2012 Annual Coalbed Methane Regional Groundwater Monitoring Report:

Powder River Basin, Montana

Montana Bureau of Mines and Geology Open-File Report 631

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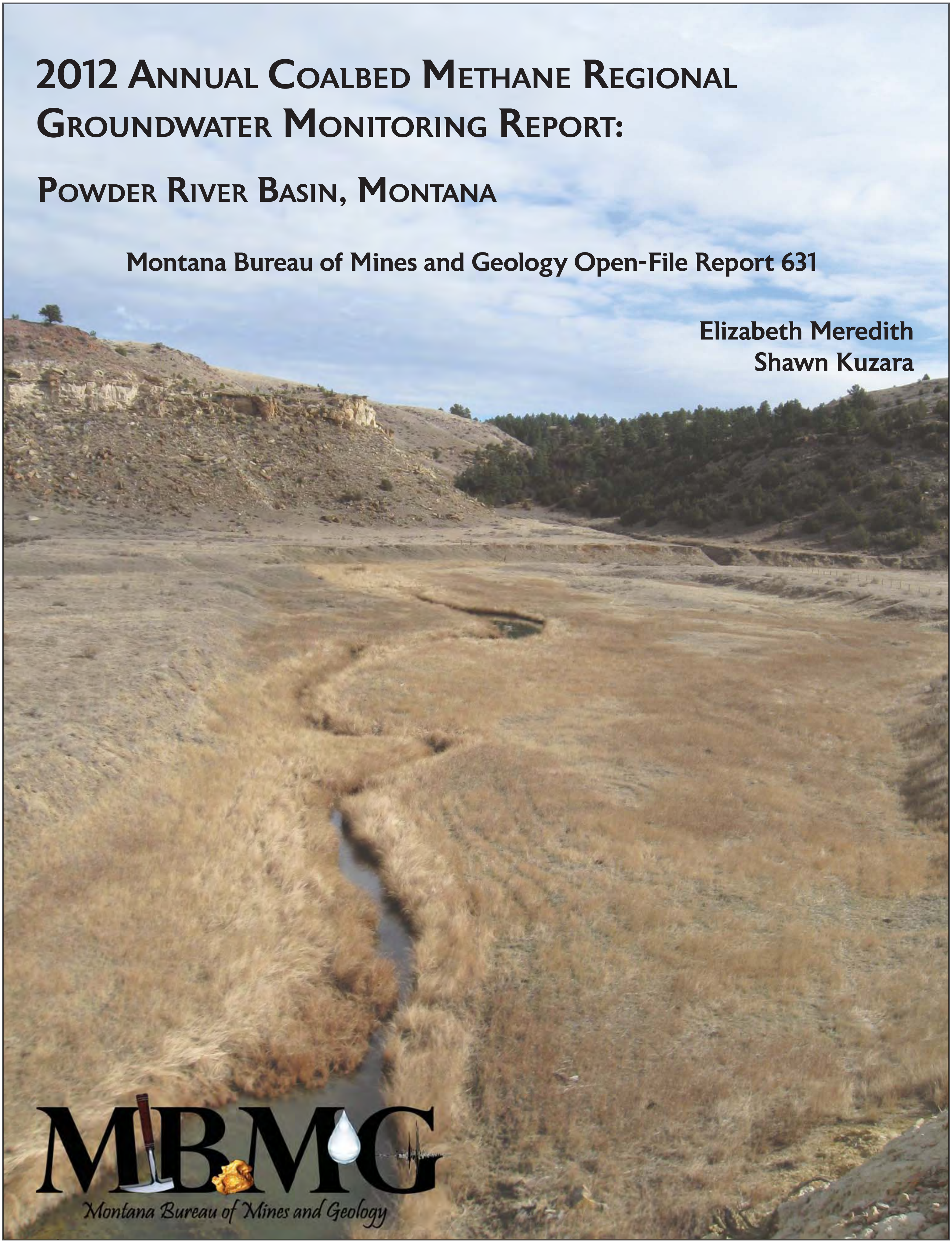

MBMG
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ABSTRACT

This report presents groundwater data collected through September 2012 from within the Montana portion of the Powder River Basin, with an emphasis on data collected during water year 2012 (October through September). This is the tenth 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, determine actual groundwater impacts, document recovery, help present factual data, and provide data and interpretations to aid environmental analyses and permitting decisions. The current monitoring network consists of 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 now operated by Fidelity Exploration and Production Company. Montana had 575 CBM wells that produced methane, water, or both during 2012, 175 fewer wells than 2011. A total of 4.16 million mscf (1 mscf = 1,000 standard cubic feet) of CBM was produced in Montana during 2012, 88 percent of which came from the CX field; the other 12 percent came from the Dietz, Coal Creek, and Waddle Creek fields.

Methane-producing coalbeds in the Powder River Basin of Montana contain water dominated by sodium and bicarbonate. Sodium adsorption ratios (SARs) 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 typically is acceptable for domestic and livestock use; however, the high SAR makes it undesirable for direct application to soils.

Water levels were measured in a 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. Summit Gas Resources (Summit; formerly Pinnacle Gas Resources, Inc.) provided water-level measurements from monitoring wells and 24-hour shut-in tests of selected CBM wells, and Spring Creek mine shared their water-level monitoring data. 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 ft or more within areas of production. The potentiometric surface in the Canyon coal has been lowered more than 600 ft. After 13 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 CBM production area boundary. These distances are somewhat less than the approximately 4-mile radius originally predicted in the Montana CBM environmental impact statement (U.S. Department of the Interior, Bureau of Land Management, 2003) and computer modeling by the MBMG. The extent of the 20-foot drawdown contour beyond production area boundaries will increase if the duration and magnitude of CBM production increases; however, the distances have not noticeably changed since 2004 (Wheaton and others, 2005; Wheaton and Metesh, 2002). 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 (Meredith and others, 2011), particularly on scissor faults. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after CBM production ceases, but it is anticipated that it will take decades to regain baseline levels. The full 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, the MBMG has documented water-level recovery due to discontinuation or reduction in CBM

production in wells near the Montana–Wyoming state line in the far western part of the study area. Drawdown in these wells ranged from 19 to 152 ft. Estimates based on current recovery rates indicate that baseline water levels will be reached in approximately 30 years; however, this time frame is for fields where there is still some CBM production. Recovery rates may increase as more CBM wells are taken out of production.

Modeled projections are important to evaluate 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 keys 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 Ground Water Information Center (GWIC); 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. The methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping groundwater from coal seams allows methane to desorb and be collected. Groundwater co-produced with CBM 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. Because these coal seams are also important aquifers, CBM production water extraction raises concerns about potential loss of stock and domestic water supplies due to groundwater drawdown (reduction of hydrostatic pressure). The drawdown 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. There are also concerns regarding the management of the water due to potential impacts to surface-water quality and soils. Due to concern regarding the magnitude, extent, and duration of this drawdown and water-quality concerns, the Montana regional monitoring program was established.

The benefits to Montana from CBM production include tax revenue, increased employment, secondary local economic effects, and potential royalty payments to landowners (Blend, 2002). Revenues, taxes, and royalties depend upon gas prices. The spot Henry Hub price for natural gas was more than $15/MMBtu in 2005 but currently is just below $3/MMBtu (www.eia.gov/dnav/ng/hist/rngwhhdm.htm).

This annual report presents groundwater data and interpretations from the northern Powder River Basin, mainly in Montana. This is the tenth year in which the Montana regional CBM groundwater monitoring network has actively documented baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, quantified groundwater impacts and lack of impacts, recorded groundwater recovery, and provided data and interpretations for use in environmental analyses and permitting decisions. Additional background is presented in Wheaton and Donato (2004). Annual reports have been prepared since 2003 and currently present data by water year (October through September).

This annual report includes: (1) a description of groundwater conditions outside of CBM production areas to provide an overview of normal variation, help improve understanding of the groundwater regime in southeastern Montana, and provide 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 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) Ground-Water Information Center (GWIC) database. To access data stored in GWIC, connect to http://mbmg-gwic.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 wellhead. Choose the project and type of data by clicking on the appropriate button. For supported browsers, data can be copied and pasted from GWIC to a spreadsheet.

Methane-production data and produced-water data used in this report were retrieved from the Montana Board of Oil and Gas Conservation (MBOGC) directly and through their 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 on the Wyoming side of the Powder River Basin. This report includes detail for only that activity in Wyoming townships 57N and 58N, covering a distance of about 9 miles south from the Montana– Wyoming state line (plate 1).

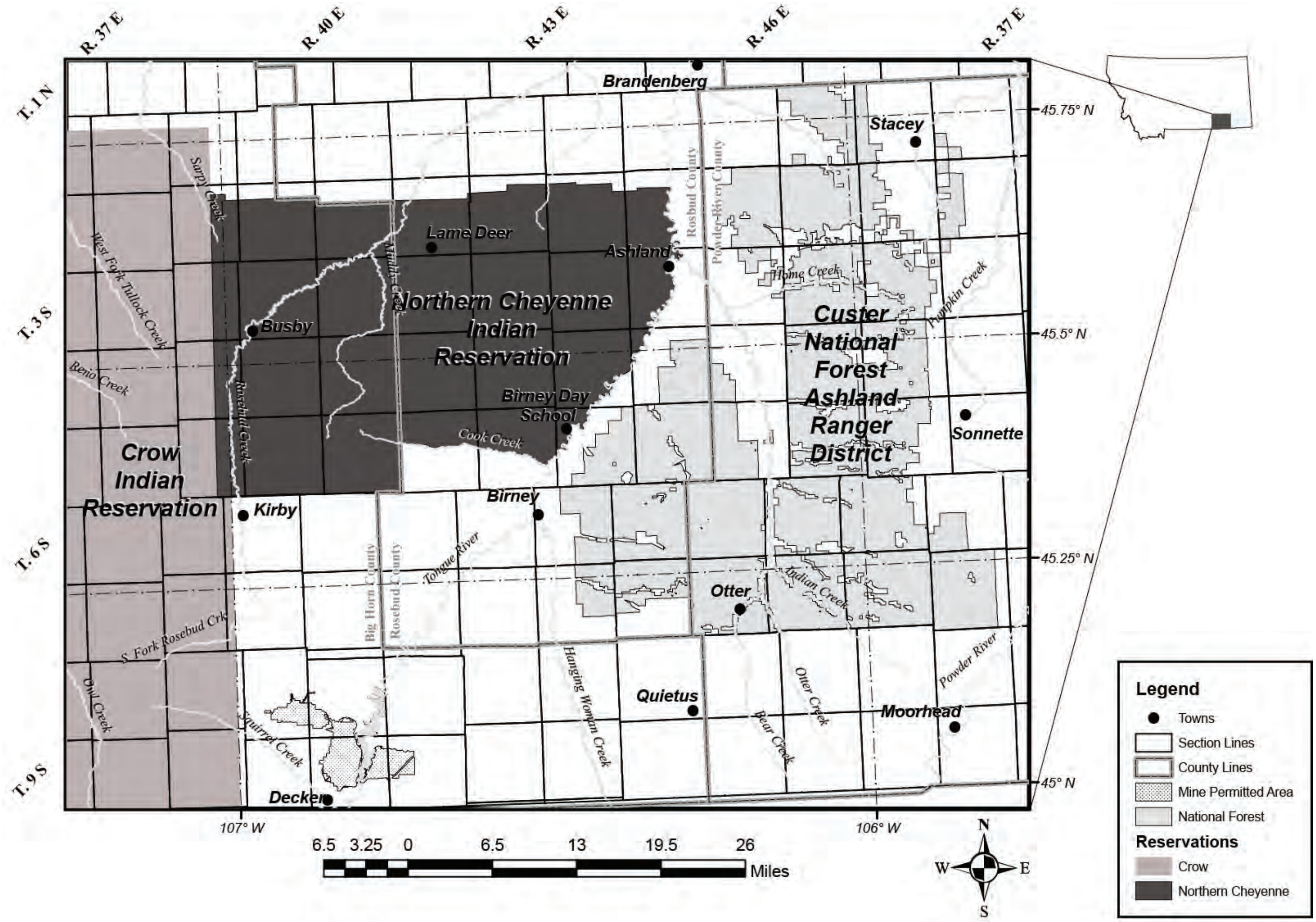


Figure 1. The MT regional CBM monitoring network covers the area considered to have medium to high potential for CBM development in the PRB. This area extends from the Wolf Mountains in the west to the Powder River in the ast, and from the MT–WY state line north to Ashland.

Hydrogeologic data were collected by the MBMG at 209 wells, 14 springs, and 2 streams during the 2012 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). Summit Gas Resources supplied 44 water-level measurements from 44 wells: 6 from the Anderson/Dietz coal zone, 3 from the Canyon coal, 8 from the Cook coal, 18 from the Wall coal, and 9 from the Flowers–Goodale coal. Spring Creek mine supplied 65 water levels for 22 monitoring wells (Plates 2, 3, 4, and 5). 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 2012 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. 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 (USFS) provides funding in support of monitoring on the Ashland Ranger District in the Custer National Forest. The Montana Department of Natural Resources and Conservation and the Rosebud, Big Horn, and Powder River Conservation Dis-

tricts have been long-term supporters of coal and coalbed methane hydrogeology work. The Coalbed Methane Protection Program has supported the publication of 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 Powder River Basin bounded by the Montana–Wyoming line on the south, roughly the Powder River on the east, the Wolf Mountains on the west, and extending north to near the town of Ashland (fig. 1 and plate 1). This is the area of the Powder River Basin in Montana that is anticipated to have medium to high potential for CBM development (Van Voast and Thale, 2001). CBM production information from the Powder River Basin in Wyoming only includes the area adjacent to the Montana–Wyoming state line (townships 57N and 58N).

Geologic Setting

The Powder River Basin 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 coarser 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 a cross section (plate 1) 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). Appendix D contains a discussion of general Fort Union Formation coal geology and nomenclature, including a summary of coal aquifer aqueous geochemistry.

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 discharge to alluvial aquifers, form springs at bedrock outcrops, or seep vertically into underlying 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 Powder River Basin in areas where aquifers crop out and by vertical leakage from the overlying local flow systems. Regionally, groundwater flows northward from Wyoming into Montana and generally toward the Yellowstone River. Groundwater in the regional flow system will leave the Powder River Basin as deep groundwater flow, discharge at springs, contribute to streams and alluvium, and/or evapotranspirate. 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 unconfined aquifers respond to seasonal variations in precipitation. Deeper confined aquifers show small, if any, measurable seasonal water-level changes except for slow reaction to climatic periods of below or above average precipitation.

Precipitation data 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 in, based on records from 1970 through the end of 2011 (Western Regional Climate Center, 2013). During the water year 2012, Moorhead received 9.11 ins of precipitation, which is 2.89 ins lower than the average annual precipitation (fig. 2). Long-term precipitation trends that may affect groundwater levels are illustrated by the departure from average (black bars in fig. 2). The early 2000s marked a period of average-to-low precipitation, while precipitation has generally been above average from 2005 to 2011.

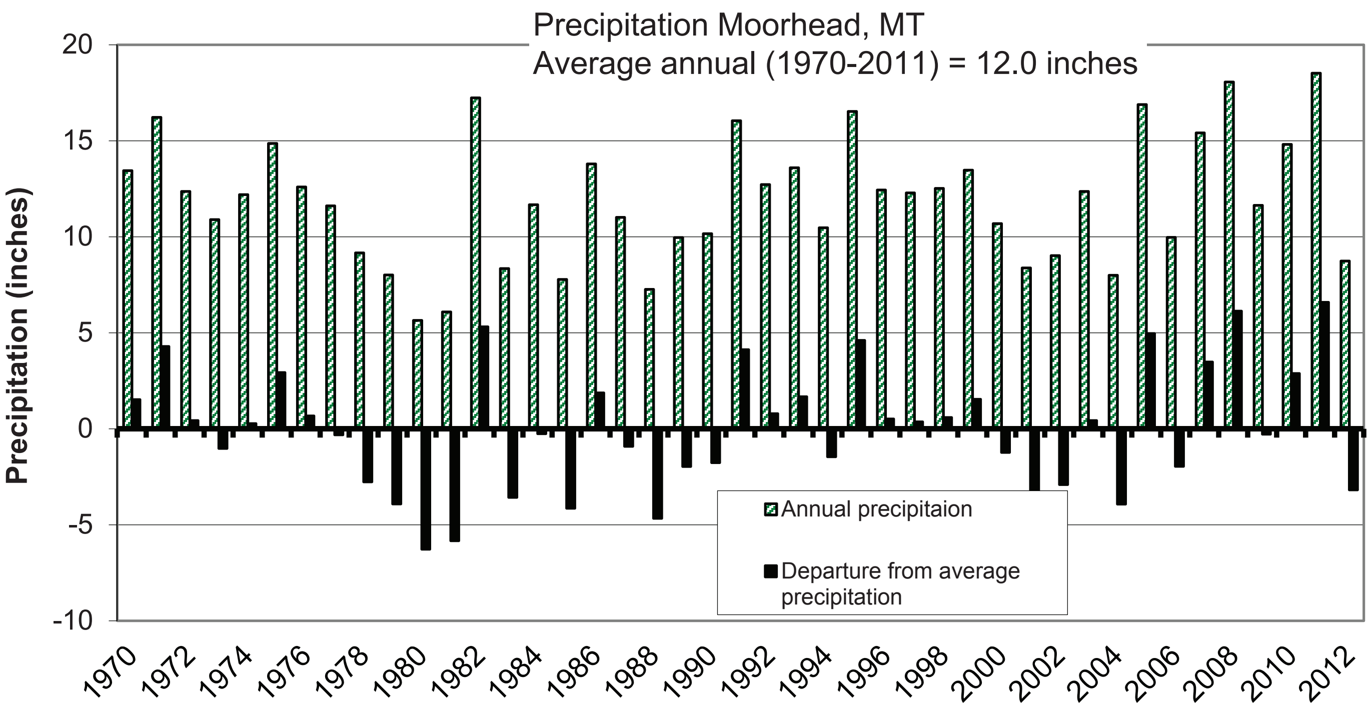


Figure 2. Annual precipitation (striped bar graph) at Moorhead, MT. Departure from average precipitation (solid bar graph) provides a perspective on the long-term moisture trends that may affect groundwater recharge.

Coalbeds in the Powder River Basin are generally separated from other aquifers by shale units. At a few selected locations, overburden and underburden aquifers are monitored and, due to these confining layers, water-level drawdown in response to CBM production, in most areas, is limited to the coal aquifers and does not migrate vertically to impact overlying or underlying aquifers.

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 along a fault 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 so far demonstrate that this fault limits groundwater flow. However, long-term water-monitoring at other sites demonstrates that some fault systems allow slow across-fault leakage.

In the Powder River Basin, 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 to other aquifers may, however, cause changes in shallow groundwater quality. To assess possible changes, water-quality data are collected semi-annually from some shallow aquifers.

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 coals, 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; groundwater also moves vertically downward into underlying bedrock to become deep groundwater flow. 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 cooperatively between the Northern Cheyenne Tribe and the USGS. Monitoring wells NC02-1 through NC02-6 (GWIC ID numbers 223238, 223240, 223242, 223243, 223236, and 223237; USGS ID numbers 05S40E31BDCC01, 05S42E14ADDC02, 05S41E17ADBD01, 05S40E13ADAB01, 05S42E16CCAB01, and 05S41E14BDCD01) monitor the water levels of the Wall (2), Flowers–Goodale, Pawnee, and Knobloch (2) coals. These wells are monitored periodically and as of the last reported measurements these wells show no significant water-level change 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/).

During the previous 7 years of monitoring at site CBM02-1 near the town of Kirby just to the east of Rosebud Creek (fig. 3), water levels in the Brewster–Arnold coal and the unnamed “local” coal showed subtle responses to seasonal precipitation patterns, whereas the Knobloch showed very little water-level fluctuation. However, after unusually high precipitation in spring 2011, all aquifers responded upward. The low storage that generally typifies deep coal aquifers caused the water-level response in the Knobloch to be greater than that observed in the shallower coals. In July–September 2012, water levels in all the wells were declining.

At monitoring site WO, along Otter Creek, alluvial water levels are responsive to local, recent precipitation (fig. 4). During the heavy spring rains in 2011, alluvial water levels rose uniformly across the valley; despite the dramatic increase in water levels, the direction of groundwater flow toward the creek did not change. The flow in Otter Creek varies along its length, at times disappearing into the alluvium altogether, transitioning between a gaining and losing stream; the transition’s exact location 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, show relationships among meteorological conditions, groundwater levels, and surface-water flow (fig. 5). Detailed precipitation data for the Rosebud Creek site (fig. 5B) illustrates 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 in 2011, groundwater levels were only slightly higher than previously recorded high conditions.

Water-quality samples were collected in October 2011 and June 2012 from well RBC-2. This well is completed in alluvium of Rosebud Creek. Similar to previous years, TDS concentrations were 581 and 561 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 (appendix C).

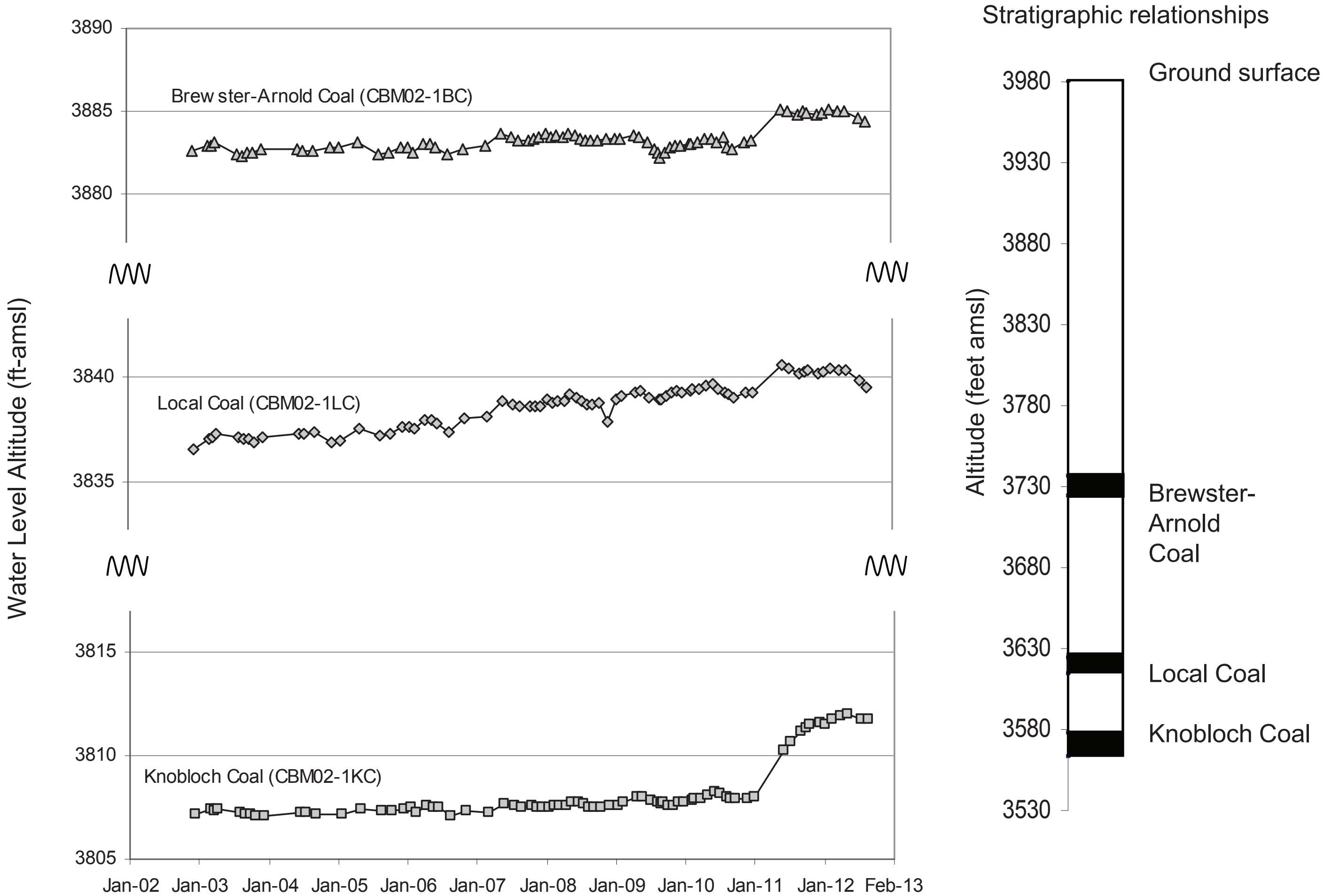


Figure 3. A downward hydrostatic gradient is evident between the Brewster–Arnold coal, local coal, and Knobloch coal at the CBM02-1 site. This monitoring site is near the town of Kirby, just east of Rosebud creek. Water-level data from the Brewster–Arnold coal and the local coal demonstrate a slight 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. In 2011, high amounts of precipitation caused water levels to rise in all three wells. Currently, the water levels are declining back to previous levels. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different. The Y axis scale is broken to show better hydrograph detail.

SPRING AND STREAM FLOW AND WATER QUALITY

Flow rates and specific conductivity data were collected at 14 springs and one stream within the project area but outside the influence of CBM production during 2012. The locations of monitored springs and the streams are shown in plate 1, site data are in appendix B, and water chemistry data for selected springs are in appendix C.

In the southern end of the Custer National Forest's Ashland Ranger District along Otter Creek, Alkali Spring discharges between 0.5 and 1.4 gpm. 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 (fig. 6) 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 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, is also likely a combination of regional flow and local recharge. This spring is associated with the Ferry coal and has moderate seasonal flow

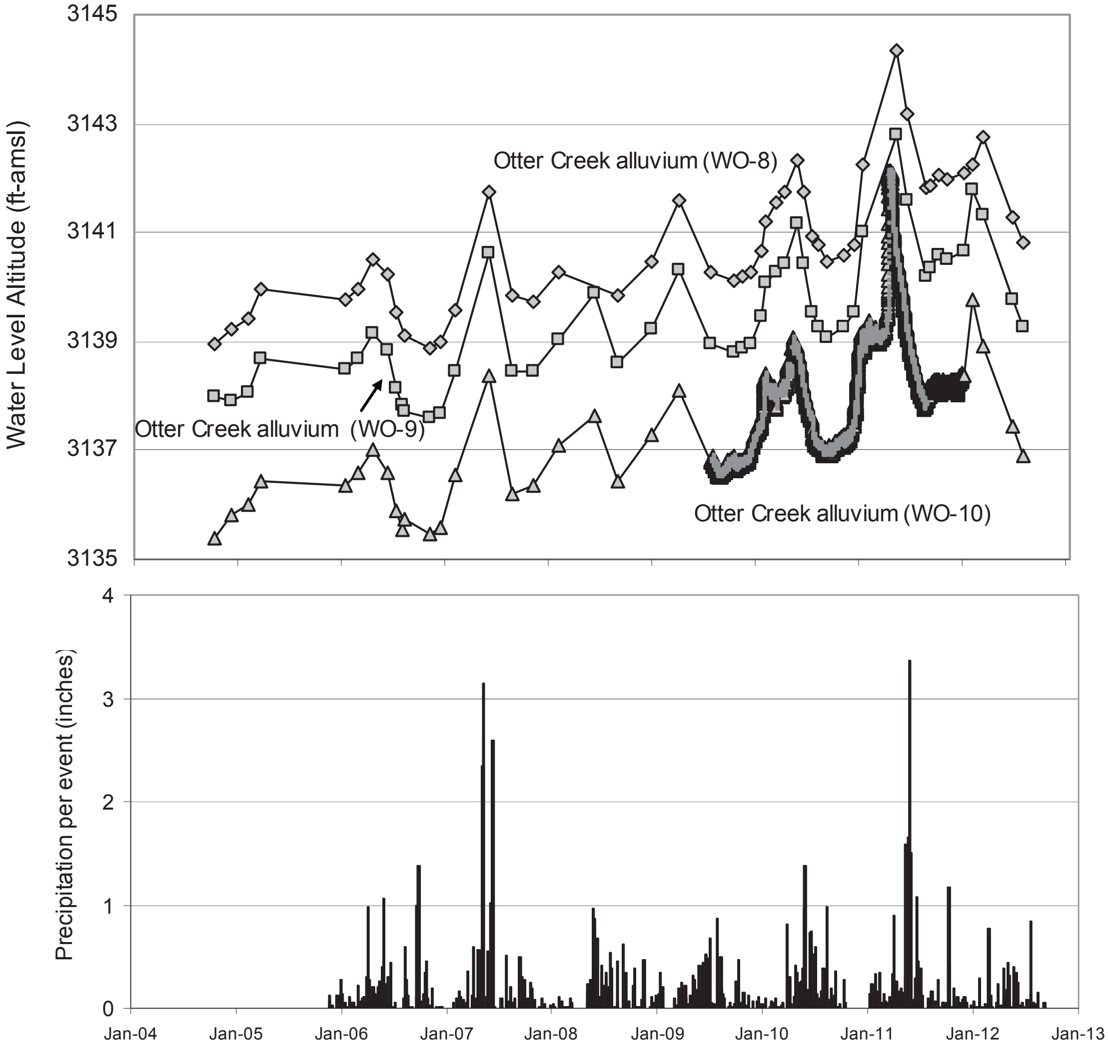
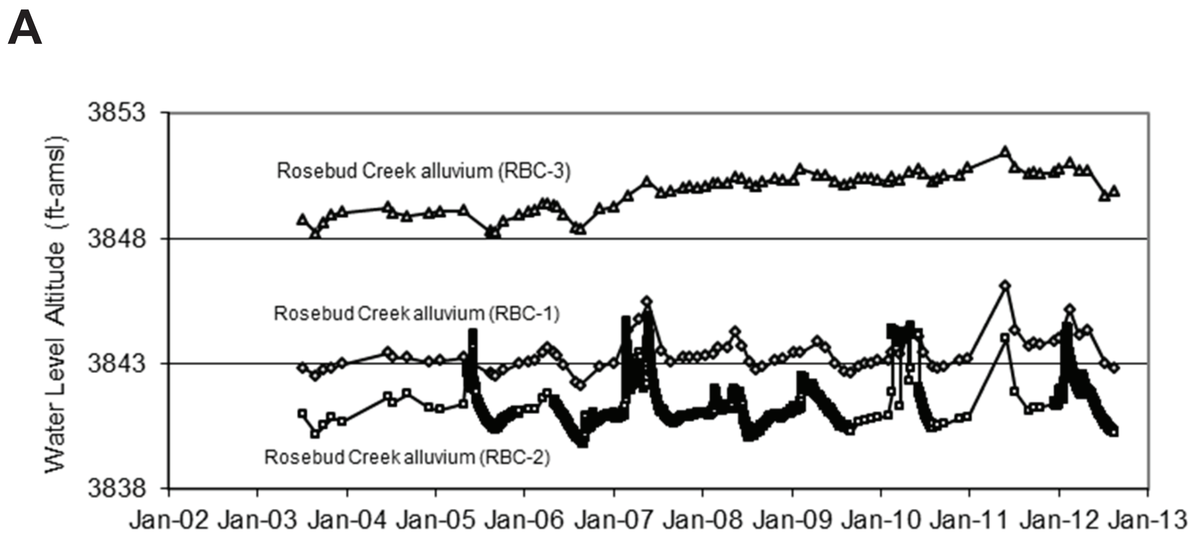


Figure 4. Water-level trends in the alluvium at the Otter Creek site closely follow the precipitation at Poker Jim weather station (shown as the total rain in inches per event in the lower graph).

variations (fig. 6). Its average discharge is 1.81 gpm. In contrast, North Fork Spring, in the southeast of the Ashland Ranger District, is located in a topographically high area. The North Fork Spring typically flows less than 1 gpm but shows moderate seasonal discharge rate fluctuations (fig. 6). This spring is associated with an isolated segment of the Canyon coal and is likely discharge from a local flow system.

Water-quality samples were collected in June 2012 from North Fork and Dead Man springs outside the area influenced by CBM production (appendix C). The salinity (2,858 and 2,958 mg/L, respectively) and SAR (6.5 and 4.0, respectively) of these springs are generally higher than those of locally recharged springs, so they may have a component of regional recharge. Several springs located on the Ashland Ranger District have flow and field chemistry monitored quarterly but do not have a water-quality analysis on record. Future plans include collecting at least two water-quality samples from every spring that is measured on the Ashland Ranger District.

