2013 Annual Coalbed-Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

MBMG Open-File Report 651

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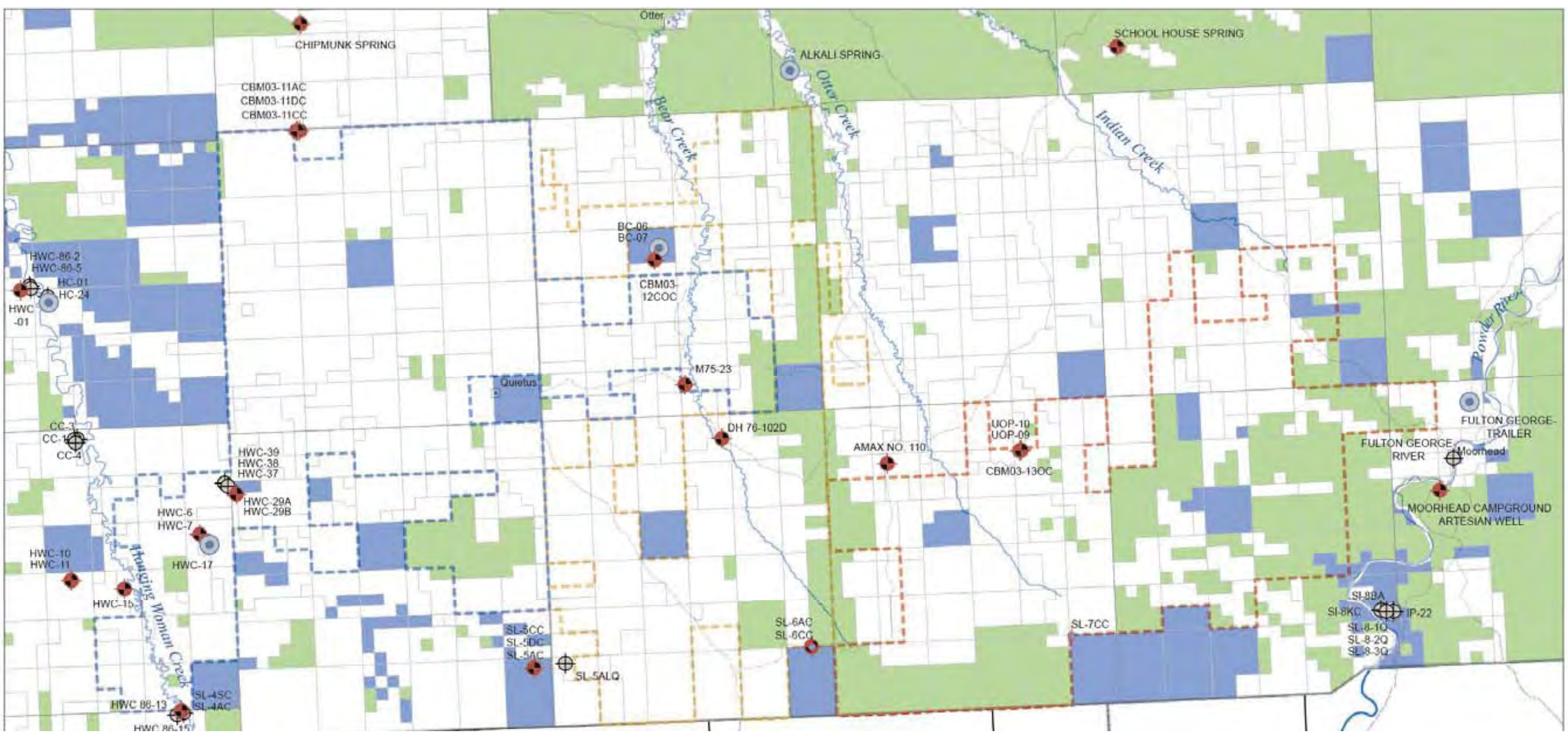

Montana Bureau of Mines and Geology

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ABSTRACT

This report presents groundwater data collected through September 2013 from within the Montana portion of the Powder River Basin, with an emphasis on data collected during water year 2013 (October through September). This is the 11th 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, monitoring wells installed 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 294 CBM wells that produced methane, water, or both during 2013, 281 fewer wells than 2012. A total of 1.91 million mscf (1 mscf = 1,000 standard cubic feet) of CBM was produced in Montana during 2013, 74 percent of which came from the CX field; the other 26 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.

The Montana Bureau of Mines and Geology (MBMG) measured water levels 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) provided water-level measurements from monitoring wells and 24-h 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 14 yr of CBM production, the 20-ft drawdown contours for the Dietz and Canyon coals extend approximately 1.0 to 1.5 mi beyond the CBM production area boundaries. These distances are less than the approximately 4-mi 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-ft 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, where measured in monitoring wells, drawdown has not been observed to migrate across fault planes; however, recent computer modeling of the Ash Creek mine area shows that the hydraulic conductivity of faults can vary significantly along their strike (Meredith and others, 2011), particularly along scissor faults. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after CBM production ceases, but it will likely 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. The amount of time required for water levels to recover to near-baseline conditions is difficult to estimate based on current recovery curves in the CX field. Initial recovery rates were as expected and could have resulted in full recovery in 30 to 100 yr; however, observations during the past 2 yr indicate recovery has stagnated and further recovery may only be seen in years of higher than average precipitation.

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 interpretation are keys to making informed development decisions and to understanding 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); one thousand standard cubic feet (mscf); sodium adsorption ratio (SAR); specific storage (S_s); specific yield (S_y); 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 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 across large areas. Because these coal seams are also important aquifers, CBM water extraction raises concerns about potential loss of stock and domestic water supplies due to drawdown (reduction of hydrostatic pressure) that may reduce yields from wells and discharge from springs. There are also concerns regarding the management of the produced water because of potential impacts to surface-water quality and soils. The Montana regional monitoring program provides data and interpretations that help governmental agencies and the public address the magnitude, extent, and duration of CBM-caused drawdown and its water-quality impact.

The benefits to Montana from CBM production include tax revenue, increased employment, 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 $3.50/MMBtu (http://www.eia.gov/naturalgas/weekly/).

This is the 11th annual report in which the MBMG has actively documented baseline hydrogeologic conditions in current and prospective CBM areas within the northern Powder River Basin, mainly in Montana; quantified groundwater impacts and lack of impacts; recorded groundwater recovery; and provided data and interpretations for use in environmental analyses and permitting decisions. The annual reports currently present data by water year (October through September). Additional background information is presented in Wheaton and Donato (2004).

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://mbmggwic.mtech.edu/. On the first visit to GWIC, select the option to create a login account (free). Users may access CBM-related data by clicking on the picture of a CBM 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 activity in Wyoming townships 57 N. and 58 N., covering a distance of about 9 mi south from the Montana–Wyoming state line (plate 1).

Hydrogeologic data were collected by the MBMG at 251 wells, 14 springs, and 2 streams during the 2013

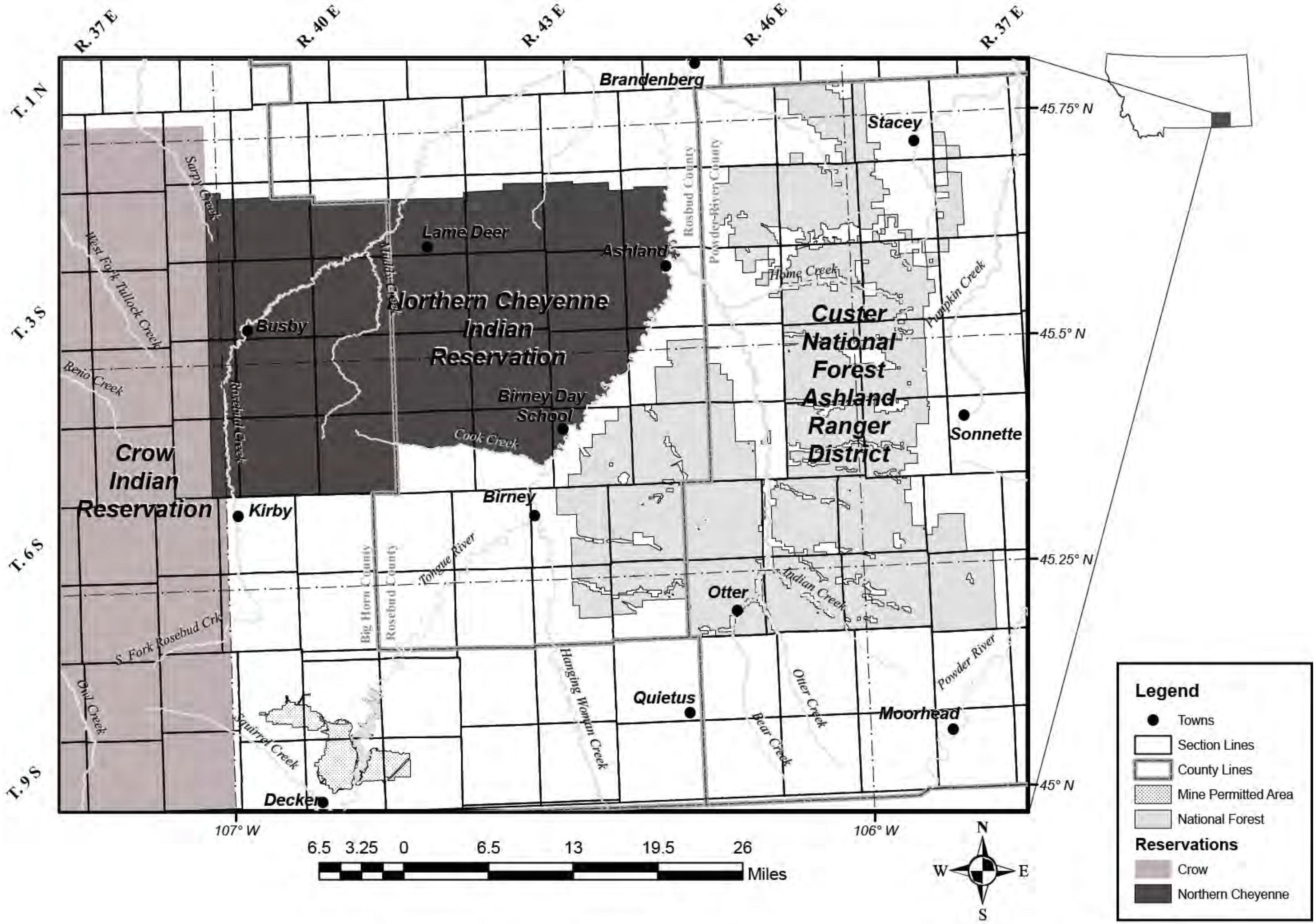


Figure 1. The Montana regional CBM monitoring network covers the area considered to have medium to high potential for CBM development in the Powder River Basin. This area extends from the Wolf Mountains in the west to the Powder River in the east, and from the MT–WY state line north to Ashland.

water year. Of those monitored sites, 21 wells, 10 springs, and 1 stream are located within 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 29 water levels from Canyon, Cook, Wall, and Flowers–Goodale coal wells. Spring Creek mine supplied 70 water levels for 21 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 2013 are listed in appendix C. Appendix D covers the background geology and general water quality in coalbeds of the Powder River Basin. Hydrographs of some monitored wells outside of development are in appendix E. The locations of all monitoring sites are shown in plate 1.

ACKNOWLEDGMENTS

The landowners and coalbed-methane producers who allowed 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 Districts 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. Coal aquifer monitoring wells installed in 2013 were funded through the MBMG Groundwater Investigation Program and the USFS. 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 an east–west line at about the latitude of Ashland, Montana (fig. 1 and plate 1). The area encompasses coal fields 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 57 N. and 58 N.).

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 relatively coarse-grained when compared to the Fort Union. 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, 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

The Powder River Basin contains shallow, local flow systems generally associated with surficial watersheds and local surface-water systems, as well as regional flow systems within deep aquifers associated with structural basins.

Recharge occurs to these local flow systems from precipitation that falls on clinker-capped ridges and outcrops and, in a few locations, as stream-flow infiltration. Near recharge areas, the local bedrock flow systems follow topography. The local flow systems discharge to alluvial aquifers, to springs at bedrock outcrops, or to underlying regional flow systems; however, this vertical seepage between aquifers is limited due to the low permeability of the numerous shale layers present in the Tongue River Member.

Regional bedrock flow systems receive recharge from streams or precipitation near the perimeter of the Powder River Basin where permeable aquifers crop out and by vertical leakage from overlying local flow systems. Regionally, groundwater flows northward from Wyoming into Montana and generally toward the Yellowstone River. Groundwater in the regional flow system leaves the Powder River Basin as deep groundwater flow, as discharge to springs, as contributions to streams and alluvium, and/or as evapotranspiration.

Hundreds of springs of both local and regional origin 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. Deep confined aquifers show small, if any, measurable seasonal water-level changes except for slow reaction to climatic periods of below- or above-average precipitation, but can show marked increases from unusually high precipitation events, such as those in 2011.

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 12.09 in, based on records from 1970 through the end of 2012 (Western Regional Climate Center, 2013). During the calendar year 2013 Moorhead received 19.04 in of precipitation (black circles in fig. 2), 6.95 in more than the average annual precipitation. Long-term precipitation trends that may affect groundwater levels are illustrated by the departure from average (black squares in fig. 2). The early 2000s marked a period of average to below-average precipitation, while precipitation was generally above average from 2005 to 2011.

Coalbeds and other aquifers in the Powder River Basin are generally separated by shale units. At a few locations where overburden and underburden aquifers are monitored in conjunction with the coals, data show that shaley confining layers limit water-level drawdown from CBM development to the coal as drawdown appears to not migrate vertically to impact overlying or underlying aquifers.

In southeastern Montana, faults in the Fort Union Formation are typically barriers to flow 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-level monitoring at other sites demonstrates that some fault systems do allow some cross-fault leakage. A computer model of the area around the Ash Creek Mine (Meredith and others, 2010) showed that groundwater flow must be occurring around the ends of scissor faults.

In the Powder River Basin, coalbed methane exists only in reduced (oxygen-poor) zones where 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.

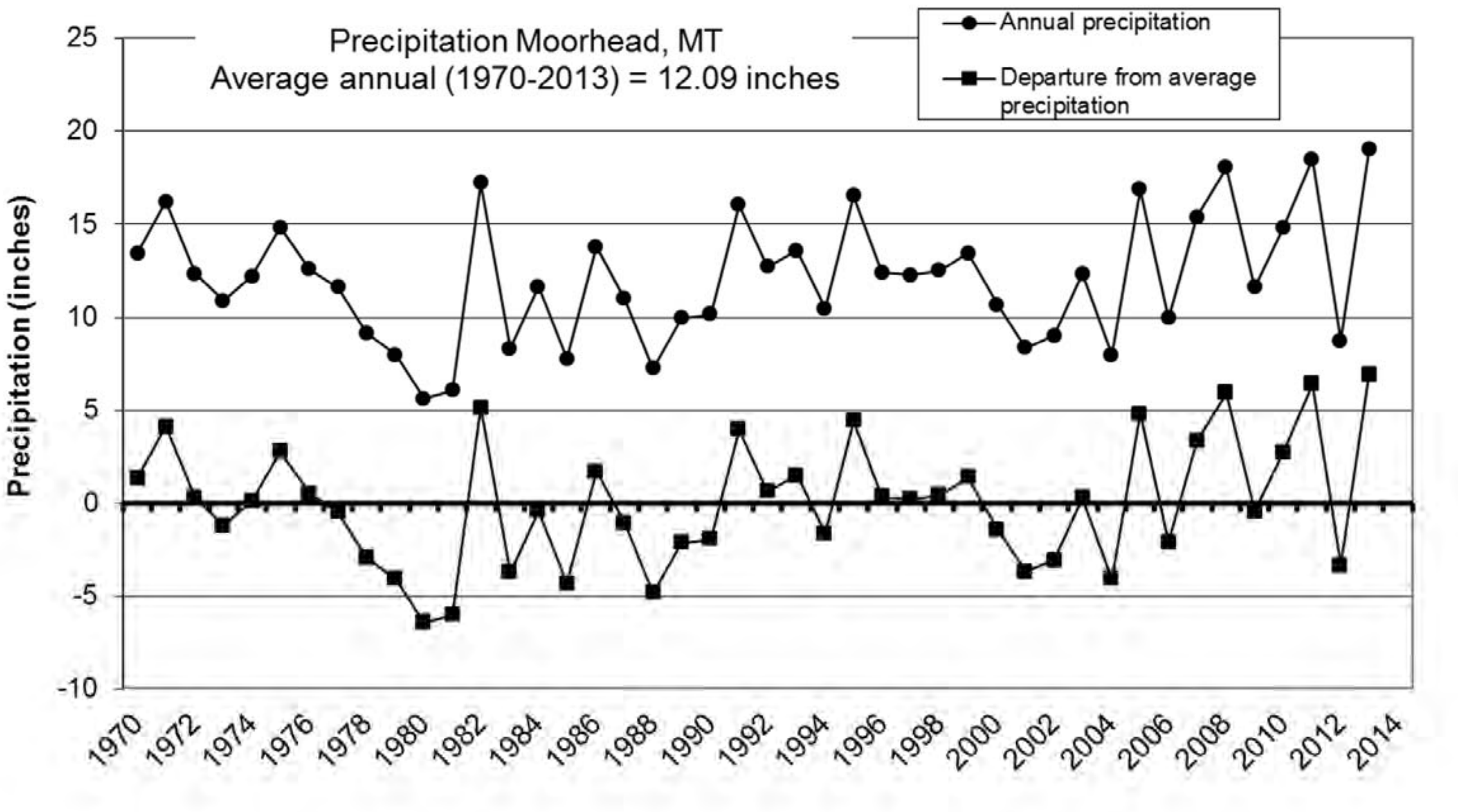


Figure 2. Annual precipitation (circles on line graph) at Moorhead, MT. Departure from average precipitation (squares on line graph) provides a perspective on the long-term moisture trends that may affect groundwater recharge.

GROUNDWATER CONDITIONS OUTSIDE OF CURRENT CBM INFLUENCE

BEDROCK- AND ALLUVIAL-AQUIFER WATER LEVELS AND WATER QUALITY

Groundwater levels (the potentiometric surface) and inferred groundwater flow directions in the Dietz and Canyon coals, as interpreted from the available data, are shown in plates 2 and 3. Near outcrops, topography exerts a strong control on flow, but regional flow is 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. Groundwater discharges at springs, domestic wells, stock wells, and CBM wells; groundwater also moves vertically downward to become deep groundwater flow. Baseline data presented in previous CBM annual reports (e.g., 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 measured cooperatively by the Northern Cheyenne Tribe and the USGS to observe any water-level change caused by CBM production. Wells NC02-1 through NC02-6 (GWIC ID numbers 223238, 223240, 223242, 223243, 223236, and 223237; USGS well names 05S40E31BDCC01, 05S42E14ADDC02, 05S41E17ADBD01, 05S40E13ADAB01, 05S42E16CCAB01, and 05S41E14BDCD01) provide groundwater levels from the Wall (2), Flowers–Goodale, Pawnee, and Knobloch (2) coals. As of the last reported measurements in some wells of May 2013, there has been 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 yr 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

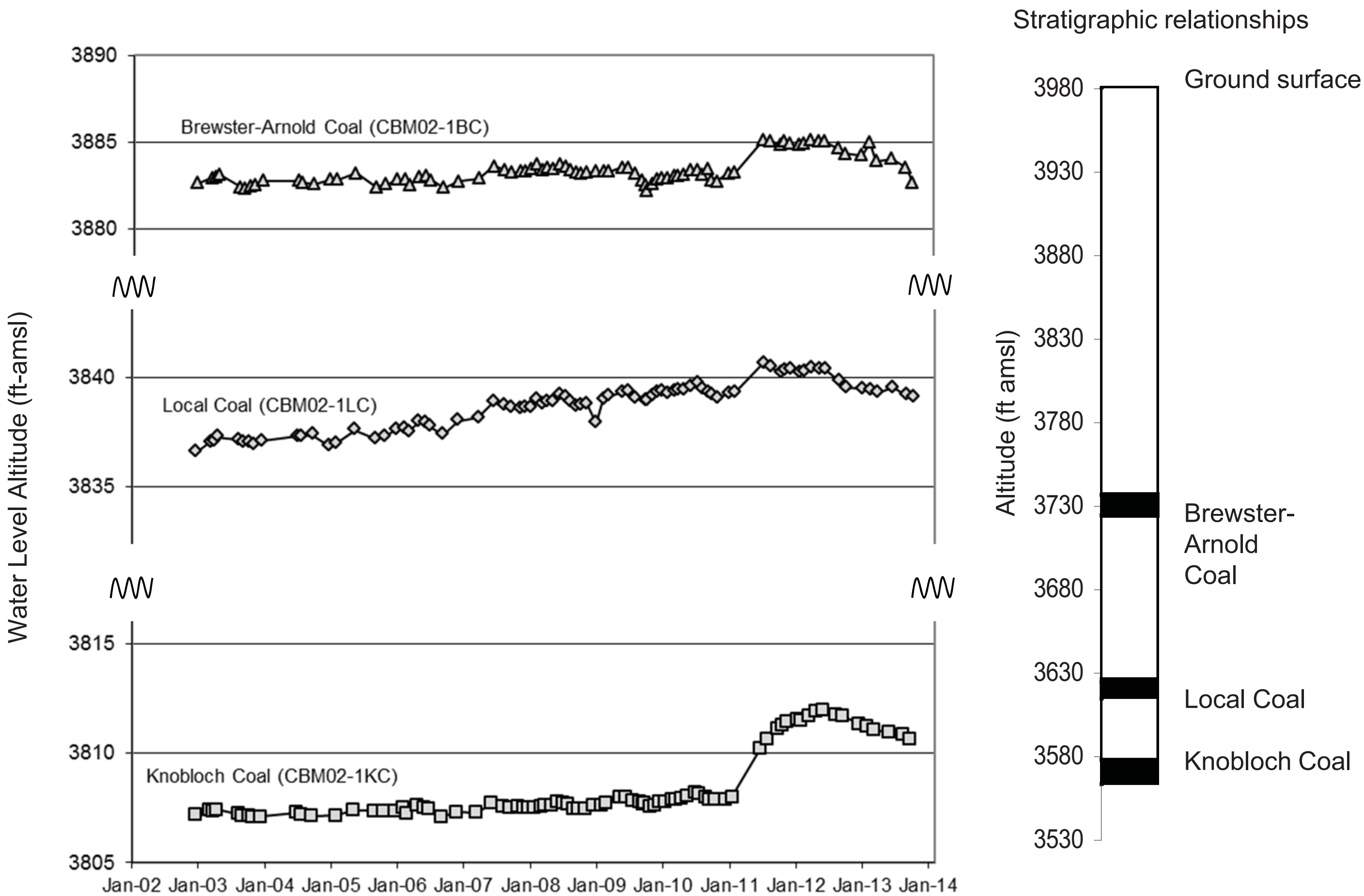


Figure 3. A downward hydrostatic gradient is evident between the Brewster–Arnold coal, local coal, and Knobloch coal at the CBM02-1 site. This monitoring site is near the town of Kirby, just east of Rosebud Creek. Water-level data from the Brewster–Arnold coal and the local coal demonstrate a slight annual cycle with the lowest levels in late summer or early fall, indicating a relationship with precipitation. 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.

to seasonal precipitation, 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. Water levels in the three wells are declining back toward baseline levels; the level in the Brewster–Arnold coal has already reached baseline.

At monitoring site WO, along Otter Creek, alluvial water levels are responsive to local, recent precipitation (fig. 4). 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 illustrate how quickly alluvial groundwater levels respond to precipitation events. Increased in-stream flow at this site usually lags behind heavy

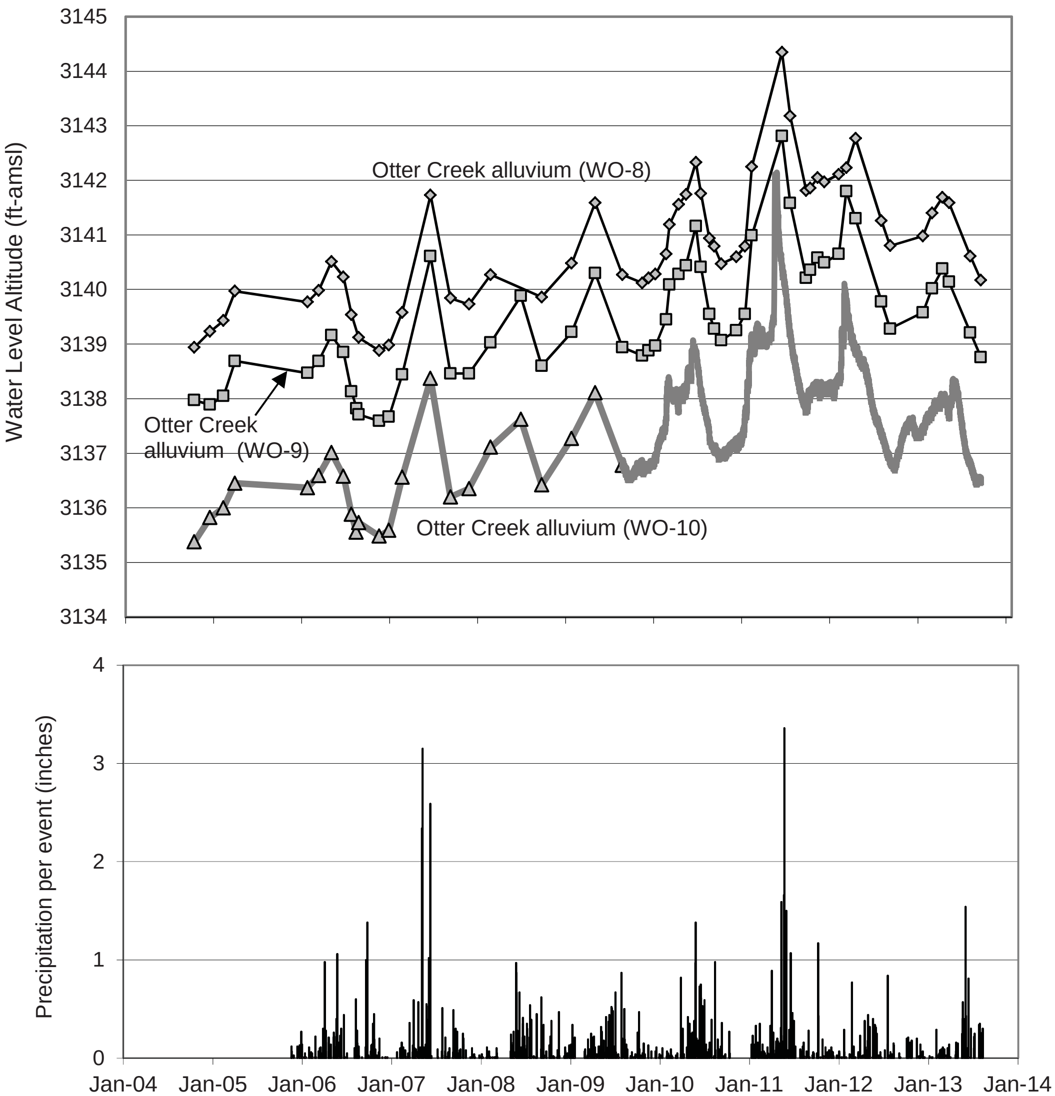


Figure 4. Water-level trends in the alluvium at the Otter Creek site closely follow the precipitation recorded at the Poker Jim weather station (shown as the total rain in inches per event in the lower graph).

rain events by 6 to 18 h; however, real-time stream gauging by the USGS was discontinued in 2011. Alluvial monitoring farther from the stream (RBC-3) shows a weaker correlation between precipitation and water level and may have a larger component of bedrock aquifer recharge.

Water-quality samples were collected in November 2012 and May 2013 from well RBC-2. Similar to previous years, TDS concentrations were 559 and 583 mg/L and SAR values were 0.8 and 0.9, respectively. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate (appendix C).

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 2013. 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 0.55 and 1.58 gpm. Alkali Spring water is a mixture of regional and local flow systems. Evidence for a regional flow system source includes a tritium analysis in 2007 that indicated a tritium-dead (old) system. However, the seasonally linked discharge rate (fig. 6) and seasonally dependent water quality (Meredith and others, 2009) indicate that there also is 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 regionally recharged water (Wheaton and others, 2008). Because this spring has a component of regional recharge, it is possible that CBM activities will impact its flow.

Water from Lemonade Spring, located east of the town of Ashland along U.S. Highway 212, is likely a combination of regional flow and local recharge. This spring is associated with the Ferry coal and typically has moderate seasonal flow variations with an average discharge generally less than 2 gpm. However, high precipitation

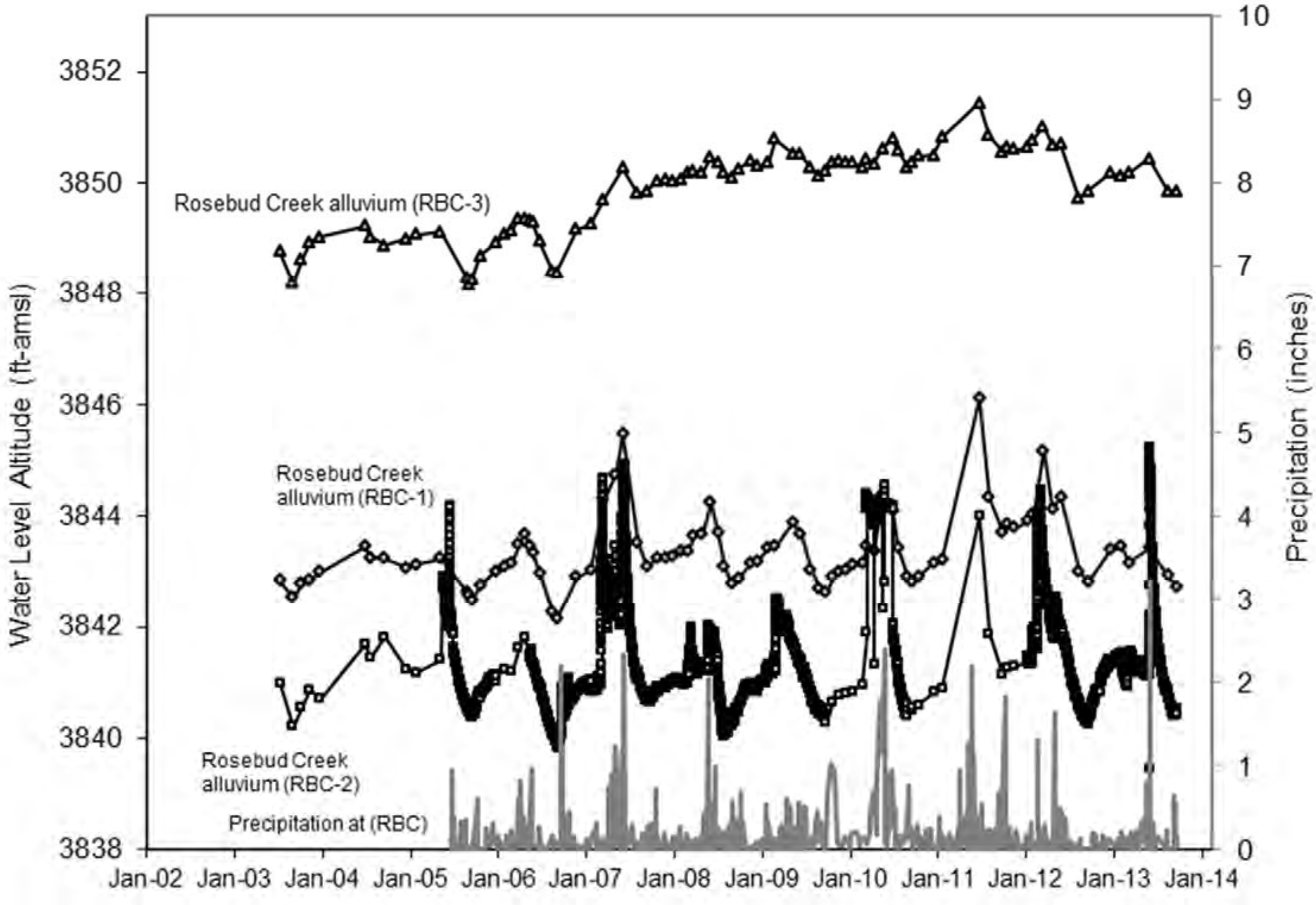


Figure 5. Groundwater levels are typically high during wet times of the year at the Rosebud Creek alluvium site. Wells RBC-1 and RBC-2 show a strong correlation with precipitation. Precipitation is shown as the total rain in inches per event, and a precipitation event is defined as continuous precipitation 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).

in 2011 caused an increase in flow that peaked in mid-2012 and is still elevated above flows measured during the previous 10 yr (fig. 6). North Fork Spring, in the southeast of the Ashland Ranger District, is located in a topographically high area. The North Fork Spring typically discharges less than 1 gpm but also has moderate seasonal fluctuations (fig. 6). This spring is associated with an isolated segment of the Canyon coal and is likely discharge from a local flow system.

The MBMG collected water-quality samples in April 2013 from Hedum Spring, which is located outside of the area influenced by CBM production (appendix C). Water from Hedum Spring violates primary drinking water standards for nitrate, arsenic, and uranium; secondary standards for sodium and sulfate (also the primary standard for sulfate in stock water); and the irrigation standard for selenium. Because the water contains unusually high concentrations of trace elements, Hedum Spring was resampled in November 2013, and the new analyses showed similar concentrations for the elements of concern; however, nitrate and uranium concentrations were slightly lower than found in the earlier analysis and were below the drinking water standard. Hedum spring originates from sandstone with a clinker outcrop nearby.

Several springs located on the Ashland Ranger District have flow and field chemistry monitored quarterly, but have not been sampled for a full water-quality analysis. Future sampling plans include collecting at least two water-quality samples from every spring being monitored on the Ashland Ranger District.

