2015 Annual Coalbed Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

Montana Bureau of Mines and Geology Open-File Report 679

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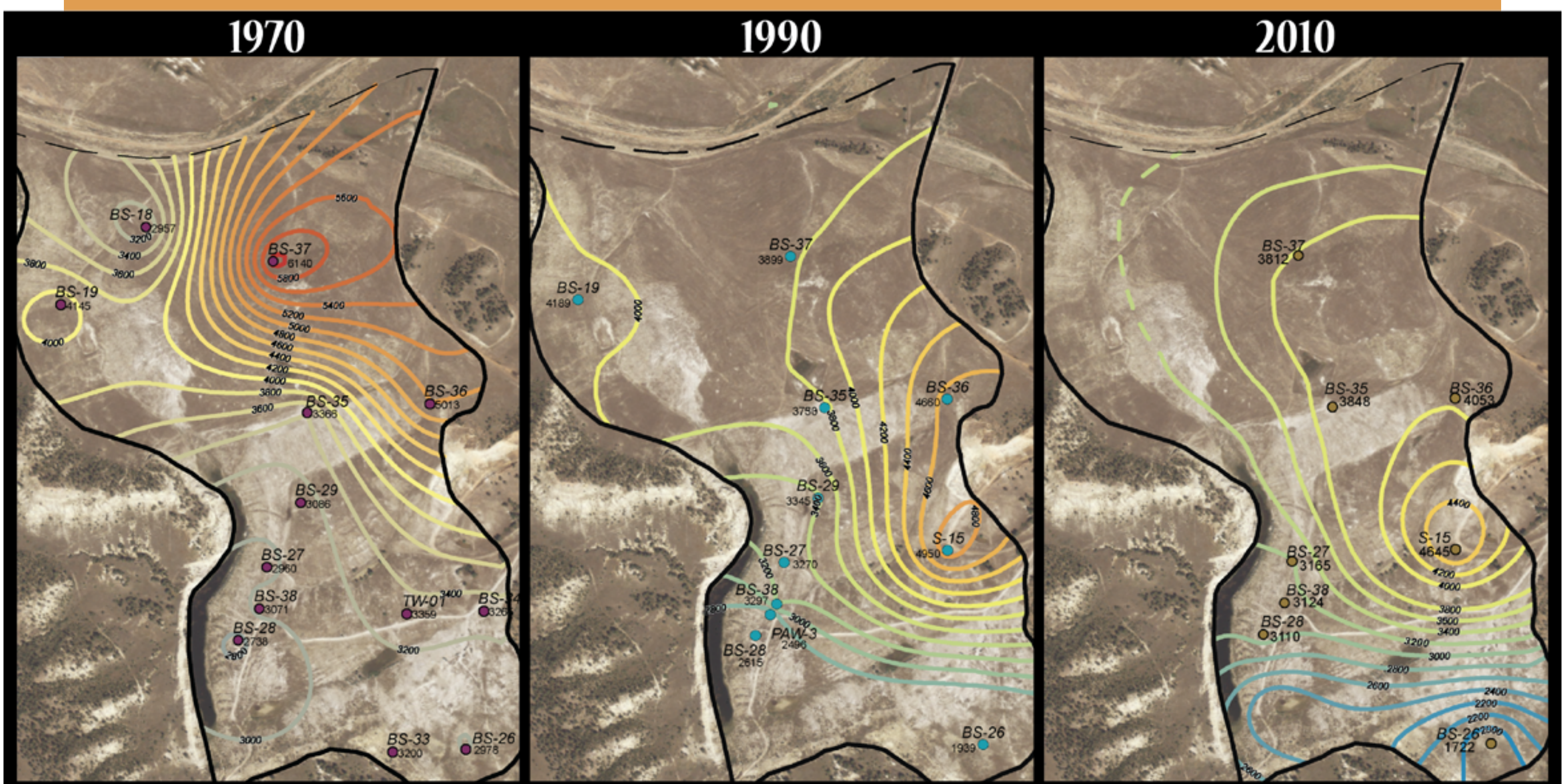

Montana Bureau of Mines and Geology

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ABSTRACT

A regional groundwater monitoring network has been active in the Montana portion of the Powder River Basin for 13 years. In this annual report we present data collected through September 2015, with an emphasis on data collected during Water Year 2015 (October 2014–September 2015). The network was initiated to document baseline hydrogeologic conditions in current and prospective areas of coalbed methane (CBM) development in southeastern Montana to determine actual groundwater impacts, document groundwater recovery, and aid environmental analyses and permitting decisions. The 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.

In Montana 90 CBM wells produced methane, water, or both during 2015. This is the same number that produced in 2014. These wells produced a total of 391 mmscf (1 mmscf = 1,000,000 standard cubic feet) of methane gas in 2015. Over half of the production came from the Dietz field, almost 40 percent came from the Coal Creek field, and less than 10 percent was from the Waddle Creek field.

In the Powder River Basin, methane-producing coalbeds contain water dominated by sodium and bicarbonate. Sodium adsorption ratios (SARs) are generally between 40 and 50, and total dissolved solids concentrations are between 1,000 and 2,500 mg/L. Sulfate concentrations are low. CBM produced water is typically acceptable for domestic and livestock use; however, its high SAR makes it undesirable for direct application to soils.

The Montana Bureau of Mines and Geology (MBMG) monitored the groundwater network 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. The Spring Creek coal mine provided 123 water levels for 26 wells completed in the Anderson/Dietz and Canyon coals. Monitoring well density and coverage are best in the Anderson/Dietz and Canyon coalbeds, so they are the primary focus of this report.

Development of CBM requires reducing hydrostatic pressure in the coalbeds. Hydrostatic heads in the Dietz coal aquifer have been lowered 200 ft or more within areas of production. In the Canyon coal aquifer, heads have been lowered more than 600 ft. After 16 years of CBM production, the 20-ft drawdown contours for the Dietz and Canyon coals extended approximately 1.0 to 1.5 mi beyond the active 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 has not noticeably changed since 2004 due to fewer than anticipated CBM wells and extensive faulting that limits drawdown (Wheaton and others, 2005; Wheaton and Metesh, 2002). Faults in the study area 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, computer modeling of the Ash Creek mine area shows that the hydraulic conductivity of faults varies significantly along their strike (Meredith and others, 2011), particularly along scissor faults. Vertical migration of drawdown is 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 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; amount, timing and location of precipitation; and other significant groundwater withdrawals such as by 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 years; however, observations dur-

ing the past 6 years indicate recovery has stagnated. Further recovery may only occur in years of higher than average precipitation or, if drawdown in Wyoming fields has migrated around faults, only after water levels in Wyoming coal fields return to near baseline.

Modeled projections such as those presented in Wheaton and Metesh (2002) are important to evaluate potential future impacts. However, long-term monitoring is necessary to test the accuracy of computer models, improve the 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 standard cubic feet (mmscf); Montana Board of Oil and Gas Conservation (MBOGC); Montana Bureau of Mines and Geology (MBMG); million British Thermal Units (MMBtu); Montana Ground Water Information Center (GWIC); sodium adsorption ratio (SAR); specific storage (Ss); specific yield (Sy); storativity (S); total dissolved solids (TDS); tritium units (TU); United States Department of the Interior, Bureau of Land Management (BLM); United States Geological Survey (USGS); Wyoming Oil and Gas Conservation Commission (WOGCC).

INTRODUCTION

In the Powder River Basin, coalbed methane (CBM) is created by the biogenic breakdown of coal by microbes. The methane is held in coal seams by adsorption to coal due to weak bonding and water pressure. Pumping from coalbeds reduces water pressure and 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 coalbeds are also important aquifers, CBM water extraction raises concern about potential loss of stock and domestic water supplies due to drawdown that may reduce yields from wells and discharge from springs. Other concerns include management of the produced water because of potential impacts to surface-water quality and soils. The Montana regional monitoring program provides critical data and science-based interpretation that helps governmental agencies and the public address the magnitude, extent, and duration of CBM-caused drawdown as well as water-quality impacts.

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 natural gas prices. The spot Henry Hub price for natural gas was more than $15/MMBtu in 2005 but in January 2016 was just over $2.00/MMBtu (http://www.eia.gov/naturalgas/weekly/).

This is the 13th annual report in which the MBMG has documented baseline hydrogeologic conditions in current and prospective CBM areas within the northern Powder River Basin. This work has been carried out mainly in Montana. We have 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 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 study area covered by the Montana regional CBM groundwater monitoring network is shown in figure 1 and plate 1.

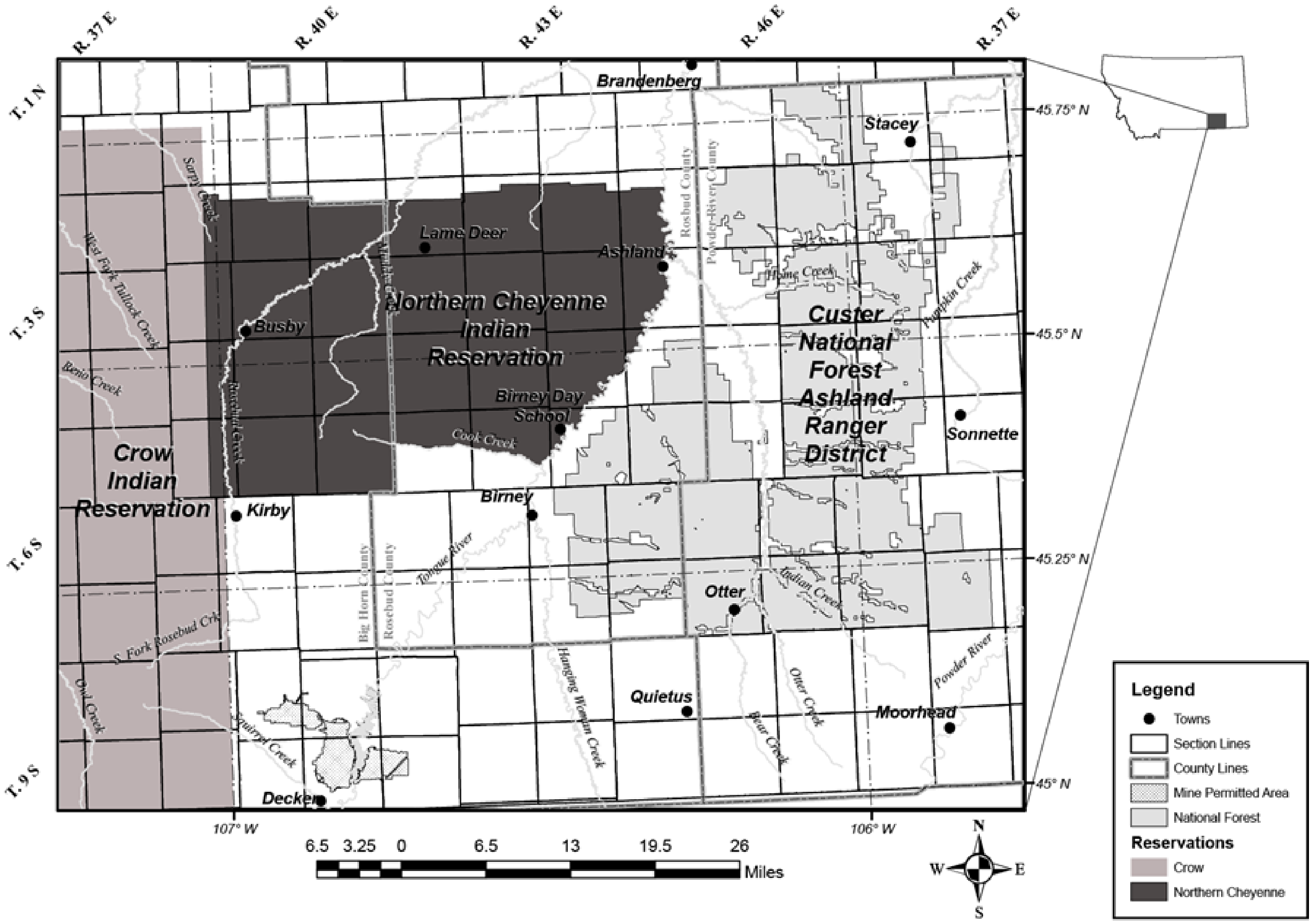


Figure 1. The Montana regional CBM monitoring network covers the area considered to have medium to high potential for CBM development in the Powder River Basin. This area extends from the Wolf Mountains in the west to the Powder River in the east, and from the MT–WY state line north to Ashland.

All hydrogeologic data collected under the Montana regional CBM groundwater monitoring program 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 from 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 226 wells and 14 springs during the 2015 water year. Six monitoring wells, located on the Northern Cheyenne Reservation, are monitored by tribal employees and the United States Geological Survey (USGS), 2012. The Spring Creek mine supplied 123 water levels for 26 monitoring wells (plates 2 and 3). 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 the 2015 water year 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, coalbed-methane producers, and coalmine operators who allowed monitoring access or provided monitoring data are gratefully acknowledged. 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, 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. Technical discussions and reviews by the BLM, USFS, and cooperating groups continue to be invaluable.

Location, Description, and General Hydrogeology

The study area is the 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 includes only 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 and overlying Wasatch. Both formations consist of sandstone, siltstone, shale, and coal units; however, the Wasatch Formation tends to be relatively coarse grained when compared to the Fort Union Formation. 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 (illustrated in appendix D) 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 the 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 the underlying regional flow systems. This vertical seepage between aquifers is limited by the low permeability of numerous interbedded shale layers in the Tongue River Member of the Fort Union Formation.

Regional bedrock flow systems receive recharge from streams or precipitation near the perimeter of the Powder River Basin where permeable bedrock aquifers crop out. Vertical leakage from overlying local flow systems also provides a limited amount of recharge. 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 adjustment to periods of below- or above-average precipitation. However, the deep aquifers can show marked increases from unusually intense precipitation events, such as those in 2011.

The Moorhead weather station is located in the southeast part of the study area along the Powder River, near the Montana–Wyoming state line. Precipitation data indicate that average annual precipitation is 12.10 in. (1970–2015; Western Regional Climate Center, 2016). During the calendar year 2015, the Moorhead station received 12.82 in. of precipitation (black circles in fig. 2), 0.72 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, and precipitation was generally above average from 2005 to 2011.

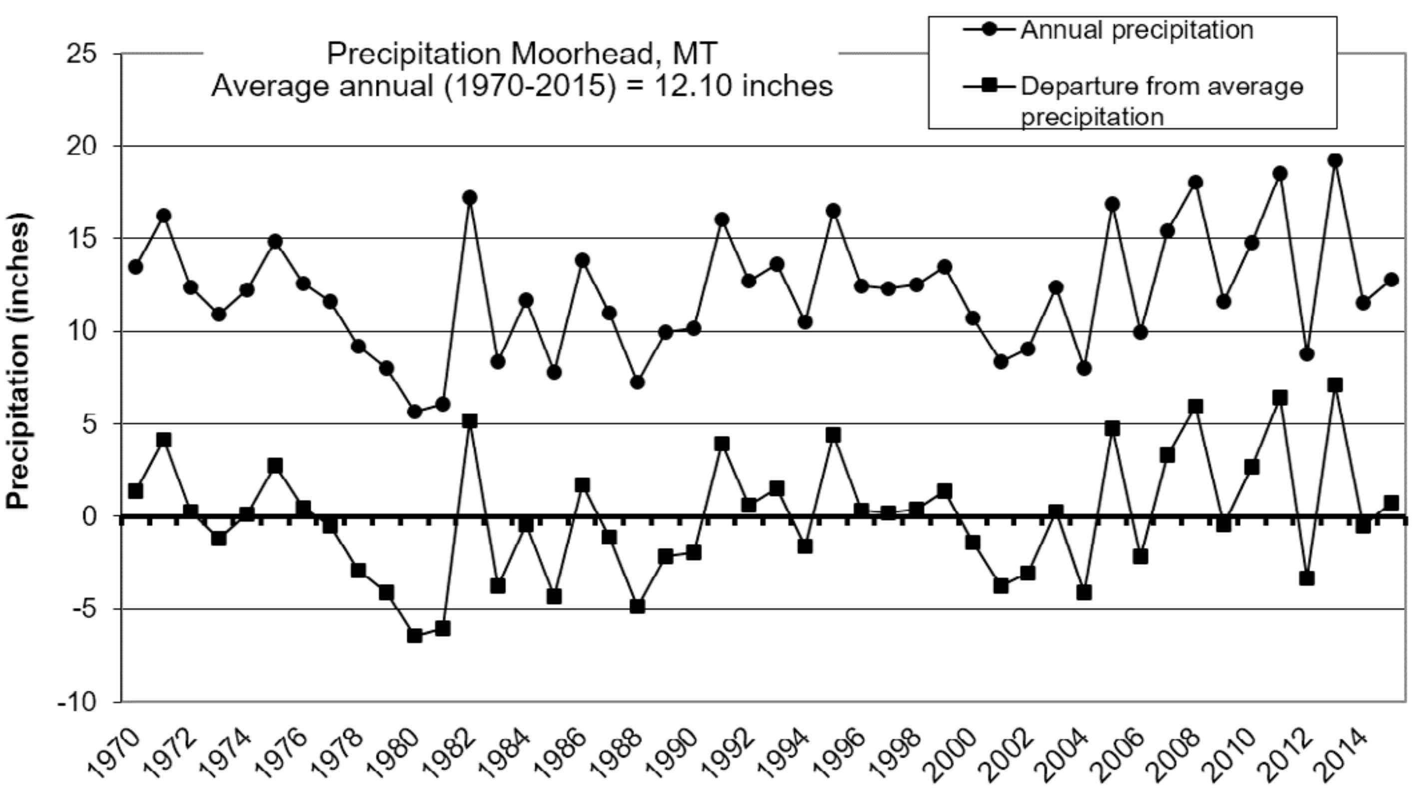


Figure 2. Annual precipitation (circles on line graph) at Moorhead, MT. Departure from average precipitation (squares on line graph) provides a perspective on the long-term moisture trends that may affect groundwater recharge.

Coalbeds and other aquifers in the Powder River Basin are generally separated by shale units. At a few locations where overburden and interburden aquifers are monitored in conjunction with the coalbeds, data show that the coals are confined. The shale layers limit the extent of drawdown from CBM development.

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). Continued monitoring demonstrates 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 occur 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 coalbeds is not expected to change in response to CBM production. Infiltration of produced water to other aquifers may, however, cause changes in groundwater quality in shallow aquifers. To assess possible changes, water-quality data are collected semi-annually from some shallow aquifers.

