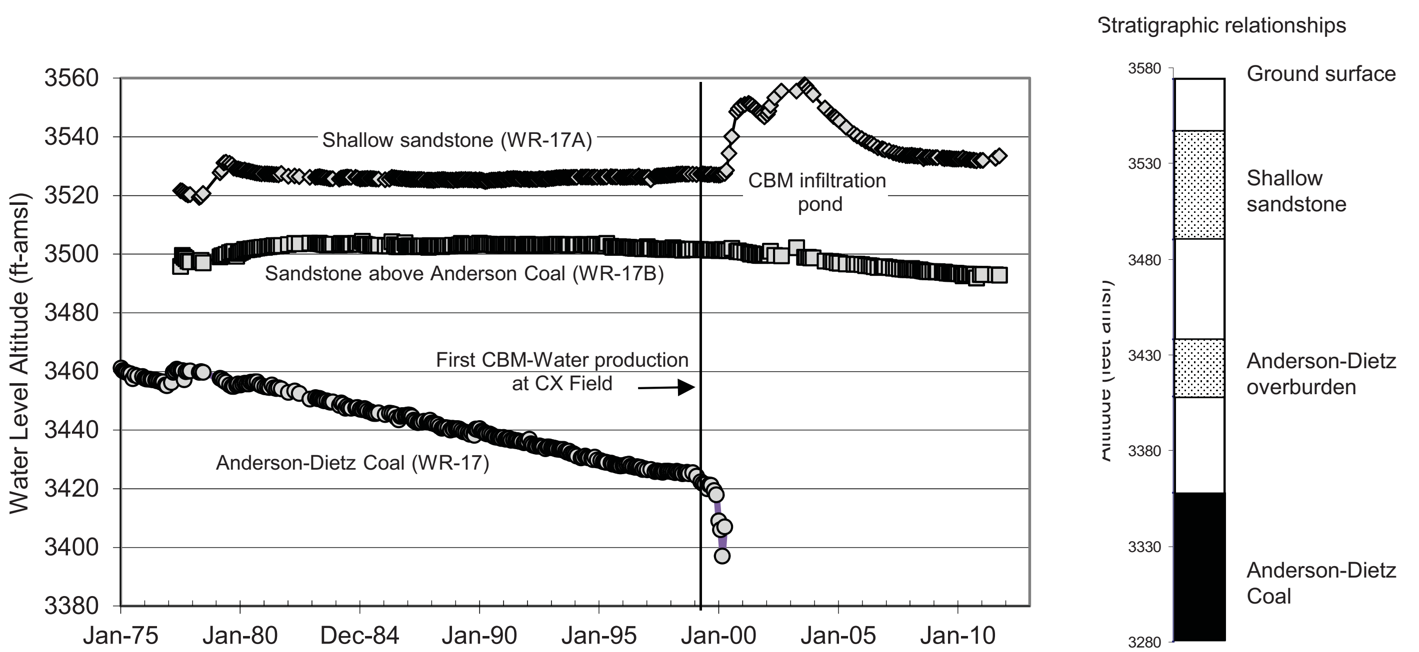


Figure 17. The rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water; therefore the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in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

has returned to near baseline. The deeper overburden aquifer (WR-17B) at this site shows no response to the infiltration pond.

Monitoring of the Wall coal near the Coal Creek and Dietz fields shows that water levels were lowered about 12 feet from April 2005 to May 2007 (fig. 18). The nearest shut-in CBM wells range from about 1.75 to 2.5 miles from this monitoring well, while the nearest producing wells are over 4 miles away. CBM production in the immediate area was discontinued in March 2007 and the water level recovered through October 2007. Since that time water levels have fluctuated in response to water pumped intermittently from CBM wells along the Tongue River (2.5 miles away), which are completed in the Wall coal. The water level has not recovered here despite the nearest wells being shut-in. However, there are currently 18 wells producing from the Wall coal in the Coal Creek and Dietz fields that may be preventing water levels from recovering. Additionally, it is possible that the open-hole well completion in the coal has degraded. The well will be checked for this possibility.

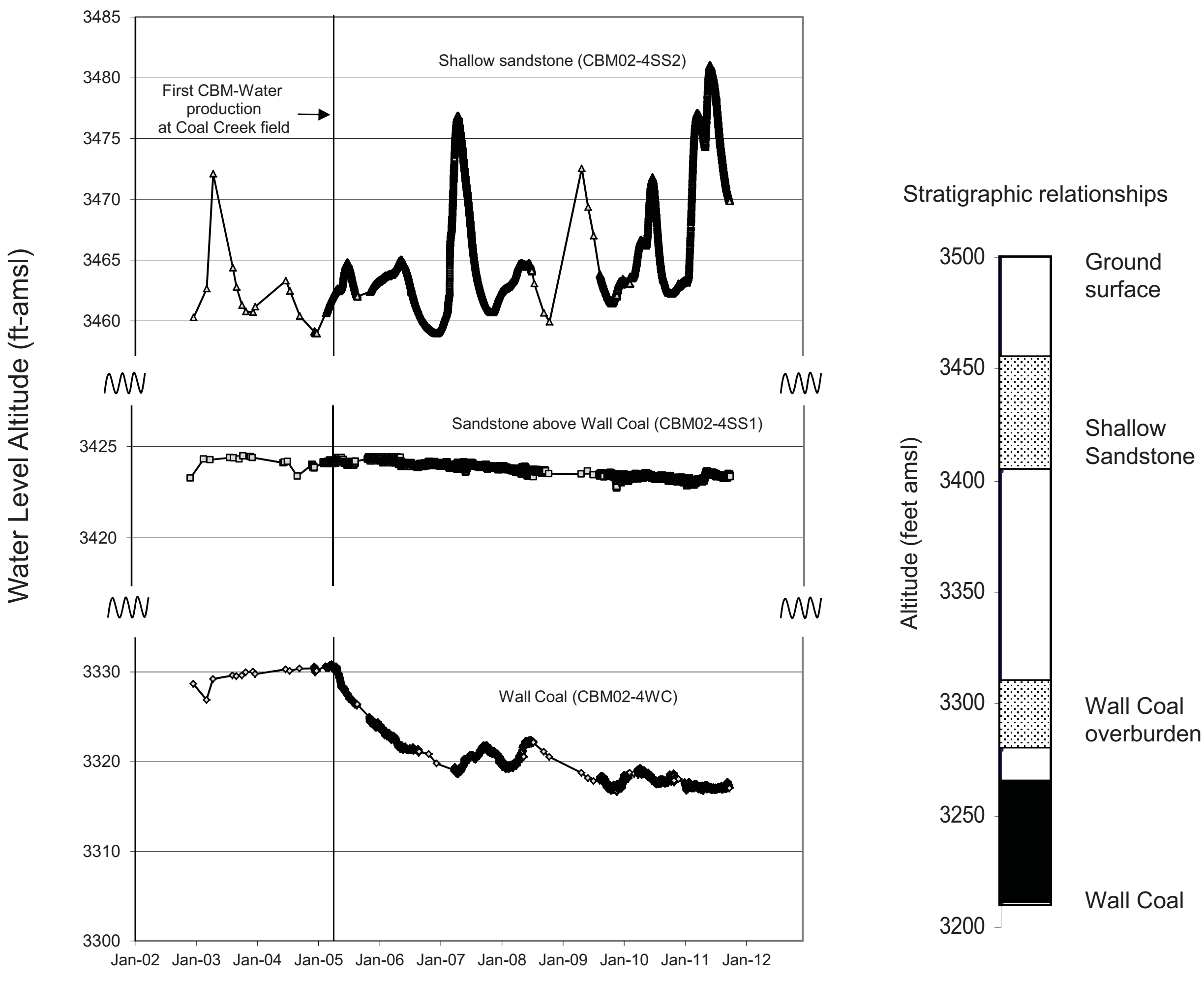


Figure 18. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal (CBM02-4WC) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in water level that might be related to meteorological patterns or may result from enhanced seepage into the underlying Wall coal. The shallow sandstone (CBM02-4SS2) water-level trend is likely related to meteorological patterns.

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

Water Quality. Water-quality samples were collected in September 2010 and June 2011 from Upper and Lower Anderson Springs, both of which discharge from the Anderson coalbed. Water quality is quite different between the two: Upper Anderson had TDS concentrations of 3,723 and 5,419 mg/L and SAR values of 9.8 and 6.0, while Lower Anderson had TDS concentrations of 1,529 and 1,742 mg/L and SAR values of 3.2 and 3.1. The spring 2011 sample collected from the Upper Anderson Spring showed an increase in TDS concentration of 31 percent over previous samples. This sudden increase may be a result of the record-breaking spring precipitation. Records from a nearby meteorological station indicate the area received 12 inches of rain in May and June. Precipitation in excess of normal levels saturates the soil and allows more water to recharge the aquifer, bringing with it mobilized soluble salts.

Tongue River Alluvial-Aquifer Water Levels and Water Quality

Water-quality samples were collected in September 2010 and May 2011 (appendix C) from the Squirrel Creek alluvium near the Squirrel Creek–Tongue River Confluence (fig. 19). The TDS concentrations increased from 5,710 mg/L in June 1991 to 6,709 mg/L in June 2009, an increase of 17 percent. The SAR value increased from 5.6 to 6.4 over approximately the same time period (fig. 19). These peaks have been followed by lower TDS values and slightly lower SAR values. The Tongue River TDS and SAR values have not shown similar trends. The river water chemistry varies seasonally; the TDS and SAR tend to drop as flow rate increases. The relationship between river discharge rate and specific conductance (SC) is discussed in more detail by Osborne and others (2010). The alluvial groundwater chemistry is dominated by sodium, magnesium, and sulfate.

Further downstream along the Tongue River (fig. 20), a domestic well north of the Tongue River reservoir is regularly sampled; it was sampled most recently in September 2010 (appendix C). The TDS concentration varies by as much as 60 percent; however, total concentrations are relatively low. This variability could be natural or controlled by dam releases. Groundwater levels appear to mimic the discharge of the Tongue River at this site, but neither water level nor river discharge rate appears to be closely linked to TDS. The upward trend in TDS from September 2006 to October 2008 (747 to 1,074 mg/L) has been mirrored in the upward trend from June 2009 (775 mg/L) to July 2011 (1,425), which serves to reiterate the importance of regular monitoring. SAR is relatively low. The alluvial groundwater chemistry is dominated by calcium and bicarbonate.

Hanging Woman Creek enters the Tongue River near the town of Birney. Approximately 20 miles from the state line near this confluence, well HWC86-7 is completed in the Hanging Woman Creek alluvium (fig. 21). This well was sampled in September 2010 and May 2011. The TDS was 3,676 and 3,632 mg/L and SAR was 8.7 and 8.5, respectively. Since sampling began in 1987, the TDS and SAR have generally increased; however, future monitoring will be required to determine if these values represent a trend or a temporary perturbation. Because water-quality monitoring sites closer to CBM development have not shown an effect, it seems unlikely that these changes are related to CBM development.

Further downstream, water-quality samples were collected from alluvial monitoring well WA-2 near Birney Day Village in September 2010 and June 2011 (fig. 22; appendix C). The TDS concentration of the Tongue River alluvial water in this area has been relatively steady from August 2006 to June 2011. The SAR values have varied slightly, from 20 in August 2006 to 23 in September 2010. Alluvial groundwater levels mimic the river stage in this area. The water chemistry is dominated by sodium and bicarbonate.

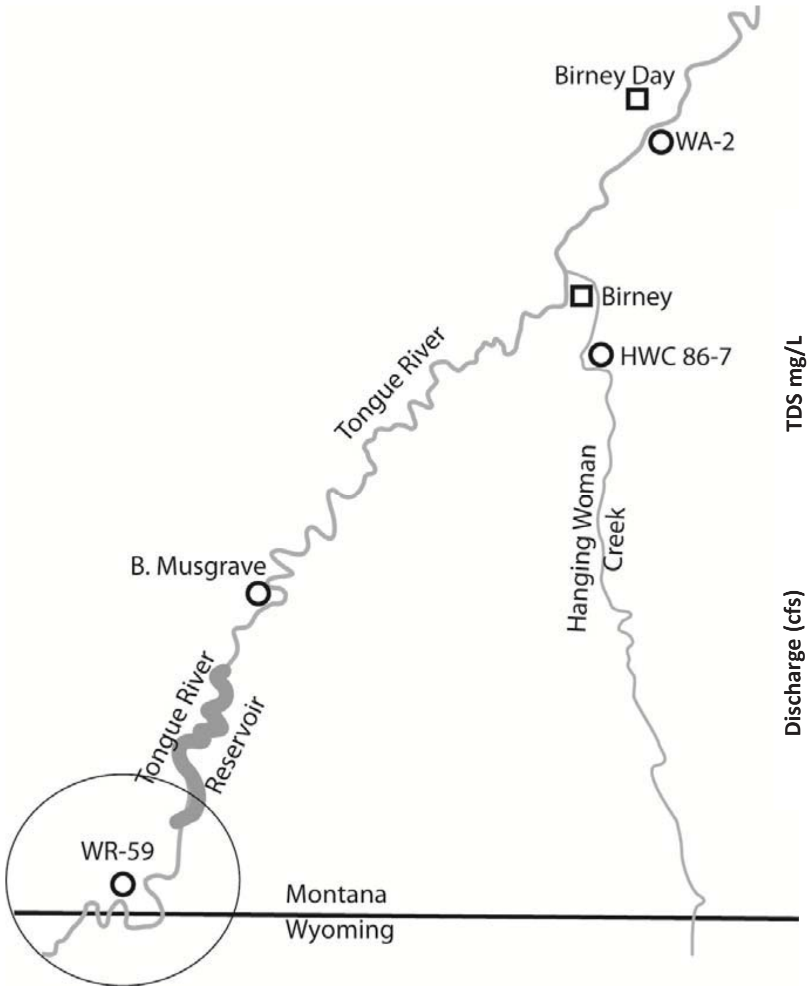
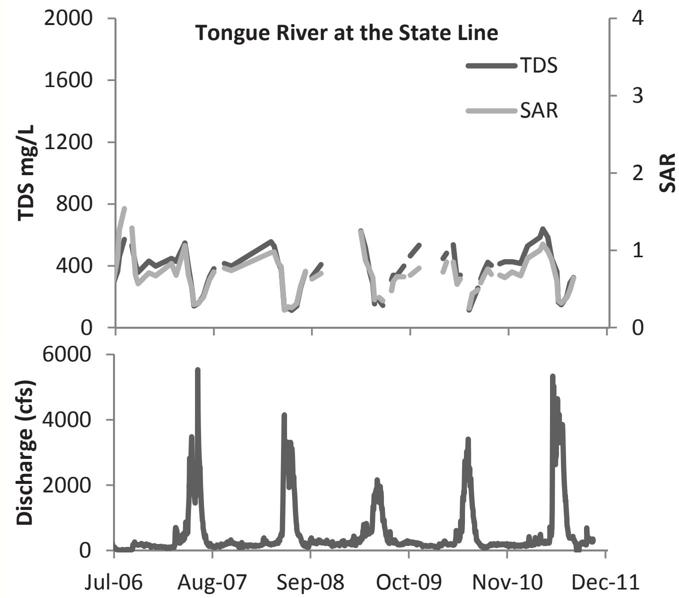
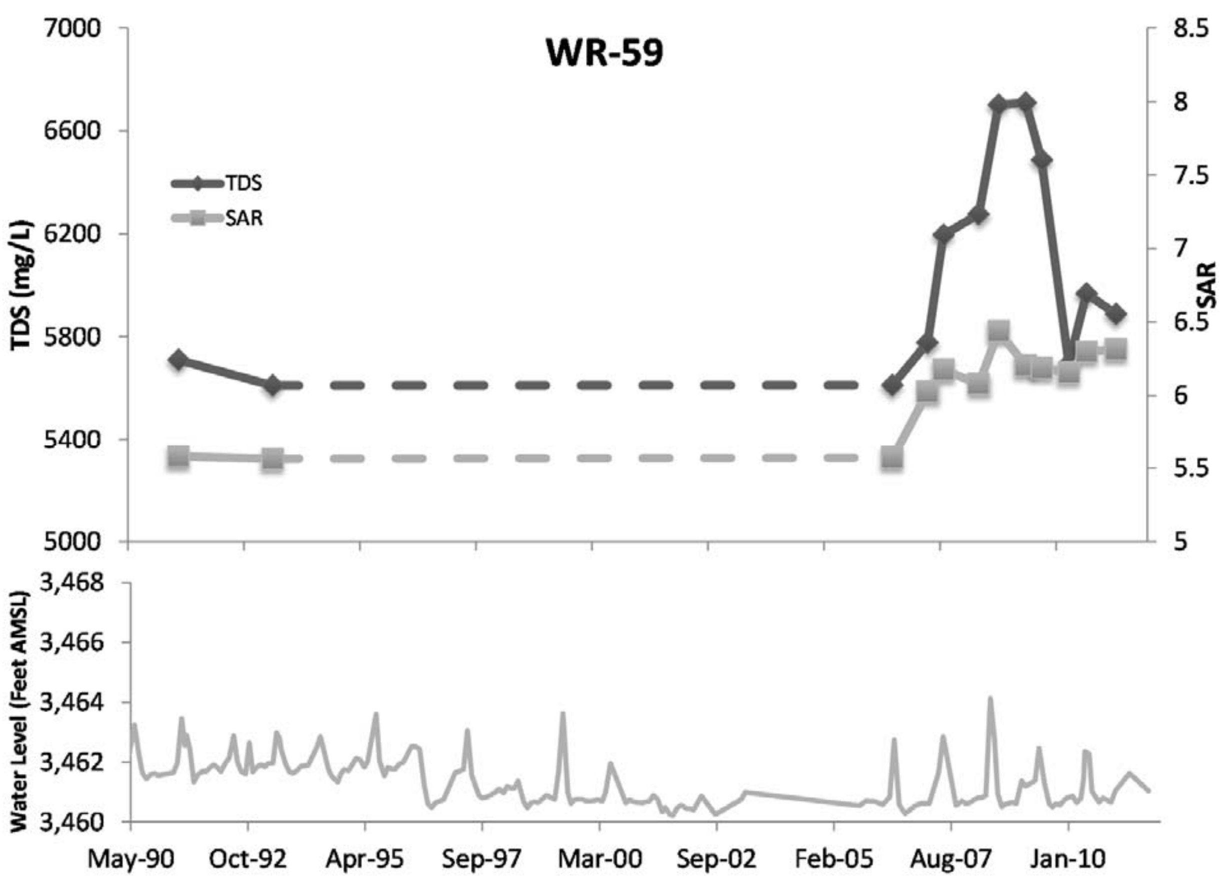


Figure 19. TDS, SAR and Water Level / Stream Discharge for well WR-59 near the Squirrel Creek-Tongue River confluence and for the Tongue River at the state line.





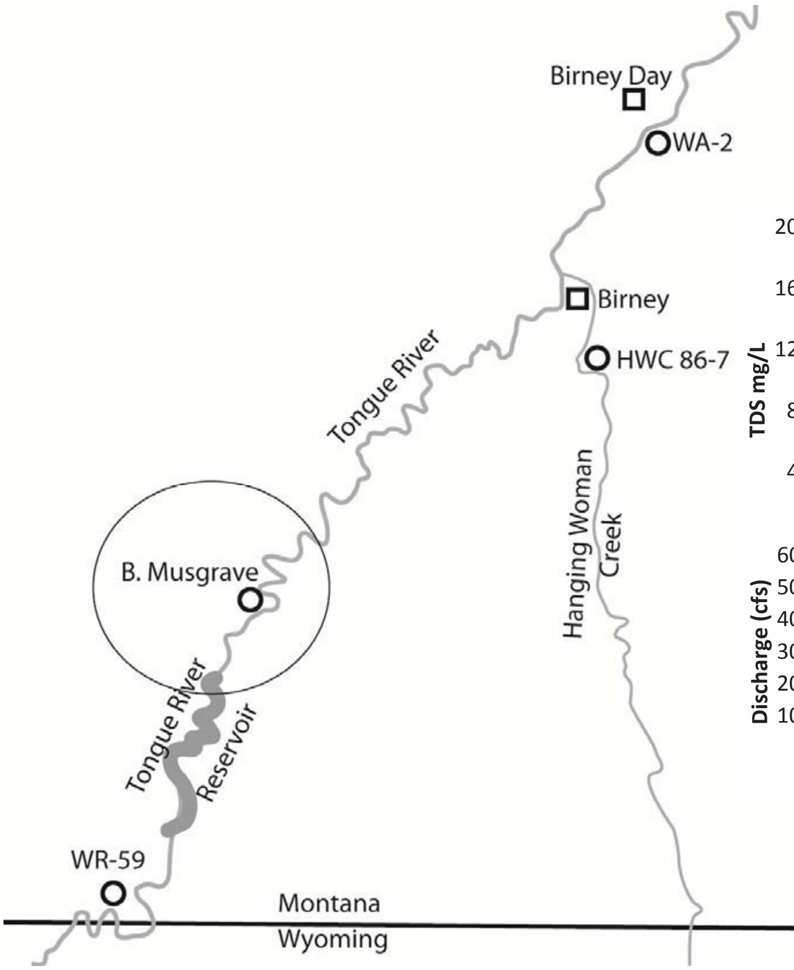
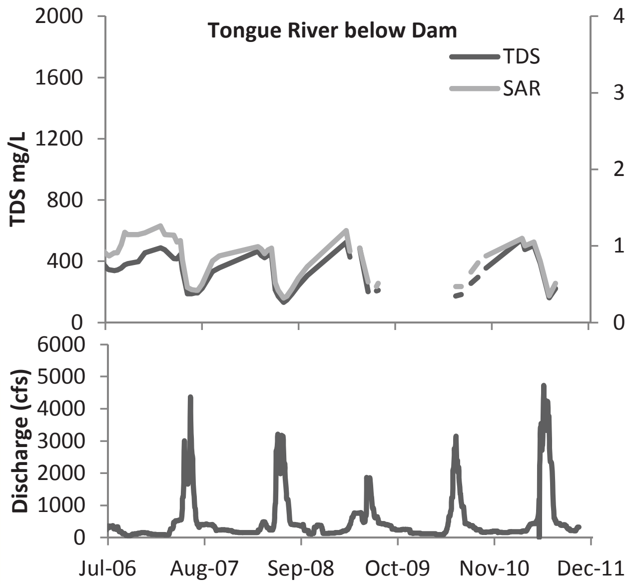
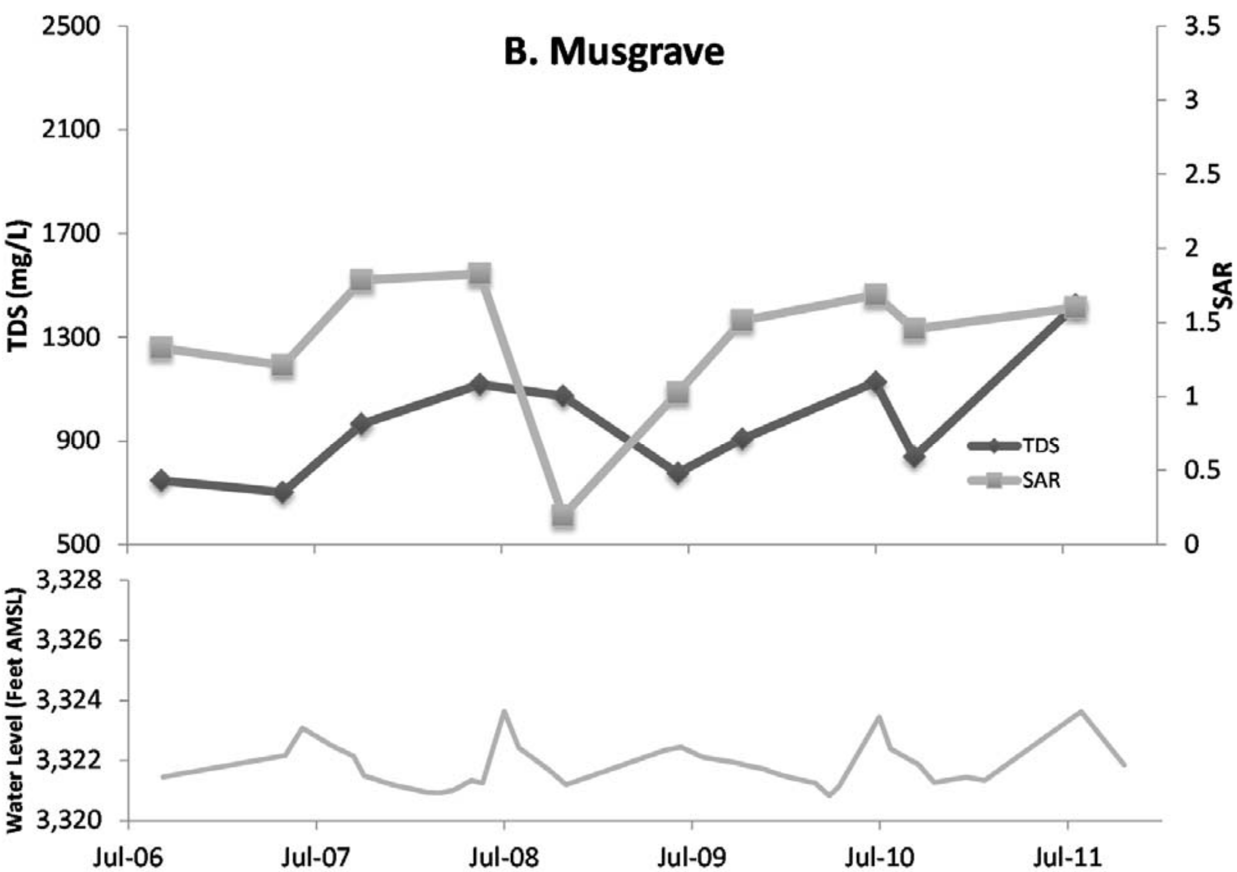


Figure 20. TDS, SAR and Water Level/Stream Discharge for a well at B. Musgrave's residence and the Tongue River north of the Tongue River Reservoir dam.