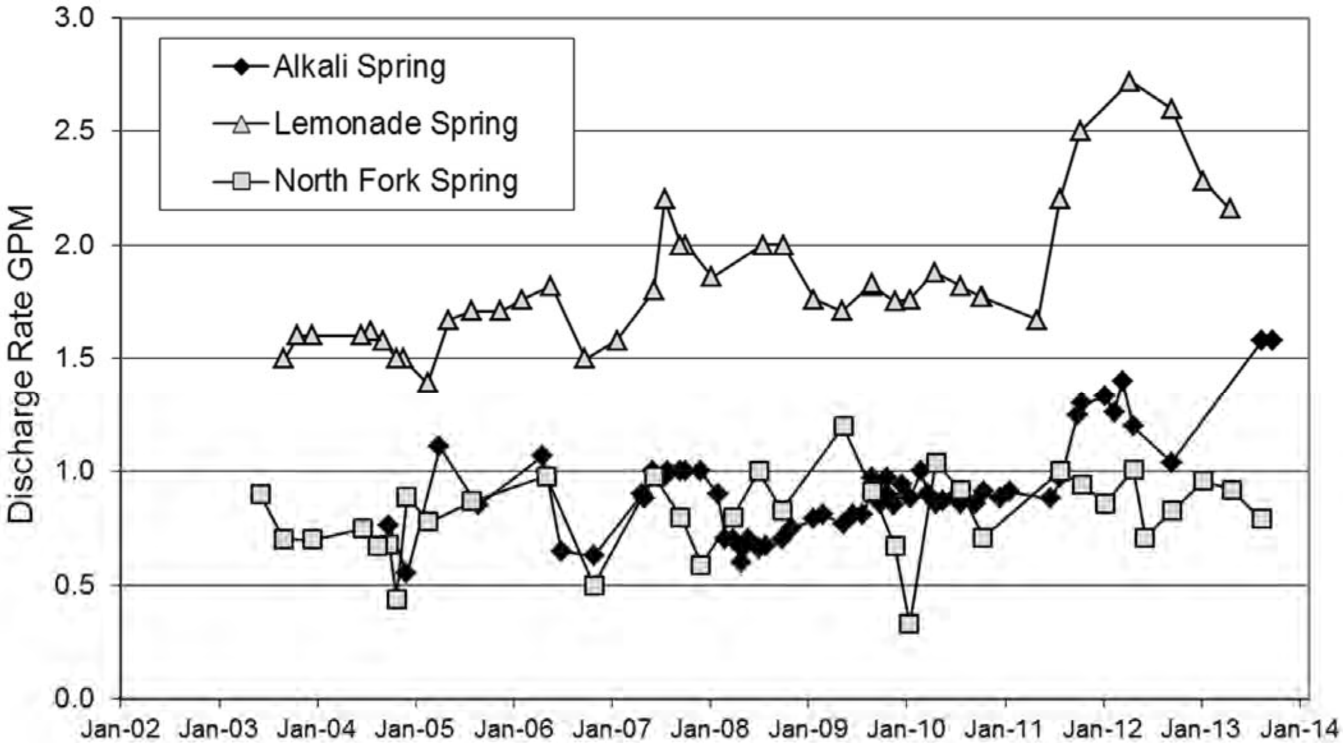


Figure 6. Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.92 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.81 gpm. Lemonade Spring appears to be locally recharged by the Ferry coalbed. The spring has an average discharge rate of 1.83 gpm.

The East Fork Hanging Woman Creek site is located on the Ashland Ranger District boundary, east of Birney. Record-breaking precipitation events, recorded during the spring of 2011 at the Poker Jim meteorological station, located near the creek's headwaters, caused flooding that washed out monitoring equipment. During the summer of 2012, the MBMG repaired the site, but repairs to the weir were unsuccessful due to the extensive flood damage. Some stream flow still passes around the weir plate, which causes inaccurate flow measurements.

GROUNDWATER CONDITIONS WITHIN AREAS OF CBM INFLUENCE

Contiguous areas of producing or reclaimed 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 2013 were retrieved for Montana (MBOGC, 2013) and Wyoming (WOGCC, 2013) and are summarized in table 1. A total of 378 Montana wells produced methane and/or water at some point during 2013; all but 33 of these were shut-in during 2013 (this number differs from table 2 because table 1 includes all wells that were active at any time in water year 2013, rather than just those active in October 2013). The 378 wells produced a total of 9.9 million barrels (bbls) of water (1,270 acre-ft) during water year 2013. In the same time period, 891 wells in the two Wyoming townships nearest Montana (57 N. and 58 N.) produced 60 million bbls (7,757 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 2013 was approximately 333 million bbls or 40,600 acre-ft.

Coalbed methane permitted wells in Montana are summarized by county and field in table 2. As of October 2013, CBM companies had allowed all pending permits to expire (all statuses listed as “permitted” had moved

Table 1. Annual summary for all wells in Montana and northern Wyoming (townships 57 N. and 58 N.) reporting either gas or water production during 2013.

	Field	Well Count	Gas (MCF) 2013	Annual+ total water production in bbls *1,000 (acre-ft) 2013	2012	2011	2010	2009	2008	2007
Montana	Coal Creek	30	148,209	1,486 (192)	886 (114)	1,848 (238)	2,262 (292)	2,055 (265)	1,782 (230)	2,389 (308)
	CX	294	1,419,243	7,142 (921)	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	53	319,136	1,229 (158)	921 (119)	1,239 (160)	1,817 (234)	1,790 (231)	2,837 (366)	2,159 (278)
	Waddle Creek	1	19,203	0 (0)	15.6 (2.0)	92.4 (12)	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**378**	**1,905,791**	**9,857 (1,270)**	**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	300	10,569,266	20,131 (2,595)	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	128	1,585,450	10,208 (1,316)	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	463	5,363,819	29,836 (3,846)	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	**891**	**17,518,535**	**60,176 (7,757)**	**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 web page (http://bogc.dnrc.mt.gov/default.asp); Wyoming source: WOGCC web page (http://wogcc.state.wy.us/).

to "expired permit"). As of October 21, 2013, there were 875 shut-in or abandoned wells in the CX field; water levels have begun to recover in this field as a result of these changes (see *Montana CBM Fields: Bedrock-aquifer water levels and water quality*).

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 observed average water production rate for CBM wells in the Montana side of the Powder River Basin, based on 155 mo of production data, generally falls below the predicted production rate (solid line, fig. 7). The 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.

Very early and very late produced-water data do not appear to reflect hydrologic responses, but indicate either the effects of well start-up or the lack of statistically significant late data (only three wells have produced for 151 mo and only one has produced for longer than 151 mo). The average amount of water initially produced from each CBM well is less than was expected (fig. 7). However, the Bureau of Land Management (2008) predicted water-production rate is between the 80th and 90th percentile of actual production. The predicted and observed rates are similar at approximately 72 mo. Between 6 and 10 yr of production, the average actual CBM water per well production rate levels out and exceeds the predicted rate. After 10 yr the average water production rate begins to rise, most likely because most wells producing for longer than 10 yr were in the CX field, where more water had to be produced to keep the overall water level in the coal drawn down until the field was shut-in. Overall, the Environmental Impact Statement somewhat overpredicted water production. The lesser quantity of CBM water that was actually produced decreases the amount of water that had to be managed and decreases the anticipated stress on the aquifers.

Gas production for an average CBM well in the Montana side of the Powder River Basin increases sharply during the well's first 5 mo of active production and is then relatively stable between 5 and 35 mo (fig. 8). The peak production for an average well occurs in its second year at around 2,500 MCF/mo. After 35 mo 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.

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	Oct. 2013
Big Horn	Coal Creek	Permit/Spudded	9	7	4	5	5	0	0
		Expired Permit	0	0	2	2	2	6	6
		Producing	**13**	**26**	**23**	**20**	**14**	**17**	**18**
		Shut-In/Abandoned	49	35	39	44	50	46	45
	CX	Permit/Spudded	44	44	9	0	0	0	0
		Expired Permit	231	251	288	288	288	288	288
		Producing	**741**	**705**	**676**	**623**	**508**	**275**	**10**
		Shut-In/Abandoned	110	168	212	270	385	619	875
		Water Well, Released	0	0	0	0	0	2	11
	Dietz	Permitted Injection Well	1	1	1	1	1	0	0
		Permit/Spudded	1	0	0	0	0	0	0
		Expired Permit	42	42	42	42	42	42	42
		Producing	**96**	**92**	**36**	**61**	**55**	**38**	**34**
		Shut-In/Abandoned	10	5	61	45	51	59	63
	Other (Deer Creek, Four Mile, Forks Ranch, Waddle Creek, Wildcat BH)	Permit/Spudded	34	56	35	36	35	0	0
		Expired Permit	38	49	67	67	68	103	103
		Producing	**2**	**2**	**3**	**1**	**1**	**2**	**1**
		Shut-In/Abandoned	21	27	29	24	24	30	28
		Water Well, Released	0	1	1	1	1	1	4
Other Counties Carbon, Custer, Gallatin, Powder River, Rosebud		Permit/Spudded	124	2	2	2	2	1	1
		Expired Permit	35	157	157	157	157	158	158
		Producing	**2**	**2**	**3**	**2**	**1**	**0**	**0**
		Shut-In/Abandoned	15	14	16	19	21	21	21
		Water Well, Released	0	0	0	1	1	1	1

Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ accessed Oct. 21, 2013.

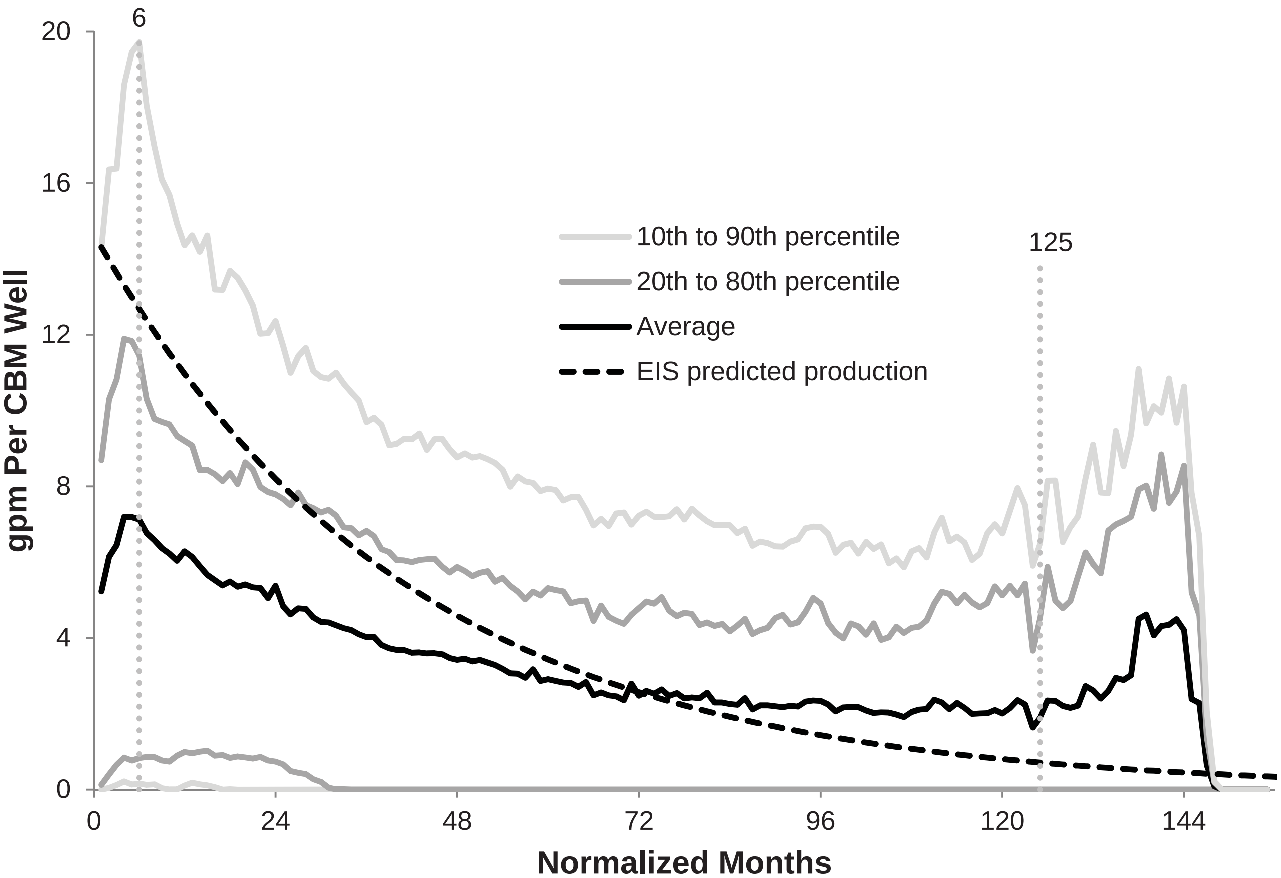


Figure 7. Normalized CBM produced water in gallons per minute (gpm) in the Montana portion of the Powder River Basin (data from the MTBOGC website). The actual average production (solid black line) falls below the EIS predicted production (dashed line: y=14.661 e^(-0.0242x); U.S. BLM, 2003) for the first 6 years of production. Because 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 more than 160 months.

Since mid-2008, wells that produce relatively large amounts of water compared to the amount of gas have been shut-in, which causes the trend in number of producing wells to mirror the slope of the monthly water production trace (fig. 9). Water production per month decreases in the years immediately following years when few new wells were installed (e.g., 2003, 2008). When wells are taken offline, water production quickly declines (e.g. 2009, 2010, and 2013). As the price of methane drops, more wells are taken out of production, such as since mid-2008 (fig. 9). The overall changes in water production and producing wells in Montana are mirrored in the changes in all of the Powder River production in Wyoming (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, 2013). During 2013, a total of 294 CX field CBM wells produced either water or gas, or both. Production was 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 2013 water production was 7.1 million barrels (921 acre-ft). Most wells in the CX gas field have been shut-in and abandoned, as indicated by red well symbols on plate 1. CBM wells in Wyoming are also being shut-in. Water levels have begun to recover in areas where CBM water production has decreased; wells WR-27 and WR-38 (fig. 10)

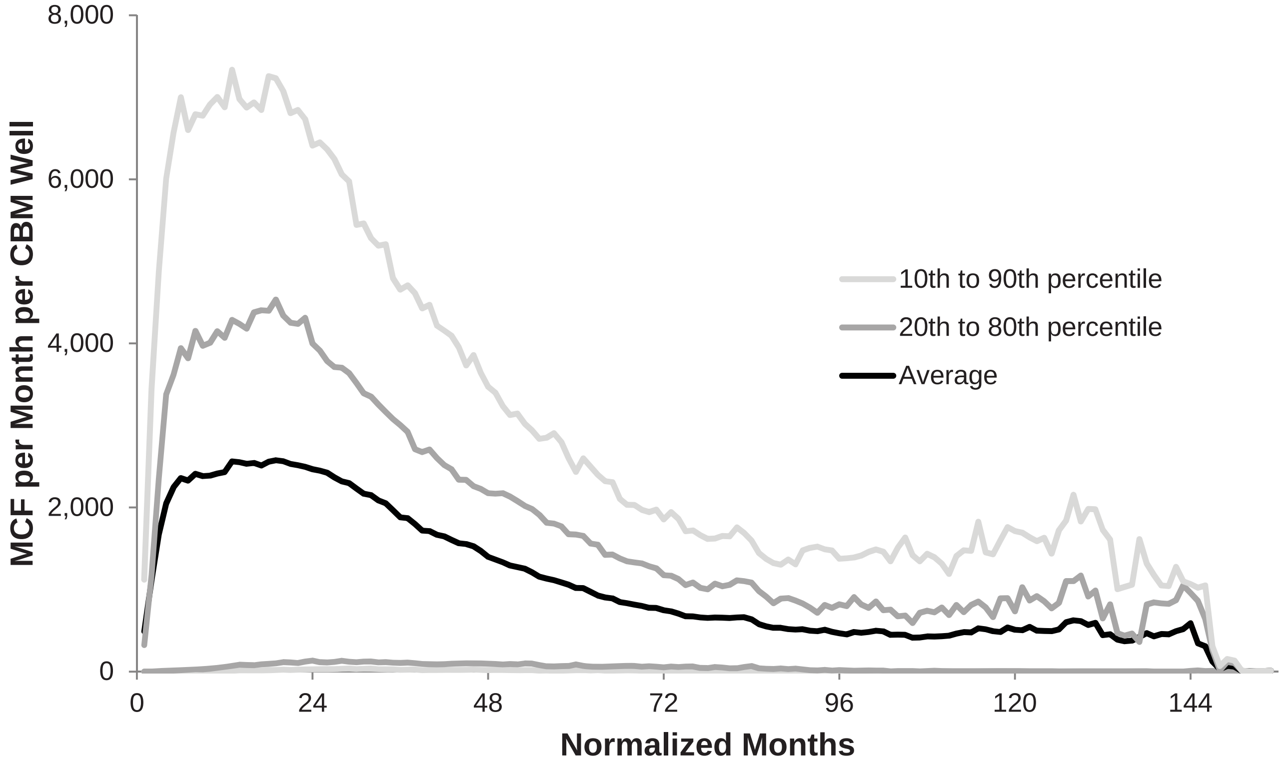


Figure 8. Normalized gas production (MCF) per month for individual CBM wells in the Montana portion of the Powder River Basin (data from MTBOGC website). The solid black line represents the average gas production per well per month.

illustrate typical water-level recovery. Well WR-27 had recovered to within 37.5 ft of baseline by August 2011; however, 2 yr later, in August 2013, the water level was still 37.4 ft below baseline. Initial recovery rates were as expected and could have resulted in full recovery in 30 to 100 yr; however, observations during the past 2 yr indicate recovery has stagnated and further recovery may only be seen in years of higher than average precipitation. The amount of time required for water levels to recover to near-baseline conditions is difficult to estimate based on current recovery curves in the CX field.

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, 2013). 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 2013, a total of 30 CBM wells produced water or gas (table 1) from the Wall and Flowers–Goodale coalbeds in the Coal Creek field (appendix D). Total water production for the 12-mo period was 1.5 million bbls (192 acre-ft). A total of 53 CBM wells produced water or gas in the Dietz field during 2013 (plate 1, table 1) from the Dietz, Canyon, Carney, and Wall coalbeds (appendix D). The total water production for the 12-mo period was 1.2 million bbls (158 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 Anderson and Dietz 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

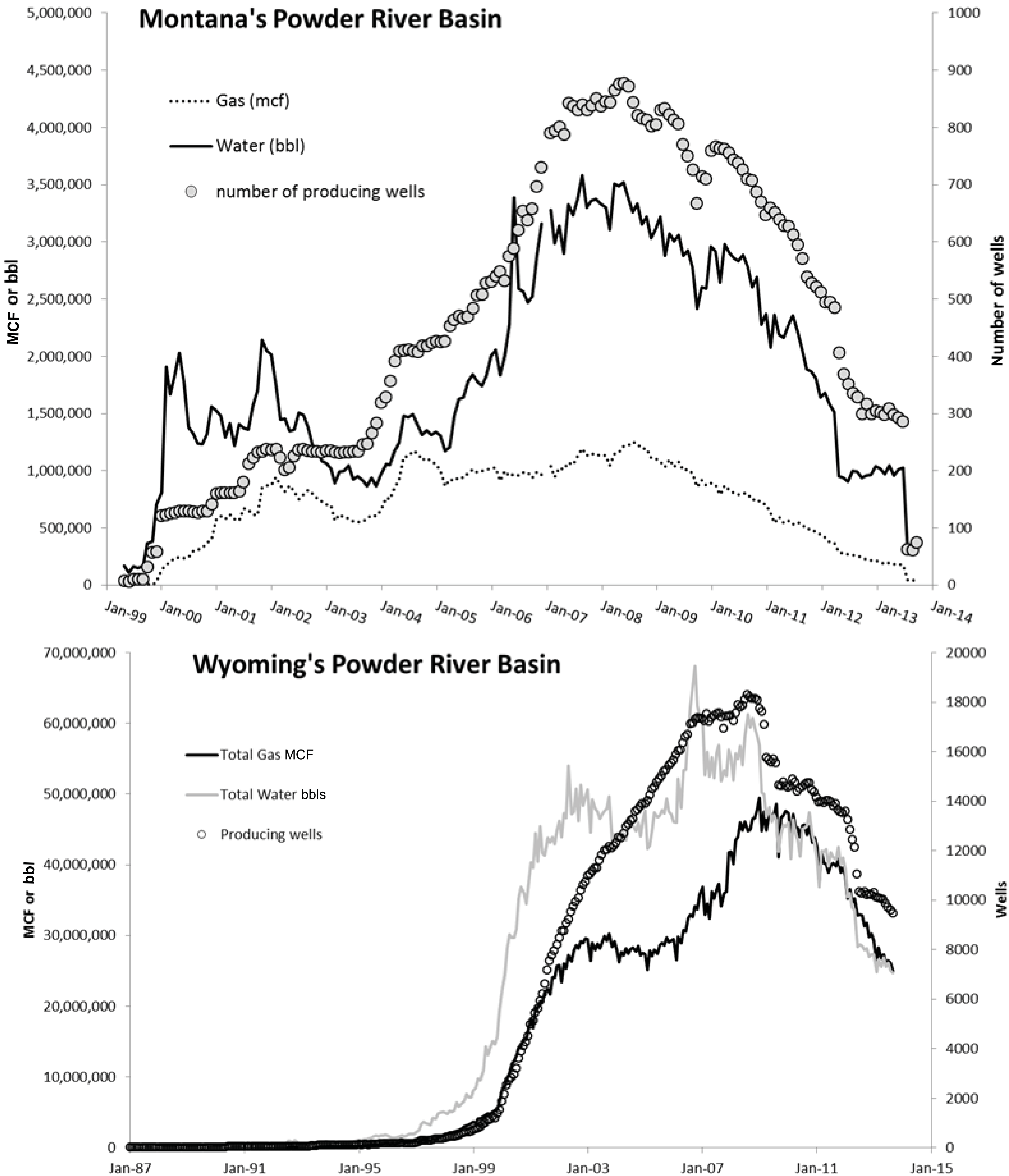


Figure 9. Monthly totals of water and gas produced from Montana and Wyoming CBM wells in the Powder River Basin and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production. The total number of producing wells and the amount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

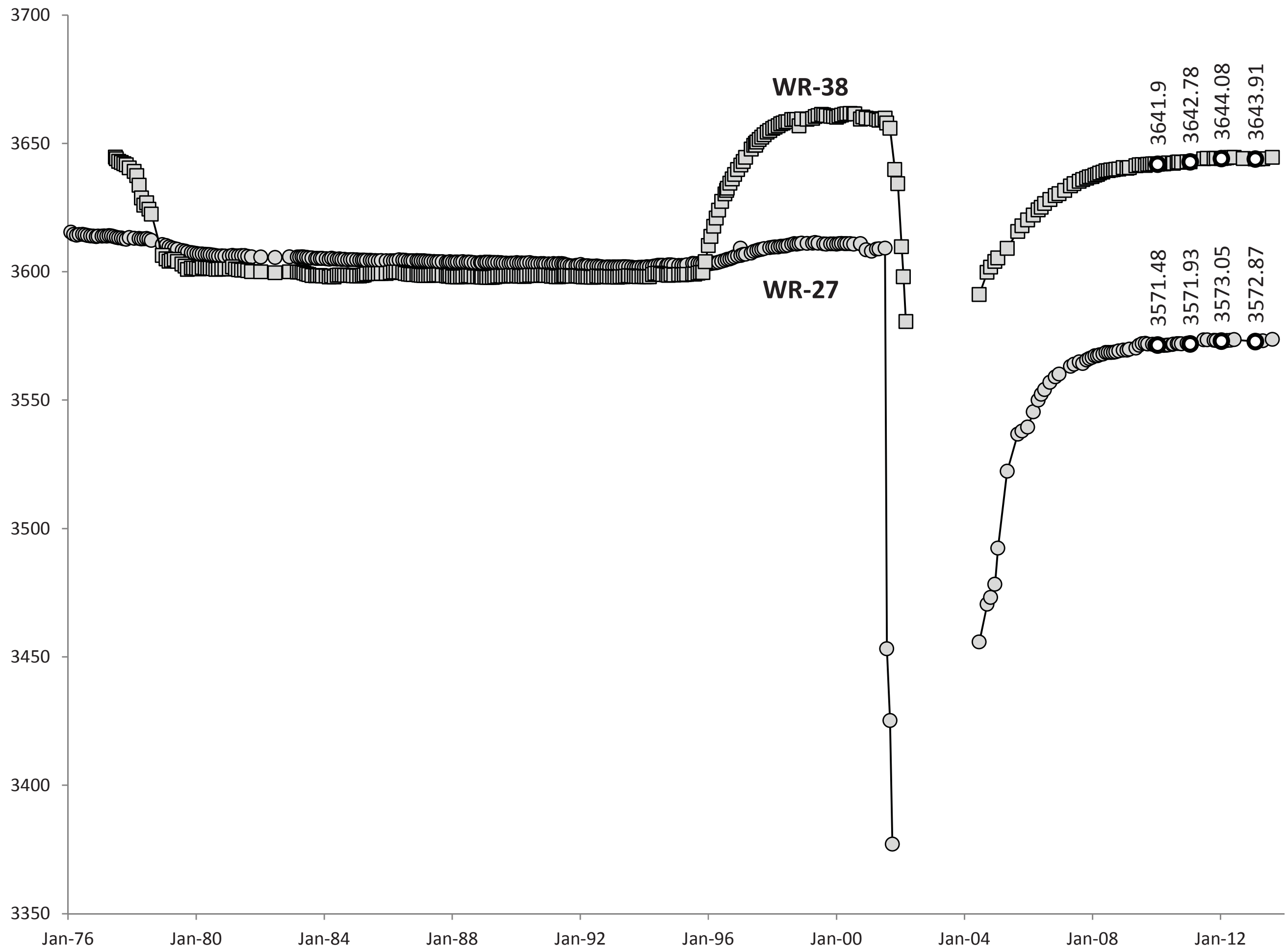


Figure 10. Water-level records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production. The recovery water levels are flattening; however, they have not reached baseline conditions. Water levels for January 2010, 2011, 2012, and 2013 are labeled.

that drawdown of at least 50 ft typically reaches a distance of about 1 mi beyond the active field boundaries, but has reached as much as ~1.5 mi in some areas. For the Canyon coal, the extent of CBM-related drawdown appears similar to that in the Dietz; 20 ft of drawdown reaches about 1 mi beyond the field boundaries (plate 5).

Drawdown was predicted to reach 20 ft at a distance of 2 mi after 10 yr of CBM production (Wheaton and Metesh, 2002), and 20 ft at a maximum of 4 to 5 mi if production continued for 20 yr in any specific area (U.S. Department of the Interior, Bureau of Land Management, 2008). Measured drawdown is less than that predicted primarily because of restrained CBM development, shorter than anticipated production duration, faults that isolate drawdown, and lower than predicted CBM water production.

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. Between 2001 and 2003, CBM production lowered groundwater levels at WR-34 to about 150 ft below baseline. The magnitude of drawdown from CBM development in WR-34 as compared to that from coal mine dewatering is primarily due to the close proximity of active CBM production. Since March 2003, water levels have recovered to within 27.2 ft of baseline altitudes, 82 percent recovery during 10 yr; this is primarily because of the reduced number of nearby

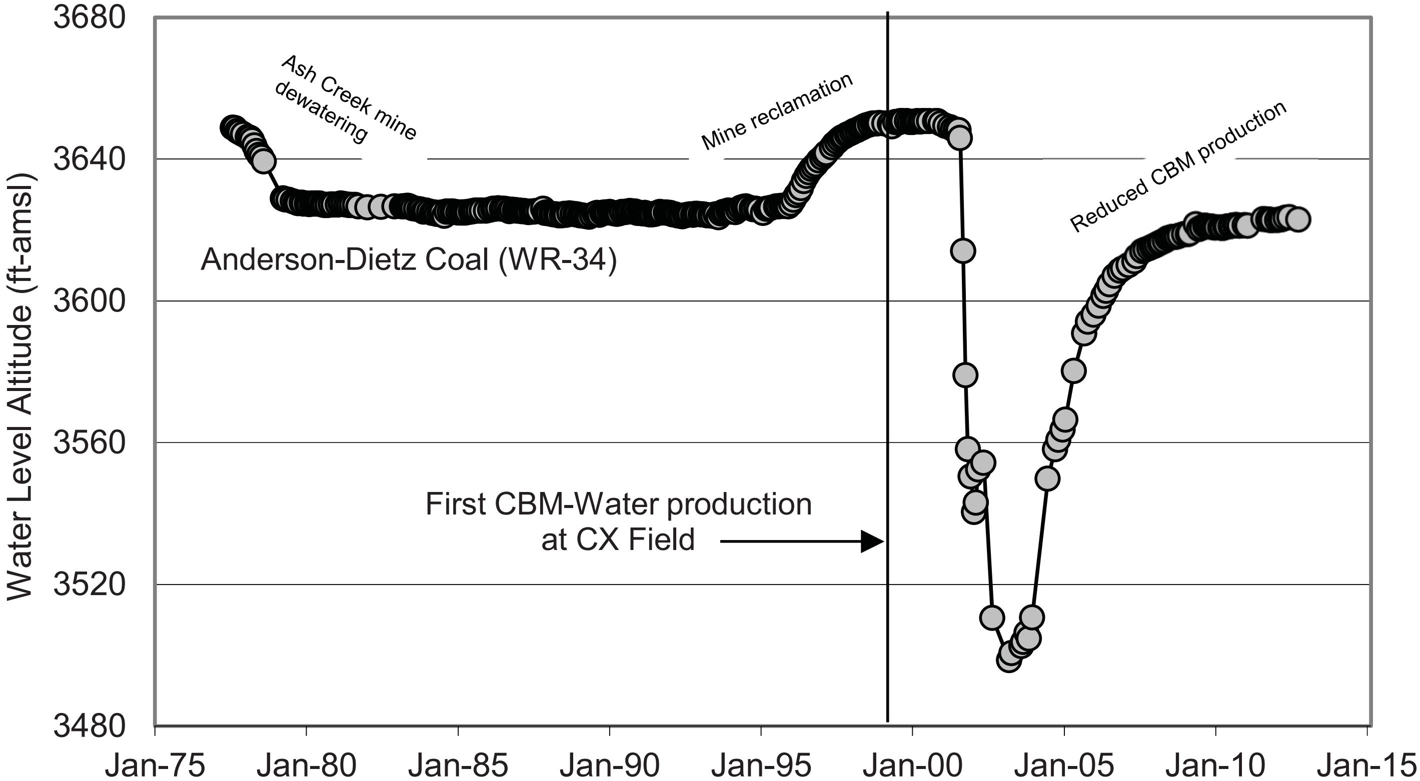


Figure 11. Water levels in the combined Anderson–Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed-methane production. The water-level recovery that began in 2003 is in response to decreased production in the CX field.

producing CBM wells. There are 281 fewer wells producing in the CX field in 2013 as compared to 2012 (514 fewer than 2011); however, the rate of water-level recovery does not reflect this decrease.

Groundwater-level response caused by 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 17 ft of baseline altitudes (79 percent), but have fluctuated around 0.5 ft during the last year, indicating that recovery may have stagnated. Although the mine pit created water-level response in the adjacent, confined coal aquifer, water levels in well BF-01 completed in unconfined spoils that backfill the pit did not noticeably react to CBM production. The lack of a measurable response is not surprising because unconfined aquifers have much greater storativity than do confined aquifers.

Monitoring wells installed in the Fort Union Formation show that the monitored fault sections 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 mi north of a monitored fault, has lowered water levels in the Anderson coal and overburden aquifers for more than 25 yr. However, there has been no response to East Decker mine pit dewatering in aquifers 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 with no apparent communication to areas north of the fault. The lowest recorded water levels south of the fault were more than 180 ft below baseline. The isolated mine pit dewatering and the CBM dewatering 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 to the north of the fault, and also to CBM production south of the fault. Reduced hydrostatic pressure from coal mining may have migrated around the end of the fault. Drawdown from CBM production may be causing a reduction in the hydrostatic pressure in the overlying aquifers, or CBM-produced drawdown may have been transmitted to the Smith coal because variable offset along scissor faults allows hydraulic connection between aquifers.

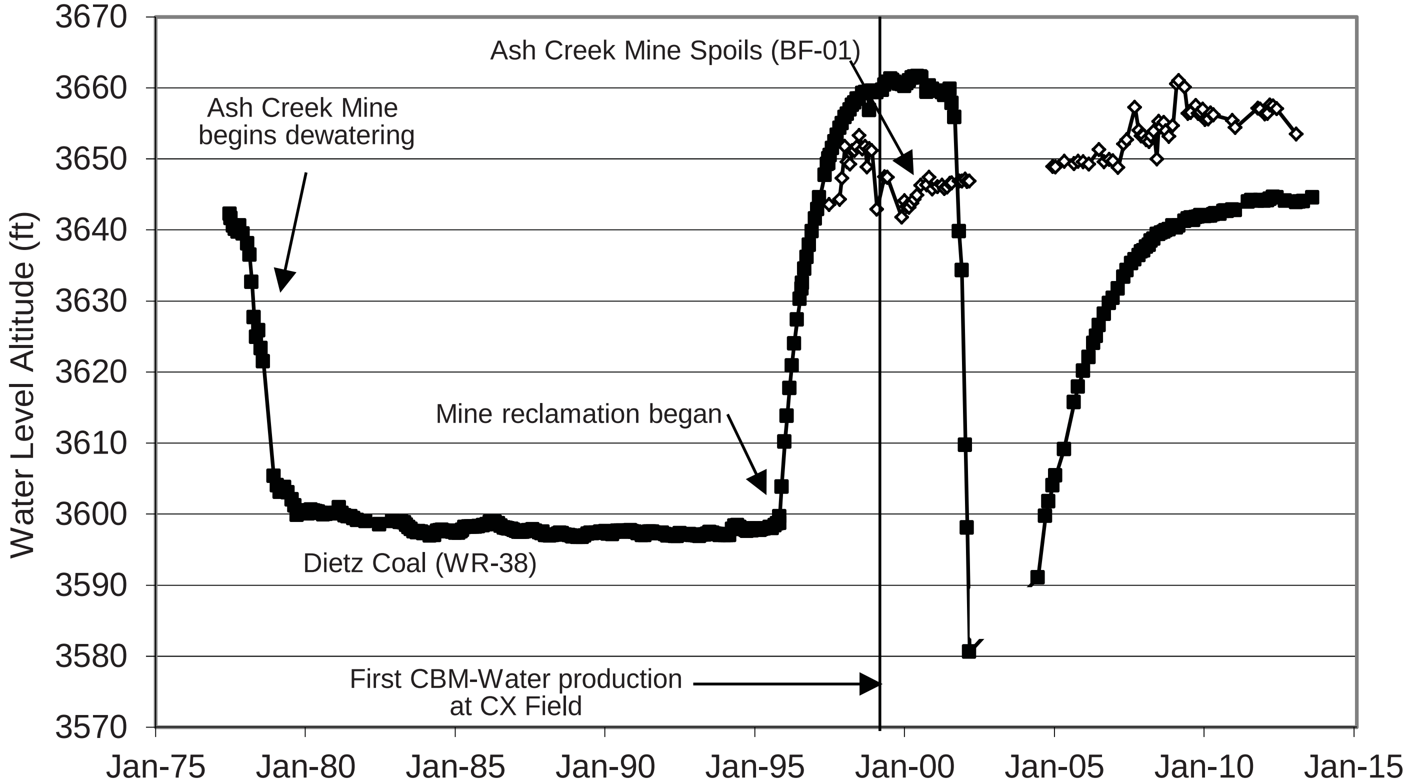


Figure 12. Water levels in the Dietz coal (well WR-38) decreased by at least 80 ft in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping, which illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses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

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 responded to distant CBM-related drawdown since monitoring began in 2003; water levels are now 20 ft lower than when first measured (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 mi 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, and began to recover in early 2006, but recovery has not yet reached pre-2005 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 quick decline in 2005 followed by recovery beginning in 2006 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. In 2008, most likely due to reduced nearby CBM activity, water levels in the three coal aquifers recovered slightly, but since 2009 water levels in wells WRE-12 and WRE-13 have resumed declines at a rate similar to that experienced during coal mining. Well PKS-1179, in the Dietz 2 coal, is still recovering. The large drawdown in the deeply buried Dietz 2 aquifer is driven by the necessity to lower CBM production water levels to near the top of the aquifer. At the lowest measured water level, all three wells had water levels very near the top of their respective coals.