The East Fork Hanging Woman Creek site is located on the Ashland Ranger District boundary, east of Birney. The spring of 2011 marked record-breaking precipitation events at the Poker Jim meteorological station, located near the creek's headwaters. The following flood washed out monitoring equipment, resulting in lost data. During the summer of 2012, the MBMG repaired the site.



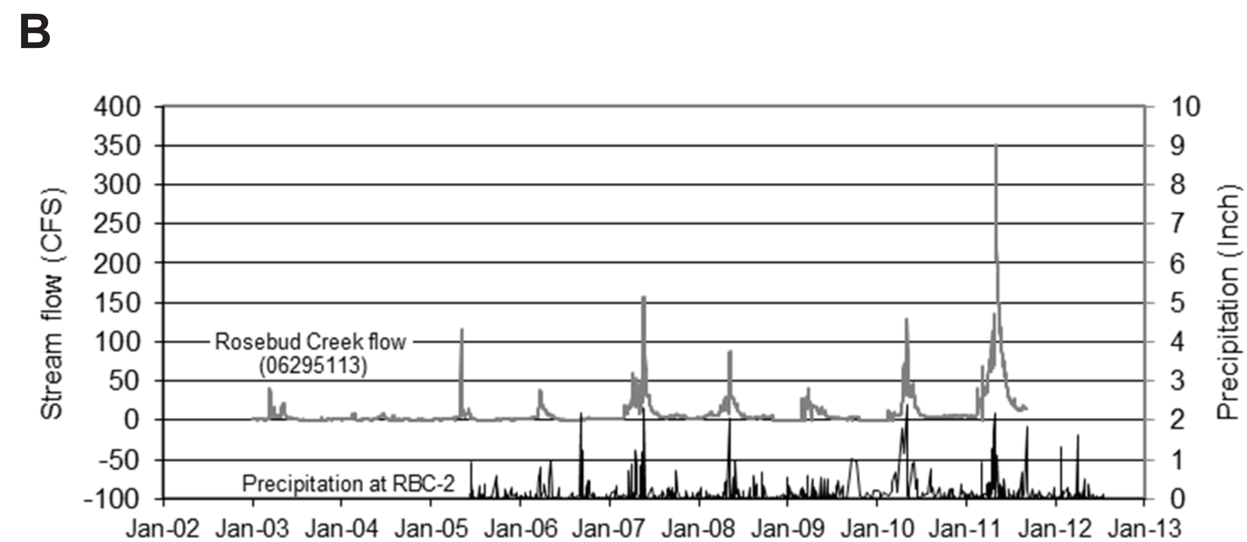


Figure 5. (A) Groundwater levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. (B) In previous years the Rosebud Creek stream flow follows precipitation trends. Precipitation is shown as the total rain in inches per event in the lower graph (flow data from USGS 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). As of October 2011 the USGS has discontinued gauging station 06295113.

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.

Produced-water volume data for 2012 were retrieved for Montana (MBOGC, 2012) and Wyoming (WOGCC, 2012) and are summarized in table 1. A total of 575 Montana wells produced methane and/or water during 2012 (this number differs from table 2 because table 1 includes all wells that were active in water year 2012, rather than just those active in October 2012). The 575 wells produced a total of 15.8 million barrels (bbls) of water (2,041 acre-ft) during water year 2012. In the same time period, 1,107 wells in the two Wyoming townships nearest Montana (57N and 58N) produced 61 million bbls (7,897 acre-ft) of water. The total amount of water co-produced with CBM in the Powder River Basin in all of Wyoming during water year 2012 was approximately 415 million bbls or 53,467 acre-ft.

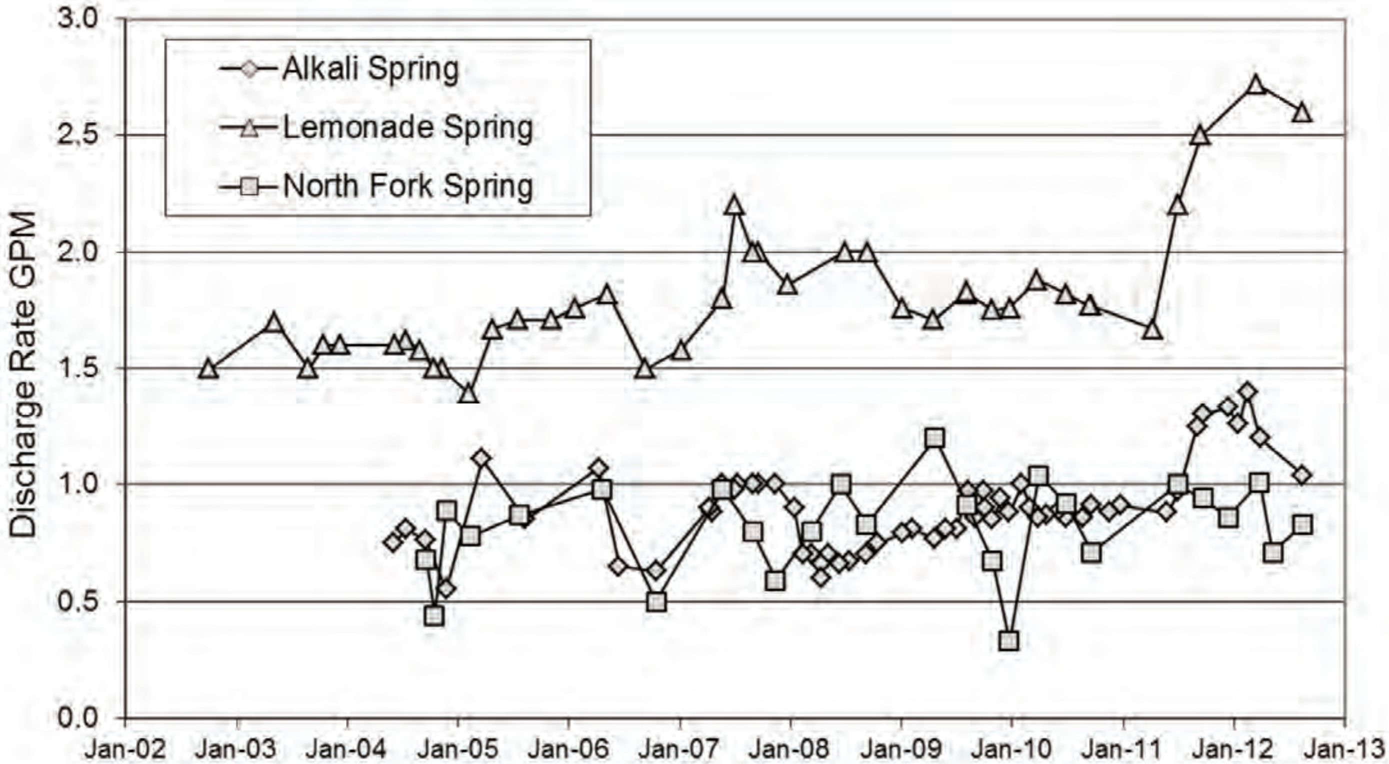


Figure 6. Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.89 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.81 gpm. Lemonade Spring appears to be locally recharged by the Ferry coalbed. The spring has an average discharge rate of 1.81 gpm.

Coalbed methane permitted wells in Montana are summarized by county and field in table 2. As of October 2012, there were no active permits for wells; companies allowed all permits to expire. There are currently 619 shut-in or abandoned wells in the CX field; water levels have begun to recover in this older field as a result of these changes (see Montana CBM Fields: Bedrock-aquifer water levels and water quality).

Estimated average discharge rates per well were used to predict aquifer drawdown and water-management impacts from CBM development in the CBM Environmental Impact Statement and computer modeling efforts. 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 estimated average water production rate per CBM well (dashed line, fig. 7). The average water production rate presented here is based on 155 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 the lack of statistically significant late data (only three wells have produced for 151 months and only one has produced for longer than 151 months). The average amount of water initially produced from each CBM well is less than was expected (fig. 7). However, the impact statement's predicted water-production rate was between the 80th and 90th percentile of actual production. The predicted and observed rates are similar at approximately 72 months. Between 6 and 10 years of production, the average actual CBM water per well production rate levels out but exceeds the predicted rate. After 10 years the average water production rate begins to rise, most likely because wells producing for longer than 10 years are in the CX field and must produce more water to keep the overall water level in the coal drawn down despite many wells being shut-in. Overall, the Environmental Impact Statement somewhat over-predicted water production. The lesser quantity of CBM water that was actually produced decreases the amount of water that must be managed and decreases the anticipated stress on the aquifers.

Table 1. Annual summary for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2012.

	Field	Well Count	Gas (MCF) 2012	Annual+ total water production in **Bbls *1,000** (acre-feet)					
				2012	2011	2010	2009	2008	2007
Montana	Coal Creek	19	145,229	886 (114)	1,848 (238)	2,262 (292)	2,055 (265)	1,782 (230)	2,389 (308)
	CX	497	3,662,084	14,010 (1,806)	23,760 (3,062)	29,310 (3,778)	31,625 (4,176)	35,414 (4,565)	34,686 (4,471)
	Dietz	58	334,249	921 (119)	1,239 (160)	1,817 (234)	1,790 (231)	2,837 (366)	2,159 (278)
	Waddle Creek	1	22,796	15.6 (2.0)	92.4 (12)	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**575**	**4,164,358**	**15,833 (2,041)**	**26,939 (3,472)**	**33,540 (4,323)**	**35,621 (4,591)**	**40,121 (5,171)**	**39,234 (5,057)**
Wyoming	Prairie Dog Creek	515	16,928,134	24,643 (3,176)	29,677 (3,825)	35,938 (4,632)	45,052 (5,807)	56,947 (7,340)	51,259 (6,607)
	Hanging Woman Creek	145	2,160,437	9,849 (1,270)	13,309 (1,715)	15,641 (2,016)	19,269 (2,484)	24,589 (3,169)	22,342 (2,880)
	Near Powder River	447	5,530,292	26,780 (3,452)	30,412 (3,920)	34,957 (4,506)	40,233 (5,186)	45,396 (5,851)	38,187 (4,922)
	WY Combined	**1,107**	**24,618,863**	**61,272 (7,897)**	**73,398 (9,460)**	**86,535 (11,154)**	**104,554 (13,477)**	**126,932 (16,361)**	**111,788 (14,409)**

Note. Montana source: MBOGC website (http://bogc.dnrc.mt.gov/default.asp); Wyoming source: WOGCC website (http://wogcc.state.wy.us/).
+Totals reflect production during the water year for 2008–2012 and calendar year 2007.

Gas production for an average well in the Powder River Basin increases sharply during the well's first 5 months of active production and is then relatively stable between 5 and 35 months (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, produced gas slowly decreases throughout the well's remaining life. Production by individual wells varies greatly as illustrated by the 10th to 90th production percentiles; however, the 80th and 90th percentile lines follow the same pattern as average well production.

Since mid-2008, wells that produce relatively large amounts of water compared to the amount of gas 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).

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 Montana Board of Oil and Gas Conservation website (MBOGC, 2012). During 2012, a total of 497 CX field CBM wells produced either water or gas, or both. Production is from the Smith, Anderson (D1), Dietz 1 (D2), Dietz 2 (D3), Canyon (Monarch), Carney, Wall, King, and Flowers–Goodale coalbeds (table 1; appendix D). The total 2012 water production was 14.0 million barrels (1,806 acre-ft). 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 reduced rates as the methane production has 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; wells WR-27 and WR-38 (fig. 10) illustrate typical water level recoveries.

Coal Creek and Dietz gas fields. Data from CBM production wells in the Coal Creek and Dietz fields (plate 1) were retrieved from the MBOGC website (MBOGC, 2012). Summit (at the time Pinnacle Gas Resources, Inc.) first produced gas 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 2012, a total of 19 CBM wells produced

Table 2. 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	Oct. 2012
Big Horn	Coal Creek	Permit/Spudded	9	7	4	5	5	0
		Expired Permit	0	0	2	2	2	6
		Producing	**13**	**26**	**23**	**20**	**14**	**17**
		Shut In/Abandoned	49	35	39	44	50	46
	CX	Permit/Spudded	44	44	9	0	0	0
		Expired Permit	231	251	288	288	288	288
		Producing	**741**	**705**	**676**	**623**	**508**	**275**
		Shut In/Abandoned	110	168	212	270	385	619
		Water Well, Released	0	0	0	0	0	2
	Dietz	Permitted Injection Well	1	1	1	1	1	0
		Permit/Spudded	1	0	0	0	0	0
		Expired Permit	42	42	42	42	42	42
		Producing	**96**	**92**	**36**	**61**	**55**	**38**
		Shut In/Abandoned	10	5	61	45	51	59
	Other (Deer Creek, Four Mile, Forks Ranch, Waddle Creek, Wildcat BH)	Permit/Spudded	34	56	35	36	35	0
		Expired Permit	38	49	67	67	68	103
		Producing	**2**	**2**	**3**	**1**	**1**	**2**
		Shut In/Abandoned	21	27	29	24	24	30
		Water Well, Released	0	1	1	1	1	1
Other Counties Carbon, Custer, Gallatin, Powder River, Rosebud		Permit/Spudded	124	2	2	2	2	1
		Expired Permit	35	157	157	157	157	158
		Producing	**2**	**2**	**3**	**2**	**1**	**0**
		Shut In/Abandoned	15	14	16	19	21	21
		Water Well, Released	0	0	0	1	1	1

Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ [Accessed Oct. 4, 2012]

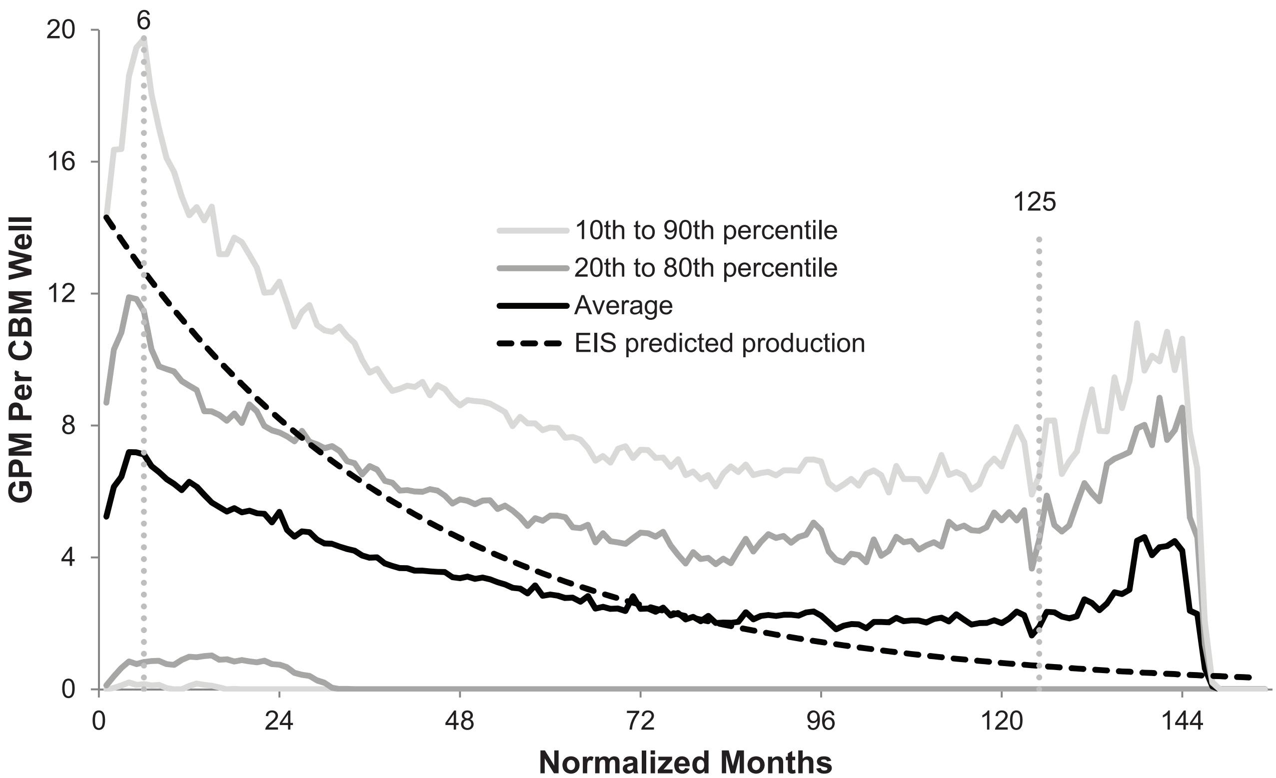


Figure 7. Normalized CBM produced water in gallons per minute (GPM) in the Montana portion of the Powder River Basin (data from the MT BOGC website). The actual average production (solid black line) falls below the EIS predicted production (dashed line: y=14.661 e^(-0.0242x); US BLM, 2003) for the first 6 years of production. Since most water is produced early, the EIS somewhat overpredicted total water production. Trends from 1 to 6 months and over 125 are not considered to be representative of hydrogeologic responses to CBM production. There was no water produced from wells that have been active for over 148 months.

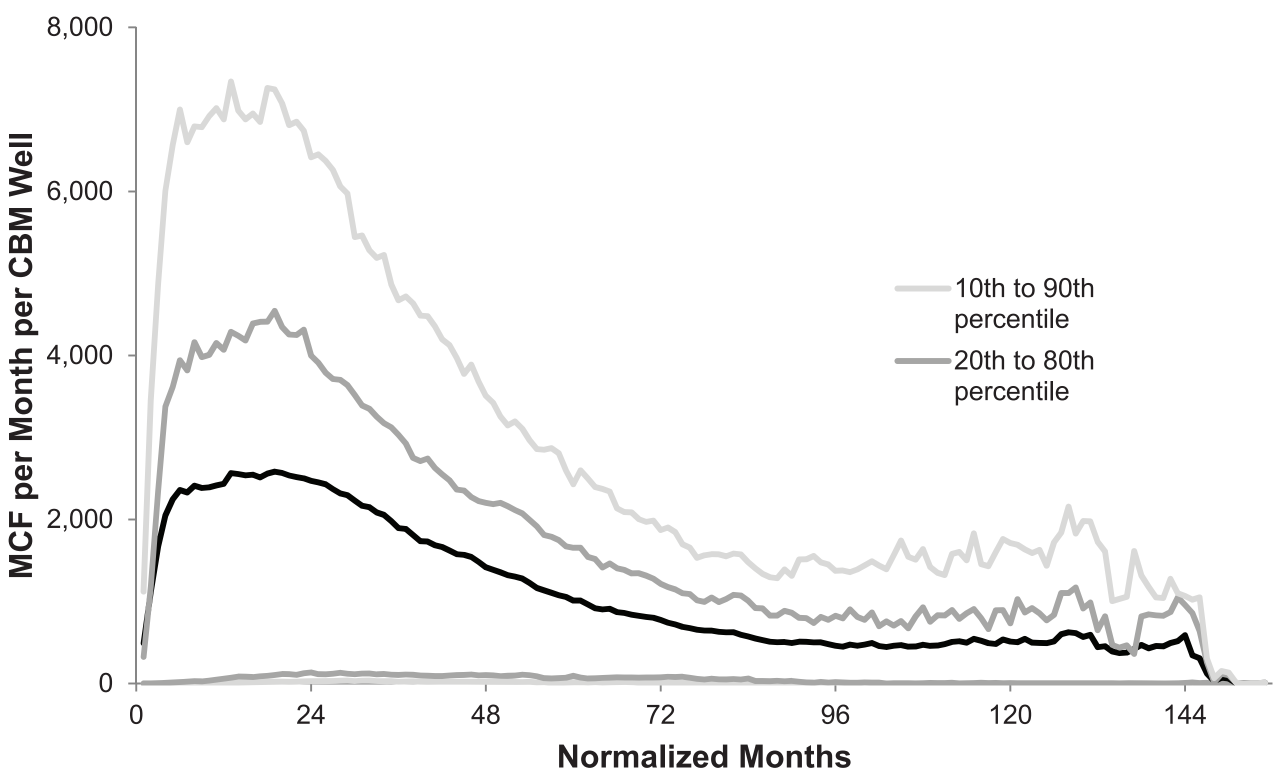


Figure 8. Normalized gas production (MCF) per month for individual CBM wells in the Montana portion of the Powder River Basin (data from MT BOGC website). The solid black line represents the average gas production per well per month.

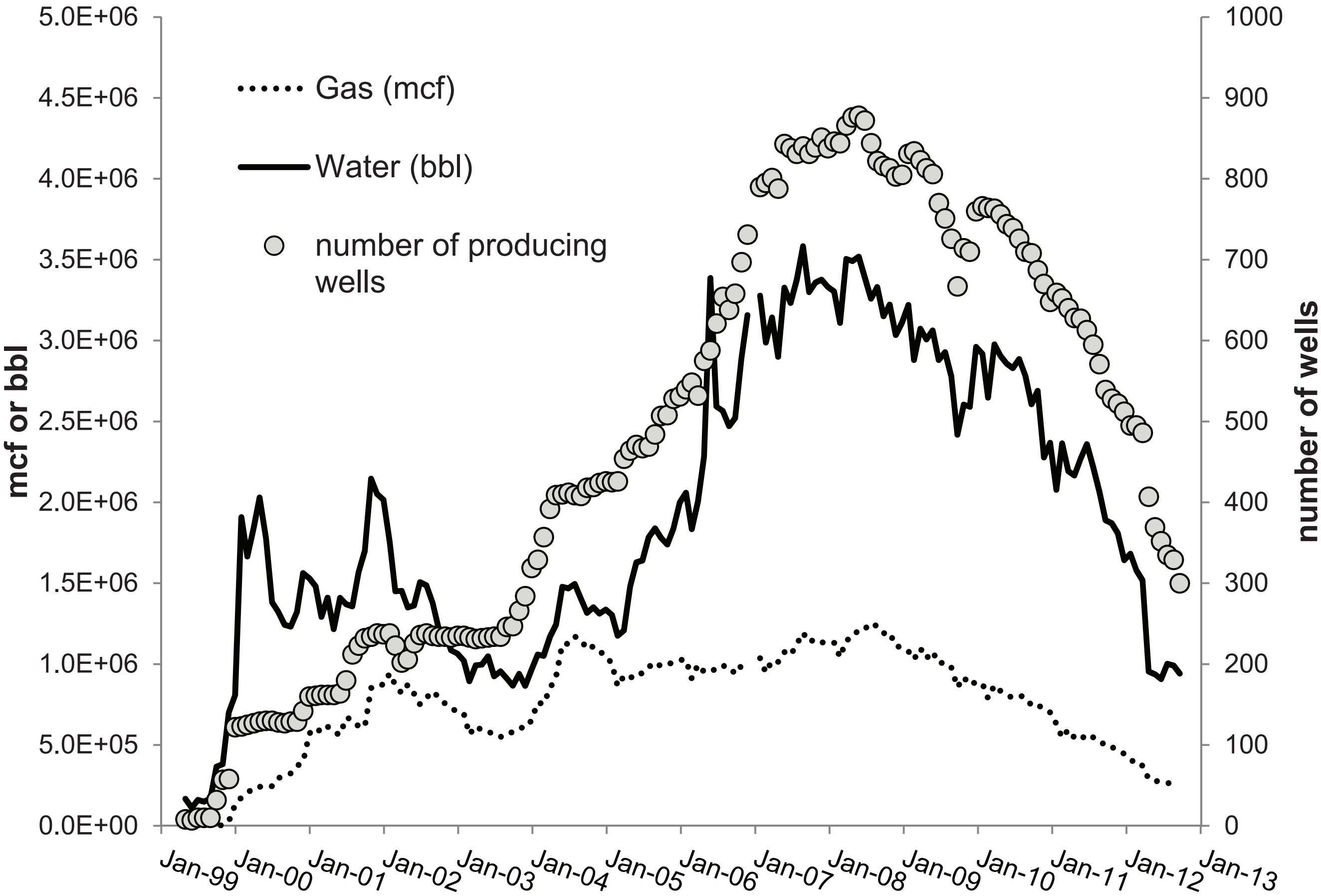


Figure 9. Monthly totals of water and gas produced from Montana CBM wells and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production. The total number of producing wells and the amount of water and gas produced has dropped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

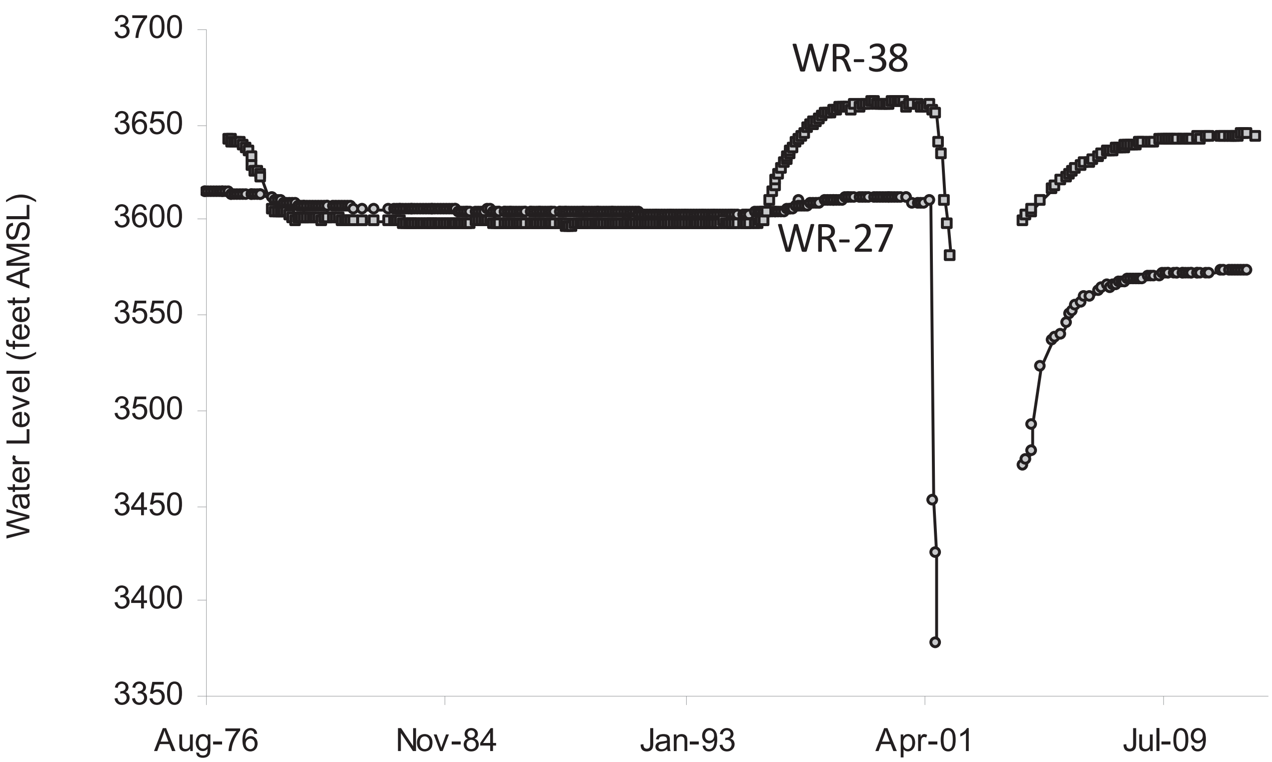


Figure 10. Water-level records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production. The recovery water levels are flattening; however, they still have not reached baseline conditions.This is probably due to other wells still producing nearby.

water or gas in the Coal Creek field (table 1) from the Wall and Flowers–Goodale coalbeds (appendix D). Total water production for the 12-month period was 886,000 bbls (114 acre-ft). A total of 58 CBM wells produced water or gas in the Dietz field during 2012 (plate 1, table 1) from the Dietz, Canyon, Carney, and Wall coalbeds (appendix D). The total water production for the 12-month period was 921,000 bbls (119 acre-ft).

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. Coal mining and CBM production together 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 interpreted to be specific to CBM production (plate 4) shows that drawdown of at least 20 ft typically reaches a distance of about 1 mile beyond the active field boundaries, but has reached as much as ~1.5 miles in some areas. For the Canyon coal, drawdown appears similar to that in the Dietz; 20 ft of drawdown reaches about 1 mile beyond the field boundaries (plate 5).

Drawdown was predicted to reach 20 ft at a distance of 2 miles after 10 years of CBM production (Wheaton and Metesh, 2002), and 20 ft at a maximum 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 drawdown primarily due to restrained 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 20 ft 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 reduced water levels until reclamation and recovery began in 1995. By 1998, water levels had returned to near-baseline conditions. Between 2001 and 2003, CBM production lowered groundwater levels at WR-34 to about 150 ft below baseline conditions. The greater magnitude of drawdown from CBM development in WR-34 as compared to that from coal mine dewatering is primarily due to its close proximity to active CBM production. Since March 2003, water levels have recovered to within 27.8 ft of baseline altitudes, 82 percent recovery during a period of 9 years, due primarily to a reduction in the number of nearby producing CBM wells. There are 233 fewer wells producing in the CX field in 2012 as compared to 2011; however, the rate of water-level recovery does not appear to have increased.

Groundwater-level response due to the Ash Creek mine pit dewatering is also evident at well WR-38 (fig. 12). In 2001 the water level in this well dropped at least 80 ft in response to CBM production. Because pumping in nearby CBM wells has decreased, water levels in WR-38 have now recovered to within 16.5 ft of baseline conditions, or 79 percent. Although the mine pit created water-level response in the adjacent, confined coal aquifer, water levels in well BF-01, completed in unconfined spoils, did not noticeably react to CBM production. The lack of a measurable response is not surprising due to unconfined aquifers having much greater storativity.

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, but there has been no response to East Decker mine pit dewatering south of the fault (fig. 13). Recent monitoring south of the fault (plate 2) shows that CBM production has lowered water levels in the Anderson coal significantly without a similar decrease north of the fault. The lowest recorded water levels south of the fault were more than 180 ft below baseline. The isolated mine pit vs.

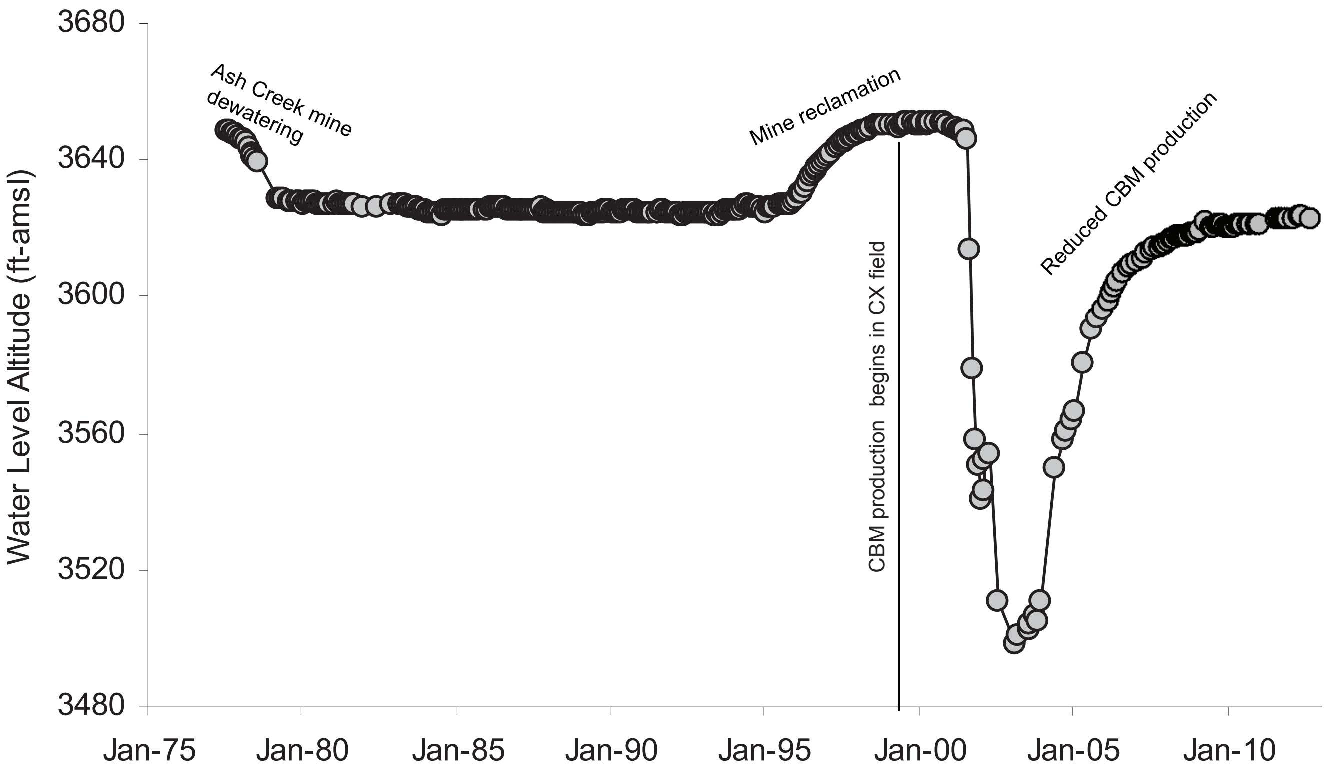


Figure 11. Water levels in the combined Anderson–Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed-methane production. The water level recovered starting in 2003 in response to decrease production in this portion of the CX field.