GROUNDWATER CONDITIONS OUTSIDE OF CURRENT CBM INFLUENCE

Bedrock- and Alluvial-Aquifer Water Levels and Water Quality

Groundwater levels (the potentiometric surface) and inferred groundwater flow directions in the Dietz and Canyon coal aquifers 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. Some recharge occurs 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 slowly downward to become deep groundwater flow. Significant and interesting changes that occurred in the current water year, including those that are not related to CBM development, are presented in this report. Baseline data presented in previous CBM annual reports (e.g., MBMG Open-File Report 600) can be found in appendix E.

Several monitoring wells on the southern border of the Northern Cheyenne Reservation (plate 1) are measured cooperatively by the Northern Cheyenne Tribe and the USGS to watch for potential water-level changes 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 (two wells), Flowers–Goodale, Pawnee, and Knobloch (two wells) coal aquifers. As of the last reported measurements, no significant water-level change has occurred 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 13 years of monitoring at site CBM02-1, near Kirby, Montana, water levels in the Brewster–Arnold coal aquifer and the "Local Coal" aquifer showed subtle responses to seasonal precipitation, whereas water levels in the Knobloch aquifer showed little fluctuation (fig. 3). However, following unusually high precipitation in spring 2011, water levels rose in all three wells. The shallowest coalbed, the Brewster–Arnold, experienced only a slight upward water-level movement and quickly returned to more typical levels. The already climbing water level in the Local Coal was only slightly increased in 2011 and appears to reflect more long-term climatic influences. Of the three aquifers, the Knobloch coal showed the most dramatic response to the recharge event of 2011, rising 4 ft from 2011 to 2012.

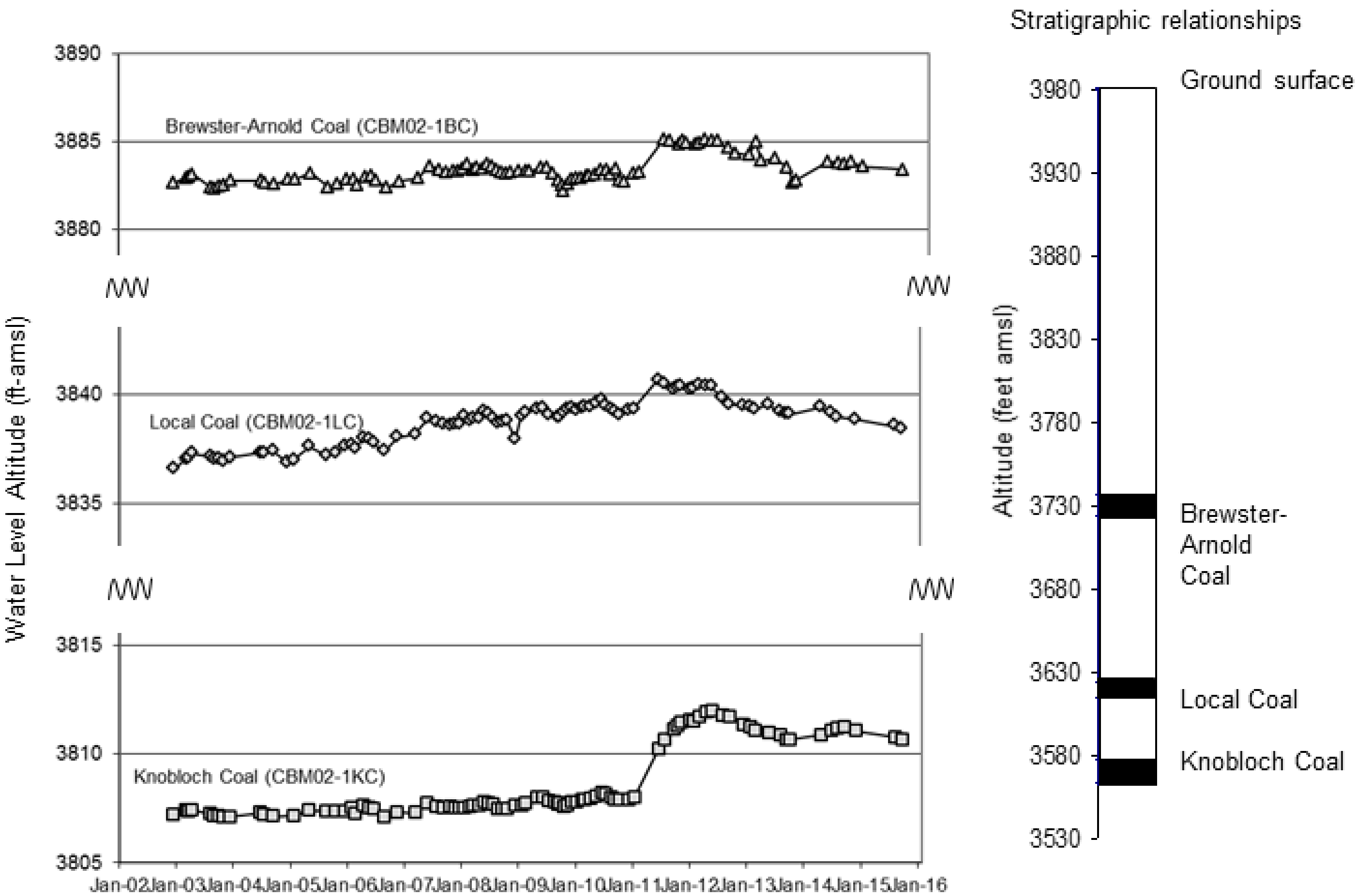


Figure 3. A downward hydrostatic gradient is evident between the Brewster–Arnold coal, Local Coal, and Knobloch coal at the CBM02-1 site. This monitoring site is near the town of Kirby, just east of Rosebud Creek. Water-level data from the Brewster–Arnold coal and the Local Coal demonstrate a slight annual cycle with the lowest levels in late summer or early fall, indicating a relationship with precipitation. The 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. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different. The Y axis scale is broken to show better hydrograph detail.

Alluvial water levels, such as at monitoring site WO (fig. 4A) along Otter Creek and RBC along Rosebud Creek (fig. 4B), respond to local, recent precipitation. Along Otter Creek the alluvial groundwater flows from the valley edge to the center. Rosebud Creek alluvial water levels quickly respond to precipitation events.

Water-quality samples were collected in October 2013 from well RBC-2. The TDS concentration was 565 mg/L and the SAR was 0.8. The average TDS and SAR based on 18 samples is 569 mg/L and 0.8, respectively. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate (appendix C). This well will no longer be sampled semi-annually because of its long history of sampling and consistent water quality.

Spring and Stream Flow and Water Quality

Flow rates and specific conductivity data were collected at four springs within the project area, but outside the influence of CBM production during 2015. Ten additional water-quality samples were collected from springs located on the Custer National Forest. The locations of the four monitored springs and National Forest springs are shown in plate 1, site data are in appendix B, and water-chemistry data for selected springs are in appendix C. Additional information about spring water quality on the National Forest can be found in Meredith and Schwartz (2016).

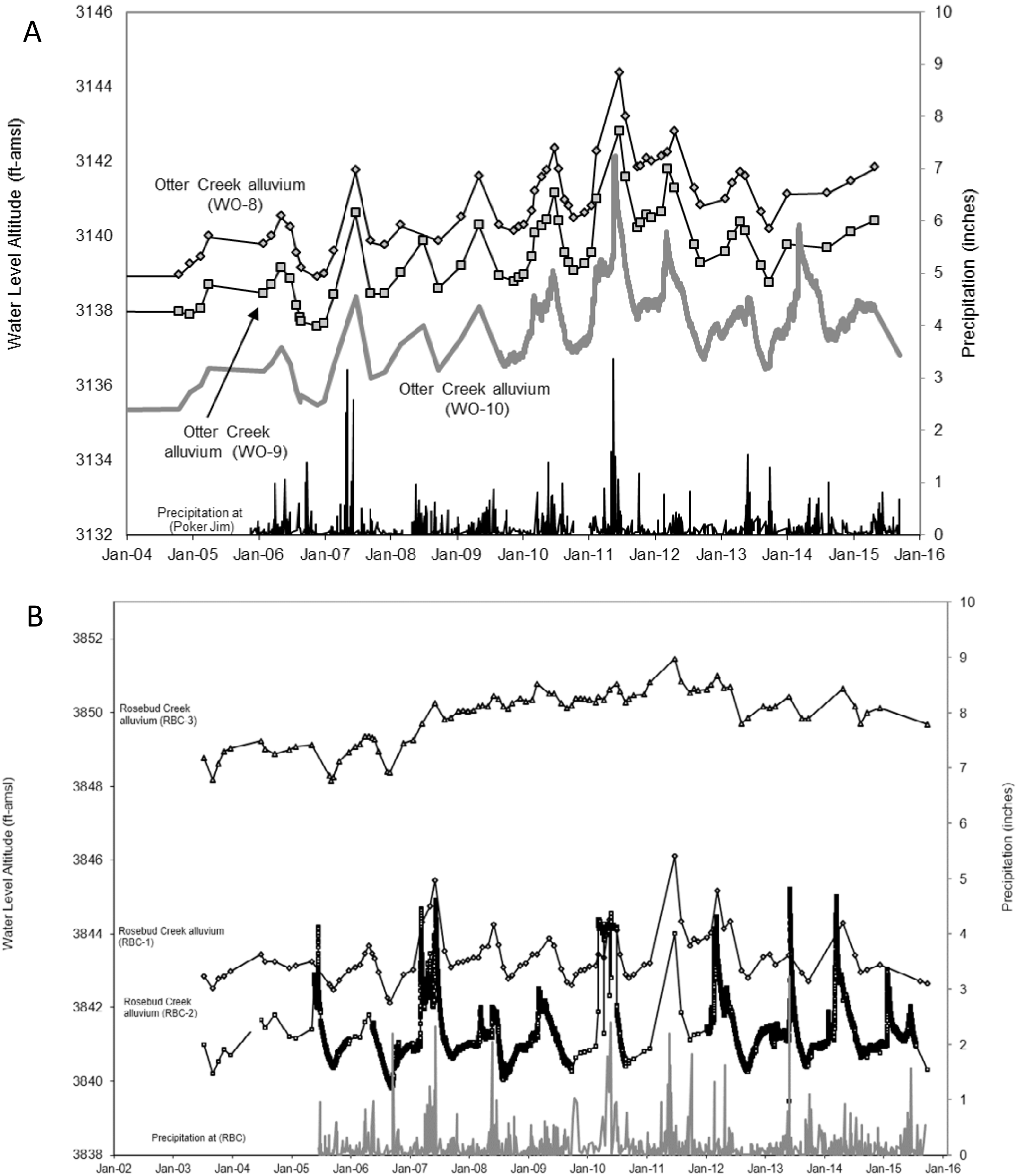


Figure 4. (A) Seasonal water-level change in the alluvium at the Otter Creek site closely follows the precipitation recorded at the Poker Jim weather station (shown as the total rain in inches per event in the lower graph). (B) Groundwater levels are typically high during wet times of the year at the 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).

Located in the southern end of the Custer National Forest's Ashland Ranger District along Otter Creek, Alkali Spring generally discharges between 0.5 and 1.7 gpm. Discharge from Alkali Spring is a mixture of regional and local flow systems. Evidence supporting a regional flow system source is tritium analysis from 2007 that indicated a tritium-dead (old) system. Based on stratigraphic relationships and the regional nature of the spring, it appears that the Otter coalbed supplies some of the regionally recharged water (Wheaton and others, 2008). However, the seasonally linked discharge rate (fig. 5) and seasonally dependent water quality (Meredith and others, 2009) indicate that there also is a local source of water.

Water from Lemonade Spring (just off Forest Service owned property), 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 coalbed and flows typically vary seasonally; the average discharge is less than 2 gpm. However, high precipitation in 2011 caused increased flow that peaked in mid-2012 (fig. 5).

North Fork Spring, in the southeast part 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. 5). This spring discharges from an isolated segment of the Canyon coalbed and is likely discharge from a local flow system.

GROUNDWATER CONDITIONS WITHIN AREAS OF CBM INFLUENCE

Contiguous areas of producing CBM wells in Montana cover an area of approximately 3 mi^2, down from a high of approximately 50 mi^2 (plate 1). Most production is east of the Tongue River.

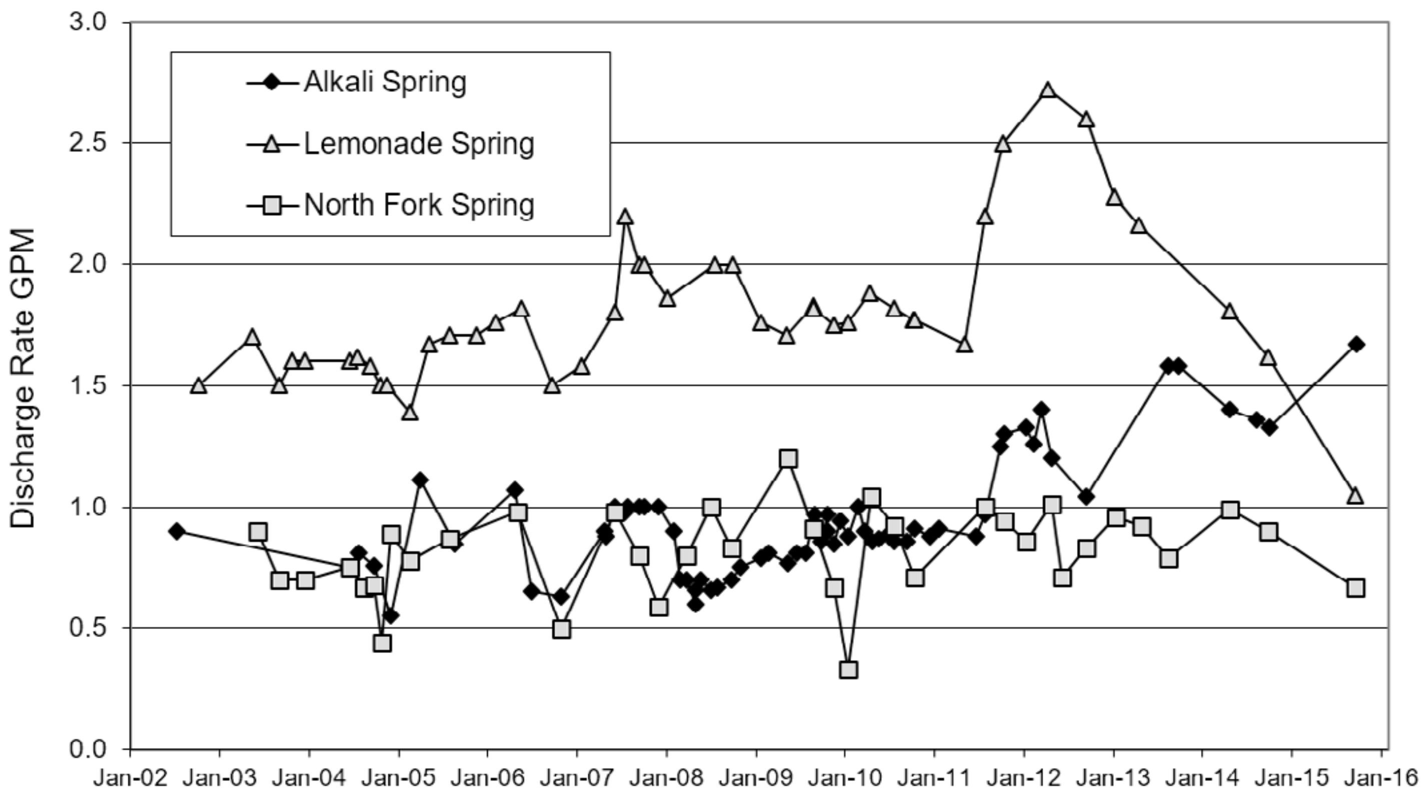


Figure 5. Discharge from Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.95 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.81 gpm. Lemonade Spring appears to be locally recharged by the Ferry coalbed. The spring has an average discharge rate of 1.80 gpm.

Produced water volume data for water year 2015 were retrieved for Montana (MBOGC, 2016) and Wyoming (WOGCC, 2016) and are summarized in table 1. A total of 90 Montana wells produced methane and/or water at some point during 2015. The 90 wells produced 2.4 million barrels (bbls) of water (304 acre-ft) during water year 2015, 38 percent less than in 2014. In the same time period, 148 wells in the two tiers of Wyoming townships nearest Montana (57 N. and 58 N.) produced 33.5 million bbls (4,322 acre-ft) of water, 28 percent less than in 2014. The total amount of water co-produced with CBM in the Powder River Basin in all of Wyoming during water year 2015 was approximately 214 million bbls or 27,500 acre-ft (WOGCC, 2016).

Coalbed methane permitted wells in Montana are summarized by county and field in table 2. While table 1 includes all wells that were active at any time in water year 2015, table 2 only includes those active in December 2015. As of December 2015 all of the remaining production is in Big Horn County (table 2).

Since mid-2008, a variety of factors have caused CBM producers in Montana to shut-in wells, including the cost of produced water management and the price of methane gas. As the price of methane gas drops, producers take more wells out of production and the amount of water and gas produced falls (fig. 6A). The changes in water production and number of active producing wells in Montana are mirrored by changes in Wyoming (figs. 6A, 6B).

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, 2016). During 2015, there were no producing CBM wells in the CX field. This is only the second year since 1999, when CBM production began in Montana, that the CX field has not produced CBM.

CBM wells in Wyoming across the state line from the CX field are also being shut-in. Water levels began recovering in areas where CBM water production decreased; wells WR-27 and WR-38 (fig. 7) illustrate typical water-level recovery. Initial recovery rates were as expected and could have resulted in full recovery in 30 to 100

Table 1. Annual summary for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2014.

	Field	Well Count	Gas (MCF) 2015	Annual+ total water production in Bbls *1,000 (acre-ft)								
				2015	2014	2013	2012	2011	2010	2009	2008	2007
Montana	Coal Creek	28	143,073	1,275 (164)	2,495 (322)	1,486 (192)	886 (114)	1,848 (238)	2,262 (292)	2,055 (265)	1,782 (230)	2,389 (308)
	CX	0	0	0 (0)	0 (0)	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	60	221,615	1,086 (140)	1,323 (171)	1,229 (158)	921 (119)	1,239 (160)	1,817 (234)	1,790 (231)	2,837 (366)	2,159 (278)
	Waddle Creek	2	26,220	0 (0)	0 (0)	0 (0)	15.6 (2.0)	92.4 (12)	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**90**	**390,908**	**2,361 (304)**	**3,818 (492)**	**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	0*	1,910,091	10,156 (1,309)	14,471 (1,865)	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	0*	701,336	4,296 (554)	6,369 (821)	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	148	3,695,752	19,080 (2,459)	25,747 (3,319)	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	**148**	**6,307,179**	**33,532 (4,322)**	**46,589 (6,005)**	**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)**

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

+Totals reflect production during the water year for 2008-2014 and calendar year 2007

*Wyoming well count reflects only those wells that were producing at the end of 2015. Production ceased in July 2015.