Changes in Tongue River Reservoir stage affect water levels in aquifers such as the Anderson–Dietz coal, which underlies 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

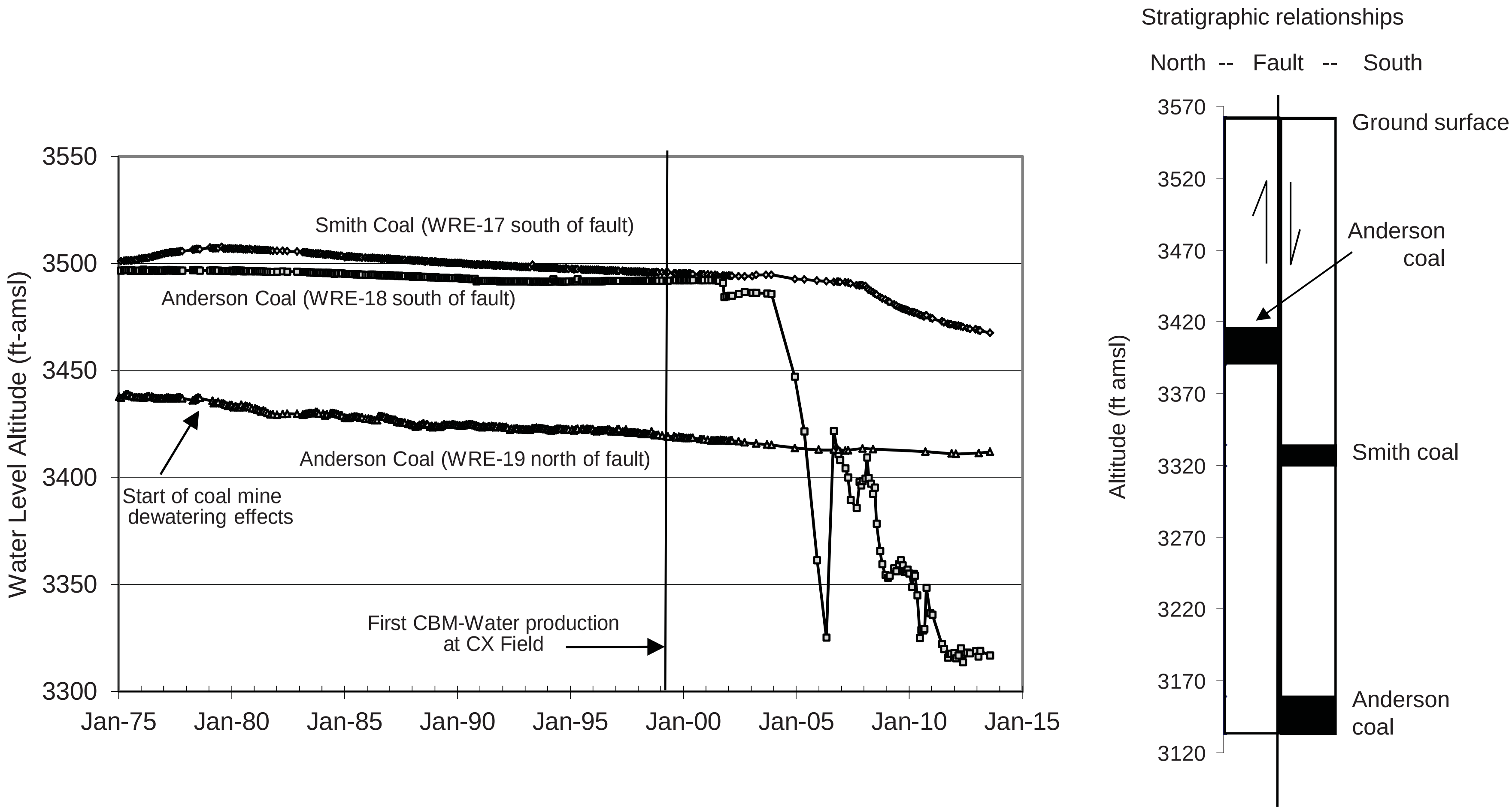


Figure 13. Drawdown from either coal mining or coalbed-methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970s, and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980s. The pressure reduction has probably migrated around the end of the fault. Coalbed methane production south of the fault is apparent in WRE-18 but not north of the fault in WRE-19.

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

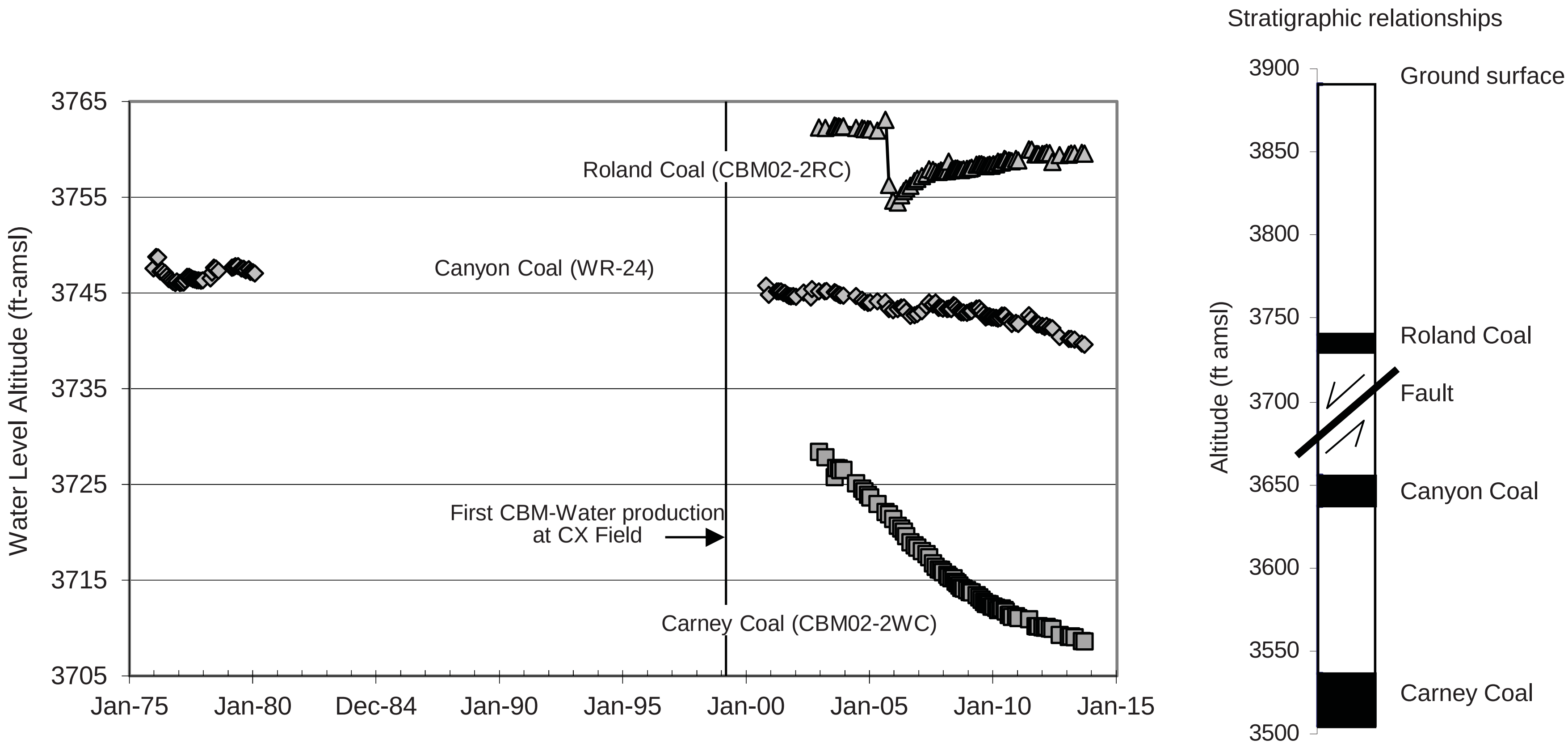


Figure 14. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has shown a response to CBM-related drawdown since its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

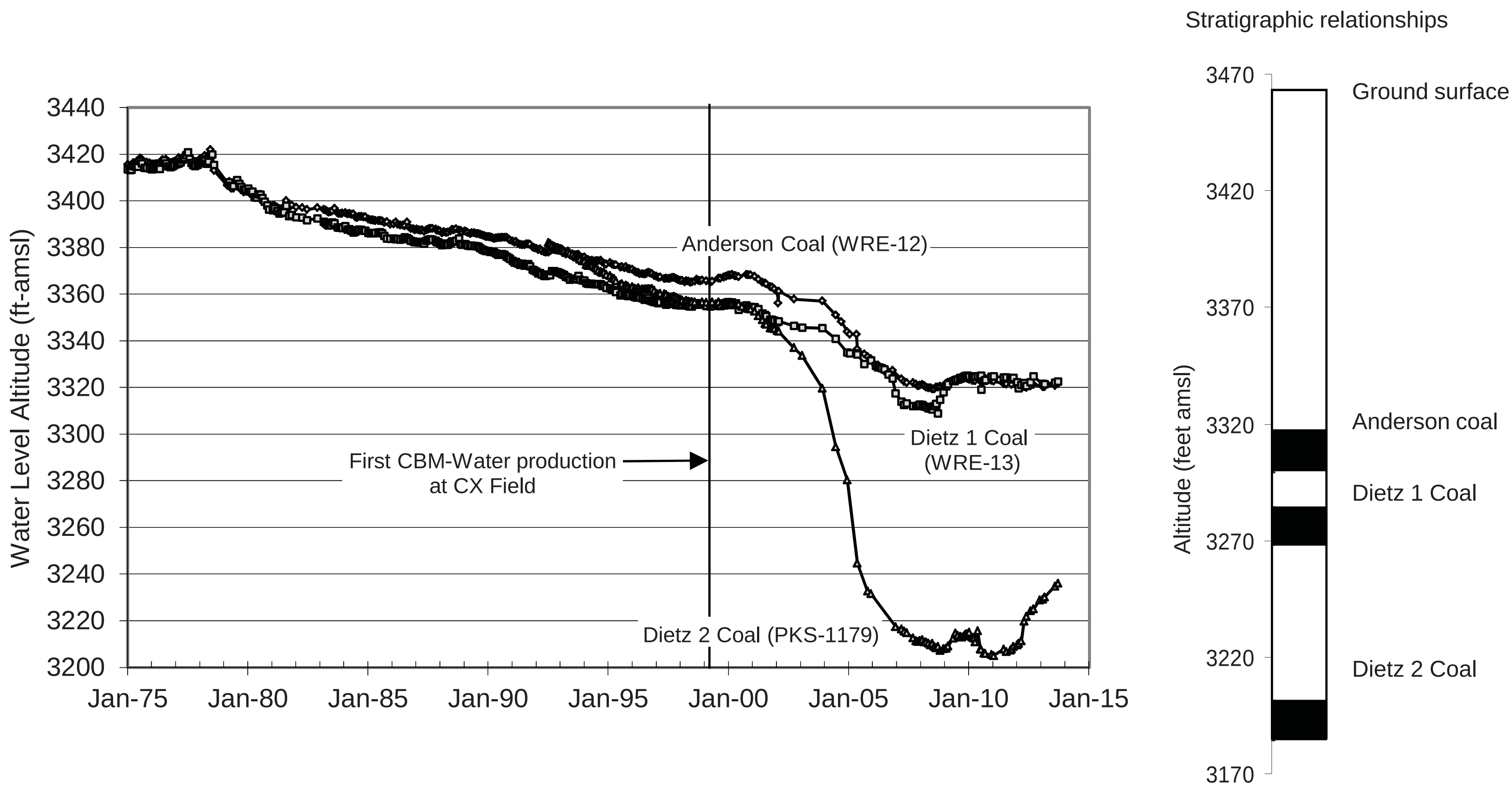


Figure 15. CBM production requires drawdown to near the top of the producing zone; this is the case for wells WRE-12, WRE-13, and PKS-1179. The three coal seams have water-level elevations just above the coal seam elevation. Well PKS-1179 has been recovering.

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 1, 2013). Average reservoir stage during this time has been about 3,420 ft amsl, which is higher than the Anderson–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 2013 was 3,420 ft amsl, which is the same as the historical average. In previous years, the yearly average stage has been higher than the historical average. 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 likely result in more water seeping into the coal from the reservoir (plate 2).

By 2000 water levels in the Squirrel Creek watershed in well WR-17, completed in the Anderson–Dietz coal (fig. 17), had been lowered 37 ft by coal mine dewatering and an additional 30 ft by CBM development. However, monitoring was at that time because of methane gas in the borehole. Declining water levels (over 8 ft since the year 2000) in Anderson–Dietz overburden at this site (well WR-17B) show possible migration of water because of CBM production from underlying coalbeds or coal mining. However, this sandstone aquifer is separated from the Anderson–Dietz 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 in response to leakage from an infiltration pond. In 2005 the discharge to the pond was discontinued and water levels in WR-17A have returned to near baseline. The deep 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 mi distant, but the nearest producing wells are more than 4 mi away. CBM production in the immediate 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 mi away). Water levels have not recovered in CBM02-4WC despite the nearest wells being shut-in, and it is possible that should recharge to this part of the aquifer be from the southeast, CBM development in that direction may be impacting recovery. Additionally, well 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 54.5-ft shale stringer at a depth of 237.5 ft within the Wall coal. 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 its failure to recover to baseline water levels.

Water Quality. Upper and Lower Anderson Springs, within the current CBM producing area, were sampled in November 2012 and May 2013 (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. The TDS of Lower Anderson Spring was minimally influenced by the increased precipitation during 2011, rising from 1,500 mg/L to 1,700 mg/L. Upper Anderson Spring water TDS rose from 3,700 mg/L to more than 5,500 mg/L after 2011's high precipitation. The high salinity in Upper Anderson Spring was driven by calcium/ magnesium/sulfate sources that lowered the SAR during this period from 9.8 to 6.0. The salinity in the most recent samples is again between 3,700 and 3,880 mg/L, and SAR values are again 8.9 and 8.2, similar to pre-2011 levels. The water-quality and flow rate changes in Upper Anderson Spring indicate a significant component of local recharge. None of the monitored springs within the area influenced by CBM development have shown impacts that can be distinguished from natural variability.

Tongue River Alluvial-Aquifer Water Levels and Water Quality

Water-quality samples were collected in September 2012 and May 2013 (appendix C) from well WR-59, completed in the Squirrel Creek alluvium near the Squirrel Creek–Tongue River confluence (fig. 19). The TDS

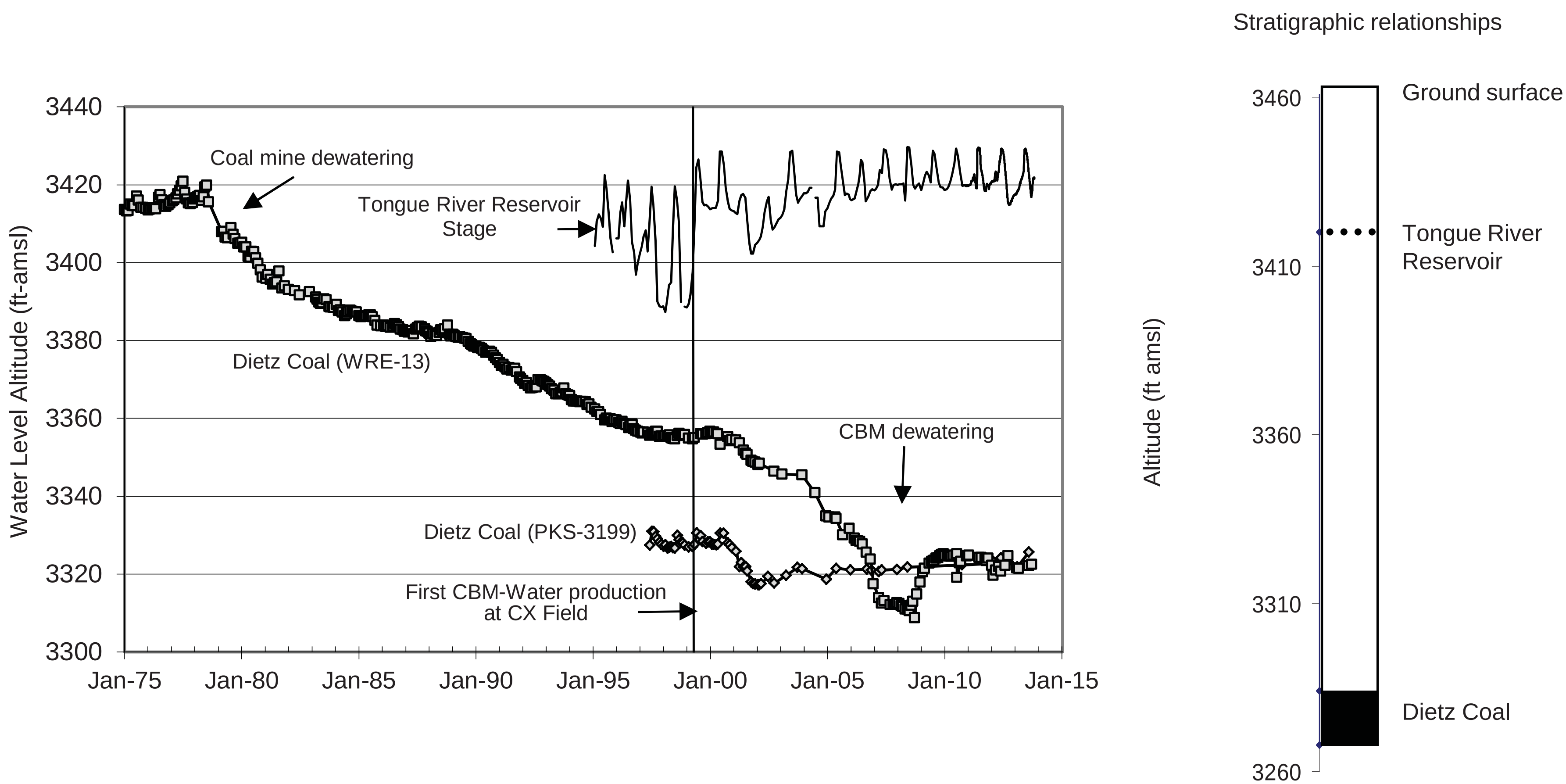


Figure 16. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Anderson–Dietz coal (WRE-13 and PKS-3199) prior to mining and CBM production. Since 1979, coal mining and CBM influences dominate the hydrographs.

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

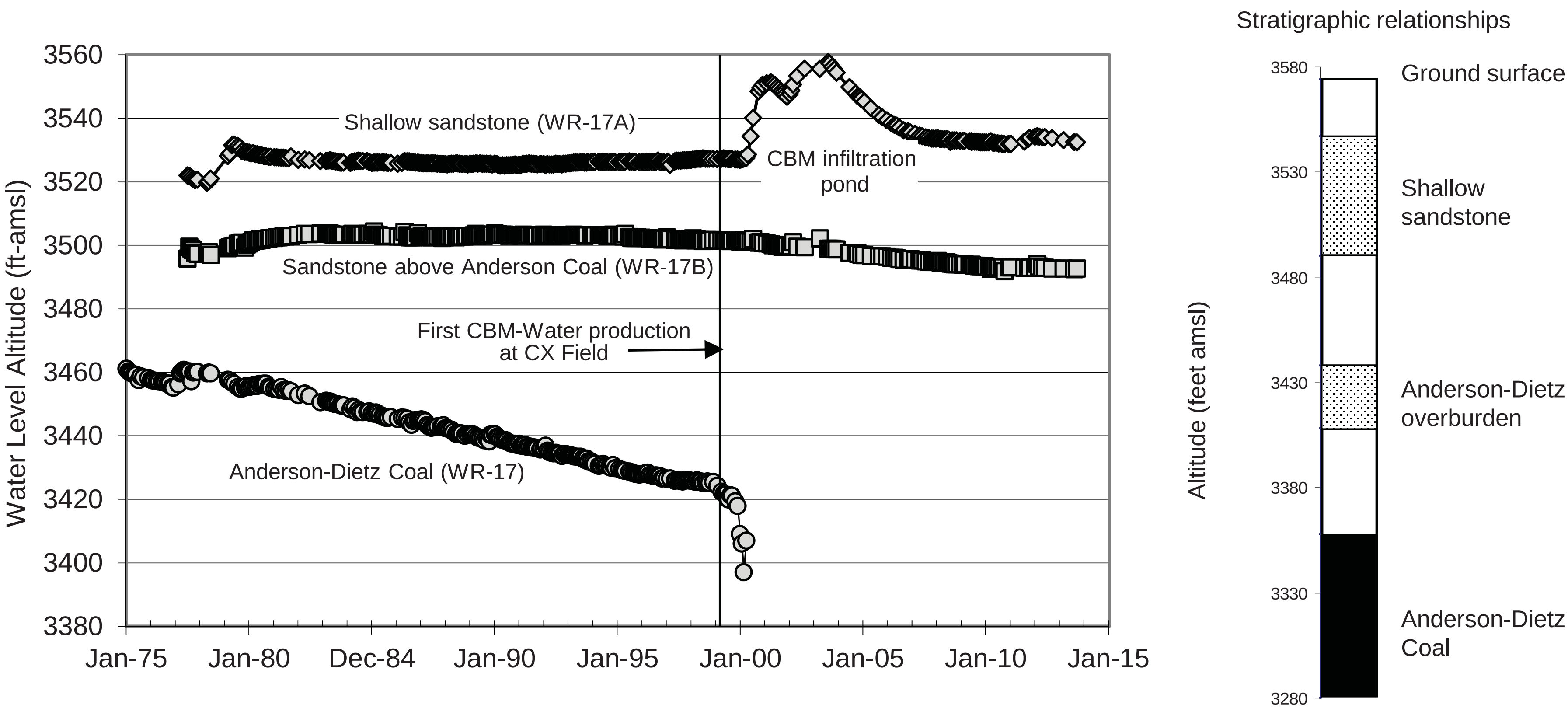


Figure 17. The water table rise in 1999 at WR-17A is in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water; therefore, the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in the Squirrel Creek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

Note: The vertical scales of the stratigraphic relationship and the hydrograph are different

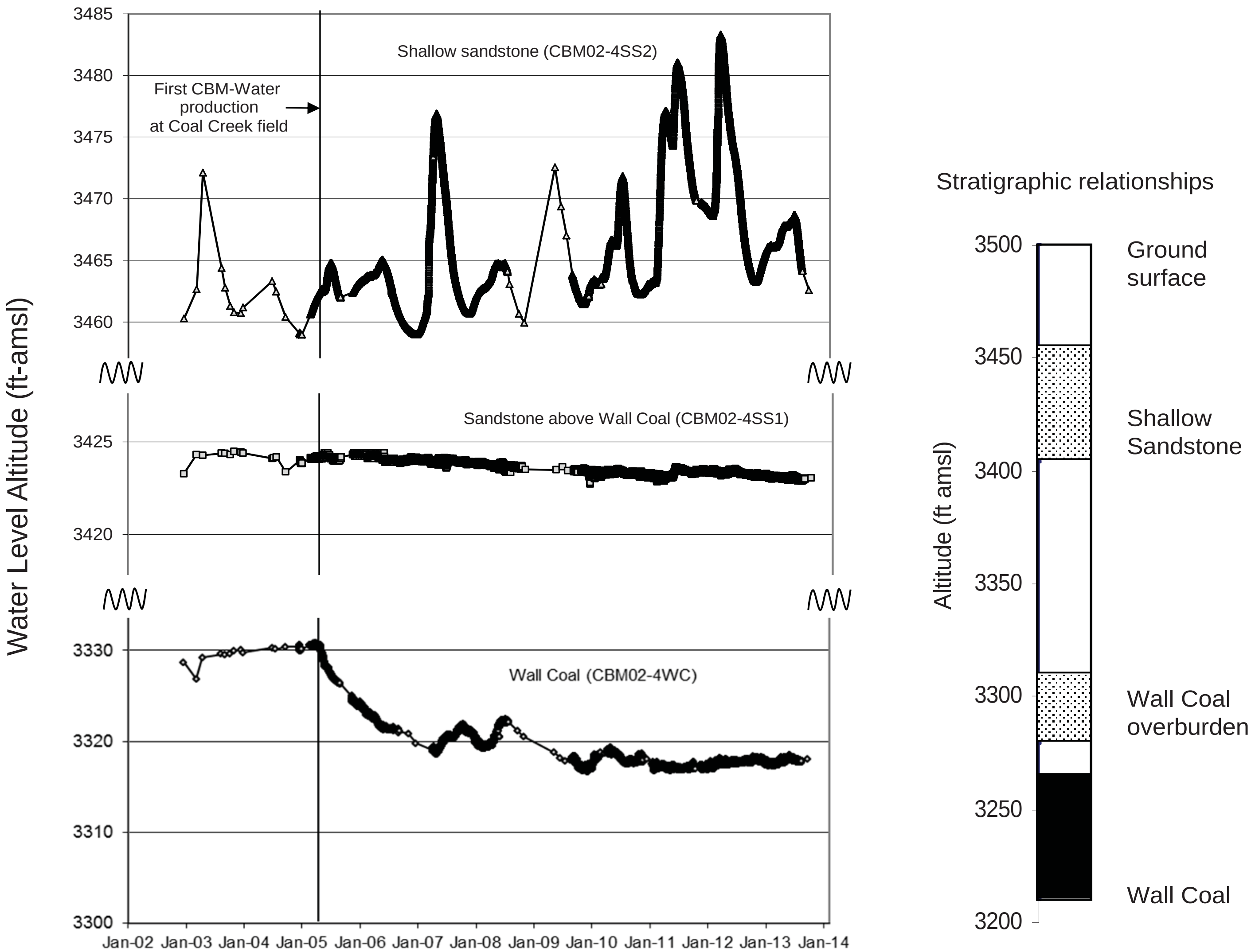


Figure 18. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal (CBM02-4WC) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in water level that 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 climatic variations.
Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.
The Y axis scale is broken to show better hydrograph detail.

concentrations increased from 5,710 mg/L in June 1991 to 6,709 mg/L in June 2009, an increase of 17 percent. The SAR value increased from 5.6 to 6.4 during approximately the same time period (fig. 19). A similar peak also occurred in October 2011. The Tongue River TDS and SAR values have not shown similar patterns even though the river water chemistry varies seasonally; TDS and SAR tend to drop as flow rate increases. The relationship between river discharge 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 samples are from September 2012 and May 2013 (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 increased TDS between September 2006 and October 2008 (747 to 1,074 mg/L) is repeated between June 2009 (775 mg/L) and

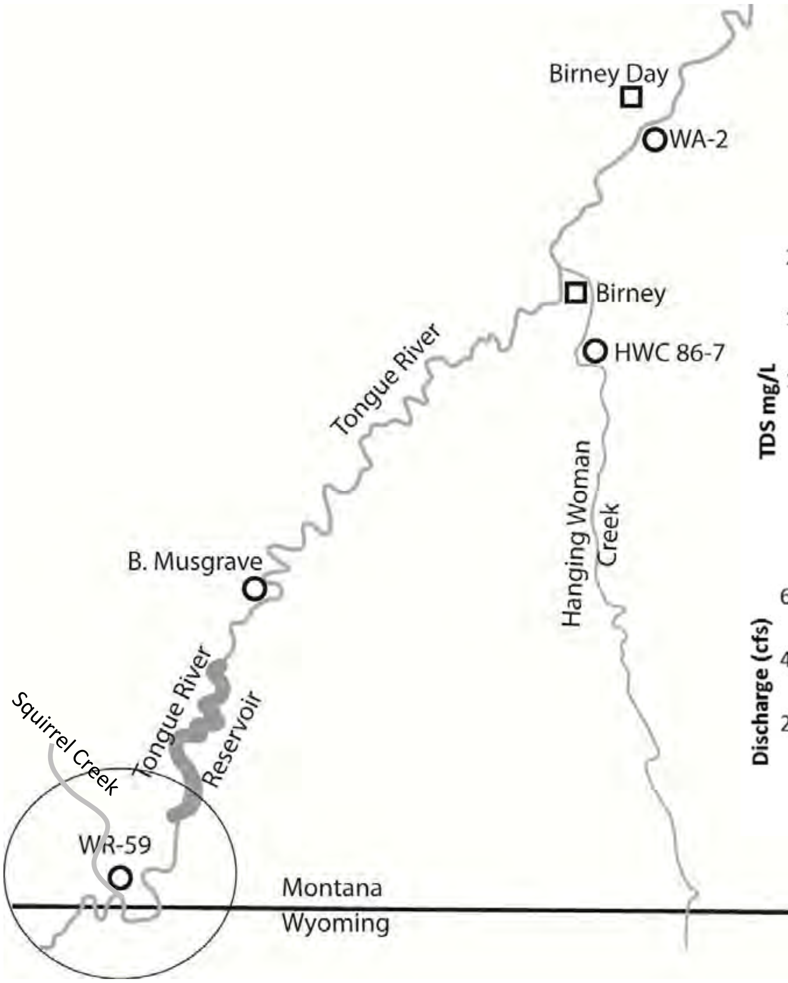
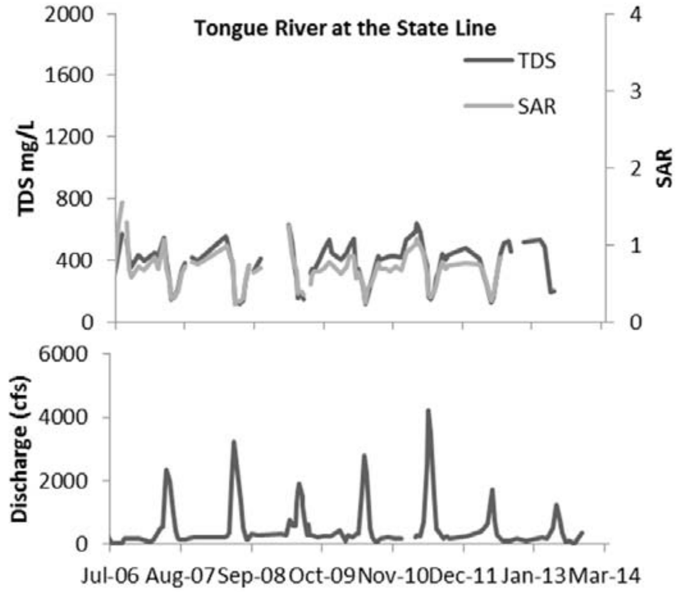


Figure 19. TDS, SAR, and water level / stream discharge for well WR-59 near the Squirrel Creek–Tongue River confluence and for the Tongue River at the state line.