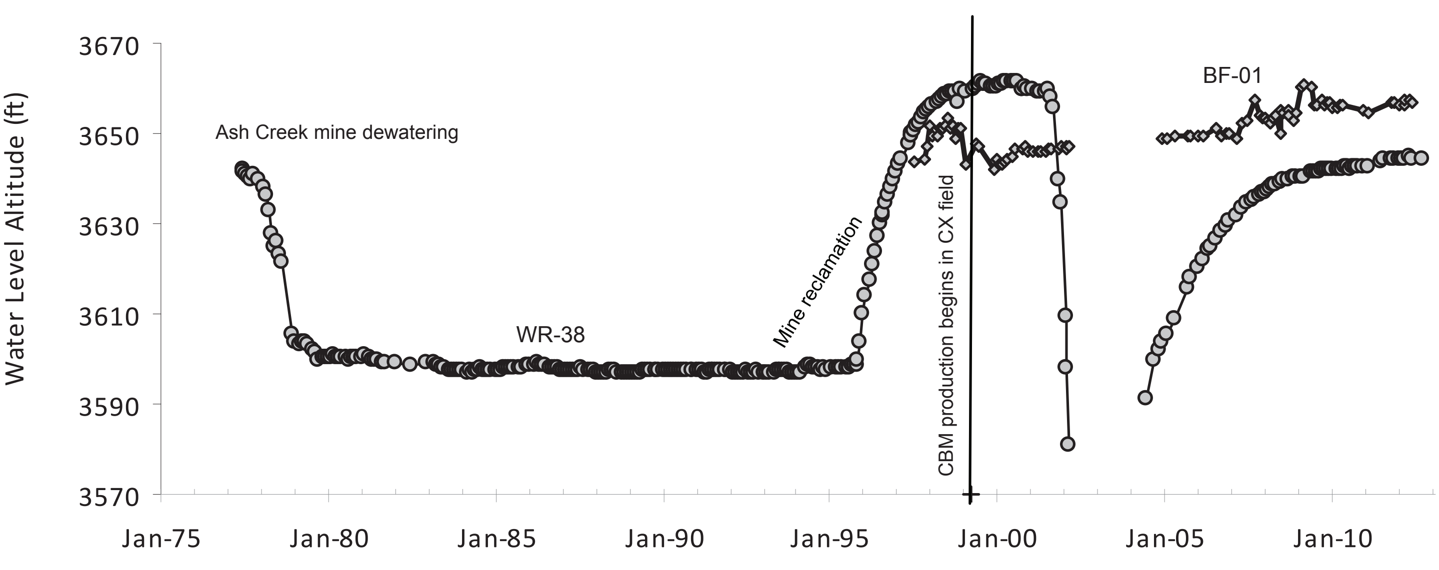


Figure 12. Water levels in the Dietz coal (well WR-38) decreased by at least 80 ft in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping. This illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses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

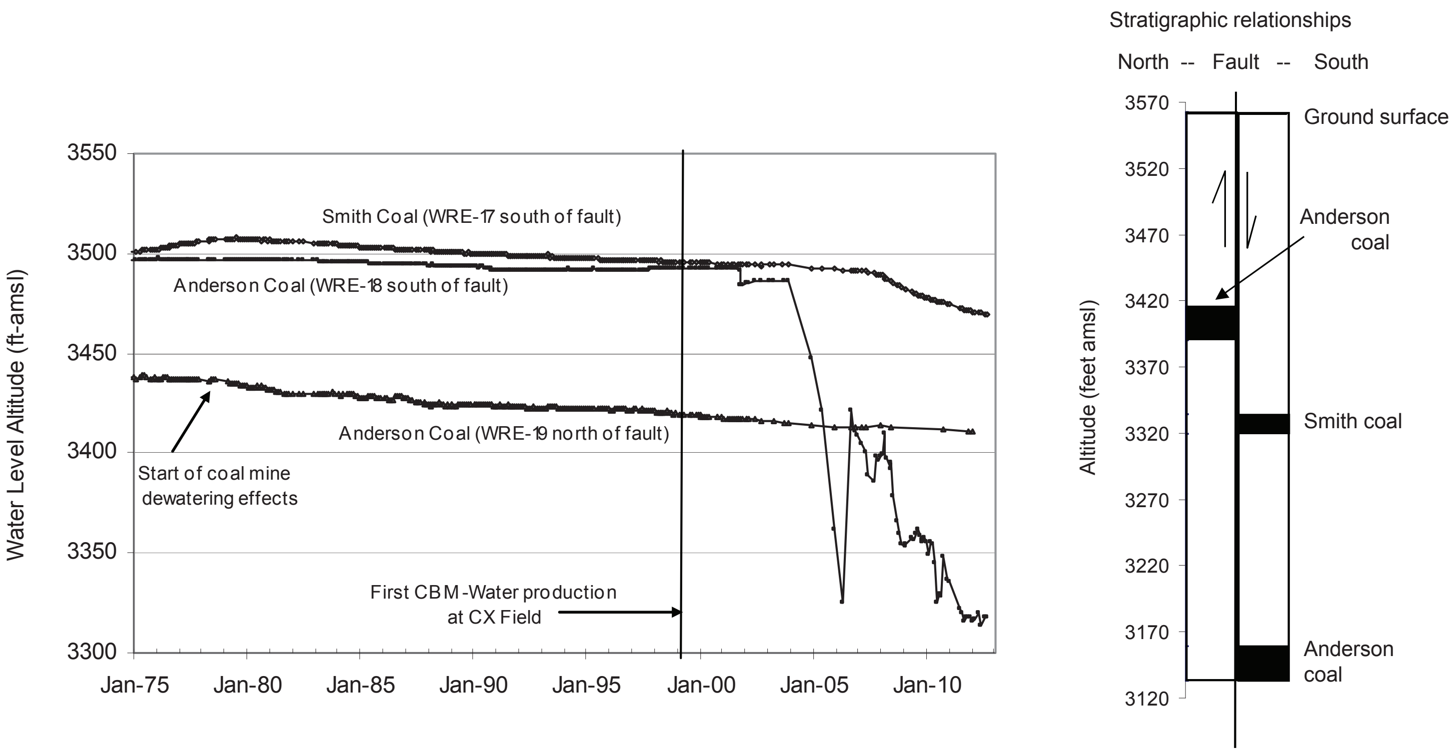


Figure 13. Drawdown from both coal mining and coalbed-methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970s, and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980s. The pressure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

CBM-dewatering drawdown effects indicate that the fault acts as a barrier to flow within the Anderson coalbed. However, at well WRE-17 south of the fault, water levels in the Smith coal respond slightly to coal mining north, and also CBM production south of the fault. Reduced pressure from coal mining may have migrated around the end of the fault. Reduced hydrostatic pressure from CBM production may be causing a reduction in the hydrostatic 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 potentially isolated by faults from nearby CBM wells, water levels in the Carney coal, monitored by well CBM 02-2WC, have been responding to more distant CBM-related drawdown since monitoring began in 2003; water levels are now 19.1 ft lower than the first measurement (fig. 14). It appears that the declining water levels result from drawdown being preferentially directed along a SW–NE-trending fault block from active CBM wells approximately 3.5 miles to the northeast on Squirrel Creek. Water levels in the Canyon coal at this site have steadily declined either in response to CBM production or possibly 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 ft during 2005, began to recover in early 2006, but has not yet reached previous water levels. The cause of the water-level change in the Roland coal is not apparent, but it is unlikely to be related to CBM development because the recovery beginning in2006 has not been observed in the other coal aquifers at this site.

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). In 2003 the rate of water level drawdown increased, particularly in the Dietz 2 coal, in response to nearby CBM production. Most likely due to reduced CBM activity in the area, water levels in the three coal aquifers recovered slightly in 2008, and then have stabilized (WRE-12 and WRE-13)or risen slightly (PKS-1179) in 2012. The more dramatic decline in the Dietz 2 aquifer is driven by the fact that, during CBM production, water levels are lowered to near the top of the aquifer, so deeply buried coals experience more drawdown than do shallower coals with similar starting water-level elevations.

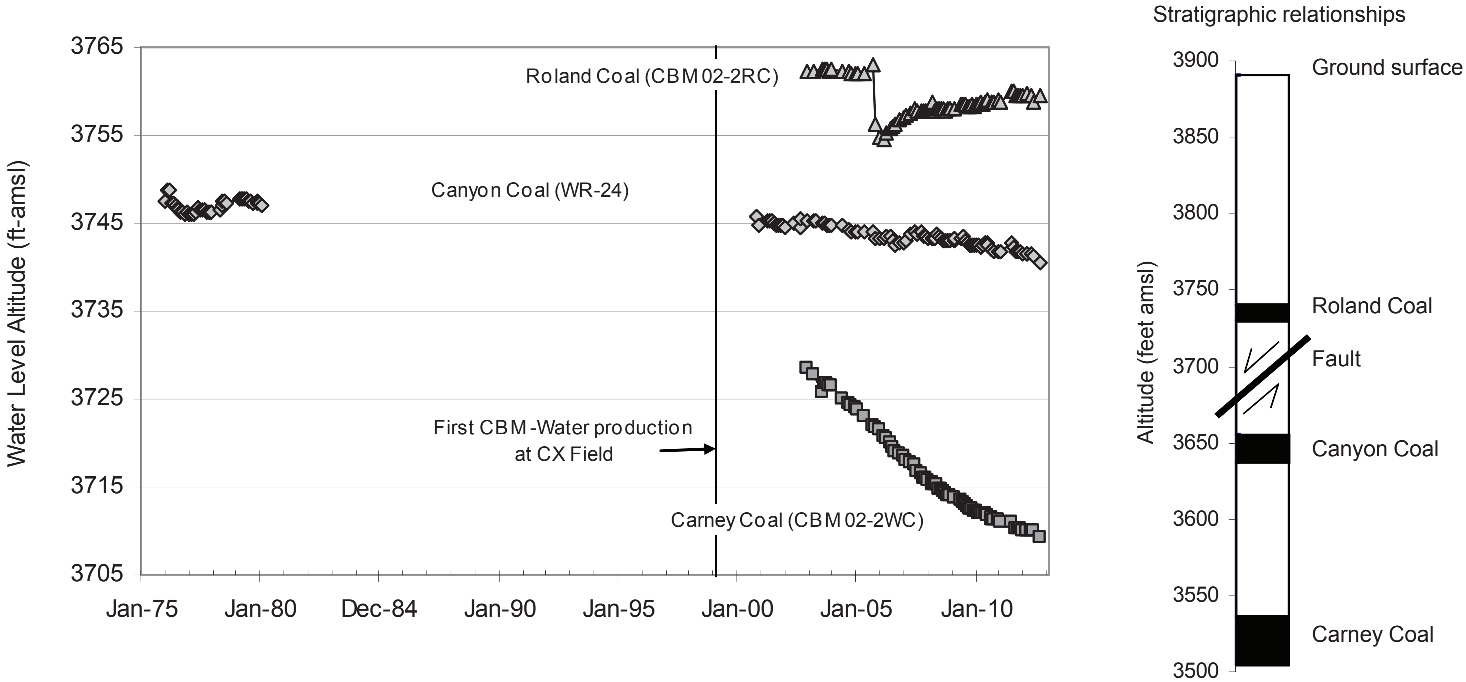


Figure 14. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM-related drawdown since its installation. 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.

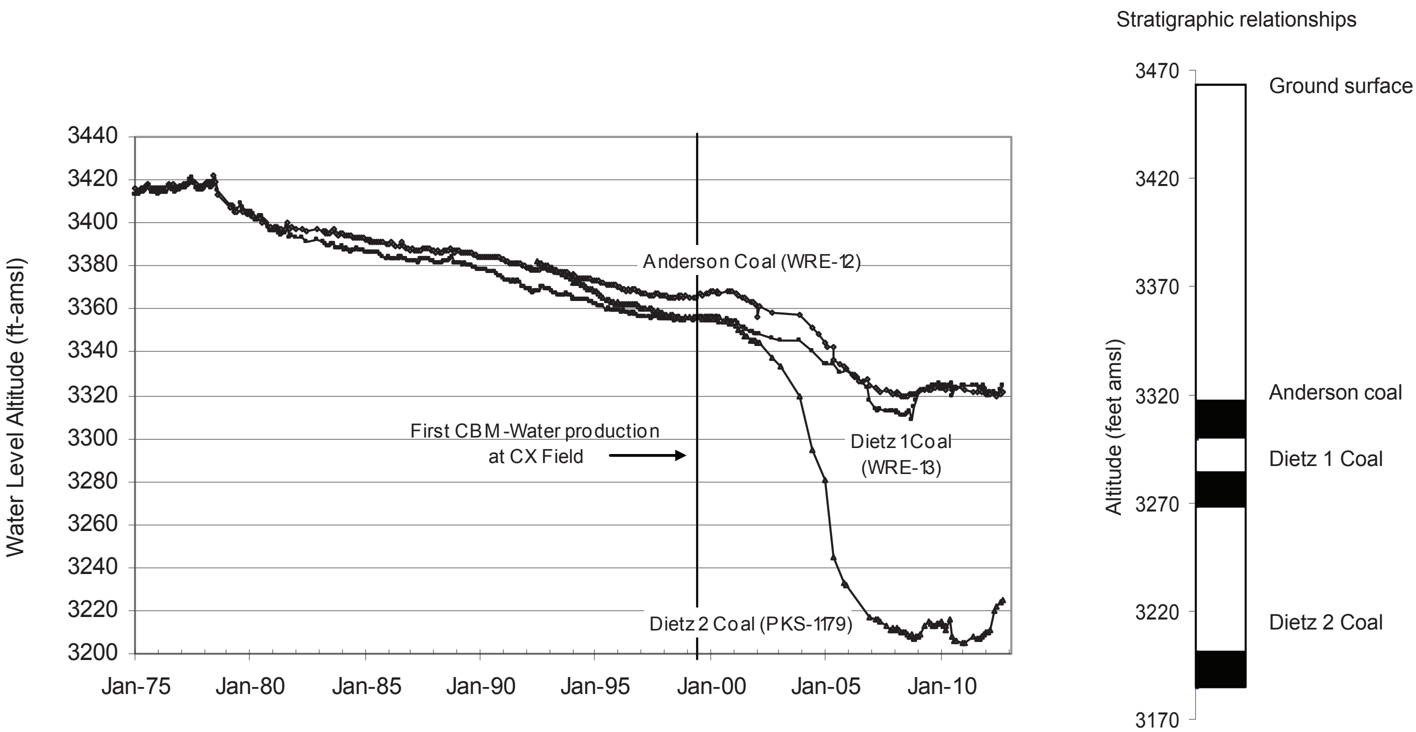


Figure 15. CBM production requires drawdown to near the top of producing zone; this is the case for both WRE-12 and WRE-13. Both coal seams have water-level elevations just above the coal seam elevation.

Changes in Tongue River Reservoir stage affect water levels in aquifers 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 reservoir stage levels, but water levels are more strongly influenced by mining and CBM production when these stresses are present (fig. 16). Since January 1995, the reservoir stage has ranged between 3,387 and 3,430 ft amsl (written commun., Mathew Nordberg, MT DNRC, November 2, 2012). Average reservoir stage during this time has been about 3,420 ft amsl, which is higher than the Dietz potentiometric surface; it is likely that some water has always seeped from the reservoir to the coal. The average stage during the water year 2012 was 3,422 ft amsl, which is higher than the historical average because reservoir storage goals have increased recently. The increased storage elevation steepens the gradient between water levels in the reservoir and water levels in the Anderson–Dietz coal, which are already depressed due to CBM production and coal mining. These factors combine to likely result in more water seeping into the coal from the reservoir (plate 2).

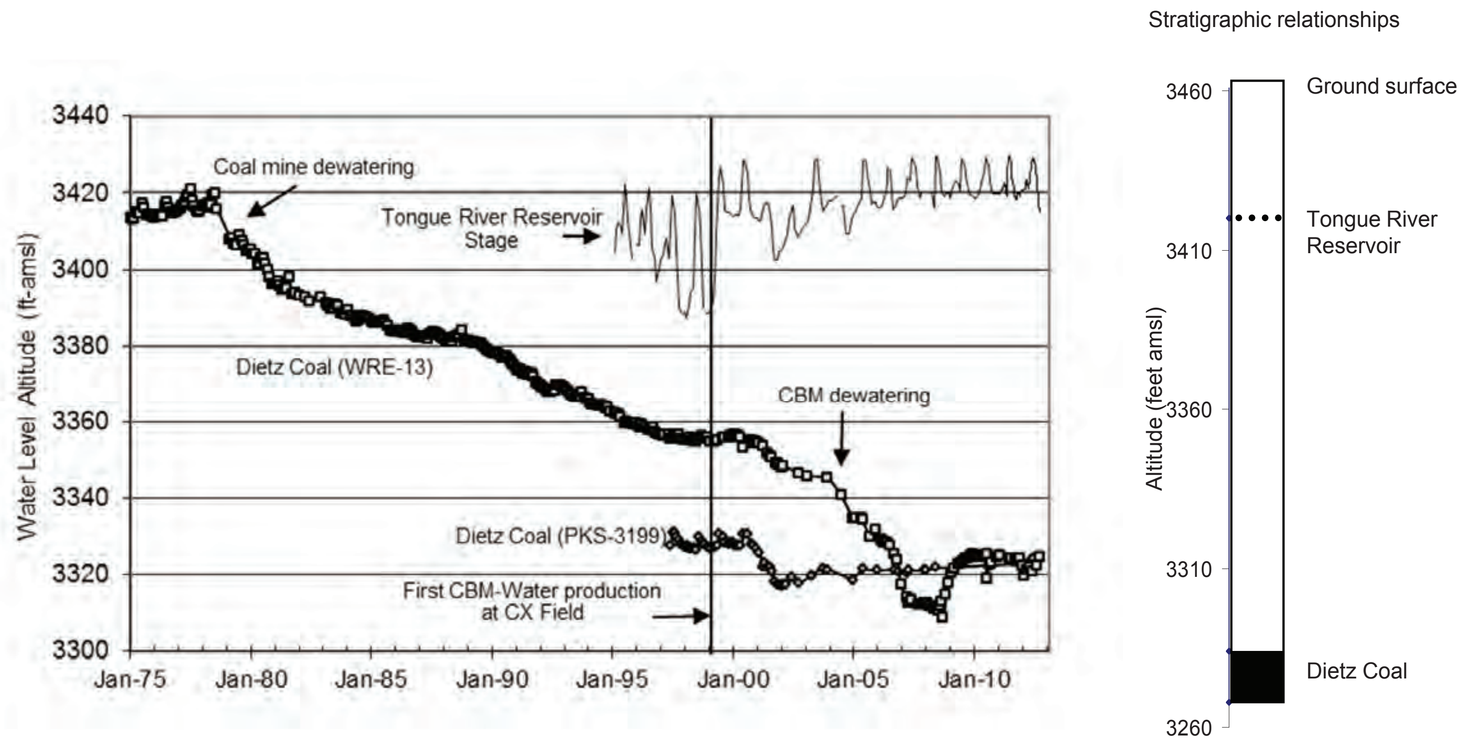


Figure 16. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Anderson–Dietz coal (WRE-13 and PKS-3199) prior to mining and CBM production. Coal mine and CBM influences dominate the hydrograph when present. Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

By 1999 water levels in the Squirrel Creek watershed in well WR-17, completed in the Anderson coal (fig. 17), were lowered 37 ft by coal mine dewatering, but by the time monitoring was suspended in 2000 had been lowered an additional 30 ft by CBM development. Water levels are no longer collected from this Anderson coal well because of hazardous methane production. Declining water levels (8.6 ft since the year 2000) in Anderson overburden at this site (well WR-17B) show a possible migration of water due to CBM production from underlying coalbeds or to surface coal mining. However, this sandstone aquifer is separated from the Anderson coal by more than 50 ft of shale, siltstone, and coal. The shallow, unconfined aquifer shows a rapid 30-ft rise following the start of CBM production, which is interpreted to be a response to leakage from an infiltration pond. In 2005 the use of the pond was discontinued and water levels in WR-17A have 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 ft between April 2005 and May 2007 (fig. 18). The nearest shut-in CBM wells are between 1.75 and 2.5 miles distant, but the nearest producing wells are more than 4 miles away. CBM production in the immedi-

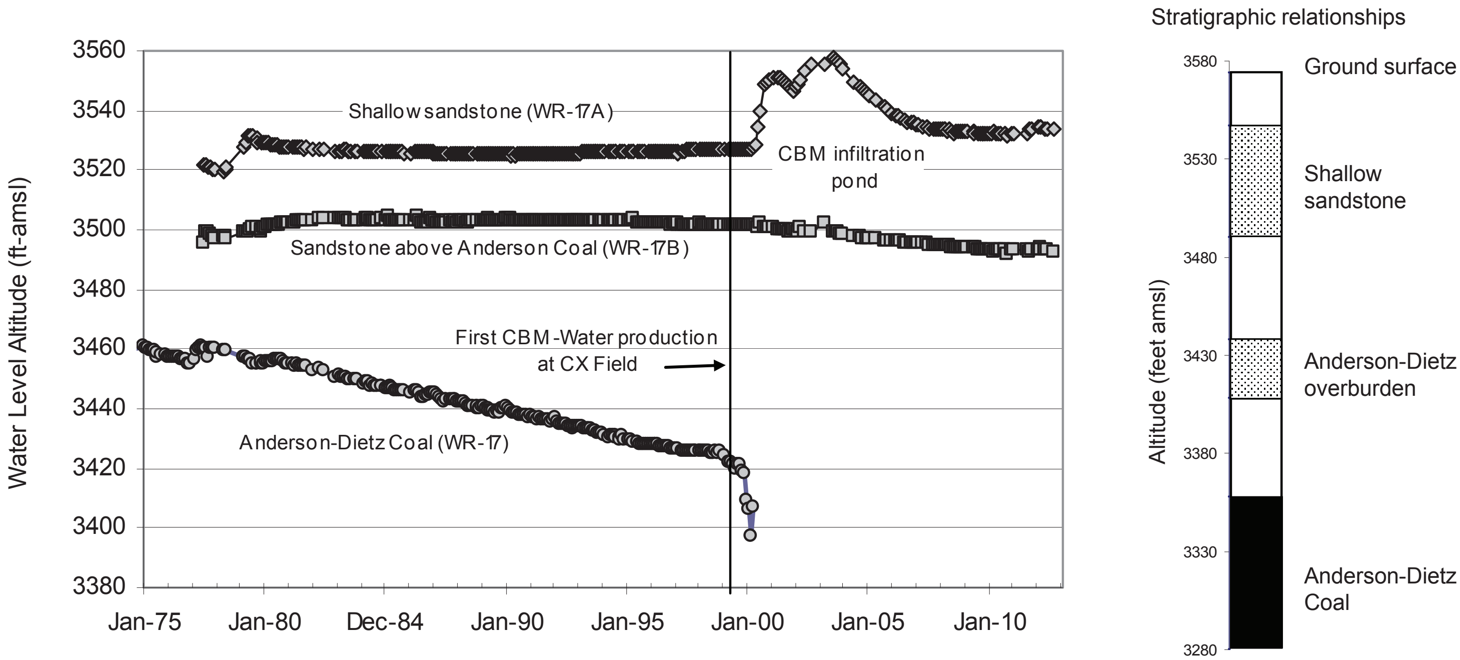


Figure 17. The water table rise in 1999 at WR-17A is in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water; therefore, the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in the Squirrel Creek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

ate area was discontinued in March 2007 and water levels in well CBM02-4WC recovered through October 2007. Since that time water levels have fluctuated in response to water pumped intermittently from CBM wells completed in the Wall coal along the Tongue River (2.5 miles away). Water levels have not recovered here despite the nearest wells being shut-in. CBM02-4WC's total depth was measured in September 2012 to be 256 ft, which is 35 ft less than the original completion depth of 291 ft. The drilling log lists a shale stringer within the Wall Coal (54.5 ft thick at 236 ft below the surface) at a depth of 237.5 ft. This well is completed open hole through the coal, so it is possible that an unlogged shale stringer at 256 ft may have squeezed in, shutting off half the aquifer to the well. This change in the well completion may be contributing to this well's failure to recover to baseline water levels.

Water Quality. Upper and Lower Anderson Springs, within the current CBM producing area, were sampled in October 2011 and June 2012 (appendix C). Both springs discharge from the Anderson coal. The TDS of Lower Anderson spring water remains around 1,500 mg/L and the SAR around 3. Unlike Upper Anderson Spring, the water quality of Lower Anderson Spring was not influenced by the increased precipitation during 2011. Upper Anderson spring water TDS rose to more than 5,000 mg/L after 2011's high precipitation. Previous salinities were typically around 3,700 mg/L. The most recent sample from June 2012 shows the salinity declining, but at 4,400 mg/L it remains above earlier years. The higher salinity was driven by calcium/magnesium salt sources that lowered the SAR during this period of high salinity from 9.8 to 5.9. The most recent sample shows an intermediate SAR value of 6.0. The water-quality changes in Upper Anderson Spring indicate a significant component of local recharge.

Tongue River Alluvial-Aquifer Water Levels and Water Quality

Water-quality samples were collected in October 2011 and June 2012 (appendix C) from well WR-59, completed in 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

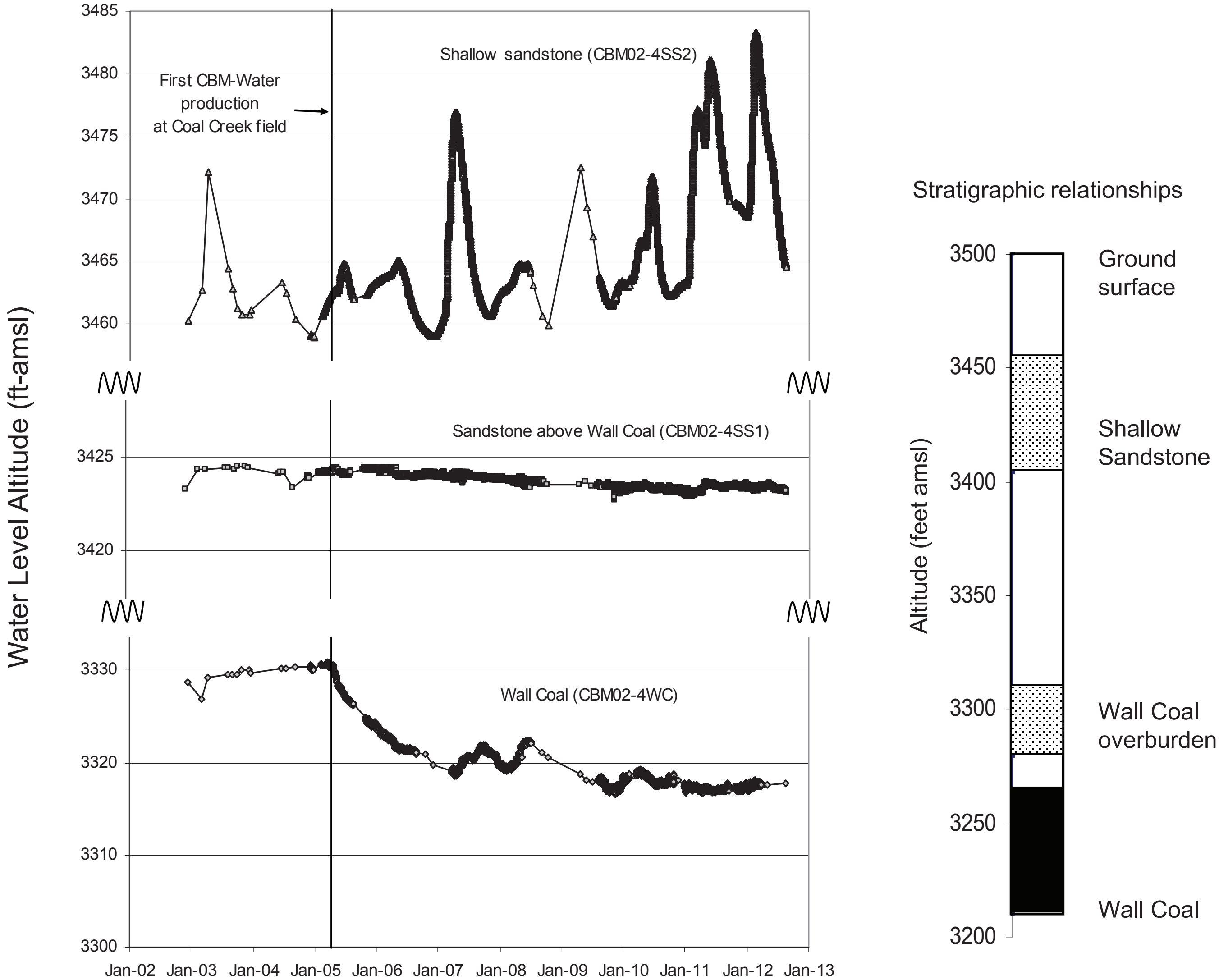
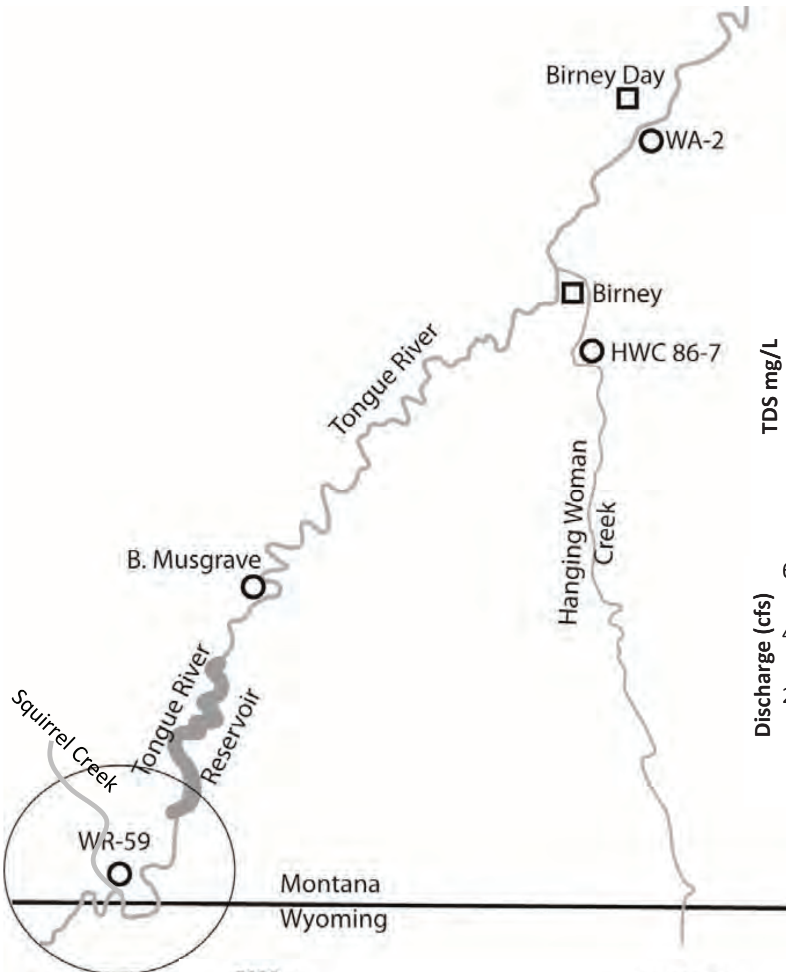


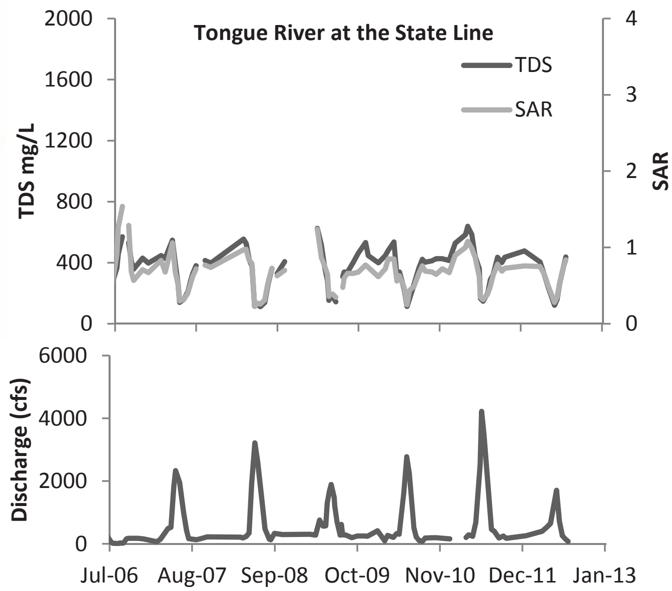
Figure 18. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal (CBM02-4WC) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in water level that might be related to long-term 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 short-term 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.