Table 2. Summary 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	Nov. 2014	Dec. 2015
Big Horn	Coal Creek	Permit/Spudded	9	7	4	5	5	0	0	0	0
		Expired Permit	0	0	2	2	2	6	6	6	6
		Producing	**13**	**26**	**23**	**20**	**14**	**17**	**18**	**20**	**9**
		Shut In/Abandoned	49	35	39	44	50	46	45	45	56
	CX	Permit/Spudded	44	44	9	0	0	0	0	0	0
		Expired Permit	231	251	288	288	288	288	288	288	288
		Producing	**741**	**705**	**676**	**623**	**508**	**275**	**10**	**2**	**1**
		Shut In/Abandoned	110	168	212	270	385	619	875	879	869
		Water Well, Released	0	0	0	0	0	2	11	12	23
	Dietz	Permitted Injection Well	1	1	1	1	1	0	0	0	0
		Permit/Spudded	1	0	0	0	0	0	0	0	0
		Expired Permit	42	42	42	42	42	42	42	42	42
		Producing	**96**	**92**	**36**	**61**	**55**	**38**	**34**	**45**	**28**
		Shut In/Abandoned	10	5	61	45	51	59	63	61	78
	Other (Deer Creek, Four Mile, Forks Ranch, Waddle Creek, Wildcat BH)	Permit/Spudded	34	56	35	36	35	0	0	0	0
		Expired Permit	38	49	67	67	68	103	103	103	103
		Producing	**2**	**2**	**3**	**1**	**1**	**2**	**1**	**2**	**2**
		Shut In/Abandoned	21	27	29	24	24	30	28	21	21
		Water Well, Released	0	1	1	1	1	1	4	3	3
Other Counties		Permit/Spudded	124	2	2	2	2	1	1	0	0
Carbon, Custer, Gallatin,		Expired Permit	35	157	157	157	157	158	158	158	158
Powder River, Rosebud		**Producing**	**2**	**2**	**3**	**2**	**1**	**0**	**0**	**0**	**0**
		Shut In/Abandoned	15	14	16	19	21	21	21	23	22
		Water Well, Released	0	0	0	1	1	1	1	1	2

Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ accessed Dec. 30 2015

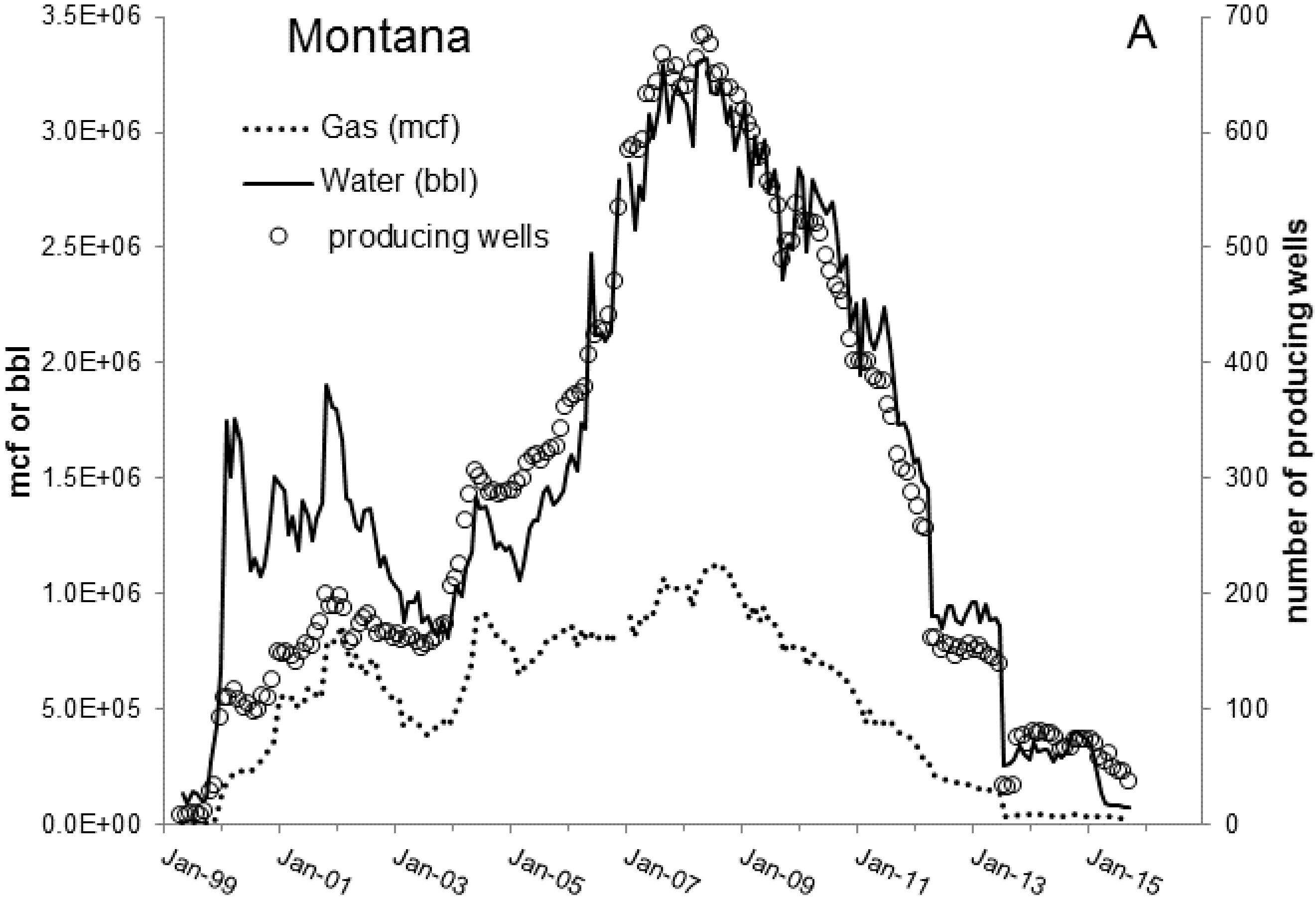
years; however, observations during the past 6 years indicate recovery has slowed or stagnated. Drawdown from Wyoming may have migrated around the ends of faults or through connected zones along scissor faults, and additional recovery in Montana wells may only occur when water levels in Wyoming recover (see following section Water Level Drawdown in Wyoming Fields). 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 were retrieved from the MBOGC website (MBOGC, 2016). The Coal Creek field northeast of the Tongue River Reservoir first produced gas in April 2005. During 2015, a total of 28 CBM wells (plate 1, table 1) produced water or gas from the Wall, Canyon, Cook, and Flowers–Goodale coalbeds (appendix D). Total water production for the 12-month period was 1.3 million bbls (164 acre-ft).

The Dietz field east of the reservoir first produced gas in November 2005. During 2015, a total of 60 CBM wells (table 1) produced water or gas from the Dietz, Canyon (Monarch), Cook, and Wall coalbeds (appendix D). The total water production for the 12-month period was 1.1 million bbls (140 acre-ft).

Bedrock-Aquifer Water Levels and Water Quality

In areas susceptible to CBM impacts near 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.



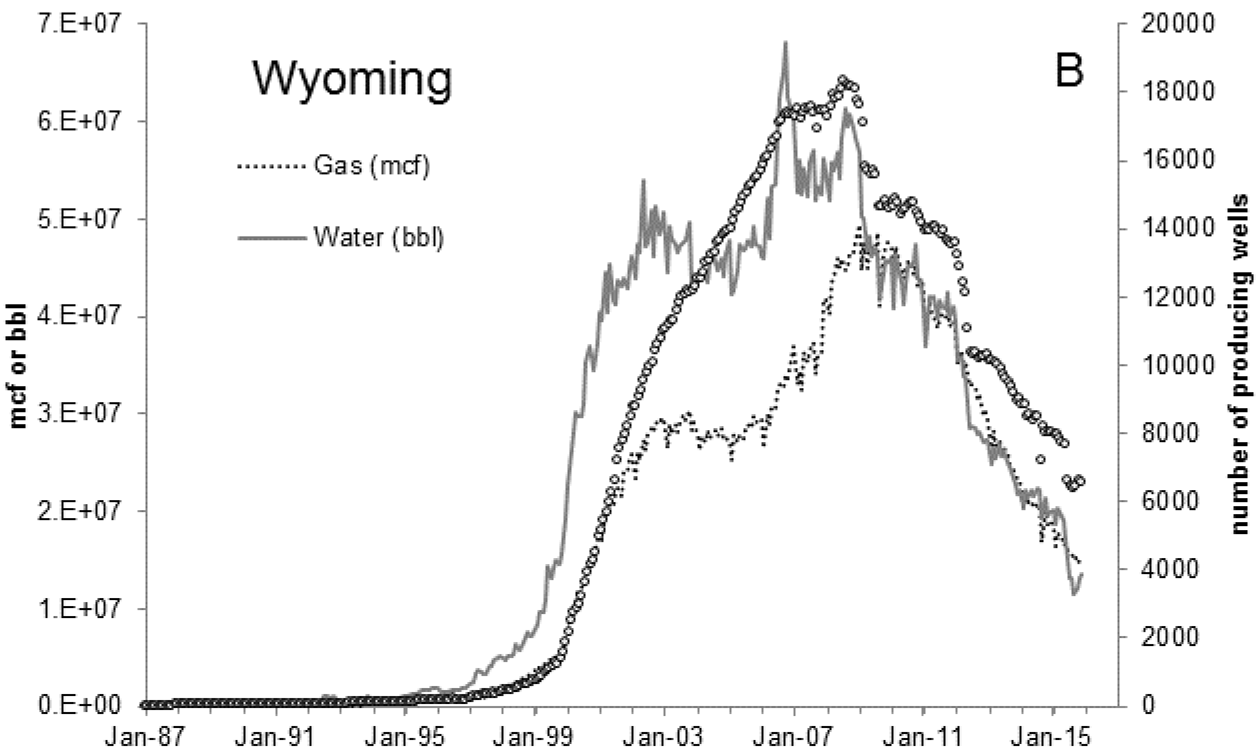


Figure 6. Monthly totals of water and gas produced from Montana (A) and Wyoming (B) CBM wells in the Powder River Basin and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production. The total number of producing wells and the amount of water and gas produced has dropped in both states since March, 2008. Note the X-Axis scale.

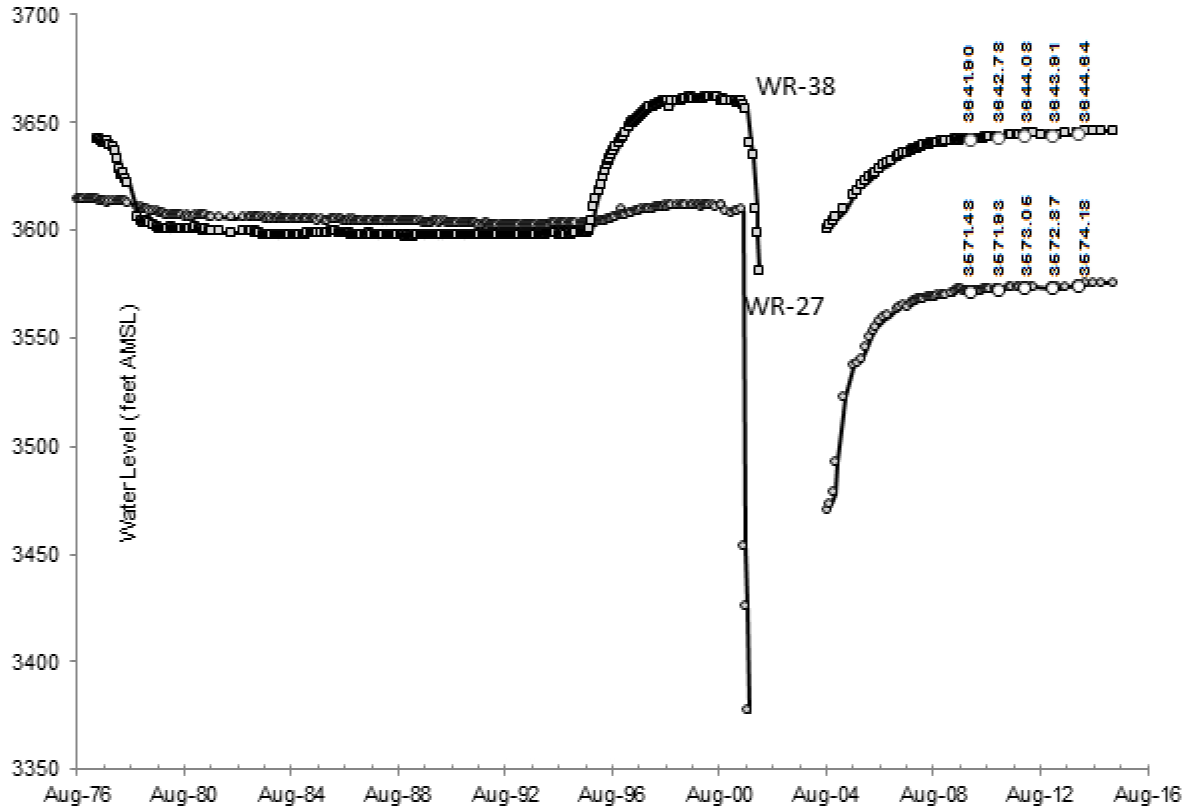


Figure 7. Water-level records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production. The recovery water levels are flattening; however, they have not reached baseline conditions. Water levels for January 2010, 2011, 2012, 2013, and 2014 are labeled.

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 of 50 ft, interpreted to be specific to CBM production from the Dietz coal, typically reaches only about 1 mi with a few instances of up to ~1.5 mi beyond the active field boundaries. For the Canyon coal, CBM-related drawdown appears similar to that in the Dietz coalbed; 20 ft of drawdown extends about 1 mi beyond the field boundaries (Meredith and Kuzara, 2015).

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

Water levels. Hydrostatic pressure in the combined Anderson and Dietz coal in wells WR-34 and WR-38 near the Ash Creek mine declined about 20 and 40 ft, respectively, between 1977 and 1979 because of mine dewatering (figs. 8, 9). Pit dewatering maintained reduced water levels until reclamation and recovery began in 1995. By 1998, water levels had returned to near-baseline altitudes. Although the mine pit created water-level response in the adjacent, confined coal aquifer, water levels in well BF-01 (fig. 9), 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. Between 2001 and 2003, CBM production lowered groundwater levels at WR-34 and WR-38 to about 150 and 80 ft below baseline, respectively. 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 from the reduction in CBM production. However, the modest rate of water-level recovery may reflect continued development in Wyoming.

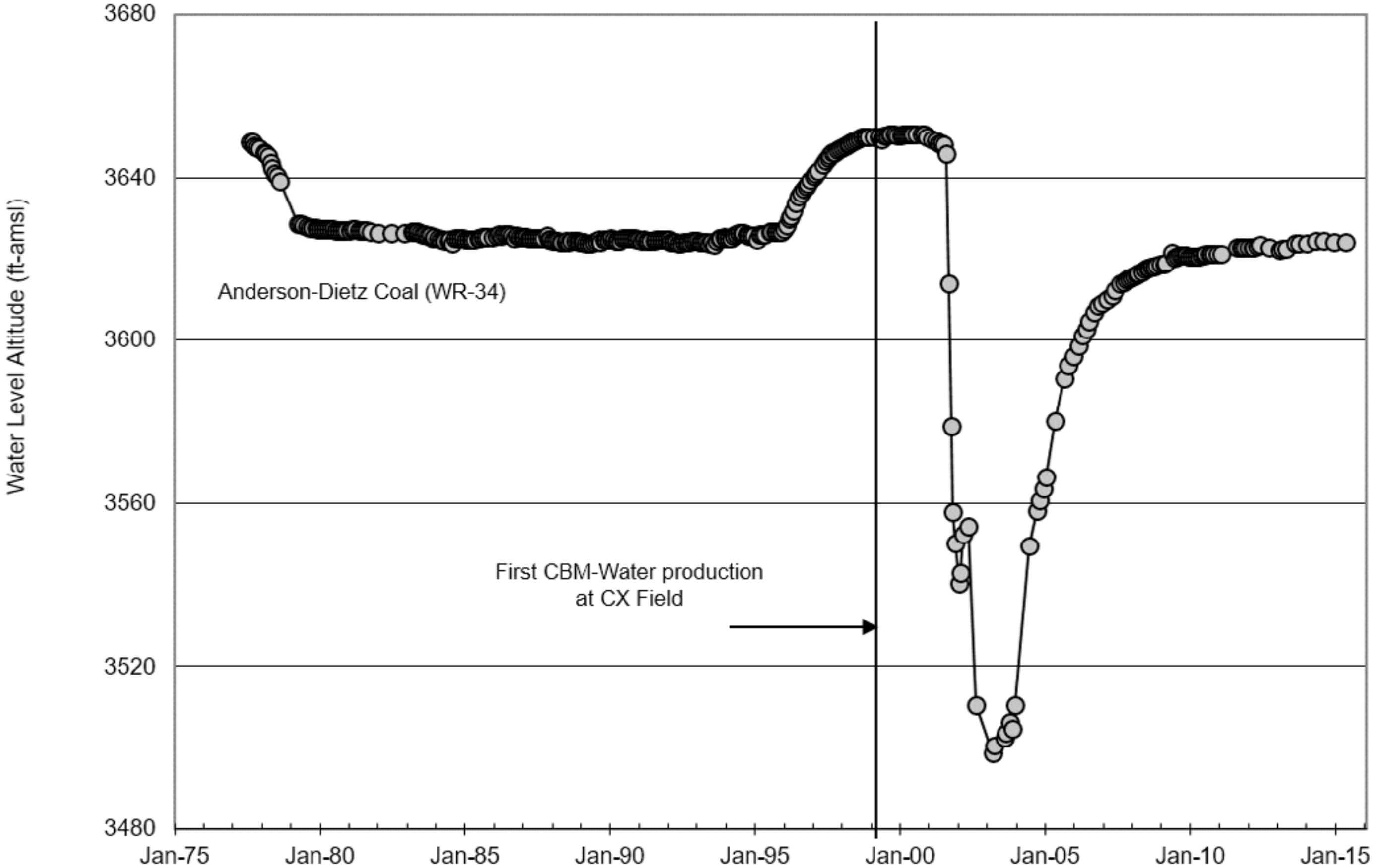


Figure 8. Water levels in the combined Anderson–Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed-methane production. The water-level recovery that began in 2003 is in response to decreased production in the CX field.