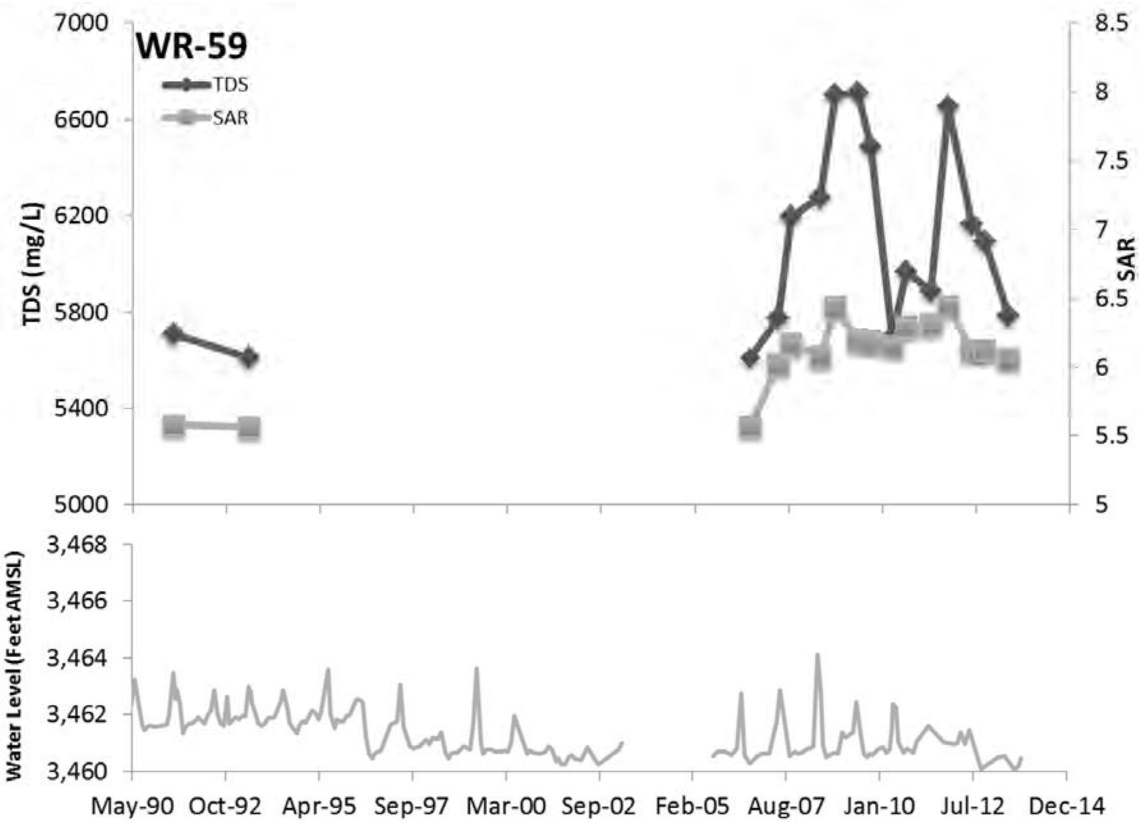
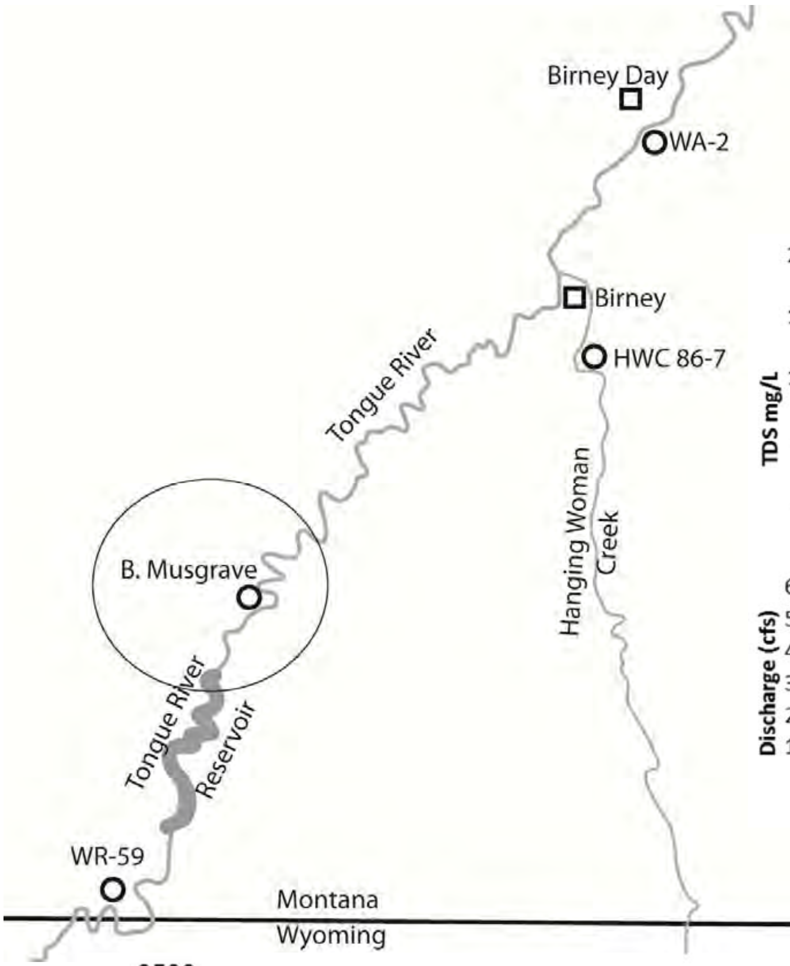
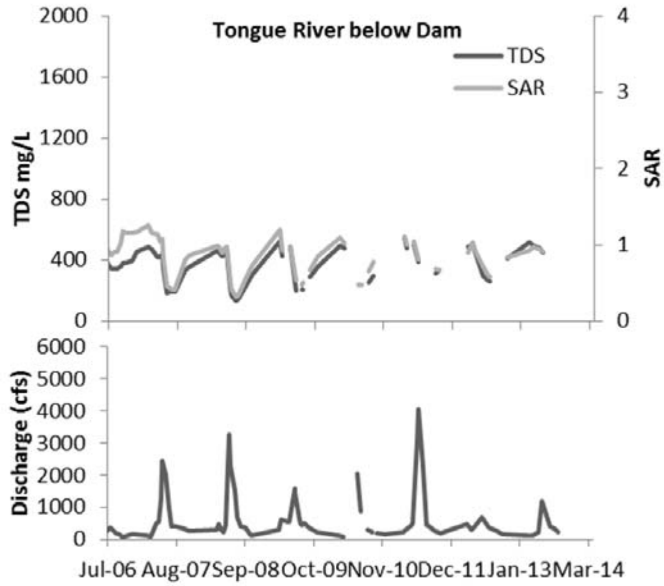
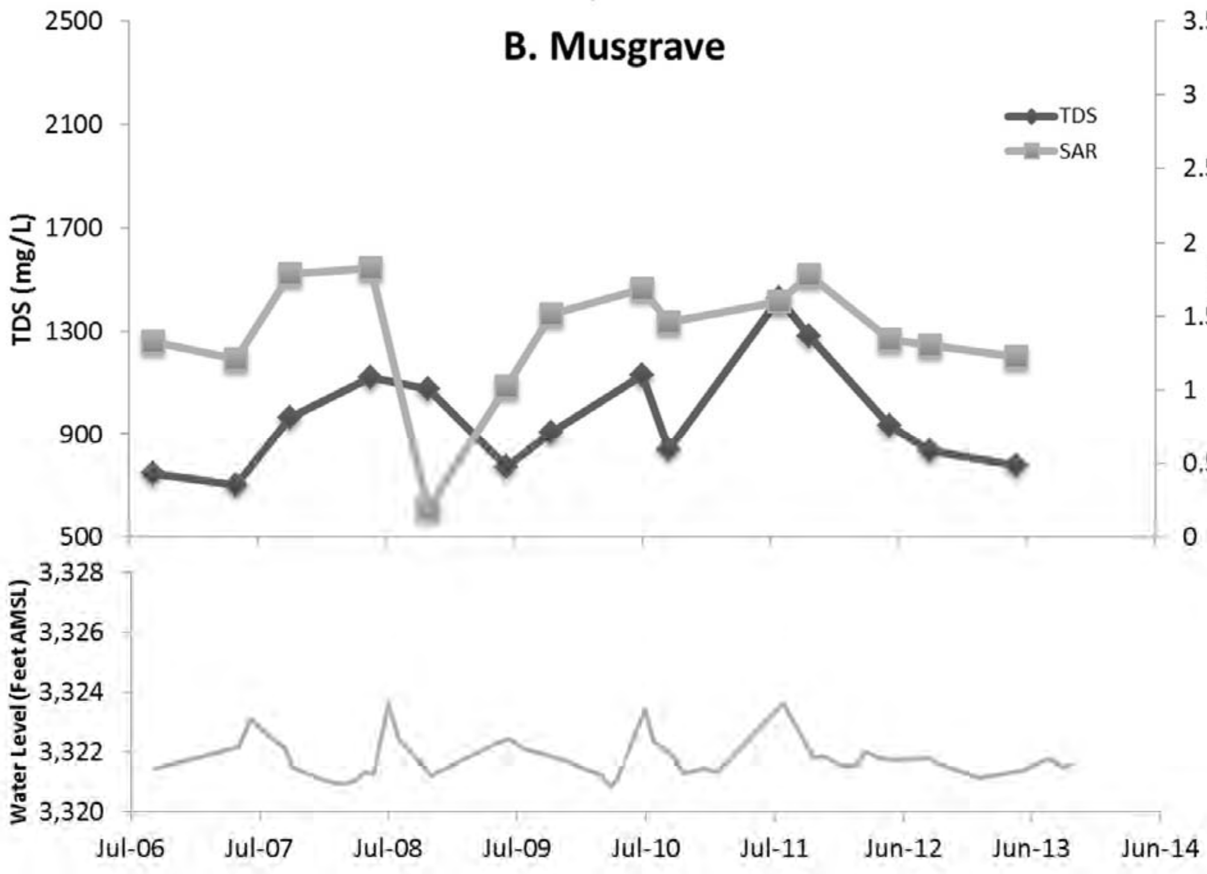


Figure 20. TDS, SAR, and water level/stream discharge for a well at B. Musgrave's residence and the Tongue River north of the Tongue River Reservoir dam.







October 2011 (1,280 mg/L), which shows that regular monitoring is vital to better understand periodic water-quality change. SARs are relatively low because the alluvial groundwater chemistry is dominated by calcium and magnesium.

Hanging Woman Creek enters the Tongue River near the town of Birney approximately 20 mi 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 September 2012 and May 2013. TDS in water from HWC86-7 was 4,040 and 3,969 mg/L and SARs were 8.8 and 8.7, respectively. Since sampling began in 1987, TDS and SAR have generally increased; however, future monitoring will be required to determine if these values represent an impact to the aquifer 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 September 2012 and May 2013 (fig. 22; appendix C) show TDS concentrations in Tongue River alluvial water at this location have been relatively steady throughout the sampling history (August 2006 through May 2013). SAR values are relatively high for alluvium in this area, but only vary between 20 and 23. 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 57 N. and 58 N. 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 2013, 300 CBM wells produced methane and/or water in the Prairie Dog Creek field, a decrease of 215 wells from 2012. Cumulative water production for 2013 was 20.1 million bbls. Monthly water production in the field peaked in mid-2002 at nearly 7 million bbls per month. For the next 5 yr water production fluctuated between 4 and 5 million bbls per month; however, since August 2008 the water production has fallen steadily, and by fall of 2013 was only about 1 million bbls per month (fig. 23). Gas production rose fairly consistently until early 2008 but has fallen steadily since (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 were 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 2013, 128 CBM wells produced methane and/or water in the Hanging Woman Creek field, a decrease of 17 wells from 2012. Total water production for the 12-mo period was 10.2 million bbls. Water production began to

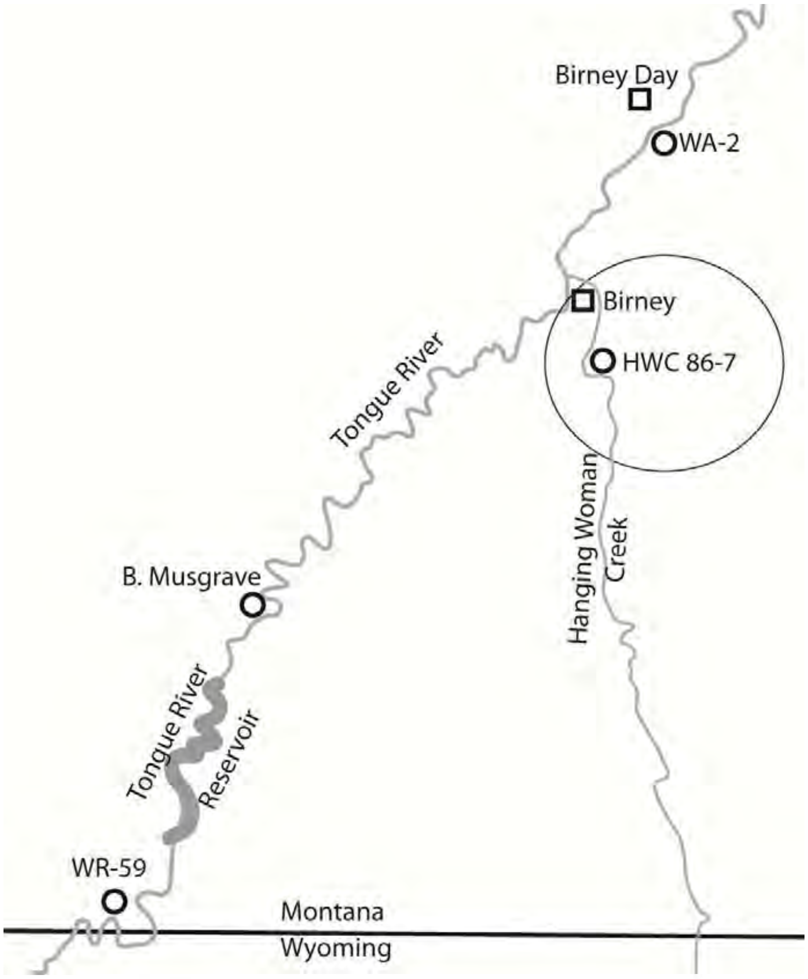


Figure 21. TDS, SAR, and water level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.

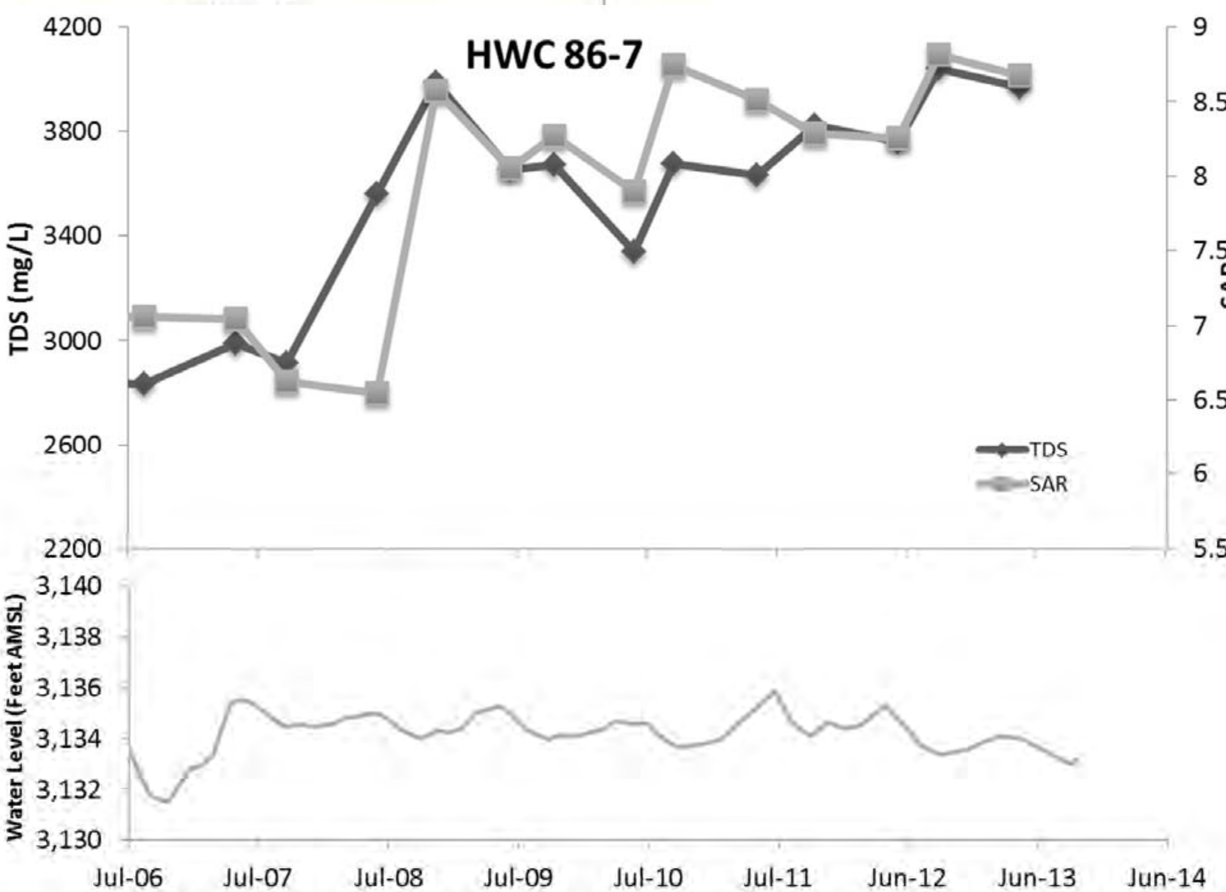
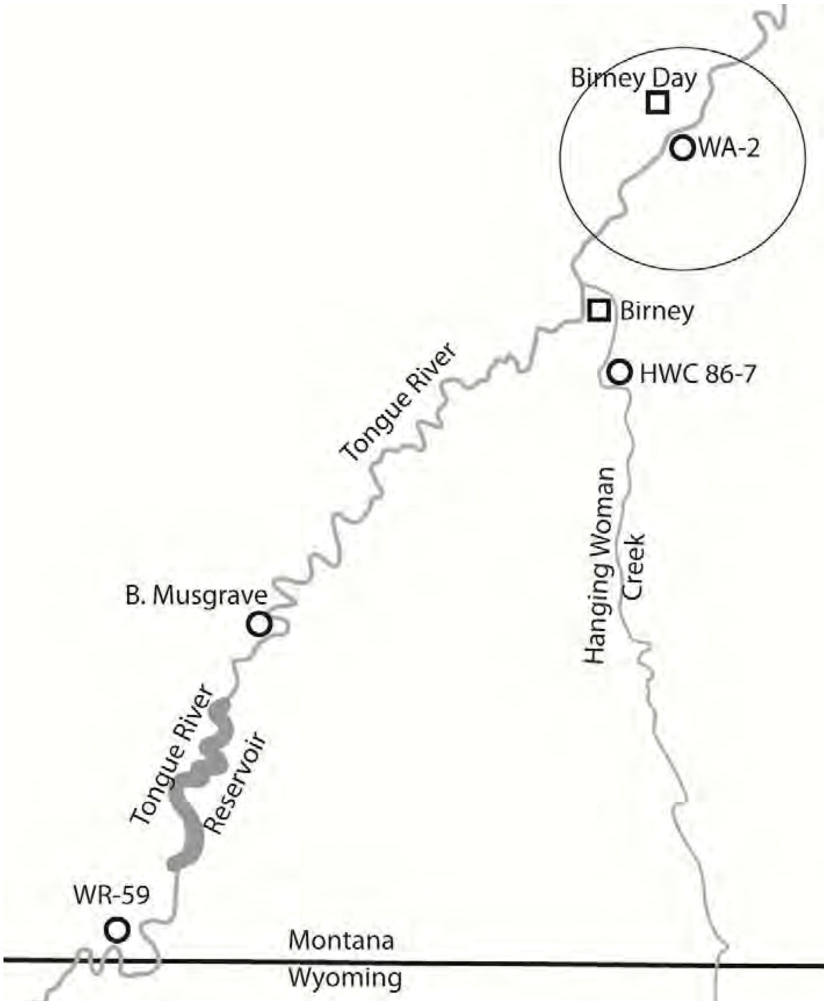
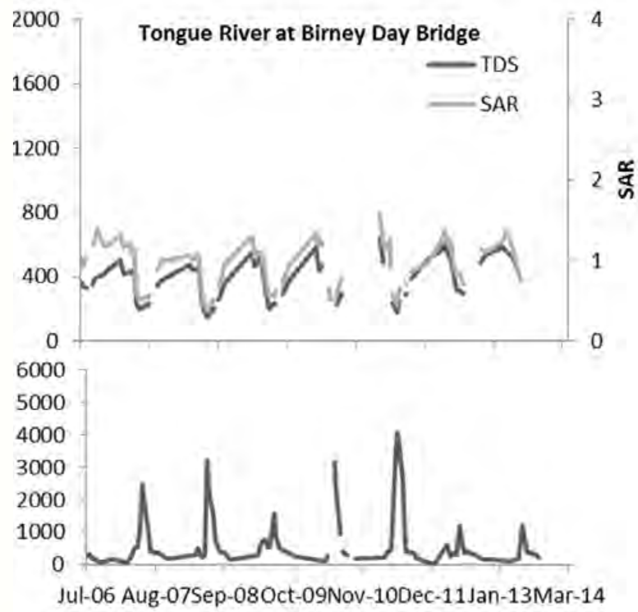
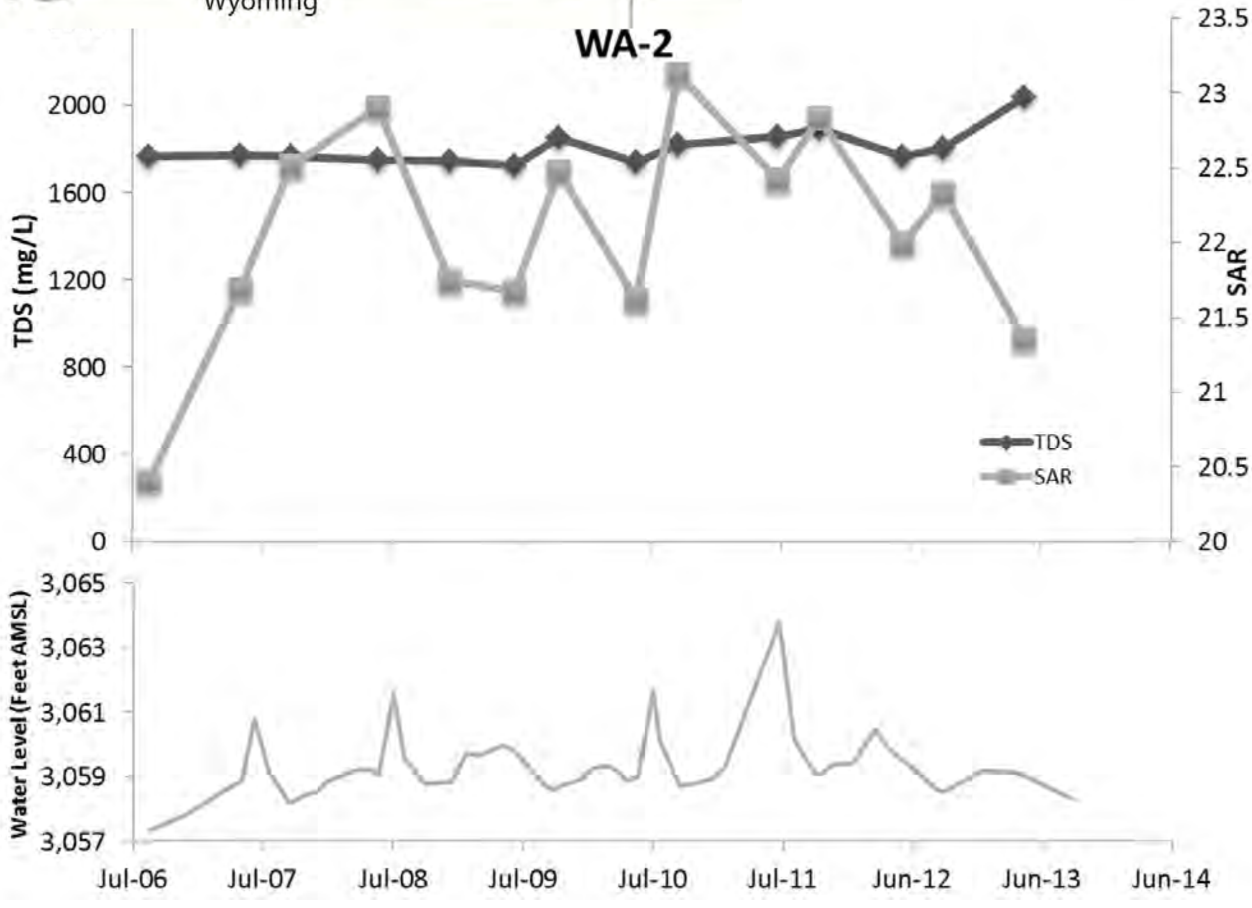
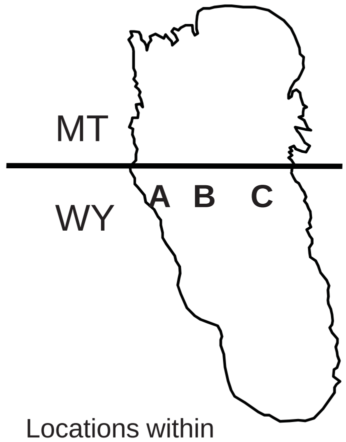


Figure 22. TDS, SAR, and water level / stream discharge for well WA-2 in the alluvium of the Tongue River and the Tongue River at Birney Day Bridge.









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

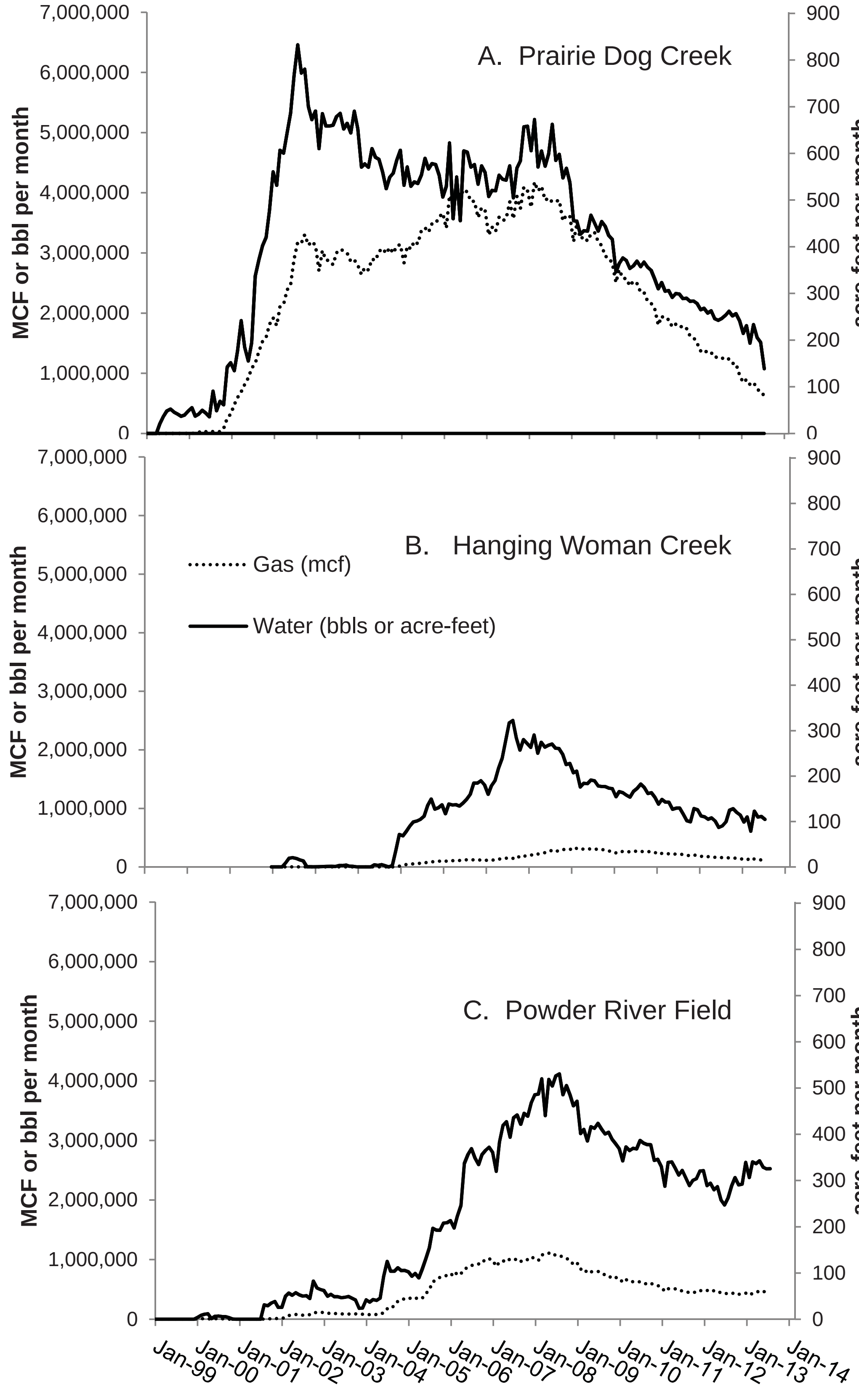


Figure 23. Total water (solid line) and gas (dashed line) produced per month in northern Wyoming CBM fields T. 57 N. and 58 N.

climb in November 2004, and peaked in September 2007 at 2.5 million bbls/mo (fig. 23). Since that time, water production has fallen to less than 1 million bbls /mo. Gas production has been low compared to that of nearby fields throughout the life of the field.

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 mi 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 dropped almost 58.5 ft, but beginning in January 2012, has risen about 10 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 135.8 ft (fig. 25) since monitoring began in May 2005.

Monitoring well site SL-4 is located about 1 mi 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 76.1 ft lower than when monitoring began (fig. 27). The water level in the Smith coal has also dropped slightly; 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. The water-level recovery beginning in late 2012 may indicate less local use of this aquifer or a response to reduced CBM production in Wyoming fields. This monitoring well is located approximately 150 ft from the Forks Ranch Headquarters well, which was completed in the Smith coal in June 2006.

Monitoring well site SL-5 is located to the northeast and approximately 4 mi distant from the nearest CBM development in the Anderson, Canyon, Cook, Kendrick, and Roberts coals in Wyoming (plate 1). The Anderson and Canyon coal monitoring wells appear to be connected, and the water levels are slowly equilibrating (fig. 28). The increasing water level in the Canyon and decreasing water level in the Anderson may be a result of a failed seal in the neat cement in the Canyon coal well causing communication along the well bore between the Canyon and the higher-pressure Anderson coal. Alternatively, it may be that a nearby well has allowed the two aquifers to communicate. There is no noticeable trend in Dietz coal water levels in well SL-5DC.

Alluvial-aquifer water levels and water quality. Based on water-level trends and lithology, the Hanging Woman Creek and North Fork Waddle Creek alluvium near the state line do not interact with the Anderson and Smith coalbeds (fig. 25). Changes in alluvial water levels reflect responses to seasonal weather patterns (figs. 29, 30).

Water-quality samples were collected from wells HWC 86-13 and HWC 86-15 during September 2012 and May 2013 (appendix C). During the sampling events, TDS concentrations in the alluvial water ranged from 6,184 to 7,998 mg/L and SAR values ranged from 10.5 to 11.2. 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 September 2012 and May 2013 (appendix C). TDS and SAR concentrations have varied little since sampling began in 2005; during these sampling events TDS values were 3,731 and 3,762 mg/L and SAR values were 5.0 and 4.9, respectively. The water chemistry is dominated by a balance of cations (calcium, magnesium, and sodium in nearly equal parts) and sulfate. There appears to be no discernible effect from CBM development in the alluvial aquifer at SL-3Q.

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 2013, a total of 463 wells produced methane and/or water, an increase of 16 wells since 2012. The cumulative water production for the 12-mo period was 29.8 million bbls. Water production in these fields increased steadily from January 2004 through July 2008, when it peaked at just over 4 million bbls/mo. As of September 2013, water production is approximately 2.5 million bbls/mo. Gas production also peaked in 2008 and has been declining steadily since (fig. 23).

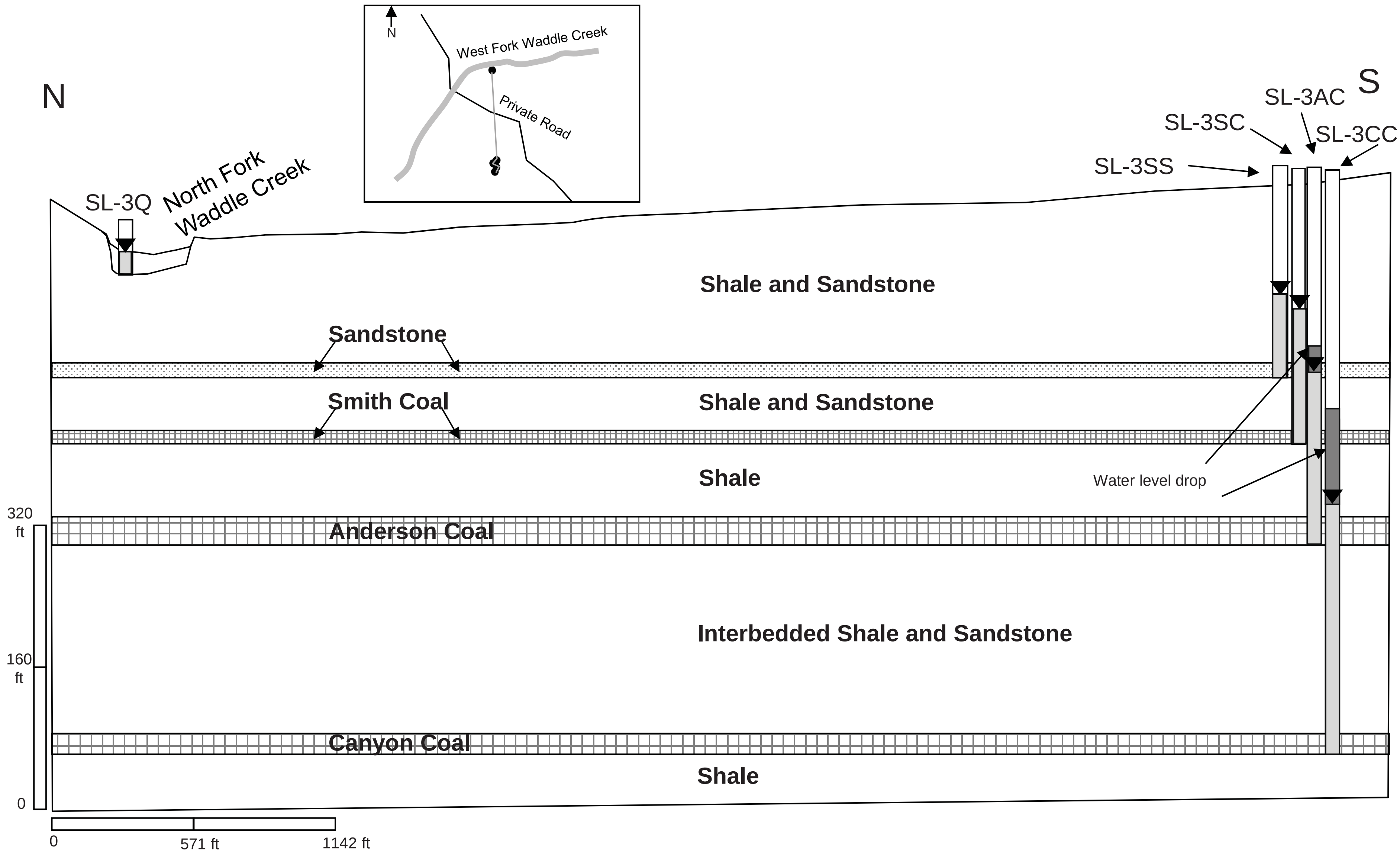


Figure 24. Geologic cross section for alluvium, an overburden sandstone, and Smith, Anderson, and Canyon coalbeds located at T. 9 S., R. 42 E., sec. 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2013. The 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 135.8 ft since well installation. The wells are located roughly 1 mi north of the nearest CBM field. Vertical exaggeration is 3.6:1.

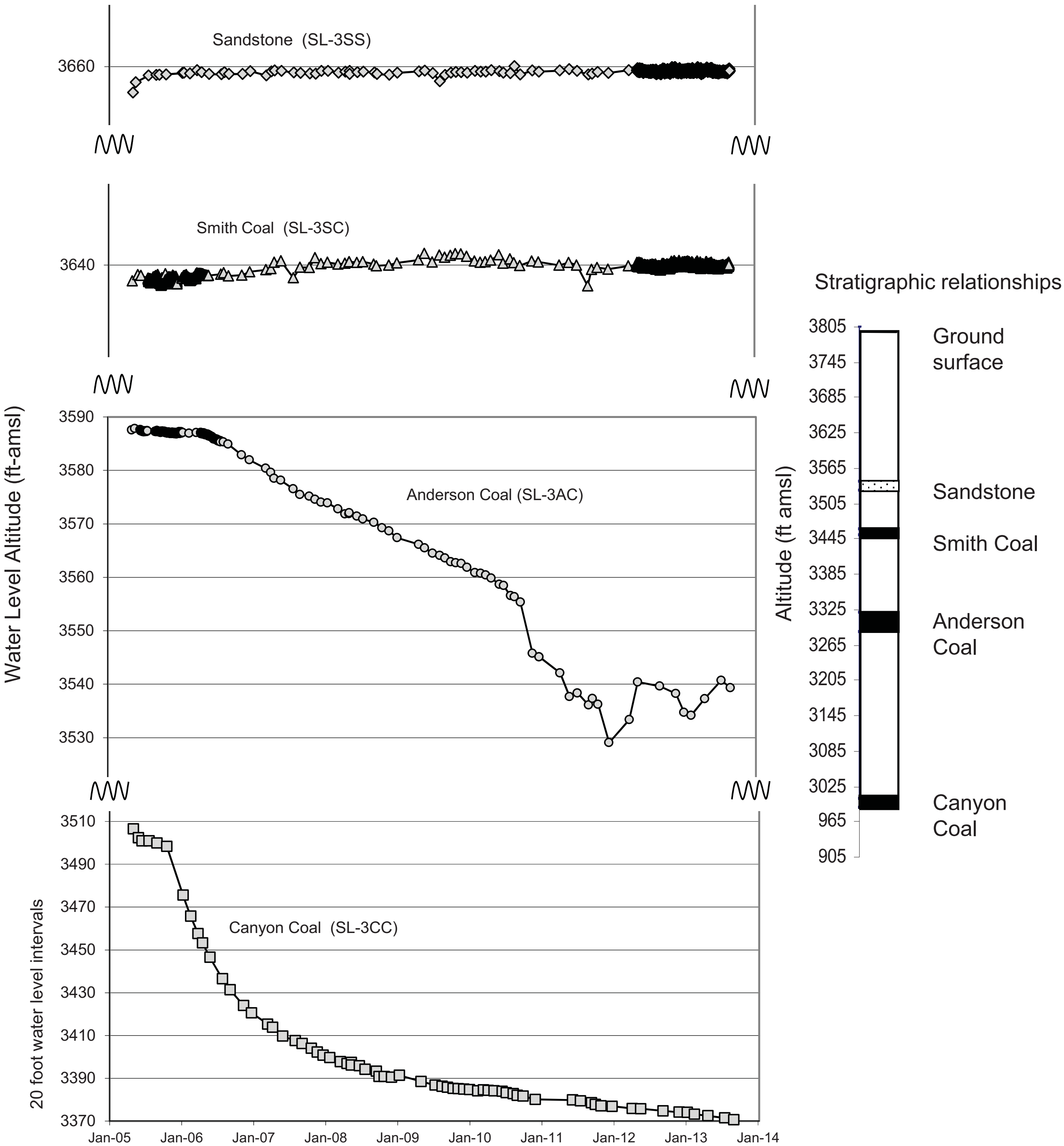


Figure 25. Water levels in the overburden sandstone (SL-3SS) and Smith (SL-3SC) coals are not responding to CBM development. The water level in the Canyon coal dropped about 135.8 ft in response to CBM production. The water levels in the Anderson coal had a maximum drop of about 58.5 ft in response to CBM production. However, water levels are rising in response to 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.