SAR value increased from 5.6 to 6.4 during approximately the same time period (fig. 19). A similar peak also occurred in October 2011. 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), the B. Musgrave domestic well north of the Tongue River reservoir is regularly sampled; the most recent sample is from June 2012 (appendix C). TDS concentrations vary 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 Tongue River discharge, but neither water level nor river discharge appear to be closely linked to TDS. The upward TDS trend between September 2006 and October 2008 (747 to 1,074 mg/L) is repeated between June 2009 (775 mg/L) and October 2011 (1,280 mg/L), which shows that regular monitoring is vital to better understand cyclic water-quality change. SARs are relatively low because the alluvial groundwater chemistry is dominated by calcium and magnesium.

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.





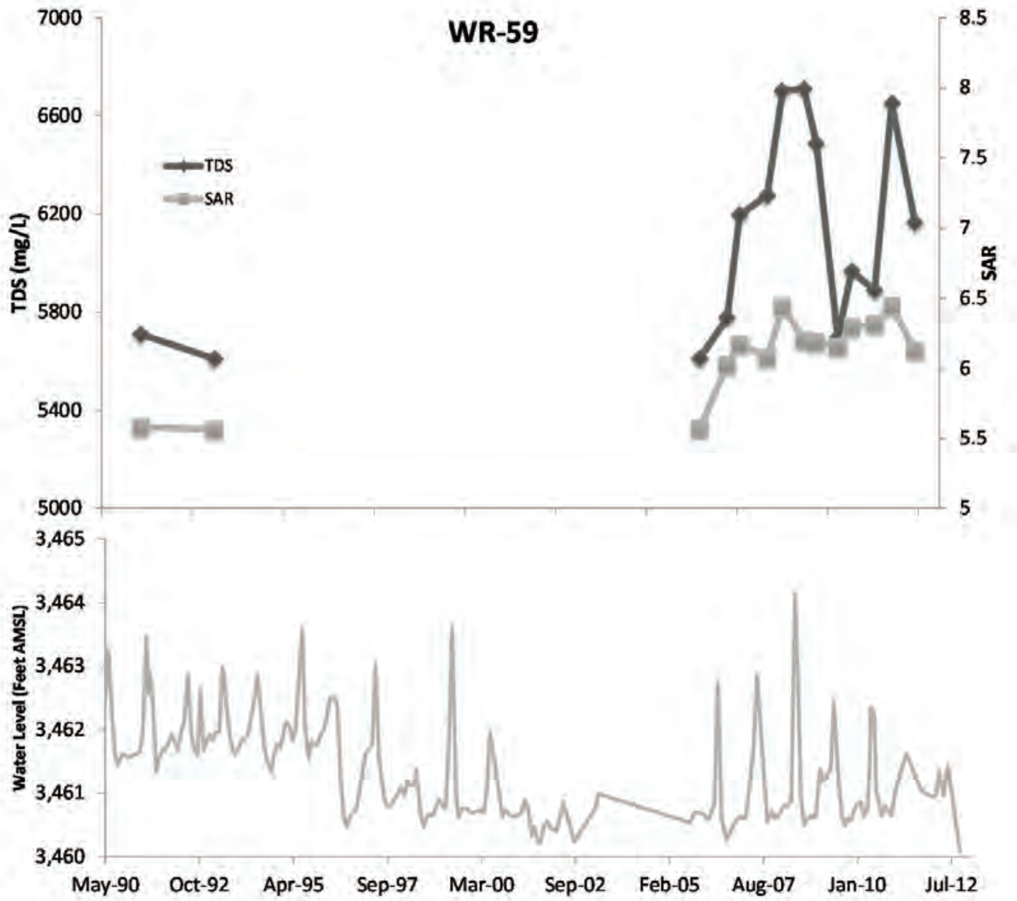
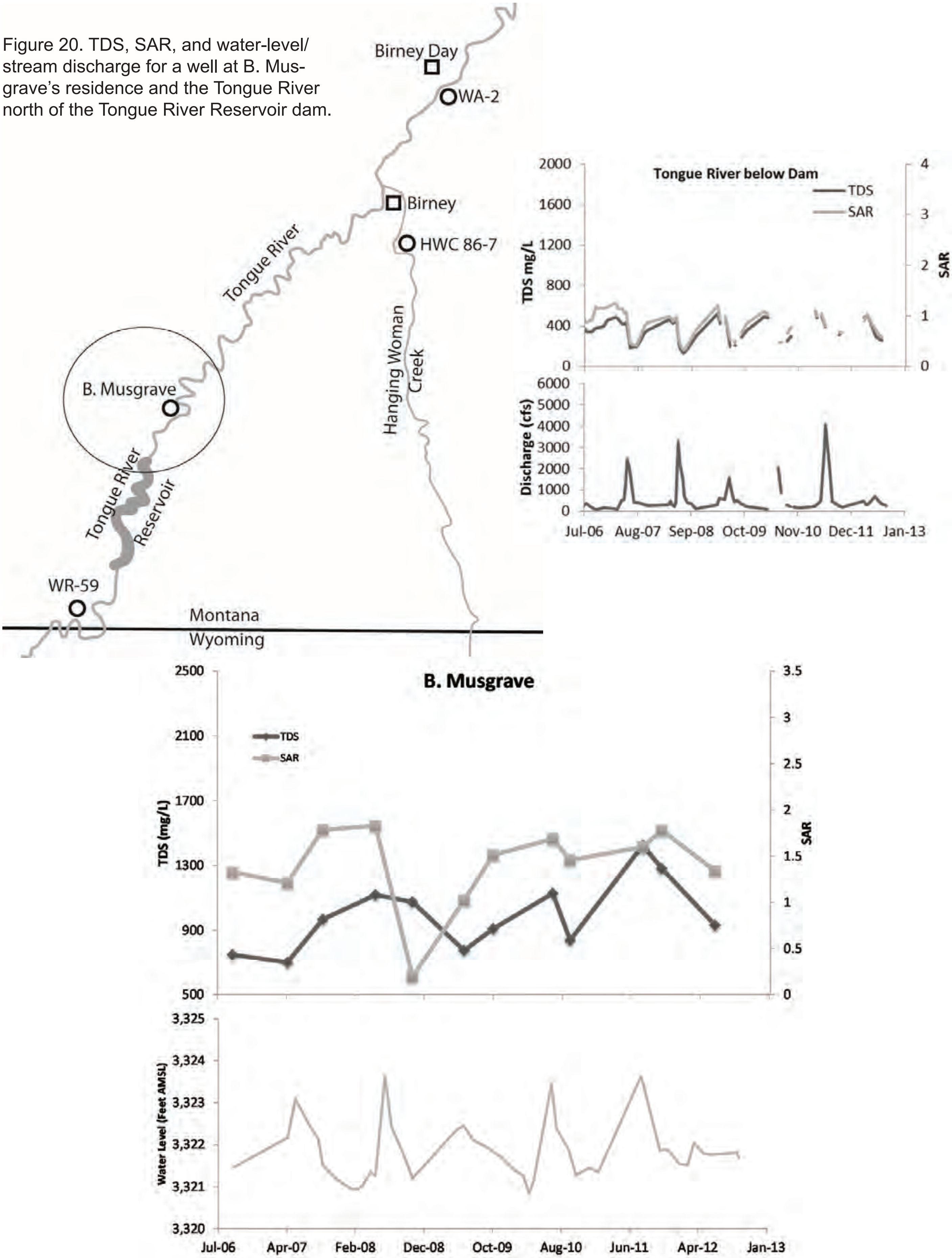


Figure 20. TDS, SAR, and water-level/stream discharge for a well at B. Musgrave's residence and the Tongue River north of the Tongue River Reservoir dam.



Hanging Woman Creek enters the Tongue River near the town of Birney approximately 20 miles north of the state line. Near the confluence, well HWC86-7 is completed in the Hanging Woman Creek alluvium (fig. 21) and was sampled in October 2011 and June 2012. TDS in water from HWC86-7 was 3,824 and 3,763 mg/L and SARs were 8.3 and 8.3, respectively. Since sampling began in 1987, 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 similar increases, it is unlikely that these changes are related to CBM development.

Further downstream, water-quality samples collected from alluvial monitoring well WA-2 near Birney Day School Bridge in October 2011 and June 2012 (fig. 22; appendix C) show TDS concentrations in Tongue River alluvial water have been relatively steady between August 2006 and June 2012. SAR values are very high but have varied only from about 20 in August 2006 to 23 in August 2010. Alluvial groundwater levels mimic the river stage. The water chemistry is dominated by sodium and bicarbonate, which may reflect the influence of coal aquifer discharge to the alluvium.

WYOMING CBM FIELDS NEAR THE MONTANA BORDER

Data for CBM wells in Wyoming are available from the Wyoming Oil and Gas Conservation Commission website (http://wogcc.state.wy.us/). For this report, only water production data for wells located in Wyoming townships 57N and 58N were considered (plate 1). For the purpose of this report the CBM producing areas near the state line are referred to as the Prairie Dog Creek and Hanging Woman Creek 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 Montana's CX field. Methane is produced from the Roland, Smith, Anderson, Dietz, Canyon, Carney, Cook, King, and Flowers–Goodale (Roberts) coals (appendix D). During 2012, 515 CBM wells produced methane and/or water in the Prairie Dog Creek field, a decrease of 340 wells from 2011. Cumulative water production for 2012 was 16.9 million bbls. Monthly water production in the field peaked in mid-2002 at nearly 7 million bbls per month. For the next 5 years water production fluctuated between 4 and 5 million bbls per month; however, since August 2008 the water production has fallen steadily, and in the fall of 2012 was only about 2 million bbls per month (fig. 23). Gas production rose fairly consistently until early 2008; since then production has fallen steadily (fig. 23).

Aquifer water levels. Water-level drawdown in Montana attributed to CBM production in the Prairie Dog Creek field cannot be separated from drawdown caused by Montana production in the CX field; therefore Prairie Dog Creek water levels are included in the earlier CX field discussion.

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). This field produces from the Roland, Anderson, Dietz, Canyon, Cook, Brewster–Arnold, Knobloch, Flowers–Goodale (Roberts), and Kendrick coalbeds (appendix D). During 2012, 145 CBM wells produced methane and/or water in the Hanging Woman Creek field, a decrease of 89 wells from 2011. Total water production for the 12-month period was 9.8 million bbls. Water production began to climb in November 2004, and peaked in September 2007 at 2.5 million bbls/month (fig. 23). Since that time, water production has fallen to less than 1 million bbls per month. Gas production has been low compared to nearby fields throughout the life of the field.

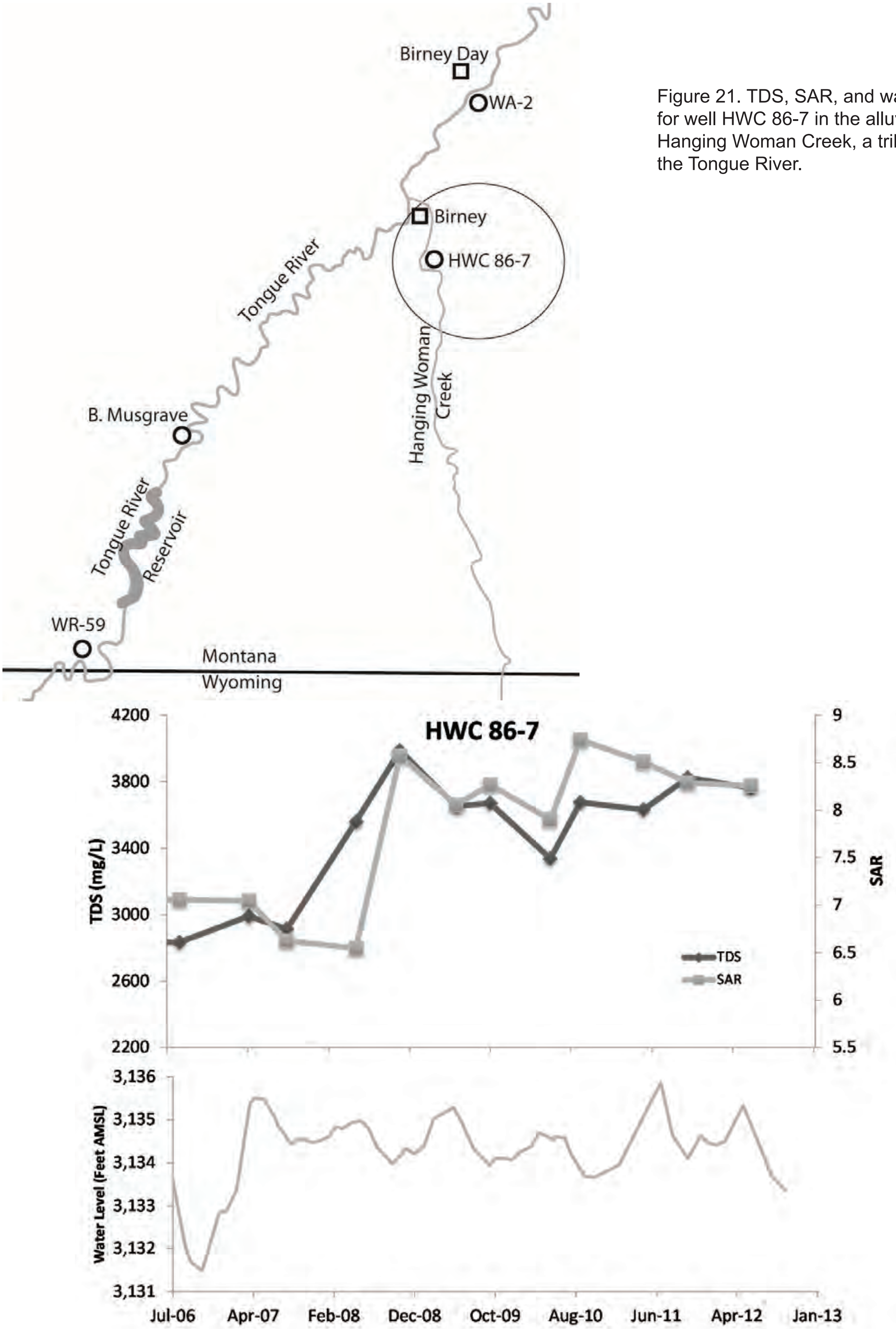


Figure 21. TDS, SAR, and water level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.

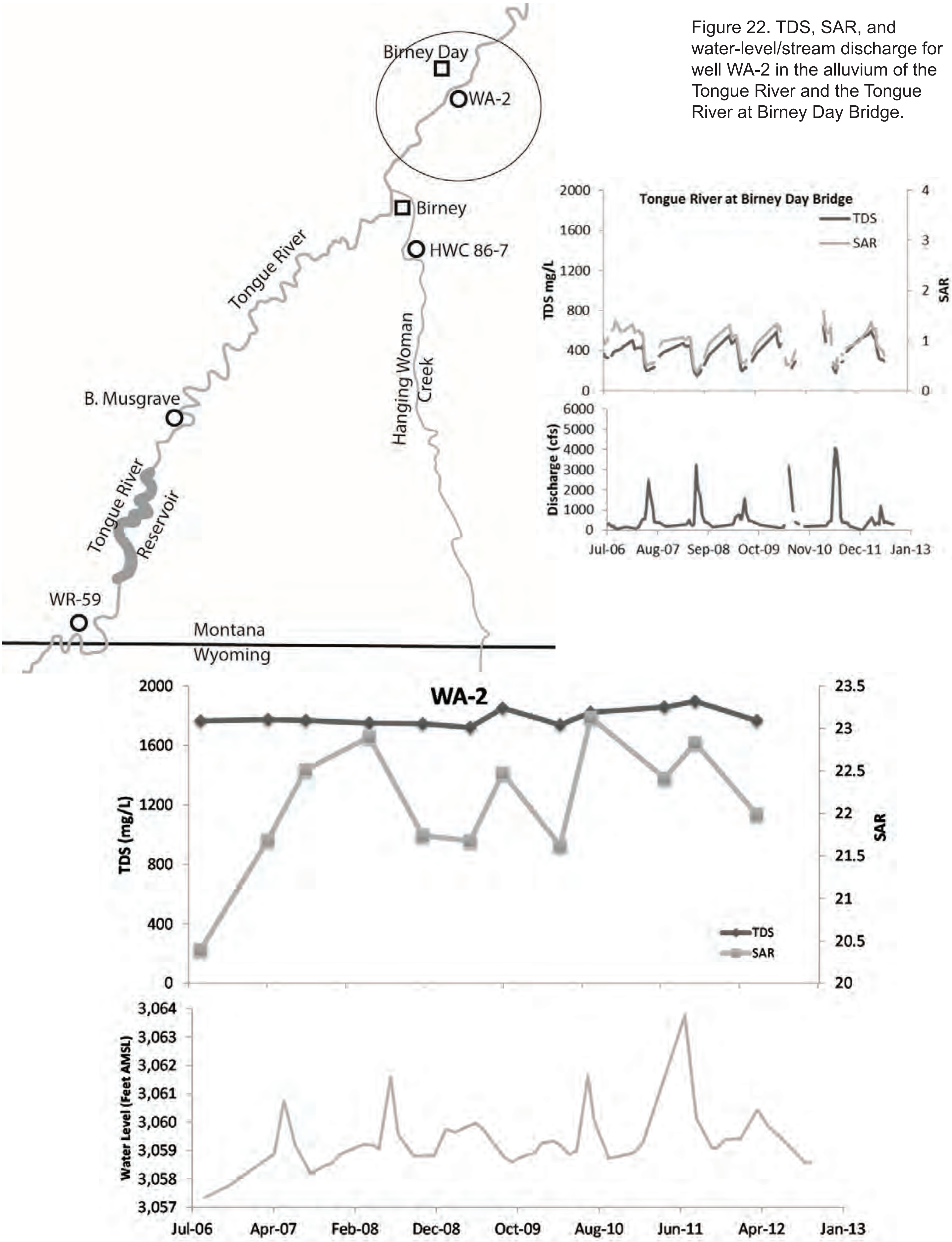


Figure 22. TDS, SAR, and water-level/stream discharge for well WA-2 in the alluvium of the Tongue River and the Tongue River at Birney Day Bridge.

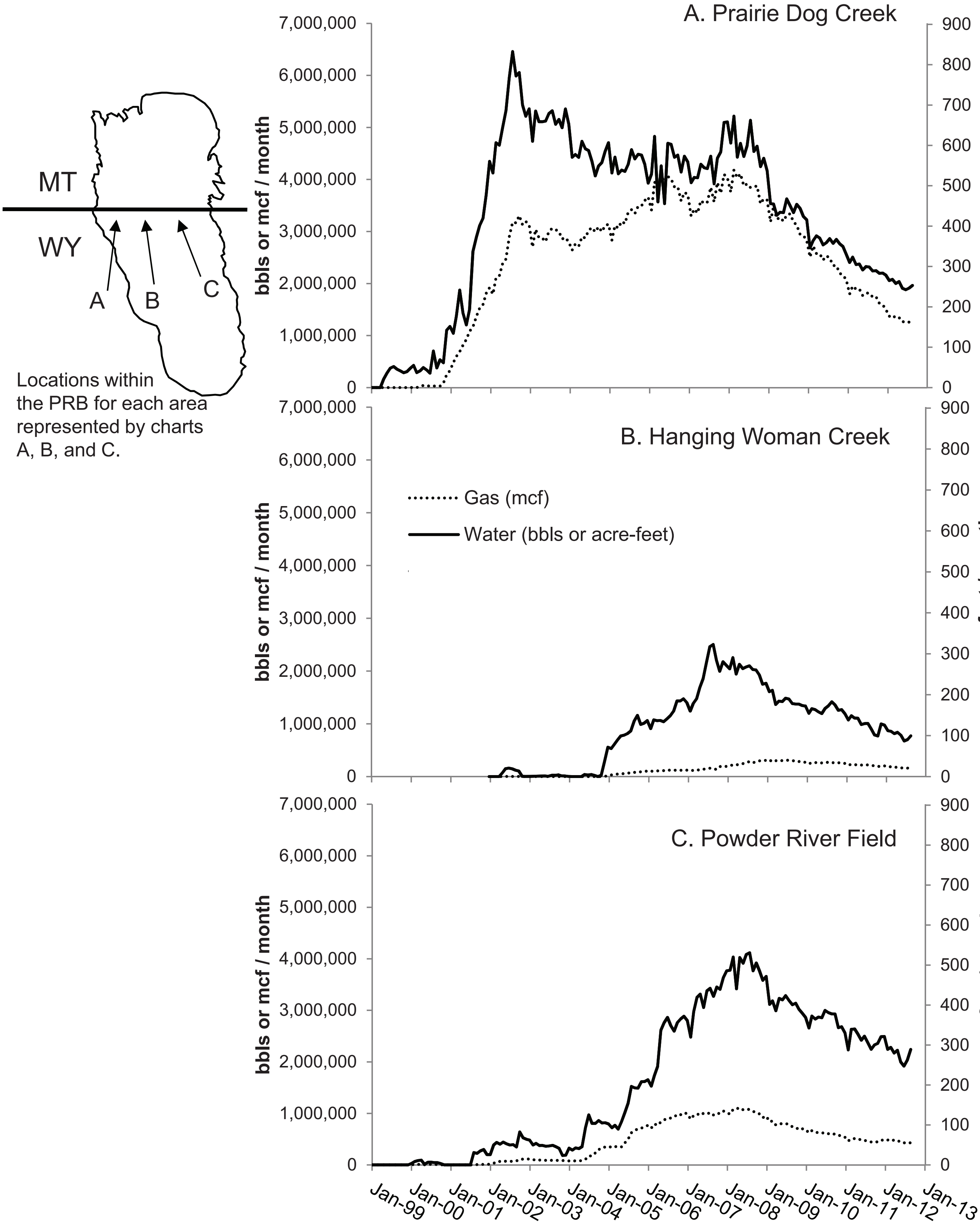


Figure 23. Total water (solid line) and gas (dashed line) produced per month in northern Wyoming CBM fields.

Bedrock-aquifer water levels. Drawdown due to Hanging Woman Creek gas field production 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 the Smith, Anderson, and Canyon coals (fig. 24). Water levels in the alluvium, overburden sandstone, and Smith coal do not respond to CBM production. The water level in the Anderson coal has dropped almost 59 ft, but since about January 2012 has risen about 5 ft. The rising water level is likely a response from Wyoming CBM wells being shut-in. The water level in the Canyon coal has dropped about 132 ft (fig. 25) since January 2006.

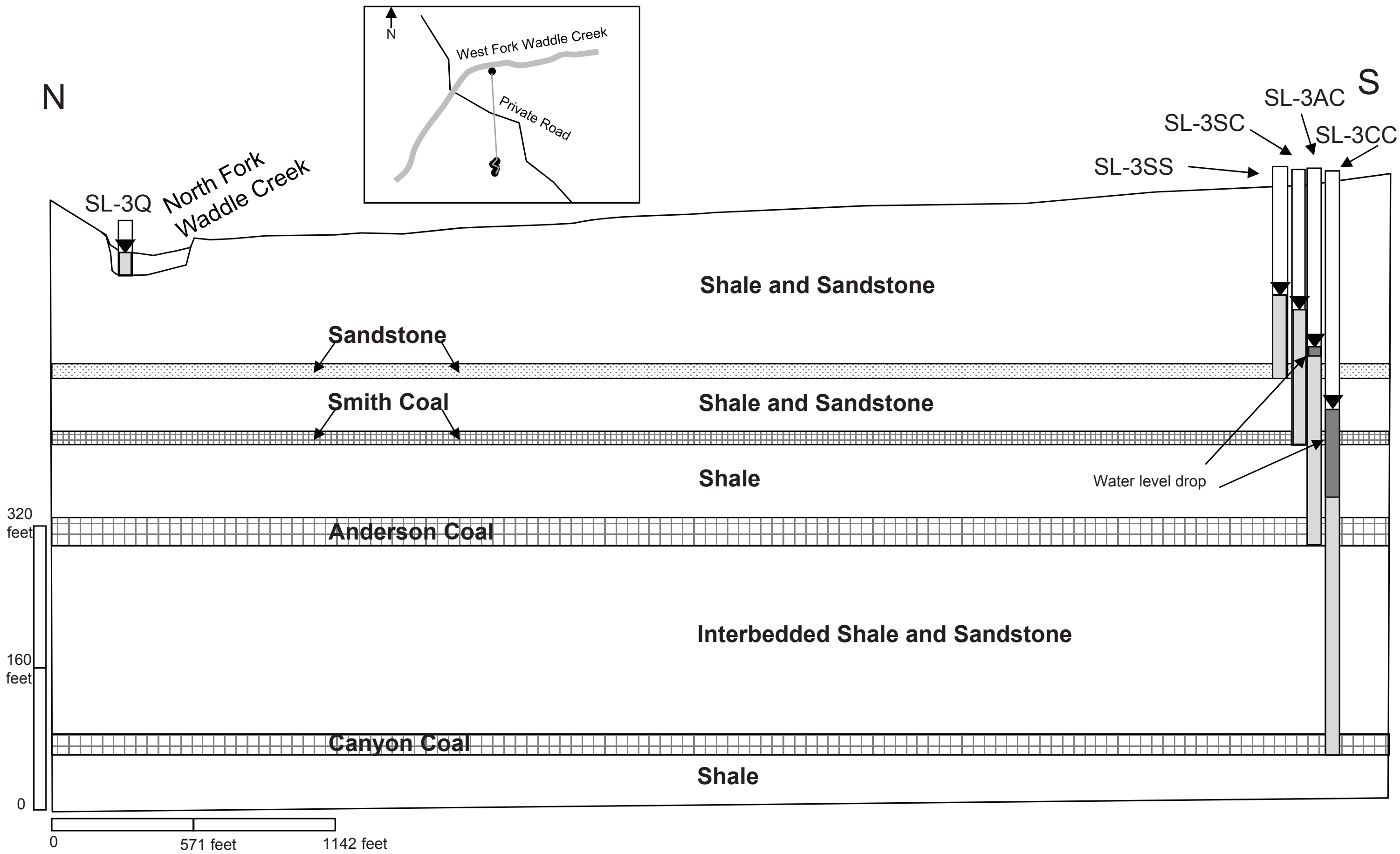


Figure 24. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coalbeds located at T. 9 S., R. 42 E., section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2012. The water level in the Anderson Coal has lowered about 58.5 ft and now is recovering. The rising water level is likely a response of nearby CBM wells being shut-in. The Canyon coal has lowered about 131.7 ft since well installation. The wells are located roughly 1 mile north from nearest CBM field. Vertical exaggeration is 3.6:1.

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 in the Smith and Anderson coals (fig. 26). The water level in the Anderson coal responds to CBM production in Wyoming and is currently 67.2 ft lower than when monitoring began. In July 2010, water levels in SL-4AC recovered 9 ft, 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 has also dropped slightly (13.1 ft overall); the installed data logger shows high frequency oscillations characteristic of pumping in nearby wells 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 ft from the Forks Ranch Headquarters well, which was completed in the Smith coal in June 2006.

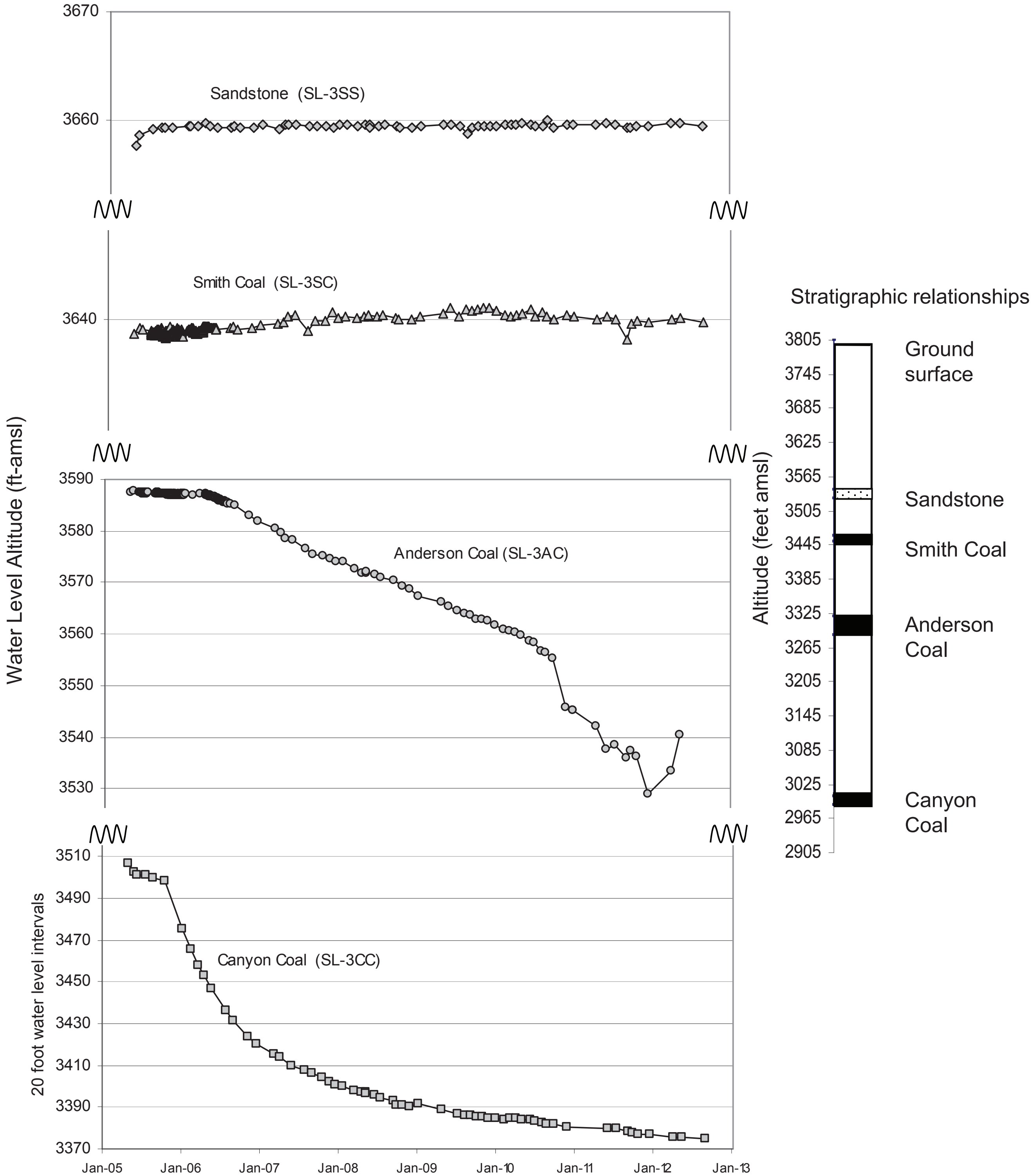


Figure 25. Water levels in the overburden sandstone (SL-3SS) and Smith (SL-3SC) coals are not responding to CBM development. The water level in the Canyon coal dropped about 130 ft in response to CBM production. The water levels in the Anderson coal have dropped about 60 ft in response to CBM production. However, the water levels are rising, and this is likely a response from nearby CBM wells being shut-in . Note: The vertical scales of the stratigraphic relationship and the hydrograph are different. The Y axis scale is broken to show better hydrograph detail.