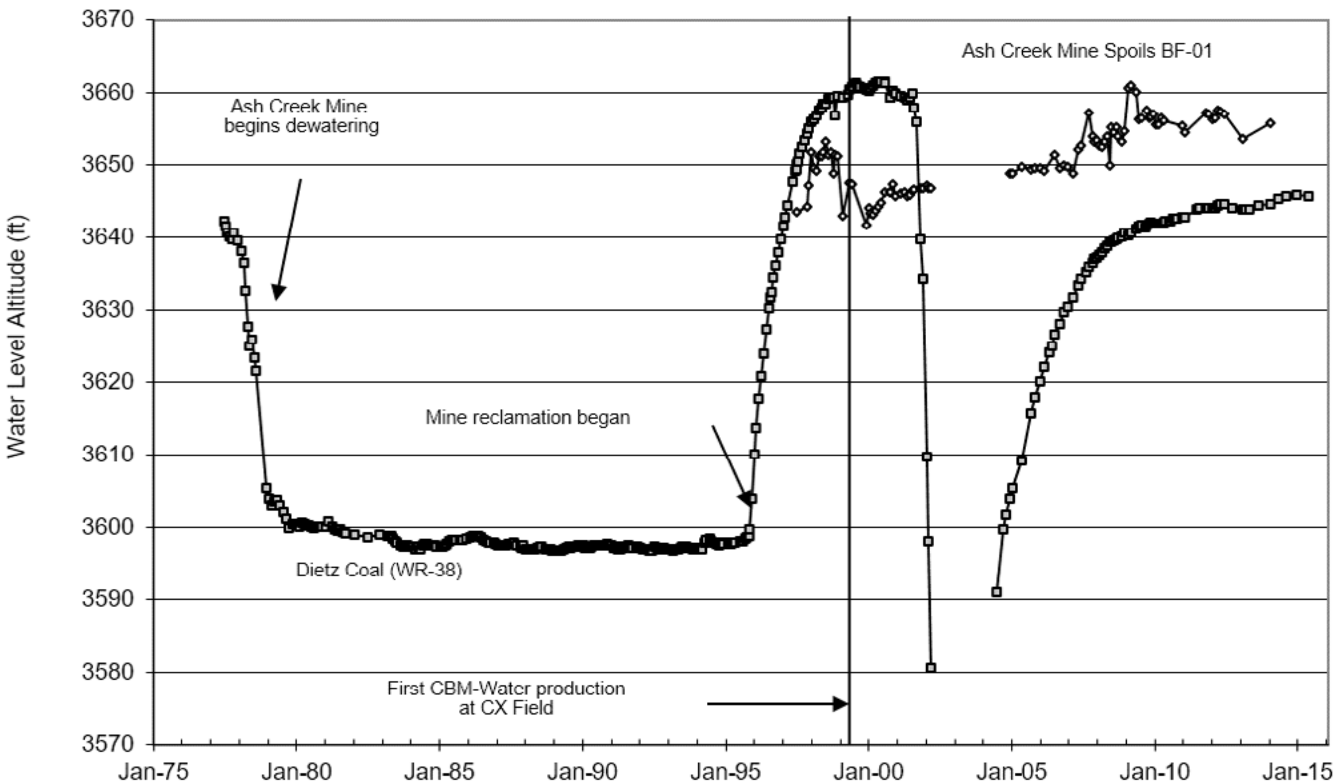


Figure 9. Water levels in the Dietz coal (well WR-38) decreased by at least 80 ft in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping, which illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses to drawdown.

Monitoring wells installed in the Fort Union Formation show that 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 depressed water levels in the Anderson coal and overburden aquifers for more than 25 years. However, there has been no response to the dewatering in aquifers south of the fault (fig. 10). Monitoring south of the fault (plate 2) shows that CBM production has depressed water levels in the Anderson coalbed to more than 180 ft below baseline with no apparent communication to the north. That the mine pit-dewatering and the CBM-dewatering effects are isolated shows that the fault acts as a flow barrier within the Anderson coalbed.

At well WRE-17 south of the fault, water levels in the Smith coalbed respond slightly to coal mining north of the fault and also to CBM production further to the south. The response suggests that 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 coalbed because variable offset along a scissor fault allows hydraulic connection between aquifers.

Near the western edge of the CX field, but potentially isolated by faults from nearby CBM wells, water levels in the Carney coalbed 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. 11). 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 coalbed at this site have steadily declined, either in response to CBM production or possibly due to long-

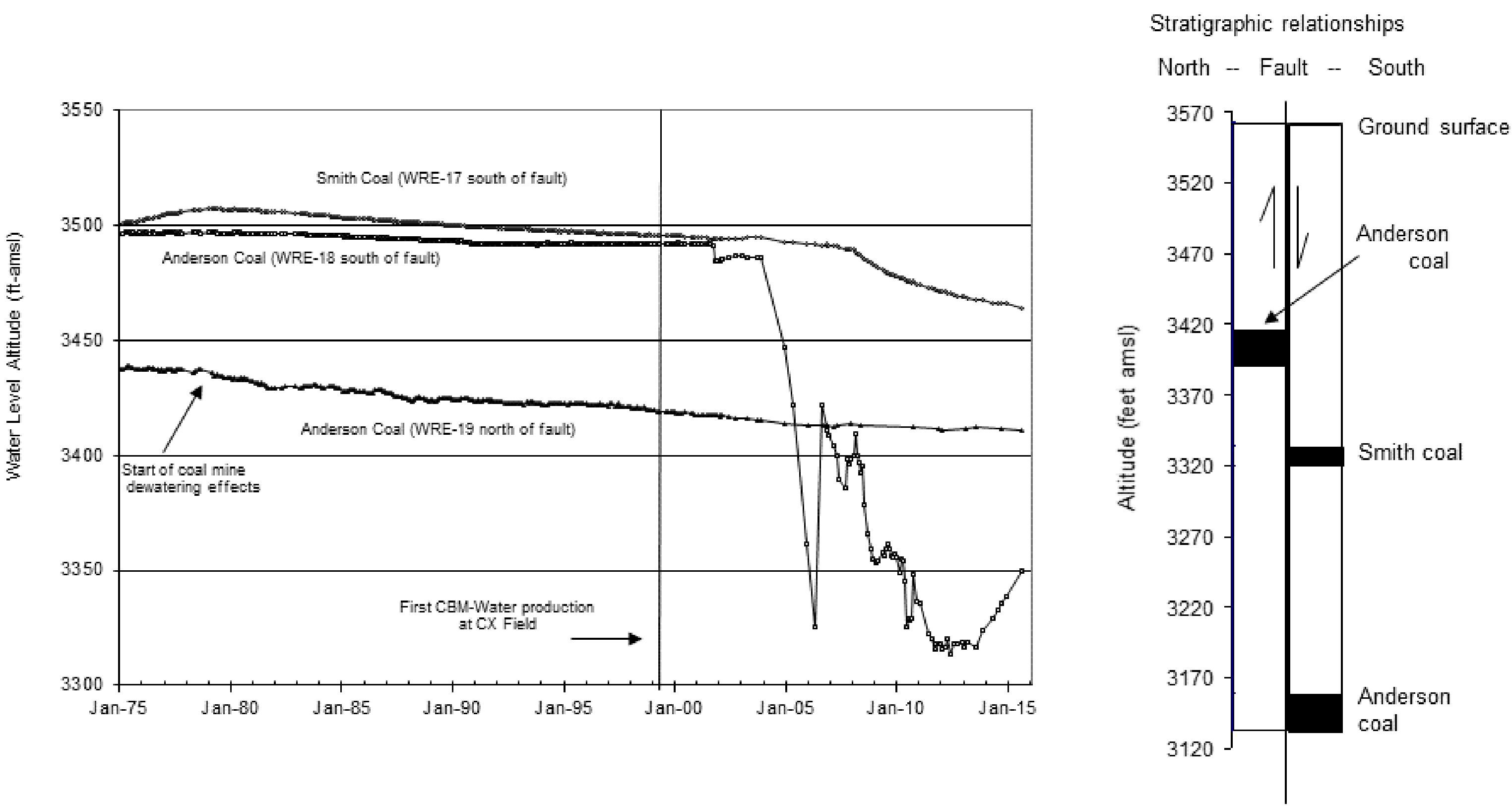


Figure 10. Drawdown from either coal mining or coalbed-methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970s, and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980s. The pressure 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. Water levels have begun to recover in WRE-18 in response to decreased production in the CX field. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.

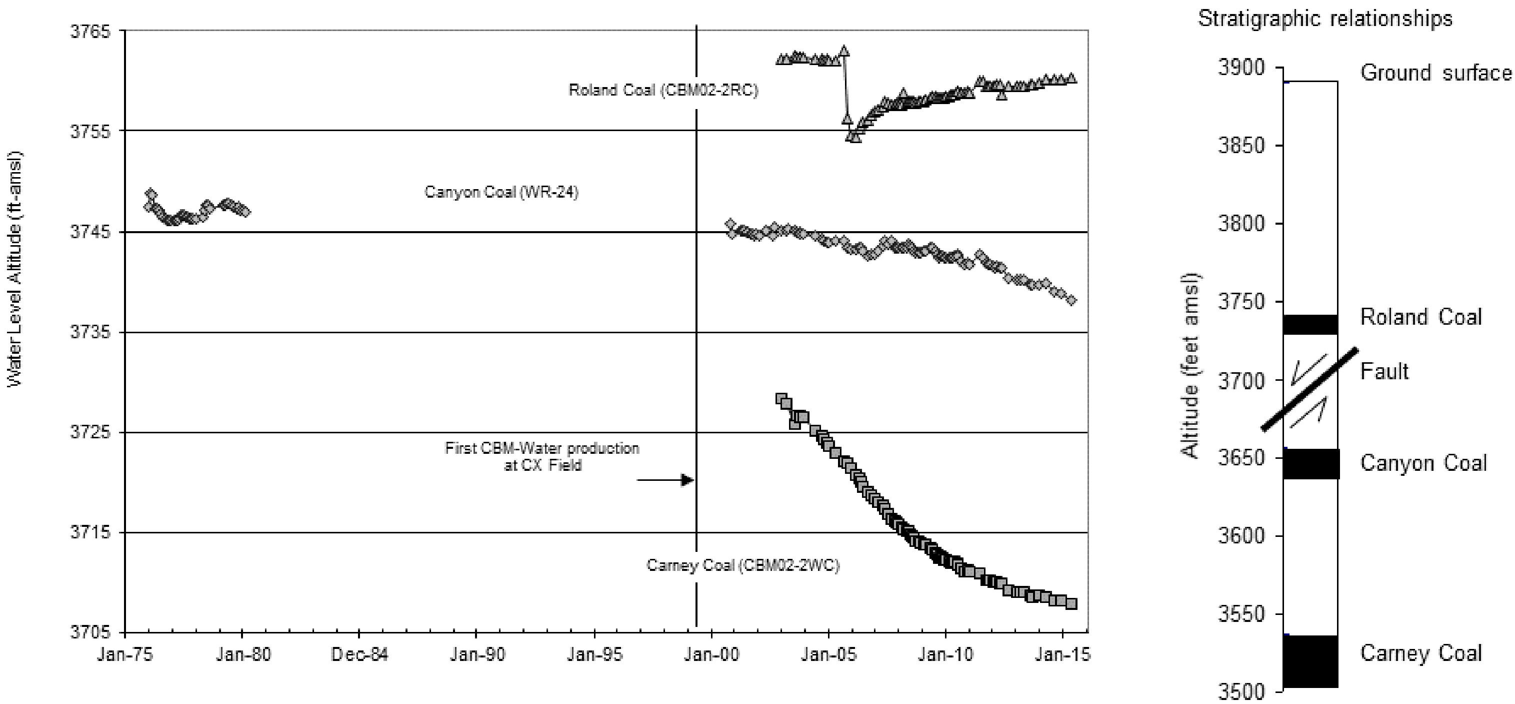


Figure 11. The decrease in water levels in the Canyon coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM-related drawdown since well installation. The Roland coal has not been developed for CBM production and the cause of the sharp water-level decline followed by slow recovery in 2005 is unlikely to be related to CBM activity. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.

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 but began to recover in early 2006. Recovery has not yet reached pre-2005 elevations. The cause of the water-level change in the Roland coalbed is not apparent, but it is not likely related to CBM development because the quick decline in 2005 followed by slow recovery has not been observed in the CBM-responsive 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 coalbeds (fig. 12). From 2003 to 2008 the water-level drawdown temporarily increased, particularly in the Dietz 2 coalbed, in response to nearby CBM production. Since 2008, water levels in wells WRE-12 and WRE-13 have resumed rates of decline similar to that caused by coal mining alone. Water levels in well PKS-1179, in the Dietz 2 coalbed, are currently recovering, but are still about 40 ft below where expected from coal mining alone. The large drawdown in the deeply buried Dietz 2 aquifer is necessary to lower CBM production water levels to near the top of the aquifer. The lowest water levels in all three wells are near or at the top of their respective coals.

Changes in Tongue River Reservoir stage affect water levels in aquifers, such as the Anderson–Dietz coalbed, that underlie the reservoir. Water levels in the Anderson–Dietz coalbed south of the reservoir showed annual responses to reservoir stage levels, but water levels are more strongly influenced by mining and CBM production when these stresses are present (fig. 13). Since January 1995, the reservoir stage has ranged between 3,387 and 3,430 ft amsl (written commun., Brandon Watne, MT DNRC, December 14, 2015). Average reservoir stage during this time has been about 3,422 ft amsl, which is higher than the current Anderson–Dietz potentiometric surface. Pre-mining water levels in well WRE-13, completed in the Anderson–Dietz coalbed, were higher than average reservoir water levels before the reservoir level was raised in 2007. Without the drawdown caused by mining and CBM, the Anderson–Dietz coalbed could have switched from losing water to the Tongue River to gaining from the Tongue River after 2007. The average stage during water year 2015 was 3,423 ft amsl, which is approximately the same as the historical average. The increased storage elevation steepens the gradi-

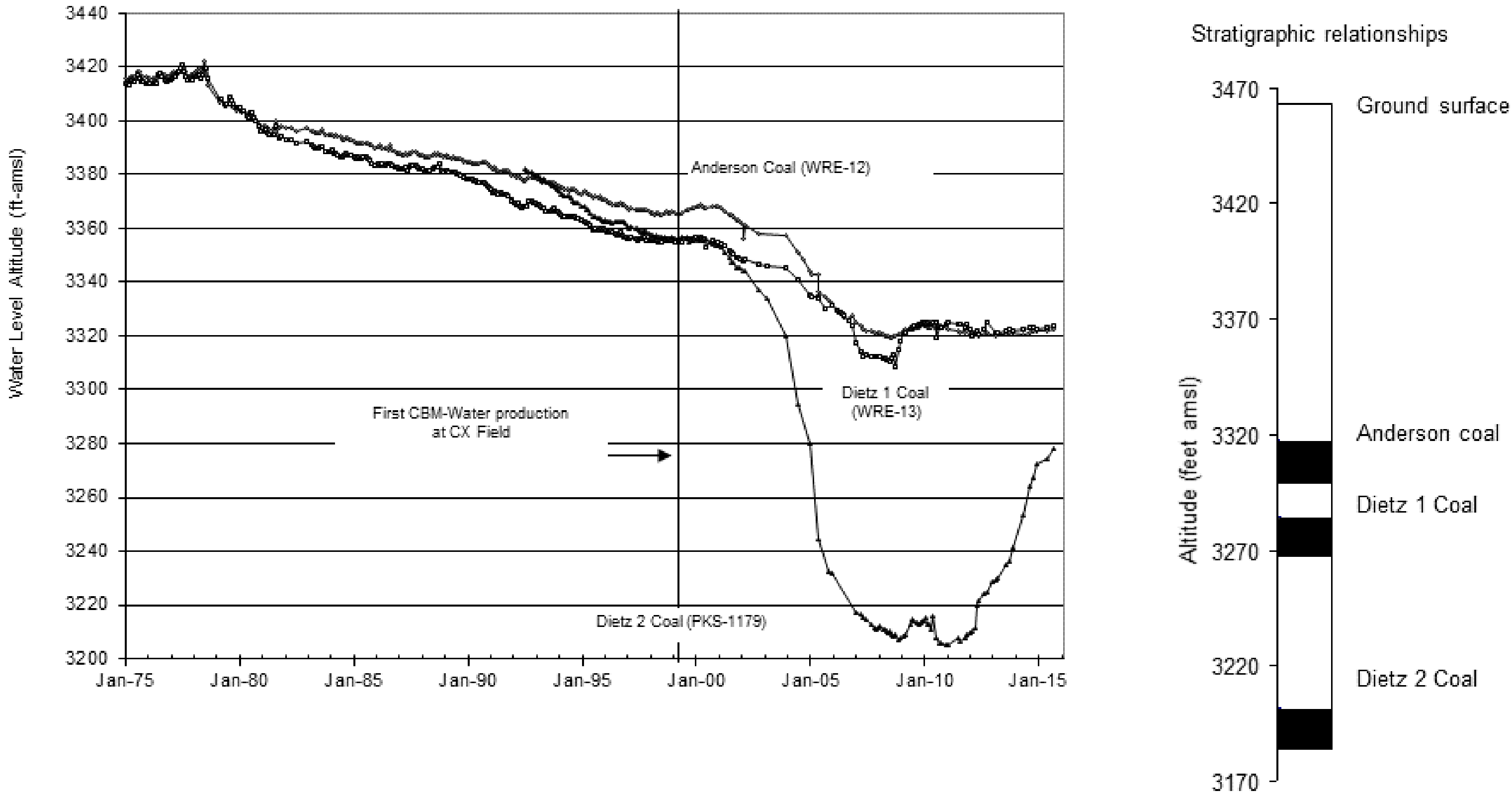


Figure 12. CBM production requires drawdown to near the top of the producing zone; this is the case for wells WRE-12, WRE-13, and PKS-1179. The three coal seams have water-level elevations just above their tops. Well PKS-1179 has been recovering.