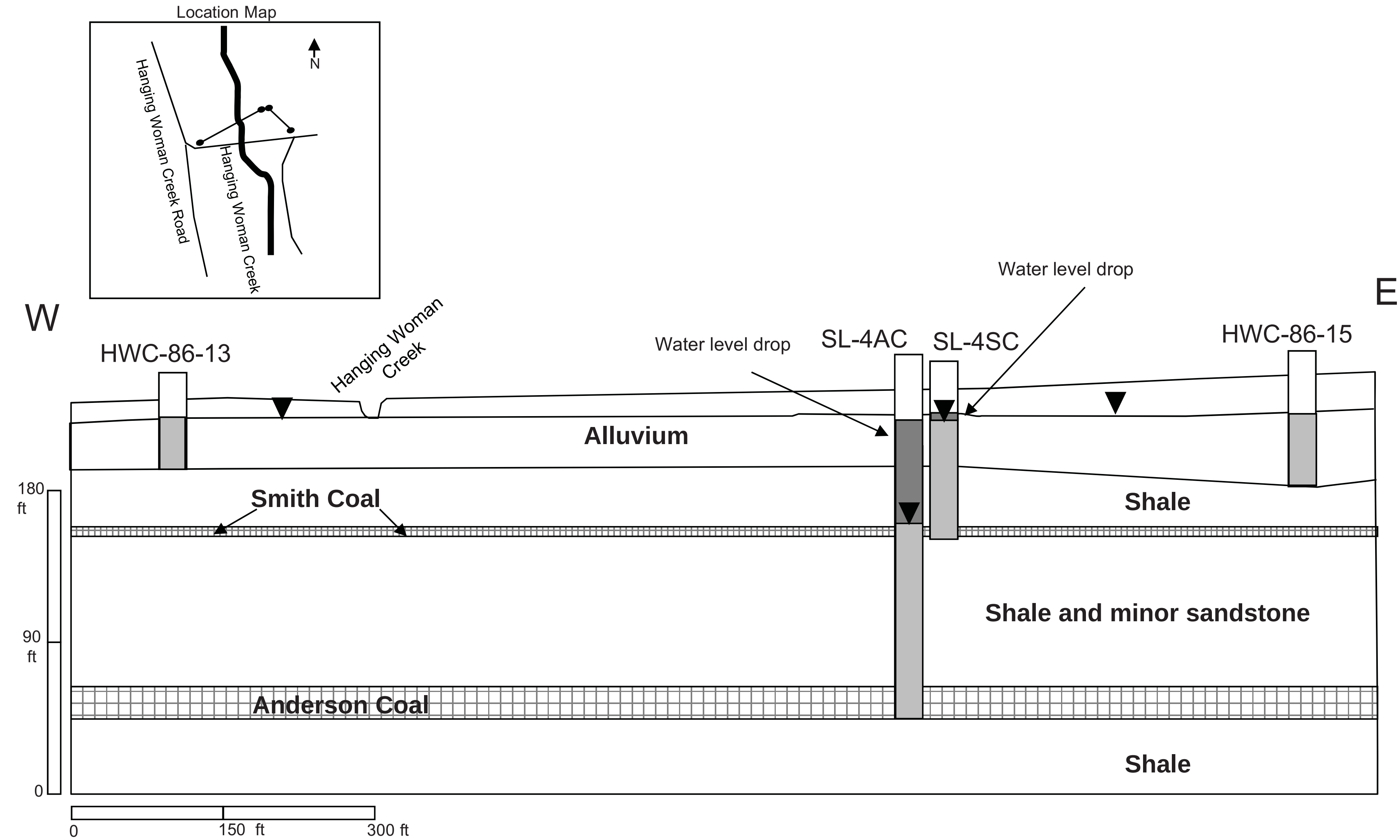


Figure 26. Geological cross section for the alluvium and bedrock wells near the Montana/Wyoming state line on Hanging Woman Creek located in T. 10 S., R. 43 E., sec. 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson coal and Smith coal have lowered in response to CBM production. The Anderson has lowered by about 76.1 ft. Water levels in the Smith Coal had lowered about 17.5 ft since well installation, and recent data indicate a recovering water-level response. These wells are located roughly 1 mi north of the nearest CBM field. Water levels for the cross section were taken in September 2013. Vertical exaggeration is 7:1.

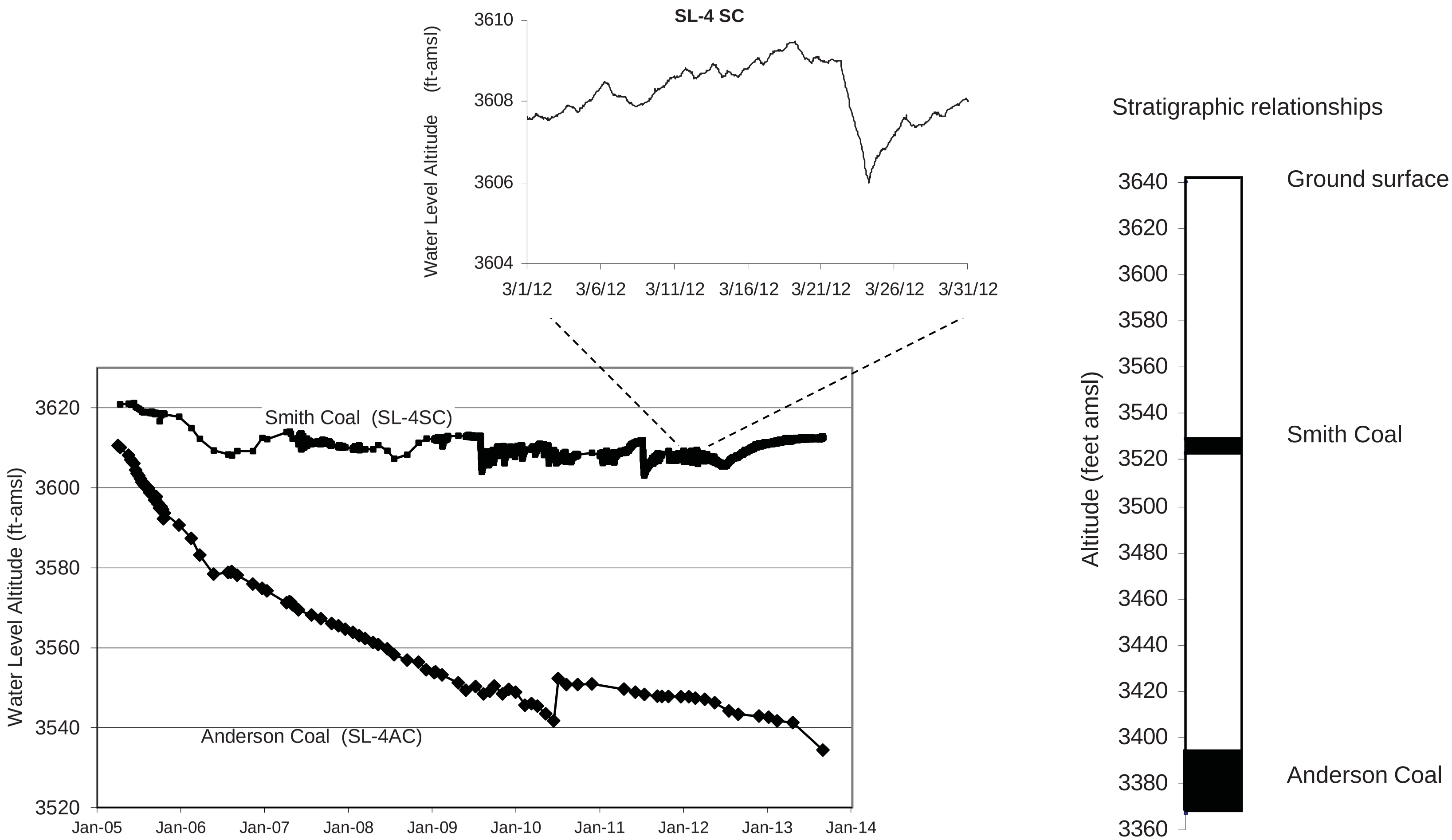


Figure 27. The SL-4 site is located about 1 mi north of the nearest CBM field. Water levels in the Anderson coal appear to have lowered about 76.1 ft from April 2005 to September 2013 in response to CBM development; however, it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft, presumably due to activities in the nearby 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.

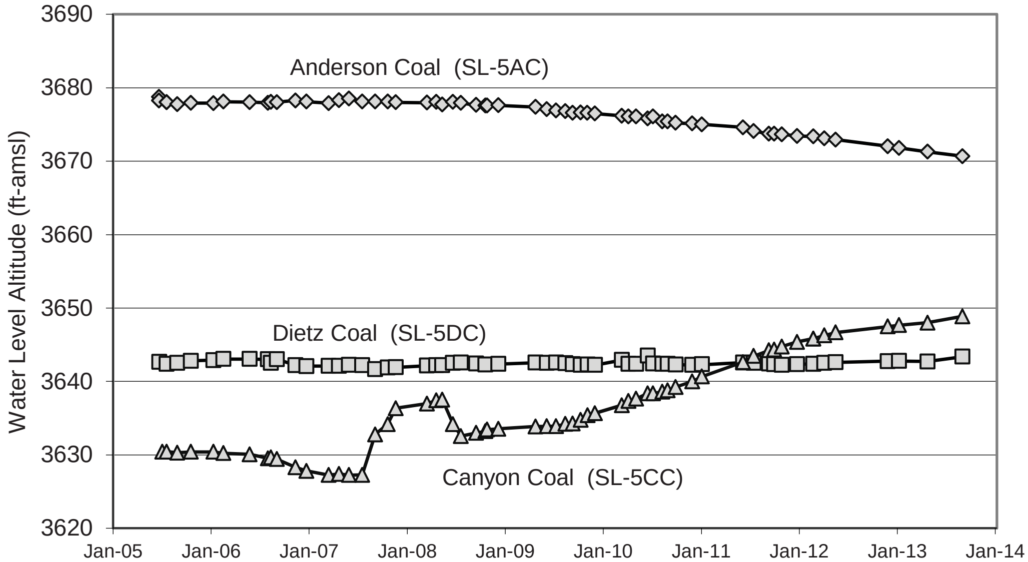


Figure 28. Coalbed-methane development in the Anderson coal may be causing a slight decline in water level in the Anderson coal at the SL-5 site. The Canyon water level has risen since mid-2007 and now has a higher level then the Dietz coal water level. The water-level increase may be a result of a failed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

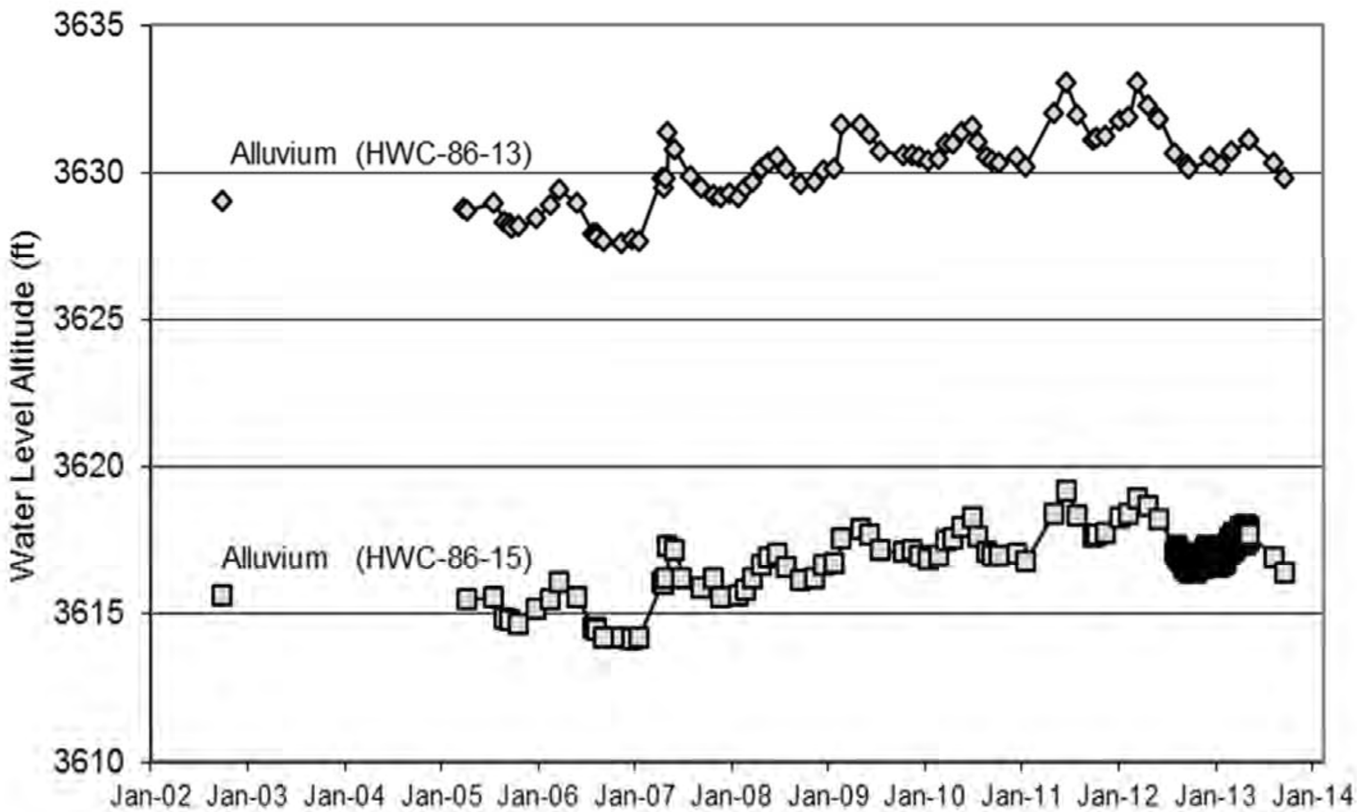


Figure 29. The water level in the Hanging Woman Creek alluvial aquifer near the Montana–Wyoming state line reflects water table response to meteorological patterns. Shown in plate 1.

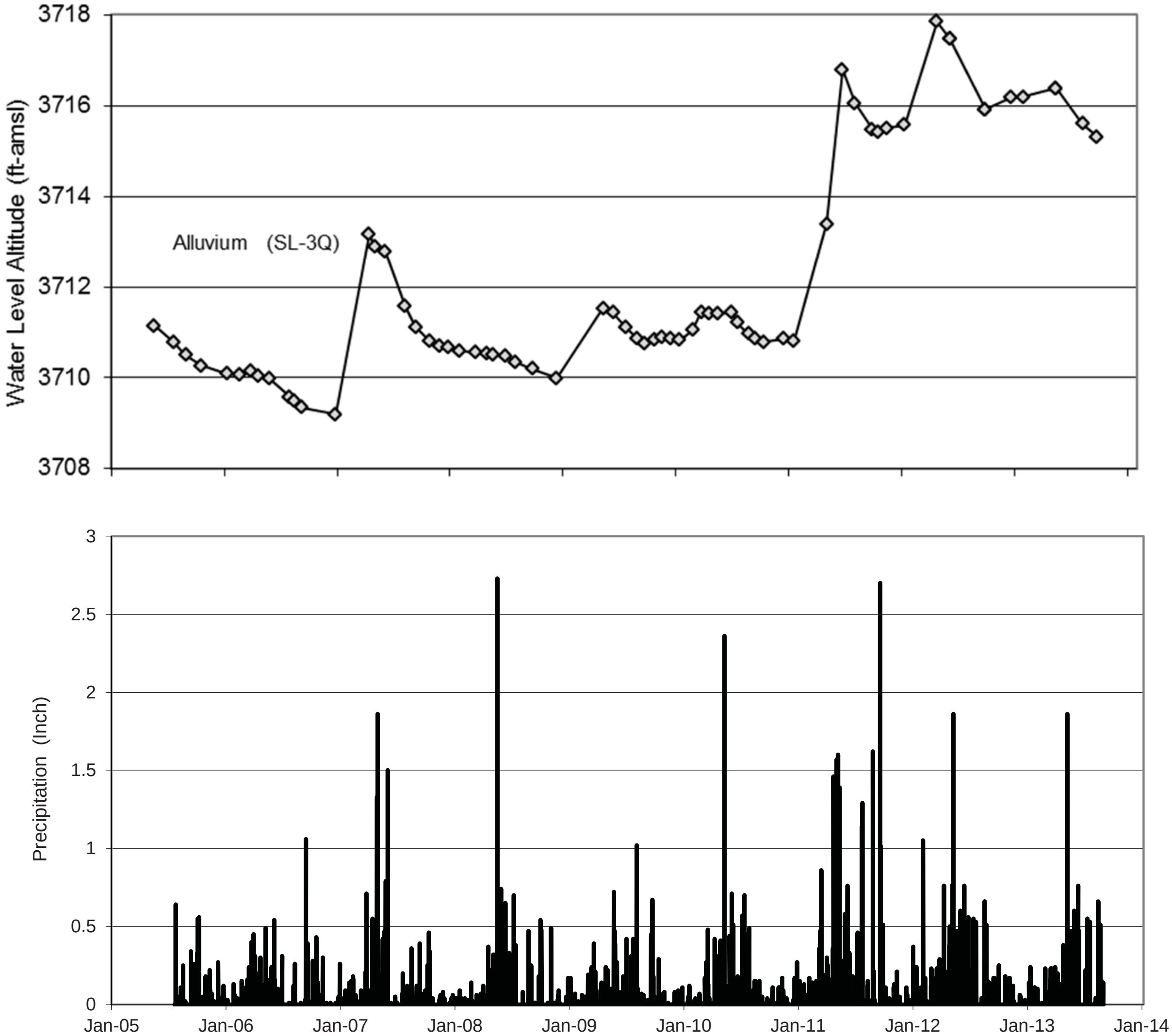


Figure 30. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to plate 1. Precipitation at the SL-3 weather station is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous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

Bedrock-aquifer water levels. Monitoring well SL-7CC is completed in the Canyon coal less than 1 mi north of the state line near Wyoming CBM production. This well releases methane when opened, so it is not monitored due to safety concerns (discussed in Wheaton and others, 2006). Gas migration was occurring prior to local CBM development, so at least some of the venting is due to naturally migrating free gas.

Two monitoring wells at site SL-6 are located 6 mi west of SL-7CC. Well SL-6CC is completed in the Canyon coal and releases gas similarly to 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.

New bedrock wells were installed at the SL-8 site in July 2013. This site previously only had monitoring wells in the alluvium and a flowing well completed in sandstone. Wells were completed in the Knobloch and Brewster–Arnold coals. For more information on these wells, please see the section below on installation of new coal monitoring wells.

Alluvial-aquifer water levels and water quality. South of Moorhead, Montana, groundwater flow through the Powder River alluvium is roughly parallel to the river valley (figs. 31, 32). Site SL-8 is located on a large meander, and the river likely loses flow to the alluvium on the meander's upgradient end and gains flow from the alluvium at the lower end. A stock well producing from an 86-ft thick 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 respond to CBM production or water management in Wyoming.

Water-quality samples were collected from SL-8-2Q in September 2012 and May 2013 (appendix C). TDS concentrations were 2,654 and 2,015 mg/L and SAR values 4.1 and 3.8, 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) than in wells SL8-3Q and SL8-1Q, but no CBM impacts are apparent. The alluvial water at SL-8-2Q generally has uranium concentrations of about 20 µg/L, but the sample collected in October 2008 had a concentration of 35.8 µg/L, which exceeds the drinking water standard of 30 µg/L.

INSTALLATION OF NEW COAL MONITORING WELLS

The MBMG installed three new monitoring wells in the Powder River Basin in 2013. Two wells were installed in July at the existing SL-8 monitoring site, south of Moorhead, Montana along the Powder River in the Knobloch and Brewster–Arnold coals, to complement existing alluvial groundwater monitoring. Total depths for the wells were 416 and 113 ft for the Knobloch and Brewster–Arnold coal wells, respectively. The GWIC ID for the Knobloch well is 277326 and for the Brewster–Arnold well is 277327. These wells are positioned to monitor potential water-level drawdown due to CBM development in Wyoming; the area around the Powder River is one of the few places experiencing an increase in CBM production. These wells are also positioned to monitor potential drawdown from Summit's new plan of CBM development in Montana (fig. 33) [DNRC BOGC, February 2013 dockets 80-2013 and 81-2013 (http://bogc.dnrc.mt.gov/PDF/February2013Docket.pdf) approved by orders 48-2013 and 49-2013, and June 2013 dockets 261-2013, 262-2013, 263-2013, and 264-2013 (http://bogc.dnrc.mt.gov/PDF/June2013Docket.pdf) approved by orders 244-2013, 246-2013, 245-2013, and 247-2013]. The proposed development covers approximately the southernmost two townships in Montana, 8 S. and 9 S., from range 43 E. to 48 E., and includes the uppermost watersheds of Bear Creek and Otter Creek and some small tributaries to the Powder River. The target coals include all the coals in the Tongue River member of the Fort Union Formation.

An additional Knobloch coal well (10-mi KC1) was installed in September on the Ashland Ranger District approximately 10 mi south of Ashland and 3 mi east of Otter Creek. The total depth of this well is 71 ft, and the GWIC ID is 276654. This well will aid in monitoring potential water-level drawdown in the Knobloch coal from the proposed surface coal mine. Another exploration hole was drilled approximately 1 mi east of the 10-mi KC1 well site to a depth of 120 ft. The borehole was unable to be completed as a well because unconsolidated materials extended to 90 ft below land surface. The GWIC ID for the abandoned borehole is 276653.

Linked to these ID numbers in the GWIC database are the well completion, cutting logs, location, water levels, and all water-quality information available for the sites.

UPDATE ON FIRE-AFFECTED WELLS AND SPRINGS

The summer of 2012 saw more acres burned by wildfire in Montana than at 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, 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. Several monitored springs and wells were directly affected, including Lemonade Spring, Upper 15-Mile Spring, Joe Anderson Spring, Hedum Spring,

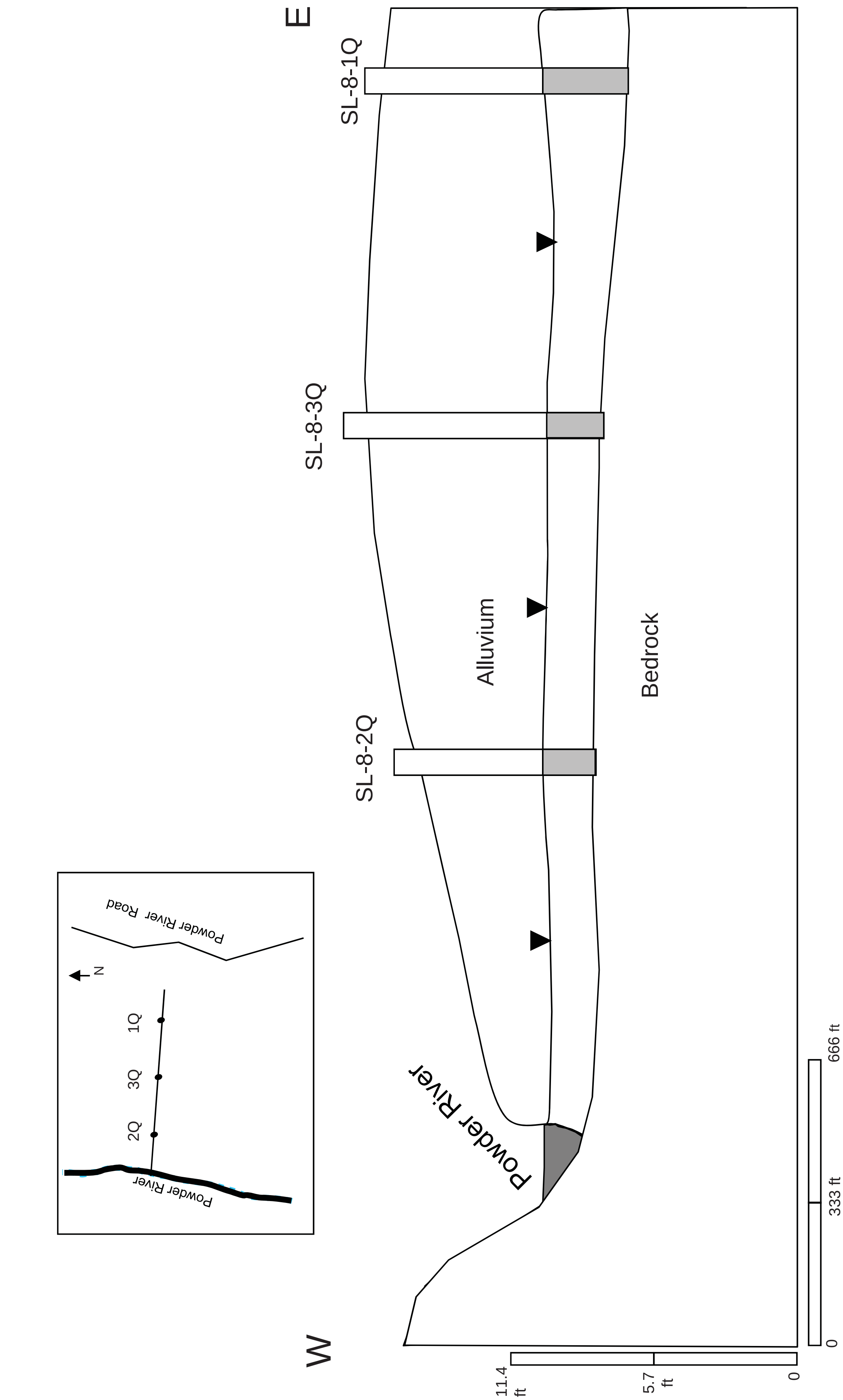


Figure 31. Cross section of alluvial wells south of Moorhead near the Powder River, located in T. 09 S., R. 47 E., sec. 25. Groundwater in the alluvium appears to flow parallel to the river valley. Water levels for this cross section were taken in September 2013. Vertical exaggeration is 58:1.

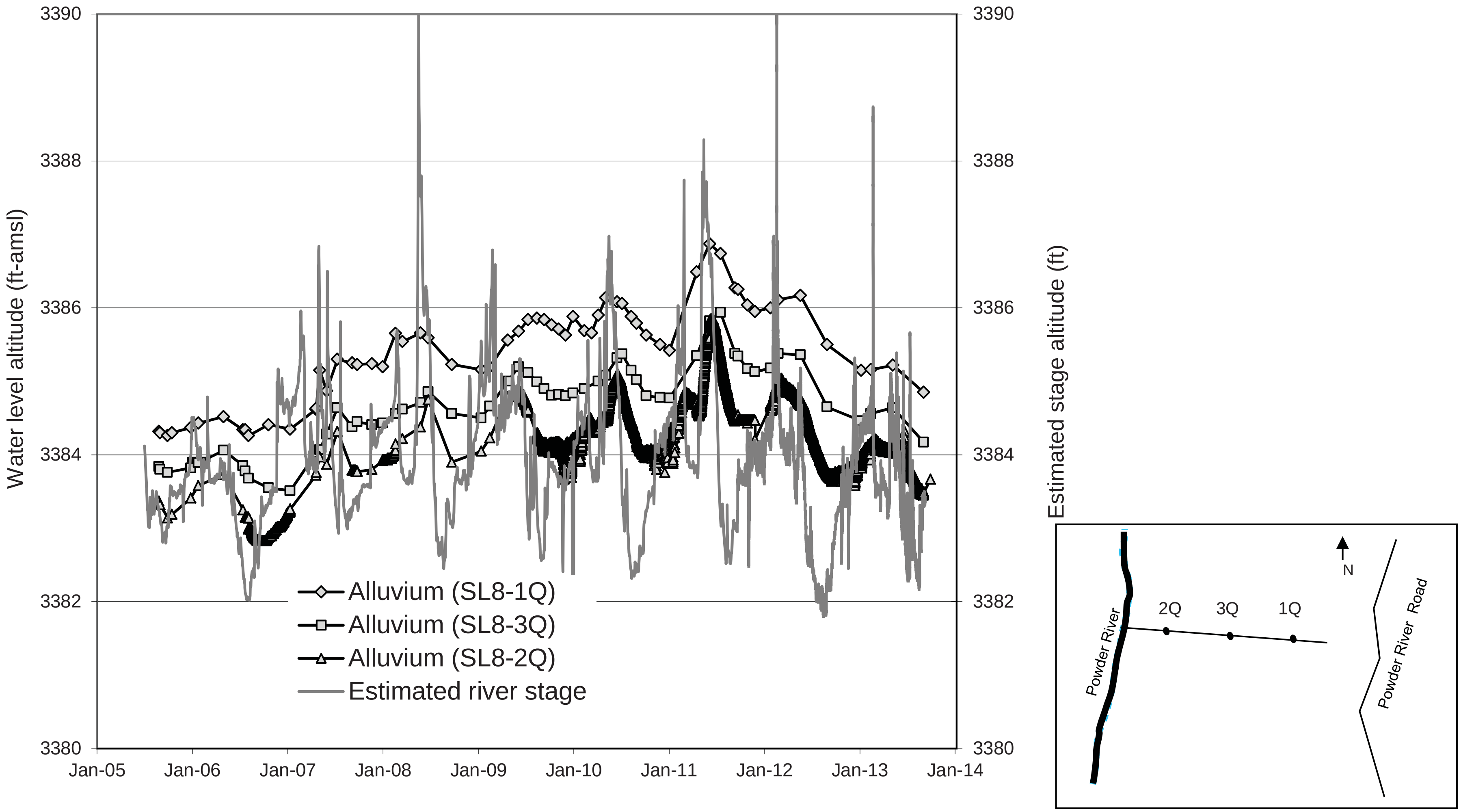


Figure 32. Groundwater flow in the alluvial aquifer at SL-8 is generally toward the Powder River. The groundwater-level trends follow river-stage trends. The river alternates between gaining (summer) and losing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gauging station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

Figure 33. Proposed plan of development by Summit Energy for the Bear Creek, East Bear Creek, and Bradshaw Federal units.

School House Spring, Whitetail Ranger Station Well, Spring Creek Pipeline Well, and the Taylor Creek Pipeline Well. However, all wells and springs could still be monitored. 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 on 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 increased flow, water levels in wells may rise, and water chemistry may change as additional salts and nutrients are mobilized from surface soils and ash.

Short-term monitoring after the Taylor Creek fire did not show any direct impact to the monitored springs and wells in the fire-affected areas. There were no distinct changes in the salinity, temperature, or flow rate of the springs and no directly identifiable increase in water levels in wells. Changes to the spring chemistry or flow rate that fall within or near the natural variability will not be observable with the current short-term quarterly monitoring. Long-term monitoring more frequent than quarterly may identify impacts that are slow to emerge.

CHANGES TO SEMI-ANNUAL ALLUVIAL SAMPLING

A review of semi-annual alluvial sampling reveals three sampling locations, RBC-2, WA-2, and SL-3Q, that have been adequately characterized by 7 to 10 yr of sampling (15 to 17 samples, including samples collected in October 2013, not included in this report). The water chemistry at these three sites is well constrained by the existing samples (fig. 34) and any future sampling at these sites will have a robust baseline for comparison.

These three sites will not be sampled in 2014. Instead, alternative wells and/or springs will be chosen based upon: (1) long records of water chemistry with few or no recent samples; (2) locations within areas of interest such as wells showing significant drawdown or recovery; or (3) sites that have had few to no water-chemistry analyses. Wells that will be considered for one-time sampling in spring or fall 2014 include WR-17A, HWC 86-2, WO-10, WR-21, CBM03-10AC, CBM03-10SS, WR-19, WR-20, WR-33, WRN-15, DS-05A, DS-05B, DS-02A, WRE-12, and WR-39.

SUMMARY AND 2014 MONITORING PLAN

Coalbed-methane production continues near the Tongue River Reservoir in Montana; however, the number of producing wells has been greatly reduced in recent years. In contrast to this trend, a new CBM plan of development has been approved that encompasses much of the area between Hanging Woman Creek and the Powder River in ranges 8 and 9 south. Depending upon a number of factors including economic forces and industry priorities, CBM development could expand into that area within the next several years. The MBMG regional groundwater monitoring network documents baseline conditions outside current production areas, changes to groundwater systems within 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 more than 200 ft in the produced coalbeds, and 14-plus yr of CBM production has caused drawdown of up to 20 ft in coalbeds at maximum distances of 1 to 1.5 mi 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 mi after 10 yr of CBM production.

Major faults generally act as barriers to groundwater flow, and the monitoring network has documented only

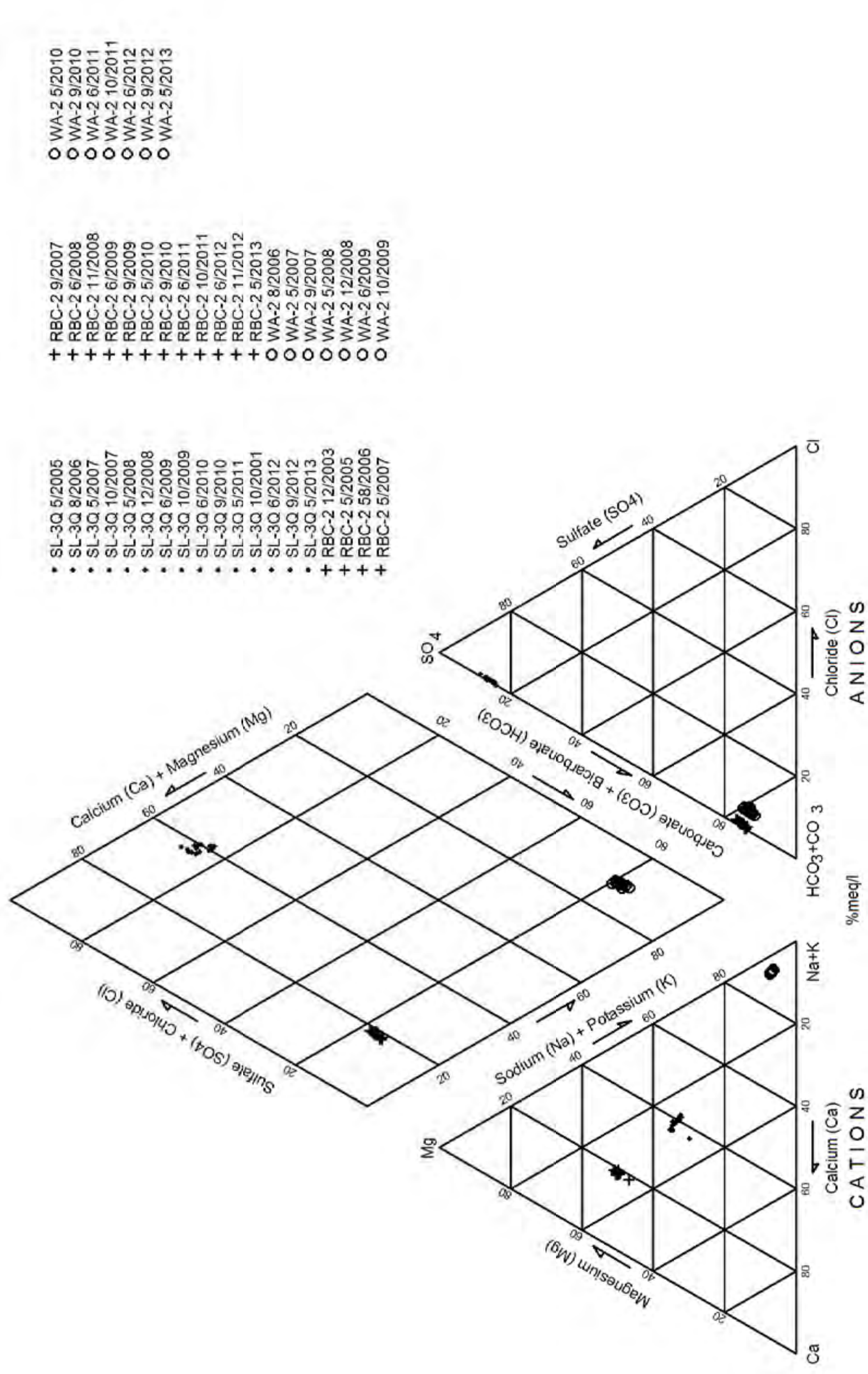


Figure 34. Years of testing on alluvial wells SL-3Q, RBC-2, and WA-2 have thoroughly characterized the water quality in these aquifers. There is very little variation in the water quality at these sites.

rare drawdown migration across fault planes. However, where fault offsets are less than about 10 ft greater 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-level recovery curves suggest that full recovery will depend upon infrequent recharge events during times of high precipitation.