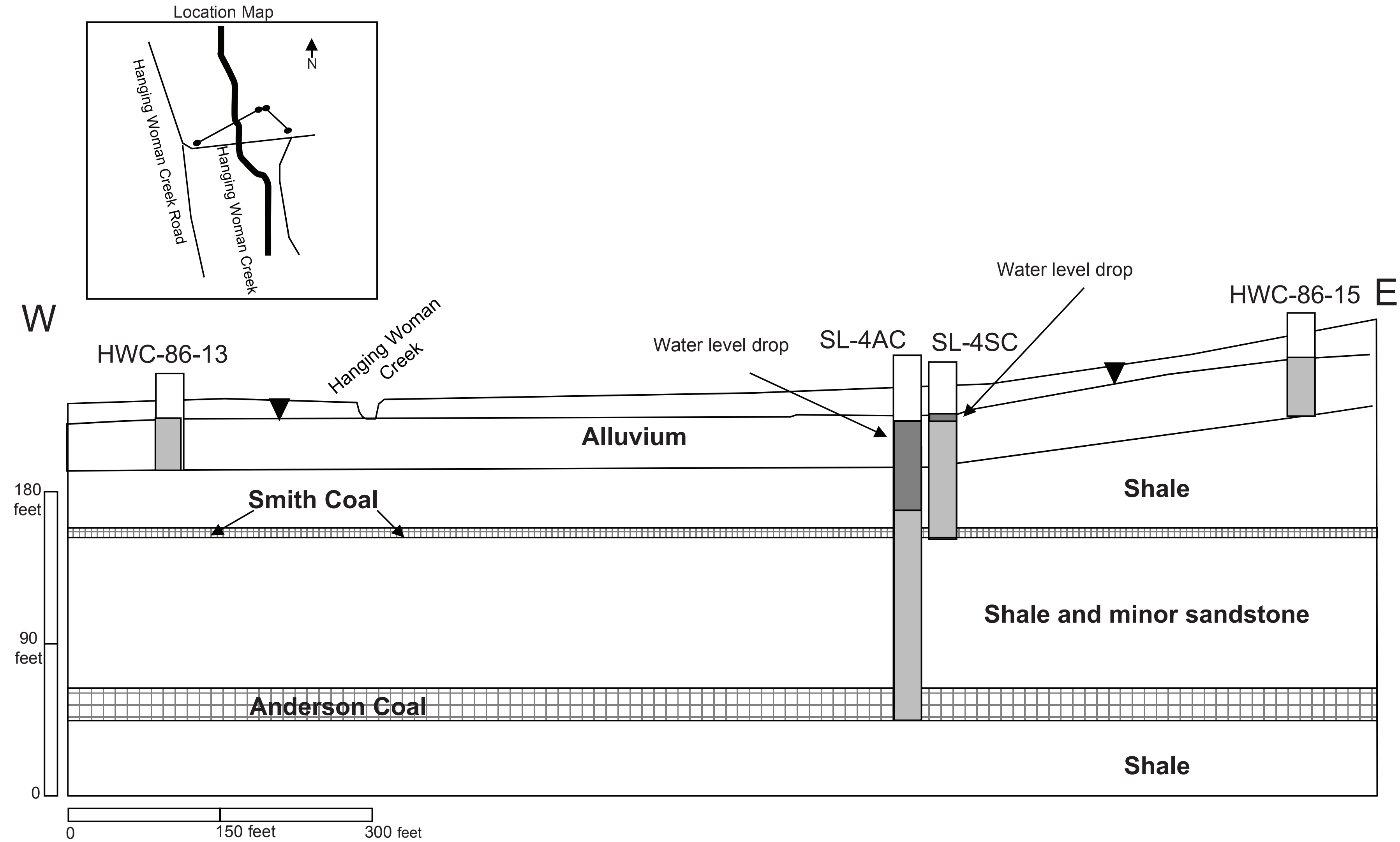


Figure 26. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Woman Creek located in T.10 S., R. 43 E., section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson coal and Smith coal have lowered in response to CBM production. The Anderson has lowered by about 67.2 ft and the Smith has lowered about 13.1 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 Septermber 2012. Vertical exaggeration is 7:1.

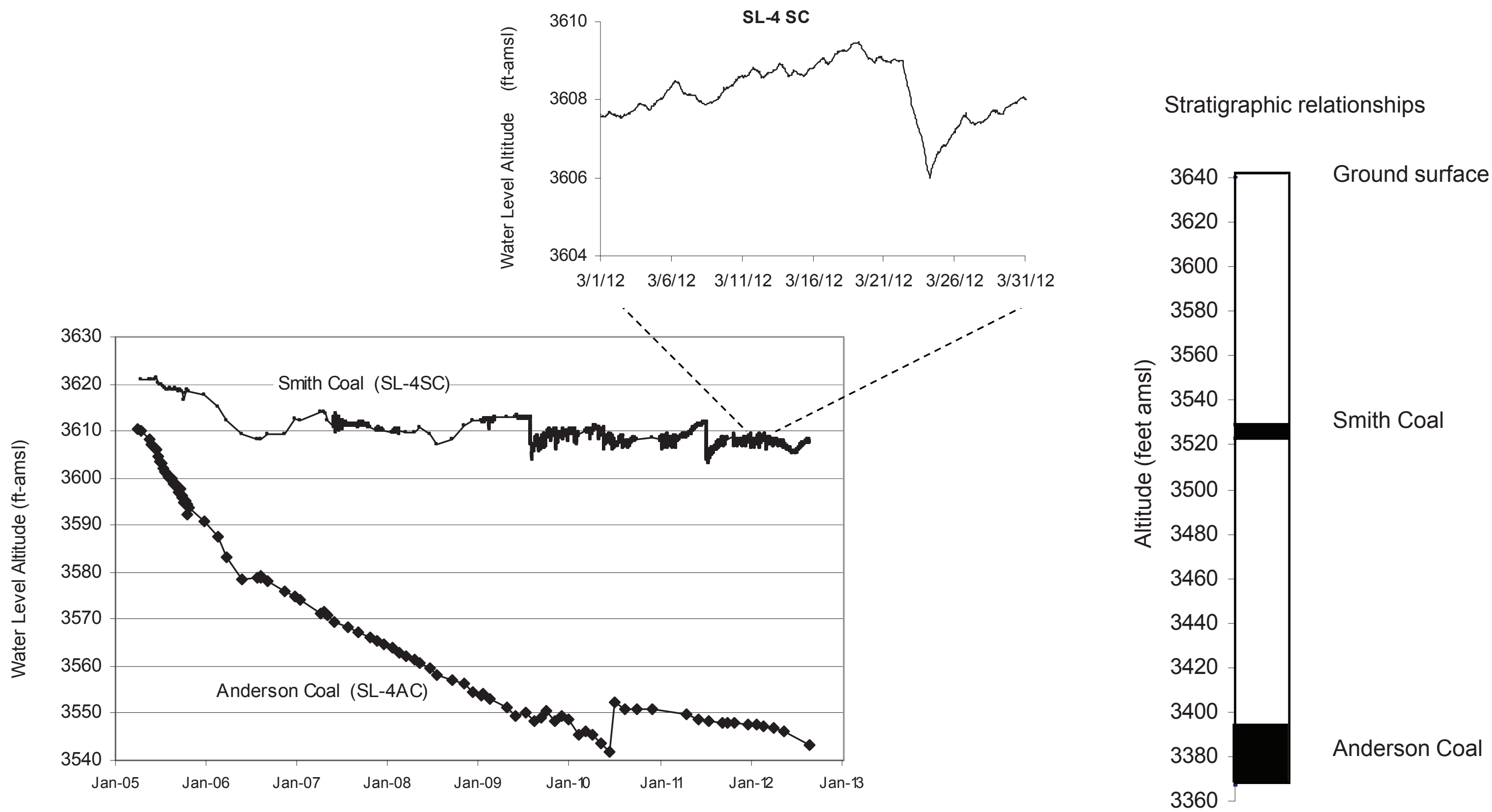


Figure 27. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson coal appear to have lowered about 67 ft from April 2005 to September 2012 in response to CBM development; however, it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft; this is presumably due to activities in the nearby CBM 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.

Monitoring well site SL-5 is located to the northeast and approximately 4 miles distant from the nearest CBM development from the Anderson, Canyon, Cook, Kendrick and Roberts coals in Wyoming (plate 1). Drawdown in the Anderson coal has been about 5.8 ft at this site. There is no noticeable trend in Dietz coal water levels in well SL-5DC. The Canyon coal water level has risen more than 16.2 ft since monitoring began in July 2005 (fig. 28). The rise may be a response to climatic variability; however, aquifers over 400 ft below the surface, such as the Canyon coal in this location, are usually insulated from all but the most long-term climatic patterns. Additionally, water levels at the other wells at SL-5 show no evidence of climatic influence. 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 upward movement. The increasing water level may be a result of a failed seal in the neat cement in the Canyon coal well. There may be communication along the well bore between the Canyon and the higher-pressure Anderson coal. The water-level decline in the Anderson coal may be a result of equilibration between these two aquifers rather than from CBM development. Alternatively, it may be a nearby CBM or domestic well that has allowed the two aquifers to communicate. Evidence for seal failure in SL5-CC includes the linkage of the initial water-level rise with attempted sample collection. No sample was collected because methane gas caused the pump to cavitate.

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 alluvial water levels reflect responses to seasonal weather patterns (figs. 29 and 30).

Water-quality samples were collected from wells HWC 86-13 and HWC 86-15 during October 2011 and June

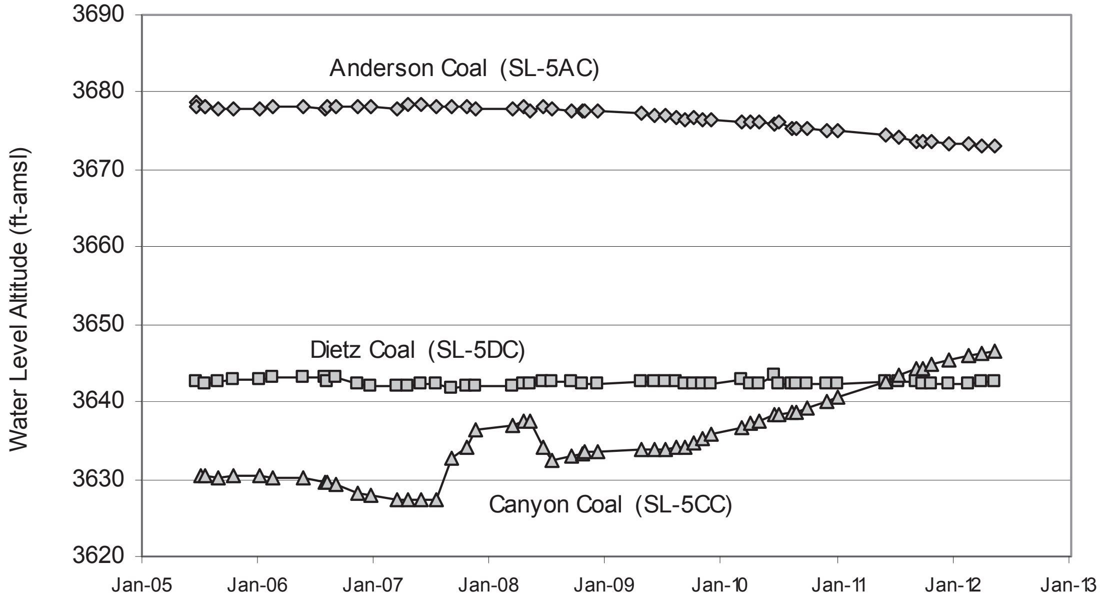


Figure 28. Coalbed-methane development in the Anderson coal may be causing a slight decline in water level in the Anderson coal at the SL-5 site. The Canyon water level has risen since mid-2007 and is now at approximately the same level as the Dietz coal water level. The water-level increase may be a result of a failed well seal in the Canyon coal well or nearby development that connected the aquifers. The nearest CBM development is approximately 4 miles away in Wyoming.

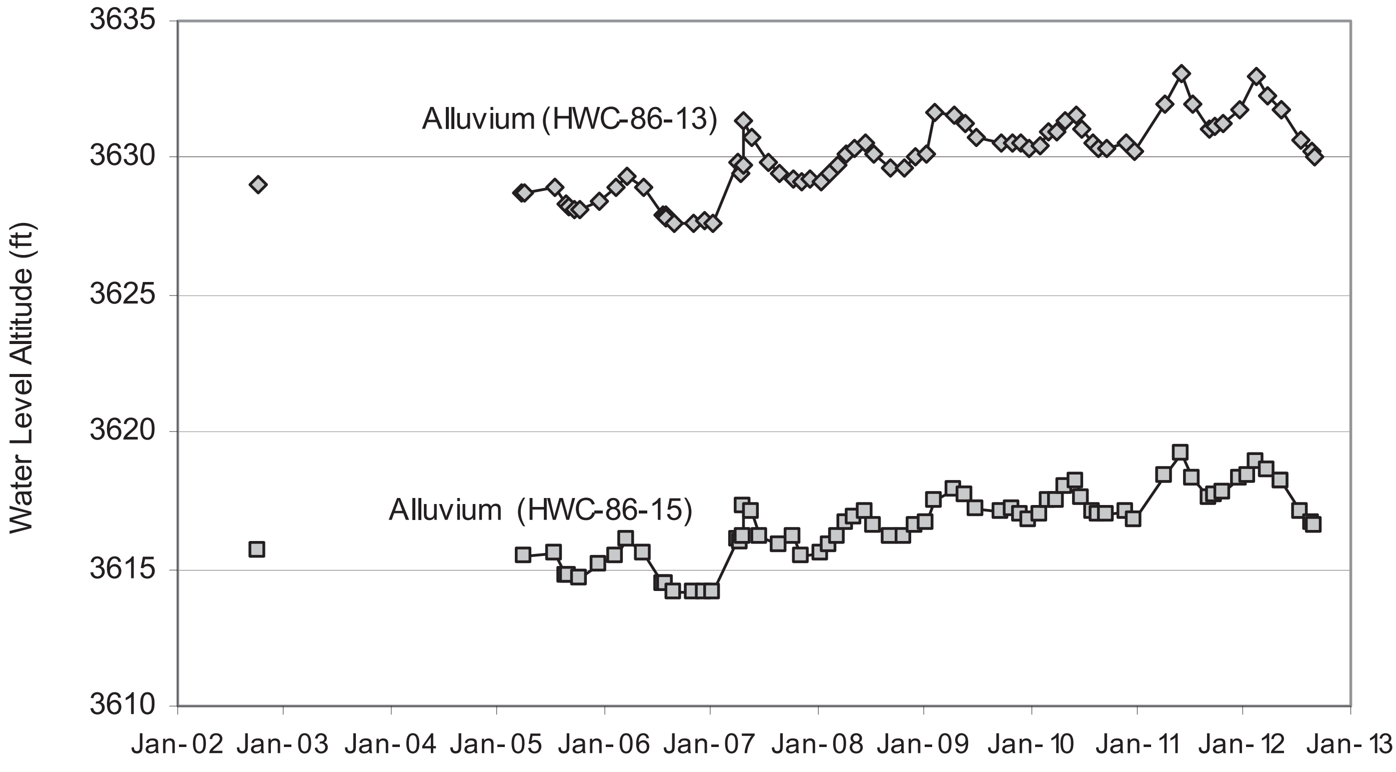


Figure 29. The water level in the Hanging Woman Creek alluvial aquifer near the Montana–Wyoming state line reflects water table response to meteorological pattern. Shown in plate 1.

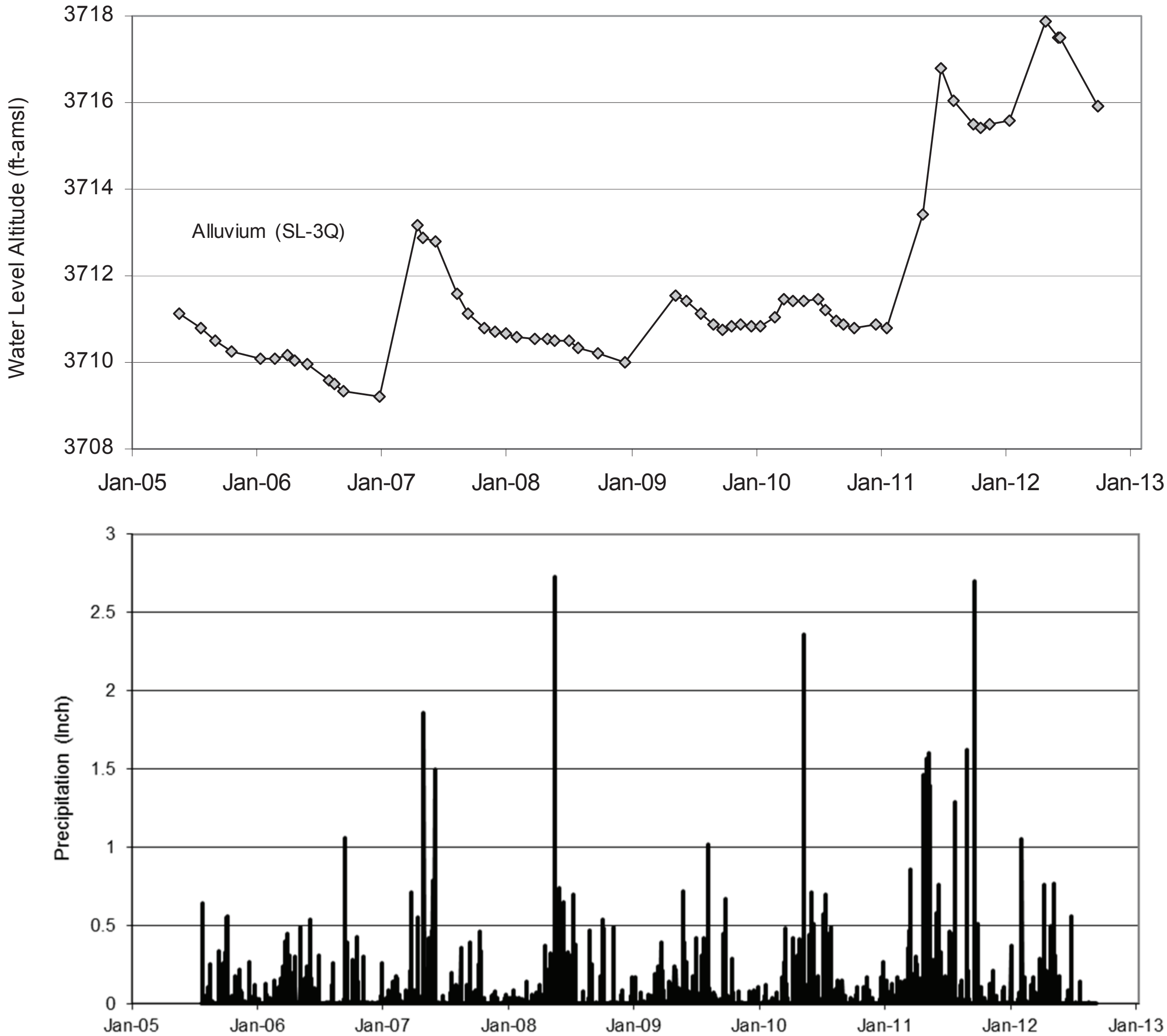


Figure 30. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to plate 1. Precipitation at the SL-3 weather station is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous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

2012 (appendix C). During the sampling events, TDS concentrations in the alluvial water range from 6,359 to 8,383 mg/L and SAR values range from 10.8 to 11.0. Sodium and sulfate dominate the alluvial water chemistry. There is a natural variation of approximately 1,000 mg/L in water from both wells since sampling began in 1987. Water-quality samples were also collected on North Fork Waddle Creek at SL-3Q during October 2011 and June 2012 (appendix C). TDS and SAR concentrations have varied little since sampling began in 2005; during these sampling events TDS values were 3,818 and 3,731 mg/L and SAR values were 4.9 and 5.0, respectively. The water chemistry is dominated by sodium and sulfate. There appears to be no discernible 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 coals (appendix D). During water year 2012, a total of 447 wells produced methane and/or water. The cumulative water production for the 12-month period was 26.8 million bbls, but water production in these fields increased steadily from January 2004 through July 2008, when it peaked at just more than 4 million bbls per month. As of September 2012, water production is approximately 2.5 million bbls per month. Gas production also peaked in 2008 and has been declining steadily since (fig. 23).

Bedrock-aquifer water levels. Monitoring well SL-7CC is completed in the Canyon coal less than 1 mile north of the state line near Wyoming CBM production. Water levels are not currently monitored in this well due to the volume of free gas released (discussed in the 2005 annual monitoring report; Wheaton and others, 2006). Gas migration was occurring prior to CBM development in this area, so at least some portion of the venting is due to naturally migrating 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 as described for SL-7CC. For personnel safety, water levels are not currently measured at SL-6CC. Well SL-6AC is completed in the Anderson coal and no CBM-related water-level change or gas releases 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, 32). Site SL-8 is located on a large meander, and the river likely loses flow to the alluvium on its upgradient end and gains at the lower end. A stock well producing from an 86-ft sandstone unit 500 ft below ground surface (MBMG file data) at this location is flowing under artesian pressure, indicating an upward gradient with depth. Water levels in alluvial monitoring wells at this site do not indicate responses to CBM production or water management in Wyoming.

Water-quality samples were collected from SL-8-2Q in October 2011 and June 2012 (appendix C). TDS concentrations ranged from 2,719 and 2,189 mg/L and SAR values from 4.4 to 3.7, respectively. The water chemistry is dominated by calcium, sodium, and sulfate. The TDS and SAR values are higher in the well closest to the Powder River (fig. 31), but no CBM impacts are apparent. Data are insufficient to identify seasonality trends.

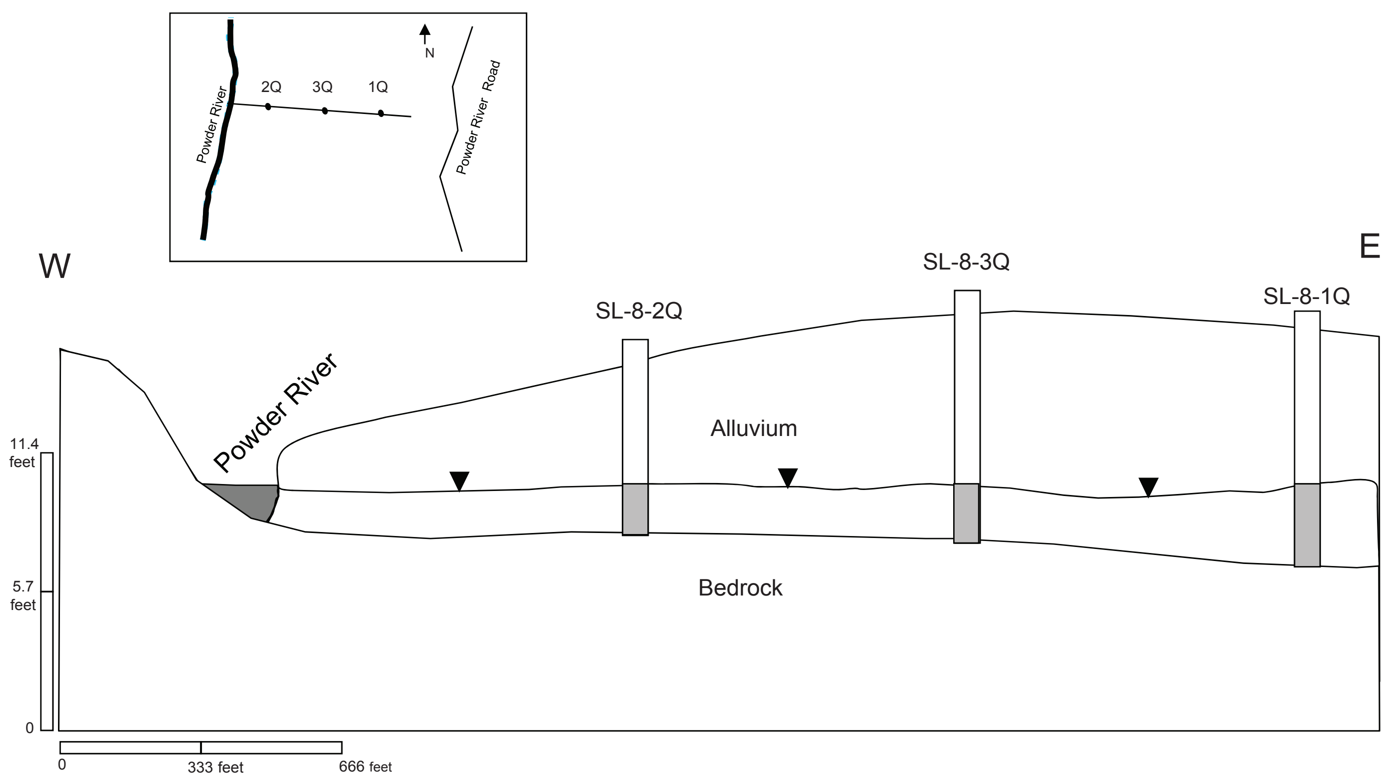


Figure 31. Cross section of alluvial wells south of Moorhead near the Powder River located in T. 9 S., R. 47 E., section 25. Groundwater in the alluvium appear to flow parallel to the river valley. Water levels for this cross section were taken in September 2012. Vertical exaggeration is 58:1.

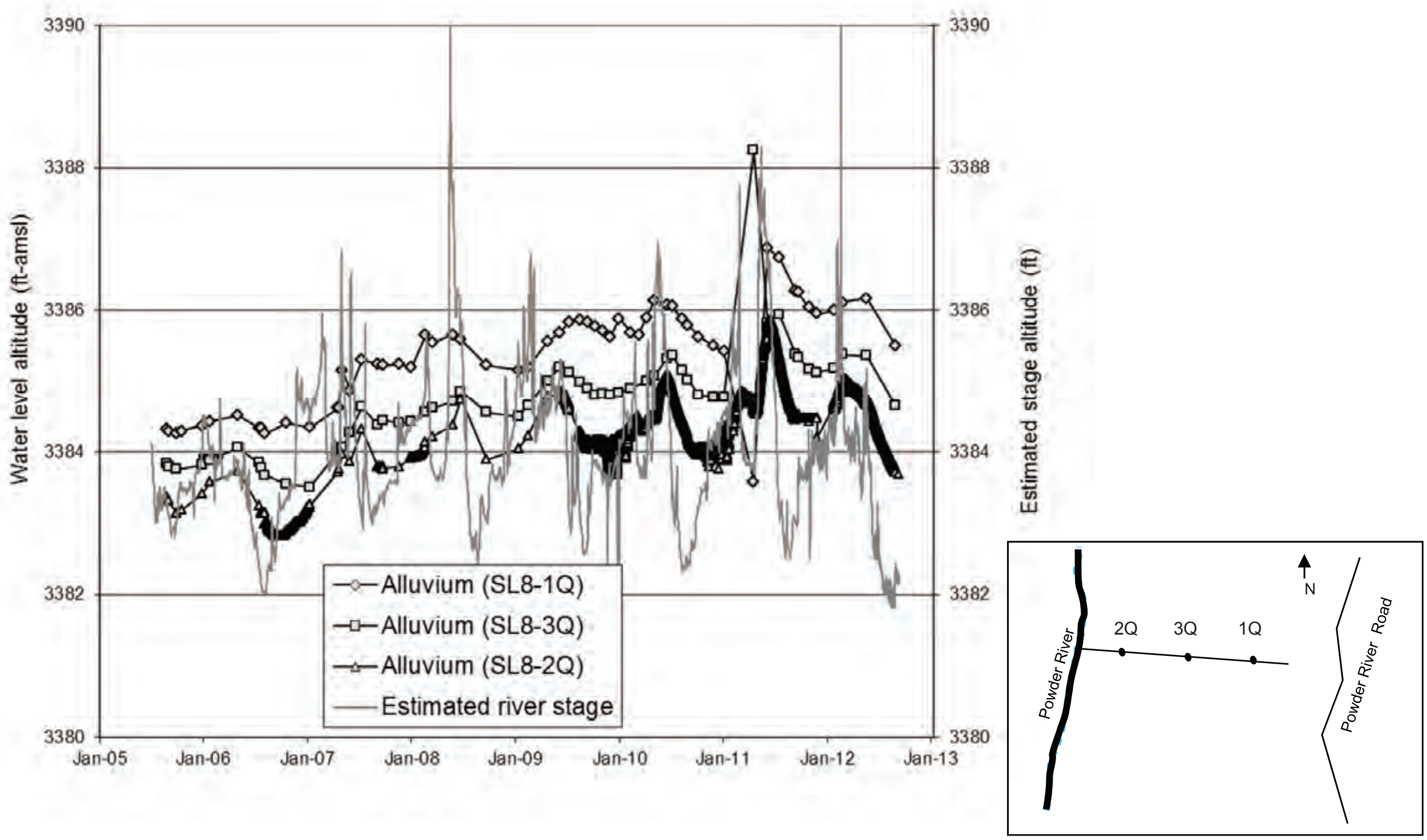


Figure 32. Groundwater flow in the alluvial aquifer at SL-8 is generally toward the Powder River. The groundwater-level trends follow river-stage trends. The river alternates between gaining (summer) and losing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gauging station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

EFFECTS OF WILDFIRE ON GROUNDWATER HYDROLOGY

The summer of 2012 saw more acres burned by wildfire in Montana than any time since the historic 1910 fires. Statewide, more than 1.1 million acres burned (Thackeray, 2012). Several large fires occurred within the CBM monitoring area boundary (fig. 33), including the 249,562-acre Ash Creek fire north of Ashland and a fire that burned the entire Taylor Creek watershed, a tributary to Otter Creek. Severely dry weather conditions throughout the summer impacted the MBMG's ability to get to monitored wells and springs each month, as many landowners restricted all motorized vehicle use. Several monitored springs and wells including Lemonade Spring, Upper 15-Mile Spring, Joe Anderson Spring, Hedum Spring, School House Spring, Whitetail Ranger Station Well, Spring Creek Pipeline Well, and the Taylor Creek Pipeline Well were directly affected. The WO-series wells, which monitor the Otter Creek alluvium and adjacent shallow coal aquifers, are immediately downgradient from the Taylor Creek fire.

Fire can have a significant effect an area's groundwater hydrology. Plant removal reduces transpiration demand, potentially allowing much greater recharge/runoff rates. Springs in burned areas with local recharge components may experience higher flow, water levels in wells may rise, and the water chemistry may change as additional salts and nutrients are mobilized from surface soils and ash. The effect of fire upon groundwater quantity and quality has been investigated and reported on in the scientific literature. While factors controlling groundwater levels are numerous and interconnected, in general, shallow groundwater levels increase with the removal of vegetation (Jung and others, 2009; Minshall and others, 1997; Tucker, 2007; Woodsmith and others, 2004). In an attempt to verify potential post-burn changes, the MBMG will increase monitoring of

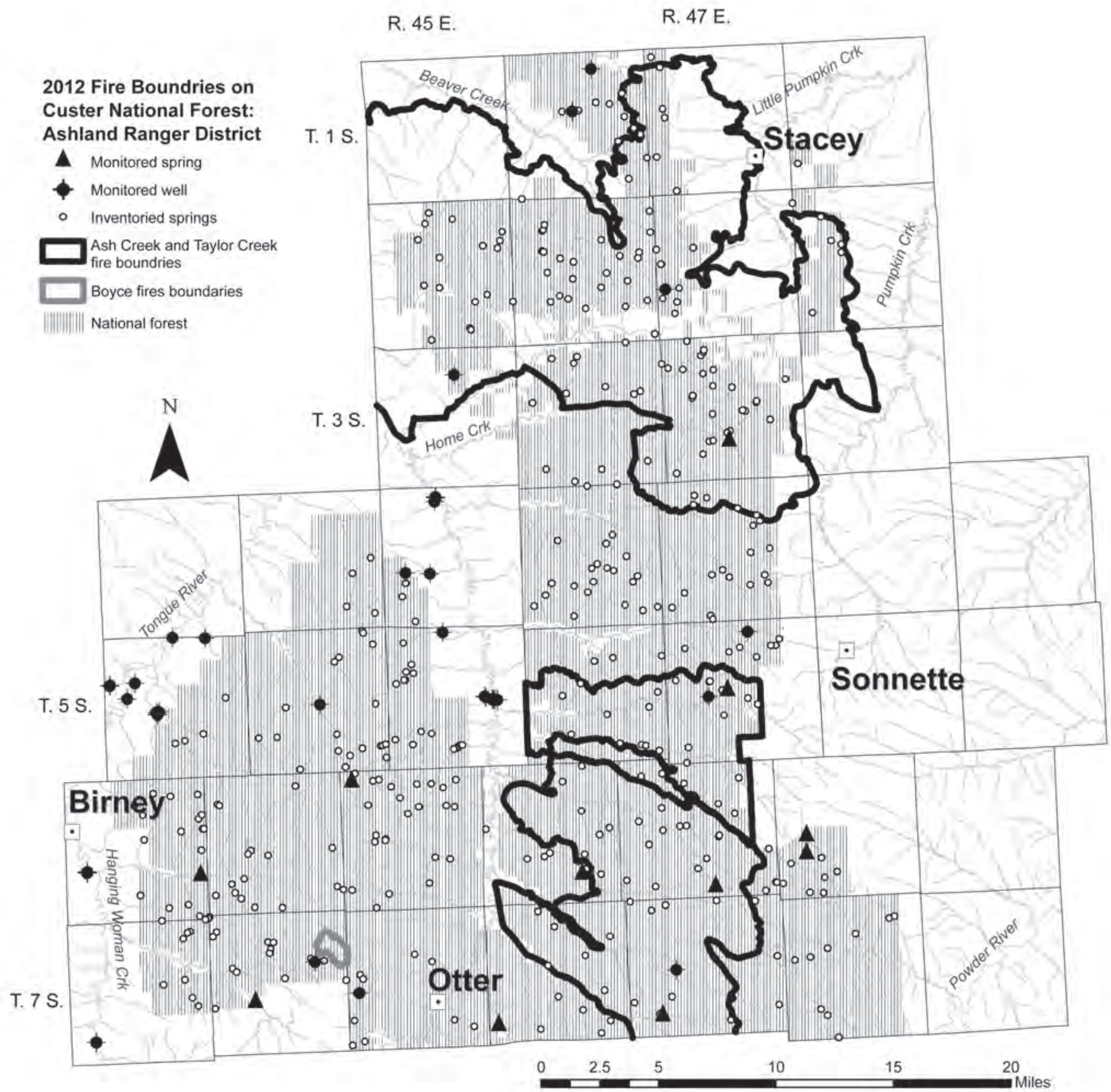


Figure 33. Boundaries of fires that occurred on the Ashland Ranger District in 2012. Several monitored springs (solid triangles) and wells (solid circles) fell within or downgradient from the burned areas. The U.S. forest land is marked with stripes.

water levels in wells and flow rates and field water chemistry at springs in areas impacted by the 2012 fires. Groundwater level, flow, and chemistry change tied to wildfire occurrence can help delineate recharge locations and vegetation removal impacts, which are otherwise difficult to determine.