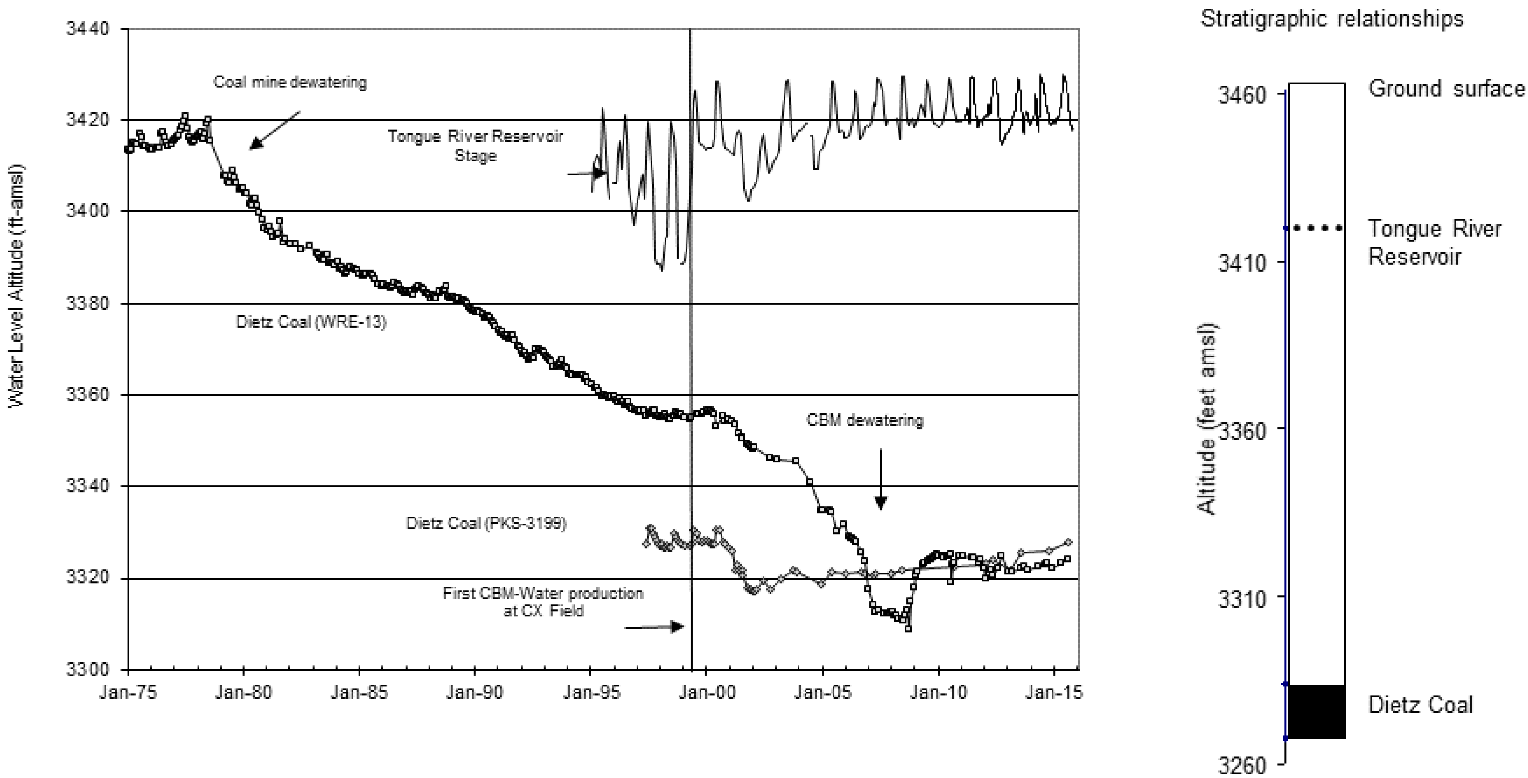


Figure 13. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Anderson–Dietz coal (WRE-13 and PKS-3199) prior to mining and CBM production. Since 1979, coal mining and CBM influences dominate the hydrographs. Note: the vertical scales of the stratigraphic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

ent between water levels in the reservoir and water levels in the Anderson–Dietz coalbed, 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). Periodic water-quality sampling, for example from well WRE-13, identifies this influence (Meredith and others, 2010).

By 2000, water levels in the Squirrel Creek watershed (fig. 14) in well WR-17, completed in the Anderson–Dietz coalbed, had been lowered 37 ft by coal mine dewatering and an additional 30 ft by CBM development. However, monitoring was suspended at that time because of methane gas in the borehole. The well was revisited again in September and December 2014 and found to still be producing gas. Declining water levels (over 8 ft since the year 2000) in the Anderson–Dietz overburden at this site (well WR-17B) show possible migration of water-level drawdown because of CBM production from underlying coalbeds and coal mining. However, this sandstone aquifer is separated from the Anderson–Dietz coalbed by more than 50 ft of shale, siltstone, and coal. Water levels in the shallow, unconfined sandstone aquifer (well WR-17A) show a rapid 30-ft rise at the time CBM production started in response to produced water holding pond infiltration. In 2005 the discharge to the pond was discontinued and water levels in WR-17A have returned to near baseline. The deep sandstone aquifer (WR-17B) at this site shows no response to the infiltration pond.

Monitoring of the Wall coal aquifer near the Coal Creek and Dietz fields shows that water levels were lowered about 12 ft between April 2005 and May 2007 (fig. 15). The nearest producing CBM wells are more than 4 mi away from monitoring site CBM02-4WC and 1.5 mi away from a Wall coal monitoring well in the Paradox field. CBM production in the immediate area was discontinued in March 2007 and water levels in well CBM02-4WC recovered through October 2007. Since then, water levels in CBM02-4WC and Paradox 11-7W have fluctuated in response to water pumped intermittently from CBM wells completed in the Wall coalbed along the Tongue River (2.5 mi away). CBM development in the Wall coal may be impacting water levels in CBM02-4WC and

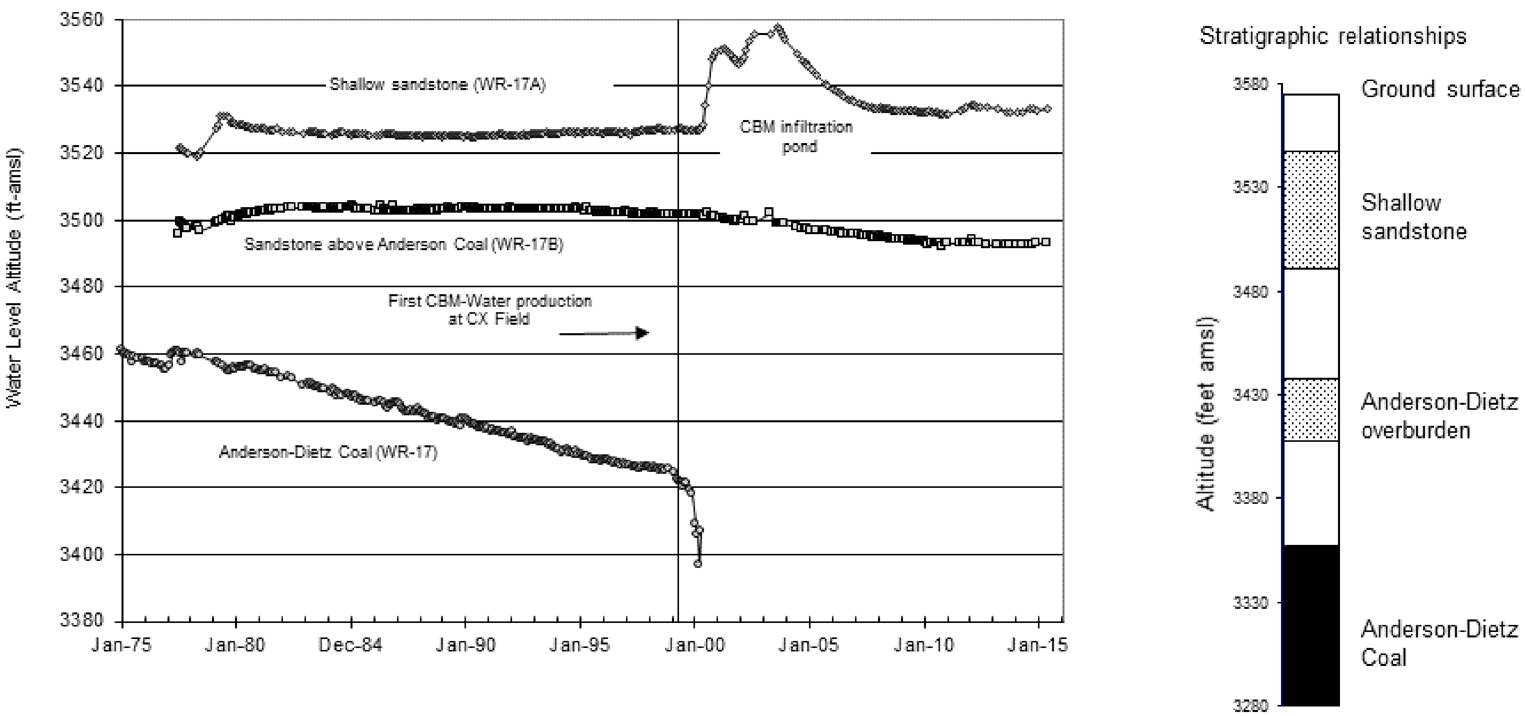


Figure 14. The water table rise in 1999 at WR-17A is in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water; therefore the water level in this aquifer dropped. Recently, water levels have shown a slight increase. Water-level trends in the Anderson overburden (WR-17B) in the Squirrel Creek area may relate either 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.

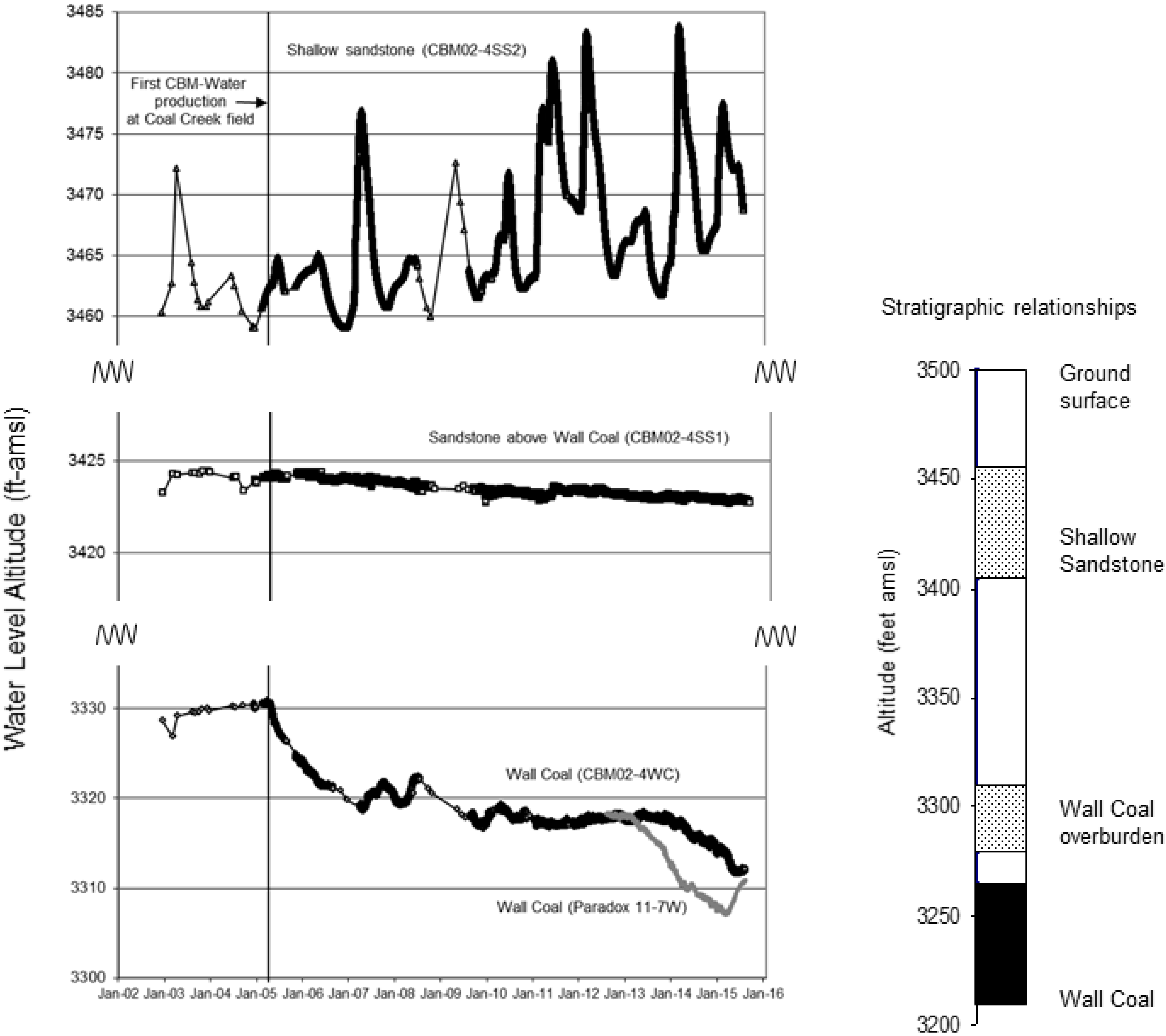


Figure 15. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water levels in the Wall coal (CBM02-4WC and Paradox 11-7W) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in water level that might be related to either 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.

Paradox 11-7W, and recent water levels indicate the aquifer is recovering. Water-level declines in the overlying sandstone aquifer (CBM02-4SS1; fig. 15) indicated slow vertical leakage into the drawn-down Wall coal aquifer.

Water quality. Upper and Lower Anderson Springs within the current CBM producing area were sampled in September 2014 and May 2015 (appendix C). Both springs discharge from the Anderson coalbed. The chemistry of Lower Anderson spring water is relatively constant, with TDS concentrations of 1,579 and 1,487 mg/L and SAR values of 3.07 and 2.90 for the two sample dates, respectively. Upper Anderson Spring is more variable. TDS values were 3,918 and 4,012 mg/L and SAR values were 8.02 and 6.93 for the two sample dates, respectively. The water-quality and flow 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 October 2014 and May 2015 (appendix C) from well WR-59, completed in the Squirrel Creek alluvium near the Squirrel Creek–Tongue River confluence (fig. 16). The TDS concentration was 17 percent higher in June 2009 than in June 1991. The SAR value increased from 5.6 to 6.4 during approximately the same time period (fig. 16). However, continued monitoring from 2009 through 2015 illustrates the variable groundwater quality at this site. The periodic increases in salinity and SAR appear to be a natural cycle. The record from WR-59 is a good example of the importance of long-term monitoring when attempting to distinguish natural variability from development-related impacts. The alluvial groundwater chemistry is dominated by sodium, magnesium, and sulfate.

Hanging Woman Creek enters the Tongue River near the town of Birney approximately 20 mi north of the Montana–Wyoming state line. Near the confluence, well HWC86-7 is completed in the Hanging Woman Creek alluvium (fig. 17) and was sampled in September 2014 and May 2015. Since sampling began in 1987, TDS and SAR in the alluvial groundwater have generally increased. Future monitoring will be required to determine if the elevated values represent an impact to the aquifer or a temporary change. Because water-quality monitoring sites closer to CBM development than HWC86-7 have not shown similar increases (e.g., HWC 86-2, -13, and -15), it is unlikely that these changes are related to CBM development.

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, water and gas production data for all CBM wells located in Wyoming townships 57 N. and 58 N. were considered (plate 1). This report refers to CBM producing areas near the state line such as the Prairie Dog Creek field, Hanging Woman Creek field, and the Powder River field (fig. 18 and 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) coalbeds (appendix D). At the end of 2015, there were no producing CBM wells in the Prairie Dog Creek field, a decrease of 220 wells since 2014. Production ceased in July; up to that point 10 million bbls (table 1) of water were produced during 2015. Monthly water production in the field peaked in mid-2002 at nearly 7 million bbls per month (fig. 18). Gas production rose fairly consistently until early 2008 but fell steadily until July 2015 when the field was shut-in (fig. 18).

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, SM Energy (previously called St. Mary Land and Exploration and 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). At the end of 2015, there were no producing CBM wells in the Hanging Woman Creek Field, a decrease of 113 wells since 2014. Production ceased in July; up until that point the field had produced 4.3 million bbls (table 1) during 2015. Water production peaked in September 2007 at 2.5 million bbls/month (fig. 18).