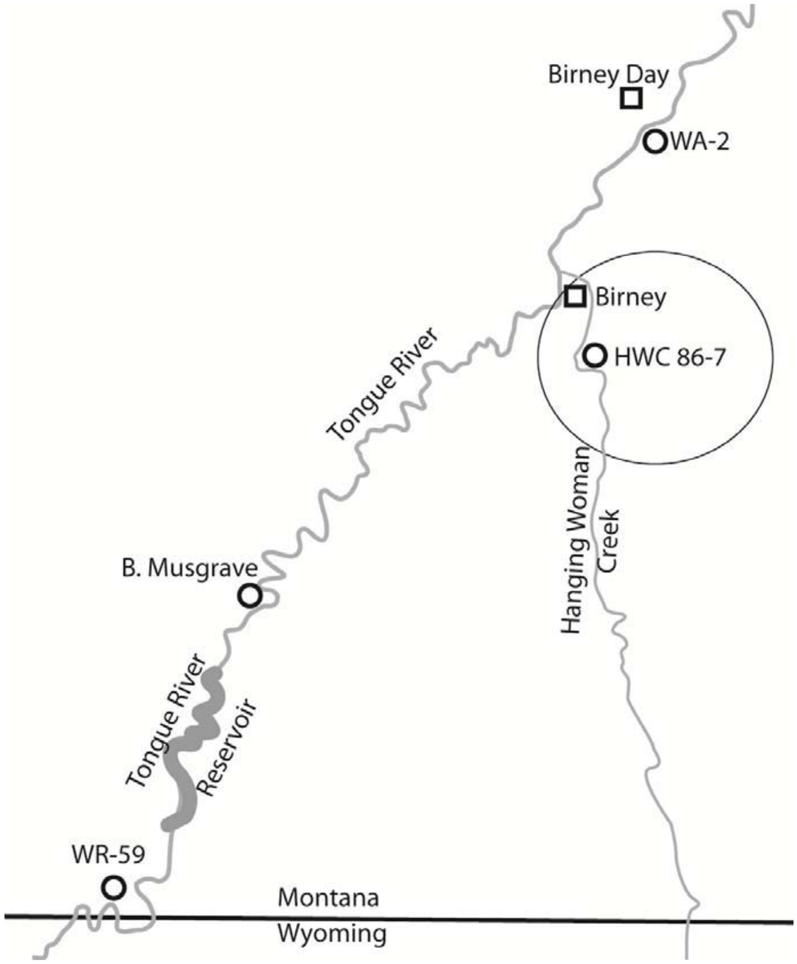
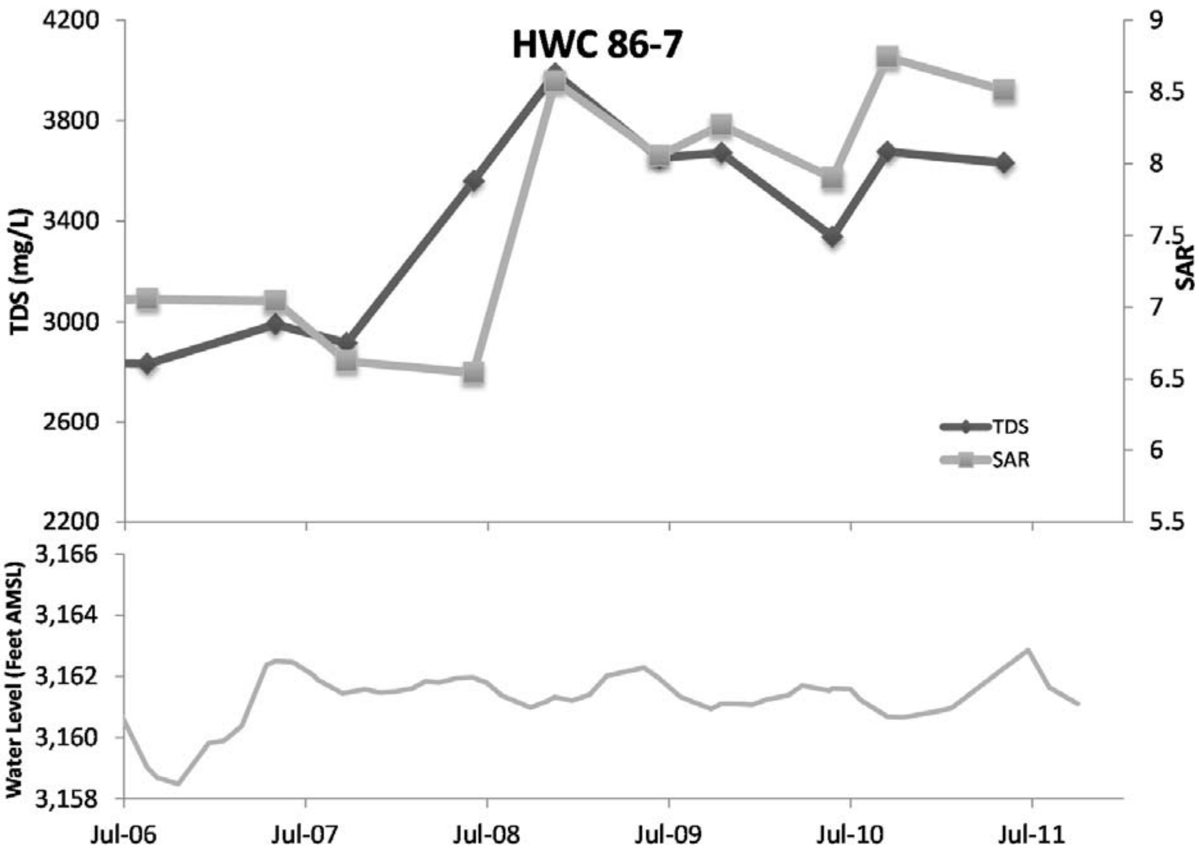


Figure 21. TDS, SAR and Water Level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.



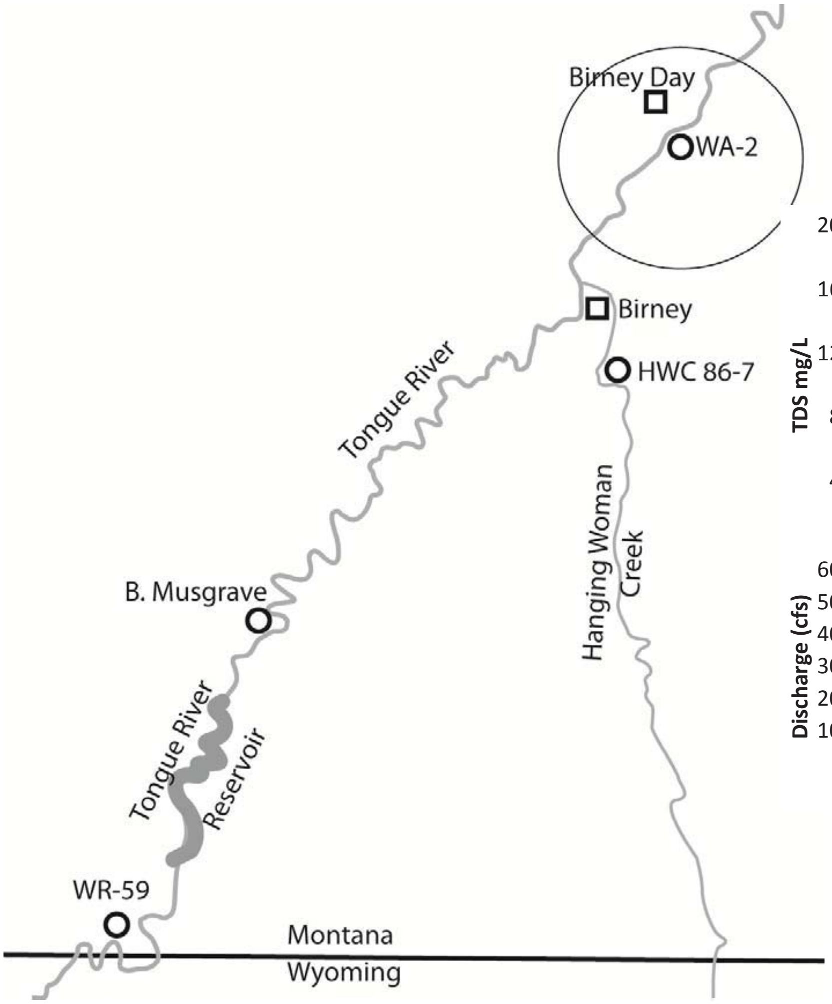
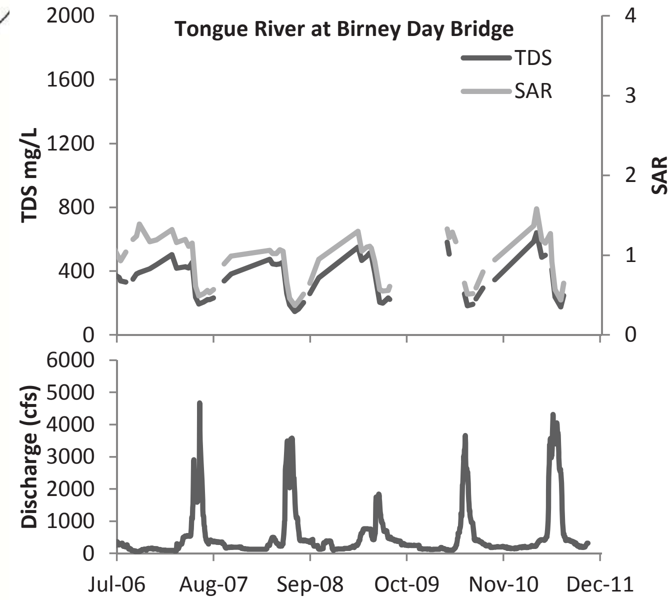
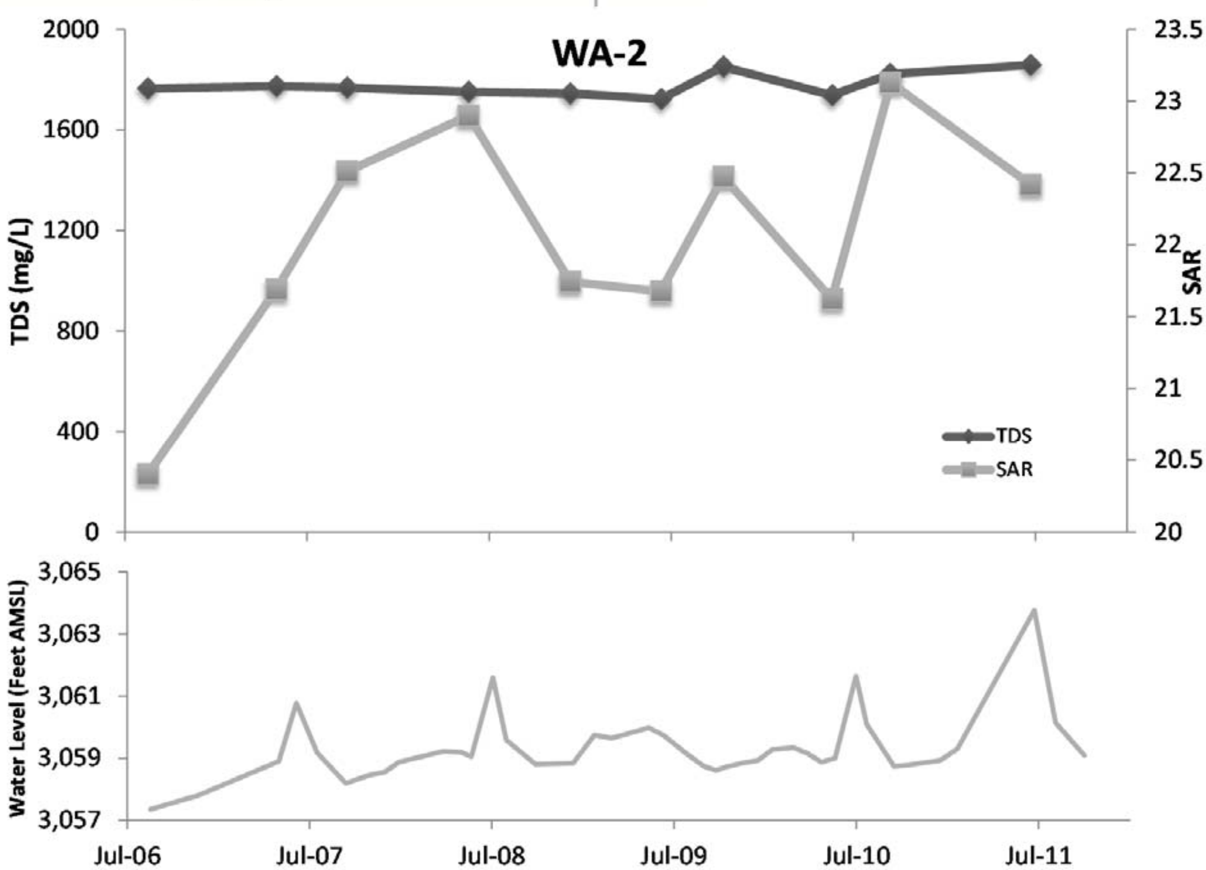


Figure 22. TDS, SAR and Water Level / Stream Discharge for well WA-2 in the alluvium of the Tongue River and the Tongue River at Birney Day Bridge.





Wyoming CBM Fields near the Montana Border

Data for CBM wells in Wyoming are available from the WOGCC website (http://wogcc.state.wy.us/). For this report, only those wells in Wyoming townships 57N and 58N were considered (plate 1). Water production data were downloaded for CBM wells located in these townships. For the purposes 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

Methane and 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 (appendix D). During 2011, a total of 855 CBM wells produced methane and/or water in the Prairie Dog Creek Field. Cumulative water production for the year was 29.6 million barrels. Monthly water production in the field peaked in mid-2002 at nearly 900 acre-feet per month. For the next 5 years the water production fluctuated between 500 and 600 acre-feet per month; however, since August 2008 the water production has fallen steadily and was approximately 300 acre-feet per month in fall 2011 (fig. 23). Gas production rose fairly consistently until early 2008, after which gas production has fallen steadily (fig. 23).

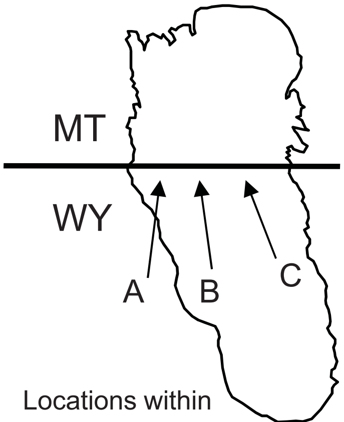
Aquifer water levels. Water-level drawdown in Montana that results from CBM production in the Prairie Dog Creek Field cannot be separated from the drawdown that results from Montana production in the CX Field and therefore is included in the earlier discussion on the CX Field in this report.

Hanging Woman Creek Gas Field

Methane and water production. During November 2004, St. Mary Land and Exploration (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). CBM production in this field is from the Roland, Anderson, Dietz, Canyon, Cook, Brewster–Arnold, Knobloch, Flowers–Goodale (Roberts), and Kendrick coalbeds (appendix D). During 2011, a total of 234 CBM wells produced methane and/or water in the Hanging Woman Creek Field. The total water production for the 12-month period was 13.3 million barrels. Water production began to climb in November 2004, reaching a peak in September 2007 with 319 acre-feet per month (2.5 million barrels; fig. 23). Since that time, water production fell to less than 200 acre-feet per month and has remained fairly constant at that rate for the past year. Gas production has been low throughout the life of the field.

Bedrock-aquifer water levels. Drawdown due to production from the Hanging Woman Creek gas field is monitored primarily by state line sites SL-3, SL-4 ,and SL-5 (plate 1). Site SL-3 is located about 1 mile north of the nearest Wyoming CBM well. Monitoring wells at SL-3 include wells completed in the alluvium of North Fork Waddle Creek, an overburden sandstone, and Smith, Anderson, and Canyon coals (fig. 24). Water levels in the alluvium, sandstone overburden, and Smith coal are not responding to CBM production. The water level in the Anderson coal has dropped about 51 feet, and the water level in the Canyon coal has dropped about 128 feet (fig. 25).

Monitoring well site SL-4 is located about 1 mile north of the nearest CBM well in the Hanging Woman Creek gas field (plate 1). Monitoring wells at this site are completed in the alluvium and the Smith and Anderson coalbeds (fig. 26). The water level in the Anderson coal is responding to CBM production in Wyoming and is currently 63 feet lower than when monitoring began at this site. In July 2010, the water levels recovered 9 feet, presumably a response to changes in production rates in the nearby CBM field (fig. 27). Water levels continued downward after this recovery, most likely due to continued or renewed CBM development. The water level in the Smith coal also dropped slightly (13 feet overall); the installed data logger shows high frequency oscil-



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

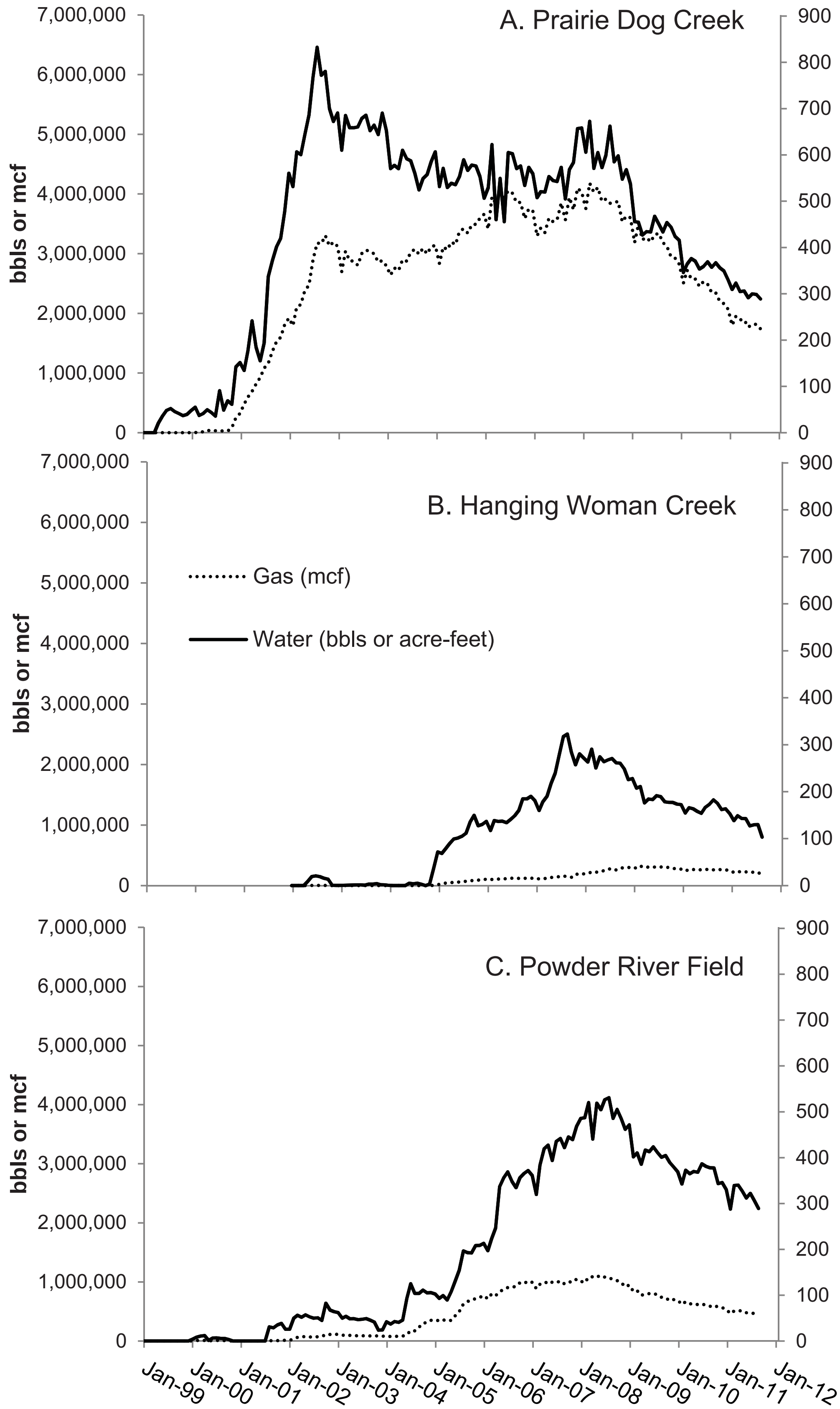


Figure 23. Total water (solid line) and gas (dashed line) produced per month in Wyoming CBM fields. Wyoming development is increasing to the east by the Powder River.

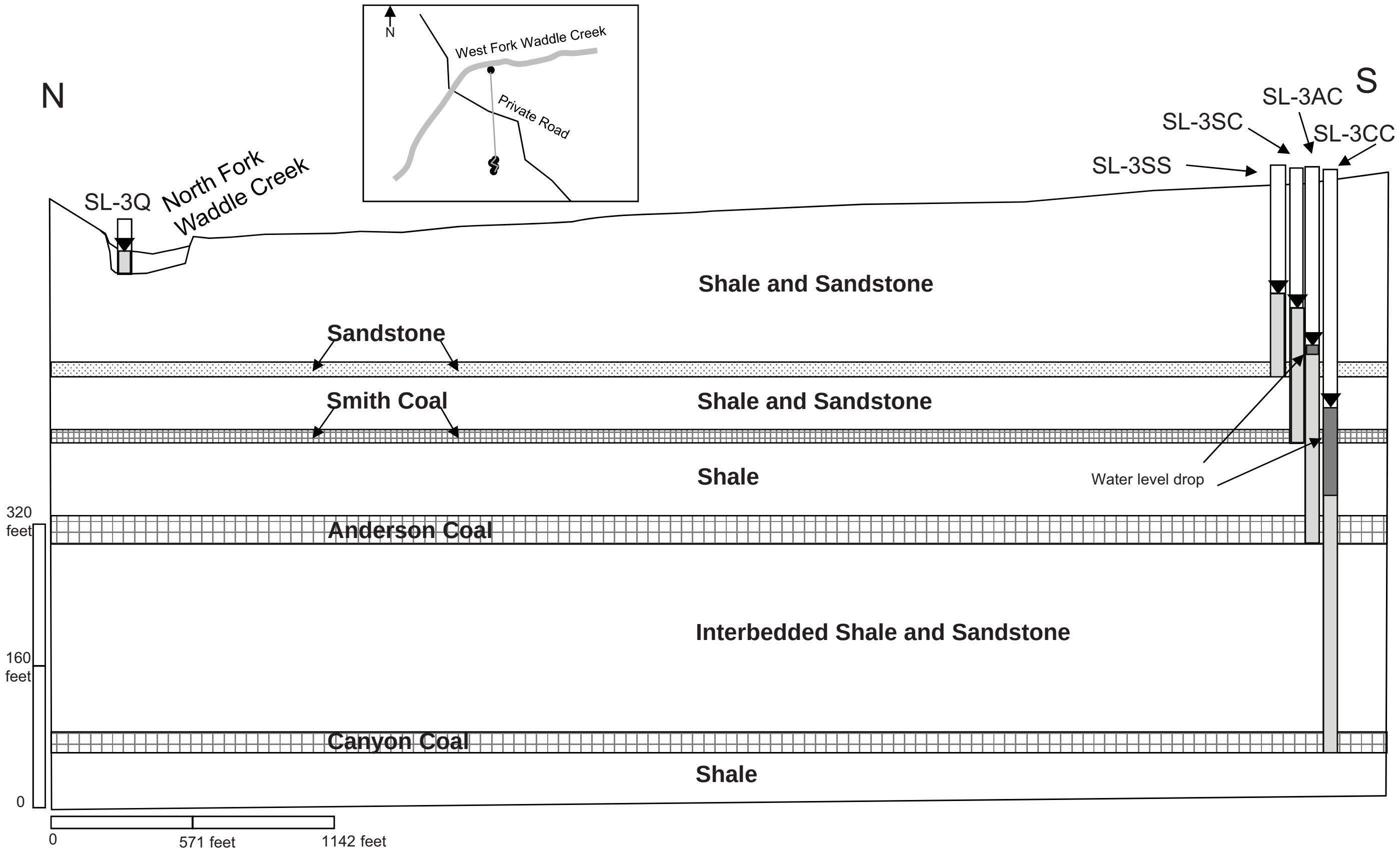


Figure 24. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coalbeds located at T. 9 S. R. 42 E., sec. 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2011. The water level in the Anderson Coal has lowered about 51 ft and the Canyon coal has lowered about 128 ft since well installation. The wells are located roughly 1 mile north from nearest CMB field. Vertical exaggeration is 3.6:1.

lations characteristic of pumping in nearby wells completed in the same aquifer for stock watering or cistern filling (fig. 27 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, which is also completed in the Smith coal.

Monitoring well site SL-5 is located approximately 4 miles to the northeast from the nearest CBM development in Wyoming (plate 1). Drawdown in the Anderson coal has been about 5 feet at this site. There is no noticeable change in the Dietz coal aquifer water level. The Canyon coal water level has risen over 13 feet since monitoring began in July 2005 (fig. 28). Production of CBM from the nearby field in Wyoming (T. 58 N., R. 79 W.) is from the Anderson, Canyon, Cook, Kendrick and Roberts coals.