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

Monitoring plans for water year 2014 are included in appendices A and B and shown in plate 6. During water year 2014, monitoring sites located within approximately 6 mi of existing or proposed development will be monitored monthly. At distances greater than 6 mi, 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. All MBMG-monitored springs on the Ashland Ranger District have been sampled at least once for a complete water-quality analysis. Future sampling sites will be chosen to ensure all springs have representative samples from both the spring and fall season. In the spring of 2014, sample sites will include Lemonade and School House springs on the Ashland Ranger district. Monitoring priorities will be adjusted as new areas of production are proposed or developed.

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Appendix A

Site details and water-level data for water year 2013 and monitoring plan for water year 2014

Appendix A. Site details, water-level data, and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	Land altitude (feet)	Aquifer	Well total depth (feet)	Date Completed	Most recent SWL date	Average SWL (feet)	2014 SWL monitoring plan	2014 QW sample collection	2014 Possible QW samples
7573	MBMG MONITORING WELL WO-15	-106.1855	45.5186	04S	45E	4	BDDB	3022	110ALVM	73	12/7/1979	9/26/2013	7.71	Monthly		
7574	MBMG MONITORING WELL WO-16	-106.1861	45.5158	04S	45E	4	CAAC	3040	110ALVM	61	12/10/1979	9/26/2013	22.94	Monthly		
7589	USDA FOREST SERVICE - NEWELL PIPELINE W	-106.2143	45.4727	04S	45E	19	DADD	3290	125KNCB	325	4/20/1958	1/19/2011	278.05	Quarterly		
7755	MBMG MONITORING WELL 77-26 O-22	-106.1839	45.4352	05S	45E	4	ABCC	3284	125KNCB	216.8		1/28/2013	145.28	Quarterly		
7770	MBMG MONITORING WELL WO-8	-106.1411	45.3922	05S	45E	23	ABCA	3155	110ALVM	34	11/14/1979	9/26/2013	14.16	Monthly		
7772	MBMG MONITORING WELL WO-9	-106.1419	45.3925	05S	45E	23	ABCA	3150	110ALVM	45	11/15/1979	9/26/2013	10.51	Monthly		
7775	MBMG MONITORING WELL WO-10	-106.1430	45.3925	05S	45E	23	ABCB	3145	110ALVM	43	11/27/1979	9/26/2013	7.18	Monthly		X
7776	MBMG MONITORING WELL WO-5	-106.1386	45.3922	05S	45E	23	ABDA	3160	125KNUB	192	11/8/1979	9/26/2013	16.7	Monthly		
7777	MBMG MONITORING WELL WO-6	-106.1386	45.3922	05S	45E	23	ABDA	3160	125LKCB	82	11/8/1979	9/26/2013	23.77	Monthly		
7778	MBMG MONITORING WELL WO-7	-106.1386	45.3922	05S	45E	23	ABDA	3160	110ALVM	40	11/9/1979	9/26/2013	25.69	Monthly		
7780	MBMG MONITORING WELL WO-1	-106.1494	45.3947	05S	45E	23	BBAA	3190	125KNUB	172	11/2/1979	9/26/2013	36.93	Monthly		
7781	MBMG MONITORING WELL WO-2	-106.1494	45.3947	05S	45E	23	BBAA	3188	125LKCB	112	11/6/1979	10/16/2013	43.37	Monthly		
7782	MBMG MONITORING WELL WO-3	-106.1494	45.3947	05S	45E	23	BBAA	3186	125KNOB	66	11/6/1979	9/26/2013	45.4	Monthly		
7783	MBMG MONITORING WELL WO-4	-106.1486	45.3941	05S	45E	23	BBAA	3140	110ALVM	31.5	11/7/1979	9/26/2013	8.14	Monthly		
7903	MBMG MONITORING * HWC-86-9	-106.5030	45.2965	06S	43E	19	DACD	3170	110ALVM	44		9/25/2013	10.2	Monthly		
7905	MBMG RESEARCH WELL HWC-86-7	-106.5040	45.2956	06S	43E	19	DDBA	3143	110ALVM	71		10/16/2013	8.71	Monthly	Semi-Annual	
7906	USGS RESEARCH WELL HWC-86-8	-106.5030	45.2961	06S	43E	19	DDBA	3170	110ALVM	67		9/25/2013	7.88	Monthly		
8074	MBMG MONITORING WELL WR-21	-106.9808	45.0877	08S	39E	32	DBBC	3890	125D1D2	206	8/20/1975	9/23/2013	56.54	Monthly		X
8101	MBMG MONITORING WELL HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	3460	110ALVM	50	9/29/1986	9/24/2013	19.11	Monthly		X
8103	MBMG MONITORING WELL HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	3455	110ALVM	40	9/30/1986	9/24/2013	14.43	Monthly		
8107	MBMG MON WELL HWC-01 * DITCH WELL	-106.4827	45.1254	08S	43E	20	DDDD	3530	125CNCB	232	5/8/1974	10/15/2013	92.09	Monthly		
8110	NEAR MOUTH OF HORSE CREEK * HC-01 O-	-106.4750	45.1313	08S	43E	21	BBDA	3455	110ALVM	19.7		1/27/2009	9.2			
8118	MBMG MONITORING WELL * HC-24 O-10	-106.4747	45.1297	08S	43E	21	BDBB	3490	125CNOB	150	12/29/1980	1/31/2013	42.87	Semi-Annual		
8140	MBMG MONITORING WELL FC-01	-106.5166	45.1025	08S	43E	31	BBDA	3735	125ANCB	133		3/7/2013	129.05	Monthly		
8141	MBMG MONITORING WELL FC-02	-106.5166	45.1025	08S	43E	31	BBDA	3735	125DICB	260		3/7/2013	242.6	Monthly		
8191	MBMG MONITORING WELL BC-06 O-42	-106.2121	45.1355	08S	45E	16	DBCB	3715	125CNCB	188		9/26/2013	88.01	Monthly		
8192	MBMG MONITORING WELL BC-07 O-43	-106.2121	45.1355	08S	45E	16	DBCB	3715	125CNOB	66		9/26/2013	33.35	Monthly		
8347	MBMG MONITORING WELL WR-23	-106.9905	45.0922	09S	38E	1	AADC	3960	125D1D2	322	8/28/1975	9/23/2013	82.89	Monthly		
8368	MBMG MONITORING WELL SH-391	-107.0330	45.0412	09S	38E	22	DADC	3987	125D1D2	175	9/27/1972	8/14/2013	61.45	Monthly		
8371	MBMG MONITORING WELL SH-388	-107.0205	45.0391	09S	38E	23	CDAD	3975	125DICB	190	9/28/1972	9/23/2013	78.03	Monthly		
8372	MBMG MONITORING WELL SH-396	-107.0088	45.0490	09S	38E	24	BBBC	3939	125AND2	280		9/23/2013	55.06	Monthly		
8377	MBMG MONITORING WELL SH-394	-107.0075	45.0329	09S	38E	25	BCBA	3909	125DICB	242		9/23/2013	91.37	Monthly		
8379	MBMG MONITORING WELL SH-422	-107.0061	45.0261	09S	38E	25	CBDC	3917	125DICB	187		4/26/2013	121.94	Semi-Annual		
8387	MBMG MONITORING WELL SH-395	-107.0180	45.0359	09S	38E	26	ABAB	3900	125DICB	299		9/23/2013	63.13	Monthly		
8412	MBMG MONITORING WELL WR-58	-106.9122	45.0408	09S	39E	14	DDBD	3631.29	110ALVM	55	8/23/1977	9/23/2013	14.09	Monthly		
8413	MBMG MONITORING WELL WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	3627.41	110ALVM	27	8/25/1977	9/23/2013	13.61	Monthly		
8417	MBMG MONITORING WELL WR-19	-106.9505	45.0525	09S	39E	16	AABA	3835.4	125D1D2	305	8/14/1975	9/23/2013	134.33	Monthly		X
8419	MBMG MONITORING WELL WR-20	-106.9505	45.0525	09S	39E	16	AABA	3835.3	125ANCB	166	8/18/1975	9/23/2013	107	Monthly		X
8428	MBMG MONITORING WELL WR-54A	-106.8902	45.0147	09S	39E	25	DADB	3631.2	125ADOB	211	8/30/1977	9/23/2013	127.14	Monthly		

Appendix A. Site details, water-level data, and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	Land altitude (feet)	Aquifer	Well total depth (feet)	Date Completed	Most recent SWL date	Average SWL (feet)	2014 SWL monitoring plan	2014 QW sample collection	2014 Possible QW samples
8430	MBMG MONITORING WELL WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	3607.9	125ADOB	187	8/29/1977	9/23/2013	108.79	Monthly		
8436	MBMG MONITORING WELL WR-24	-106.9877	45.0202	09S	39E	29	BBDD	3777.2	125CNCB	146		9/23/2013	32.86	Monthly		
8441	MBMG MONITORING WELL WR-33	-106.9760	45.0067	09S	39E	32	ACAA	3732.3	125ADKC	165	6/6/1977	9/23/2013	50.37	Monthly		X
8444	MBMG MONITORING WELL WR-27	-106.9590	45.0009	09S	39E	33	DBBD	3672	125AND2	363	1/21/1976	8/15/2013	76.8	Monthly		
8446	MBMG MONITORING WELL WR-45	-106.9538	44.9962	09S	39E	33	DDCC	3638.2	110ALVM	64	6/21/1977	9/23/2013	9.65	Monthly		
8447	MBMG MONITORING WELL WR-44	-106.9528	44.9962	09S	39E	33	DDCD	3636.9	110ALVM	64	6/21/1977	9/23/2013	9.21	Monthly		
8451	MBMG MONITORING WELL WR-42	-106.9509	44.9962	09S	39E	33	DDDD	3636.7	110ALVM	66		9/23/2013	9.99	Monthly		
8456	MBMG MONITORING WELL WRN-10	-106.8094	45.0733	09S	40E	3	DABA	3433.3	125D2CB	79	12/5/1974	9/23/2013	24.72	Monthly		
8461	MBMG MONITORING WELL WRN-15	-106.8275	45.0638	09S	40E	9	AADD	3499.8	125D2CB	140	12/5/1974	8/8/2013	90.75	Monthly		X
8471	MBMG MONITORING WELL DS-05A	-106.8338	45.0555	09S	40E	9	DCAB	3505.5	125D2CB	166	5/21/1976	8/8/2013	105.3	Monthly		X
8500	MBMG MONITORING WELL WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	3510.7	125D2CB	232	11/1/1974	8/8/2013	166.03	Monthly		
8501	MBMG MONITORING WELL WRE-10	-106.7741	45.0383	09S	40E	13	DCCB	3518.5	125DICB	183	11/1/1974	8/8/2013	147.28	Monthly		
8504	MBMG MONITORING WELL WRE-11	-106.7736	45.0383	09S	40E	13	DCCD	3508.9	125ANCB	127	11/15/1974	8/8/2013	82.7	Monthly		
8574	MBMG MONITORING WELL DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	3430	125D2CB	150	5/20/1976	8/8/2013	54.65	Monthly		X
8650	MBMG MONITORING WELL WR-55	-106.8874	45.0302	09S	40E	19	CBBD	3591.2	125AND2	288	8/16/1977	1/11/2012	162.42	Monthly		
8651	MBMG MONITORING WELL WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	3591.1	125ADOB	72	8/17/1977	9/23/2013	45.29	Monthly		
8687	MBMG MONITORING WELL WRE-12	-106.8050	45.0307	09S	40E	23	BCCD	3463.2	125ANCB	172	11/18/1974	9/23/2013	88.4	Monthly		X
8692	MBMG MONITORING WELL WRE-13	-106.8050	45.0308	09S	40E	23	BCCD	3462.6	125DICB	206	11/18/1974	9/23/2013	93.37	Monthly		
8698	MBMG MONITORING WELL WRE-16	-106.7690	45.0351	09S	40E	24	AACB	3550.5	125ANCB	458	11/18/1974	8/8/2013	62.02	Monthly		
8706	MBMG MONITORING WELL WR-17B	-106.8656	45.0227	09S	40E	29	BBAC	3574.7	125ADOB	160	6/28/1977	9/23/2013	74.26	Monthly		
8708	MBMG MONITORING WELL WR-51	-106.8622	45.0186	09S	40E	29	BDCB	3541	125AND2	344	6/29/1977	9/23/2013	136.66	Monthly		
8709	MBMG MONITORING WELL WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	3541.3	125ADOB	187	7/12/1977	9/23/2013	40.72	Monthly		
8710	MBMG MONITORING WELL WR-52B	-106.8627	45.0147	09S	40E	29	CACB	3518.83	110ALVM	55	7/14/1977	9/23/2013	11.25	Monthly		
8721	MBMG MONITORING WELL WRE-27	-106.7391	45.0586	09S	41E	8	CABC	3523.8	125ANCB	77	10/28/1974	8/8/2013	47.24	Monthly		
8723	MBMG MONITORING WELL WRE-28	-106.7391	45.0586	09S	41E	8	CABC	3525.2	125D1CB	153	10/28/1974	8/8/2013	61.79	Monthly		
8726	MBMG MONITORING WELL WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	3523.3	125D2CB	217	10/29/1974	8/8/2013	111.82	Monthly		
8754	MBMG MONITORING WELL CC-01	-106.4655	45.0872	09S	43E	4	ABDD	3525	110ALVM	28	12/12/1979	9/24/2013	14.15	Monthly		
8757	MBMG MONITORING WELL CC-04	-106.4659	45.0874	09S	43E	4	ABDD	3511	110ALVM	25	12/18/1979	9/24/2013	7.07	Monthly		
8758	MBMG MONITORING * CC-03	-106.4654	45.0864	09S	43E	4	ACAA	3521	110ALVM	34.5	12/13/1979	9/24/2013	14.27	Monthly		
8777	HWC-38 USGS OBS WELL	-106.4028	45.0719	09S	43E	12	ADBB	3586	110ALVM	40.5	6/15/1977	9/24/2013	18.63	Monthly		
8778	MBMG MONITORING WELL HWC-17	-106.4142	45.0575	09S	43E	13	BCAA	3610	125ANCB	82	8/10/1976	9/24/2013	50.19	Monthly		
8779	MBMG MONITORING WELL HWC-07	-106.4094	45.0536	09S	43E	13	CAAA	3595	125ANCB	66	7/16/1975	9/24/2013	27.65	Monthly		
8782	MBMG MONITORING WELL HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	3600	125ANCB	129	8/4/1976	9/24/2013	37.08	Monthly		
8796	MBMG MONITORING WELL HWC-29B	-106.3974	45.0697	09S	44E	7	BBCC	3620	125ANCB	92	5/14/1977	9/24/2013	45.19	Monthly		
8835	MBMG MONITORING WELL AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	3965	125DICB	240		9/26/2013	166.78	Monthly		
8846	MBMG MONITORING WELL UOP-09 KB-33 O	-106.0578	45.0720	09S	46E	11	BBBA	3929	125CNCB	261.5	6/13/2002	9/26/2013	155.92	Monthly		
8847	MBMG MONITORING WELL UOP-10 KB-34 O	-106.0578	45.0720	09S	46E	11	BBBA	3930	125CNOB	207.3		9/26/2013	141.67	Monthly		
8863	FULTON RANCH-TRAILER * TRAILER	-105.8634	45.0807	09S	48E	5	ACDD	3380	125TGRV	410	12/2/1958	10/9/2013	16.85	Quarterly		
8888	MBMG MONITORING WELL HWC-86-13	-106.4262	45.0020	10S	43E	2	ABCA	3640	110ALVM	53	10/8/1986	10/16/2013	9.93	Monthly	Semi-Annual	
94661	USFS- LISCOM BUTTE WELL	-106.0329	45.7782	01S	46E	3	DBAA	3275	125TGRV	135	7/11/1946	10/8/2013	96.18	Quarterly		
94666	USFS- COYOTE WEL	-106.0511	45.7524	01S	46E	16	AACC	3294	125TGRV	190	9/27/1963	10/8/2013	135.02	Quarterly		

Appendix A. Site details, water-level data, and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	Land altitude (feet)	Aquifer	Well total depth (feet)	Date Completed	Most recent SWL date	Average SWL (feet)	2014 SWL monitoring plan	2014 QW sample collection	2014 Possible QW samples
100472	USFS EAST FORK	-106.1648	45.5935	03S	45E	10	BACB	3210	125KNUB	193	4/1/1961	10/8/2013	136.62	Quarterly		
103155	USFS- PADGET CREEK	-106.2940	45.3939	05S	44E	22	BBBD	3385	125TGRV	135	4/30/1981	8/13/2013	56.31	Quarterly		
105007	USFS- TOOLEY CREEK	-106.2703	45.2153	07S	45E	19	CAAA	3755	125CNOB	110	11/5/1978	10/8/2013	35.55	Quarterly		
121669	MBMG MONITORING WELL WRE-18	-106.7690	45.0335	09S	40E	24	AACD	3573.1	125ANCB	445	11/4/1974	8/8/2013	103.63	Monthly		
122766	MBMG MONITORING WELL WR-59	-106.8526	45.0050	09S	40E	32	ACAD	3470.1	110ALVM	34	8/31/1977	10/17/2013	8.45	Monthly	Semi-Annual	
122767	MBMG MONITORING WELL WRE-20	-106.7716	45.0369	09S	40E	24	ABAB	3519.4	125ANCB	120	12/11/1974	8/8/2013	93.31	Monthly		
122769	MBMG MONITORING WELL WR-38	-106.9660	44.9939	54N	84W	23	BBCB	3692.9	125D1D2	286	6/14/1977	8/14/2013	74.47	Monthly		
122770	MBMG MONITORING WELL WR-39	-106.9555	44.9957	58N	84W	23	ABBC	3666	125AND2	312	6/14/1977	9/23/2013	65.96	Monthly		X
123795	MBMG MONITORING WELL WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	3549.4	125ANCB	114.5	10/29/1974	8/8/2013	61.39	Monthly		
123796	MBMG MONITORING WELL WR-17A	-106.8656	45.0227	09S	40E	29	BBAC	3573.9	125ADOB	88	6/17/1977	9/23/2013	44	Monthly		X
123797	MBMG MONITORING WELL WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	3520.3	125ANCB	140	11/18/1974	8/8/2013	94.6	Monthly		
123798	MBMG MONITORING WELL WRN-11	-106.8094	45.0733	09S	40E	3	DABA	3436.8	125ADKC	50	12/5/1974	9/23/2013	23.64	Monthly		
127605	MBMG MONITORING WELL WR-54	-106.8902	45.0147	09S	39E	25	DADB	3629.9	125AND2	384	8/15/1977	9/23/2013	214.57	Monthly		
130475	MBMG MONITORING WELL WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	3552.1	125D1CB	154	10/29/1994	8/8/2013	68.08	Monthly		
130476	MBMG MONITORING WELL WR-31	-106.9863	45.0163	09S	39E	29	CBAA	3895.2	125ANCB	316	6/2/1977	9/23/2013	181.37	Monthly		
132716	MBMG MONITORING WELL WR-48	-106.9660	44.9939	58N	84W	23	BBCB	3693.8	125ANCB	167	6/24/1977	8/14/2013	39.93	Monthly		
132903	MBMG MONITORING WELL WR-58A	-106.9125	45.0406	09S	39E	14	DDBD	3631.35	110ALVM	24	8/24/1977	9/23/2013	13.96	Monthly		
132907	MBMG MONITORING WELL WR-53	-106.8900	45.0129	09S	39E	25	DDAA	3607.1	125AND2	384	8/11/1977	9/23/2013	192.41	Monthly		
132908	MBMG MONITORING WELL WR-30	-106.9874	45.0165	09S	39E	29	CBAB	3894.6	125D1D2	428	6/1/1977	9/23/2013	199.8	Monthly		
132909	MBMG MONITORING WELL WR-34	-106.9700	45.0027	09S	39E	33	CBBB	3772.1	125AND2	522	6/7/1977	9/23/2013	149.49	Monthly		
132910	MBMG MONITORING WELL WRE-02	-106.7758	45.0712	09S	40E	1	DBCC	3456.8	110ALVM	79		8/8/2013	38.86	Monthly		
132958	MBMG MONITORING WELL WRE-21	-106.7726	45.0376	09S	40E	24	ABAB	3529.4	125ANCB	130	12/1/1974	8/8/2013	84.44	Monthly		
132959	MBMG MONITORING WELL WRE-17	-106.7683	45.0341	09S	40E	24	AACD	3561.9	125SMCB	250	11/18/1974	8/8/2013	64.92	Monthly		
132960	MBMG MONITORING WELL WR-52C	-106.8625	45.0157	09S	40E	29	CABC	3530	110ALVM	62	7/14/1977	9/23/2013	18.58	Monthly		
132961	MBMG MONITORING WELL WR-52D	-106.8612	45.0157	09S	40E	29	CABD	3529.3	110ALVM	40	7/15/1977	9/23/2013	22.53	Monthly		
132973	MBMG MONITORING WELL PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	3458	125D2CB	282	6/3/1992	9/23/2013	150.23	Monthly		
144969	LOHOF PIPELINE WELL 7(PL-1W)	-106.3074	45.2354	07S	44E	14	ABD	3850	125TGRV	225	5/25/1992	8/1/2013	140.09	Quarterly		
157879	MBMG MONITORING WELL 5072B * 5072B	-106.4910	45.7393	01S	42E	24	ACBB	3160	125RBCB	86	9/12/1996	8/7/2013	33.35	Quarterly		
157882	MBMG MONITORING WELL 5072C * 5072C	-106.4911	45.7394	01S	42E	24	ACBB	3160	125RBOB	68	9/12/1996	8/7/2013	27.24	Quarterly		
157883	MBMG MONITORING WELL 5080B * 5080B	-106.5132	45.7199	01S	42E	26	DCBA	3260	125KNCB	88.5	9/11/1996	8/7/2013	41.21	Quarterly		
157884	MBMG MONITORING WELL 5080C * 5080C	-106.5132	45.7200	01S	42E	26	DCBA	3260	125KNOB	46	9/11/1996	8/7/2013	35.05	Quarterly		
161749	MBMG MONITORING WELL BF-01	-106.9667	44.9897	58N	84W	22	ACCC	3680	111SPBK	125	4/30/1996	1/31/2013	29.65	Monthly		
166351	MBMG MONITORING WELL PKS-3204-79	-106.8299	45.1067	08S	40E	28	ADA	3500	125ADKB	82	4/4/1997	9/23/2013	73.18	Monthly		
166358	MBMB MONITORING WELL PKS-3203-79	-106.8302	45.1068	08S	40E	28	ADA	3500	125CNCB	201	4/3/1997	9/23/2013	118.17	Monthly		
166359	MBMG MONITORING WELL PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	3438	110ALVM	60	3/5/1997	8/8/2013	38.72	Monthly		
166362	MBMG MONITORING WELL PKS-3201	-106.7971	45.0437	09S	40E	14	CAA	3438	125CNCB	390	3/5/1997	8/8/2013	106.94	Monthly		
166370	MBMG MONITORING WELL PKS-3200	-106.7969	45.0440	09S	40E	14	CAA	3438	125D2CB	242	2/28/1997	8/8/2013	172.37	Monthly		
166388	MBMG MONITORING WELL PKS-3199	-106.7966	45.0443	09S	40E	14	CAA	3439	125D1CB	165	2/27/1997	8/8/2013	114.25	Monthly		
166389	MBMG MONITORING WELL PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	3440	125ANCB	112	2/25/1997	8/8/2013	85.65	Monthly		
166761	MBMG MONITORING WELL WR-29R	-106.8151	45.0456	09S	40E	15	ACCD	3461	125ADKC	72	10/23/1997	9/23/2013	44.63	Monthly		
183559	NANCE CATTLE CO * BRIDGE ARTESIAN IP-1	-106.4555	45.4114	05S	43E	8	CDCB	3085	125FGUB	540	1/1/1947	10/8/2013	-15.5	Quarterly		

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GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	Land altitude (feet)	Aquifer	Well total depth (feet)	Date Completed	Most recent SWL date	Average SWL (feet)	2014 SWL monitoring plan	2014 QW sample collection	2014 Possible QW samples
183560	NANCE CATTLE CO * ALLUVIAL-CORRAL	-106.4211	45.4387	05S	43E	4	AAAB	3035	111ALVM	20		10/8/2013	9.87	Quarterly		
183563	FULTON RANCH -RIVER * RIVER	-105.8715	45.0637	09S	48E	8	CABC	3360	111ALVM	30		10/9/2013	15.79	Quarterly		
183564	WHITETAIL RANGER STATION	-105.9764	45.6404	02S	47E	19	CDCA	4045	125TGRV	60		10/8/2013	40.24	Quarterly		
183565	SKINNER GULCH PIPELINE WELL * SKINNER	-105.9177	45.4275	05S	47E	3	BCCD	3730	125PWUB	167		10/8/2013	46.75	Quarterly		
184222	MBMG WELL SH-624	-107.0917	45.0725	09S	38E	7	DADB	4644.7	125ADCB	435.1		8/14/2013	348.03	Quarterly		
184223	MBMG WELL SH-625	-107.0522	45.1133	08S	38E	28	DADB	4186.6	125DICB	187	6/24/1976	9/23/2013	46.17	Quarterly		
184224	MBMG WELL SH-625A	-107.0522	45.1133	08S	38E	28	DADB	4186.7	125ANCB	91	6/24/1976	9/23/2013	51.49	Quarterly		
184225	MBMG WELL SH-634	-107.0728	45.1422	08S	38E	17	DADD	4480.5	125DICB	348	8/9/1976	8/14/2013	151.29	Semi-Annual		
184226	MBMGWELL SH-634A	-107.0730	45.1425	08S	38E	17	DADD	4481.2	125ANCB	159	8/9/1976	8/14/2013	114.79	Semi-Annual		
186195	MBMG WELL WR-41	-106.9498	44.9962	09S	39E	34	CCCC	3642.67	110ALVM	40	6/20/1977	9/23/2013	17.36	Monthly		
189743	MBMG WELL HWC-29A	-106.3974	45.0697	09S	44E	7	BBCC	3619		98	5/13/1977	9/24/2013	43.64	Monthly		
189802	MBMG WELL HWC-37	-106.4028	45.0719	09S	43E	12	ADBB	3578		32	6/14/1977	9/24/2013	9.37	Monthly		
189838	MBMG WELL HWC-39 AL-46	-106.4015	45.0710	09S	43E	12	ADBD	3591		39	6/16/1977	9/24/2013	25.34	Monthly		
190902	MBMG WELL HWC-10	-106.4695	45.0444	09S	43E	21	BADA	3615		229	7/22/1975	9/24/2013	98.57	Monthly		
190904	MBMG WELL HWC-11	-106.4696	45.0444	09S	43E	21	BADA	3610		135	7/28/1975	9/24/2013	52.55	Monthly		
191139	MBMG WELL 20-LW	-106.7801	45.3391	06S	40E	1	CDDC	3940		253		4/25/2013	49.58	Quarterly		
191155	MBMG 22-BA	-106.6954	45.3484	06S	41E	3	BADD	3530		262		4/24/2012	105.19	Quarterly		
191163	MBMG 28-W	-106.7256	45.3197	06S	41E	16	BBCC	3715		144		9/25/2013	107.09	Quarterly		
191169	MBMG 32-LW	-106.7076	45.2943	06S	41E	21	DDDC	3530		51		9/25/2013	36.22	Quarterly		
191634	MBMG WELL M75-23	-106.2011	45.0966	08S	45E	34	BDBC	3780		247		9/26/2013	132.64	Monthly		
192874	MBMG WELL YA-109	-107.0530	45.0465	09S	38E	22	DADC	3830		43.8		9/23/2013	32.58	Monthly		
198465	MBMG WELL HWC-06	-106.4092	45.0536	09S	43E	13	CAAA	3595		184	7/15/1975	9/24/2013	68.82	Monthly		
198489	MBMG WELL HWC-86-15	-106.4235	45.0025	10S	43E	2	AABC	3630		62.52	10/8/1986	10/16/2013	12.98	Monthly	Semi-Annual	
203646	MBMG WELL CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	3980.3		417	10/4/2002	10/15/2013	171.91	Monthly		
203655	MBMG MONITORING WELL CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	3983.86		255.5	10/8/2002	10/15/2013	100.51	Monthly		
203658	MBMG MONITORING WELL CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	3981.76		366	10/8/2002	10/15/2013	143.06	Monthly		
203669	MBMG MONITORING WELL CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	3792		290	9/11/2002	9/23/2013	76.25	Monthly		
203670	MBMG MONITORING WELL CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	3890		159	9/14/2002	9/23/2013	131.09	Monthly		
203676	MBMG MONITORING WELL CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	3920		376.4	10/24/2002	8/14/2013	301.77	Monthly		
203678	MBMG MONITORING WELL CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	3920		235	10/24/2002	8/14/2013	186.17	Monthly		
203680	MBMG MONITORING WELL CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	3500		291	10/18/2002	9/25/2013	181.6	Monthly		
203681	MBMG MONITORING WELL CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	3500		221	10/19/2002	9/25/2013	76.6	Monthly		
203690	MBMG MONITORING WELL CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	3500		96.6	10/20/2002	9/25/2013	32.51	Monthly		
203693	MBMG MONITORING WELL CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	3900		263.4	9/27/2002	9/23/2013	164.11	Monthly		
203695	MBMG MONITORING WELL CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	3900		190.3	9/28/2002	9/23/2013	89.74	Monthly		
203697	MBMG MONITORING WELL CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	3262.3		208	11/8/2002	9/25/2013	157.98	Quarterly		
203699	MBMG MONITORING WELL CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	3262.19		224	11/11/2002	9/25/2013	160.36	Quarterly		
203700	MBMG MONITORING WELL CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	3260.5		446	11/13/2002	9/25/2013	102.53	Quarterly		
203701	MBMG MONITORING WELL CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	3260.63		480.4	11/11/2002	9/25/2013	102.14	Quarterly		

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203703	MBMG MONITORING WELL CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	4130		560	4/21/2003	9/24/2013	531.32	Monthly		X
203704	MBMG MONITORING WELL CBM03-10SS	-106.6045	45.1141	08S	42E	29	ADAD	4130		462	4/23/2003	9/24/2013	372.51	Monthly		X
203705	MBMG MONITORING WELL CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	3950		211	4/28/2003	9/24/2013	154.79	Monthly		
203707	MBMG MONITORING WELL CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	3950		271	5/7/2003	9/24/2013	227.87	Monthly		
203708	MBMG MONITORING WELL CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	3950		438	5/7/2003	9/24/2013	382.36	Monthly		
203709	MBMG MONITORING WELL CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	3715		351	5/16/2003	9/26/2013	166.24	Monthly		
203710	MBMG MONITORING WELL CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	3931		500	5/22/2003	9/26/2013	333	Monthly		
205082	USFS- SPRING CREEK	-105.9538	45.3883	05S	47E	20	ACAC	3630		50		8/13/2013	15.64	Quarterly		
207064	MBMG MONITORING WELL RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	3854.69		26.77	7/9/2003	9/23/2013	11.34	Monthly		
207066	MBMG MONITORING WELL RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	3849.42		16.9	7/9/2003	10/15/2013	7.94	Monthly	Fall only	
207068	MBMG MONITORING WELL RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	3859.85		24.55		9/23/2013	9.97	Monthly		
207075	MBMG MONITORING WELL YA-114	-107.0543	45.0463	09S	38E	21	ADBD	4000				8/14/2013	11.95	Quarterly		
207076	MBMG MONITORING WELL YA-105	-107.0527	45.0465	09S	38E	21	ACAC	4015				8/14/2013	10.6	Quarterly		
207080	MBMG MONITORING WELL TA-100	-107.0090	45.0478	09S	38E	23	BBCC	3900				9/23/2013	13.26	Quarterly		
207081	MBMG MONITORING WELL TA-101	-107.0090	45.0481	09S	38E	24	BBCC	3910				9/23/2013	15.03	Quarterly		
207083	MBMG MONITORING WELL TA-102	-107.0076	45.0484	09S	38E	24	BBCB	3910				9/23/2013	20.18	Quarterly		
207096	MBMG MONITORING WELL IB-2	-106.4372	45.3930	05S	43E	21	BBDB	3191.59				9/25/2013	119.64	Quarterly		
207097	MBMG MONITORING WELL MK-4	-106.4363	45.3919	05S	43E	21	BBDC	3195.31				9/25/2013	119.52	Quarterly		
207098	MBMG MONITORING WELL NM-4	-106.4361	45.3916	05S	43E	21	BCAB	3195.31				9/25/2013	119.91	Quarterly		
207099	MBMG MONITORING WELL WL-2	-106.4358	45.3918	05S	43E	21	BBDC	3187.6				9/25/2013	117.33	Quarterly		
207101	MBMG MONITORING WELL OC-28	-106.1928	45.4717	04S	45E	21	CCBD	3171				1/28/2013	57.02	Quarterly		
207143	MBMG MONITORING WELL HC-01 O-4	-106.4750	45.1314	08S	43E	21	BBDA	3457				1/31/2013	9.12	Semi-Annual		
210094	MBMG MONITORING WELL WO-14	-106.1849	45.5183	04S	45E	4	BDDB	3010			12/6/1979	9/26/2013	4.05	Monthly		
214096	HWCQ-2 (DIAMOND CROSS)	-106.5010	45.1913	07S	43E	32		3340			9/10/2004	12/19/2012	10.89	Monthly		
214097	HWCQ-1 (DIAMOND CROSS)	-106.5010	45.1912	07S	43E	32		3340			9/10/2004	12/19/2012	11	Monthly		
214354	MBMG MONITORING WELL WA-7	-106.4347	45.3933	05S	43E	21	BABC	3179				9/25/2013	52.67	Quarterly		
215085	MBMG MONITORING WELL WO-11	-106.1433	45.3927	05S	45E	23		3145			11/28/1979	9/26/2013	7.82	Monthly		
219125	MBMG MONITORING WELL SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	3925			5/25/2005	9/24/2013	341.96	Monthly		
219136	MBMG MONITORING WELL SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	3725			4/7/2005	9/24/2013	12.79	Monthly	Fall only	
219138	MBMG MONITORING WELL SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	3805			4/29/2005	9/24/2013	165.1	Monthly		
219139	MBMG MONITORING WELL SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	3805			4/12/2005	9/24/2013	220.9	Monthly		
219140	MBMG MONITORING WELL SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	3805			4/18/2005	9/24/2013	399.61	Monthly		
219141	MBMG MONITORING WELL SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	3640			4/7/2005	9/24/2013	30.36	Monthly		
219169	MBMG MONITORING WELL SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	3640			4/1/2005	9/24/2013	69.42	Monthly		
219617	MBMG MONITORING WELL SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	3805			4/26/2005	9/24/2013	145.41	Monthly		
219927	MBMG MONITORING WELL SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	3810			6/6/2005	9/24/2013	133.61	Monthly		
219929	MBMG MONITORING WELL SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	3810			6/3/2005	9/24/2013	167.68	Monthly		
220062	MBMG MONITORING WELL SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	4220			6/23/2005	8/15/2013	377.88	Monthly		
220064	MBMG MONITORING WELL SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	4220			6/17/2005	6/23/2011	521.62	Monthly		
220069	MBMG MONITORING WELL SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	4173			7/8/2005	4/20/2010	456.32	Monthly		
220076	MBMG MONITORING WELL SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	3810			6/10/2005	9/24/2013	173.74	Monthly		