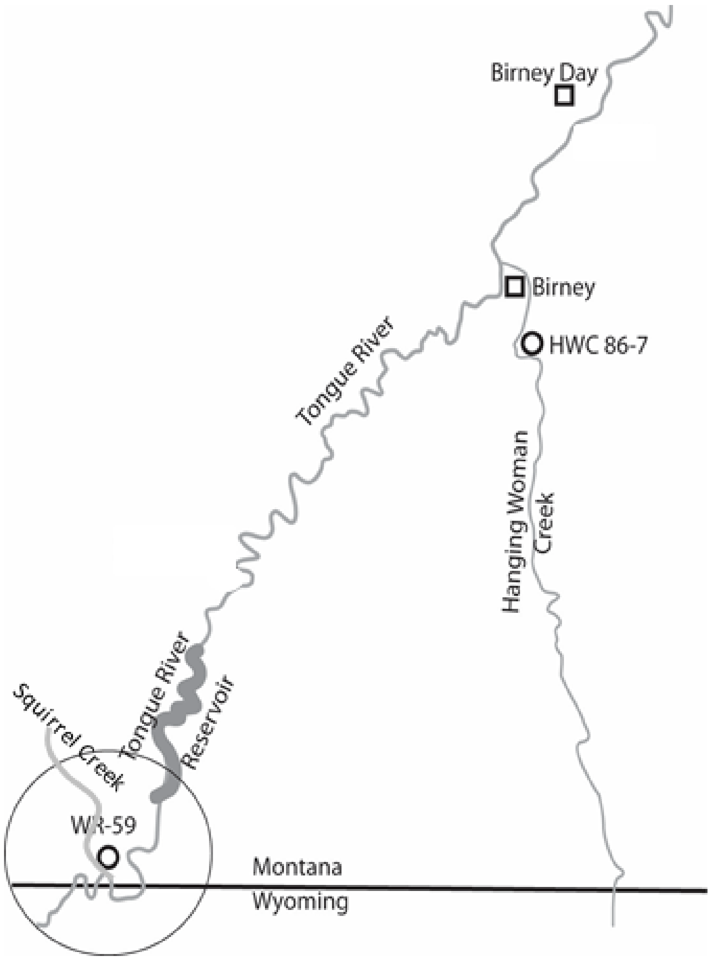
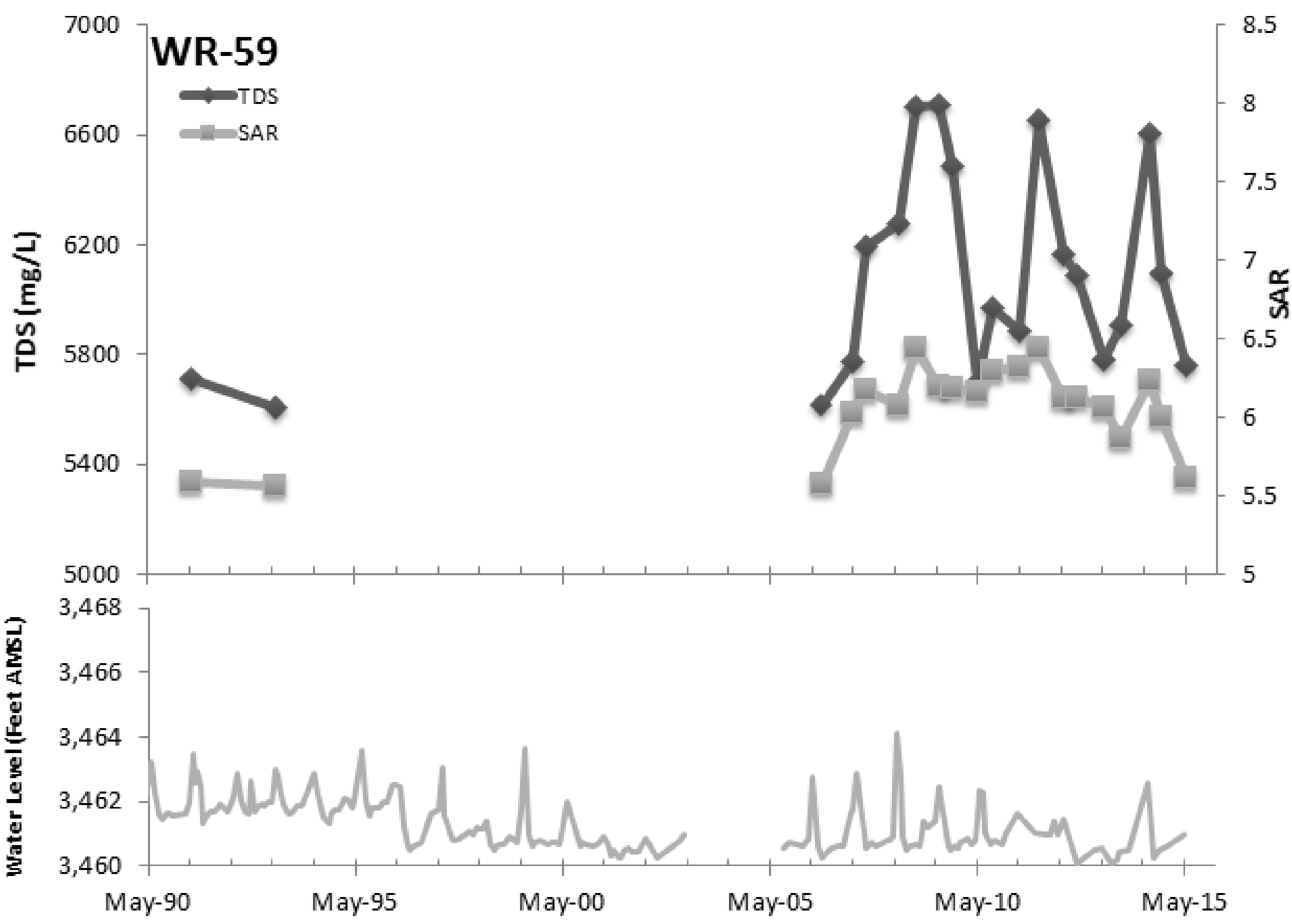
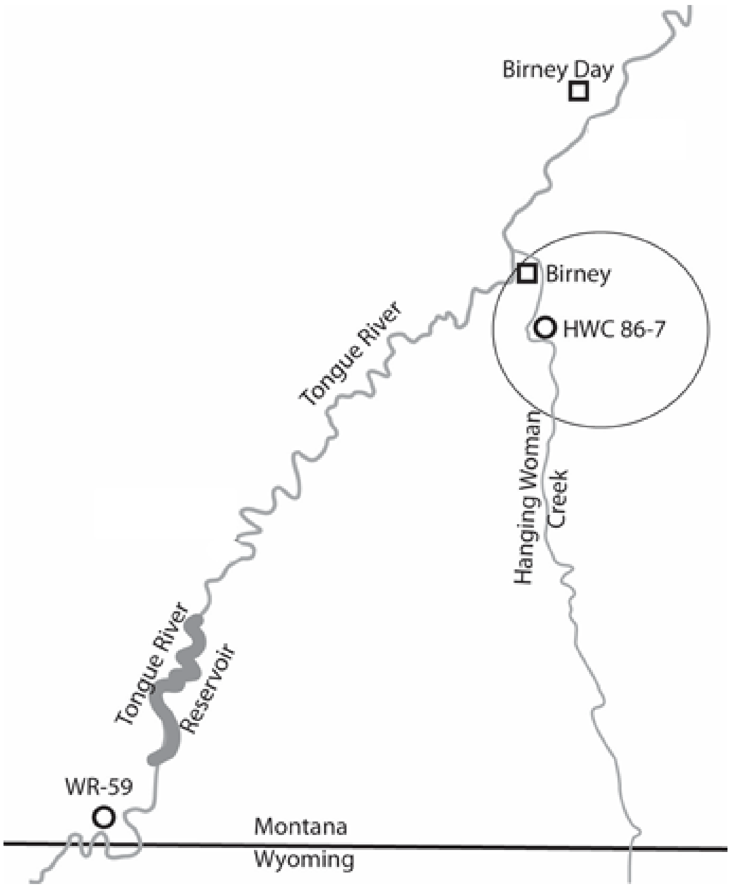


Figure 16. TDS, SAR, and water level/stream discharge for well WR-59 near the Squirrel Creek–Tongue River confluence and for the Tongue River at the state line.





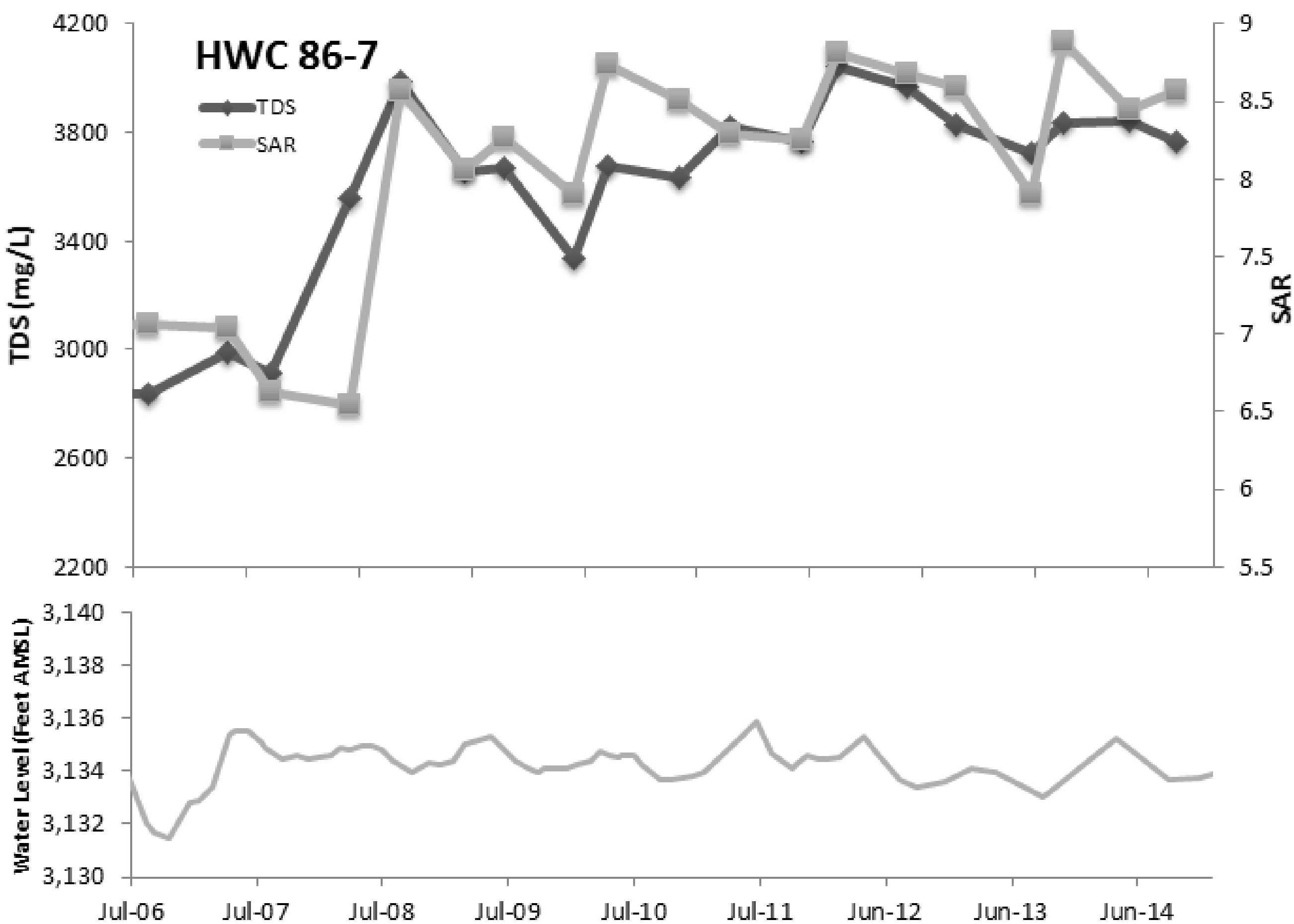


Figure 17. TDS, SAR, and water level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.

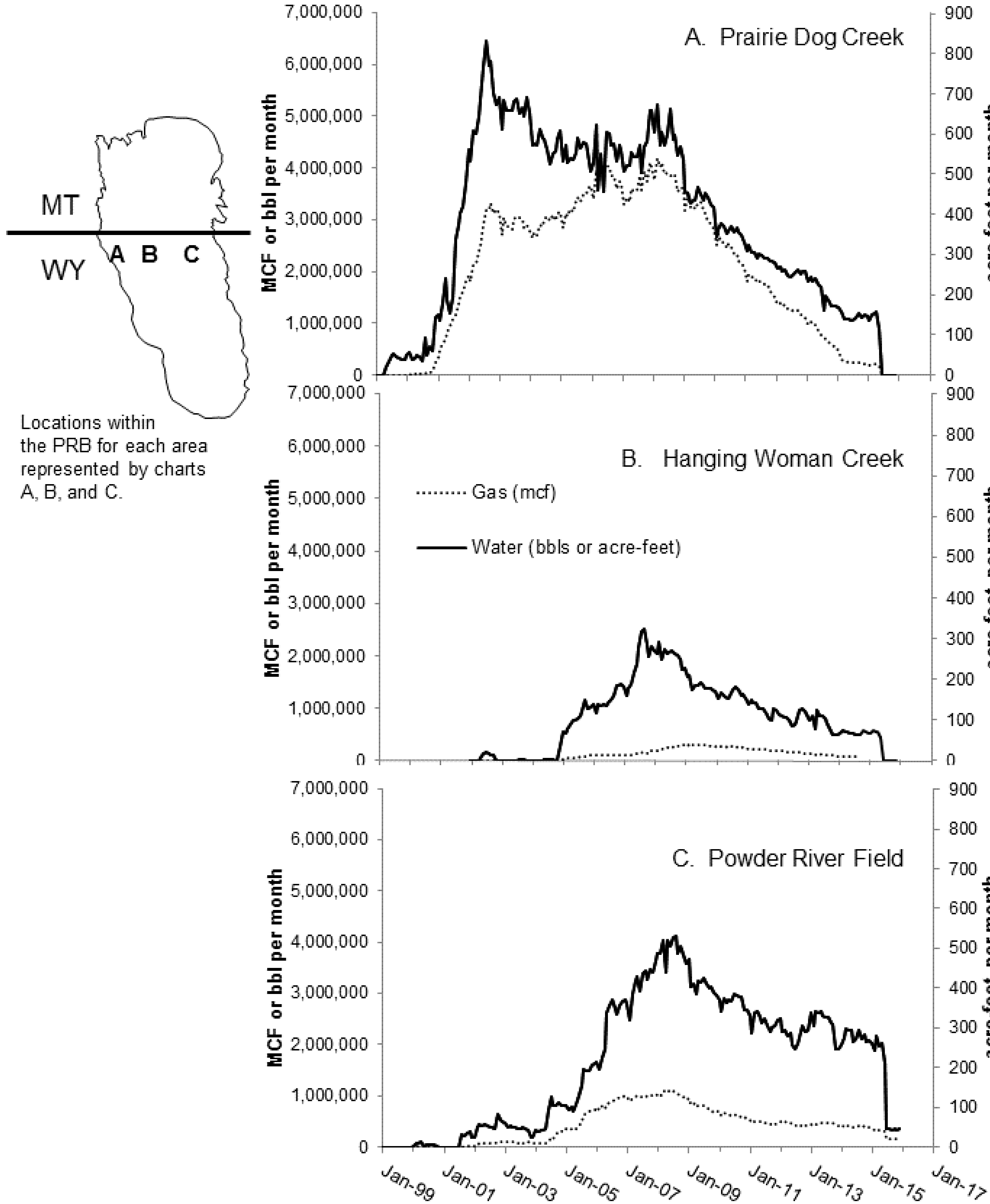


Figure 18. Total water (solid line) and gas (dashed line) produced per month in northern Wyoming CBM fields T. 57 N. and 58 N.

Bedrock-aquifer water levels. Drawdown caused by 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 coalbeds (fig. 19). Water levels in the alluvium overburden sandstone and Smith coalbed do not respond to CBM production (fig. 20). The water level in the Anderson coalbed has dropped 58 ft, and in 2012 and 2013 has been fairly consistently 10 ft higher than its lowest altitude. In 2014 and 2015 water-level declines have resumed. The slowed rate of declining water levels is likely a response from Wyoming CBM wells being shut-in. The water level in the Canyon coalbed has dropped about 145 ft due to CBM production since monitoring began in May 2005.

Monitoring well site SL-4 is located about a mile north of the nearest CBM well in the Hanging Woman Creek gas field (plate 1). Monitoring wells at this site are completed in the alluvium, and in the Smith and Anderson coalbeds (fig. 21). The water level in the Anderson coalbed responds to CBM production in Wyoming and is currently 78 ft lower than when monitoring began (fig. 22). The water level in the Smith coalbed has also dropped slightly; the high-frequency oscillations are caused by pumping in nearby wells for stock watering or cistern filling. However, since 2012 the pumping signal has stopped, indicating the nearby well(s) are no longer used. Water levels have begun to recover, supporting the hypothesis that drawdown was related to local uses (Meredith and Kuzara, 2015). This monitoring well is located approximately 150 ft from the Forks Ranch Headquarters well, which was completed in the Smith coalbed in June 2006.

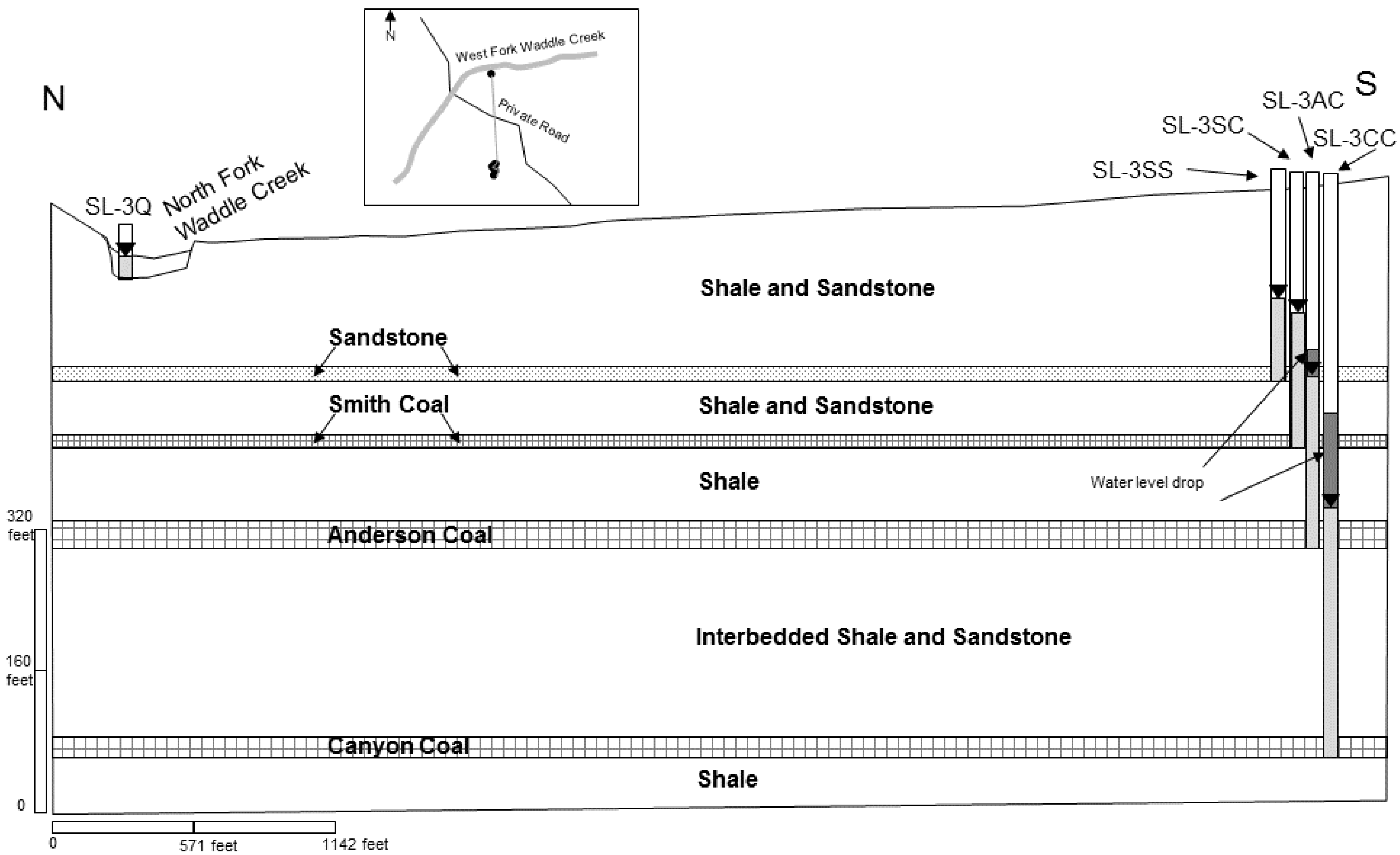


Figure 19. Geologic cross section for alluvium, an overburden sandstone; Smith, Anderson, and Canyon coalbeds located at T. 9 S., R. 42 E., sec. 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2015. The water level in the Anderson coal has lowered about 58 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 145 ft since well installation. The wells are located roughly 1 mi north from nearest CBM field. Vertical exaggeration is 3.6:1.