A number of factors could cause the water level to rise in well SL-5CC (fig. 28). The rise may be a response to climatic changes; however, aquifers over 400 feet below the surface, such as the Canyon coal in this location, are usually insulated from all but the most long-term climatic patterns. The increase may be related to lowered CBM production rates in the Canyon coal; however, monitoring in other Canyon coal wells does not show a similar response. The increasing water level may be a result of a failed well seal in the Canyon coal well. There may be communication along the well bore between the Canyon coal and the higher pressure Anderson coal. The drop in the water level of the Anderson coal may be a result of equilibration between these two aquifers rather than from CBM development. Alternatively, it may be a nearby well, CBM or domestic, that has allowed the two aquifers to communicate. Evidence suggesting that it may be the monitoring well that has failed includes the timing of monitoring. The first water-level rise was measured in the month following an attempted sample collection from the well. No sample was collected because the gas caused the pump to cavitate.

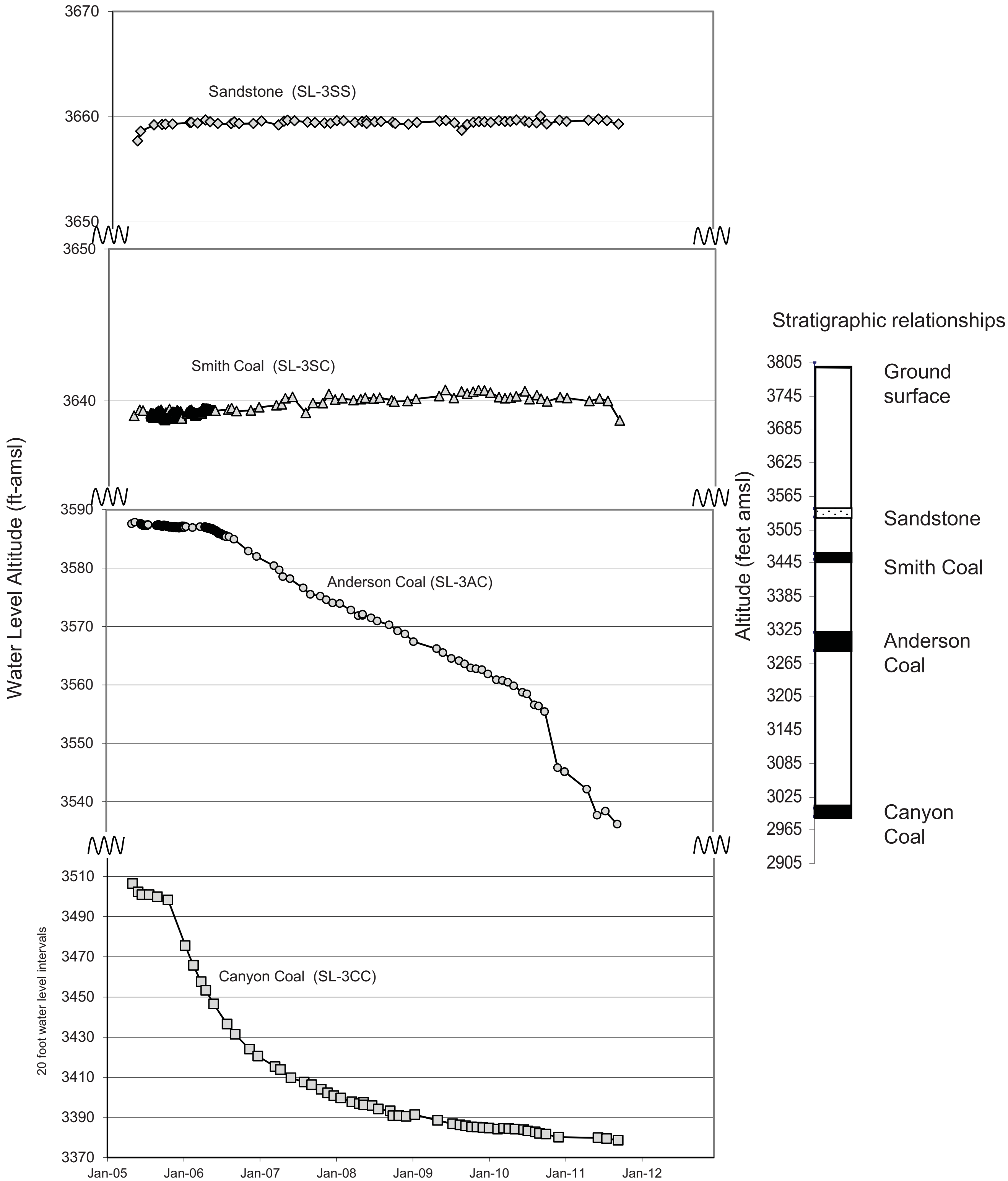


Figure 25. Water levels in the overburden sandstone and Smith coals are not responding to CBM development. However, the water level in the Anderson and Canyon Coal have dropped about 51 and 128 ft, respectively, in response to CBM production.

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

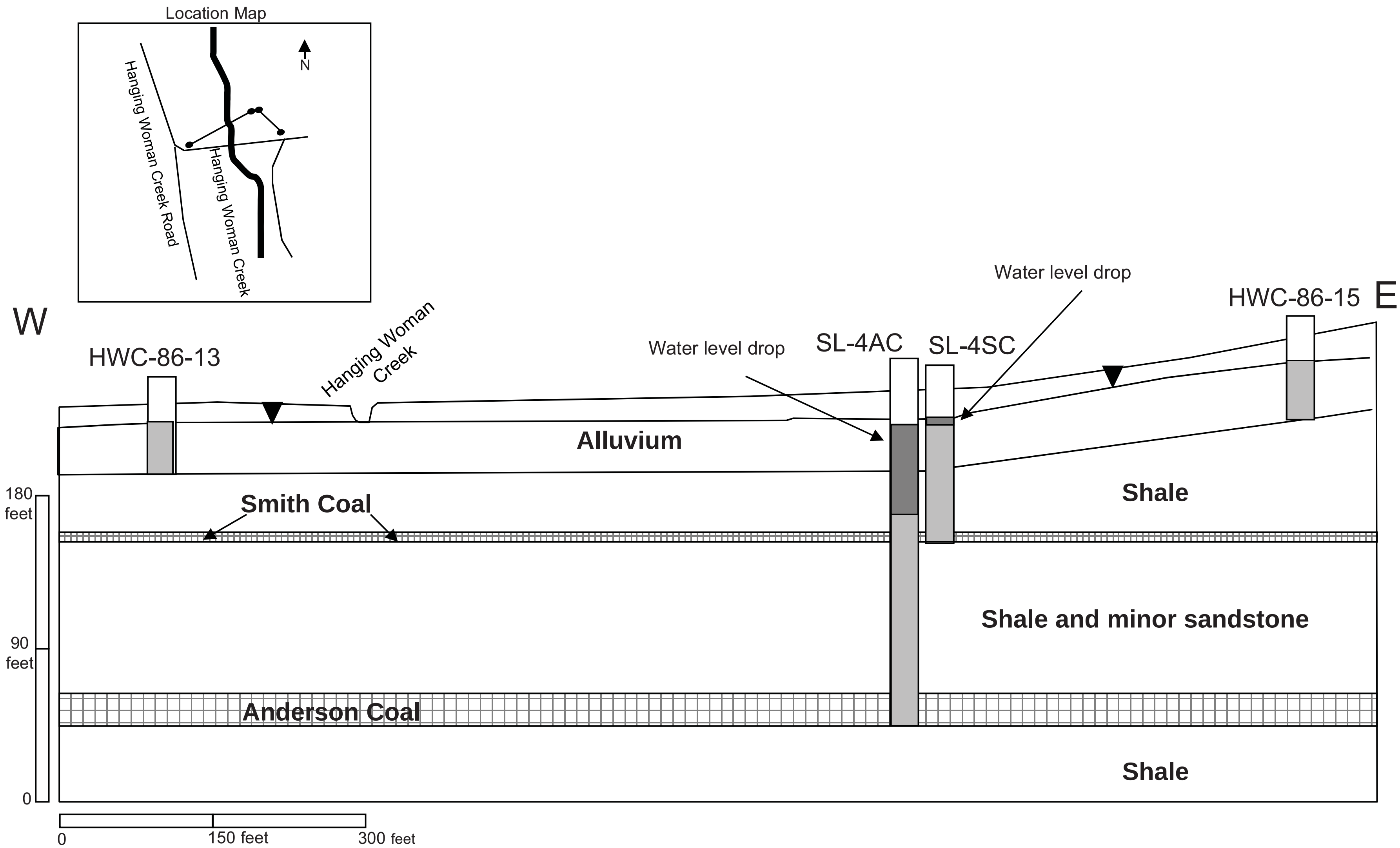


Figure 26. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 63 ft and the Smith has lowered about 13 ft since well instillation (shown in cross section). These wells are located roughly 1 mile north of the nearest CBM field. Water levels for the cross section were taken in August 2010. Vertical exaggeration is 7:1.

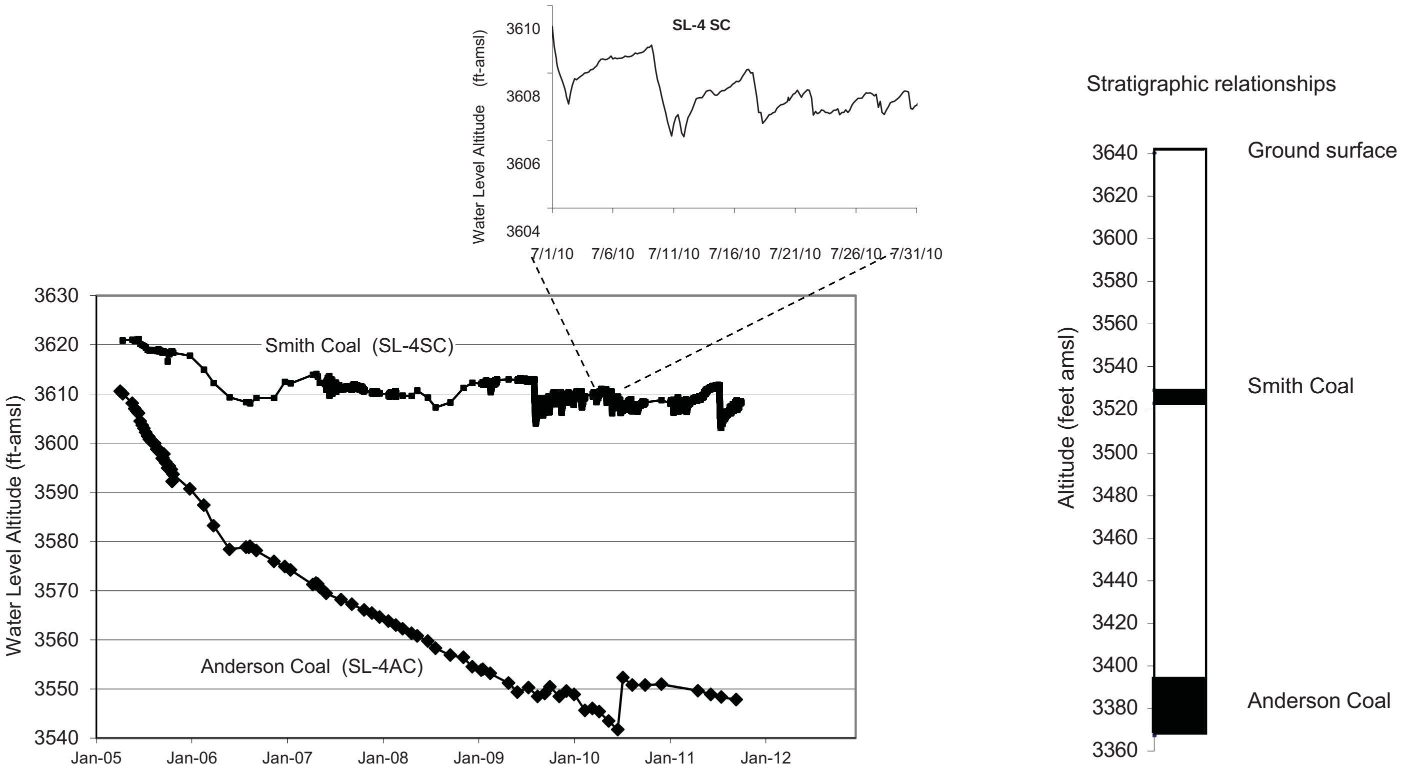


Figure 27. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson Coal appear to have lowered about 63 ft from April 2005 to September 2011 in response to CBM development; however, it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft, presumably due to activities in the nearby CMB field. 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.

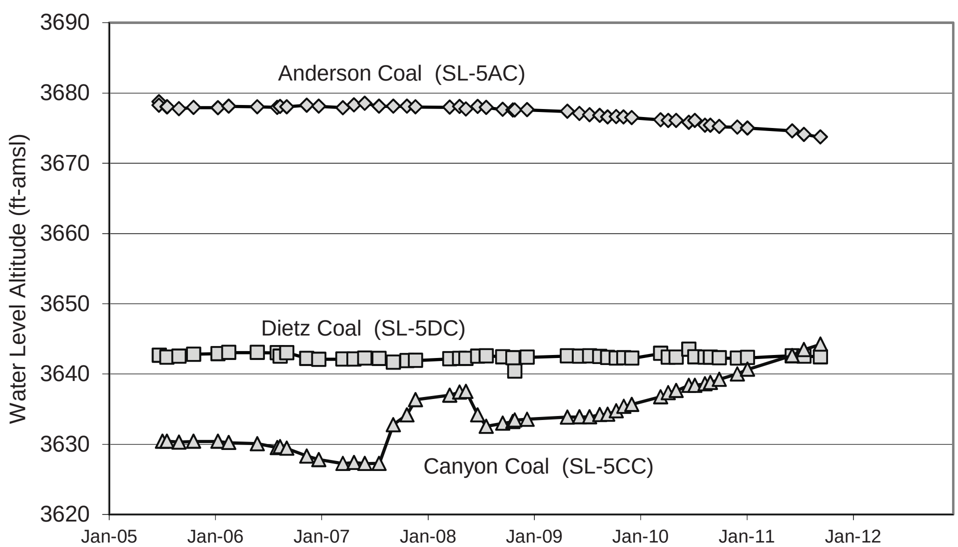


Figure 28. Coalbed-methane development in the Anderson coal is causing a slight decline in water level in the Anderson coal at the SL-5 site. The Canyon coal decreased slightly until July 2007 then began to rise. The Canyon and Dietz water levels are currently at the same level. The water level increase may be a result of a failed well seal in the Canyon coal well. The nearest CBM development is approximately 4 miles away in Wyoming.

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 (fig. 25). Changes in water levels in the alluvium reflect water-table response to seasonal weather patterns (figs. 29 and 30).

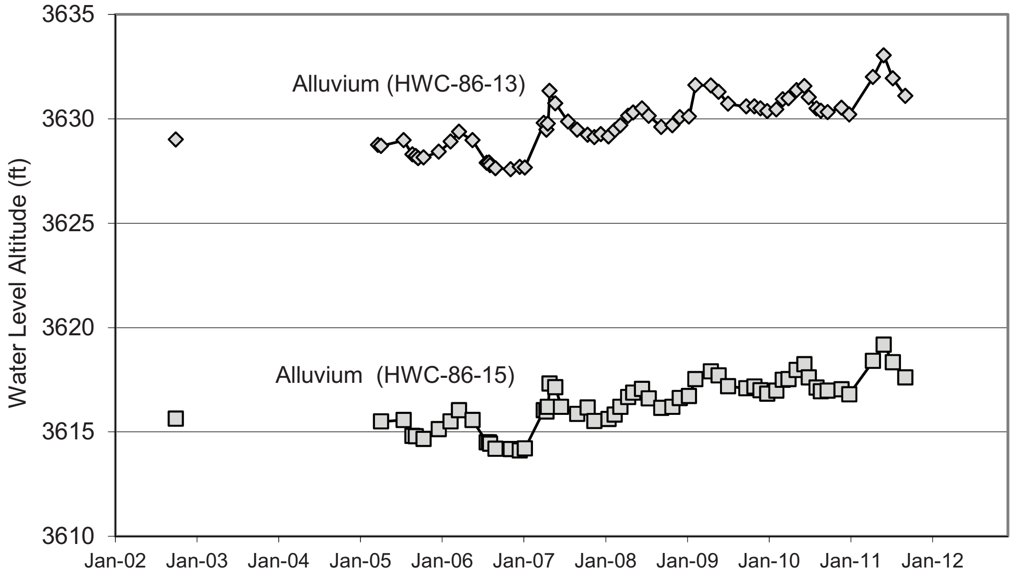


Figure 29. The water level in the Hanging Woman Creek alluvial aquifer near the Montana–Wyoming state line reflects water table response to meteorological pattern. Shown on plate 1.

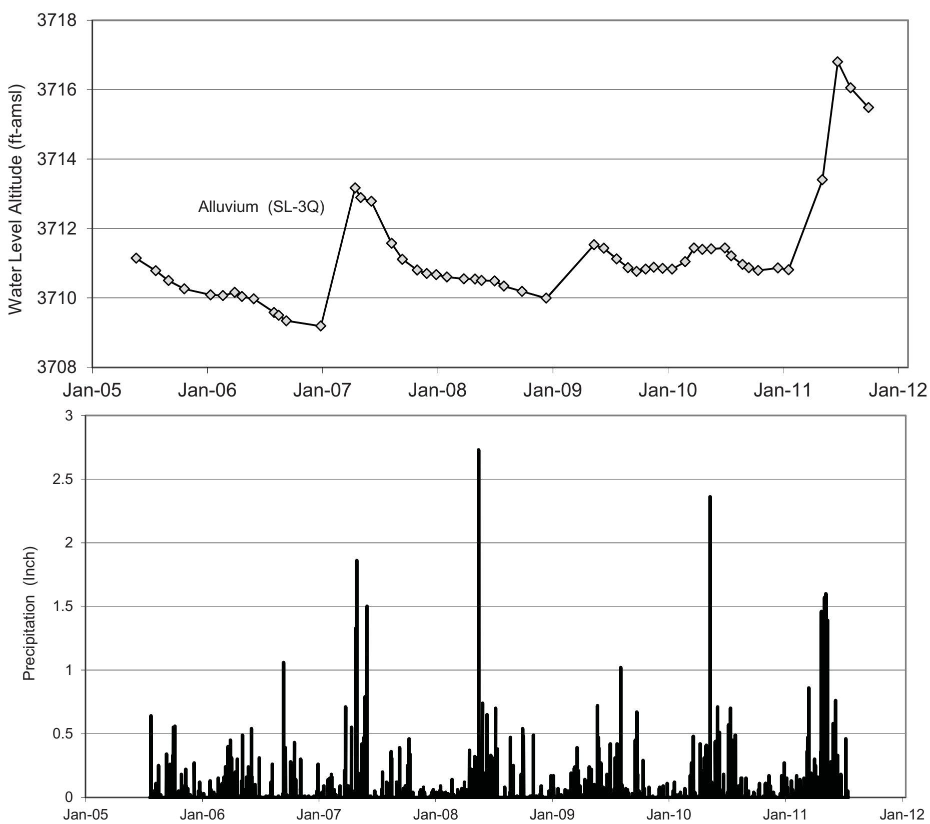


Figure 30. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to plate 1. Precipitation at the SL-3 weather station is shown as the total rain in inches per event in the lower graph.
A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation.

Water-quality samples were collected from wells HWC 86-13 and HWC 86-15 during September 2010 and May 2011 (appendix C). For the two sampling events, the TDS concentrations in the alluvial water ranged from 6,403 to 8,493 mg/L and SAR values ranged from 11.3 to 12.0. The water chemistry in the alluvium was dominated by sodium and sulfate. There is a natural variation of approximately 1000 mg/L in both these wells since sampling began in 1987. Water-quality samples were collected on North Fork Waddle Creek at SL-3Q during September 2010 and May 2011 (appendix C). TDS and SAR concentrations varied little since sampling began in 2005, and during these sampling events had TDS values of 3,406 and 3,845 mg/L and SAR of 5.4 and 5.7, respectively. The water chemistry was dominated by sodium and sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site.

Gas Fields near Powder River

Methane and 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 (appendix D). During water year 2011, a total of 485 wells produced methane and/or water in this area. The cumulative production for the 12-month period was 30.4 million barrels of water. 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. As of September 2011, water production is approximately 300 acre-feet per month. Gas production peaked in 2008 and has steadily declined since (fig. 23).

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 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.

Alluvial-aquifer water levels and water quality. South of Moorhead, Montana, groundwater flow through the Powder River alluvium is roughly parallel to the river valley (figs. 31 and 32). This site is located on a large meander of the river, and the river likely loses flow to the alluvium on the upgradient 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-8-1Q in September 2010 and from SL-8-2Q in September 2010 and May 2011 (appendix C). TDS concentrations ranged from 2,272 to 3,087 mg/L and SAR values ranged from 4.1 to 5.1. The water chemistry was dominated by calcium, sodium, and sulfate. The TDS and SAR values were higher in the well closest to the Powder River (fig. 31), but no CBM impacts were apparent. Data are insufficient to identify seasonality trends.

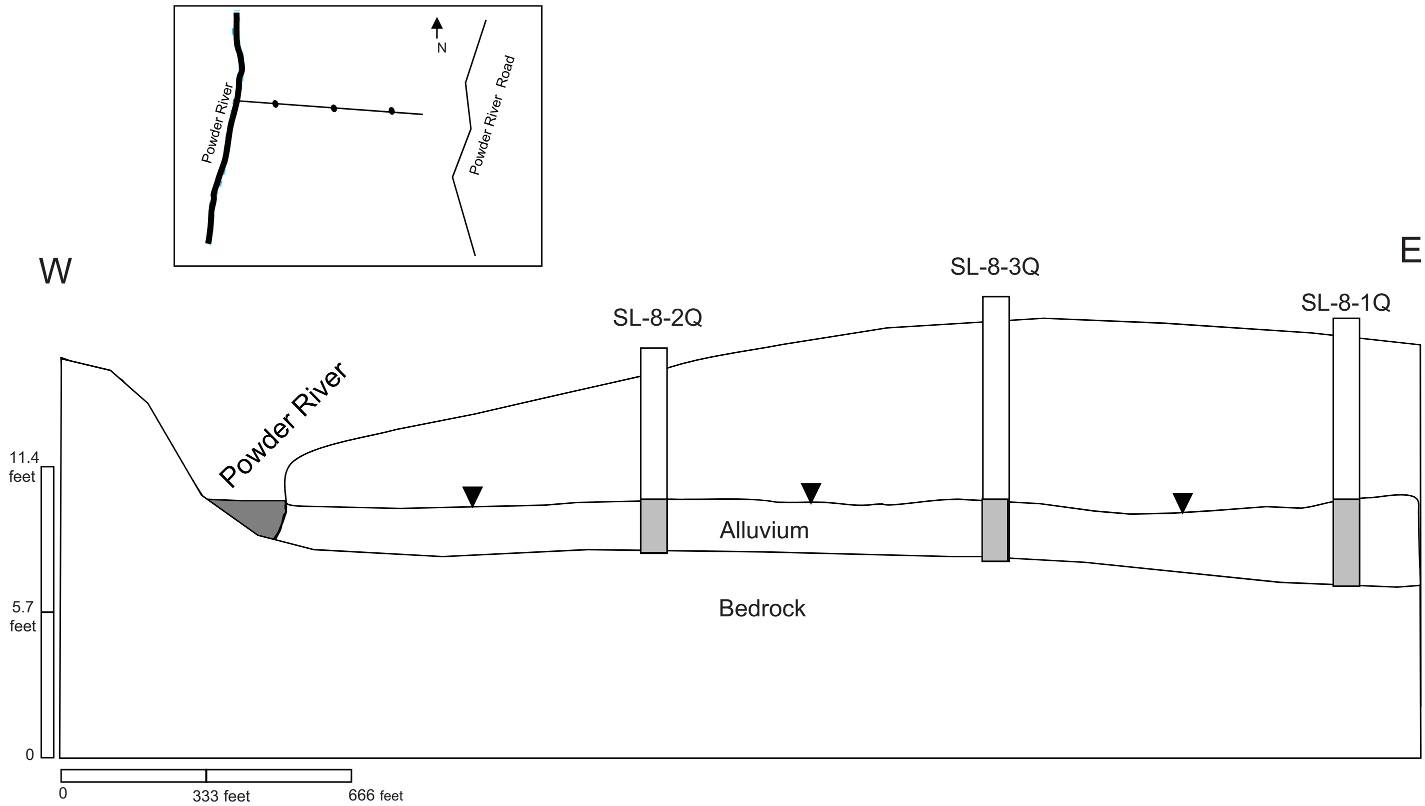


Figure 31. Cross section of alluvial wells south of Moorhead near the Powder River located in T. 9 S., R. 47 E., sec. 25. Groundwater in the alluvium appear to flow parallel to the river valley. Water levels for this cross section were taken in September 2011. Vertical exaggeration is 58:1.