SUMMARY AND 2013 MONITORING PLAN

Coalbed-methane production continues near the Tongue River Reservoir in Montana and new 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 groundwater systems within the CBM's current area of influence, and the current extent of drawdown within the monitored aquifers. Outside the area of CBM production influence, groundwater conditions reflect typical responses 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 ft in the producing coalbeds. The actual amount of drawdown in some wells cannot be measured due to unsafe conditions caused by methane. More than 13 years of CBM production has caused drawdown of up to 20 ft in coalbeds at maximum distances of 1 to 1.5 miles outside production areas. These distances, which are less than predicted in the Montana CBM Environmental Impact Statement, have not changed substantially since 2004 (Wheaton and others, 2005). The Environmental Impact Statement predicted that 20 ft of drawdown would reach 2 miles after 10 years of CBM production.

Major faults generally act as barriers to groundwater flow, and so far the monitoring network has documented only rare drawdown migration across fault planes. However, where fault offsets are less than about 10 ft more than the thickness of the coal, or where offsets scissor around a hinge point, faults are less likely to be barriers. Vertical migration of drawdown tends to be limited by shale layers; however, in some cases the network has documented minor changes in overburden water levels.

Water levels will recover after CBM production ceases, but recovery will take decades to return to pre-development levels. The extent of drawdown and recovery rates will mainly be determined by the rate, size, and continuity of CBM development, site-specific aquifer characteristics, the extent of faulting, proximity to recharge areas, and amount of recharge.

Water from CBM wells has 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 exceeded 80 (appendix D).

Monitoring plans for water year 2013 are included in appendices A and B and shown in plate 6. During water year 2013, 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 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, 2013’s spring sampling will include South Fork Harris Creek Spring and Hedum Spring on the Ashland Ranger district. Coal aquifer water-quality sampling will include the three newly installed wells at SL-9. Equipment problems and high fire danger prohibited sampling these wells in 2011 and 2012. Monitoring priorities will be adjusted as new areas of production are proposed or developed and to account for changes due to wildfire.

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Appendix A

Site details, water-level data, and water year 2013 monitoring plan for wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
7573	WO-15	-106.1855	45.5186	04S	45E	4	BDDB	P. River	3022	Alluvium
7574	WO-16	-106.1861	45.5158	04S	45E	4	CAAC	P. River	3040	Alluvium
7589	Newell Pipeline Well	-106.2143	45.4727	04S	45E	19	DADD	P. River	3290	Tongue River
7755	77-26	-106.1839	45.4352	05S	45E	4	ABCC	P. River	3284	Knobloch Coal
7770	WO-8	-106.1411	45.3922	05S	45E	23	ABCA	P. River	3155	Alluvium
7772	WO-9	-106.1419	45.3925	05S	45E	23	ABCA	P. River	3150	Alluvium
7775	WO-10	-106.1430	45.3925	05S	45E	23	ABCB	P. River	3145	Alluvium
7776	WO-5	-106.1386	45.3922	05S	45E	23	ABDA	P. River	3160	Knobloch Underburden
7777	WO-6	-106.1386	45.3922	05S	45E	23	ABDA	P. River	3160	Lower Knobloch Coal
7778	WO-7	-106.1386	45.3922	05S	45E	23	ABDA	P. River	3160	Alluvium
7780	WO-1	-106.1494	45.3947	05S	45E	23	BBAA	P. River	3190	Knobloch Underburden
7781	WO-2	-106.1494	45.3947	05S	45E	23	BBAA	P. River	3188	Lower Knobloch Coal
7782	WO-3	-106.1494	45.3947	05S	45E	23	BBAA	P. River	3186	Knobloch Overburden
7783	WO-4	-106.1486	45.3941	05S	45E	23	BBAA	P. River	3140	Alluvium
7903	HWC86-9	-106.5027	45.2966	06S	43E	19	DACD	Rosebud	3170	Alluvium
7905	HWC86-7	-106.5033	45.2958	06S	43E	19	DDBA	Rosebud	3170	Alluvium
7906	HWC86-8	-106.5030	45.2961	06S	43E	19	DDBA	Rosebud	3170	Alluvium
8074	WR-21	-106.9791	45.0877	08S	39E	32	DBBC	Big Horn	3890	Dietz 1 and Dietz Coals Combined
8101	HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	Big Horn	3460	Alluvium
8103	HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	Big Horn	3455	Alluvium
8107	HWC-01	-106.4866	45.1338	08S	43E	20	DDDD	Big Horn	3530	Canyon Coal
8110	HC-01 O-4	-106.4750	45.1313	08S	43E	21		Big Horn	3455	Alluvium
8118	HC-24	-106.4747	45.1297	08S	43E	21	BDBB	Big Horn	3500	Canyon Overburden
8140	FC-01	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Anderson Coal
8141	FC-02	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Dietz Coal
8191	BC-06	-106.2100	45.1387	08S	45E	16	DBCB	P. River	3715	Canyon Coal
8192	BC-07	-106.2100	45.1387	08S	45E	16	DBCB	P. River	3715	Canyon Overburden

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
8347	WR-23	-106.9905	45.0922	09S	38E	1	AADC	Big Horn	3960	Dietz 1 and Dietz Coals Combined
8368	SH-391	-107.0320	45.0413	09S	38E	22	DADC	Big Horn	3987	Dietz 1 and Dietz Coals Combined
8371	SH-388	-107.0205	45.0391	09S	38E	23	CDAD	Big Horn	3975	Dietz Coal
8372	SH-396	-107.0088	45.0491	09S	38E	24	BBBC	Big Horn	3939	Anderson-Dietz 1 and 2 Coals
8377	SH-394	-107.0075	45.0330	09S	38E	25	BCBA	Big Horn	3909	Dietz Coal
8379	SH-422	-107.0061	45.0261	09S	38E	25	CBDC	Big Horn	3917	Dietz Coal
8387	SH-395	-107.0618	45.0361	09S	38E	26	ABAB	Big Horn	3900	Dietz Coal
8412	WR-58	-106.9122	45.0408	09S	39E	14	DDBD	Big Horn	3631	Alluvium
8413	WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	Big Horn	3627	Alluvium
8417	WR-19	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Dietz 1 and Dietz Coals Combined
8419	WR-20	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Anderson Coal
8428	WR-54A	-106.8902	45.0147	09S	39E	25	DADB	Big Horn	3631	A-D 1 and 2 Overburden
8430	WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	Big Horn	3608	A-D 1 and 2 Overburden
8436	WR-24	-106.9877	45.0202	09S	39E	29	BBDD	Big Horn	3777	Canyon Coal
8441	WR-33	-106.9758	45.0066	09S	39E	32	ACAA	Big Horn	3732	Anderson-Dietz 1 Clinker and Coal
8444	WR-27	-106.9658	45.0008	09S	39E	33	DBBD	Big Horn	3672	Anderson-Dietz 1 and 2 Coals
8446	WR-45	-106.9538	44.9966	09S	39E	33	DDCC	Big Horn	3638	Alluvium
8447	WR-44	-106.9522	44.9966	09S	39E	33	DDCD	Big Horn	3637	Alluvium
8451	WR-42	-106.9502	44.9966	09S	39E	33	DDDD	Big Horn	3637	Alluvium
8456	WRN-10	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3433	Dietz 2 Coal
8461	WRN-15	-106.8275	45.0638	09S	40E	9	AADD	Big Horn	3500	Dietz 2 Coal
8471	DS-05A	-106.8338	45.0555	09S	40E	9	DCAB	Big Horn	3506	Dietz 2 Coal
8500	WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	Big Horn	3511	Dietz 2 Coal
8501	WRE-10	-106.7741	45.0383	09S	40E	13	DCCB	Big Horn	3519	Dietz Coal
8504	WRE-11	-106.7736	45.0383	09S	40E	13	DCCD	Big Horn	3509	Anderson Coal
8574	DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	Big Horn	3430	Dietz 2 Coal
8650	WR-55	-106.8858	45.0300	09S	40E	19		Big Horn	3591	Tongue River

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
8651	WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	Big Horn	3591	A-D 1 and 2 Overburden
8687	WRE-12	-106.8038	45.0311	09S	40E	23	BCCD	Big Horn	3463	Anderson Coal
8692	WRE-13	-106.8044	45.0311	09S	40E	23	BCCD	Big Horn	3463	Dietz Coal
8698	WRE-16	-106.7697	45.0352	09S	40E	24	AACB	Big Horn	3551	Anderson Coal
8706	WR-17B	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3575	A-D 1 and 2 Overburden
8708	WR-51	-106.8620	45.0186	09S	40E	29		Big Horn	3541	Tongue River Formation
8709	WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	Big Horn	3541	A-D 1 and 2 Overburden
8710	WR-52B	-106.8627	45.0147	09S	40E	29	CACB	Big Horn	3519	Alluvium
8721	WRE-27	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3524	Anderson Coal
8723	WRE-28	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3525	Dietz Coal
8726	WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	Big Horn	3523	Dietz 2 Coal
8754	CC-1	-106.4646	45.0875	09S	43E	4	ABDD	Big Horn	3520	Alluvium
8757	CC-4	-106.4659	45.0874	09S	43E	4	ABDD	Big Horn	3511	Alluvium
8758	CC-3	-106.4654	45.0864	09S	43E	4	ACAA	Big Horn	3521	Alluvium
8777	HWC-38	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3586	Alluvium
8778	HWC-17	-106.4133	45.0570	09S	43E	13	BCAA	Big Horn	3610	Anderson Coal
8779	HWC-07	-106.4094	45.0536	09S	43E	13	CAAA	Big Horn	3595	Anderson Coal
8782	HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	Big Horn	3600	Anderson Coal
8796	HWC-29B	-106.3969	45.0688	09S	44E	7	BBCC	Big Horn	3620	Anderson Coal
8835	AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	P. River	3965	Dietz Coal
8846	UOP-09	-106.0578	45.0720	09S	46E	11	BBBA	P. River	3929	Canyon Coal
8847	UOP-10	-106.0578	45.0720	09S	46E	11	BBBA	P. River	3930	Canyon Overburden
8863	Fulton George *NO.6	-105.8628	45.0807	09S	48E	5	ACDD	P. River	3380	Tongue River
8888	HWC 86-13	-106.4262	45.0020	10S	43E	2	ABCA	P. River	3640	Alluvium
94661	Liscom Well	-106.0323	45.7782	01S	46E	3	DBAA	P. River	3275	Fort Union Formation
94666	Coyote Well	-106.0505	45.7524	01S	46E	16	AACC	P. River	3294	Fort Union Formation
100472	East Fork Well	-106.1642	45.5935	03S	45E	10	B	P. River	3210	
103155	Padget Creek Pipeline Well	-106.2940	45.3939	05S	44E	22	BBBD	Rosebud	3385	Tongue River

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
105007	Tooley Creek Well	-106.2697	45.2153	07S	45E	19	CAAA	P. River	3755	Fort Union
121669	WRE-18	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3573	Anderson Coal
122766	WR-59	-106.8526	45.0050	09S	40E	32	ACAD	Big Horn	3470	Alluvium
122767	WRE-20	-106.7716	45.0369	09S	40E	24	ABAB	Big Horn	3519	Anderson Coal
122769	WR-38	-106.9650	44.9938	37N	63E	23	BBCB	Sheridan	3693	Dietz 1 and Dietz Coals Combined
122770	WR-39	-106.9555	44.9952	37N	63E	23	ABBC	Sheridan	3666	Anderson-Dietz 1 and 2 Coals
123795	WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	Big Horn	3549	Anderson Coal
123796	WR-17A	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3574	A-D 1 and 2 Overburden
123797	WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	Big Horn	3520	Anderson Coal
123798	WRN-11	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3437	Anderson-Dietz 1 Clinker and Coal
127605	WR-54	-106.8902	45.1470	09S	39E	25		Big Horn	3630	Anderson and Dietz Coal
130475	WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	Big Horn	3552	Dietz Coal
130476	WR-31	-106.9863	45.0163	09S	39E	29	CBAA	Big Horn	3895	Anderson Coal
132716	WR-48	-106.9650	44.9933	37N	63E	23	BBCB	Sheridan	3694	Anderson Coal
132903	WR-58A	-106.9123	45.0403	09S	39E	14	DDBD	Big Horn	3631	Alluvium
132907	WR-53	-106.8880	45.0125	09S	39E	25		Big Horn	3607	Anderson and Dietz Coal
132908	WR-30	-106.9874	45.0165	09S	39E	29	CBAB	Big Horn	3895	Dietz 1 and Dietz Coals Combined
132909	WR-34	-106.9702	45.0015	09S	39E	33	CBBB	Big Horn	3772	Anderson-Dietz 1 and 2 Coals
132910	WRE-02	-106.7756	45.0712	09S	40E	1	DBCC	Big Horn	3457	Alluvium
132958	WRE-21	-106.7730	45.0386	09S	40E	24	ABAB	Big Horn	3529	Anderson Coal
132959	WRE-17	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3562	A-D 1 and 2 Overburden
132960	WR-52C	-106.8629	45.0164	09S	40E	29	CABC	Big Horn	3530	Alluvium
132961	WR-52D	-106.8616	45.0164	09S	40E	29	CABD	Big Horn	3529	Alluvium
132973	PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	Big Horn	3458	Dietz 2 Coal
144969	Pipeline Well 7(PL-1W) LOHOF	-106.3074	45.2354	07S	44E	14	ABD	Rosebud	3850	Tongue River
157879	5072B	-106.4904	45.7393	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
157882	5072C	-106.4905	45.7394	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal Overburden
157883	5080B	-106.5126	45.7199	01S	42E	26	DCBA	Rosebud	3260	Knobloch Coal
157884	5080C	-106.5126	45.7200	01S	42E	26	DCBA	Rosebud	3260	Knobloch Overburden
161749	BF-01	-106.9667	44.9897	58N	84W	22	ACCC	Sheridan	3680	Coal Mine Spoils Bank
166351	PKS-3204	-106.8299	45.1067	08S	40E	28	ADA	Big Horn	3500	Anderson-Dietz1 Coalbed
166358	PKS-3203	-106.8302	45.1068	08S	40E	28	ADA	Big Horn	3500	Canyon Coal
166359	PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	Big Horn	3438	Alluvium
166362	PKS-3201	-106.7971	45.0437	09S	40E	14	CAA	Big Horn	3438	Canyon Coal
166370	PKS-3200	-106.7969	45.0440	09S	40E	14	CAA	Big Horn	3438	Dietz 2 Coal
166388	PKS-3199	-106.7966	45.0443	09S	40E	14	CAA	Big Horn	3439	Dietz Coal
166389	PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	Big Horn	3440	Anderson Coal
166761	WR-29R	-106.8153	45.0465	09S	40E	15	ACCD	Big Horn	3461	Anderson-Dietz 1 Clinker and Coal
183559	Nance IP-11 Bridge	-106.4549	45.4114	05S	43E	8	BCDC	Rosebud	3085	Tongue River
183560	Nance Properties INC	-106.4205	45.4387	05S	43E	4	AAAB	Rosebud	3035	Alluvium
183563	Fulton George	-105.8709	45.0637	09S	48E	8	CABC	P. River	3360	Alluvium
183564	Whitetail Ranger Station	-105.9758	45.6404	02S	47E	19	CDCA	P. River	4045	Fort Union Formation
183565	Skinner Gulch Pipeline Well	-105.9171	45.4275	05S	47E	3	BCCD	P. River	3730	Tongue River
184222	SH-624	-107.0917	45.0725	09S	38E	7	DADB	Big Horn	4645	Anderson-Dietz1 Coalbed
184223	SH-625	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Dietz Coal
184224	SH-625A	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Anderson Coal
184225	SH-634	-107.0728	45.1422	08S	38E	17	DADD	Big Horn	4481	Dietz Coal
184226	SH-634A	-107.0883	45.1422	08S	38E	17	DADD	Big Horn	4481	Anderson Coal
186195	WR-41	-106.9498	44.9950	09S	39E	34	CCCC	Big Horn	3643	Alluvium
189743	HWC-29A	-106.3974	45.0697	09S	44W	7	BBCC	Big Horn	3619	
189802	HWC-37	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3578	Alluvium
189838	HWC-39	-106.4004	45.0713	09S	43E	12	ADBD	Big Horn	3591	Alluvium
190902	HWC-10	-106.4695	45.0444	09S	43E	21	BADA	Big Horn	3610	Dietz Coal
190904	HWC-11 TR-77	-106.4696	45.0444	09S	43E	21	BADA	Big Horn	3615	Anderson Coal

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
191139	20-LW	-106.7801	45.3391	06S	40E	1	CDDC	Big Horn	3940	Wall Coal
191155	22-BA	-106.6954	45.3484	06S	41E	3	BADD	Rosebud	3530	Brewster-Arnold Coal
191163	28-W	-106.7292	45.3211	06S	41E	16	BBCC	Rosebud	3715	Wall Coal
191169	32-LW	-106.7098	45.2955	06S	41E	21	DDDC	Rosebud	3530	Wall Coal
191634	75-23	-106.2011	45.0966	08S	45E	34	BDBC	P. River	3780	Canyon Coal
192874	YA-109	-107.0312	45.0407	09S	38E	22	DADC	Big Horn	3830	Alluvium
198465	HWC-6	-106.4093	45.0536	09S	43E	13	CAAA	Big Horn	3595	Dietz Coal
198489	HWC 86-15	-106.4235	45.0025	10S	43E	2	AABC	Big Horn	3630	Alluvium
203646	CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3980	Knobloch Coal
203655	CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3984	Brewster-Arnold Coal
203658	CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3982	Local Coals
203669	CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	Big Horn	3792	Carney Coal
203670	CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	Big Horn	3890	Roland Coal
203676	CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	Big Horn	3920	Canyon Coal
203678	CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	Big Horn	3920	Dietz Coal
203680	CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	Big Horn	3500	Wall Coal
203681	CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	Rosebud	3500	Wall Coal Overburden
203690	CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	Big Horn	3500	Canyon Underburden
203693	CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	Big Horn	3900	Canyon Coal
203695	CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	Big Horn	3900	Canyon Overburden
203697	CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	Rosebud	3262	Knobloch Coal
203699	CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	Rosebud	3262	Knobloch Underburden
203700	CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Overburden
203701	CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Coal
203703	CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson Coal
203704	CBM03-10SS	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	A-D 1 and 2 Overburden
203705	CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	Big Horn	3950	Anderson Coal

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
203707	CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	Big Horn	3950	Dietz Coal
203708	CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	Big Horn	3950	Canyon Coal
203709	CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	P. River	3715	Cook Coal
203710	CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	P. River	3931	Otter Coal
205082	Spring Creek Pipeline Well	-105.9538	45.3883	05S	47E	20	ACAC	P. River	3630	Tongue River Formation
207064	RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	Big Horn	3855	Alluvium
207066	RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	Alluvium
207068	RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	Big Horn	3860	Alluvium
207075	YA-114	-107.0543	45.0461	09S	38E	21	ADBD	Big Horn	4000	Alluvium
207076	YA-105	-107.0527	45.0465	09S	38E	21	ACAC	Big Horn	4015	Alluvium
207080	TA-100	-107.0090	45.0479	09S	38E	23	BBCC	Big Horn	3900	Alluvium
207081	TA-101	-107.0090	45.0482	09S	38E	24	BBCC	Big Horn	3910	Alluvium
207083	TA-102	-107.0076	45.0486	09S	38E	24	BBCB	Big Horn	3910	Alluvium
207096	IB-2	-106.4372	45.3930	05S	43E	21	BBDB	Rosebud	3192	Knobloch Underburdern
207097	MK-4	-106.4363	45.3919	05S	43E	21	BBDC	Rosebud	3195	Knobloch Coal
207098	NM-4	-106.4361	45.3916	05S	43E	21	BCAB	Rosebud	3195	Nance Coal
207099	WL-2	-106.4358	45.3919	05S	43E	21	BBDC	Rosebud	3188	Knobloch Coal
207101	OC-28	-106.1928	45.4717	04S	45E	21	CCBD	P. River	3171	Knobloch Coal
207143	HC-01	-106.4750	45.1314	08S	43E	21	BBDA	Big Horn	3457	Alluvium
210094	WO-14	-106.1849	45.5183	04S	45E	4	BDDB	P. River	3010	
214096	HWCQ-2	-106.5009	45.1913	07S	43E	32	AAAA	Rosebud	3340	Alluvium
214097	HWCQ-1	-106.5005	45.1912	07S	43E	32	AAAA	Rosebud	3340	Alluvium
214354	WA-7	-106.4347	45.3933	05S	43E	21	BABC	Rosebud	3179	Alluvium
215085	WO-11	-106.1433	45.3927	05S	45E	23	ABCC	P. River	3145	Alluvium
219125	SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	Big Horn	3925	Anderson Coal
219136	SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	Big Horn	3725	Alluvium
219138	SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	Big Horn	3805	Smith Coal
219139	SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Anderson Coal
219140	SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	Big Horn	3805	Canyon Coal
219141	SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	Big Horn	3640	Smith Coal
219169	SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	Big Horn	3640	Anderson Coal
219617	SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Smith Coal Overburden
219927	SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Anderson Coal

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	County	Land altitude (feet)	Aquifer
219929	SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Dietz Coal
220062	SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	Big Horn	4220	Anderson Coal
220064	SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	Big Horn	4220	Canyon Coal
220069	SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	Big Horn	4173	Canyon Coal
220076	SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	Big Horn	3810	Canyon Coal
220385	SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	Big Horn	3920	Canyon Coal
220851	SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	P. River	3397	Alluvium
220857	SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	P. River	3394	Alluvium
220859	SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	P. River	3398	Alluvium
221592	IP-22	-105.9003	45.0177	09S	47E	25	DDBD	P. River	3395	
223236	452355106333701	-106.5603	45.3986	05S	42E	16	CCAB	Rosebud	3400	
223237	452408106382201	-106.6397	45.4022	05S	41E	14	BDCD	Rosebud	3510	
223238	452139106504701	-106.8464	45.3608	05S	40E	31	BDCC	Big Horn	4440	
223240	452411106301601	-106.5044	45.4030	05S	42E	14	ADDC	Rosebud	3220	
223242	452416106413001	-106.6917	45.4044	05S	41E	17	ADBD	Rosebud	3740	
223243	452429106435201	-106.7311	45.4080	05S	40E	13	ADAB	Big Horn	3940	
223687	RBC-4	-106.9863	45.3332	06S	39E	8		Rosebud	3840.95	
223695	Moorhead CG Well	-105.8773	45.0542	09S	48E	17	BCBB	P. River	3400	Pawnee
223801	SL-5ALQ	-106.2579	45.0129	09S	45E	31	BBA	P. River	3810	Alluvium
223869	Poker Jim MET	-106.3164	45.3098	06S	44E	23	BBAA	Rosebud	4115	
223890	Taylor Creek Pipeline Well	-105.9928	45.2213	07S	47E	21	BBCC	P. River	3910	Tongue River Formation
223952	WA-2	-106.4621	45.4020	05S	43E	17	BCDD	Rosebud	3069	Alluvium
226919	NC05-1	-106.4769	45.4106	05S	43E	7	C	Rosebud	3170	
227246	DH 76-102D	-106.1862	45.0798	09S	45E	3	ADCC	Rosebud	3811	Dietz Coal
228592	Musgrave Bill	-106.7319	45.1639	08S	41E	5	ACDB	Big Horn	3335	Alluvium
231583	RBC-MET	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	
231591	SL-3 MET	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3725	
251797	GC09-KC	-106.391897	45.437635	05S	43E	2	BAB			Knobloch
251798	GC09-FG	-106.391897	45.437635	05S	43E	2	BAB			Flowers-Goodale
251799	GC09-TC	-106.391897	45.437635	05S	43E	2	BAB			Terret
259683	SL-09BA	45.00678577	-105.81746	09S	48E	34	DAA	P. River	3640	Brewster-Arnold Coal
259684	SL-09PC	45.00678577	-105.81746	09S	48E	34	DAA	P. River	3640	Pawnee
259676	SL-09OC	45.00678577	-105.817459	09S	48E	34	DAA	P. River	3640	Otter Coal