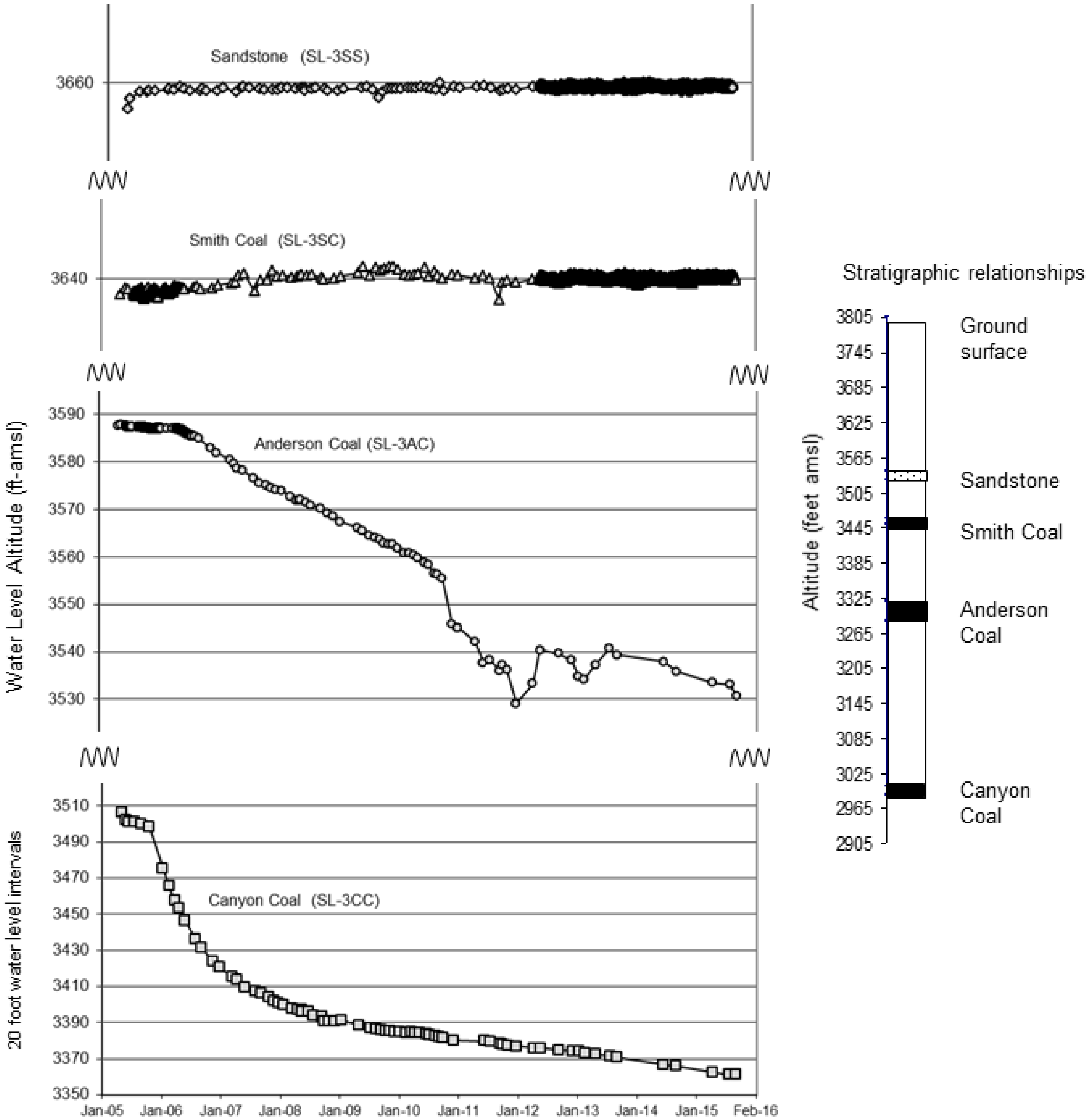


Figure 20. Water levels in the overburden sandstone (SL-3SS) and Smith (SL-3SC) coals are not responding to CBM development. The water level in the Canyon coal dropped about 145 ft in response to CBM production. The water levels in the Anderson coal had a maximum drop of about 58 ft in response to CBM production. The water levels fluctuated in 2012 to 2013 in response to nearby CBM wells being shut-in, and recently the water levels have been declining. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different. The Y axis scale is broken to show better hydrograph detail.

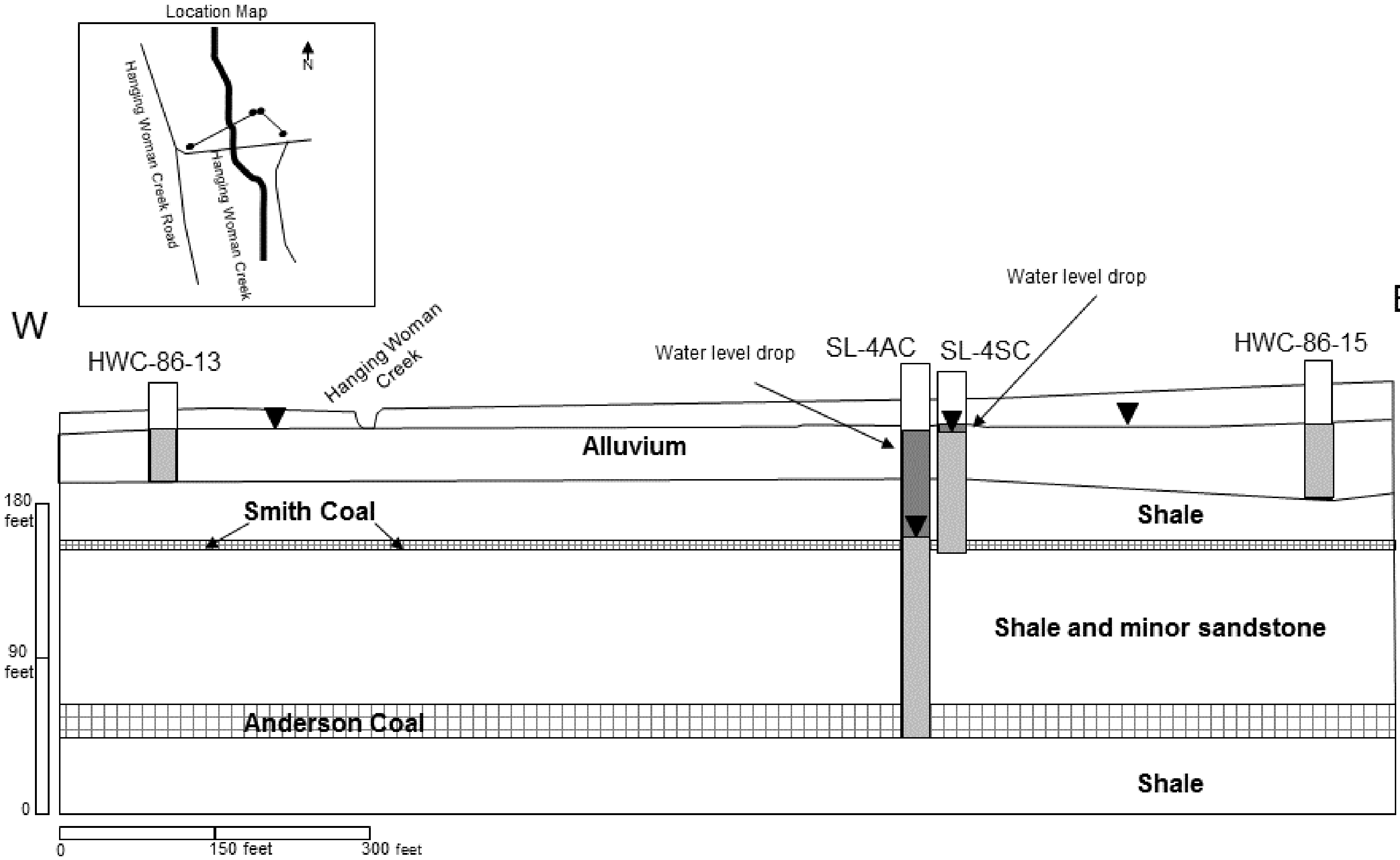


Figure 21. Geological cross section for the alluvium and bedrock wells near the Montana/Wyoming state line on Hanging Women Creek located in T. 10 S., R. 43 E., sec. 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson coal and Smith coal have lowered in response to CBM production. The Anderson has lowered by about 78 ft. Water levels in the Smith coal had lowered about 17 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 2015. Vertical exaggeration is 7:1.

Monitoring well site SL-5 is located to the northeast and approximately 4 mi distant from the Hanging Woman Creek Field, which produces CBM from the Anderson, Canyon, Cook, Kendrick, and Roberts coalbeds in Wyoming (plate 1). The Anderson and Canyon coalbed monitoring wells at this site appear to be hydraulically connected, and the water levels are slowly equilibrating (fig. 23). The increasing water level in the Canyon coalbed and decreasing water level in the Anderson coalbed may be a result of a failed annular seal in the Canyon coal well allowing communication along the well bore between the Canyon and the higher water pressure in the Anderson coal. Alternatively, it may be that a nearby well has allowed the two aquifers to communicate. The nearest producing well in 58 N., 79 W., sec. 24 (API 49-033-26223, in Wyoming) is completed in the Anderson, Canyon, and Cook coalbeds. There is no noticeable trend in Dietz coal aquifer 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 alluviums near the state line at monitoring sites SL-3 and SL-4 do not interact hydrogeologically with the Anderson and Smith coalbeds (fig. 20). Changes in alluvial water levels reflect responses to seasonal weather patterns (appendix E-9 and E-10).

Water-quality samples were collected from alluvial wells HWC 86-13 and HWC 86-15 during October 2014 and May 2015 (appendix C). Water from HWC86-13 contained TDS from 6,462 to 6,285 mg/L and SAR values from 10.94 to 10.58, respectively. Water from well HWC 86-15 contained TDS from 8,434 to 8,200 mg/L and SAR values from 10.96 to 10.58, respectively. Sodium and sulfate dominate the alluvial water chemistry. Salinity in the groundwater has a natural variation of approximately 1,000 mg/L (GWIC, 2015).

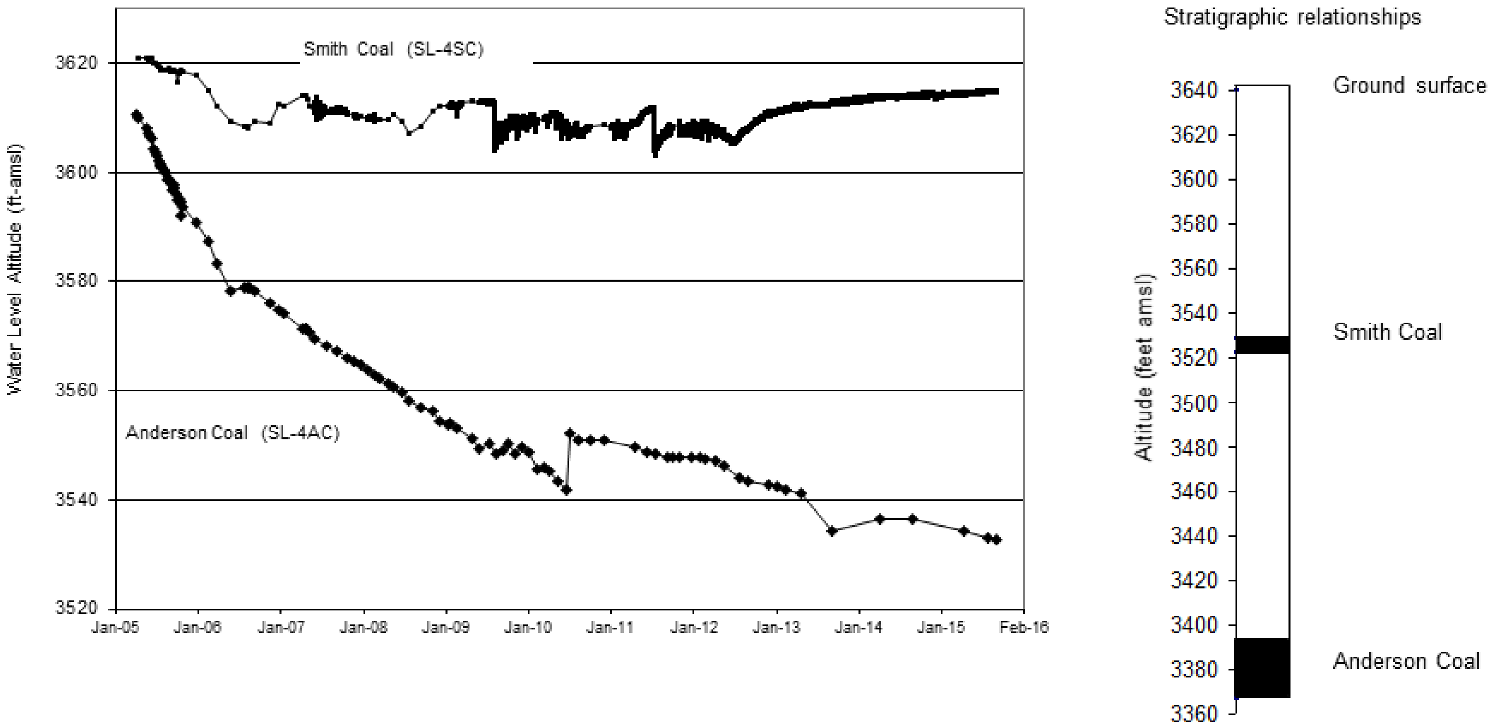


Figure 22. The SL-4 site is located about 1 mi north of the nearest CBM field. Water levels in the Anderson coal appear to have lowered about 78 ft from April 2005 to September 2015 in response to CBM development; however, it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft; this is presumably due to activities in the nearby CBM field. Water levels in the Smith coal have decreased and currently increased, but a clear relationship to CBM has not been established. Water production from CBM wells in this field began during November 2004. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.

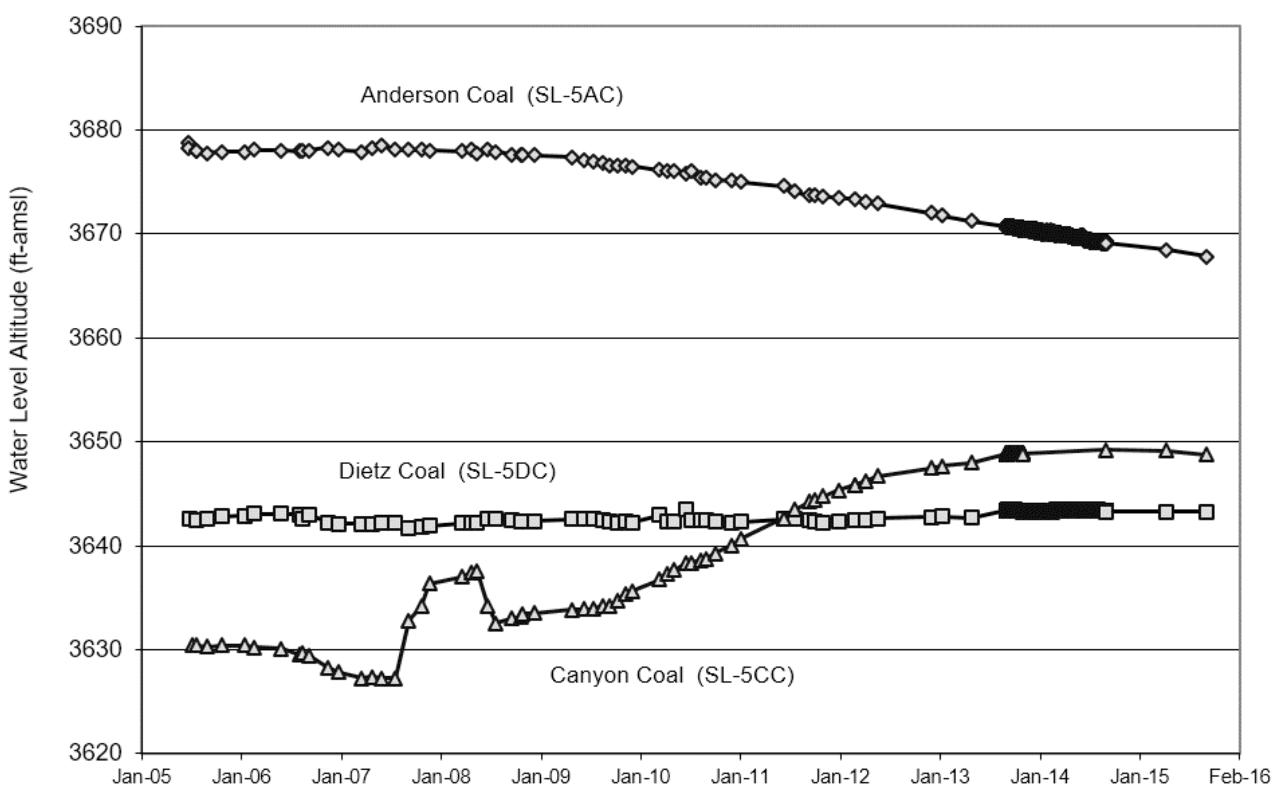


Figure 23. The increasing water level in the Canyon and decreasing water level in the Anderson may be a result of a failed seal in the neat cement in the Canyon coal well causing communication along the well bore. Alternatively, it may be that a nearby well has allowed the two aquifers to communicate.

Gas Fields near the Powder River

Methane and water production. Near the Powder River (plate 1), CBM is being produced from the combined Anderson and Dietz (Wyodak), Canyon, Cook, Wall, Pawnee, and Cache coalbeds (appendix D). At the end of 2015, 148 wells produced methane and/or water, a decrease of 287 wells since 2014. The cumulative water production for the 12-month period was 19 million bbls. Water production in these fields increased steadily from January 2004 through July 2008, peaking at just over 4 million bbls per month. Water production dropped substantially in July 2015 from around 2,500,000 to around 350,000 bbl/month (45 acre-ft; fig. 18).