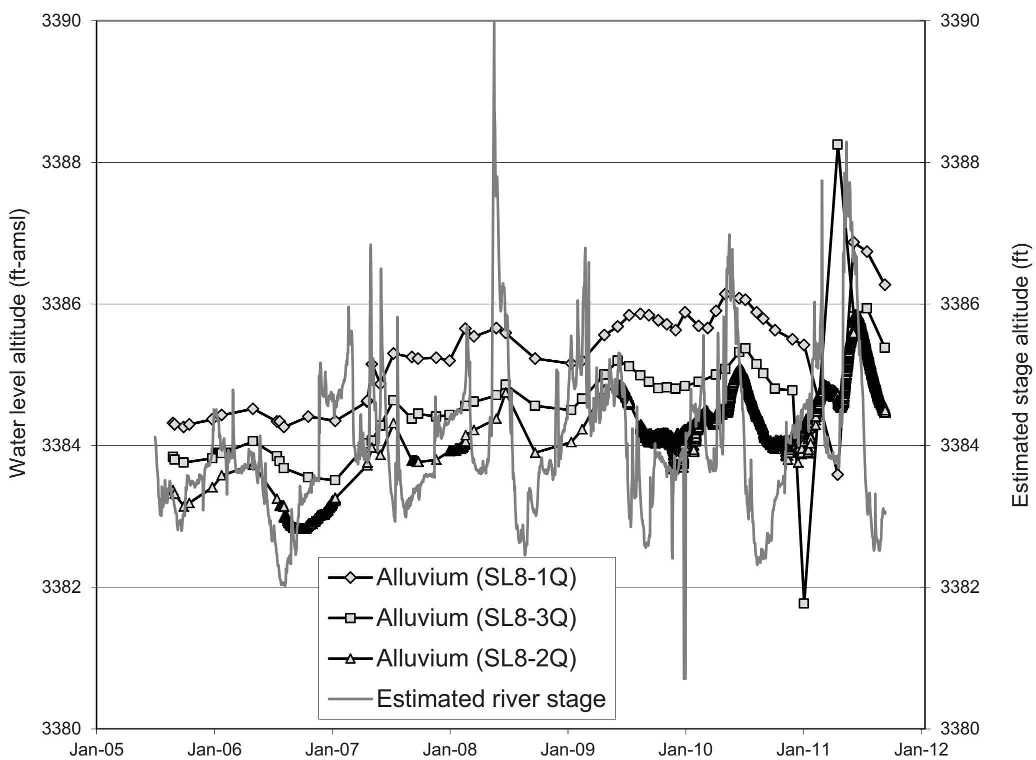


Figure 32. Groundwater flow in the alluvial aquifer at SL-8 is generally toward the Powder River. The groundwater-level trends follow river-stage trends. The river alternates between gaining (summer) and losing (winter).
Estimated Powder River stage at SL-8 is based on stage at Moorhead gauging station (USGS data) and the surveyed river water-level altitude of 3383.93 ft measured on 1/27/06.

SUMMARY AND 2012 MONITORING PLAN

Coalbed-methane production continues near the Tongue River Reservoir in Montana; however, 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 could expand into those areas in the next several years. The MBMG regional groundwater monitoring network documents baseline conditions outside production areas, changes to the groundwater systems within the area of influence, and the extent of drawdown within the monitored aquifers. Outside the area of influence of CBM production, groundwater conditions reflect normal response to precipitation. Within the area of influence, water levels reflect the drawdown required for CBM production.

Within the CX field, groundwater levels have been drawn down over 200 feet in the producing coalbeds. The actual amount of drawdown in some wells cannot be measured due to safety concerns over the presence of methane. After over 12 years of CBM production, drawdown of up to 20 feet has been measured in the coalbeds at a distance of roughly 1 to 1.5 miles outside the production areas. This distance, which is less than was predicted in the Montana CBM Environmental Impact Statement, has not changed substantially since 2004 (Wheaton and others, 2005). The Environmental Impact Statement predicted 20 feet of drawdown would reach 2 miles after 10 years of CBM production.

Major faults generally act as barriers to groundwater flow, and drawdown rarely migrates across fault planes where measured in monitoring wells. However, in cases where faults are not offset at least 10 feet more than the thickness of the coal, or where they scissor around a hinge point, 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 water levels have been observed.

Water levels will recover after production ceases, but it will take decades 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, the site-specific aquifer characteristics, the extent of faulting, proximity to recharge areas, and amount of recharge.

Water from CBM wells have TDS concentrations generally between 1,000 mg/L and 2,500 mg/L. Sodium adsorption ratios in methane-bearing coal seams are relatively high, generally between 30 and 40, and have been measured to exceed 80 (appendix D).

Monitoring plans for water year 2012 are included in appendices A and B and shown in plate 6. During water year 2012, 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. Water-quality samples will be collected semi-annually from selected alluvial sites and annually from selected deep wells. In an effort to ensure all springs have been sampled at least twice, this year's fall sampling will include the second sampling of springs Hagen 2 and Joe Anderson on the Ashland Ranger district. Coal aquifer water-quality sampling in 2012 will include the three newly installed wells at SL-9. Equipment problems prohibited sampling these coal wells in 2011. Monitoring priorities will be adjusted as new areas of production are proposed or developed.

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Appendix A

Site details, water-level data, and water year 2012 monitoring plan for wells

Appendix A. Site details, water-level data, and 2012 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2012 SWL monitoring	2012 QW sample collection
7573	WO-15	-106.1855	45.5186	04S	45E	4	BDDB	Powder River	3022	Alluvium	63	12.0	9/30/2011	7.88	3014.1	Monthly	
7574	WO-16	-106.1861	45.5158	04S	45E	4	CAAC	Powder River	3040	Alluvium	61	3.7	9/30/2011	23.25	3016.8	Monthly	
7589	Newell Pipeline Well	-106.2143	45.4727	04S	45E	19	DADD	Powder River	3290	Tongue River Formation	325	5.0	1/19/2011	278.05	3012.0	Quarterly	
7755	77-26	-106.1839	45.4352	05S	45E	4	ABCC	Powder River	3284	Knobloch Coal	217	3.6	10/13/2010	145.76	3138.2	Quarterly	
7770	WO-8	-106.1411	45.3922	05S	45E	23	ABCA	Powder River	3155	Alluvium	33	12.0	9/30/2011	14.41	3140.6	Monthly	
7772	WO-9	-106.1419	45.3925	05S	45E	23	ABCA	Powder River	3150	Alluvium	45	21.8	9/30/2011	10.75	3139.3	Monthly	
7775	WO-10	-106.1430	45.3925	05S	45E	23	ABCB	Powder River	3145	Alluvium	41		9/30/2011	7.20	3137.8	Monthly	
7776	WO-5	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Knobloch Underburden	192	20.4	9/30/2011	16.83	3143.2	Monthly	
7777	WO-6	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Lower Knobloch Coal	82	7.0	9/30/2011	24.01	3136.0	Monthly	
7778	WO-7	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Alluvium	40	29.0	9/30/2011	25.96	3134.0	Monthly	
7780	WO-1	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3190	Knobloch Underburden	172	8.0	9/30/2011	37.04	3153.0	Monthly	
7781	WO-2	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3188	Lower Knobloch Coal	112	19.0	9/30/2011	43.97	3144.0	Monthly	
7782	WO-3	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3186	Knobloch Overburden	66	17.8	9/30/2011	45.52	3140.5	Monthly	
7783	WO-4	-106.1486	45.3941	05S	45E	23	BBAA	Powder River	3140	Alluvium	32		9/30/2011	8.23	3131.8	Monthly	
7903	HWC86-9	-106.5027	45.2966	06S	43E	19	DACD	Rosebud	3170	Alluvium	44		9/30/2011	10.24	3159.8	Monthly	
7905	HWC86-7	-106.5033	45.2958	06S	43E	19	DDBA	Rosebud	3170	Alluvium	71		9/30/2011	8.65	3161.4	Monthly	Semi-Annual
7906	HWC86-8	-106.5030	45.2961	06S	43E	19	DDBA	Rosebud	3170	Alluvium	67		9/30/2011	7.96	3162.0	Monthly	
8074	WR-21	-106.9791	45.0877	08S	39E	32	DBBC	Big Horn	3890	Dietz 1 and Dietz Coals Combined	206	4.0	9/28/2011	56.50	3833.5	Monthly	
8101	HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	Big Horn	3460	Alluvium	50		9/30/2011	19.15	3440.9	Monthly	
8103	HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	Big Horn	3455	Alluvium	33		9/30/2011	14.26	3440.7	Monthly	
8107	HWC-01	-106.4866	45.1338	08S	43E	20	DDDD	Big Horn	3530	Canyon Coal	232	7.5	10/10/2011	90.05	3440.0	Monthly	
8110	HC-01 O-4	-106.4750	45.1313	08S	43E	21		Big Horn	3455	Alluvium	20	16.5	1/27/2009	9.20	3445.8		
8118	HC-24	-106.4747	45.1297	08S	43E	21	BDBB	Big Horn	3500	Canyon Overburden	150	7.1	7/28/2011	42.50	3447.5	Semi-Annual	
8140	FC-01	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Anderson Coal	133	0.0	7/28/2011	129.05	3606.0	Monthly	
8141	FC-02	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Dietz Coal	260		7/28/2011	243.11	3491.9	Monthly	
8191	BC-06	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Coal	188	4.6	9/29/2011	87.84	3627.2	Monthly	
8192	BC-07	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Overburden	66	0.8	9/29/2011	33.96	3681.0	Monthly	
8347	WR-23	-106.9905	45.0922	09S	38E	1	AADC	Big Horn	3960	Dietz 1 and Dietz Coals Combined	322	6.0	9/28/2011	82.84	3877.2	Monthly	
8368	SH-391	-107.0320	45.0413	09S	38E	22	DADC	Big Horn	3987	Dietz 1 and Dietz Coals Combined	175		9/28/2011	61.41	3925.6	Monthly	
8371	SH-388	-107.0205	45.0391	09S	38E	23	CDAD	Big Horn	3975	Dietz Coal	190		9/28/2011	78.12	3896.9	Monthly	
8372	SH-396	-107.0088	45.0491	09S	38E	24	BBBC	Big Horn	3939	Anderson-Dietz 1 and 2 Coals	280	25.0	9/28/2011	54.91	3884.1	Monthly	
8377	SH-394	-107.0075	45.0330	09S	38E	25	BCBA	Big Horn	3909	Dietz Coal	242	5.0	9/28/2011	91.43	3817.6	Monthly	
8379	SH-422	-107.0061	45.0261	09S	38E	25	CBDC	Big Horn	3917	Dietz Coal	187		8/2/2011	121.95	3795.1	Semi-Annual	
8387	SH-395	-107.0618	45.0361	09S	38E	26	ABAB	Big Horn	3900	Dietz Coal	299	15.0	9/28/2011	63.23	3836.8	Monthly	
8412	WR-58	-106.9122	45.0408	09S	39E	14	DDBD	Big Horn	3631	Alluvium	55	21.0	9/28/2011	14.16	3617.1	Monthly	
8413	WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	Big Horn	3627	Alluvium	27	15.0	9/28/2011	14.14	3613.3	Monthly	
8417	WR-19	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Dietz 1 and Dietz Coals Combined	305	20.0	9/28/2011	134.14	3701.3	Monthly	
8419	WR-20	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Anderson Coal	166	15.0	9/28/2011	106.74	3728.6	Monthly	
8428	WR-54A	-106.8902	45.0147	09S	39E	25	DADB	Big Horn	3631	Anderson-Dietz 1 and 2 Overburden	211	1.0	9/28/2011	127.10	3504.1	Monthly	

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GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2012 SWL monitoring	2012 QW sample collection
8430	WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	Big Horn	3608	Anderson-Dietz 1 and 2 Overburden	187		9/28/2011	108.77	3499.1	Monthly	
8436	WR-24	-106.9877	45.0202	09S	39E	29	BBDD	Big Horn	3777	Canyon Coal	146		9/28/2011	32.50	3744.7	Monthly	
8441	WR-33	-106.9758	45.0066	09S	39E	32	ACAA	Big Horn	3732	Anderson-Dietz 1 Clinker and Coal	165		9/28/2011	50.42	3681.9	Monthly	
8444	WR-27	-106.9658	45.0008	09S	39E	33	DBBD	Big Horn	3672	Anderson-Dietz 1 and 2 Coals	363	25.0	8/2/2011	76.07	3595.9	Monthly	
8446	WR-45	-106.9538	44.9966	09S	39E	33	DDCC	Big Horn	3638	Alluvium	64	30.0	8/2/2011	9.73	3628.5	Monthly	
8447	WR-44	-106.9522	44.9966	09S	39E	33	DDCD	Big Horn	3637	Alluvium	64	30.0	8/2/2011	9.23	3627.7	Monthly	
8451	WR-42	-106.9502	44.9966	09S	39E	33	DDDD	Big Horn	3637	Alluvium	66	30.0	8/2/2011	10.00	3626.7	Monthly	
8456	WRN-10	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3433	Dietz 2 Coal	79	3.4	9/28/2011	24.55	3408.8	Monthly	
8461	WRN-15	-106.8275	45.0638	09S	40E	9	AADD	Big Horn	3500	Dietz 2 Coal	140		9/29/2010	90.90	3408.9	Monthly	
8471	DS-05A	-106.8338	45.0555	09S	40E	9	DCAB	Big Horn	3506	Dietz 2 Coal	166	5.0	9/29/2010	105.24	3400.3	Monthly	
8500	WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	Big Horn	3511	Dietz 2 Coal	232		9/29/2010	165.14	3345.6	Monthly	
8501	WRE-10	-106.7741	45.0383	09S	40E	13	DCCB	Big Horn	3519	Dietz Coal	183		9/29/2010	146.86	3371.6	Monthly	
8504	WRE-11	-106.7736	45.0383	09S	40E	13	DCCD	Big Horn	3509	Anderson Coal	127		9/29/2010	82.51	3426.4	Monthly	
8574	DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	Big Horn	3430	Dietz 2 Coal	150		9/29/2010	55.43	3374.6	Monthly	
8650	WR-55	-106.8858	45.0300	09S	40E	19		Big Horn	3591	Tongue River Formation	288	15.0	9/28/2011	161.80	3429.4	Monthly	
8651	WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	Big Horn	3591	Anderson-Dietz 1 and 2 Overburden	72		9/28/2011	45.28	3545.8	Monthly	
8687	WRE-12	-106.8038	45.0311	09S	40E	23	BCCD	Big Horn	3463	Anderson Coal	172		9/28/2011	86.39	3376.8	Monthly	
8692	WRE-13	-106.8044	45.0311	09S	40E	23	BCCD	Big Horn	3463	Dietz Coal	206		9/28/2011	91.62	3371.0	Monthly	
8698	WRE-16	-106.7697	45.0352	09S	40E	24	AACB	Big Horn	3551	Anderson Coal	458		9/28/2011	61.19	3489.3	Monthly	
8706	WR-17B	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3575	Anderson-Dietz 1 and 2 Overburden	160		9/28/2011	74.02	3500.7	Monthly	
8708	WR-51	-106.8620	45.0186	09S	40E	29		Big Horn	3541	Tongue River Formation	344	4.4	9/28/2011	131.59	3409.4	Monthly	
8709	WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	Big Horn	3541	Anderson-Dietz 1 and 2 Overburden	187		9/28/2011	41.00	3500.3	Monthly	
8710	WR-52B	-106.8627	45.0147	09S	40E	29	CACB	Big Horn	3519	Alluvium	55	59.7	9/28/2011	11.24	3507.6	Monthly	
8721	WRE-27	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3524	Anderson Coal	77	0.5	9/29/2010	47.12	3476.7	Monthly	
8723	WRE-28	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3525	Dietz Coal	153		9/29/2010	61.63	3463.6	Monthly	
8726	WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	Big Horn	3523	Dietz 2 Coal	217		9/29/2010	110.31	3413.0	Monthly	
8754	CC-1	-106.4646	45.0875	09S	43E	4	ABDD	Big Horn	3520	Alluvium	28	4.2	9/29/2011	14.08	3510.9	Monthly	
8757	CC-4	-106.4659	45.0874	09S	43E	4	ABDD	Big Horn	3511	Alluvium	25	4.8	9/29/2011	6.96	3504.0	Monthly	
8758	CC-3	-106.4654	45.0864	09S	43E	4	ACAA	Big Horn	3521	Alluvium	35	4.6	9/29/2011	14.21	3506.8	Monthly	
8777	HWC-38	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3586	Alluvium	41		8/3/2011	18.64	3567.4	Monthly	
8778	HWC-17	-106.4133	45.0570	09S	43E	13	BCAA	Big Horn	3610	Anderson Coal	82	6.9	9/29/2011	50.28	3559.7	Monthly	
8779	HWC-07	-106.4094	45.0536	09S	43E	13	CAAA	Big Horn	3595	Anderson Coal	66		9/29/2011	27.86	3567.1	Monthly	
8782	HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	Big Horn	3600	Anderson Coal	129	10.0	9/29/2011	33.46	3566.5	Monthly	
8796	HWC-29B	-106.3969	45.0688	09S	44E	7	BBCC	Big Horn	3620	Anderson Coal	92		8/3/2011	45.27	3574.7	Monthly	
8835	AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	Powder River	3965	Dietz Coal	240	1.4	9/29/2011	166.75	3798.3	Monthly	
8846	UOP-09	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3929	Canyon Coal	262	0.8	9/29/2011	155.84	3773.2	Monthly	
8847	UOP-10	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3930	Canyon Overburden	207	4.4	9/29/2011	141.86	3788.1	Monthly	
8863	Fulton George *NO.6	-105.8628	45.0807	09S	48E	5	ACDD	Powder River	3380	Tongue River Formation	410	4.0	10/10/2011	16.54	3363.5	Quarterly	
8888	HWC 86-13	-106.4262	45.0020	10S	43E	2	ABCA	Big Horn	3640	Alluvium	53	3.9	9/29/2011	10.21	3629.8	Monthly	Semi-Annual
94661	Liscom Well	-106.0323	45.7782	01S	46E	3	DBAA	Powder River	3275	Fort Union Formation	135	10.0	7/25/2011	96.18	3178.8	Quarterly	
94666	Coyote Well	-106.0505	45.7524	01S	46E	16	AACC	Powder River	3294	Fort Union Formation	190	5.0	10/10/2011	134.99	3159.0	Quarterly	
100472	East Fork Well	-106.1642	45.5935	03S	45E	10	B	Powder River	3210		193	5.0	10/10/2011	137.85	3072.2	Quarterly	

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GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2012 SWL monitoring	2012 QW sample collection
103155	Padget Creek Pipeline Well	-106.2940	45.3939	05S	44E	22	BBBD	Rosebud	3385	Tongue River Formation	135	10.0	7/28/2011	61.54	3323.5	Quarterly	
105007	Tooley Creek Well	-106.2697	45.2153	07S	45E	19	CAAA	Powder River	3755	Fort Union Formation	110	12.0	10/10/2011	35.55	3719.5	Quarterly	
121669	WRE-18	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3573	Anderson Coal	445		9/28/2011	97.81	3475.3	Monthly	
122766	WR-59	-106.8526	45.0050	09S	40E	32	ACAD	Big Horn	3470	Alluvium	34	10.0	9/28/2011	8.41	3461.7	Monthly	Semi-Annual
122767	WRE-20	-106.7716	45.0369	09S	40E	24	ABAB	Big Horn	3519	Anderson Coal	120		9/29/2010	93.15	3426.3	Monthly	
122769	WR-38	-106.9650	44.9938	37N	63E	23	BBCB	Sheridan	3693	Dietz 1 and Dietz Coals Combined	286	3.8	8/2/2011	75.41	3617.5	Monthly	
122770	WR-39	-106.9555	44.9952	37N	63E	23	ABBC	Sheridan	3666	Anderson-Dietz 1 and 2 Coals	312		8/2/2011	65.48	3600.5	Monthly	
123795	WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	Big Horn	3549	Anderson Coal	115		9/29/2010	61.26	3488.1	Monthly	
123796	WR-17A	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3574	Anderson-Dietz 1 and 2 Overburden	88		9/28/2011	44.11	3529.8	Monthly	
123797	WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	Big Horn	3520	Anderson Coal	140		9/29/2010	94.41	3425.9	Monthly	
123798	WRN-11	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3437	Anderson-Dietz 1 Clinker and Coal	50		9/28/2011	23.28	3413.5	Monthly	
127605	WR-54	-106.8902	45.1470	09S	39E	25		Big Horn	3630	Anderson and Dietz Coal	384	20	9/28/2011	209.67	3420.2	Monthly	
130475	WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	Big Horn	3552	Dietz Coal	154	20.0	9/29/2010	67.60	3484.5	Monthly	
130476	WR-31	-106.9863	45.0163	09S	39E	29	CBAA	Big Horn	3895	Anderson Coal	316	2.0	8/29/2011	181.36	3713.8	Monthly	
132716	WR-48	-106.9650	44.9933	37N	63E	23	BBCB	Sheridan	3694	Anderson Coal	167		8/2/2011	39.98	3653.8	Monthly	
132903	WR-58A	-106.9123	45.0403	09S	39E	14	DDBD	Big Horn	3631	Alluvium	24	8.0	9/28/2011	14.03	3617.3	Monthly	
132907	WR-53	-106.8880	45.0125	09S	39E	25		Big Horn	3607	Anderson and Dietz Coal	384	20.0	9/28/2011	187.60	3419.5	Monthly	
132908	WR-30	-106.9874	45.0165	09S	39E	29	CBAB	Big Horn	3895	Dietz 1 and Dietz Coals Combined	428	5.0	9/28/2011	199.85	3694.8	Monthly	
132909	WR-34	-106.9702	45.0015	09S	39E	33	CBBB	Big Horn	3772	Anderson-Dietz 1 and 2 Coals	522		9/28/2011	149.51	3622.6	Monthly	
132910	WRE-02	-106.7756	45.0712	09S	40E	1	DBCC	Big Horn	3457	Alluvium	79		9/29/2010	38.96	3417.8	Monthly	
132958	WRE-21	-106.7730	45.0386	09S	40E	24	ABAB	Big Horn	3529	Anderson Coal	130		9/29/2010	84.04	3445.4	Monthly	
132959	WRE-17	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3562	Anderson-Dietz 1 and 2 Overburden	250		9/28/2011	63.89	3498.0	Monthly	
132960	WR-52C	-106.8629	45.0164	09S	40E	29	CABC	Big Horn	3530	Alluvium	62	20.0	9/28/2011	18.58	3511.4	Monthly	
132961	WR-52D	-106.8616	45.0164	09S	40E	29	CABD	Big Horn	3529	Alluvium	40	1.0	9/28/2011	22.53	3506.8	Monthly	
132973	PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	Big Horn	3458	Dietz 2 Coal	282	5.0	9/28/2011	142.26	3315.7	Monthly	
144969	Pipeline Well 7(PL-1W) LOHOF	-106.3074	45.2354	07S	44E	14	ABD	Rosebud	3850	Tongue River Formation	225	15.0	7/28/2011	140.76	3709.2	Quarterly	
157879	5072B	-106.4904	45.7393	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal	109	2.0	8/17/2011	33.53	3126.5	Quarterly	
157882	5072C	-106.4905	45.7394	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal Overburden	106	0.3	8/17/2011	27.32	3132.7	Quarterly	
157883	5080B	-106.5126	45.7199	01S	42E	26	DCBA	Rosebud	3260	Knobloch Coal	89	1.3	8/17/2011	41.27	3218.7	Quarterly	
157884	5080C	-106.5126	45.7200	01S	42E	26	DCBA	Rosebud	3260	Knobloch Overburden	110	0.3	8/17/2011	35.11	3224.9	Quarterly	
161749	BF-01	-106.9667	44.9897	58N	84W	22	ACCC	Sheridan	3680	Coal Mine Spoils Bank	125		1/18/2011	30.22	3649.8	Monthly	
166351	PKS-3204	-106.8299	45.1067	08S	40E	28	ADA	Big Horn	3500	Anderson-Dietz1 Coalbed	82		9/28/2011	73.18	3426.8	Monthly	
166358	PKS-3203	-106.8302	45.1068	08S	40E	28	ADA	Big Horn	3500	Canyon Coal	201		9/28/2011	115.32	3384.7	Monthly	
166359	PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	Big Horn	3438	Alluvium	60	5.0	9/29/2010	39.24	3398.8	Monthly	
166362	PKS-3201	-106.7971	45.0437	09S	40E	14	CAA	Big Horn	3438	Canyon Coal	390	50.0	9/29/2010	96.66	3341.3	Monthly	
166370	PKS-3200	-106.7969	45.0440	09S	40E	14	CAA	Big Horn	3438	Dietz 2 Coal	242	20.0	9/29/2010	172.76	3265.2	Monthly	
166388	PKS-3199	-106.7966	45.0443	09S	40E	14	CAA	Big Horn	3439	Dietz Coal	165	20.0	9/29/2010	114.16	3324.8	Monthly	
166389	PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	Big Horn	3440	Anderson Coal	112		9/29/2010	86.16	3353.8	Monthly	
166761	WR-29R	-106.8153	45.0465	09S	40E	15	ACCD	Big Horn	3461	Anderson-Dietz 1 Clinker and Coal	72		9/28/2011	44.74	3416.3	Monthly	
183559	Nance IP-11 Bridge	-106.4549	45.4114	05S	43E	8	BCDC	Rosebud	3085	Tongue River Formation	540		10/10/2011	-15.25	3100.3	Quarterly	
183560	Nance Properties INC	-106.4205	45.4387	05S	43E	4	AAAB	Rosebud	3035	Alluvium	20		10/10/2011	9.92	3025.1	Quarterly	
183563	Fulton George	-105.8709	45.0637	09S	48E	8	CABC	Powder River	3360	Alluvium	30	1.0	10/10/2011	15.89	3344.1	Quarterly	