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
7573	63	12.0	9/30/2011	7.88	3014.1	Monthly	
7574	61	3.7	9/30/2011	23.25	3016.8	Monthly	
7589	325	5.0	1/19/2011	278.05	3012.0	Quarterly	
7755	217	3.6	10/13/2010	145.76	3138.2	Quarterly	
7770	33	12.0	9/30/2011	14.41	3140.6	Monthly	
7772	45	21.8	9/30/2011	10.75	3139.3	Monthly	
7775	41		9/30/2011	7.20	3137.8	Monthly	
7776	192	20.4	9/30/2011	16.83	3143.2	Monthly	
7777	82	7.0	9/30/2011	24.01	3136.0	Monthly	
7778	40	29.0	9/30/2011	25.96	3134.0	Monthly	
7780	172	8.0	9/30/2011	37.04	3153.0	Monthly	
7781	112	19.0	9/30/2011	43.97	3144.0	Monthly	
7782	66	17.8	9/30/2011	45.52	3140.5	Monthly	
7783	32		9/30/2011	8.23	3131.8	Monthly	
7903	44		9/30/2011	10.24	3159.8	Monthly	
7905	71		9/30/2011	8.65	3161.4	Monthly	Semi-Annual
7906	67		9/30/2011	7.96	3162.0	Monthly	
8074	206	4.0	9/28/2011	56.50	3833.5	Monthly	
8101	50		9/30/2011	19.15	3440.9	Monthly	
8103	33		9/30/2011	14.26	3440.7	Monthly	
8107	232	7.5	10/10/2011	90.05	3440.0	Monthly	
8110	20	16.5	1/27/2009	9.20	3445.8		
8118	150	7.1	7/28/2011	42.50	3447.5	Semi-Annual	
8140	133	0.0	7/28/2011	129.05	3606.0	Monthly	
8141	260		7/28/2011	243.11	3491.9	Monthly	
8191	188	4.6	9/29/2011	87.84	3627.2	Monthly	
8192	66	0.8	9/29/2011	33.96	3681.0	Monthly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
8347	322	6.0	9/28/2011	82.84	3877.2	Monthly	
8368	175		9/28/2011	61.41	3925.6	Monthly	
8371	190		9/28/2011	78.12	3896.9	Monthly	
8372	280	25.0	9/28/2011	54.91	3884.1	Monthly	
8377	242	5.0	9/28/2011	91.43	3817.6	Monthly	
8379	187		8/2/2011	121.95	3795.1	Semi-Annual	
8387	299	15.0	9/28/2011	63.23	3836.8	Monthly	
8412	55	21.0	9/28/2011	14.16	3617.1	Monthly	
8413	27	15.0	9/28/2011	14.14	3613.3	Monthly	
8417	305	20.0	9/28/2011	134.14	3701.3	Monthly	
8419	166	15.0	9/28/2011	106.74	3728.6	Monthly	
8428	211	1.0	9/28/2011	127.10	3504.1	Monthly	
8430	187		9/28/2011	108.77	3499.1	Monthly	
8436	146		9/28/2011	32.50	3744.7	Monthly	
8441	165		9/28/2011	50.42	3681.9	Monthly	
8444	363	25.0	8/2/2011	76.07	3595.9	Monthly	
8446	64	30.0	8/2/2011	9.73	3628.5	Monthly	
8447	64	30.0	8/2/2011	9.23	3627.7	Monthly	
8451	66	30.0	8/2/2011	10.00	3626.7	Monthly	
8456	79	3.4	9/28/2011	24.55	3408.8	Monthly	
8461	140		9/29/2010	90.90	3408.9	Monthly	
8471	166	5.0	9/29/2010	105.24	3400.3	Monthly	
8500	232		9/29/2010	165.14	3345.6	Monthly	
8501	183		9/29/2010	146.86	3371.6	Monthly	
8504	127		9/29/2010	82.51	3426.4	Monthly	
8574	150		9/29/2010	55.43	3374.6	Monthly	
8650	288	15.0	9/28/2011	161.80	3429.4	Monthly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
8651	72		9/28/2011	45.28	3545.8	Monthly	
8687	172		9/28/2011	86.39	3376.8	Monthly	
8692	206		9/28/2011	91.62	3371.0	Monthly	
8698	458		9/28/2011	61.19	3489.3	Monthly	
8706	160		9/28/2011	74.02	3500.7	Monthly	
8708	344	4.4	9/28/2011	131.59	3409.4	Monthly	
8709	187		9/28/2011	41.00	3500.3	Monthly	
8710	55	59.7	9/28/2011	11.24	3507.6	Monthly	
8721	77	0.5	9/29/2010	47.12	3476.7	Monthly	
8723	153		9/29/2010	61.63	3463.6	Monthly	
8726	217		9/29/2010	110.31	3413.0	Monthly	
8754	28	4.2	9/29/2011	14.08	3510.9	Monthly	
8757	25	4.8	9/29/2011	6.96	3504.0	Monthly	
8758	35	4.6	9/29/2011	14.21	3506.8	Monthly	
8777	41		8/3/2011	18.64	3567.4	Monthly	
8778	82	6.9	9/29/2011	50.28	3559.7	Monthly	
8779	66		9/29/2011	27.86	3567.1	Monthly	
8782	129	10.0	9/29/2011	33.46	3566.5	Monthly	
8796	92		8/3/2011	45.27	3574.7	Monthly	
8835	240	1.4	9/29/2011	166.75	3798.3	Monthly	
8846	262	0.8	9/29/2011	155.84	3773.2	Monthly	
8847	207	4.4	9/29/2011	141.86	3788.1	Monthly	
8863	410	4.0	10/10/2011	16.54	3363.5	Quarterly	
8888	53	3.9	9/29/2011	10.21	3629.8	Monthly	Semi-Annual
94661	135	10.0	7/25/2011	96.18	3178.8	Quarterly	
94666	190	5.0	10/10/2011	134.99	3159.0	Quarterly	
100472	193	5.0	10/10/2011	137.85	3072.2	Quarterly	
103155	135	10.0	7/28/2011	61.54	3323.5	Quarterly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
105007	110	12.0	10/10/2011	35.55	3719.5	Quarterly	
121669	445		9/28/2011	97.81	3475.3	Monthly	
122766	34	10.0	9/28/2011	8.41	3461.7	Monthly	Semi-Annual
122767	120		9/29/2010	93.15	3426.3	Monthly	
122769	286	3.8	8/2/2011	75.41	3617.5	Monthly	
122770	312		8/2/2011	65.48	3600.5	Monthly	
123795	115		9/29/2010	61.26	3488.1	Monthly	
123796	88		9/28/2011	44.11	3529.8	Monthly	
123797	140		9/29/2010	94.41	3425.9	Monthly	
123798	50		9/28/2011	23.28	3413.5	Monthly	
127605	384	20	9/28/2011	209.67	3420.2	Monthly	
130475	154	20.0	9/29/2010	67.60	3484.5	Monthly	
130476	316	2.0	8/29/2011	181.36	3713.8	Monthly	
132716	167		8/2/2011	39.98	3653.8	Monthly	
132903	24	8.0	9/28/2011	14.03	3617.3	Monthly	
132907	384	20.0	9/28/2011	187.60	3419.5	Monthly	
132908	428	5.0	9/28/2011	199.85	3694.8	Monthly	
132909	522		9/28/2011	149.51	3622.6	Monthly	
132910	79		9/29/2010	38.96	3417.8	Monthly	
132958	130		9/29/2010	84.04	3445.4	Monthly	
132959	250		9/28/2011	63.89	3498.0	Monthly	
132960	62	20.0	9/28/2011	18.58	3511.4	Monthly	
132961	40	1.0	9/28/2011	22.53	3506.8	Monthly	
132973	282	5.0	9/28/2011	142.26	3315.7	Monthly	
144969	225	15.0	7/28/2011	140.76	3709.2	Quarterly	
157879	109	2.0	8/17/2011	33.53	3126.5	Quarterly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
157882	106	0.3	8/17/2011	27.32	3132.7	Quarterly	
157883	89	1.3	8/17/2011	41.27	3218.7	Quarterly	
157884	110	0.3	8/17/2011	35.11	3224.9	Quarterly	
161749	125		1/18/2011	30.22	3649.8	Monthly	
166351	82		9/28/2011	73.18	3426.8	Monthly	
166358	201		9/28/2011	115.32	3384.7	Monthly	
166359	60	5.0	9/29/2010	39.24	3398.8	Monthly	
166362	390	50.0	9/29/2010	96.66	3341.3	Monthly	
166370	242	20.0	9/29/2010	172.76	3265.2	Monthly	
166388	165	20.0	9/29/2010	114.16	3324.8	Monthly	
166389	112		9/29/2010	86.16	3353.8	Monthly	
166761	72		9/28/2011	44.74	3416.3	Monthly	
183559	540		10/10/2011	-15.25	3100.3	Quarterly	
183560	20		10/10/2011	9.92	3025.1	Quarterly	
183563	30	1.0	10/10/2011	15.89	3344.1	Quarterly	
183564	60		10/10/2011	40.28	4004.7	Quarterly	
183565	167		10/10/2011	47.97	3682.0	Quarterly	
184222	435		8/2/2011	348.23	4296.5	Quarterly	
184223	186		8/2/2011	45.36	4141.2	Quarterly	
184224	91		8/2/2011	52.28	4134.4	Quarterly	
184225	348	12.0	8/2/2011	149.80	4330.7	Semi-Annual	
184226	159		8/2/2011	114.81	4366.4	Semi-Annual	
186195	40	1.0	8/2/2011	17.42	3625.3	Monthly	
189743	98		8/3/2011	43.77	3575.2	Monthly	
189802	32		8/3/2011	9.44	3568.6	Monthly	
189838	39		8/2/2011	25.49	3565.5	Monthly	
190902	229		9/29/2011	98.71	3516.3	Monthly	
190904	135	8.0	9/29/2011	51.94	3558.1	Monthly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
191139	253	0.2	7/27/2011	83.23	3856.8	Quarterly	
191155	262	0.4	7/27/2011	104.96	3425.0	Quarterly	
191163	144	1.3	7/27/2011	108.17	3606.8	Quarterly	
191169	51	0.2	7/27/2011	37.06	3492.9	Quarterly	
191634	247		9/29/2011	132.27	3647.7	Monthly	
192874	44		9/28/2011	31.26	3798.7	Monthly	
198465	152		9/28/2011	68.68	3526.3	Monthly	
198489	63	30.0	9/29/2011	13.64	3616.4	Monthly	Semi-Annual
203646	417	0.5	9/28/2011	172.60	3807.7	Monthly	
203655	256	5.0	9/28/2011	100.74	3883.1	Monthly	
203658	366	2.0	9/28/2011	143.31	3838.5	Monthly	
203669	290	10.0	9/28/2011	75.03	3717.0	Monthly	
203670	159	1.0	9/28/2011	131.19	3758.8	Monthly	
203676	376	0.3	9/28/2011	301.79	3618.2	Monthly	
203678	235	0.1	9/28/2011	185.81	3734.2	Monthly	
203680	291	0.2	10/18/2011	180.93	3319.1	Monthly	
203681	221	5.0	10/18/2011	76.43	3423.6	Monthly	
203690	97	30.0	10/18/2011	33.93	3466.1	Monthly	
203693	263	1.5	9/28/2011	164.14	3735.9	Monthly	
203695	190	5.0	9/28/2011	89.76	3810.2	Monthly	
203697	208	1.0	7/27/2011	157.98	3104.3	Quarterly	
203699	224	10.0	1/19/2011	160.00	3102.2	Quarterly	
203700	446	0.3	7/27/2011	102.58	3157.9	Quarterly	
203701	480	0.5	7/27/2011	102.14	3158.5	Quarterly	
203703	560	0.3	9/28/2011	531.31	3598.7	Monthly	
203704	462	1.0	9/28/2011	372.52	3757.5	Monthly	
203705	211	1.0	9/30/2011	155.20	3794.8	Monthly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
203707	271	0.2	9/30/2011	227.94	3722.1	Monthly	
203708	438	1.5	9/30/2011	382.42	3567.6	Monthly	
203709	351	3.0	9/29/2011	166.24	3548.8	Monthly	
203710	500	1.5	9/29/2011	335.29	3595.7	Monthly	
205082	50		7/26/2011	14.65	3615.4	Quarterly	
207064	27		9/28/2011	11.40	3843.3	Monthly	
207066	17		9/28/2011	8.18	3841.2	Monthly	Semi-Annual
207068	25		9/28/2011	10.07	3849.8	Monthly	
207075			8/2/2011	11.78	3988.2	Quarterly	
207076			8/2/2011	10.71	4004.3	Quarterly	
207080			9/28/2011	13.22	3886.8	Quarterly	
207081			9/28/2011	15.11	3894.9	Quarterly	
207083			9/28/2011	20.43	3889.6	Quarterly	
207096	245		7/28/2011	119.70	3071.9	Quarterly	
207097	188		7/28/2011	119.59	3075.7	Quarterly	
207098	294		7/28/2011	120.16	3075.2	Quarterly	
207099	199		7/28/2011	117.41	3070.2	Quarterly	
207101			7/26/2011	62.20	3108.8	Quarterly	
207143	20	17.0	7/28/2011	3466.60	-9.6	Semi-Annual	
210094	66		9/30/2011	4.13	3005.9	Monthly	
214096	19		6/22/2011	10.95	3329.1	Monthly	
214097	20		6/22/2011	11.04	3329.0	Monthly	
214354			7/28/2011	54.04	3125.0	Quarterly	
215085	39		9/30/2011	8.01	3137.0	Monthly	
219125	671		9/29/2011	341.74	3583.3	Monthly	
219136	40	2.0	9/29/2011	13.86	3711.1	Monthly	Semi-Annual
219138	358	2.0	9/29/2011	165.80	3639.2	Monthly	
219139	523	2.0	9/29/2011	220.28	3584.7	Monthly	
219140	817	0.1	9/29/2011	393.01	3412.0	Monthly	
219141	120	2.0	10/18/2011	30.14	3609.9	Monthly	
219169	279	2.0	9/29/2011	65.21	3574.8	Monthly	
219617	278	5.0	9/29/2011	145.58	3659.4	Monthly	
219927	223	1.0	9/29/2011	132.87	3677.1	Monthly	

GWIC ID	Well total depth (feet)	Well yield (gpm)	Most recent SWL	Average SWL (feet)	Ave. SWL altitude (feet)	2013 SWL monitoring plan	2013 QW sample collection
219929	322	0.7	9/29/2011	167.59	3642.4	Monthly	
220062	492	0.1	9/29/2011	377.76	3842.2	Monthly	
220064	685	0.5	6/23/2011	521.62	3698.4	Monthly	
220069	515	1.0	4/20/2010	456.32	3716.7	Monthly	
220076	431	6.0	9/29/2011	176.02	3634.0	Monthly	
220385	1301		9/29/2011	449.96	3470.0	Monthly	
220851	19	1.0	9/29/2011	11.40	3385.3	Monthly	
220857	14	0.3	9/29/2011	10.04	3384.1	Monthly	Semi-Annual
220859	19	1.0	9/29/2011	13.86	3384.6	Monthly	
221592			1/19/2011	-15.79	3410.79	Monthly	
223236	376		11/3/2009	261.13	3138.9		
223237	360		11/3/2009	237.10	3272.9		
223238	681		6/6/2005	617.65	3822.4		
223240	420		11/3/2010	105.82	3114.2		
223242	353		11/3/2009	180.52	3559.5		
223243	380		11/3/2009	198.73	3741.3		
223687	5.05		9/28/2011	4.58	3836.37		
223695			1/19/2011		3400.0	Monthly	
223801	35		9/29/2011	7.41	3802.6	Monthly	
223869						Monthly	
223890	150		7/26/2011	104.77	3805.2	Quarterly	
223952			10/1/2011	9.19	3059.3	Monthly	Semi-Annual
226919	780						
227246	144		9/29/2011	18.71	3792.3	Monthly	
228592	22		7/27/2011	13.13	3321.9	Monthly	Semi-Annual
231583						Monthly	
231591						Monthly	
251797			3/25/2010			Quarterly	
251798			3/25/2010			Quarterly	
251799			3/25/2010			Quarterly	
259683	291		9/29/2011			Monthly	
259684	169		9/29/2011			Monthly	
259676	378		9/29/2011			Monthly	

Appendix B

Site details, discharge data, and water year 2013 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	2013 planned flow monitoring	2013 planned QW sample collection
197247		Anderson	Regional	3690	1.52	10/17/2011	Monthly	One time
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	One time
199572	Sandstone	Canyon	Local	3940	1.31	7/26/2011	Quarterly	
205004	Clinker	Anderson/Dietz	Local	3890	0.71	7/28/2011	Quarterly	
205010		Canyon	Local	3960	0.79	7/26/2011	Quarterly	
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 2012

	Gwic Id	Site Name	Sampled in 2011	Latitude	Longitude	Location (TRS)	County	Site Type	Aquifer
Sites currently outside areas of potential CBM influence	183560	Nance, Jay	One-time	45.4386949	-106.421082	05S 43E 4 DDDD	Rosebud	Well	111ALVM
	207066	Well RBC-2	Semi-annual	45.3327	-106.9844	06S 39E 8 CAAA	Big Horn	Well	110ALVM
	205010	North Fork Spring	One-time	45.2996	-105.8736	06S 48E 20 BDCA	Powder River	Spring	110ALVM
	199572	Dead Man Spring	One-time	45.2903	-105.8743	06E 48E 29 BABB	Powder River	Spring	
Sites within current areas of potential CBM influence	223952	WA-2	Semi-annual	45.4032	-106.4566	05S 43E 17 BCDD	Rosebud	Well	110ALVM
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S 43E 19 DDBA	Rosebud	Well	110ALVM
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S 43E 2 ABCA	Big Horn	Well	110ALVM
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S 43E 2 AABC	Big Horn	Well	110ALVM
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386	09S 42E 36 BBAD	Big Horn	Well	110ALVM
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09S 47E 25 DCDB	Powder River	Well	110ALVM
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S 40E 32 ACAD	Big Horn	Well	110ALVM
	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

	Gwic Id	Depth (ft)	Comp Date	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)
Sites currently outside areas of potential CBM influence	183560	20		4/10/2012 9:13	640	1.8	9.7	7.61	1049.8	79.26	46.56	81.26	16.78
	207066	16.9	7/9/2003	10/19/2011 16:22	581	0.9	8.8	7.58	914	70.27	68.45	42.29	9.36
				6/4/2012 10:40	561	0.8	9.4	7.49	901	65.95	64.63	39.83	9.04
	205010			6/5/2012 17:08	2858	6.5	9.9	7.11	3420	205.3	157.38	509.42	8.72
	199572			6/5/2012 17:26	2958	4.0	10.4	7.01	3280	275.55	221.25	367.37	8.18
Sites within current areas of potential CBM influence	223952	37.8	8/16/1978	10/17/2011 10:10	1897	22.8	11	7.66	2770	26.43	28.3	709.15	6.53
				6/6/2012 19:10	1767	22.0	9.6	7.7	2760	25.09	27.07	667	6.96
	7905	71		10/17/2011 13:09	3824	8.3	9.6	7.4	4470	184.4	242.08	726.58	21.49
				6/6/2012 17:37	3763	8.3	9.3	7.47	4350	176.63	230.95	708.28	20.95
	8888	53	10/8/1986	10/18/2011	6441	10.9	10.1	7.1	6680	386.98	330.58	1208.83	13.04
				6/6/2012 15:05	6359	10.8	10.3	7.11	6620	367.88	318.13	1168.5	11.37
	198489	62.52	10/8/1986	10/18/2011 13:44	8383	11.0	11.5	7.99	7910	511.18	482.05	1437	12.23
				6/6/2012 14:05	8197	10.8	10.8	7.05	7850	491.78	467.73	1395.17	13.03
	219136	40	4/7/2005	10/18/2011 11:02	3818	4.9	8.9	7.19	4030	334.53	251.93	491.65	6.82
				6/6/2012 11:06	3731	5.0	9.1	7.16	4090	326.23	249.05	488.63	6.69
	220857	13.8	8/26/2005	10/10/2011 16:11	2719	4.4	13.7	7.28	3430	351.3	98.06	362.9	7.34
				6/7/2012 12:22	2189	3.7	9.3	7.32	2750	295.62	82.99	283.29	5.54
	122766	34	8/31/1977	10/18/2011 8:32	6651	6.4	12	7.23	6390	300.3	646.55	865.1	33.67
				6/4/2012 12:52	6165	6.1	9.7	7.23	6080	277.43	584.9	784.08	30.06
	228776			10/17/2011 15:15	5517	6.0	12.6	7.31	5740	256.93	526.78	730.23	13.4
				6/5/2012 10:10	4418	6.0	11.4	7.25	4830	196.78	390.7	633.2	8.17
	240578			10/17/2011 16:05	1583	3.2	14.3	7.16	2130	115.43	140.95	215.02	11.51
				6/5/2012 11:25	1467	3.0	15.2	7.17	2344.7	106.13	131	197.75	8.97
	228592	21.5		10/18/2011 10:36	1280	1.8	13.3	7.25	1865	167.7	113.55	121.53	5.99
				6/4/2012 18:15	932	1.3	10.4	7.35	1390	122.58	81.25	78.05	4.44

	Gwic Id	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)	Cl (mg/l)	NO3-N (mg/l)	F (mg/l)	OPO4-P (mg/l)
Sites currently outside areas of potential CBM influence	183560	<0.013 U	<0.005 U	18.97	374.49	0	192.2	14.06	6.87	0.32	<0.020 U
	207066	0.979	0.209	26.91	560.61	0	82.28	3.65	<0.010 U	0.67	<0.020 U
		0.573	0.214	26.4	554.9	0	77.25	3.48	<0.010 U	0.6	<0.020 U
	205010	1.396	0.213 J	10.65	829.28	0	1552	4.64	0.07	0.27	<0.020 U
	199572	0.476	0.090 J	12.42	553.5	0	1787	14.28	<0.010 U	0.28	<0.020 U
Sites within current areas of potential CBM influence	223952	0.077	0.01	10.48	1693.01	0	224	54.96	<0.010 U	2.69	0.11
		0.051 J	<0.010 U	10.45	1527.86	0	218.5	56.25	<0.010 U	2.64	0.040 J
	7905	0.673	0.884	21.89	948.73	0	2133	23.67	<0.050 U	1.13	<0.100 U
		0.758	0.815	21.07	864.6	0	2150	26.45	<0.010 U	1.07	<0.020 U
	8888	6.25	1.826	13.43	879.07	0	4035	10.67	<0.050 U	0.61	<0.100 U
		6.06	1.884	12.84	797.74	0	4067	10.66	<0.050 U	0.55	<0.100 U
	198489	8.927	1.944	14.3	917.15	0	5446	16.52	<0.050 U	0.56	<0.100 U
		9.028	1.993	14.13	812.19	0	5388	16.13	<0.050 U	0.48	<0.100 U
	219136	1.876	0.577	9.55	486.01	0	2470	10.17	<0.050 U	0.43	<0.100 U
		1.82	0.598	8.79	385.96	0	2448	9.95	<0.050 U	0.35	<0.100 U
	220857	0.198	0.756	21.23	508.51	0	1441	186.1	0.06	0.37	<0.020 U
		0.146	0.395	17.96	417.1	0	1160	138	0.06	0.3	<0.020 U
	122766	4.728	0.793	21.16	732.72	0	4391	24.51	0.3	0.74	<0.100 U
		6.312	0.919	20.15	642.42	0	4122	22.33	<0.050 U	0.59	<0.100 U
	228776	0.077	0.109	9.41	750.67	0	3573	37.4	<0.050 U	0.6	<0.100 U
		0.301	0.101 J	8.24	709.2	0	2808	23.98	0.38	0.48	<0.100 U
	240578	0.042	<0.003 U	16.44	662.76	0	743.6	12.44	<0.010 U	0.78	<0.020 U
		0.037 J	<0.005 U	16.4	591.3	0	704.9	10.08	<0.010 U	0.71	<0.020 U
	228592	0.055	0.031	21.1	552.56	0	473.8	84.44	19.3	0.31	<0.020 U
		0.097	0.035 J	19.28	432.17	0	374.5	38.78	0.12	0.27	<0.020 U

	Gwic Id	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 currently outside areas of potential CBM influence	183560	<0.250 U	25.35	0.580 J	70.5	41.55	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	5.71	19.02
	207066	<0.100 U	22.82	2.1	114.7	77.75	<0.100 U	<10.000 U	<0.100 U	0.140 J	0.150 J	<0.100 U	40.09
		<0.100 U	24.06	2.03	104.87	73.52	<0.100 U	92	<0.100 U	0.240 J	<0.100 U	0.110 J	43.37
	205010	<1.000 U	<4.000 U	<1.000 U	110.27	11.18	<1.000 U	<10.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	148.44
	199572	<1.000 U	<4.000 U	<1.000 U	105.28	19.59	<1.000 U	<10.000 U	<1.000 U	<1.000 U	<1.000 U	1.290 J	121.89
Sites within current areas of potential CBM influence	223952	<0.500 U	<2.000 U	<0.500 U	297.62	25.08	<0.500 U	276	<0.500 U	<0.500 U	1.140 J	0.570 J	90.29
		<0.500 U	<2.000 U	0.540 J	295.97	24.96	<0.500 U	281	<0.500 U	<0.500 U	<0.500 U	2.010 J	96.88
	7905	<1.000 U	<4.000 U	<1.000 U	344.27	28.1	<1.000 U	<50.000 U	<1.000 U	<1.000 U	2.760 J	<1.000 U	123.02
		<1.000 U	<4.000 U	1.720 J	307.85	24.36	<1.000 U	<10.000 U	<1.000 U	<1.000 U	<1.000 U	1.390 J	127.12
	8888	<1.000 U	<4.000 U	1.170 J	182.97	7.32	<1.000 U	<50.000 U	<1.000 U	1.830 J	2.780 J	1.740 J	172.16
		<1.000 U	<4.000 U	2.690 J	183.77	27.99	<1.000 U	<50.000 U	<1.000 U	2.320 J	<1.000 U	41.11	170.83
	198489	<1.000 U	<4.000 U	3.050 J	216.07	6.43	<1.000 U	<50.000 U	<1.000 U	2.090 J	2.780 J	2.360 J	201.17
		<1.000 U	<4.000 U	3.540 J	212.75	5.6	<1.000 U	<50.000 U	<1.000 U	2.410 J	<1.000 U	2.760 J	195.31
	219136	<1.000 U	40.71	<1.000 U	84.36	7.96	<1.000 U	<50.000 U	<1.000 U	<1.000 U	2.780 J	<1.000 U	113.77
		<1.000 U	34.86	<1.000 U	88.16	6.8	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	1.450 J	119.17
	220857	<0.500 U	<2.000 U	2.040 J	111.52	18.52	<0.500 U	220	<0.500 U	0.820 J	1.140 J	0.610 J	58.93
		<0.500 U	145.44	1.540 J	101.65	16.26	<0.500 U	198	<0.500 U	0.940 J	<0.500 U	1.010 J	35.95
	122766	<1.000 U	<4.000 U	<1.000 U	284.72	15.98	<1.000 U	<50.000 U	<1.000 U	<1.000 U	2.760 J	<1.000 U	277.14
		<1.000 U	130	2.880 J	237.96	13.42	<1.000 U	<50.000 U	<1.000 U	1.130 J	<1.000 U	3.680 J	271.19
	228776	<1.000 U	<4.000 U	<1.000 U	118.03	11.15	<1.000 U	<50.000 U	<1.000 U	<1.000 U	2.760 J	1.900 J	298.38
		<1.000 U	<4.000 U	<1.000 U	104.51	8.61	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	2.320 J	271.66
	240578	0.353 J	27.1	<0.250 U	238.18	18.61	<0.250 U	93	<0.250 U	<0.250 U	0.280 J	0.870 J	172.73
		<0.250 U	32.35	<0.250 U	219.73	16.98	<0.250 U	96	<0.250 U	<0.250 U	<0.250 U	0.470 J	174.02
	228592	<0.250 U	47.3	0.520 J	94.26	68.14	<0.250 U	<10.000 U	<0.250 U	<0.250 U	0.280 J	16.27	24.87
		<0.250 U	35.35	0.530 J	77.39	44.67	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	11.12	21.18

	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)
Sites currently outside areas of potential CBM influence	183560	1.230 J	1.39	0.270 J	<0.250 U	1.26	<0.250 U	545.27	1.61	<0.250 U	3.72	0.880 J	10.14
	207066	2.64	0.180 J	<0.040 U	<0.100 U	<0.100 U	<0.100 U	1067.6	0.61	<0.100 U	0.66	0.370 J	<0.200 U
		2.54	1.11	<0.040 U	<0.100 U	0.85	<0.100 U	1046.81	0.86	<0.100 U	0.67	0.66	0.800 J
	205010	<1.000 U	2.840 J	<0.400 U	<1.000 U	5.91	<1.000 U	4261.24	15.7	<1.000 U	<1.000 U	<1.000 U	<2.000 U
	199572	<1.000 U	3.760 J	<0.400 U	<1.000 U	4.660 J	<1.000 U	4952.65	15.68	<1.000 U	1.810 J	<1.000 U	<2.000 U
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.500 U	0.260 J	<0.500 U	<0.500 U	0.690 J	1631.77	0.780 J	<0.500 U	<0.500 U	<0.500 U	1.910 J
		<0.500 U	<0.500 U	<0.200 U	<0.500 U	2.310 J	<0.500 U	1569.46	2.070 J	<0.500 U	<0.500 U	<0.500 U	<1.000 U
	7905	6.74	2.110 J	<0.400 U	<1.000 U	<1.000 U	<1.000 U	2853.72	17.39	<1.000 U	13.09	<1.000 U	3.260 J
		5.75	4.150 J	<0.400 U	<1.000 U	5.23	<1.000 U	2744.16	19.89	<1.000 U	11.92	<1.000 U	<2.000 U
	8888	<1.000 U	1.610 J	<0.400 U	<1.000 U	<1.000 U	<1.000 U	5537.32	32.08	<1.000 U	15.83	<1.000 U	16.09
		<1.000 U	7.27	<0.400 U	<1.000 U	8.09	<1.000 U	5394.23	36.5	<1.000 U	15.64	<1.000 U	<2.000 U
	198489	1.250 J	1.840 J	<0.400 U	<1.000 U	<1.000 U	<1.000 U	7250.07	43.17	<1.000 U	34.95	<1.000 U	16.02
		1.220 J	9.46	<0.400 U	<1.000 U	8.57	<1.000 U	7131.75	50.61	<1.000 U	32.89	<1.000 U	<2.000 U
	219136	<1.000 U	<1.000 U	<0.400 U	<1.000 U	<1.000 U	<1.000 U	5355.06	20.82	<1.000 U	3.330 J	<1.000 U	20.08
		<1.000 U	4.100 J	<0.400 U	<1.000 U	3.660 J	<1.000 U	5304.16	25.27	<1.000 U	3.220 J	<1.000 U	<2.000 U
	220857	3.25	<0.500 U	<0.200 U	<0.500 U	0.550 J	<0.500 U	2357.29	11.95	<0.500 U	18.9	1.090 J	5.53
		2.350 J	4.15	<0.200 U	<0.500 U	1.810 J	<0.500 U	1940.44	11.59	<0.500 U	14.02	0.660 J	4.250 J
	122766	3.430 J	2.430 J	<0.400 U	<1.000 U	<1.000 U	1.330 J	6069.6	36.07	<1.000 U	30.83	<1.000 U	9.020 J
		3.280 J	5.66	<0.400 U	<1.000 U	8.53	<1.000 U	5496.76	44.17	<1.000 U	27.24	<1.000 U	<2.000 U
	228776	<1.000 U	<1.000 U	<0.400 U	<1.000 U	3.300 J	1.300 J	6273.9	30.95	<1.000 U	18.64	<1.000 U	2.480 J
		<1.000 U	3.160 J	<0.400 U	<1.000 U	11.57	<1.000 U	5070.22	28.81	<1.000 U	12.92	<1.000 U	<2.000 U
	240578	0.300 J	0.310 J	<0.100 U	<0.250 U	<0.250 U	<0.250 U	2792.84	5.79	<0.250 U	0.270 J	0.980 J	2.8
		0.270 J	1.82	<0.100 U	<0.250 U	3.09	<0.250 U	2619.66	7.07	<0.250 U	<0.250 U	1.080 J	1.250 J
	228592	0.860 J	0.410 J	0.210 J	<0.250 U	0.490 J	<0.250 U	921.15	3.67	<0.250 U	10.94	0.510 J	16.58
		0.710 J	2.07	0.210 J	<0.250 U	0.630 J	<0.250 U	659.82	3.64	<0.250 U	7.48	0.500 J	5.3

	Gwic Id	Zr (ug/l)	Ce (ug/l)	Cs (ug/l)	Ga (ug/l)	La (ug/l)	Nb (ug/l)	Nd (ug/l)	Pd (ug/l)	Pr (ug/l)	Rb (ug/l)	Th (ug/l)
Sites currently outside areas of potential CBM influence	183560	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	4.22	<0.250 U
	207066	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	10.95	<0.100 U
		<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.66	<0.100 U	13.17	<0.100 U
	205010	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	1.760 J	<1.000 U	7.84	<1.000 U
	199572	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.040 J	<1.000 U	6.86	<1.000 U
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	6.18	<0.500 U
		<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	0.640 J	<0.500 U	6.53	<0.500 U
	7905	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	13.55	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	14.06	<1.000 U
	8888	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	5.2	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.120 J	<1.000 U	6.04	<1.000 U
	198489	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	4.790 J	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.890 J	<1.000 U	5.31	<1.000 U
	219136	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.170 J	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.200 J	<1.000 U	2.660 J	<1.000 U
	220857	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	2.240 J	<0.500 U
		<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	0.740 J	<0.500 U	1.720 J	<0.500 U
	122766	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	28.21	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.500 J	<1.000 U	29.27	<1.000 U
	228776	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	5.52	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.090 J	<1.000 U	5.73	<1.000 U
	240578	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	6.1	<0.250 U
		<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	1.050 J	<0.250 U	6.63	<0.250 U
	228592	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	6.76	<0.250 U
		<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	5.37	<0.250 U

	Gwic Id	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Total N as N (mg/l)	Sum Dissolved Constituents (mg/l)	Hardness (mg/l)	Alkalinity	Procedure
Sites currently outside areas of potential CBM influence	183560	<0.250 U	<0.010 U	6.91	7.62	830	390	307	DISSOLVED
	207066	<0.100 U	<0.010 U	<0.200 U	<1.000 U	866	457	460	DISSOLVED
		<0.100 U	<0.010 U	<0.200 U	1.15	843	431	455	DISSOLVED
	205010	<1.000 U	<0.010 U	<0.200 U	5.5	3279	1160	680	DISSOLVED
	199572	<1.000 U	<0.010 U	<0.200 U	2.78	3239	1599	454	DISSOLVED
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.010 U	<0.200 U	1.9	2756	182	1389	DISSOLVED
		<0.500 U	<0.010 U	<0.200 U	3.76	2542	174	1253	DISSOLVED
	7905	<1.000 U	<0.050 U	<0.200 U	<1.000 U	4305	1457	778	DISSOLVED
		<1.000 U	<0.010 U	0.39	<1.000 U	4202	1392	709	DISSOLVED
	8888	<1.000 U	<0.050 U	0.34	3.13	6887	2327	721	DISSOLVED
		<1.000 U	<0.050 U	0.46	2.74	6764	2228	654	DISSOLVED
	198489	<1.000 U	<0.050 U	<0.200 U	1.93	8848	3261	752	DISSOLVED
		<1.000 U	<0.050 U	<0.200 U	2.78	8609	3153	666	DISSOLVED
	219136	<1.000 U	<0.050 U	<0.200 U	1.83	4065	1872	399	DISSOLVED
		<1.000 U	<0.050 U	<0.200 U	1.76	3927	1840	317	DISSOLVED
	220857	<0.500 U	<0.010 U	<0.200 U	<1.000 U	2977	1281	417	DISSOLVED
		<0.500 U	<0.010 U	<0.200 U	1.32	2401	1080	342	DISSOLVED
	122766	<1.000 U	<0.050 U	<0.200 U	<1.000 U	7023	3411	601	DISSOLVED
		<1.000 U	<0.050 U	<0.200 U	<1.000 U	6490	3100	527	DISSOLVED
	228776	<1.000 U	<0.050 U	<0.200 U	3.08	5898	2810	616	DISSOLVED
		<1.000 U	<0.050 U	0.32	3.43	4777	2099	582	DISSOLVED
	240578	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1919	868	544	DISSOLVED
		<0.250 U	<0.010 U	<0.200 U		1767	804	485	DISSOLVED
	228592	<0.250 U	0.08	18.4	19.9	1560	886	454	DISSOLVED
		<0.250 U	<0.010 U	0.55	1.23	1151	641	354	DISSOLVED

Appendix D

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

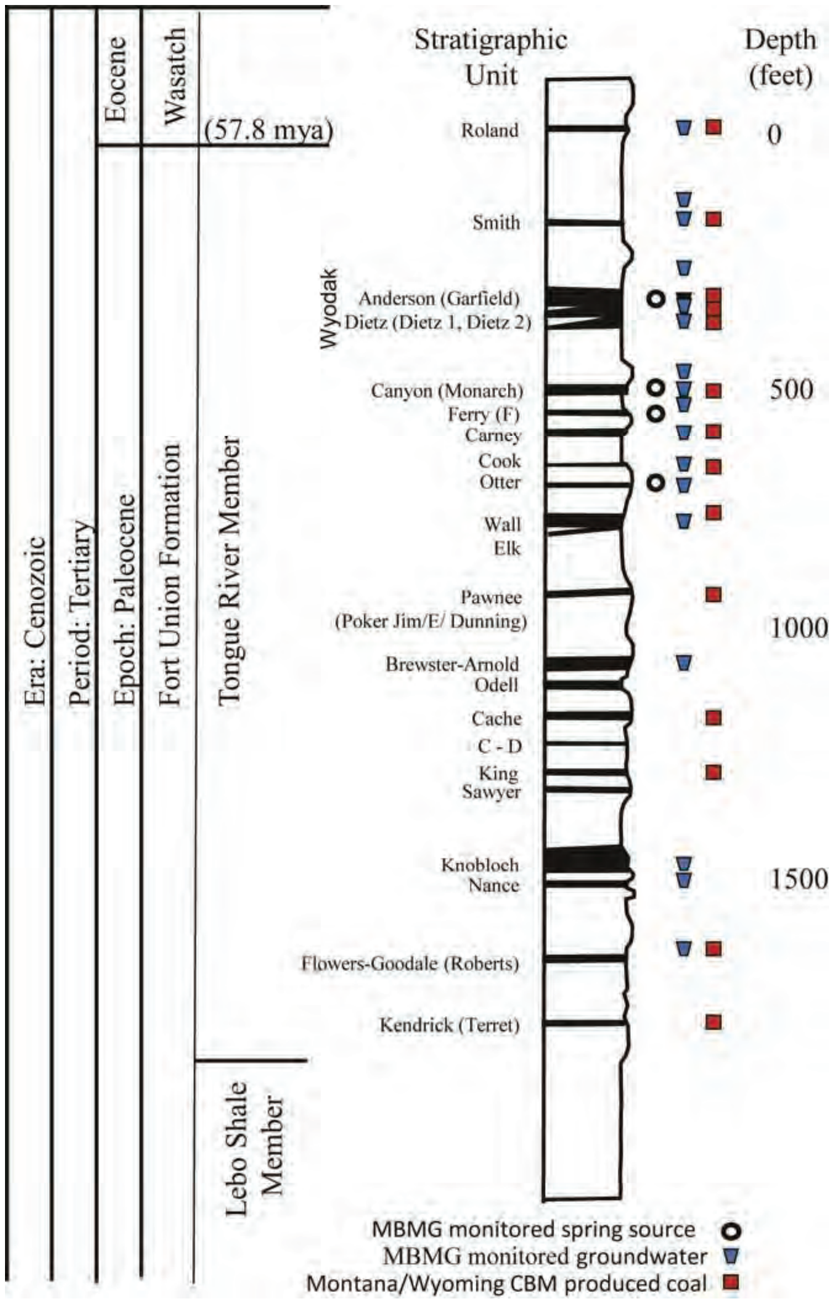
Geology and Hydrogeology of the Tongue River Member of the Fort Union Formation