Appendix A. Site details, water-level data, and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Town-ship	Range	Sect	Tract	Land altitude (feet)	Aquifer	Well total depth (feet)	Date Completed	Most recent SWL date	Average SWL (feet)	2014 SWL monitoring plan	2014 QW sample collection	2014 Possible QW samples
220385	MBMG MONITORING WELL SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	3920			8/22/1999	9/24/2013	451.72	Monthly		
220851	MBMG MONITORING WELL SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	3396.7			8/26/2005	9/26/2013	11.29	Monthly		
220857	MBMG MONITORING WELL * SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	3394.12			8/26/2005	10/22/2013	10	Monthly	Semi-Annual	
220859	MBMG MONITORING WELL SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	3398.46			8/26/2005	9/26/2013	13.81	Monthly		
221592	IP-22 MONTANA STATE LAND FLOWING WE	-105.9003	45.0177	09S	47E	25	DDBD	3395				1/19/2011	-18.58	Monthly		
223236	NC02-5 KNOBLOCH COAL WELL	-106.5603	45.3986	05S	42E	16	CCAB	3400				10/24/2012	260.95			
223237	NC02-6 KNOBLOCH COAL WELL	-106.6397	45.4022	05S	41E	14	BDCD	3510				11/24/2012	237.15			
223238	NC02-1 WALL COAL WELL	-106.8464	45.3608	05S	40E	31	BDCC	4440				6/6/2005	617.65			
223240	NC02-2 FLOWERS-GOODALE COAL WELL	-106.5044	45.4030	05S	42E	14	ADDC	3220				5/15/2013	105.84			
223242	NC02-3 PAWNEE COAL WELL	-106.6917	45.4044	05S	41E	17	ADBD	3740				5/15/2013	180.53			
223243	NC02-4 WALL COAL WELL	-106.7311	45.4080	05S	40E	13	ADAB	3940				10/24/2012	199.97			
223687	MBMG MONITORING SITE RBC-4	-106.9863	45.3332	06S	39E	8		3840.95								
223695	MOORHEAD CAMPGROUND ARTESIAN WEL	-105.8773	45.0542	09S	48E	17	BCBB	3400				1/19/2011		Monthly		
223801	SL-5ALQ	-106.2579	45.0129	09S	45E	31	BBA	3810				9/24/2013	6.64	Monthly		
223890	USFS- TAYLOR CREEK	-105.9928	45.2213	07S	47E	21	BBCC	3910				8/13/2013	117.83	Quarterly		
223952	WA-2	-106.4566	45.4032	05S	43E	17	BCDD	3068.5			8/16/1978	9/25/2013	9.21	Monthly	Fall only	
227246	DH 76-102D	-106.1862	45.0798	09S	45E	3	ADCC	3811				9/26/2013	18.24	Monthly		
228592	MUSGRAVE BILL ALLUVIAL	-106.7319	45.1639	08S	41E	5	ACDB	3335				10/17/2013	13.2	Monthly	Semi-Annual	
251797	MBMG MONITORING WELL GC09-KC	-106.3919	45.4376	05S	43E	2	BAB					10/17/2013	95.77	Quarterly		
251798	MBMG MONITORING WELL GC09-FG	-106.3919	45.4376	05S	43E	2	BAB					9/25/2013		Quarterly		
251799	MBMG MONITORING WELL GC09-TC	-106.3919	45.4376	05S	43E	2	BAB					9/25/2013		Quarterly		
259676	MBMG * SL-9OC	-105.8175	45.0068	09S	48E	34	DAA	3640			10/23/2010	10/23/2013	180.36	Monthly		
259683	MBMG * SL-9BA	-105.8175	45.0068	09S	48E	34	DAA	3640			10/26/2010	10/23/2013	153.04	Monthly		
259684	MBMG * SL-9PC	-105.8175	45.0068	09S	48E	34	DAA	3640			10/28/2010	10/23/2013	78.19	Monthly		
132965	MBMG MONITORING WELL WRE-23	-106.7335	45.0694	09S	41E	5	DCBD	3556.7	125D2CB	240	11/4/1974	8/8/2013	124.49	Monthly		
new well	MBMG MONITORING WELL KC-10MILE	-106.0949	45.4401	04S	46E	31	DAAC	3263	125KNCB	72	9/25/2013	10/16/2013	53.67	Monthly		
new well	MBMG MONITORING WELL SL-8KC	-105.9052	45.0182	09S	47E	25	DCDB	3394.12	125KNCB	420	7/17/2013	11/6/2013	-2.11	Monthly		
new well	MBMG MONITORING WELL SL-8BA	-105.9052	45.0182	09S	47E	25	DCDB	3394.12	125BACB	115	7/15/2013	11/6/2013	35.465	Monthly		

Appendix B

Site details, discharge data for water year 2013, and
monitoring plan for springs and streams for water year 2014

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
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	2014 planned flow monitoring	2014 planned QW sample collection
197247		Anderson	Regional	3690	1.42	12/19/2012	Monthly	
197452	Coal	Otter	Local	3470	1.42	12/19/2012	Monthly	
197607	Colluvium	Cook	Local	3805	1.10	9/14/2013	Quarterly	
198766		Ferry	Local	3660	1.83	4/19/2013	Quarterly	One-time
199568	Sandstone	Cook	Local	3680	1.67	8/13/2013	Quarterly	
199572	Sandstone	Canyon	Local	3940	1.84	8/13/2013	Quarterly	
205004	Clinker	Anderson/Dietz	Local	3890	0.69	8/13/2013	Quarterly	
205010		Canyon	Local	3960	0.81	8/13/2013	Quarterly	
205011		Anderson	Local	4050	8.50	8/13/2013	Quarterly	
205041	Sandstone	Canyon	Local	3735	1.36	8/13/2013	Quarterly	One-time
205049	Sandstone	Dietz	Local	3670	1.17	9/25/2013	Monthly	
228591		Dietz	Local	3620	3.48	9/25/2013	Monthly	
228776				3920	0.49	5/15/2013	Monthly	Semi-Annual
240578		Anderson	Regional & Local	3665	0.42	5/15/2013	Monthly	Semi-Annual

Appendix C

Groundwater-quality data collected during water year 2012 and 2013

	Gwic Id	Site Name	Sampled in 2012/2013	Latitude	Longitude	Location (TRS)	County	Site Type	Aquifer	Depth (ft)
Sites currently outside areas of potential CBM influence	207066	Well RBC-2	Semi-annual	45.3327	-106.9844	06S 39E 8 CAAA	Big Horn	Well	110ALVM	16.9
	251797	Well GC09-KC	Periodic	45.437635	-106.391897	05S 43E 2 BAB	Rosebud	Well	125KNCB	
	203697	Well CBM02-8KC	Periodic	45.3689	-106.5473	05S 42E 28 DDAC	Rosebud	Well	125KNCB	208
	199568	Hedum Spring	Periodic	45.2823	-106.071	06S 46E 26 CDBA	Powder River	Spring		
	100472	East Fork Pipeline Well	10-year	45.59349964	-106.1647647	03S 45E 10 BACB	Powder River	Well	125KNUB	193
	94666	Coyote Well	10-year	45.75240144	-106.0510567	01S 46E 16 AACC	Powder River	Well	125TGRV	190
	8107	Well HWC-01	Periodic	45.12537633	-106.4826579	08S 43E 20 DDDD	Big Horn	Well	125CNCB	232
Sites within current areas of potential CBM influence	223952	WA-2	Semi-annual	45.4032	-106.4566	05S 43E 17 BCDD	Rosebud	Well	110ALVM	37.8
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S 43E 19 DDBA	Rosebud	Well	110ALVM	71
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S 43E 2 ABCA	Big Horn	Well	110ALVM	53
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S 43E 2 AABC	Big Horn	Well	110ALVM	62.52
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386	09S 42E 36 BBAD	Big Horn	Well	110ALVM	40
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09S 47E 25 DCDB	Powder River	Well	110ALVM	13.8
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S 40E 32 ACAD	Big Horn	Well	110ALVM	34
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261	08S 42E 30 ADAA	Big Horn	Spring	125TGRV	
	240578	Lower Anderson Creek Spring	Semi-annual	45.1373	-106.6913	08S 41E 15 ABBB	Big Horn	Spring		
	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319	08S 41E 5 ACDB	Big Horn	Well	111ALVM	21.5
	190904	Well HWC-11	Periodic	45.0444	-106.4696	09S 43E 21 BADA	Big Horn	Well	125ANCB	135
	8782	Well HWC-15	Periodic	45.0412	-106.4468	09S 43E 22ACCA	Big Horn	Well	125ANCB	129

Appendix C. Groundwater-quality data collected in 2012–2013

	Gwic Id	Comp Date	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)
Sites currently outside areas of potential CBM influence	207066	7/9/2003	5/30/2013	583.45	0.88	8.10	7.30	941.70	67.90	69.66	42.69	10.80	0.51
			11/8/2012	558.72	0.84	9.40	7.56	893.30	66.66	63.09	40.16	9.43	0.74
	251797		11/5/2012	3822.38	9.33	14.40	7.36	5040.00	206.20	192.05	774.70	16.50	0.387 J
	203697	11/8/2002	10/30/2012	1032.47	79.81	14.40	8.41	1508.50	1.28	0.66	446.32	2.12	0.062 J
	199568		4/19/2013	3548.57	2.40	5.40	7.36	4090.00	218.35	434.95	266.80	53.83	<0.150 U
	100472	4/1/1961	10/1/2012	1028.87	38.09	16.60	8.28	1570.80	4.57	2.05	389.85	2.02	<0.038 U
	94666	9/27/1963	10/1/2012	1341.44	27.18	13.50	7.91	1879.50	10.37	5.98	444.27	2.96	0.69
	8107	5/8/1974	10/17/2012	1510.70	65.90	14.60	8.09	2222.80	3.81	2.15	648.90	5.07	0.058 J
Sites within current areas of potential CBM influence	223952	8/16/1978	5/14/2013	2035.57	21.36	10.30	7.55	3753.30	30.49	31.33	702.55	6.82	0.159 J
			9/28/2012	1802.76	22.33		7.83	3210.00	25.25	27.10	677.68	6.60	<0.150 U
	7905		5/14/2013	3969.70	8.67	10.30	7.39	5180.00	176.30	224.40	736.45	24.07	0.631 J
			9/28/2012	4040.16	8.81		7.51	5250.00	185.75	243.78	776.25	22.28	0.430 J
	8888	10/8/1986	5/15/2013	6183.60	10.58	11.00	7.17	7210.00	359.53	299.08	1121.50	12.49	6.89
			9/27/2012	6481.94	11.16	10.40	7.10	7340.00	383.48	327.30	1230.58	12.07	6.57
	198489	10/8/1986	5/15/2013	7998.16	10.49	11.20	7.10	8860.00	487.05	441.83	1328.17	13.40	9.73
			9/27/2012	7922.51	10.74	10.80	7.06	8420.00	481.08	449.45	1362.83	13.21	8.39
	219136	4/7/2005	5/15/2013	3762.07	4.92	9.80	7.20	4560.00	325.58	239.65	479.54	6.18	2.11
			9/27/2012	3731.19	4.95	8.40	7.20	4500.00	326.03	242.93	485.16	5.87	2.14
	220857	8/26/2005	5/30/2013	2015.18	3.78	8.60	7.25	2681.30	249.27	76.16	265.84	7.45	0.051 J
			9/27/2012	2653.68	4.06	14.20	7.23	3650.00	364.83	99.13	339.23	8.46	<0.075 U
	122766	8/31/1977	5/15/2013	5784.83	6.06	8.80	7.37	6540.00	261.05	538.70	746.45	30.29	6.59
			9/28/2012	6092.02	6.12	12.30	7.31	6810.00	276.70	567.13	773.83	31.52	6.49
	228776		5/15/2103	3882.00	8.24	9.80	7.20	5050.00	158.25	250.20	714.95	10.32	0.427 J
			11/8/2012	3710.72	8.87	10.00	7.24	5020.00	144.45	224.70	731.47	10.66	1.35
	240578		5/15/2013	1508.19	3.05	12.50	7.02	2085.80	108.20	127.85	198.30	9.04	<0.038 U
			11/8/2012	1504.28	3.04	12.60	7.09	1962.60	107.85	127.98	197.22	8.90	<0.038 U
	228592		5/30/2013	778.88	1.23	10.50	7.20	1195.10	95.03	60.12	62.32	4.38	0.17
			9/28/2012	834.27	1.30	12.90	7.43	1235.00	111.35	69.10	71.20	4.68	0.23
	190904	7/28/1975	10/17/2012	1810.17	49.05	11.70	8.07	2494.20	8.90	5.30	748.00	5.59	<0.075 U
	8782	8/4/1976	10/17/2012	1371.73	49.65	11.50	7.92	1810.40	4.96	3.42	586.55	4.30	0.046 J

	Gwic Id	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)	Ag (ug/l)	Al (ug/l)
Sites currently outside areas of potential CBM influence	207066	0.22	27.98	556.24	0.00	83.70	3.80	<0.010 U	0.68	<0.020 U	<0.100 U	<0.400 U
		0.19	27.82	546.47	0.00	77.75	3.47	<0.010 U	0.60	<0.020 U	<0.100 U	0.530 J
	251797	0.061 J	11.33	795.85	0.00	2216.00	11.90	<0.050 U	0.66	<0.100 U	<1.000 U	<4.000 U
	203697	<0.005 U	7.55	1079.48	20.54	0.970 J	9.76	<0.010 U	12.36	0.090 J	<0.250 U	3.290 J
	199568	<0.020 U	18.44	776.13	0.00	2155.00	7.62	10.03	1.17	0.270 J	<1.000 U	<4.000 U
	100472	<0.005 U	7.01	781.69	0.00	226.70	8.94	<0.010 U	1.54	0.070 J	<0.250 U	2.530 J
	94666	0.034 J	6.53	499.22	0.00	619.20	4.99	0.07	0.30	<0.020 U	<0.250 U	<1.000 U
	8107	<0.005 U	8.69	1659.72	0.00	1.080 J	19.54	<0.010 U	3.71	0.12	<0.250 U	1.290 J
Sites within current areas of potential CBM influence	223952	0.017 J	10.06	1861.02	0.00	271.40	63.12	<0.050 U	2.61	0.290 J	<0.500 U	<2.000 U
		<0.020 U	10.63	1636.88	0.00	194.40	51.81	<0.050 U	2.38	<0.100 U	<1.000 U	<4.000 U
	7905	1.00	18.72	947.74	0.00	2294.00	26.55	<0.050 U	1.14	0.110 J	<1.000 U	<4.000 U
		1.09	21.97	863.80	0.00	2338.00	25.26	<0.050 U	0.99	<0.100 U	<1.000 U	<4.000 U
	8888	1.81	13.11	881.37	0.00	3923.00	11.10	<0.050 U	0.61	<0.100 U	<1.000 U	<4.000 U
		2.16	14.19	858.77	0.00	4071.00	10.06	<0.050 U	0.52	<0.100 U	<1.000 U	<4.000 U
	198489	2.08	14.41	909.94	0.00	5236.00	17.06	<0.050 U	0.56	<0.100 U	<1.000 U	<4.000 U
		1.94	14.58	815.57	0.00	5174.00	15.09	<0.050 U	0.47	<0.100 U	<1.000 U	<4.000 U
	219136	0.63	9.11	498.61	0.00	2443.00	10.17	<0.050 U	0.44	<0.100 U	<1.000 U	23.65
		0.62	10.42	443.33	0.00	2431.00	9.49	<0.050 U	0.35	<0.100 U	<1.000 U	<4.000 U
	220857	1.16	17.09	440.39	0.00	1033.00	148.60	<0.010 U	0.34	<0.020 U	<0.250 U	<1.000 U
		1.39	21.27	443.82	0.00	1446.00	155.70	0.05	0.32	<0.020 U	<0.500 U	<2.000 U
	122766	0.89	20.77	733.16	0.00	3796.00	22.38	<0.050 U	0.68	<0.100 U	<1.000 U	<4.000 U
		0.93	23.42	651.94	0.00	4068.00	21.56	<0.050 U	0.61	<0.100 U	<1.000 U	<4.000 U
	228776	0.115 J	9.10	941.06	0.00	2254.00	20.58	<0.050 U	0.54	<0.100 U	<1.000 U	<4.000 U
		0.101 J	9.31	869.67	0.00	2143.00	17.60	<0.050 U	0.48	<0.100 U	<1.000 U	<4.000 U
	240578	<0.005 U	16.97	658.34	0.00	711.50	11.15	<0.010 U	0.77	<0.020 U	<0.250 U	<1.000 U
		<0.005 U	16.75	616.18	0.00	730.50	10.31	<0.010 U	0.69	<0.020 U	<0.250 U	<1.000 U
	228592	0.10	19.28	445.68	0.00	299.80	18.84	<0.010 U	0.30	<0.020 U	<0.100 U	<0.400 U
		0.087 J	20.85	431.90	0.00	316.50	26.51	0.15	0.27	<0.020 U	<0.250 U	<1.000 U
	190904	<0.010 U	9.27	1764.20	0.00	144.00	18.46	<0.010 U	1.82	0.12	<0.500 U	3.040 J
	8782	<0.005 U	8.52	1510.69	0.00	0.850 J	17.13	<0.010 U	1.76	0.12	<0.250 U	<1.000 U

	Gwic Id	As (ug/l)	As(III) (ug/l)	As(V) (ug/l)	As(other) (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)
Sites currently outside areas of potential CBM influence	207066	1.77				95.46	79.29	<0.100 U	<10.000 U	<0.100 U	0.200 J	0.270 J	<0.040 U
		2.03				113.02	83.92	<0.100 U	<10.000 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U
	251797	<1.000 U				346.73	13.05	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	203697	<0.250 U				353.56	128.59	<0.250 U	89.00	<0.250 U	<0.250 U	<0.250 U	<0.250 U
	199568	13.44				663.95	21.15	<1.000 U	<50.000 U	<1.000 U	<1.000 U	8.64	<0.400 U
	100472	2.41				164.61	21.06	<0.250 U	99.00	<0.250 U	<0.250 U	<0.250 U	5.23
	94666	<0.250 U				147.33	8.74	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	6.65
	8107	<0.250 U				86.22	397.19	<0.250 U	174.00	<0.250 U	<0.250 U	0.760 J	6.74
Sites within current areas of potential CBM influence	223952	<0.500 U				304.68	29.94	<0.500 U	397.00	<0.500 U	<0.500 U	1.090 J	4.530 J
		<1.000 U				247.94	25.33	<1.000 U	386.00	<1.000 U	<1.000 U	<1.000 U	7.66
	7905	<1.000 U				354.41	22.56	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	6.180 J
		1.130 J				352.26	27.20	<1.000 U	<50.000 U	<1.000 U	1.250 J	<1.000 U	9.64
	8888	2.570 J				194.57	3.490 J	<1.000 U	<50.000 U	<1.000 U	2.280 J	<1.000 U	10.810 J
		2.240 J				187.71	7.47	<1.000 U	<50.000 U	<1.000 U	2.680 J	<1.000 U	9.43
	198489	2.680 J				213.05	5.30	<1.000 U	<50.000 U	<1.000 U	2.560 J	<1.000 U	12.790 J
		2.710 J				202.45	6.27	<1.000 U	<50.000 U	<1.000 U	2.360 J	<1.000 U	13.50
	219136	<1.000 U				92.46	7.02	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	4.490 J
		<1.000 U				96.29	7.03	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	3.990 J
	220857	1.26				77.94	14.50	<0.250 U	167.00	<0.250 U	0.870 J	0.250 J	1.360 J
		2.460 J				134.39	23.32	<0.500 U	164.00	<0.500 U	0.920 J	<0.500 U	1.760 J
	122766	2.680 J				227.46	12.95	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	8.530 J
		2.760 J				247.94	14.35	<1.000 U	<50.000 U	<1.000 U	1.070 J	<1.000 U	7.62
	228776	<1.000 U				105.21	5.52	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	6.510 J
		<1.000 U				112.19	9.09	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	4.280 J
	240578	<0.250 U				239.71	16.64	<0.250 U	86.00	<0.250 U	<0.250 U	<0.250 U	2.630 J
		<0.250 U				225.97	17.52	<0.250 U	86.00	<0.250 U	<0.250 U	<0.250 U	1.49
	228592	0.350 J				62.51	36.75	<0.100 U	<10.000 U	<0.100 U	<0.100 U	0.220 J	9.40
		0.370 J				84.50	42.24	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	5.84
	190904	<0.500 U				79.97	525.44	<0.500 U	161.00	<0.500 U	<0.500 U	<0.500 U	8.87
	8782	<0.250 U				77.13	326.83	<0.250 U	169.00	<0.250 U	<0.250 U	<0.250 U	8.01

	Gwic Id	Hg (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)	U (ug/l)	V (ug/l)
Sites currently outside areas of potential CBM influence	207066		38.34	2.19	1.08	<0.060 U	<0.100 U	<0.100 U	<0.100 U	1068.26	0.69	<0.100 U	0.77	0.61
			42.67	2.57	1.23	<0.040 U	<0.100 U	<0.100 U	<0.100 U	1061.99	1.06	<0.100 U	0.75	0.64
	251797		181.07	<1.000 U	4.330 J	<0.400 U	<1.000 U	<1.000 U	<1.000 U	8237.60	28.79	<1.000 U	<1.000 U	<1.000 U
	203697		36.94	0.560 J	0.530 J	<0.100 U	<0.250 U	<0.250 U	<0.250 U	157.11	<0.250 U	<0.250 U	<0.250 U	<0.250 U
	199568		377.00	19.28	1.850 J	<0.600 U	<1.000 U	30.68	<1.000 U	3706.42	29.61	<1.000 U	30.49	108.65
	100472		28.13	0.660 J	<0.250 U	<0.100 U	<0.250 U	<0.250 U	0.410 J	214.55	2.39	<0.250 U	<0.250 U	<0.250 U
	94666		29.54	0.810 J	1.020 J	<0.100 U	<0.250 U	<0.250 U	<0.250 U	489.57	6.04	<0.250 U	<0.250 U	<0.250 U
	8107		128.65	<0.250 U	1.120 J	<0.100 U	<0.250 U	0.660 J	<0.250 U	301.36	<0.250 U	<0.250 U	<0.250 U	<0.250 U
Sites within current areas of potential CBM influence	223952		110.53	<0.500 U	<0.500 U	<0.300 U	<0.500 U	0.700 J	<0.500 U	1888.00	3.29	<0.500 U	<0.500 U	<0.500 U
			90.25	<1.000 U	<1.000 U	<0.400 U	<1.000 U	<1.000 U	<1.000 U	1544.26	2.290 J	<1.000 U	<1.000 U	<1.000 U
	7905		116.51	5.94	3.810 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	2684.69	30.80	<1.000 U	12.27	<1.000 U
			155.02	6.35	5.96	<0.400 U	<1.000 U	<1.000 U	<1.000 U	2894.72	25.24	<1.000 U	11.86	<1.000 U
	8888		142.34	<1.000 U	29.95	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5325.01	46.00	<1.000 U	17.31	<1.000 U
			243.92	1.190 J	8.89	<0.400 U	<1.000 U	<1.000 U	<1.000 U	5367.23	42.49	<1.000 U	18.93	<1.000 U
	198489		200.20	<1.000 U	36.33	<0.600 U	<1.000 U	<1.000 U	<1.000 U	6901.50	61.50	<1.000 U	34.47	<1.000 U
			297.38	1.190 J	11.00	0.660 J	<1.000 U	<1.000 U	<1.000 U	6823.67	54.91	<1.000 U	32.38	<1.000 U
	219136		57.130 J	<1.000 U	5.28	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5316.66	29.78	<1.000 U	3.710 J	<1.000 U
			163.24	<1.000 U	5.96	<0.400 U	<1.000 U	<1.000 U	<1.000 U	5243.79	25.97	<1.000 U	3.150 J	<1.000 U
	220857		29.22	2.38	4.69	<0.150 U	<0.250 U	0.840 J	<0.250 U	1813.59	10.40	<0.250 U	16.59	0.750 J
			61.03	4.17	6.06	<0.200 U	<0.500 U	<0.500 U	<0.500 U	2432.50	14.08	<0.500 U	21.79	1.630 J
	122766		228.92	3.390 J	18.46	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5041.58	47.42	<1.000 U	27.84	<1.000 U
			292.33	3.660 J	7.38	<0.400 U	<1.000 U	<1.000 U	<1.000 U	5431.36	43.41	<1.000 U	23.78	<1.000 U
	228776		273.78	<1.000 U	3.170 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	4810.78	28.41	<1.000 U	<1.000 U	<1.000 U
			287.59	<1.000 U	2.840 J	<0.400 U	<1.000 U	<1.000 U	<1.000 U	4636.02	28.12	<1.000 U	<1.000 U	<1.000 U
	240578		167.59	<0.250 U	0.980 J	<0.150 U	<0.250 U	<0.250 U	<0.250 U	2609.55	8.42	<0.250 U	<0.250 U	0.990 J
			174.68	<0.250 U	2.28	<0.100 U	<0.250 U	<0.250 U	<0.250 U	2657.20	9.23	<0.250 U	<0.250 U	1.050 J
	228592		16.89	0.80	2.03	<0.060 U	<0.100 U	0.330 J	<0.100 U	530.09	2.88	<0.100 U	6.84	0.260 J
			23.45	0.820 J	2.53	0.130 J	<0.250 U	<0.250 U	<0.250 U	580.38	3.41	<0.250 U	6.10	0.330 J
	190904		123.40	<0.500 U	<0.500 U	<0.200 U	<0.500 U	<0.500 U	<0.500 U	440.30	1.490 J	<0.500 U	<0.500 U	<0.500 U
	8782		81.96	<0.250 U	<0.250 U	<0.100 U	<0.250 U	0.610 J	<0.250 U	267.51	<0.250 U	<0.250 U	<0.250 U	<0.250 U

	Gwic Id	Zn (ug/l)	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	207066	0.420 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.71	<0.100 U	13.32	<0.100 U
		1.190 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.480 J	<0.100 U	14.24	<0.100 U
	251797	14.69	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	4.030 J	<1.000 U	15.58	<1.000 U
	203697	1.770 J	<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	2.17	<0.250 U
	199568	<0.500 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	42.88	<1.000 U
	100472	23.80	<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	2.94	<0.250 U
	94666	275.40	<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	2.83	<0.250 U
	8107	<0.500 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	4.82	<0.250 U
Sites within current areas of potential CBM influence	223952	<0.250 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	1.080 J	<0.500 U	3.92	<0.500 U
		<2.000 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	6.82	<1.000 U
	7905	<0.500 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	14.29	<1.000 U
		4.840 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	1.580 J	<1.000 U	14.34	<1.000 U
	8888	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.990 J	<1.000 U	6.44	<1.000 U
		3.750 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.720 J	<1.000 U	5.54	<1.000 U
	198489	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	1.840 J	<1.000 U	5.60	<1.000 U
		8.460 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	3.520 J	<1.000 U	5.04	<1.000 U
	219136	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.720 J	<1.000 U	2.780 J	<1.000 U
		<2.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.930 J	<1.000 U	2.630 J	<1.000 U
	220857	2.410 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	1.110 J	<0.250 U	2.17	<0.250 U
		3.650 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	1.280 J	<0.500 U	3.31	<0.500 U
	122766	11.770 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.720 J	<1.000 U	28.05	<1.000 U
		5.190 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	3.110 J	<1.000 U	31.49	<1.000 U
	228776	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.670 J	<1.000 U	8.51	<1.000 U
		<4.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.100 J	<1.000 U	9.26	<1.000 U
	240578	2.150 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	1.36	<0.250 U	6.76	<0.250 U
		1.940 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	1.220 J	<0.250 U	6.61	<0.250 U
	228592	15.59	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.340 J	<0.100 U	5.52	<0.100 U
		7.23	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	0.310 J	<0.250 U	5.86	<0.250 U
	190904	<1.000 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	<0.500 U	4.59	<0.500 U
	8782	8.73	<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	3.62	<0.250 U

	Gwic Id	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Kjeldahl-N (mg/l)	Total N as N (mg/l)	NH4 (mg/l)	OH (mg/l)	SO3 (mg/l)	Acidity to 4.5
Sites currently outside areas of potential CBM influence	207066	<0.100 U	<0.010 U	3.31		3.97		0.00		
		<0.100 U	<0.010 U	<0.200 U		<1.000 U		0.00		
	251797	<1.000 U	<0.050 U	<0.200 U		3.49		0.00		
	203697	<0.250 U	<0.010 U	<0.200 U		1.34		0.00		
	199568	<1.000 U	<0.050 U	9.30		9.67		0.00		
	100472	<0.250 U	<0.010 U	<0.200 U		1.47		0.00		
	94666	<0.250 U	<0.010 U	<0.200 U		1.34		0.00		
	8107	<0.250 U	<0.010 U	<0.200 U		2.67		0.00		
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.050 U	3.33		5.98		0.00		
		<1.000 U	<0.050 U	0.97		3.54		0.00		
	7905	<1.000 U	<0.050 U	3.22		3.81		0.00		
		<1.000 U	<0.050 U	<0.200 U		1.48		0.00		
	8888	<1.000 U	<0.050 U	3.38		6.01		0.00		
		<1.000 U	<0.050 U	<0.200 U		2.69		0.00		
	198489	<1.000 U	<0.050 U	2.82		4.71		0.00		
		<1.000 U	<0.050 U	<0.200 U		2.56		0.00		
	219136	<1.000 U	<0.050 U	3.30		4.69		0.00		
		<1.000 U	<0.050 U	0.71		2.60		0.00		
	220857	<0.250 U	<0.010 U	<0.200 U		10.40		0.00		
		<0.500 U	<0.010 U	<0.200 U		<1.000 U		0.00		
	122766	<1.000 U	<0.050 U	3.63		4.51		0.00		
		<1.000 U	<0.050 U	<0.200 U		1.06		0.00		
	228776	<1.000 U	<0.050 U	3.66		9.68		0.00		
		<1.000 U	<0.050 U	<0.200 U		5.64		0.00		
	240578	<0.250 U	<0.010 U	0.52		<1.000 U		0.00		
		<0.250 U	<0.010 U	<0.200 U		<1.000 U		0.00		
	228592	<0.100 U	<0.010 U	1.85		6.09		0.00		
		<0.250 U	<0.010 U	<0.200 U		<1.000 U		0.00		
	190904	<0.500 U	<0.010 U	0.27		4.15		0.00		
	8782	<0.250 U	<0.010 U	0.27		1.76		0.00		

	Gwic Id	Acidity to 8.3	Dissolved Organic Carbon (mg/l)	Dissolved Inorganic Carbon (mg/l)	Total Organic Carbon (mg/l)	Sum Dissolved Constituents (mg/l)	Hardness (mg/l)	Alkalinity	Procedure
Sites currently outside areas of potential CBM influence	207066					865.56	456.27	456.02	DISSOLVED
						835.75	426.13	447.81	DISSOLVED
	251797			82.30		4226.27	1305.36	652.86	DISSOLVED
	203697			80.60		1579.94	5.91	919.99	DISSOLVED
	199568					3942.30	2335.47	636.45	DISSOLVED
	100472					1425.65	19.85	641.37	DISSOLVED
	94666					1594.63	50.51	409.27	DISSOLVED
	8107			352.00		2352.97	18.36	1361.48	DISSOLVED
Sites within current areas of potential CBM influence	223952					2979.82	205.09	1526.34	DISSOLVED
						2633.36	174.59	1342.62	DISSOLVED
	7905					4450.70	1363.85	777.52	DISSOLVED
						4478.54	1467.22	708.63	DISSOLVED
	8888					6630.61	2128.76	722.57	DISSOLVED
						6917.79	2304.72	704.53	DISSOLVED
	198489					8459.88	3034.74	746.36	DISSOLVED
						8336.54	3051.19	669.26	DISSOLVED
	219136					4015.25	1799.37	409.27	DISSOLVED
						3955.96	1814.00	363.34	DISSOLVED
	220857					2238.43	935.90	360.88	DISSOLVED
						2878.96	1319.00	364.16	DISSOLVED
	122766					6156.75	2869.13	601.19	DISSOLVED
						6422.84	3025.23	534.75	DISSOLVED
	228776					4359.45	1424.97	771.78	DISSOLVED
						4152.15	1285.56	713.55	DISSOLVED
	240578					1842.05	796.41	539.67	DISSOLVED
						1816.83	796.07	505.23	DISSOLVED
	228592					1005.18	484.74	365.80	DISSOLVED
						1053.46	562.46	354.31	DISSOLVED
	190904			374.00		2705.21	44.04	1446.78	DISSOLVED
	8782			319.00		2138.40	26.46	1239.28	DISSOLVED

Appendix D

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

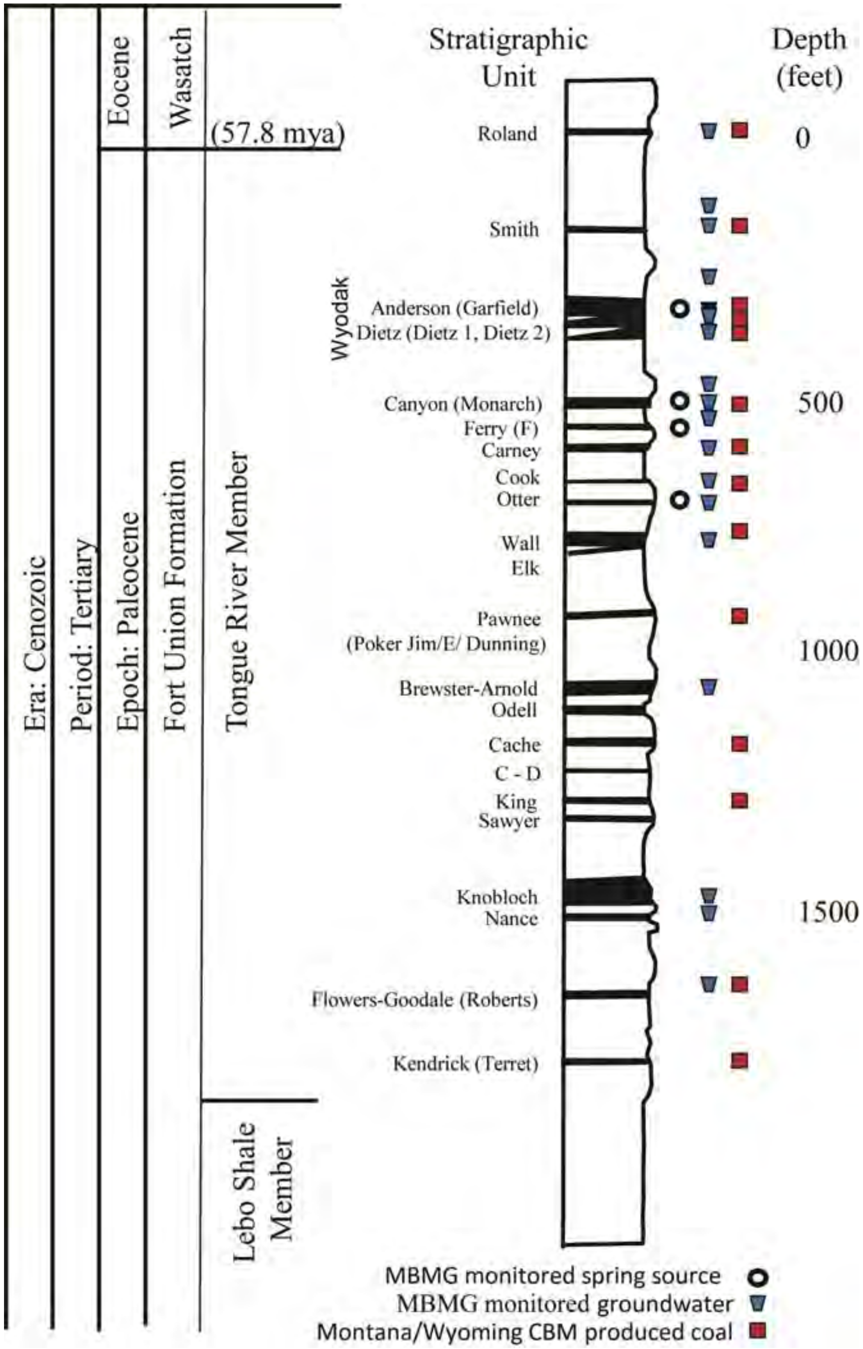
Geology and Hydrogeology of the Tongue River Member of the Fort Union Formation

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); however, there has been production from the Flowers-Goodale coal in MT.