Appendix A. Site details, water-level data, and 2012 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2012 SWL monitoring	2012 QW sample collection
183564	Whitetail Ranger Station	-105.9758	45.6404	02S	47E	19	CDCA	Powder River	4045	Fort Union Formation	60		10/10/2011	40.28	4004.7	Quarterly	
183565	Skinner Gulch Pipeline Well	-105.9171	45.4275	05S	47E	3	BCCD	Powder River	3730	Tongue River Formation	167		10/10/2011	47.97	3682.0	Quarterly	
184222	SH-624	-107.0917	45.0725	09S	38E	7	DADB	Big Horn	4645	Anderson-Dietz1 Coalbed	435		8/2/2011	348.23	4296.5	Quarterly	
184223	SH-625	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Dietz Coal	186		8/2/2011	45.36	4141.2	Quarterly	
184224	SH-625A	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Anderson Coal	91		8/2/2011	52.28	4134.4	Quarterly	
184225	SH-634	-107.0728	45.1422	08S	38E	17	DADD	Big Horn	4481	Dietz Coal	348	12.0	8/2/2011	149.80	4330.7	Semi-Annual	
184226	SH-634A	-107.0883	45.1422	08S	38E	17	DADD	Big Horn	4481	Anderson Coal	159		8/2/2011	114.81	4366.4	Semi-Annual	
186195	WR-41	-106.9498	44.9950	09S	39E	34	CCCC	Big Horn	3643	Alluvium	40	1.0	8/2/2011	17.42	3625.3	Monthly	
189743	HWC-29A	-106.3974	45.0697	09S	44W	7	BBCC	Big Horn	3619		98		8/3/2011	43.77	3575.2	Monthly	
189802	HWC-37	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3578	Alluvium	32		8/3/2011	9.44	3568.6	Monthly	
189838	HWC-39	-106.4004	45.0713	09S	43E	12	ADBD	Big Horn	3591	Alluvium	39		8/2/2011	25.49	3565.5	Monthly	
190902	HWC-10	-106.4695	45.0444	09S	43E	21	BADA	Big Horn	3610	Dietz Coal	229		9/29/2011	98.71	3516.3	Monthly	
190904	HWC-11 TR-77	-106.4696	45.0444	09S	43E	21	BADA	Big Horn	3615	Anderson Coal	135	8.0	9/29/2011	51.94	3558.1	Monthly	
191139	20-LW	-106.7801	45.3391	06S	40E	1	CDDC	Big Horn	3940	Wall Coal	253	0.2	7/27/2011	83.23	3856.8	Quarterly	
191155	22-BA	-106.6954	45.3484	06S	41E	3	BADD	Rosebud	3530	Brewster-Arnold Coal	262	0.4	7/27/2011	104.96	3425.0	Quarterly	
191163	28-W	-106.7292	45.3211	06S	41E	16	BBCC	Rosebud	3715	Wall Coal	144	1.3	7/27/2011	108.17	3606.8	Quarterly	
191169	32-LW	-106.7098	45.2955	06S	41E	21	DDDC	Rosebud	3530	Wall Coal	51	0.2	7/27/2011	37.06	3492.9	Quarterly	
191634	75-23	-106.2011	45.0966	08S	45E	34	BDBC	Powder River	3780	Canyon Coal	247		9/29/2011	132.27	3647.7	Monthly	
192874	YA-109	-107.0312	45.0407	09S	38E	22	DADC	Big Horn	3830	Alluvium	44		9/28/2011	31.26	3798.7	Monthly	
198465	HWC-6	-106.4093	45.0536	09S	43E	13	CAAA	Big Horn	3595	Dietz Coal	152		9/28/2011	68.68	3526.3	Monthly	
198489	HWC 86-15	-106.4235	45.0025	10S	43E	2	AABC	Big Horn	3630	Alluvium	63	30.0	9/29/2011	13.64	3616.4	Monthly	Semi-Annual
203646	CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3980	Knobloch Coal	417	0.5	9/28/2011	172.60	3807.7	Monthly	
203655	CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3984	Brewster-Arnold Coal	256	5.0	9/28/2011	100.74	3883.1	Monthly	
203658	CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3982	Local Coals	366	2.0	9/28/2011	143.31	3838.5	Monthly	
203669	CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	Big Horn	3792	Carney Coal	290	10.0	9/28/2011	75.03	3717.0	Monthly	
203670	CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	Big Horn	3890	Roland Coal	159	1.0	9/28/2011	131.19	3758.8	Monthly	
203676	CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	Big Horn	3920	Canyon Coal	376	0.3	9/28/2011	301.79	3618.2	Monthly	
203678	CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	Big Horn	3920	Dietz Coal	235	0.1	9/28/2011	185.81	3734.2	Monthly	
203680	CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	Big Horn	3500	Wall Coal	291	0.2	10/18/2011	180.93	3319.1	Monthly	
203681	CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	Rosebud	3500	Wall Coal Overburden	221	5.0	10/18/2011	76.43	3423.6	Monthly	
203690	CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	Big Horn	3500	Canyon Underburden	97	30.0	10/18/2011	33.93	3466.1	Monthly	
203693	CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	Big Horn	3900	Canyon Coal	263	1.5	9/28/2011	164.14	3735.9	Monthly	
203695	CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	Big Horn	3900	Canyon Overburden	190	5.0	9/28/2011	89.76	3810.2	Monthly	
203697	CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	Rosebud	3262	Knobloch Coal	208	1.0	7/27/2011	157.98	3104.3	Quarterly	
203699	CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	Rosebud	3262	Knobloch Underburden	224	10.0	1/19/2011	160.00	3102.2	Quarterly	
203700	CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Overburden	446	0.3	7/27/2011	102.58	3157.9	Quarterly	
203701	CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Coal	480	0.5	7/27/2011	102.14	3158.5	Quarterly	
203703	CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson Coal	560	0.3	9/28/2011	531.31	3598.7	Monthly	
203704	CBM03-10SS	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson-Dietz 1 and 2 Overburden	462	1.0	9/28/2011	372.52	3757.5	Monthly	
203705	CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	Big Horn	3950	Anderson Coal	211	1.0	9/30/2011	155.20	3794.8	Monthly	
203707	CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	Big Horn	3950	Dietz Coal	271	0.2	9/30/2011	227.94	3722.1	Monthly	
203708	CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	Big Horn	3950	Canyon Coal	438	1.5	9/30/2011	382.42	3567.6	Monthly	
203709	CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	Powder River	3715	Cook Coal	351	3.0	9/29/2011	166.24	3548.8	Monthly	
203710	CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	Powder River	3931	Otter Coal	500	1.5	9/29/2011	335.29	3595.7	Monthly	
205082	Spring Creek Pipeline Well	-105.9538	45.3883	05S	47E	20	ACAC	Powder River	3630	Tongue River Formation	50		7/26/2011	14.65	3615.4	Quarterly	

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207064	RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	Big Horn	3855	Alluvium	27		9/28/2011	11.40	3843.3	Monthly	
207066	RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	Alluvium	17		9/28/2011	8.18	3841.2	Monthly	Semi-Annual
207068	RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	Big Horn	3860	Alluvium	25		9/28/2011	10.07	3849.8	Monthly	
207075	YA-114	-107.0543	45.0461	09S	38E	21	ADBD	Big Horn	4000	Alluvium			8/2/2011	11.78	3988.2	Quarterly	
207076	YA-105	-107.0527	45.0465	09S	38E	21	ACAC	Big Horn	4015	Alluvium			8/2/2011	10.71	4004.3	Quarterly	
207080	TA-100	-107.0090	45.0479	09S	38E	23	BBCC	Big Horn	3900	Alluvium			9/28/2011	13.22	3886.8	Quarterly	
207081	TA-101	-107.0090	45.0482	09S	38E	24	BBCC	Big Horn	3910	Alluvium			9/28/2011	15.11	3894.9	Quarterly	
207083	TA-102	-107.0076	45.0486	09S	38E	24	BBCB	Big Horn	3910	Alluvium			9/28/2011	20.43	3889.6	Quarterly	
207096	IB-2	-106.4372	45.3930	05S	43E	21	BBDB	Rosebud	3192	Knobloch Underburdern	245		7/28/2011	119.70	3071.9	Quarterly	
207097	MK-4	-106.4363	45.3919	05S	43E	21	BBDC	Rosebud	3195	Knobloch Coal	188		7/28/2011	119.59	3075.7	Quarterly	
207098	NM-4	-106.4361	45.3916	05S	43E	21	BCAB	Rosebud	3195	Nance Coal	294		7/28/2011	120.16	3075.2	Quarterly	
207099	WL-2	-106.4358	45.3919	05S	43E	21	BBDC	Rosebud	3188	Knobloch Coal	199		7/28/2011	117.41	3070.2	Quarterly	
207101	OC-28	-106.1928	45.4717	04S	45E	21	CCBD	Powder River	3171	Knobloch Coal			7/26/2011	62.20	3108.8	Quarterly	
207143	HC-01	-106.4750	45.1314	08S	43E	21	BBDA	Big Horn	3457	Alluvium	20	17.0	7/28/2011	3466.60	-9.6	Semi-Annual	
210094	WO-14	-106.1849	45.5183	04S	45E	4	BDDB	Powder River	3010		66		9/30/2011	4.13	3005.9	Monthly	
214096	HWCQ-2	-106.5009	45.1913	07S	43E	32	AAAA	Rosebud	3340	Alluvium	19		6/22/2011	10.95	3329.1	Monthly	
214097	HWCQ-1	-106.5005	45.1912	07S	43E	32	AAAA	Rosebud	3340	Alluvium	20		6/22/2011	11.04	3329.0	Monthly	
214354	WA-7	-106.4347	45.3933	05S	43E	21	BABC	Rosebud	3179	Alluvium			7/28/2011	54.04	3125.0	Quarterly	
215085	WO-11	-106.1433	45.3927	05S	45E	23	ABCC	Powder River	3145	Alluvium	39		9/30/2011	8.01	3137.0	Monthly	
219125	SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	Big Horn	3925	Anderson Coal	671		9/29/2011	341.74	3583.3	Monthly	
219136	SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	Big Horn	3725	Alluvium	40	2.0	9/29/2011	13.86	3711.1	Monthly	Semi-Annual
219138	SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	Big Horn	3805	Smith Coal	358	2.0	9/29/2011	165.80	3639.2	Monthly	
219139	SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Anderson Coal	523	2.0	9/29/2011	220.28	3584.7	Monthly	
219140	SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	Big Horn	3805	Canyon Coal	817	0.1	9/29/2011	393.01	3412.0	Monthly	
219141	SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	Big Horn	3640	Smith Coal	120	2.0	10/18/2011	30.14	3609.9	Monthly	
219169	SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	Big Horn	3640	Anderson Coal	279	2.0	9/29/2011	65.21	3574.8	Monthly	
219617	SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Smith Coal Overburden	278	5.0	9/29/2011	145.58	3659.4	Monthly	
219927	SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Anderson Coal	223	1.0	9/29/2011	132.87	3677.1	Monthly	
219929	SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Dietz Coal	322	0.7	9/29/2011	167.59	3642.4	Monthly	
220062	SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	Big Horn	4220	Anderson Coal	492	0.1	9/29/2011	377.76	3842.2	Monthly	
220064	SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	Big Horn	4220	Canyon Coal	685	0.5	6/23/2011	521.62	3698.4	Monthly	
220069	SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	Big Horn	4173	Canyon Coal	515	1.0	4/20/2010	456.32	3716.7	Monthly	
220076	SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	Big Horn	3810	Canyon Coal	431	6.0	9/29/2011	176.02	3634.0	Monthly	
220385	SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	Big Horn	3920	Canyon Coal	1301		9/29/2011	449.96	3470.0	Monthly	
220851	SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	Powder River	3397	Alluvium	19	1.0	9/29/2011	11.40	3385.3	Monthly	
220857	SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	Powder River	3394	Alluvium	14	0.3	9/29/2011	10.04	3384.1	Monthly	Semi-Annual
220859	SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	Powder River	3398	Alluvium	19	1.0	9/29/2011	13.86	3384.6	Monthly	
221592	IP-22	-105.9003	45.0177	09S	47E	25	DDBD	Powder River	3395				1/19/2011	-15.79	3410.79	Monthly	
223236	USGS 452355106333701	-106.5603	45.3986	05S	42E	16	CCAB	Rosebud	3400		376		11/3/2009	261.13	3138.9		
223237	USGS 452408106382201	-106.6397	45.4022	05S	41E	14	BDCD	Rosebud	3510		360		11/3/2009	237.10	3272.9		
223238	USGS 452139106504701	-106.8464	45.3608	05S	40E	31	BDCC	Big Horn	4440		681		6/6/2005	617.65	3822.4		
223240	USGS 452411106301601	-106.5044	45.4030	05S	42E	14	ADDC	Rosebud	3220		420		11/3/2010	105.82	3114.2		
223242	USGS 452416106413001	-106.6917	45.4044	05S	41E	17	ADBD	Rosebud	3740		353		11/3/2009	180.52	3559.5		
223243	USGS 452429106435201	-106.7311	45.4080	05S	40E	13	ADAB	Big Horn	3940		380		11/3/2009	198.73	3741.3		
223687	RBC-4	-106.9863	45.3332	06S	39E	8		Rosebud	3840.95		5.05		9/28/2011	4.58	3836.37		

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223695	Moorhead Campground Well	-105.8773	45.0542	09S	48E	17	BCBB	Powder River	3400	Pawnee			1/19/2011		3400.0	Monthly	
223801	SL-5ALQ	-106.2579	45.0129	09S	45E	31	BBA	Powder River	3810	Alluvium	35		9/29/2011	7.41	3802.6	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		7/26/2011	104.77	3805.2	Quarterly	
223952	WA-2	-106.4621	45.4020	05S	43E	17	BCDD	Rosebud	3069	Alluvium			10/1/2011	9.19	3059.3	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		9/29/2011	18.71	3792.3	Monthly	
228592	Musgrave Bill	-106.7319	45.1639	08S	41E	5	ACDB	Big Horn	3335	Alluvium	22		7/27/2011	13.13	3321.9	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	
251797	GC09-KC	-106.391897	45.437635	05S	43E	2	BAB			Knobloch			3/25/2010			Quarterly	
251798	GC09-FG	-106.391897	45.437635	05S	43E	2	BAB			Flowers-Goodale			3/25/2010			Quarterly	
251799	GC09-TC	-106.391897	45.437635	05S	43E	2	BAB			Terret			3/25/2010			Quarterly	
259683	SL-09BA	45.00678577	-105.81746	09S	48E	34	DAA	Powder River	3640	Brewster-Arnold Coal	291		9/29/2011			Monthly	
259684	SL-09PC	45.00678577	-105.81746	09S	48E	34	DAA	Powder River	3640	Pawnee	169		9/29/2011			Monthly	
259676	SL-09OC	45.00678577	-105.817459	09S	48E	34	DAA	Powder River	3640	Otter Coal	378		9/29/2011			Monthly	

Appendix B

Site details, discharge data, and water year 2012 monitoring plan for 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	2012 planned flow monitoring	2012 planned QW sample collection
197247		Anderson	Regional	3690	1.52	10/17/2011	Monthly	
197452	Coal	Otter	Local	3470	0.85	7/28/2011	Monthly	
197607	Colluvium	Cook	Local	3805	0.98	7/26/2011	Quarterly	
198766		Ferry	Local	3660	1.76	10/10/2011	Quarterly	
199568	Sandstone	Cook	Local	3680	1.11	7/28/2011	Quarterly	
199572	Sandstone	Canyon	Local	3940	1.31	7/26/2011	Quarterly	One time
205004	Clinker	Anderson/Dietz	Local	3890	0.71	7/28/2011	Quarterly	
205010		Canyon	Local	3960	0.79	7/26/2011	Quarterly	One time
205011		Anderson	Local	4050	7.32	7/26/2011	Quarterly	
205041	Sandstone	Canyon	Local	3735	1.41	7/26/2011	Quarterly	
205049	Sandstone	Dietz	Local	3670	0.94	7/28/2011	Monthly	
223687				3841			Monthly	
223877		Otter	Regional & Local	3475		9/26/2008	Monthly	
228591		Dietz	Local	3620	3.18	10/10/2011	Monthly	
228776				3920	0.37	6/22/2011	Monthly	Semi-Annual
240578		Anderson	Regional & Local	3665	0.45	6/22/2011	Monthly	Semi-Annual

Appendix C

Groundwater quality data collected during water year 2011

Appendix C. Groundwater quality data collected in 2010-2011

	Gwic Id	Site Name	Sampled in 2011	Latitude	Longitude	Location (TRS)	County	Site Type	Aquifer	Depth (ft)
Sites outside areas of CBM influence	228591	Three Mile Spring	Semi-annual	45.1690	-106.7958	07S 40E 35 CDDD	Big Horn	Spring	125TGRV	
	207066	Well RBC-2	Semi-annual	45.3327	-106.9844	06S 39E 8 CAAA	Big Horn	Well	110ALVM	16.9
	205049	Chipmunk Spring	Semi-annual	45.212	-106.3611	07S 44E 21 CCBB	Rosebud	Spring	125TGRV	
	205004	HAGEN 2 SPRING	One time	45.345	-106.2688	06S 45E 06 ACDC	Powder River	Spring	Clinker	
	205011	JOE ANDERSON SPRING	One time	45.2715	-105.9547	06S 47E 34 CABA	Powder River	Spring		
	223877	East Fork Hanging Woman Creek Weir	Semi-annual	45.2909	-106.4041	06S 43E 25 ABDD	Rosebud	Stream		
	94661	LISCOM BUTTE WELL	One time	45.77820135	-106.0328561	01S 46E 3 DBAA	POWDER RIVER	Well	125TGRV	135
	7781	WO-2	One time	45.3947	-106.1494	05S 45E 23 BBAA	POWDER RIVER	Well	125LKCB	112
	183559	NANCE IP-11 BRIDGE	One time	45.41139364	-106.4554851	05S 43E 8 CDCB	ROSEBUD	Well	125FGUB	540
Sites within current areas of CBM influence	223952	WA-2	Semi-annual	45.4032	-106.4566	05S 43E 17 BCDD	Rosebud	Well	110ALVM	37.8
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S 43E 19 DDBA	Rosebud	Well	110ALVM	71
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S 43E 2 ABCA	Big Horn	Well	110ALVM	53
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S 43E 2 AABC	Big Horn	Well	110ALVM	62.52
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386	09S 42E 36 BBAD	Big Horn	Well	110ALVM	40
	220851	Well SL-8-1Q	One time	45.0176	-105.8998	09S 47E 25 DDAC	Powder River	Well	110ALVM	19
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09S 47E 25 DCDB	Powder River	Well	110ALVM	13.8
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S 40E 32 ACAD	Big Horn	Well	110ALVM	34
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261	08S 42E 30 ADAA	Big Horn	Spring	125TGRV	
	240578	Lower Anderson Creek Spring	Semi-annual	45.1373	-106.6913	08S 41E 15 ABBB	Big Horn	Spring		
	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319	08S 41E 5 ACDB	Big Horn	Well	111ALVM	21.5

Appendix C. Groundwater quality data collected in 2010-2011

Group	Gwic Id	Comp Date	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)
Sites outside areas of CBM influence	228591		9/14/2010 15:40	306	0.8	12.1	8.4	482	30.8	26	26.2	11.6	0.007	<0.001	20.6	154.2	2.68	102.8
	207066	7/9/2003	9/14/2010 17:30	559	0.9	8.7	8.15	937	65.4	64.3	42.5	8.76	1.24	0.17	26.1	537.8	0	80.79
			6/24/2011 18:03	593	0.8	9.4	7.51	815.4	70.17	67.99	40.59	9.16	0.525	0.229	24.73	604.69	0	76.93
	205049		9/13/2010 14:00	3082	9.8	13.3	7.88	3910	108	169	698	12.7	<0.195	<0.010	13.2	968.7	0	1569
	205004		5/3/2011 12:53	674	1.5	8	7.6	899.9	81.89	66.28	73.57	5.72	<2.00 U	<0.001 U	14.77	529.66	0	159.8
	205011		5/4/2011 15:29	421	0.4	8.5	8.17	579.2	70.63	50.73	18.5	3.91	0.017	0.006	12.28	388.16	0	69.01
	223877		9/13/2010 11:30	1009	2.4	13.6	8.28	1374	95.7	79.5	131	10.7	<0.010	<0.005	22.9	570.5	0	379
	94661	7/11/1946	7/25/2011 13:24	1550	5.7	15	7.27	1866.9	92.4	99.27	331.18	8.54	0.311	0.106	16.63	626.55	0	684.1
	7781	11/6/1979	2/16/2011 11:26	628	41.4	12	8.49	922	2.26	0.503	264	1.51	0.01	0.004	6.21	650.3	16.21	<2.5
	183559	1/1/1947	7/26/2011 9:05	1149	67.7	15.9	8.3	1605	2.56	0.97	501.6	2.4	0.023	<0.005 U	8.1	1235.52	4.29	<2.500 U
Sites within current areas of CBM influence	223952	8/16/1978	9/14/2010 12:02	1823	23.1	11.3	8.22	2900	25.5	27.4	706	7.46	0.094	0.011	10.7	1574	0	211.6
			6/22/2011 16:04	1859	22.4	8.9	7.75	2968.9	27.67	28.45	702.9	6.32	0.011	0.012	10.85	1623.43	0	223.8
	7905		9/13/2010 13:17	3678	8.7	9.6	7.71	4190	167	223	734	21.2	0.448	0.898	20.2	945.7	0	2019
			5/5/2011 18:26	3633	8.5	9.7	7.46	4707.1	158.58	215.9	700.88	22.45	0.509	0.533	20.71	885.64	0	2050
	8888	10/8/1986	9/13/2010 15:50	6407	11.3	10.4	7.78	6840	363	317	1226	11.9	6.29	1.92	13.1	824.2	0	4046
			5/5/2011 16:00	6628	11.7	10.6	7.07	8278	369.6	334.33	1293	14.36	6.732	2.006	12.78	824.81	0	4173
	198489	10/8/1986	9/13/2010 16:55	8412	12.0	11	7.37	8080	516	494	1583	12.9	11.9	2.04	15	888.6	0	5316
			5/5/2011 15:41	8501	11.3	10.6	7.02	9977.8	484.88	482.15	1470.83	14.42	9.015	1.957	12.67	837.39	0	5588
	219136	4/7/2005	9/14/2010 12:05	3411	5.5	9.4	7.61	3840	281	212	499	6.21	1.86	0.528	9.12	479.2	0	2151
			5/5/2011 12:40	3850	5.4	9.4	7.17	4692.2	312.68	248.28	526.53	3.07	2.28	0.428	8.74	455.97	0	2508
	220851	8/26/2005	9/14/2010 17:00	3044	5.1	12.1	7.37	3640	305	157	441	11.2	1.21	1.2	17.5	537.3	0	1726
	220857	8/26/2005	9/14/2010 18:00	3092	4.9	13.2	7.52	3720	380	110	425	8.46	0.572	1.16	20.3	571.4	0	1639
			5/4/2011 18:06	2273	4.1	8.5	7.32	2126.7	293.33	88.39	314.84	5.96	0.004	0.197	15.66	411.72	0	1196
	122766	8/31/1977	9/14/2010 8:43	5972	6.3	12	7.7	6150	269	557	788	31	7.05	0.926	21.5	719.8	0	3916
			5/5/2011 10:40	5893	6.3	8.6	7.28	6757.3	249.6	555.6	783.12	28.72	5.901	0.555	18.04	683.61	0	3888
	228776		9/14/2010 9:45	3727	9.8	16.3	7.55	4670	144	231	817	11.8	1.42	0.093	9.21	854.5	0	2068
			6/22/2011 19:13	5425	6.0	11.8	7.26	7125.5	286.03	548	748.82	12.24	0.219	0.085	8.72	681.73	0	3443
	240578		9/14/2010 10:30	1532	3.2		7.58	2100	109	132	211	10.6	<0.098	<0.005	16.3	632	0	726.3
			6/22/2011 18:40	1746	3.1	15	7.08	1865	134.55	161.4	227.63	9.48	0.043	0.3600 J	16.38	575.93	0	898.2
	228592		9/14/2010 10:06	838	1.4	13.4	7.78	1164	105	68.2	77.5	4.7	0.074	0.034	19.6	489	0	307.1
			7/27/2011 14:34	1426	1.6	12.8	7.37	1806	181.73	123.58	115.9	5.46	0.016	0.011	19.24	504.68	0	628.3