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

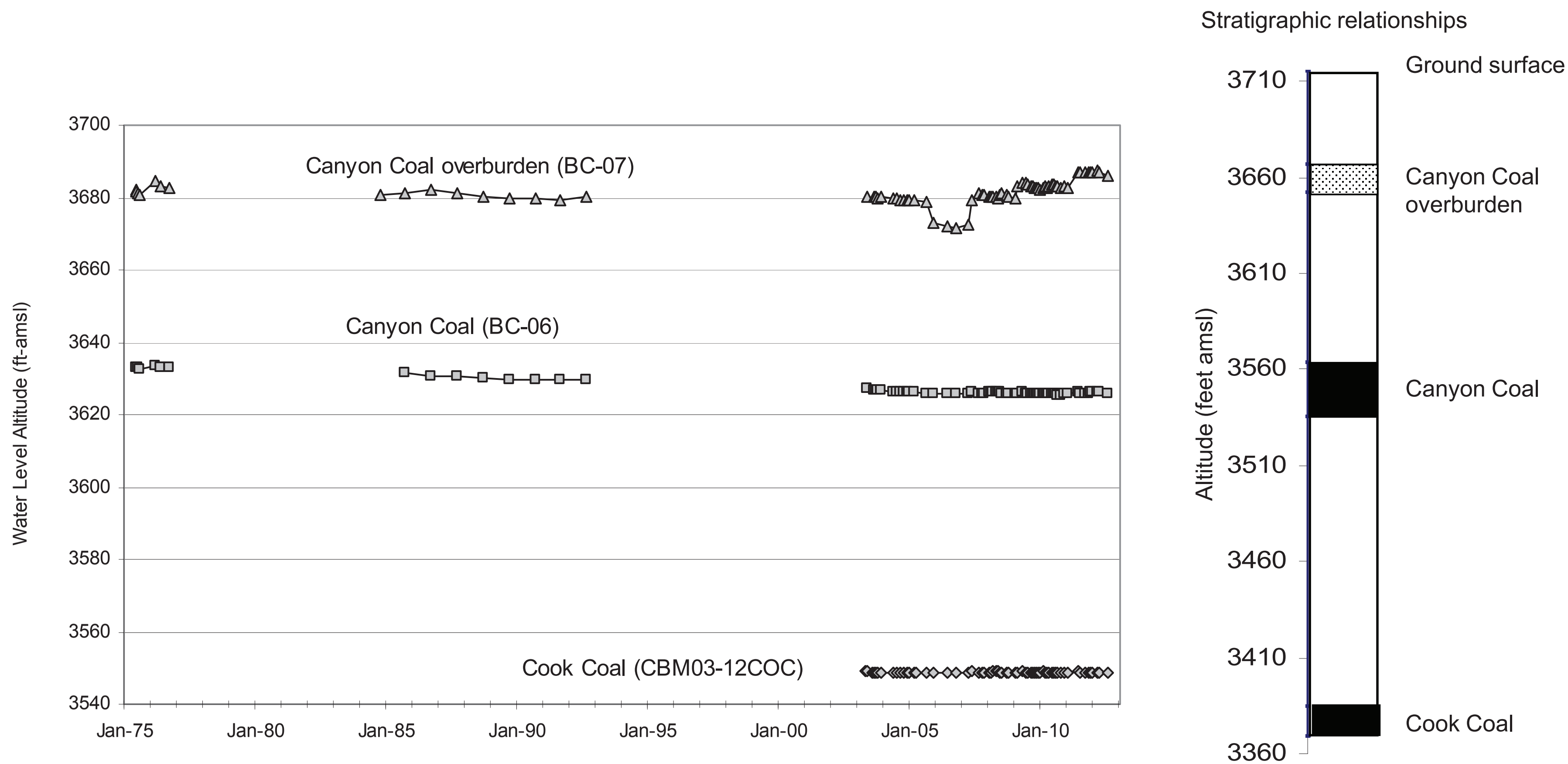


Figure E-1. Monitoring site CBM03-12 has been measured since 1974. There is a downward gradient at this site. The long-term decrease in water levels in the overburden sandstone (BC-07) and Canyon coal (BC-06), began long before the introduction of CBM and likely relate to long-term precipitation patterns (Figure 2). The 9 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.

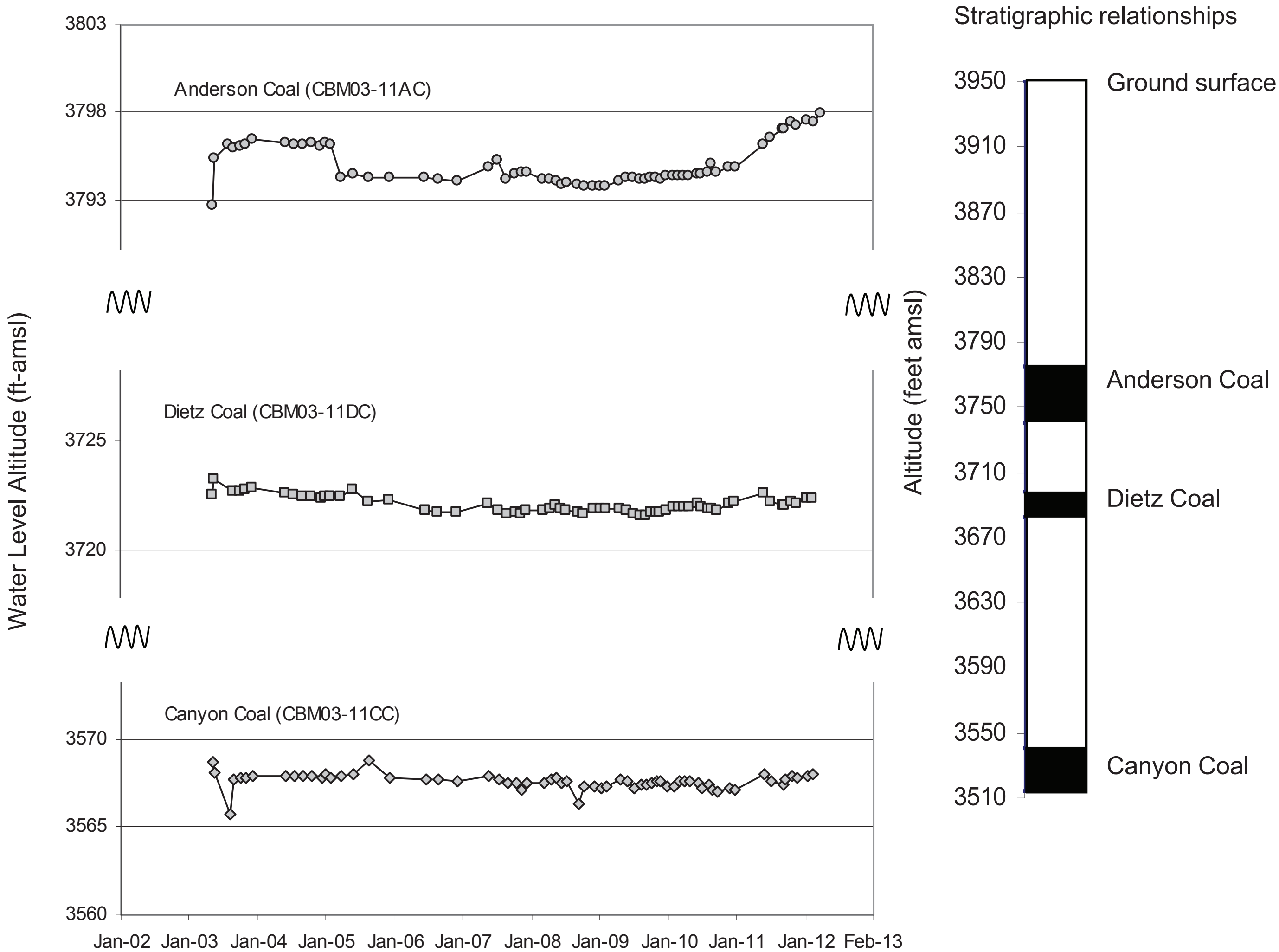


Figure E-2 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site. This site is near the Anderson coal outcrop.

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

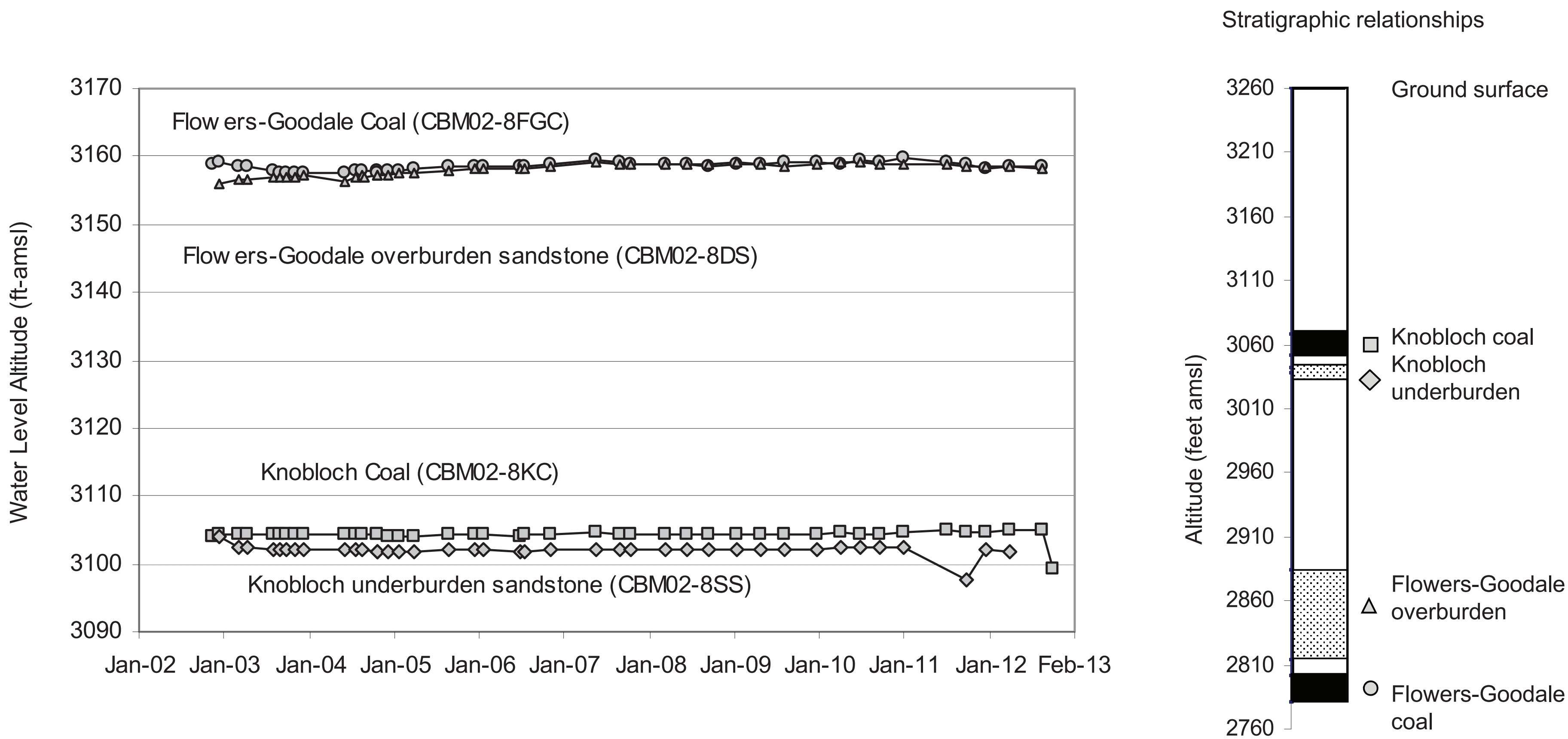


Figure E-3. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. The hydrostatic pressure in the Knobloch coal have been reduced by natural discharge to nearby outcrops. This upward gradient 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.

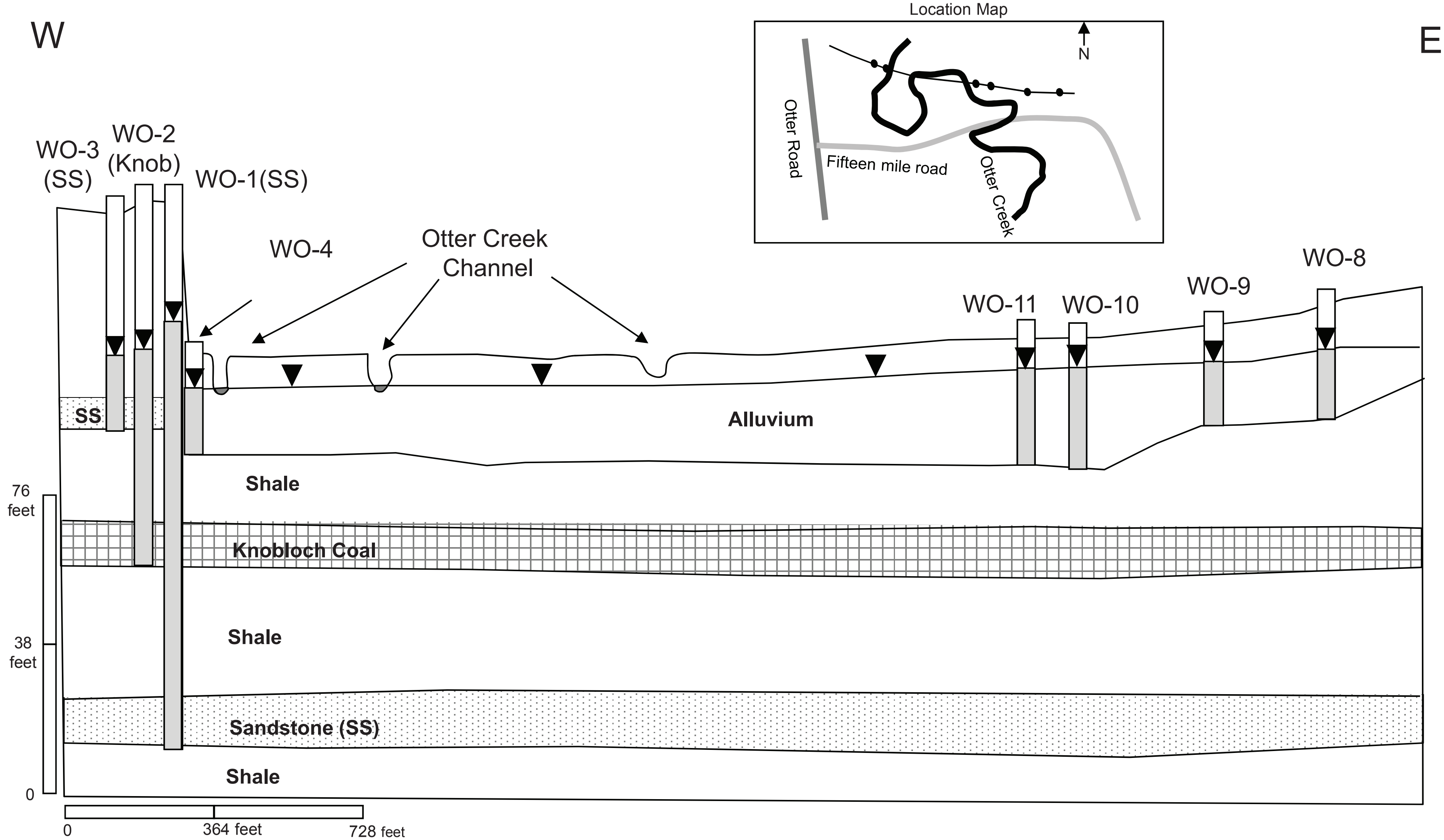


Figure E-4. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in September, 2012. Vertical exaggeration is 9.6:1. Hydrographs for these wells are presented in Figures 4 and E-5.

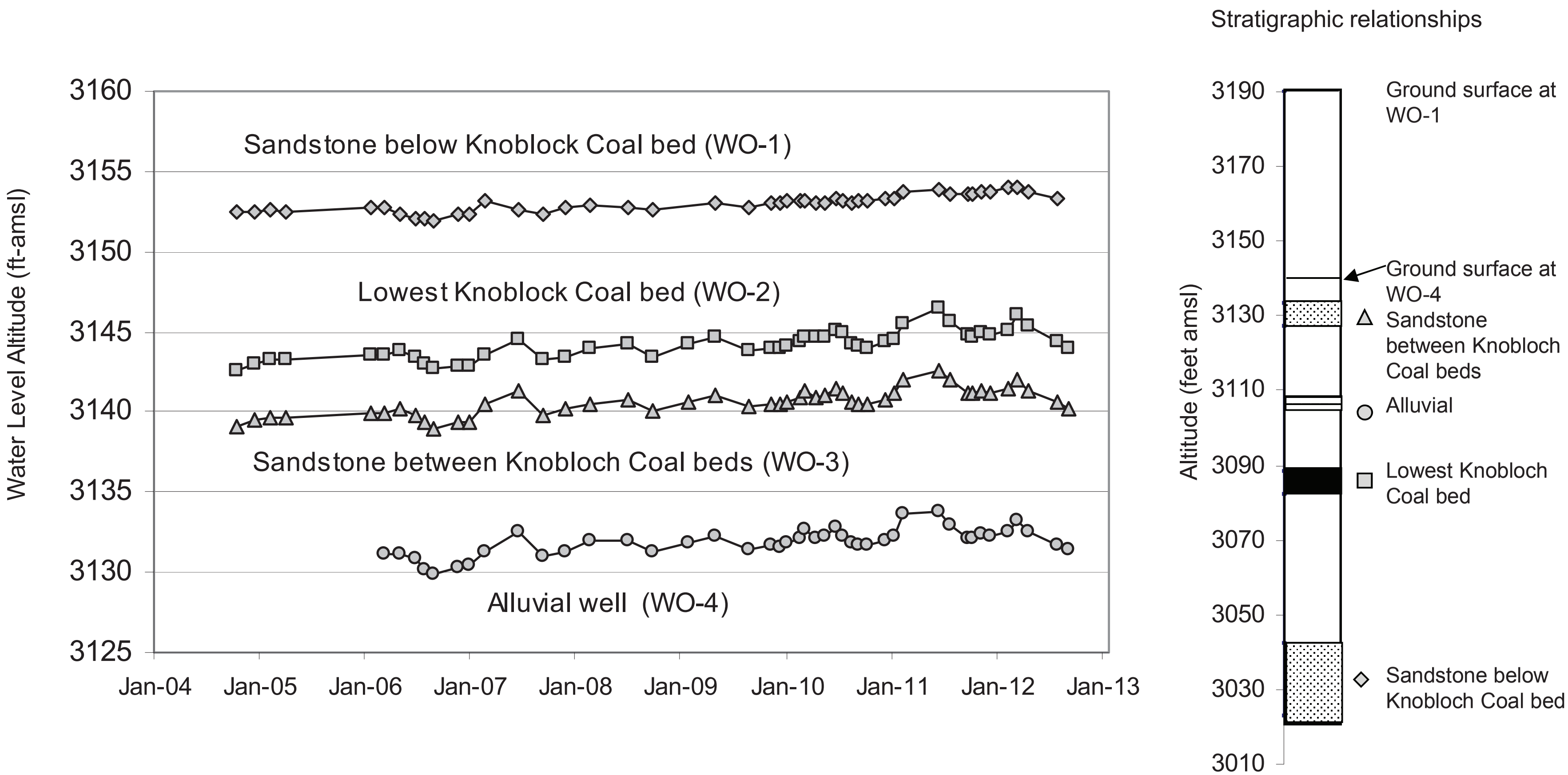


Figure E-5. At monitoring site WO, bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. This upward gradient indicates that the bedrock aquifer will discharge into the alluvium where the two units are in contact. The alluvial well appears to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

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

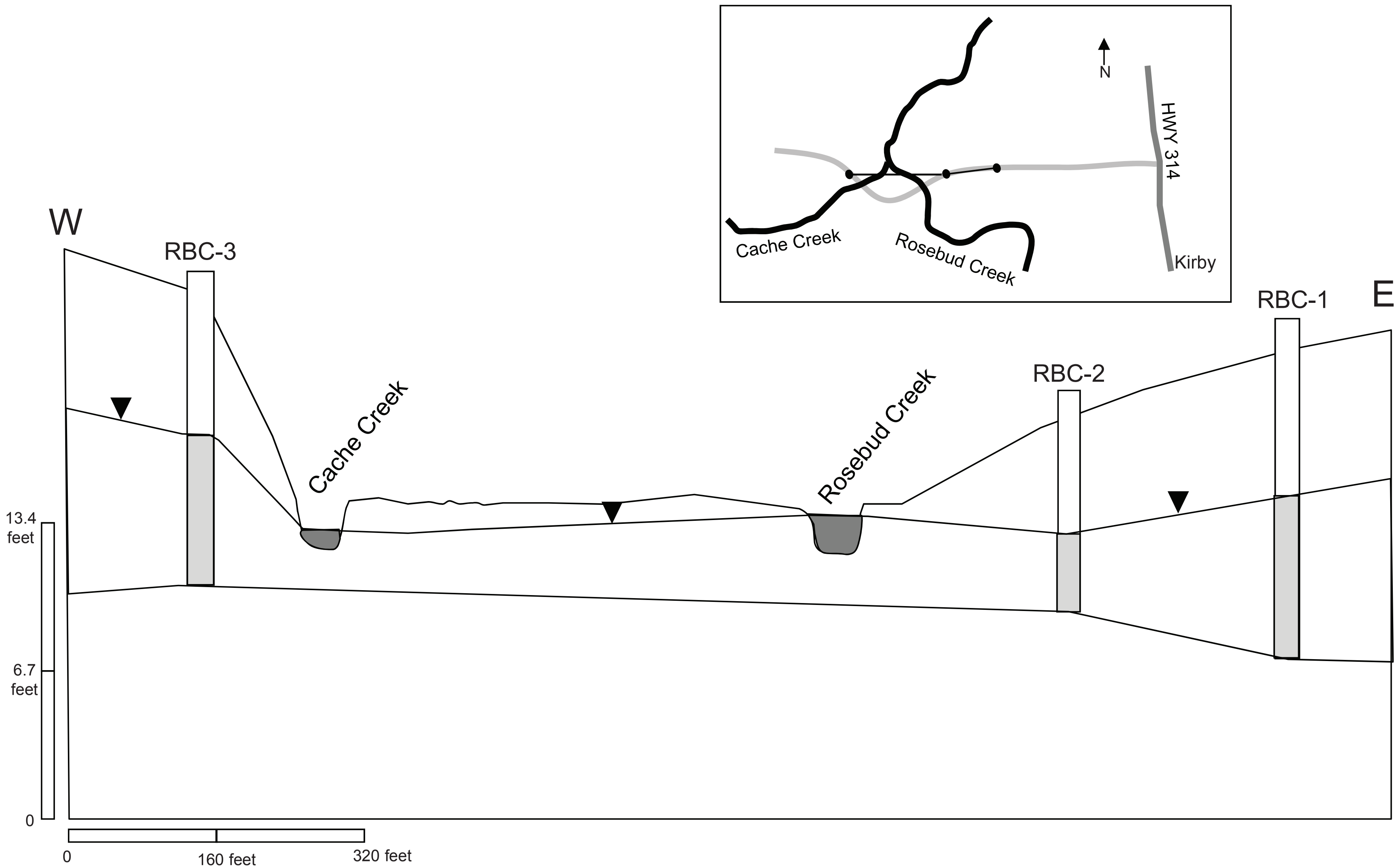


Figure E-6. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water depending 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 2012. Vertical exaggeration is 23.9:1. Hydrographs associated with this site are shown in Figure 5.

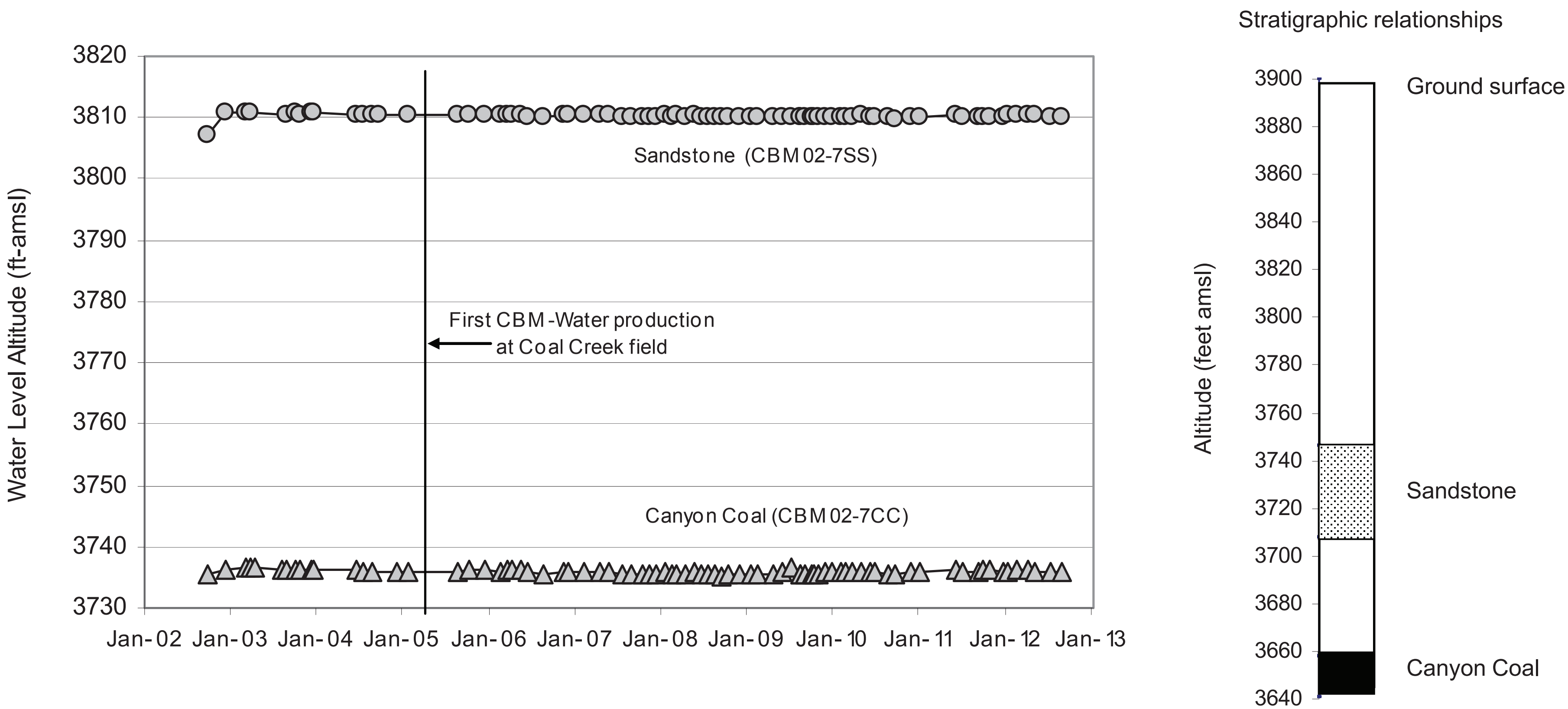


Figure E-7. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

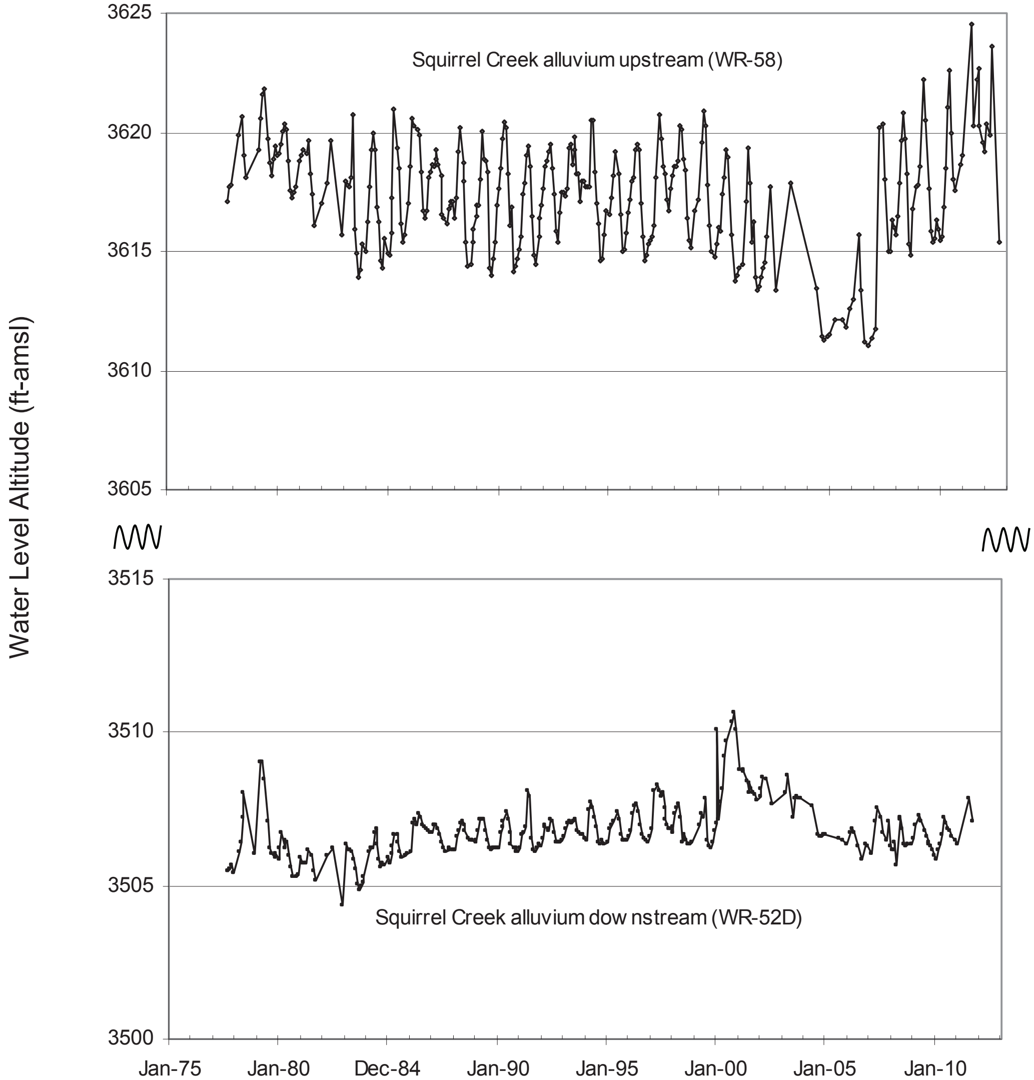


Figure E-8. These alluvial wells are within the area influenced by CBM production; however, they no longer show impacts from the nearby infiltration pond. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production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