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).

Table D-1

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

MBMG this report and B-91	USGS C-113, I-1128, I-1959-A	Decker Coal Mine Permits	Spring Creek Coal Mine Permits	Fidelity Exploration & Production Company	Pinnacle Gas Resources
Roland	Roland		Roland	Roland	
Smith	Smith		Smith	Smith	Smith
Anderson	Anderson / D1	D1 Upper		D1	Anderson
Dietz 1	D2 Upper	D1 Lower	Anderson-Dietz	D2	D2
Dietz 2	D2 Lower / D3	D2		D3	D3
Canyon	Monarch / Canyon	Canyon / D3	Canyon	Monarch	Canyon
Carney	Carney	D4	D4	Carney	Cook
Cook	Cook				
Wall	Wall	D6	D6	Wall	Wall
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

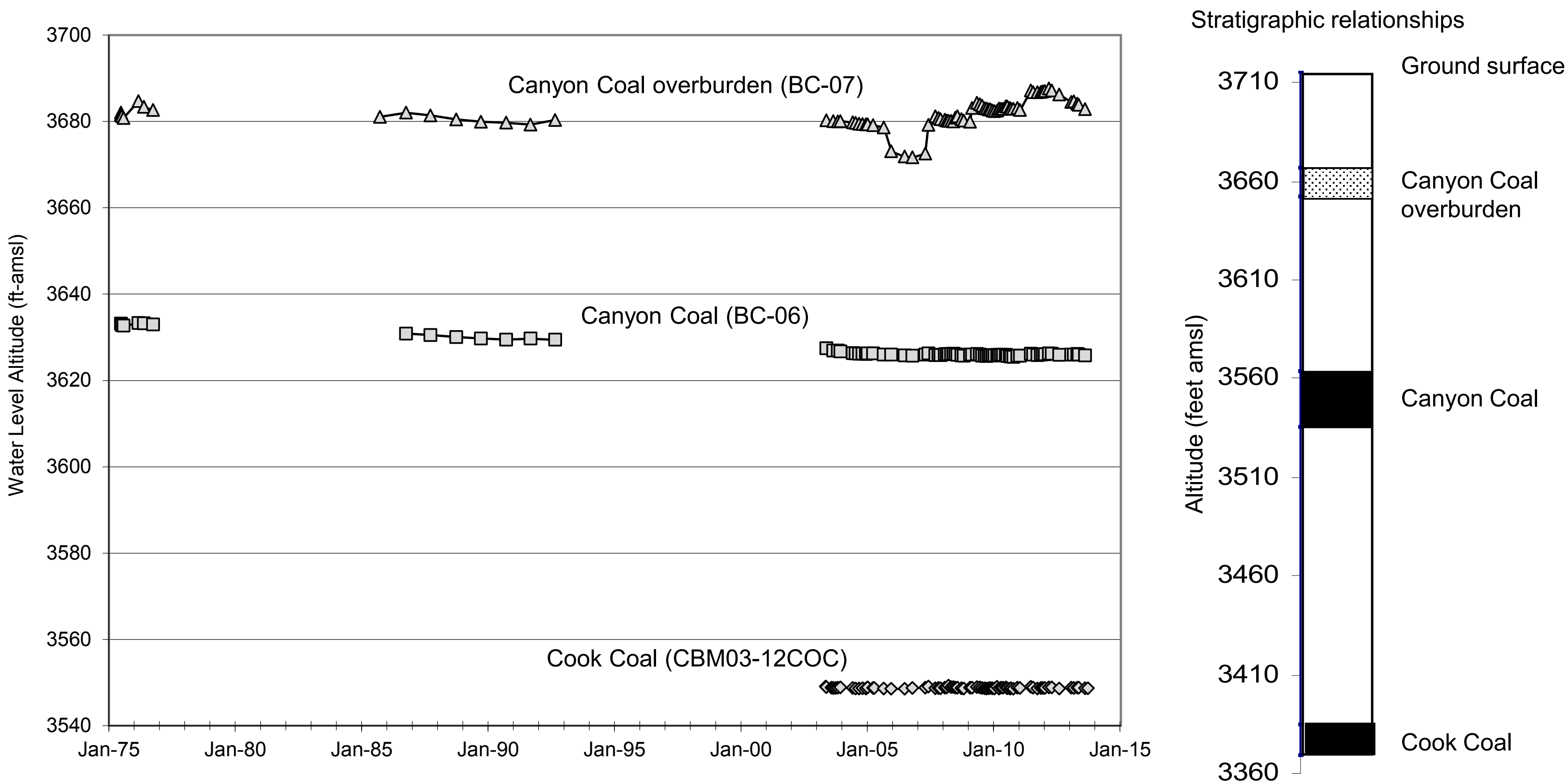


Figure E-1. Monitoring site CBM03-12 has been measured since 1974. There is a downward gradient at this site. The long-term decrease in water levels in the overburden sandstone (BC-07) and Canyon coal (BC-06), began long before the introduction of CBM and likely relate to long-term precipitation patterns (Figure 2). The 10 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.

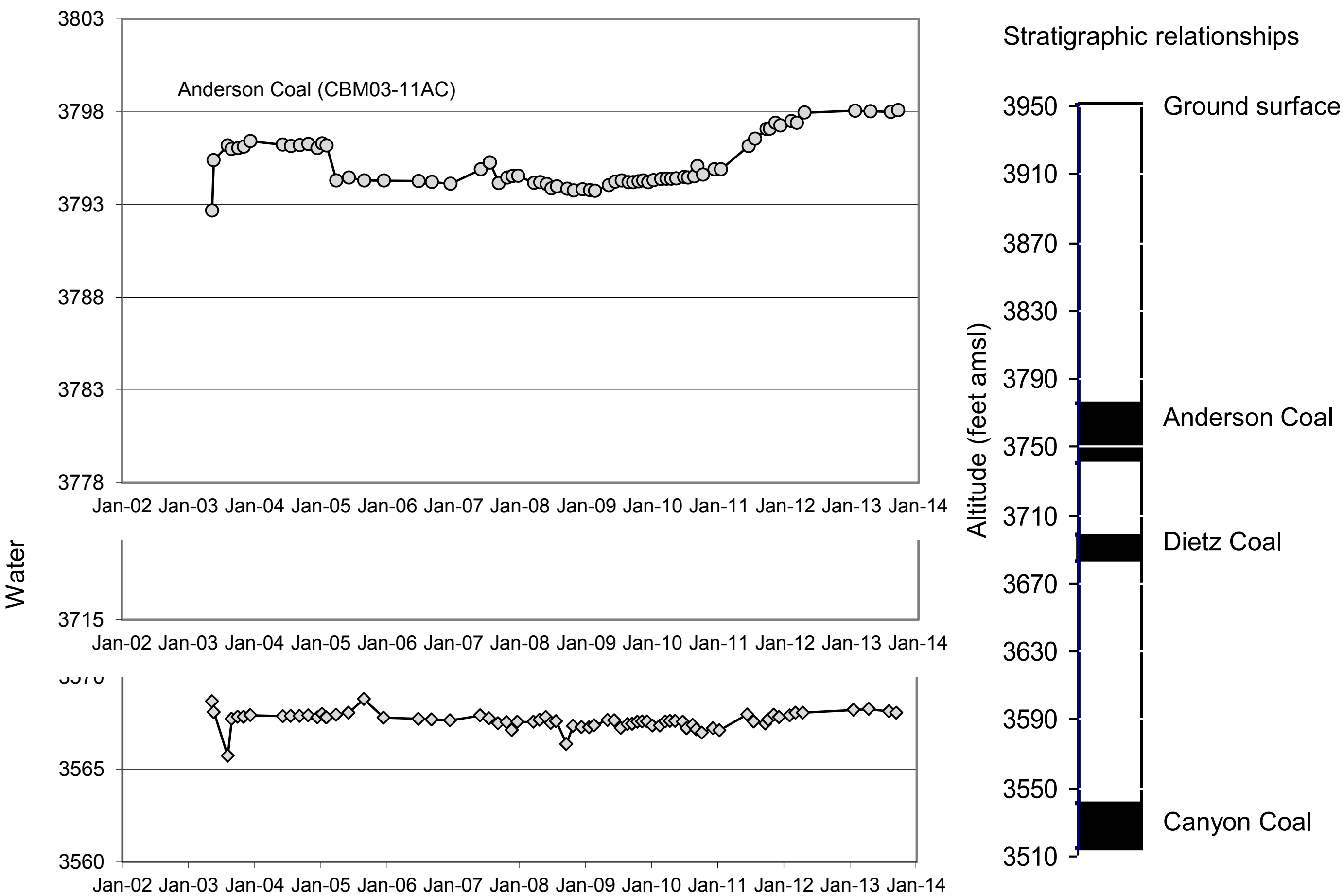


Figure E-2. A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site. This site is near the Anderson coal outcrop.

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

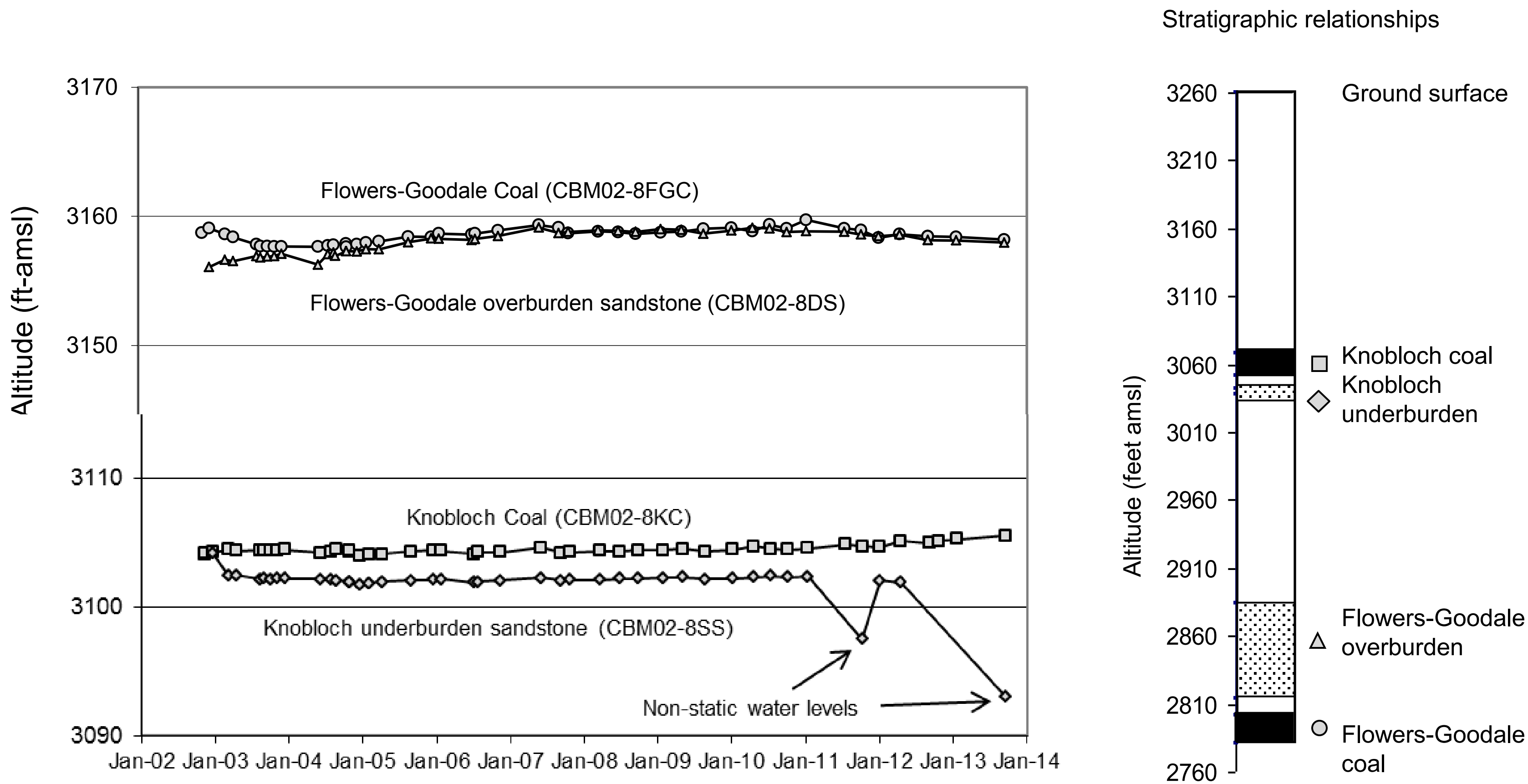


Figure E-3. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. The hydrostatic pressure in the Knobloch coal have been reduced by natural discharge to nearby outcrops. This upward gradient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

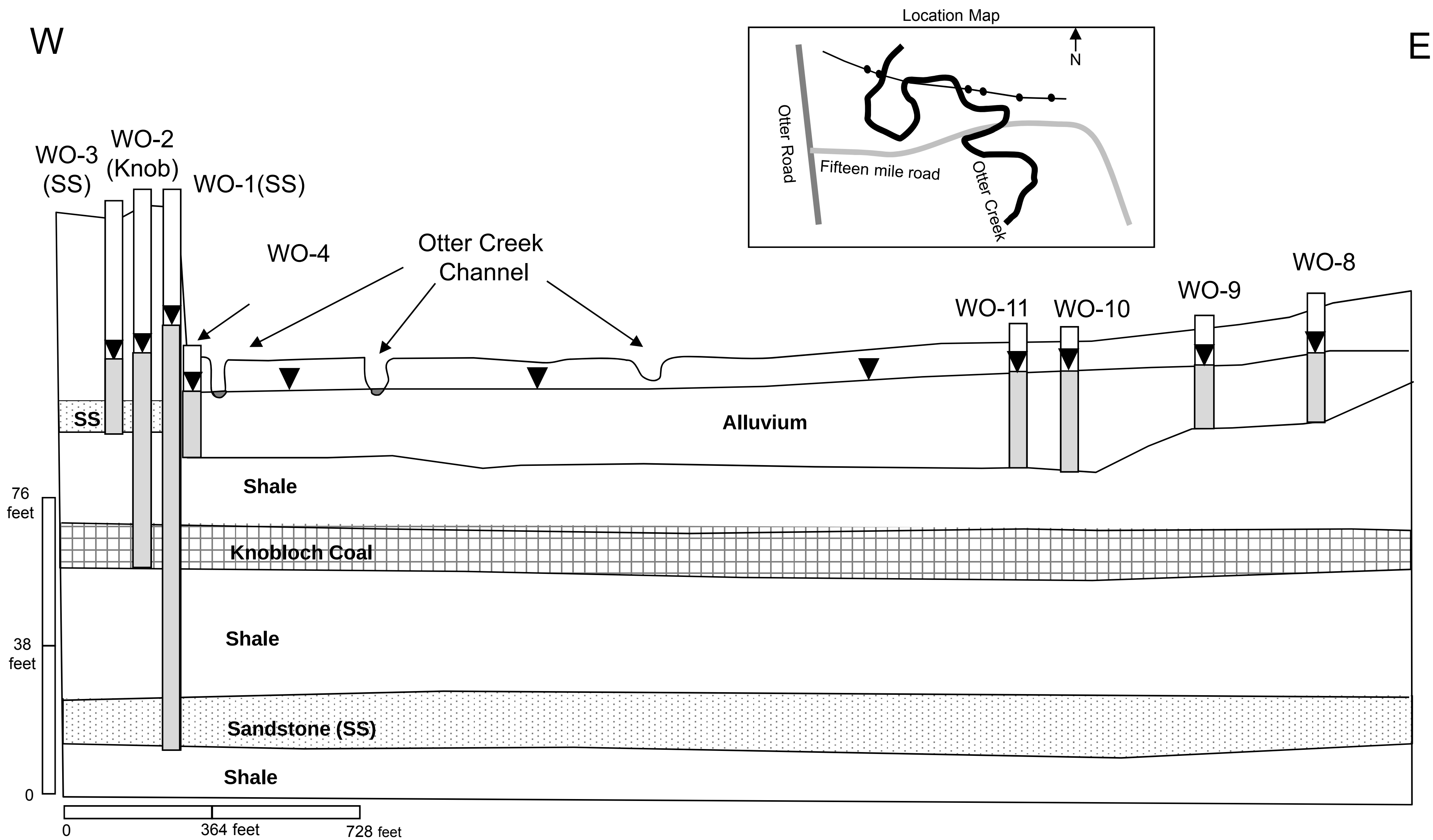
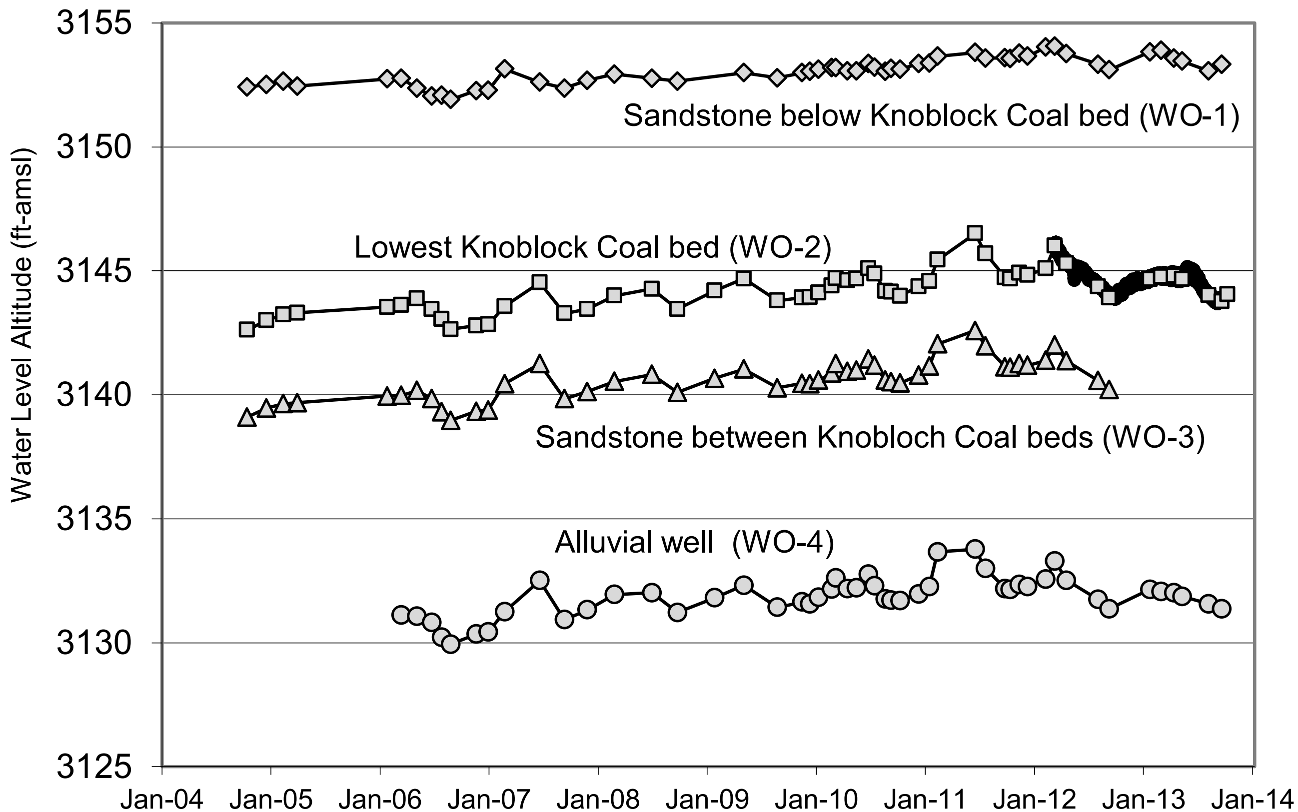


Figure E-4. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in September, 2013. Vertical exaggeration is 9.6:1. Hydrographs for these wells are presented in Figures 4 and E-5.



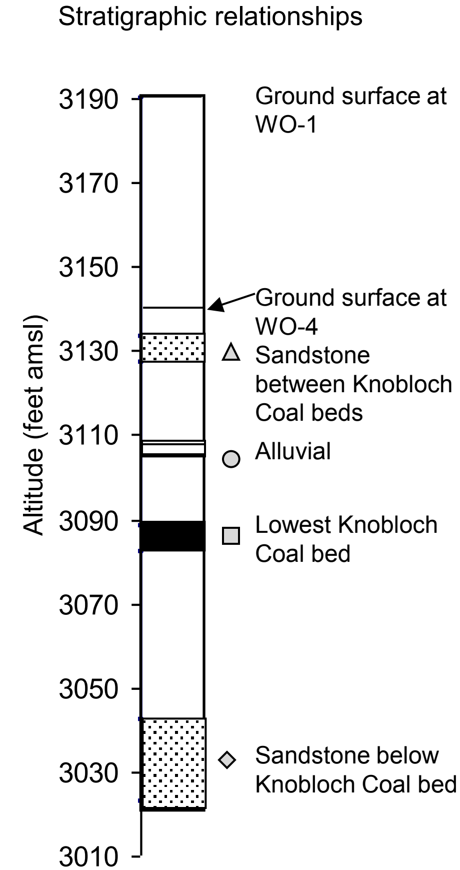


Figure E-5. At monitoring site WO, bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. This upward gradient indicates that the bedrock aquifer will discharge into the alluvium where the two units are in contact. The alluvial well appears to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

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

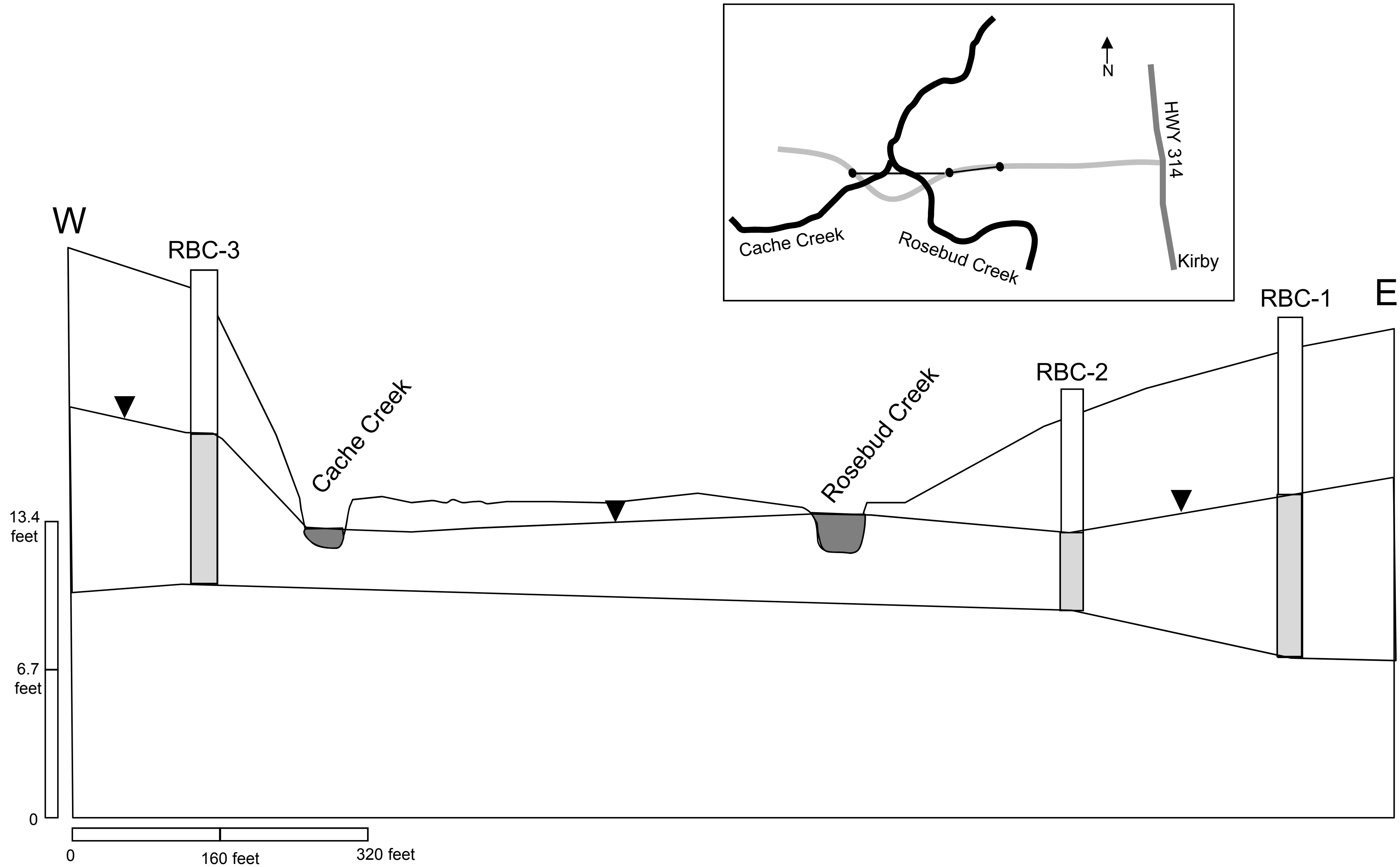


Figure E-6. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface-water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water depending 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 2013. Vertical exaggeration is 23.9:1. Hydrographs associated with this site are shown in figure 5.

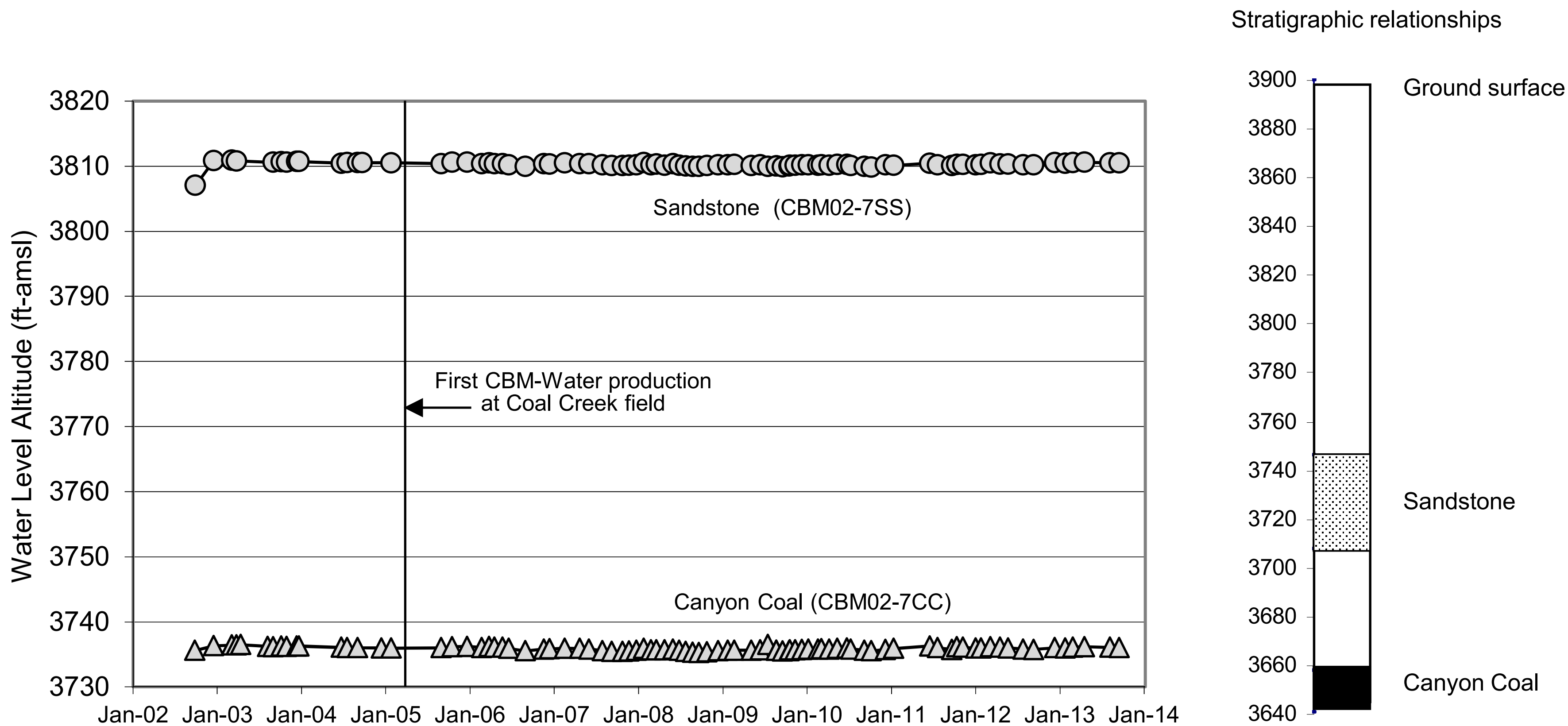


Figure E-7. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

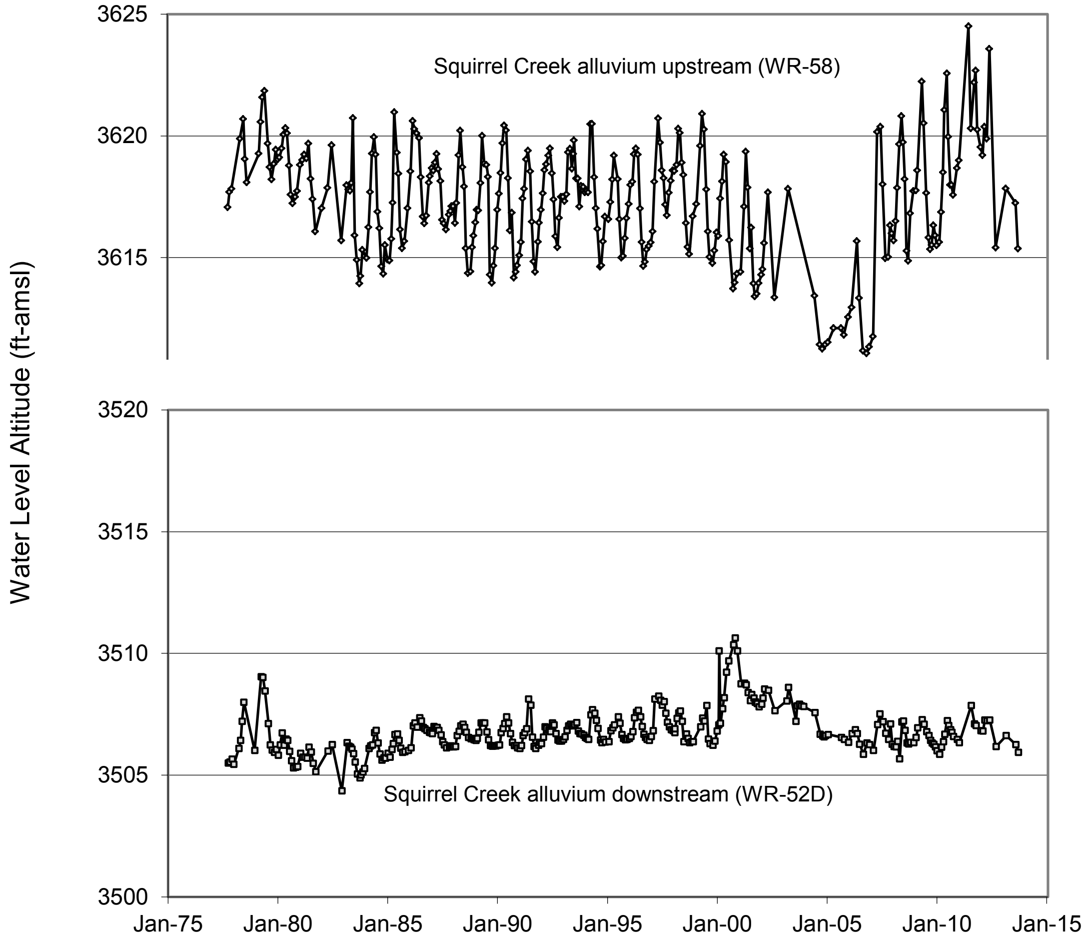


Figure E-8. These alluvial wells are within the area influenced by CBM production; however, they no longer show impacts from the nearby infiltration pond. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production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