Appendix C. Groundwater quality data collected in 2010-2011

	Gwic Id	Cl (mg/l)	NO3-N (mg/l)	F (mg/l)	OPO4-P (mg/l)	Ag (ug/l)	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)
Sites outside areas of CBM influence	228591	7.09	0.802	0.88	<0.1	<0.2	3.58	6.55	121	62.2	<0.2	91	0.257	<0.2	2.08	0.931	73.7
	207066	3.51	0.052	0.623	<0.1	<0.2	9.78	2.29	119	75	<0.2	72	<0.2	<0.2	<0.2	<0.5	48.4
		3.22	<0.05 U	0.54	<0.10 U	<0.50 U	0.7590 J	1.87	102.81	82.95	<0.50 U	<50.00 U	<0.50 U	0.2700 J	<0.50 U	<0.50 U	42.8
	205049	29.66	0.479	1.42	<0.5	<2.0	<20.0	<1.8	316	18.2	<2.0	276	<2.0	<1.8	<2.0	<5.0	156
	205004	8.25	0.15	0.78	<0.10 U	<0.50 U	9.32	0.1400 J	97.76	35.59	<0.50 U	93	<0.50 U	<0.50 U	<0.50 U	0.1500 J	52.79
	205011	3.68	<0.05 U	0.33	<0.10 U	<0.50 U	12.9	0.2100 J	23.57	215.31	<0.50 U	<50.00 U	0.4800 J	<0.50 U	0.2300 J	0.54	20.63
	223877	6.83	<0.05	1.09	<0.1	<1.0	<10.0	<0.9	219	68.1	<1.0	75	<1.0	<0.9	<1.0	<2.5	59.2
	94661	5.71	0.19	0.52	<0.100 U	<2.500 U	25.15	0.880 J	423.06	15.05	<2.500 U	<50.000 U	<2.500 U	1.800 J	<2.500 U	0.760 J	53.91
	7781	14.98	<0.05	2.27	<0.1	<0.2	4.06	<0.2	96.1	104	<0.2	131	<0.2	<0.2	<0.2	<0.5	16.5
	183559	14.63	<0.050 U	5.54	<0.100 U	<2.500 U	<10.000 U	<2.500 U	332.03	206.88	<2.500 U	98	<2.500 U	<2.500 U	<2.500 U	<2.500 U	20.37
Sites within current areas of CBM influence	223952	55.22	<0.25	2.53	<0.5	<1.0	<10.0	<0.9	270	25.7	<1.0	391	<1.0	<0.9	<1.0	<2.5	71.5
		56.21	<0.05 U	2.27	<0.10 U	<2.50 U	<10.00 U	0.6400 J	283.24	25.62	<2.50 U	250	<2.50 U	<2.50 U	0.5300 J	2.74	91.81
	7905	23.59	<0.25	1.09	<0.5	<2.0	<20.0	<1.8	287	27.3	<2.0	<250	<2.5	<1.8	<2.0	<5.0	105
		23.94	0.12	1.07	<0.10 U	<5.00 U	<20.00 U	<5.00 U	254.89	11.28	<5.00 U	185	<5.00 U	<5.00 U	<5.00 U	<5.00 U	82.66
	8888	10.73	<0.25	0.566	<0.5	<2.0	<20.0	3.39	172	8.12	<2.0	<250	<2.0	2.52	<2.0	<5.0	152
		10.81	<0.05 U	0.37	<0.10 U	<5.00 U	<20.00 U	<5.00 U	146.03	3.4700 J	<5.00 U	<50.00 U	<5.00 U	<5.00 U	<5.00 U	<5.00 U	117.4
	198489	16.39	<0.25	0.507	<0.5	<2.0	<20.0	2.99	198	6.52	<2.0	<250	<2.0	2.19	<2.0	<5.0	150
		16.87	<0.05 U	0.29	<0.10 U	<5.00 U	0.422	1.34	209.17	3.1	<5.00 U	<50.00 U	<5.00 U	1.25	<1.0 U	1.85	197.75
	219136	9.18	<0.25	0.348	<0.5	<1.0	<10.0	<0.9	77.5	7.12	<1.0	<250	<1.0	<0.9	<1.0	<2.5	112
		10.31	0.08	0.22	<0.10 U	<5.00 U	<20.00 U	<5.00 U	43.97	3.5500 J	<5.00 U	87	<5.00 U	<5.00 U	<5.00 U	<5.00 U	86.1
	220851	115.7	0.76	0.456	<0.5	<1.0	<10.0	2.06	137	23.8	<1.0	<250	<1.0	3.57	<1.0	<2.5	51.3
	220857	222.3	<0.25	0.477	<0.5	<1.0	<10.0	2.77	127	26	<1.0	395	<1.0	1.64	<1.0	<2.5	37.6
		154	0.06	0.26	<0.10 U	<0.50 U	29.55	0.2400 J	82.89	7.84	<0.50 U	181	<0.50 U	0.1900 J	<0.50 U	0.1900 J	19.49
	122766	20.93	<0.25	0.655	<0.5	<2.0	<20.0	3.63	251	15.3	<2.0	<250	<2.0	<1.8	<2.0	<5.0	239
		20.58	0.27	0.48	<0.10 U	<5.00 U	<20.00 U	1.1000 J	176.5	6.11	<5.00 U	<50.00 U	<5.00 U	<5.00 U	<5.00 U	2.8400 J	173.71
	228776	18.27	0.508	0.512	<0.5	<2.0	<20.0	<1.8	117	8.01	<2.0	<250	11	<1.8	<2.0	<5.0	338
		33.96	1.74	0.3	<0.50 U	<5.00 U	<5.00 U	1.3800 J	109.36	16.44	<5.00 U	<250.00 U	<5.00 U	<5.00 U	<5.00 U	<5.00 U	280.22
	240578	11.92	0.191	0.751	<0.1	<1.0	<10.0	<0.9	224	18.6	<1.0	117	2.41	<0.9	<1.0	<2.5	166
		11.32	0.06	0.63	<0.10 U	<2.50 U	48.24	<2.50 U	253.51	21.9	<2.50 U	71	<2.50 U	<2.50 U	<2.50 U	0.8300 J	186.47
	228592	13.82	0.109	0.308	<0.1	<1.0	<10.0	<0.9	90.8	44.4	<1.0	<50	<1.0	<0.9	<1.0	12.9	15.9
		98.52	3.82	0.34	<0.020 U	<0.250 U	52.7	0.470 J	82.27	70.41	<0.250 U	<10.000 U	<0.250 U	<0.250 U	0.280 J	14.54	21.37

Appendix C. Groundwater quality data collected in 2010-2011

	Gwic Id	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)	V (ug/l)	Zn (ug/l)	Zr (ug/l)	Ce (ug/l)	Cs (ug/l)
Sites outside areas of CBM influence	228591	5.25	4.01	<0.2	<0.2	3.3	<0.2	797	1.02	<0.2	3.28	30.2	2.06	<0.2	<0.2	<0.5
	207066	2.12	0.655	<0.2	<0.2	<0.2	<0.2	1027	0.989	<0.2	0.696	0.251	1.42	<0.2	<0.2	<0.5
		2.58	0.66	<0.20 U	<0.50 U	<0.50 U	<0.50 U	1070.69	1.21	<0.50 U	0.72	0.54	<0.50 U	<0.50 U	<0.50 U	<0.50 U
	205049	<2.0	<1.8	<2.0	<2.0	<1.8	<2.0	3030	10.3	<2.0	7.18	<2.0	<10.0	<1.8	<2.0	<5.0
	205004	1.02	0.4900 J	<0.20 U	<0.50 U	1.1	<0.50 U	1619.99	1.27	<0.50 U	3.95	0.2600 J	2.41	<0.50 U	<0.50 U	<0.50 U
	205011	0.78	0.52	0.22	<0.50 U	<0.50 U	<0.50 U	649.58	0.63	<0.50 U	0.83	<0.50 U	245.02	1.53	<0.50 U	<0.50 U
	223877	3.09	<0.9	<1.0	<1.0	1.72	<1.0	1330	4.71	<1.0	6.48	1.59	<5.0	<0.9	<1.0	<2.5
	94661	0.780 J	3.98	<1.000 U	<2.500 U	1.870 J	<2.500 U	1579.79	8.86	<2.500 U	13.3	<2.500 U	414.41	<2.500 U	<2.500 U	<2.500 U
	7781	0.653	<0.2	<0.2	<0.2	0.324	<0.5	121	<0.2	<0.2	<0.2	<0.2	0.519	0.197	<0.2	<0.5
	183559	<2.500 U	<2.500 U	<1.000 U	<2.500 U	<2.500 U	<2.500 U	222.6	<2.500 U	<2.500 U	<2.500 U	<2.500 U	1.100 J	0.540 J	<2.500 U	<2.500 U
Sites within current areas of CBM influence	223952	<1.0	<0.9	<1.0	<1.0	1.1	<1.0	1552	2.34	<1.0	<1.0	<1.0	<5.0	<0.9	<1.0	<2.5
		<2.50 U	<2.50 U	0.3000 J	<2.50 U	0.6400 J	<2.50 U	1577.71	2.0500 J	<2.50 U	<2.50 U	<2.50 U	1.4100 J	<2.50 U	<2.50 U	<2.50 U
	7905	7.33	2.08	<2.0	<2.0	<1.8	<2.0	2567	12.1	<2.0	10.9	<2.0	10.6	<1.8	<2.0	<5.0
		6.17	<5.00 U	<2.00 U	<5.00 U	<5.00 U	<5.00 U	2459.21	15.11	<5.00 U	11.81	<5.00 U	2.9400 J	<5.00 U	<5.00 U	<5.00 U
	8888	<2.0	2.31	<2.0	<2.0	2.98	<2.0	5302	22.9	<2.0	14.5	<2.0	19.8	<1.8	<2.0	<5.0
		<5.00 U	1.4600 J	<2.00 U	<5.00 U	<5.00 U	<5.00 U	5430.32	30.95	<5.00 U	17.48	<5.00 U	4.4400 J	<5.00 U	<5.00 U	<5.00 U
	198489	<2.0	3.55	<2.0	<2.0	<1.8	<2.0	7272	61.2	<2.0	38.1	<2.0	<10.0	<1.8	<2.0	<5.0
		0.63	3.32	<5.00 U	<5.00 U	<5.00 U	0.21	7284.66	42.76	<5.00 U	34.22	<5.00 U	5.17	<5.00 U	<5.00 U	<5.00 U
	219136	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	4682	20.1	<1.0	2.48	<1.0	<5.0	<0.9	<1.0	<2.5
		<5.00 U	<5.00 U	<2.00 U	<5.00 U	<5.00 U	<5.00 U	5275.39	19.12	<5.00 U	2.9900 J	<5.00 U	3.4000 J	<5.00 U	<5.00 U	<5.00 U
	220851	3	1.95	<1.0	<1.0	5.23	<1.0	2417	10.3	<1.0	20.3	<1.0	<5.0	<0.9	<1.0	<2.5
	220857	3.8	<0.9	<1.0	<1.0	2.17	<1.0	3029	10.9	<1.0	20.3	1.23	10.2	<0.9	<1.0	<2.5
		1.04	0.65	<0.20 U	<0.50 U	0.3400 J	0.1600 J	1912.49	8.75	<0.50 U	15.17	0.3000 J	6.17	<0.50 U	<0.50 U	<0.50 U
	122766	4.37	<1.8	<2.0	<2.0	<1.8	<2.0	5393	37.3	<2.0	27	<2.0	11	<1.8	<2.0	<5.0
		3.7700 J	<5.00 U	<2.00 U	<5.00 U	<5.00 U	<5.00 U	5124.61	30.21	<5.00 U	25.41	<5.00 U	6.3100 J	<5.00 U	<5.00 U	<5.00 U
	228776	<2.0	152	<2.0	<2.0	<1.8	<2.0	4469	26.4	<2.0	<2.0	<2.0	<10.0	<1.8	<2.0	<5.0
		<5.00 U	1.3600 J	<2.00 U	<5.00 U	55.24	<5.00 U	6522.46	65.84	1.2500 J	19.38	<5.00 U	<5.00 U	<5.00 U	<5.00 U	<5.00 U
	240578	<1.0	23.6	<1.0	<1.0	<0.9	<1.0	2580	4.55	<1.0	<1.0	1.2	7	<0.9	<1.0	<2.5
		<2.50 U	1.2000 J	<1.00 U	<2.50 U	<2.50 U	<2.50 U	3011.07	14.27	<2.50 U	<2.50 U	1.0400 J	1.4300 J	<2.50 U	<2.50 U	<2.50 U
	228592	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	579	3.66	<1.0	8.67	<1.0	15.2	<0.9	<1.0	<2.5
		0.900 J	0.970 J	0.81	<0.250 U	0.970 J	<0.250 U	1003.42	7.23	<0.250 U	13.56	0.580 J	10.65	<0.250 U	<0.250 U	<0.250 U

Appendix C. Groundwater quality data collected in 2010-2011

	Gwic Id	Ga (ug/l)	La (ug/l)	Nb (ug/l)	Nd (ug/l)	Pd (ug/l)	Pr (ug/l)	Rb (ug/l)	Th (ug/l)	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Total N as N (mg/l)	Dissolved Inorganic Carbon (mg/l)
Sites outside areas of CBM influence	228591	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	11.1	<0.2	0.349	<0.05	0.821P	1.06P	
	207066	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	11.5	<0.2	<0.2	<0.05	<0.2P	<1.0P	
		<0.50 U	<0.50 U	<0.50 U	<0.50 U	0.62	<0.50 U	13.11	<0.50 U	<0.50 U	<0.05 U	0.48	1.01	
	205049	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	10.9	<2.0	<2.0	<0.25	0.407P	<1.0P	
	205004	<0.50 U	<0.50 U	<0.50 U	<0.50 U	0.72	<0.50 U	3.08	<0.50 U	<0.50 U	<0.05 U	<0.20 U	<1.00 U	
	205011	<0.50 U	<0.50 U	<0.50 U	<0.50 U	0.4500 J	<0.50 U	0.69	0.1200 J	<0.50 U	<0.05 U	<0.20 U	<1.00 U	
	223877	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	7.37	<1.0	<1.0	<0.05	<0.2P	<1.0P	
	94661	<2.500 U	<2.500 U	<2.500 U	<2.500 U	<2.500 U	<2.500 U	3.99	<2.500 U	<2.500 U	<0.050 U	0.54	<1.000 U	
	7781	<0.2	<0.2	<0.5	<0.2	<0.5	<0.2	1.53	<0.2	<0.2	<0.05	<0.2P	<1.0P	87.4
	183559	<2.500 U	<2.500 U	<2.500 U	<2.500 U	<2.500 U	<2.500 U	2.83	<2.500 U	<2.500 U	<0.050 U	<0.200 U	<1.000 U	
Sites within current areas of CBM influence	223952	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	6.04	<1.0	<1.0	<0.25			
		<2.50 U	<2.50 U	<2.50 U	<2.50 U	<2.50 U	<2.50 U	7.37	<2.50 U	<2.50 U	<0.05 U	<0.25 U	2.23	
	7905	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	15.6	<2.0	<2.0	<0.25	<0.2P	<1.0P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	<5.00 U	<5.00 U	15.17	<5.00 U	<5.00 U	<0.05 U	<0.20 U	<1.00 U	
	8888	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	6.87	<2.0	<2.0	<0.25	<0.2P	2.95P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	1.3200 J	<5.00 U	6.56	<5.00 U	<5.00 U	<0.05 U	<0.00 U	2.38	
	198489	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	<5.0	<2.0	<2.0	<0.25	<0.2P	2.19P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	3.3	<5.00 U	6.15	<5.00 U	<5.00 U	<0.05 U	<0.20 U	1.65	
	219136	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	3.39	<1.0	<1.0	<0.25	<0.2P	1.75P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	1.2600 J	<5.00 U	3.0700 J	<5.00 U	<5.00 U	<0.05 U	<0.20 U	1.56	
	220851	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	4.54	<1.0	<1.0	<0.25	0.743P	1.78P	
	220857	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	3.59	<1.0	<1.0	<0.25	<0.2P	<1.0P	
		<0.50 U	<0.50 U	<0.50 U	<0.50 U	0.54	<0.50 U	1.76	<0.50 U	<0.50 U	<0.05 U	<0.20 U	<1.00 U	
	122766	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	35.1	<2.0	<2.0	<0.25	<0.2P	<1.0P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	2.4200 J	<5.00 U	25.49	<5.00 U	<5.00 U	<0.05 U	<0.20 U	<1.00 U	
	228776	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0	8.07	<2.0	<2.0	<0.25	0.37P	6.23P	
		<5.00 U	<5.00 U	<5.00 U	<5.00 U	3.3800 J	<5.00 U	5.9	<5.00 U	<5.00 U	<0.25 U	0.89	5.64	
	240578	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	7.94	<1.0	<1.0	<0.05	0.297P	<1.0P	
		<2.50 U	<2.50 U	<2.50 U	<2.50 U	0.9100 J	<2.50 U	7.43	<2.50 U	<2.50 U	<0.05 U	0.4	<1.00 U	
	228592	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0	5.42	<1.0	<1.0	<0.05			
		<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	6.5	<0.250 U	<0.250 U	0.08	5.03	5.3	

Appendix D

Geology and hydrogeology of the Tongue River Member of the Fort Union Formation

Appendix D

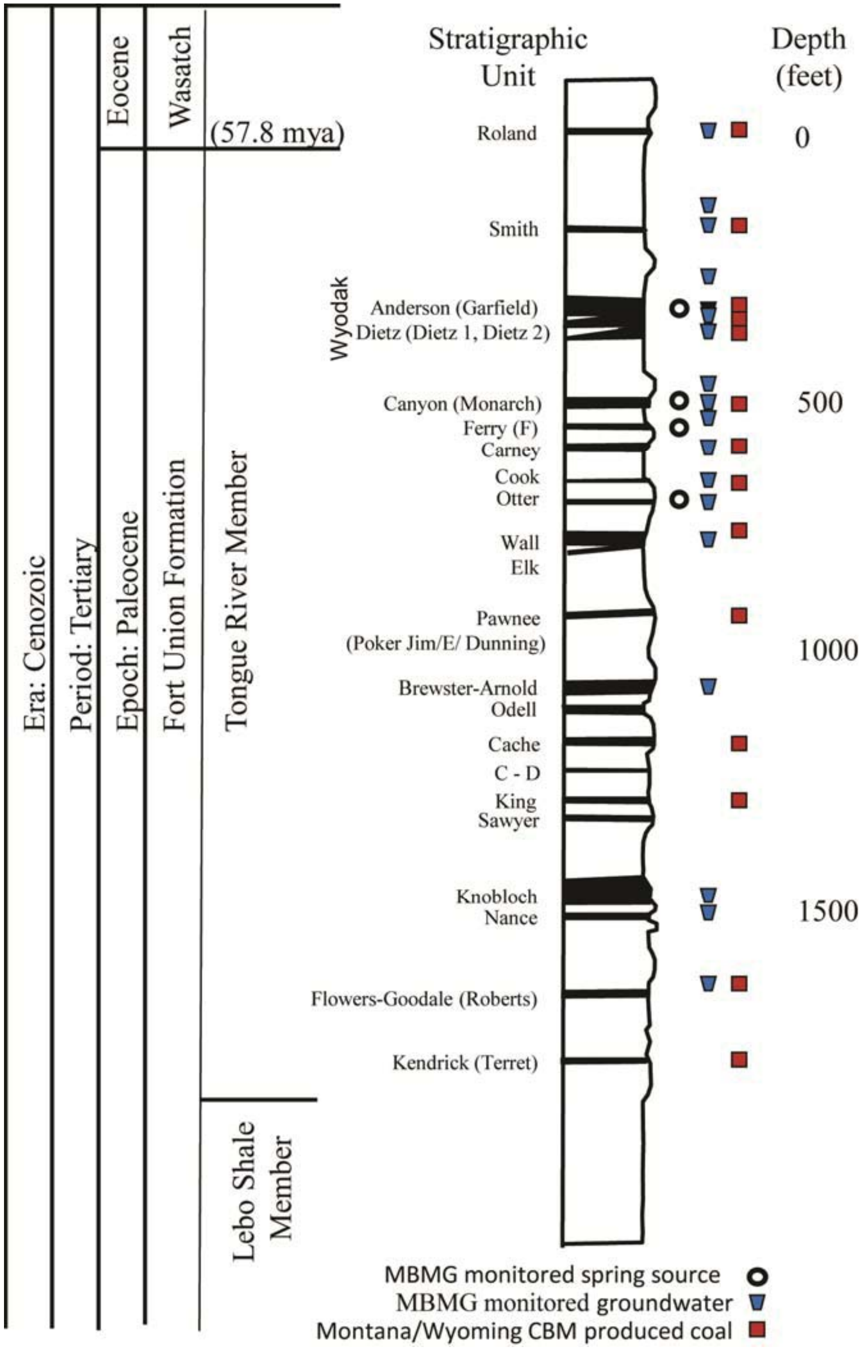
Geology and Hydrogeology of the Tongue River Member of the Fort Union Formation

The axis of the Powder River Basin 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. Generally, the zones between and including the Anderson and Knobloch coals are considered the most likely prospects for CBM in southeastern Montana (Van Voast and Thale, 2001).

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. In terms of coalbed-methane development, the Lebo Shale effectively limits the potential for impacts from reduced hydrostatic pressure and management of produced water to only those units lying stratigraphically above this aquitard.

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 are generally confined aquifers that 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^{-}.

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, is at higher elevations, or is at the base of clinker zones on ridges, the spring is assumed to be local in origin. Springs located low on hillsides or along the floors of major valleys such as Otter Creek may represent regional flow systems or a combination of local and regional recharge. A survey of springs within the northern PRB showed that most springs probably obtain their water from local flow systems (Wheaton and others, 2008).



This stratigraphic column represents the relative stratigraphic positions of the major coalbeds in the Powder River Basin. Not all coal beds shown are present across the entire basin. 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).

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
Pawnee					
Brewster-Arnold					Brewster-Arnold
Cache (Odell)					
King	King			King	King
Knobloch	Knobloch	Knobloch	Knobloch	Knobloch	Knobloch
Flowers-Goodale	Flowers-Goodale			Roberts	Flowers-Goodale

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

Water 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

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 from an individual well, only the most recent sample was chosen for inclusion in the statistical analysis. Summary statistics for individual coals are presented in the adjoining table. The number of samples from individual coals ranged from 1 to 26 (parenthetical numbers next to the coal name). 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 of 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 coal is not a source of CBM. Low sulfate concentrations in coalbed water indicate reducing conditions and can be an important tool for CBM exploration (Van Voast, 2003).

Appendix E

Hydrographs from wells outside of current CBM impacts

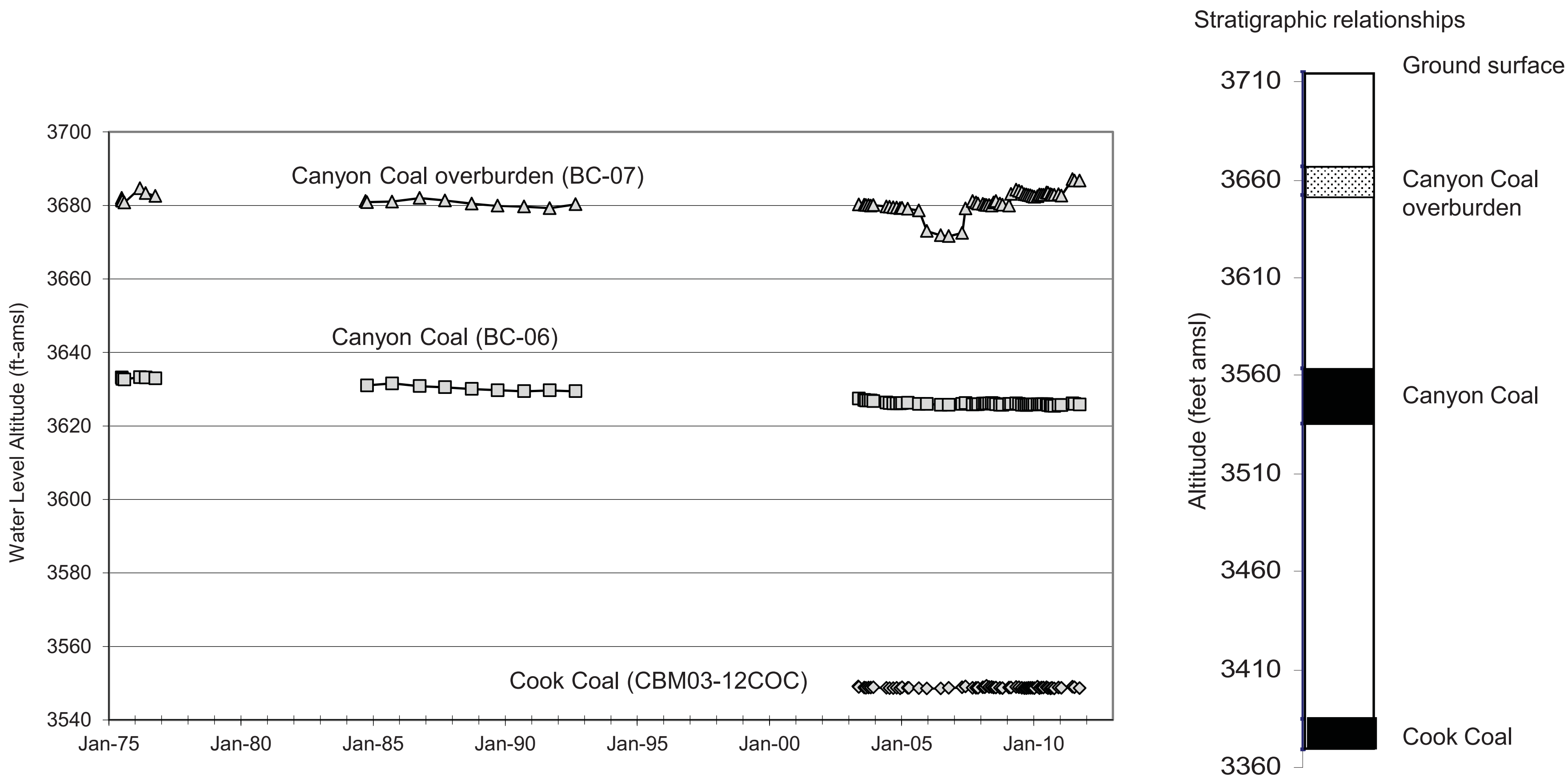


Figure E-1. Monitoring site CBM03-12 has been measured since 1974. There is a downward gradient at this site. The long-term decrease in water levels in the overburden sandstone (BC-07) and Canyon coal (BC-06), began long before the introduction of CBM and likely relate to long-term precipitation patterns (Figure 2). The 8 years of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence.

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

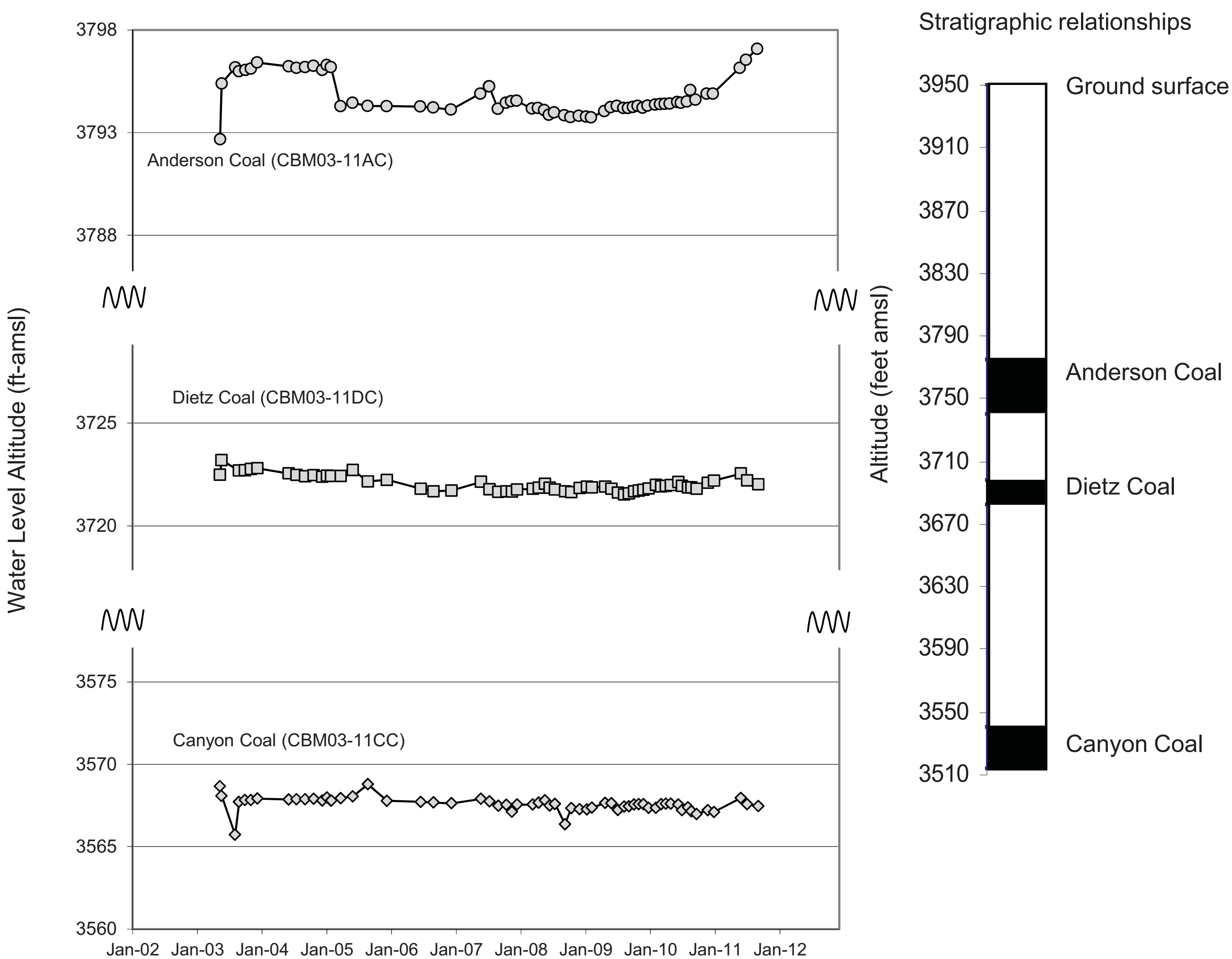


Figure E-2 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site. This site is near the Anderson coal outcrop.

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

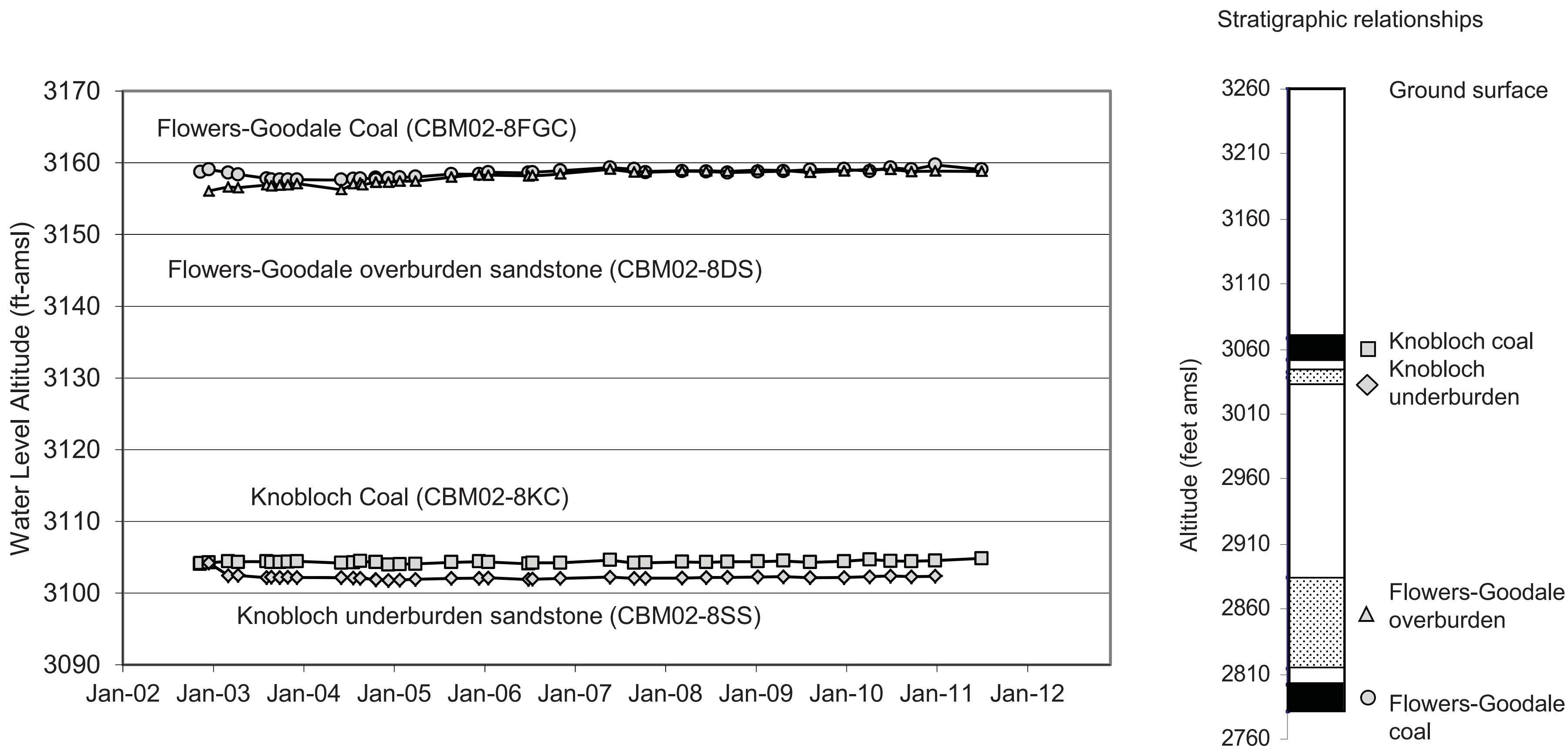


Figure E-3. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. The hydrostatic pressure in the Knobloch coal have been reduced by natural discharge to nearby outcrops. This upward gradient suggests that this is a discharge area for the Flowers-Goodale coal. 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 CBM02-8DS is completed in the "D" channel sandstone overlying the Flowers-Goodale coal. This channel sand has been identified as a possible location for injecting CBM produced water (Lopez and Heath, 2007). Yield from this well, measured during drilling, is approximately 35 gpm.

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

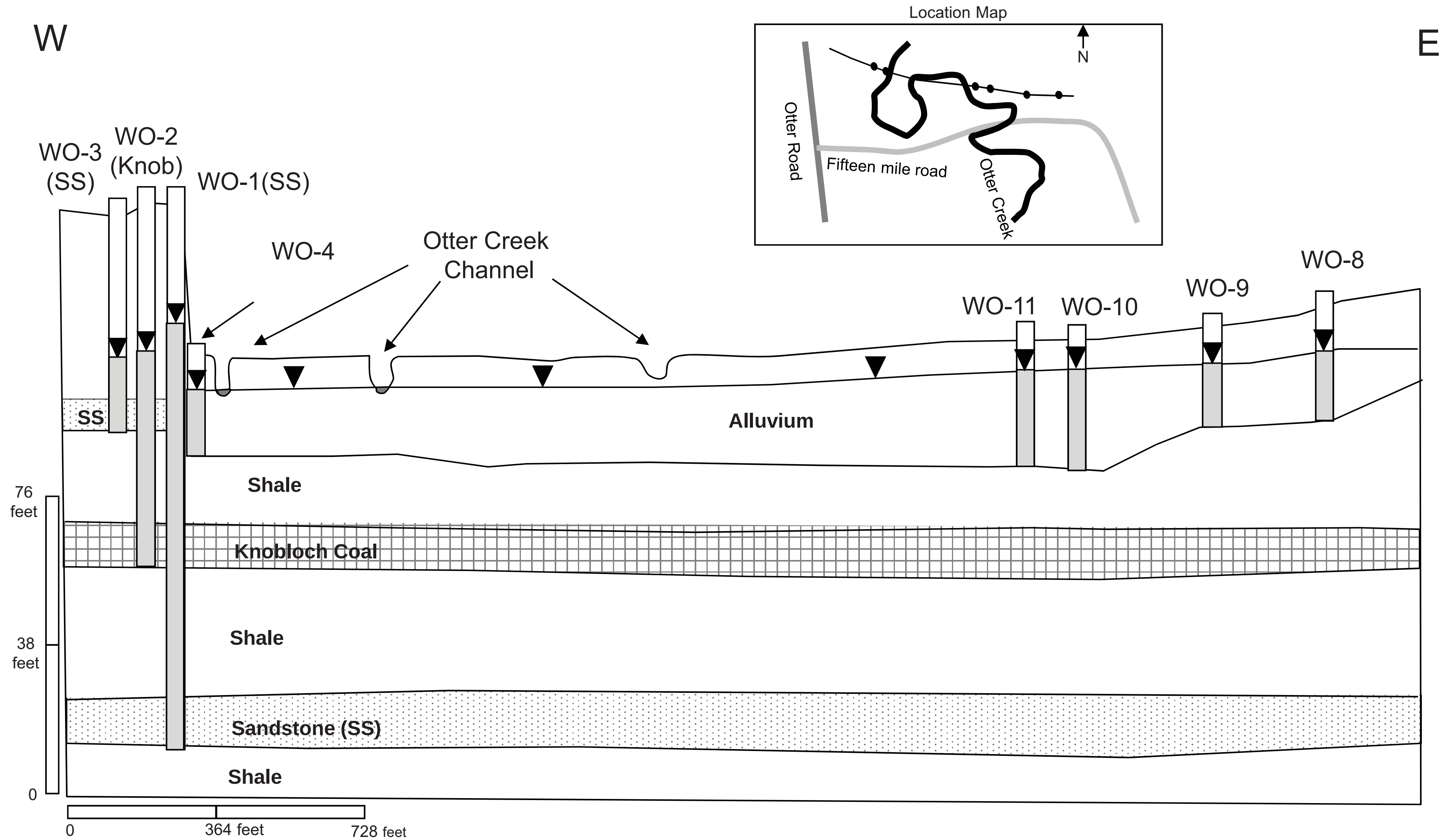


Figure E-4. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in July, 2011. Vertical exaggeration is 9.6:1. Hydrographs for these wells are presented in Figures 4 and E-5.

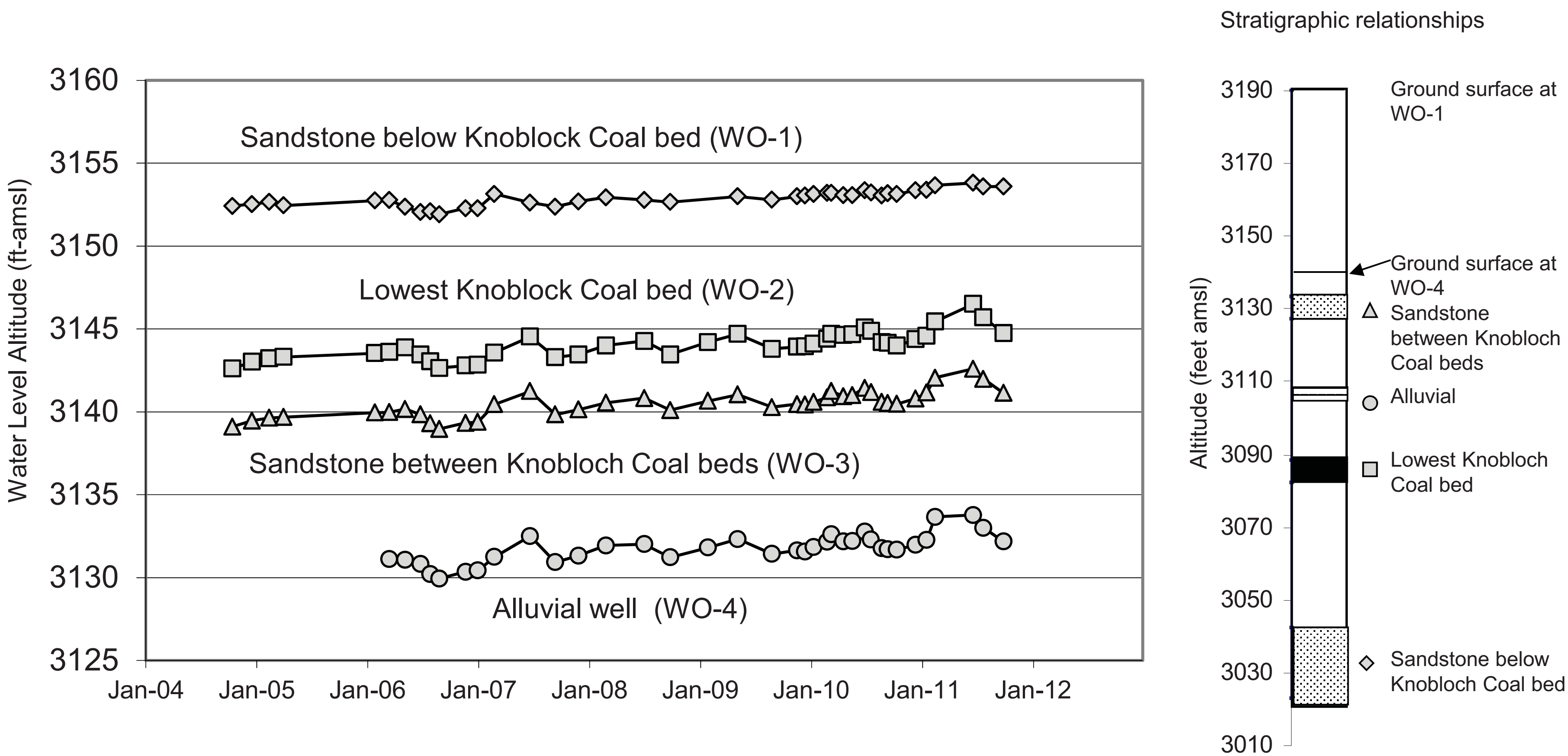


Figure E-5. At monitoring site WO, bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. This upward gradient indicates that the bedrock aquifer will discharge into the alluvium where the two units are in contact. The alluvial well appears to show the general seasonal water year cycle.

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

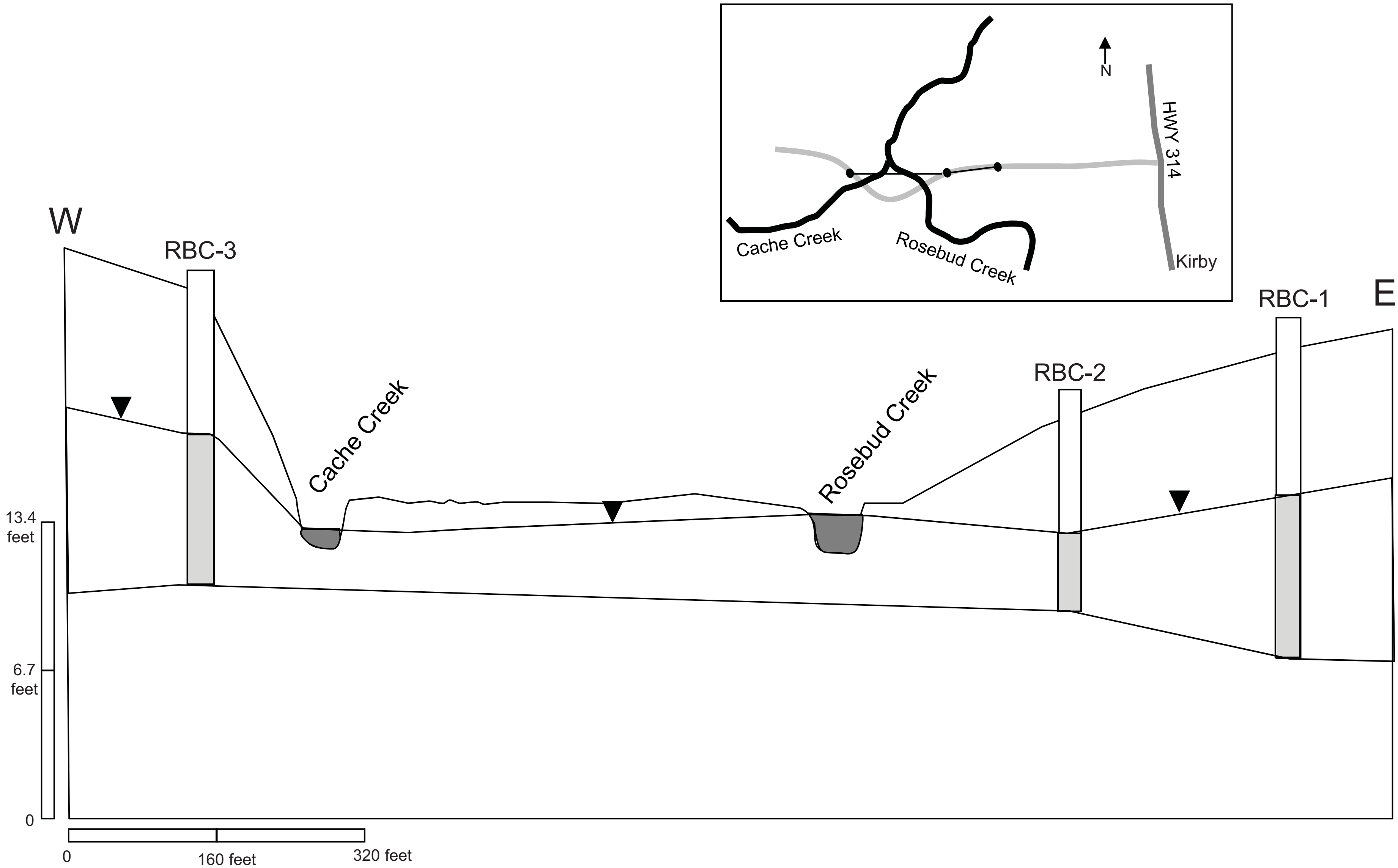


Figure E-6. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water depending on the groundwater elevation. 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 September 2011. Vertical exaggeration is 23.9:1. Hydrographs associated with this site are shown in Figure 5.

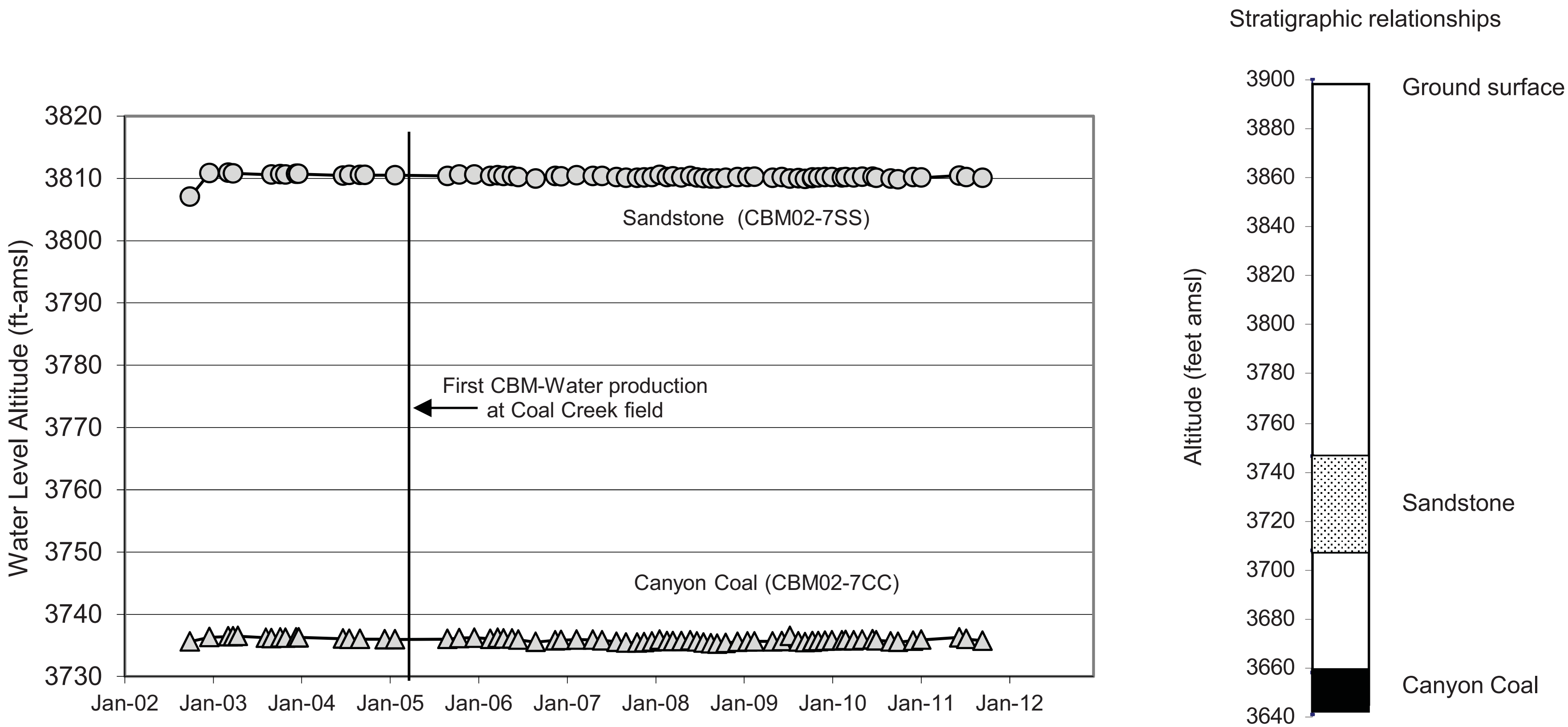


Figure E-7. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

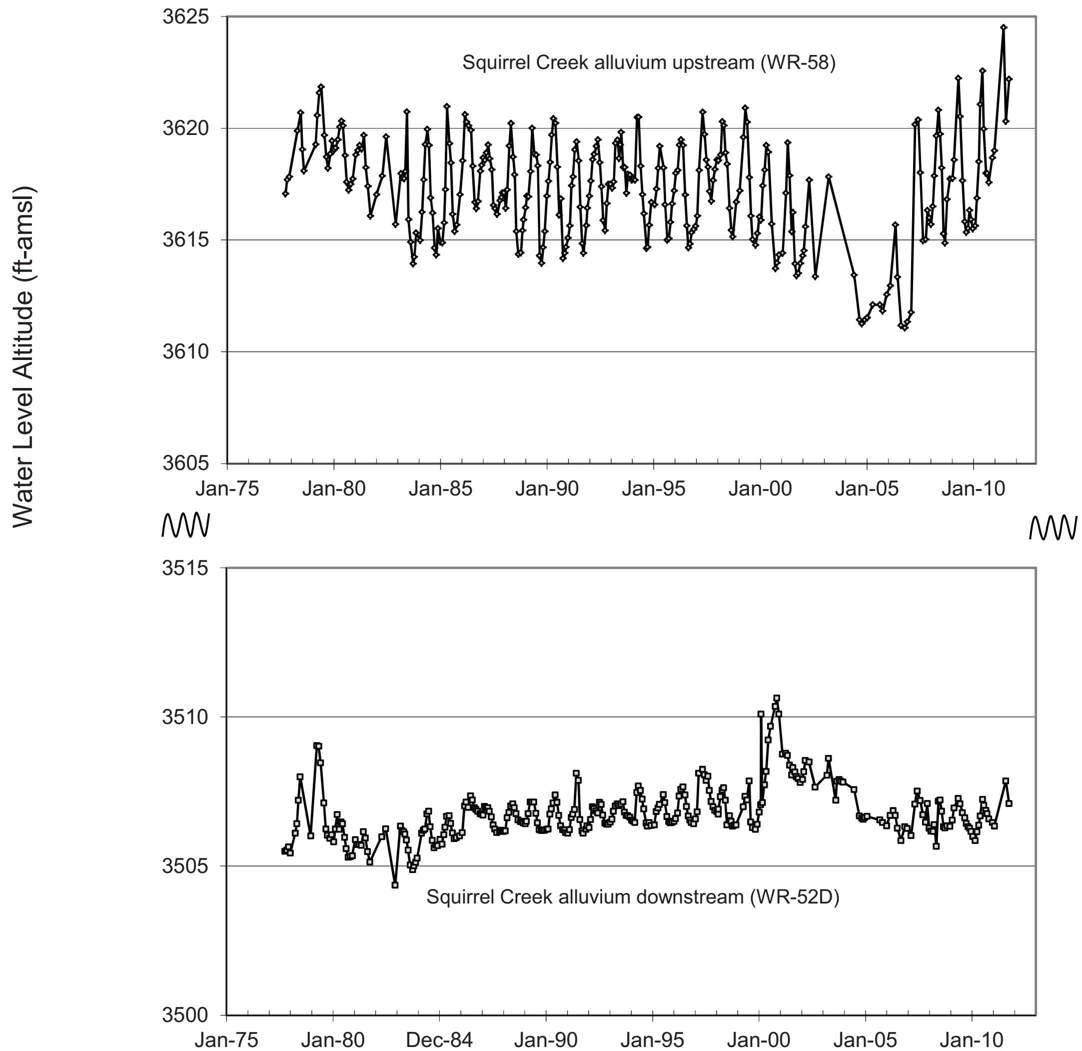
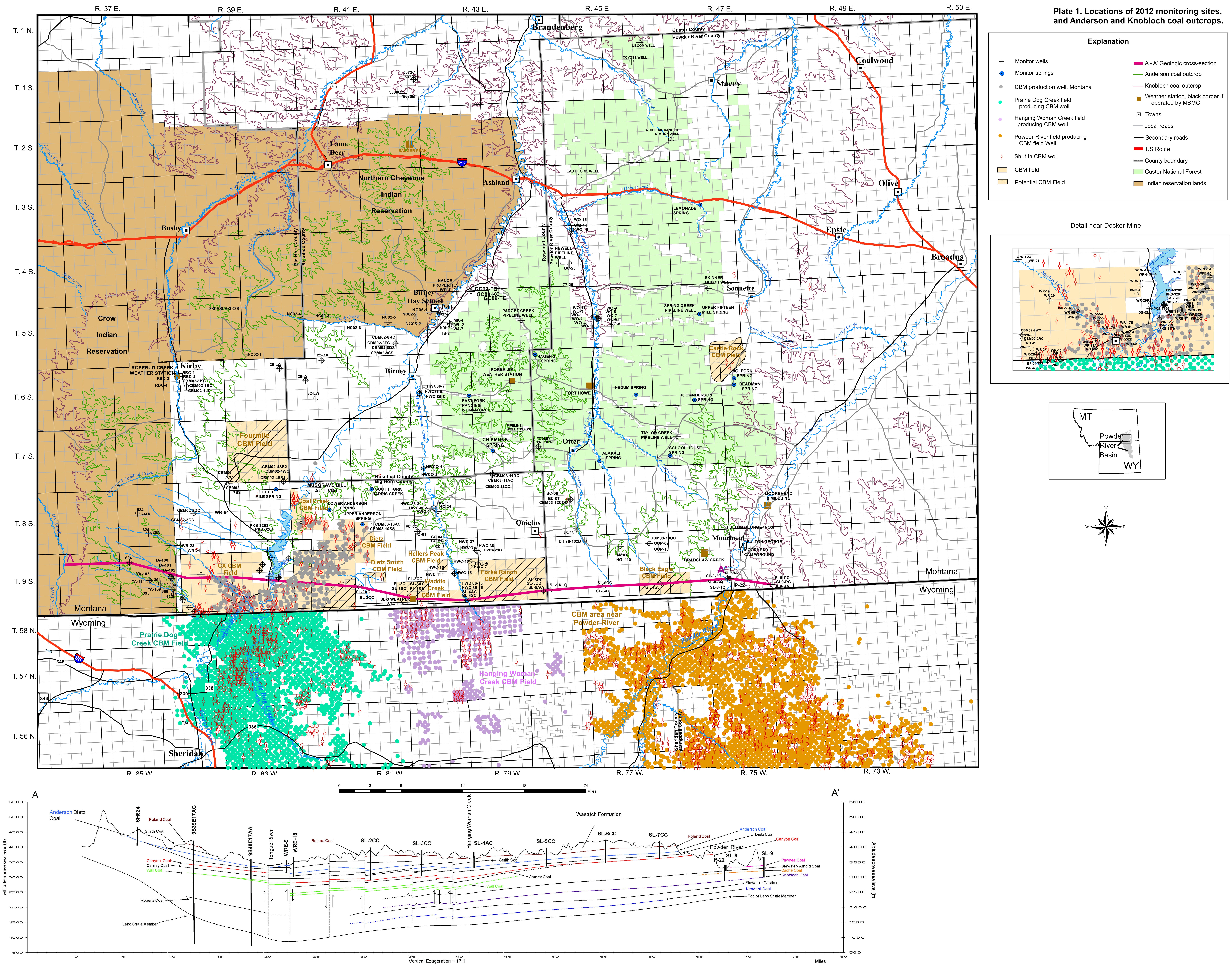


Figure E-8. These alluvial wells are within the area influenced by CBM production; however, they no longer show impacts from the nearby infiltration pond. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production 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. The water levels are now indistinguishable from pre-CBM levels (WR-52D).

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

Plate 1. Locations of 2012 monitoring sites, and Anderson and Knobloch coal outcrops.



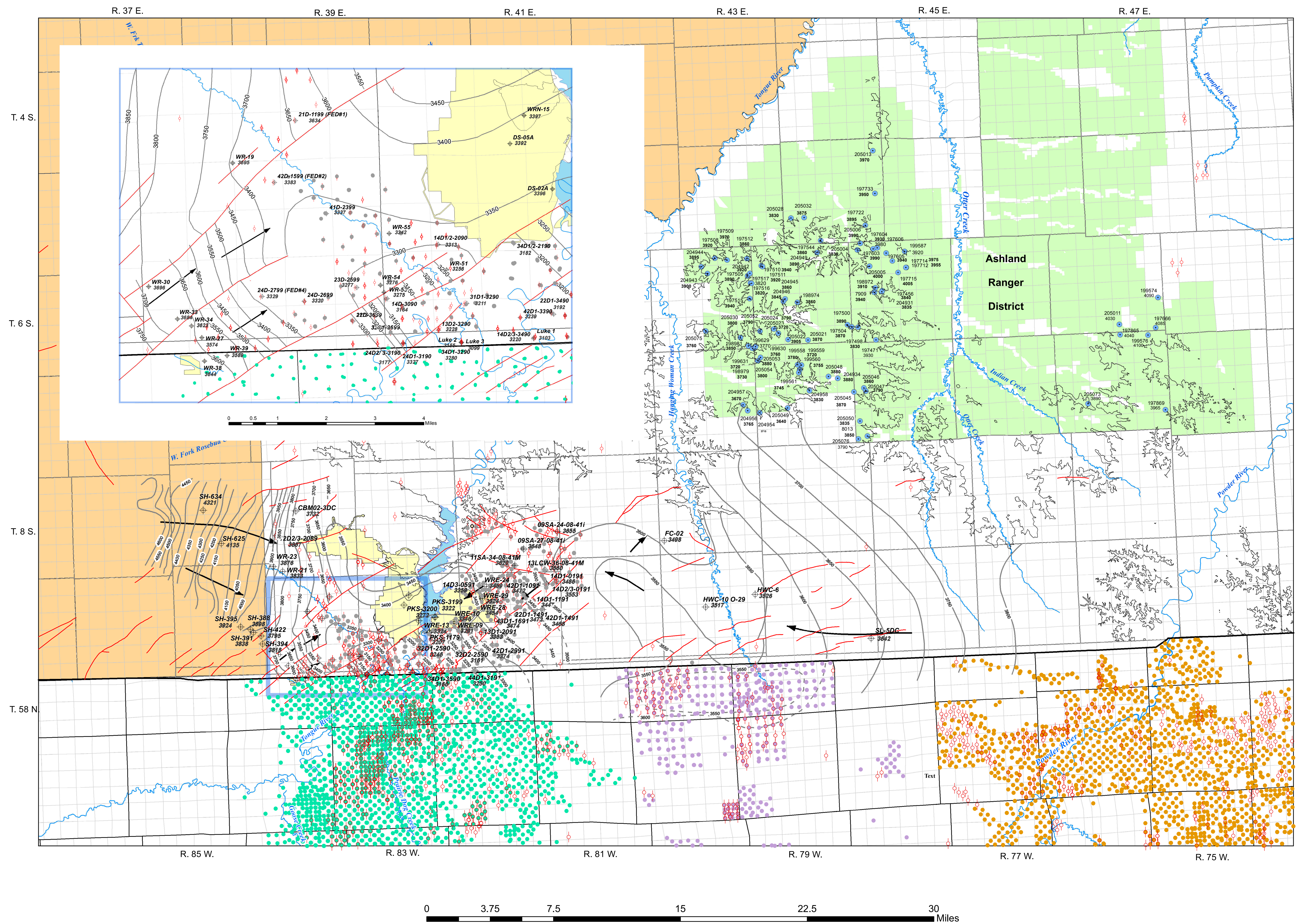
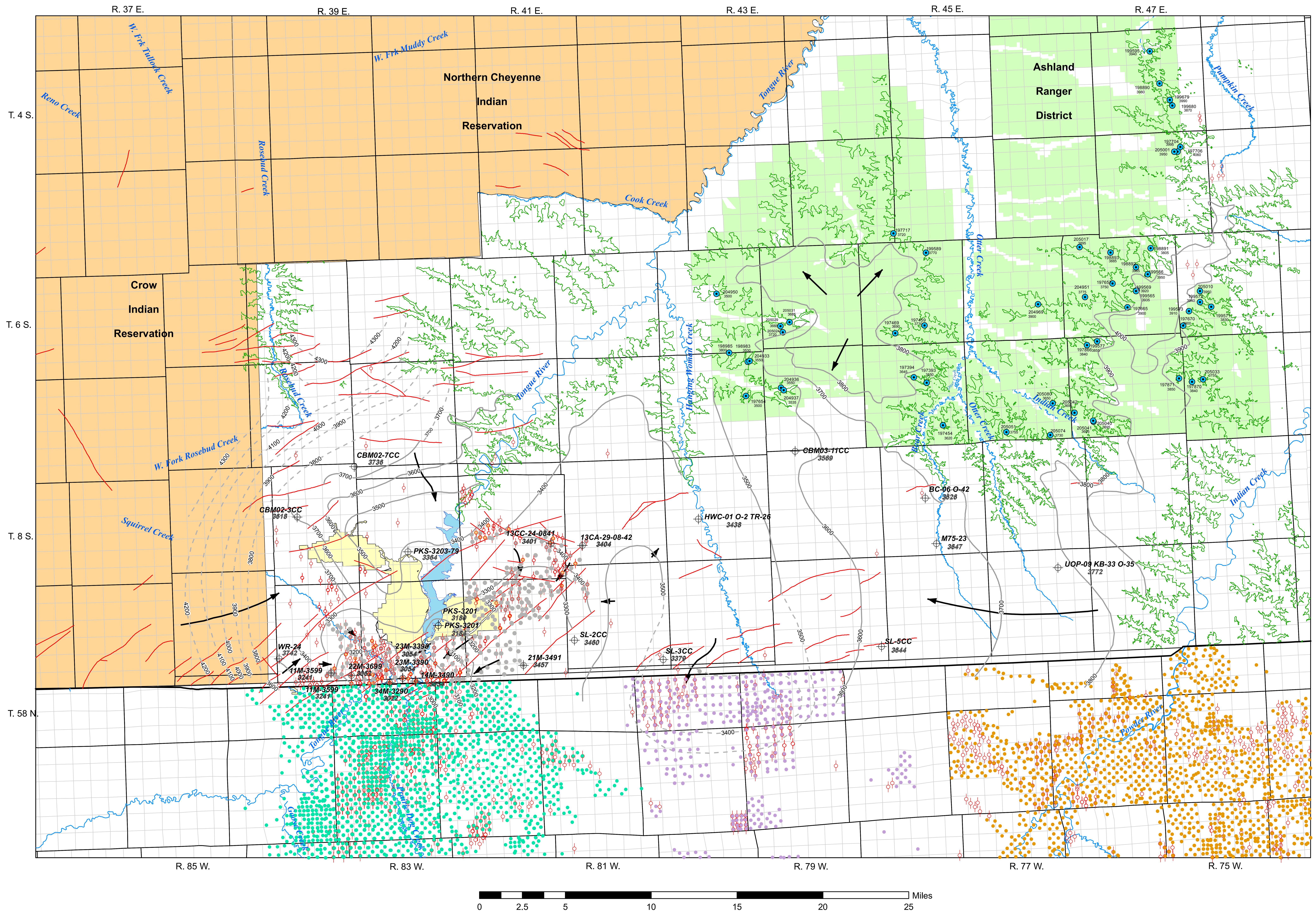


Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2011.

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 2011. (D1-Dietz 1, D2-Dietz 2)
- 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 2011.
- CBM production well was listed as shut-in at the end of water year 2011.
- 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

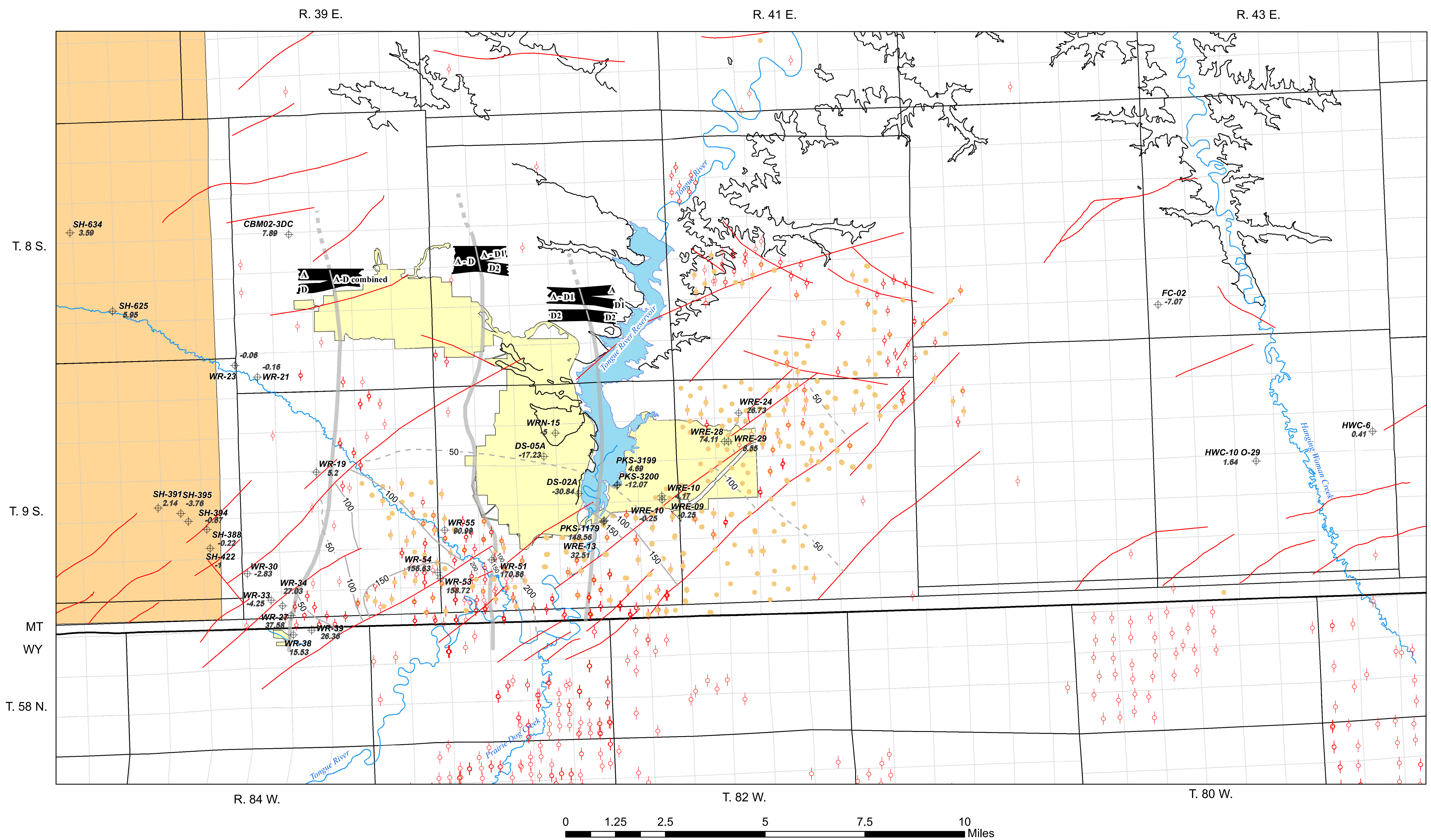
Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2011.

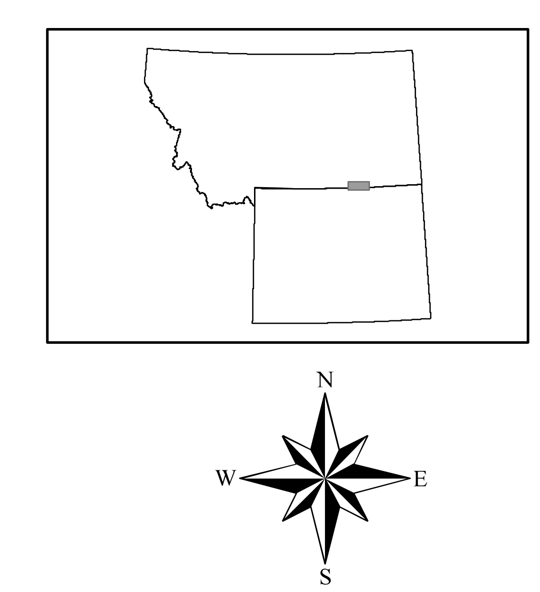


Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, water year 2011), 100-ft contour intervals
- Approximate direction of ground-water flow
- WR-24 3742 — Monitor well name, water-level altitude (ft) for last data in water year 2011.
- 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 2011.
- CBM production well was listed as shut-in at the end at the end of water year 2011.
- 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 2011





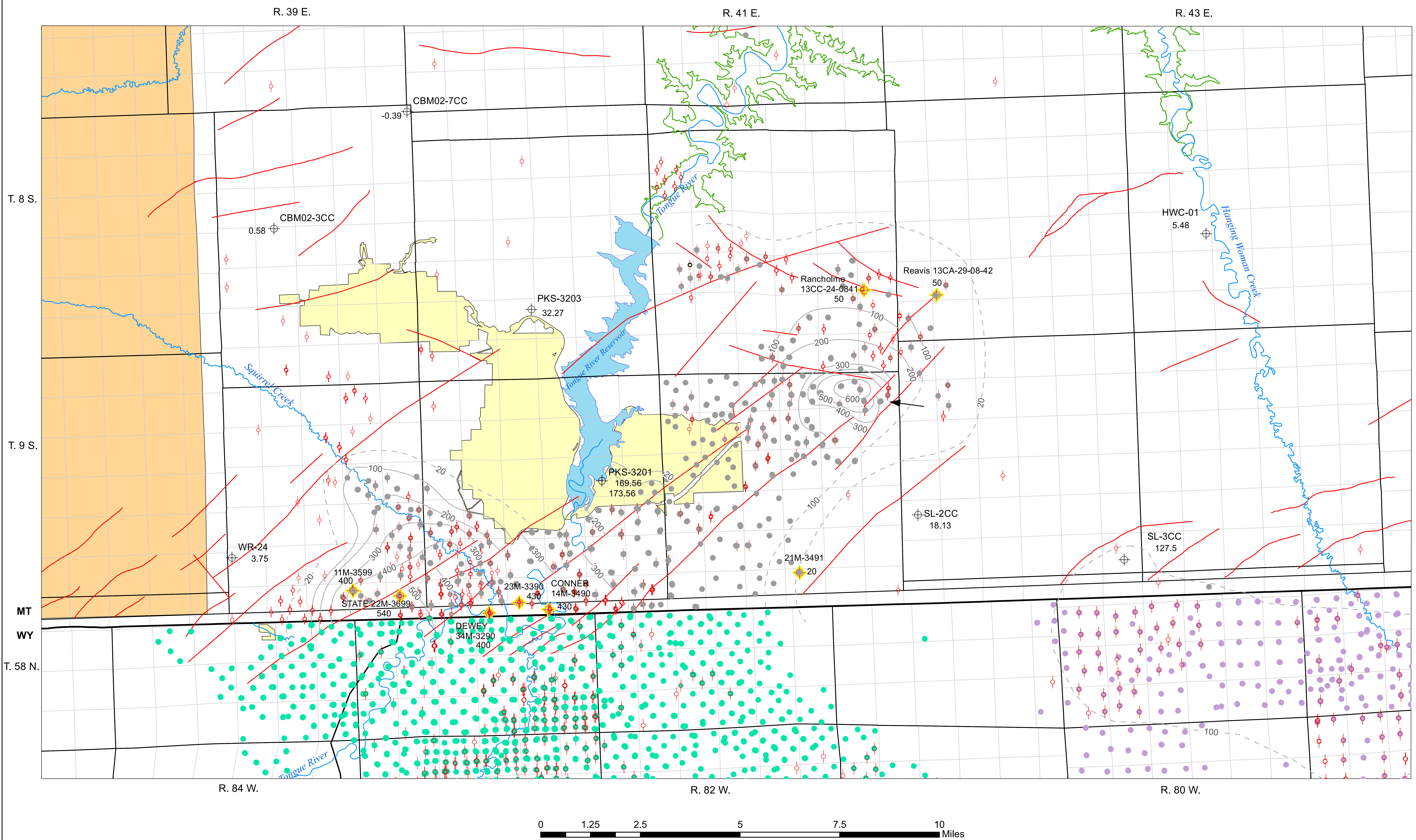
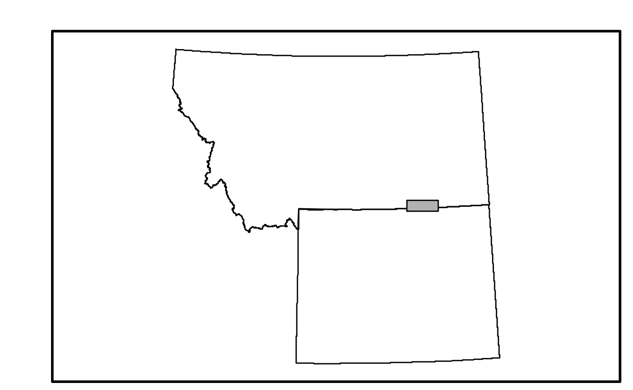
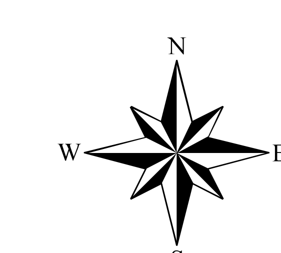


Plate 5. Area of CBM-related potentiometric decline for the Canyon coal in the southern portion of the Powder River Basin, Montana

Explanation

- Potentiometric decline: dashed where inferred, 100-ft contour intervals, 20-ft line also shown.
- WR-24 3.75 — Monitor well name, change in water-level (ft) for last data in water year 2011.
- 11M-3599 400 — Monitor well name, change in water-level (ft) for last data in water year 2011 Industry drawdown based on estimated baseline potentiometric surface.
- 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 2011.
- CBM production well was listed as shut-in at the end of water year 2011.
- Prairie Dog Creek field CBM well
- Hanging Woman Creek field CBM well
- Powder River field CBM well
- Indian Reservation land

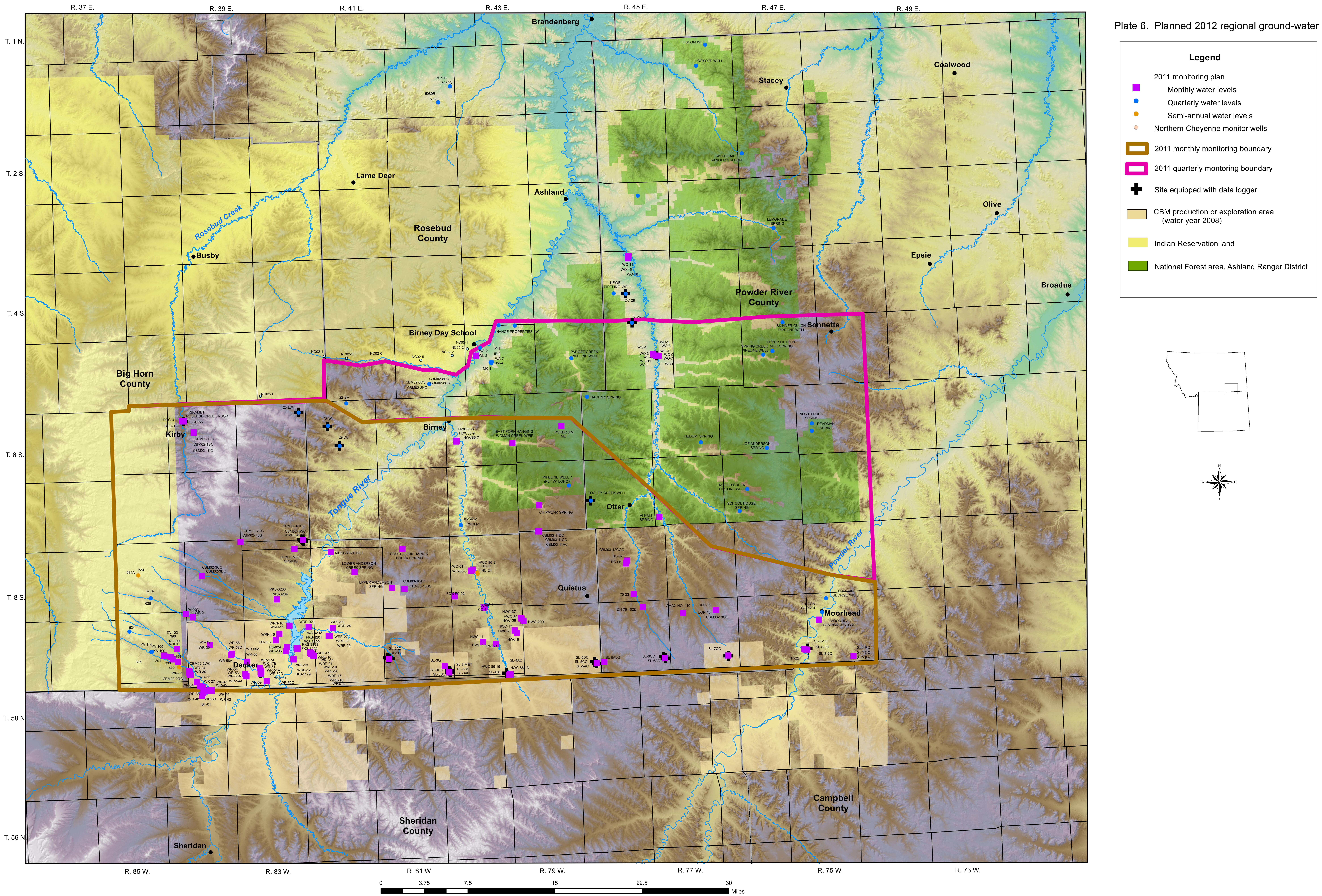


Plate 6. Planned 2012 regional ground-water plan.