Bedrock-aquifer water levels. Monitoring well SL-7CC is completed in the Canyon coalbed 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 vented gas is due to naturally migrating methane.

Two monitoring wells at site SL-6 are located 6 mi west of SL-7CC. Well SL-6CC is completed in the Canyon coalbed and releases gas like well SL-7CC. For personnel safety, water levels are not measured at SL-6CC. Well SL-6AC is completed in the Anderson coalbed and data collected to date show no CBM-related water-level changes or gas releases.

New monitoring wells completed in the Knobloch and Brewster–Arnold coals were installed at the SL-8 site in July 2013 (fig. 24). The Knobloch coalbed well flows at the land surface and required installation of a downhole packer/pressure transducer equipped with a direct read cable below the frost line to acquire water-level measurements. Water pressure in the Knobloch coalbed has fallen slightly during the same time that the Brewster–Arnold coalbed groundwater level has remained constant (fig. 25). The nearest producing CBM wells (58 N., 75 W., sec. 20; Wyoming) are completed in the Wall and Pawnee coals, but one producing CBM well is completed in the Canyon, Cook, Wall, and Pawnee coalbeds. However, naming conventions change across the state line, so it is difficult to determine where the nearest producing wells are located that could be influencing the monitoring wells at SL-8.

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. 24, 25). 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 October 2014 and May 2015 (appendix C). TDS were 3,396 and 2,083 mg/L and SAR values were 4.80 and 3.76, respectively. The water chemistry is dominated by calcium, sodium, and sulfate.

NATIONAL FOREST SYNOPTIC SAMPLING

During the falls of 2014 and 2015, the MBMG and the U.S. Forest Service (USFS) collaborated on a synoptic groundwater sampling program on the Ashland Ranger District of the Custer National Forest. The agencies selected 20 wells and springs that either are near the location of a potential coal mine or had not previously been sampled.

The groundwater chemistry predictably evolves from relatively young magnesium–bicarbonate water, to intermediate-age calcium–sulfate water, to mature sodium–bicarbonate water (fig. 26; Meredith and Schwartz, 2016). Alluvial water along Otter Creek is also a sodium–sulfate type, indicating recharge from bedrock. Water from Hedum Spring has a unique magnesium–sulfate composition, high salinity, and high levels of several trace elements of concern for drinking and stockwater. Results from other clinker-sourced springs indicate that care needs to be taken when using these sources for drinking water (human or stock). The water-quality results suggest that more extensive sampling of clinker aquifers would help to ascertain the extent of health threats.

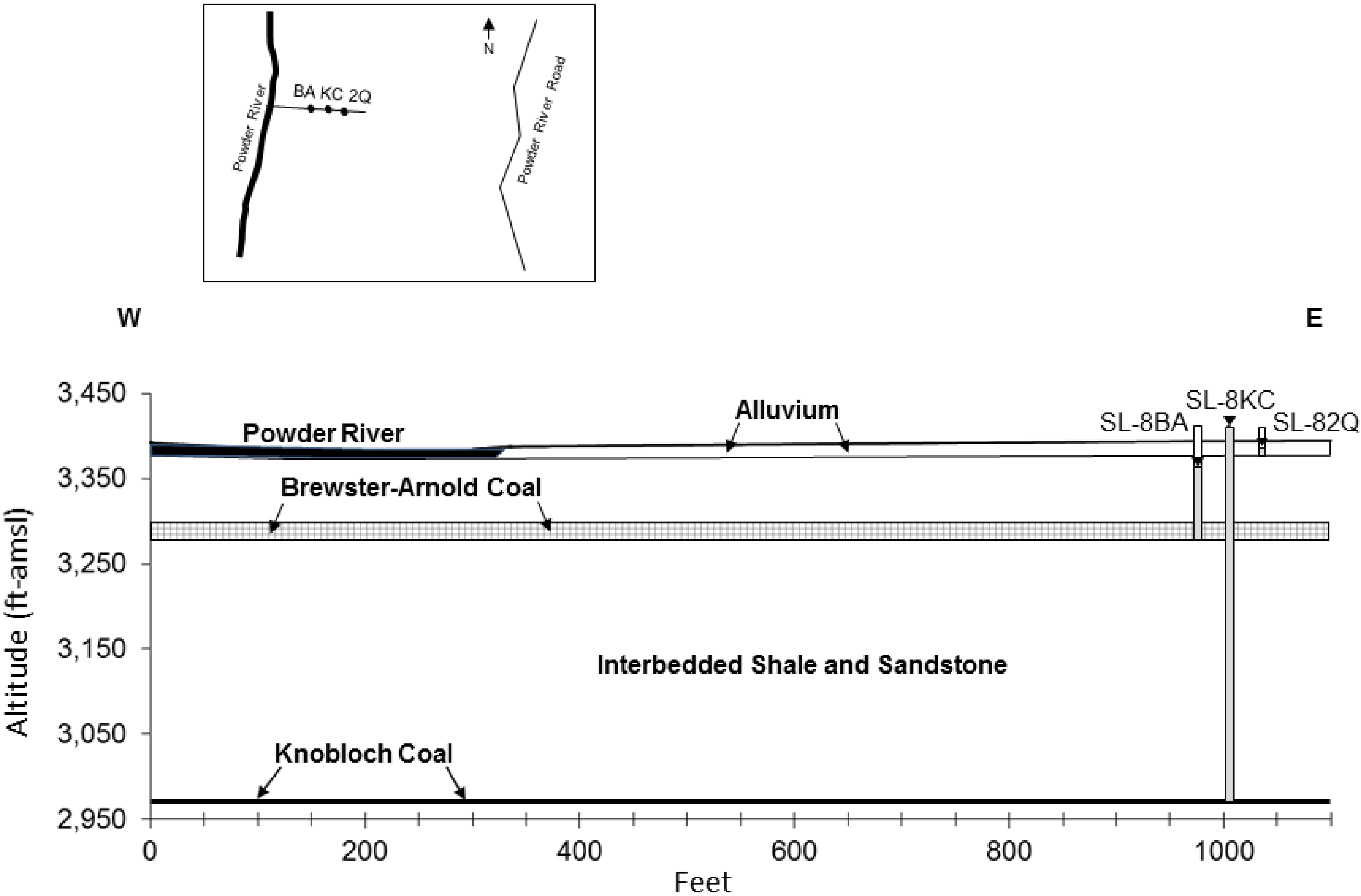


Figure 24. Cross section of the alluvial and coal aquifers south of Moorhead near the Powder River located in T. 09 S., R. 47 E., sec. 25. Groundwater in the alluvium appears to flow parallel to the river valley. An upward groundwater gradient exists between the Knobloch coal and the Brewster–Arnold and Alluvial aquifers. However, major interbedded layers of confining shale probably limit upward migration of groundwater. Water levels for this cross section were taken in September 2015.

HYDROLOGY OF THE BIG SKY MINING AREA

Mining starts at a coal outcrop with the mine operator removing any overlying material (overburden). Once the overburden is removed, the coal seam is mined, which leaves a long pit into which the spoils (the next section of overburden) are placed. The next section of coal is then mined to create a new pit. As mining progresses, overburden thicknesses generally increase and the mine operator will eventually determine the time when the cost of handling the overburden exceeds income from the coal. At that time the mine operator will close and backfill the final pit. Groundwater, which has been managed to keep the mine pits dry, resaturates the spoils during the next several years. A new groundwater flow system forms in the spoils aquifer to replace the coal aquifer removed by mining.

Overburden material is removed by breaking it into relatively small fragments with explosives. The mining equipment, typically draglines, digs downward from the top of the overburden to the coal; the overburden material is cast into the adjacent pit created by previous coal removal. When the mine is closed and a new groundwater system forms in the spoils, abundant quantities of water-soluble salts from the previously unsaturated overburden dissolve into the groundwater. Eventually, the soluble salts should be flushed from the system and water quality should approach pre-mining conditions (Van Voast and Reiten, 1988).

To better understand the process of reestablishing the hydrologic balance around coal mines, the MBMG has

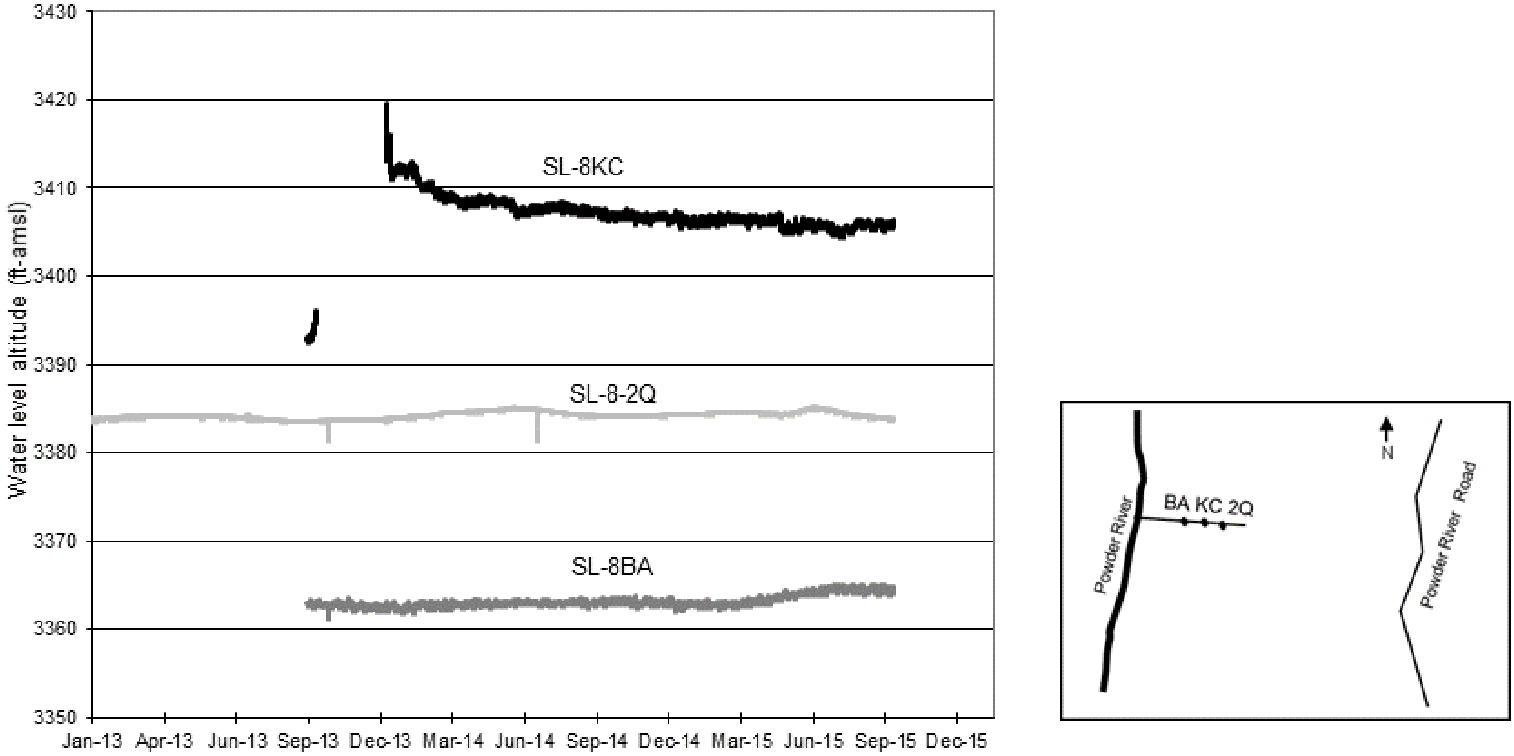


Figure 25. Groundwater flow in the alluvial aquifer at SL-82Q is roughly parallel to the Powder River. The groundwater level in the Knobloch coal has an upward gradient towards the alluvial aquifer. The cross-section for this site is displayed in figure 24.

monitored more than 100 wells in and around the coal fields in southeastern Montana since 1969. Selected wells are shown in figure 27. This long-term effort includes tracking water-level and water-chemistry responses to mining and reclamation. The intent is document impacts and recovery, and from those build predictive tools.

The Rosebud and Big Sky coal mines are located near Colstrip, Montana, and began mining in 1968 and 1969, respectively. The Rosebud Mine continues to actively extract coal from the Rosebud coal seam. The Big Sky mine targeted both the Rosebud and underlying McKay coal seams. Big Sky ceased mining in “Area A” in 1989 and has reclaimed the mine site. In March 2015, Big Sky mine Area A was one of the first mines to achieved Phase IV bond release in Montana (DEQ, 2015). Phase IV bond release means the reestablishment of essential hydrologic function has been achieved. Hydrologic function includes groundwater levels or flow, and groundwater quality.

Water-Level Responses

Water levels in the Rosebud and McKay coals dropped in response to dewatering of the advancing open mine pit (fig. 28). Monitoring wells located outside of the mined area reflect the expanding cone of depression. Water levels at monitoring well S-22, completed in the McKay coal, reflect the advancement of the mine pit as the Rosebud mine expanded westward. Water levels in this well, about 3,000 ft from the mine pit, have fallen about 20 ft.

Wells S-18 and S-19 are a nested set of wells monitoring the Rosebud and McKay coals, respectively. The open mine pit, which removes only the Rosebud coal, is now a little more than 2,000 ft from these wells. As the mine pit has advanced, the water levels in the McKay and Rosebud coals have dropped by more than 40 ft.

The monitoring shows that water levels in the underlying McKay coal have dropped more than those in the

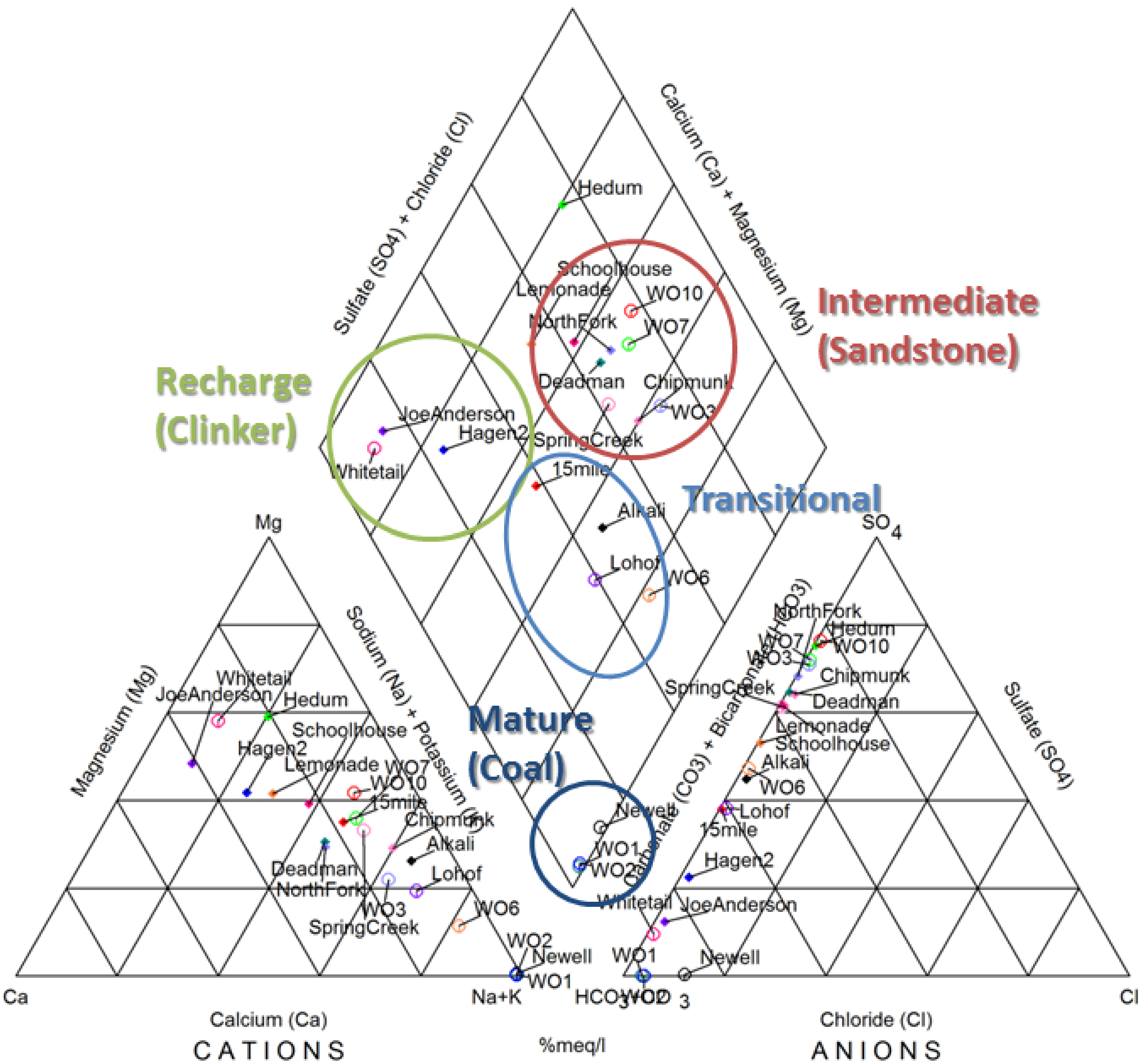


Figure 26. Spring and well sampling on the Ashland Ranger district found four distinct water types that are indicative of location along recharge pathways (from Meredith and Schwartz, 2016).

Rosebud coal. This phenomenon of larger water-level declines in deeper zones has been documented in several mining areas and may be due to decreasing aquifer storativity with depth (VanVoast and Reiten, 1988). Because the McKay coal is not physically disturbed, the water-level response may be caused by upward leakage through inadequately plugged exploration holes (Wheaton and others, 1994).

Water levels in the bedrock and spoils aquifers recover (fig. 29) as mining ends and the final pits are backfilled. Well BS-30 is completed in the Rosebud coal and nearby wells BS-28 and S-15 are completed in the spoils of the reclaimed Big Sky mine. The aquifer response showed complete resaturation over a 2- to 3-year period in the late 1970s as mining ceased. Water levels reached a new equilibrium and have remained relatively constant, showing a correlation with precipitation. Well BS-49 is in a different area of spoils and has not reached a new equilibrium. The cause for this long-term water level rise is not understood. This well also shows some correlation with precipitation.

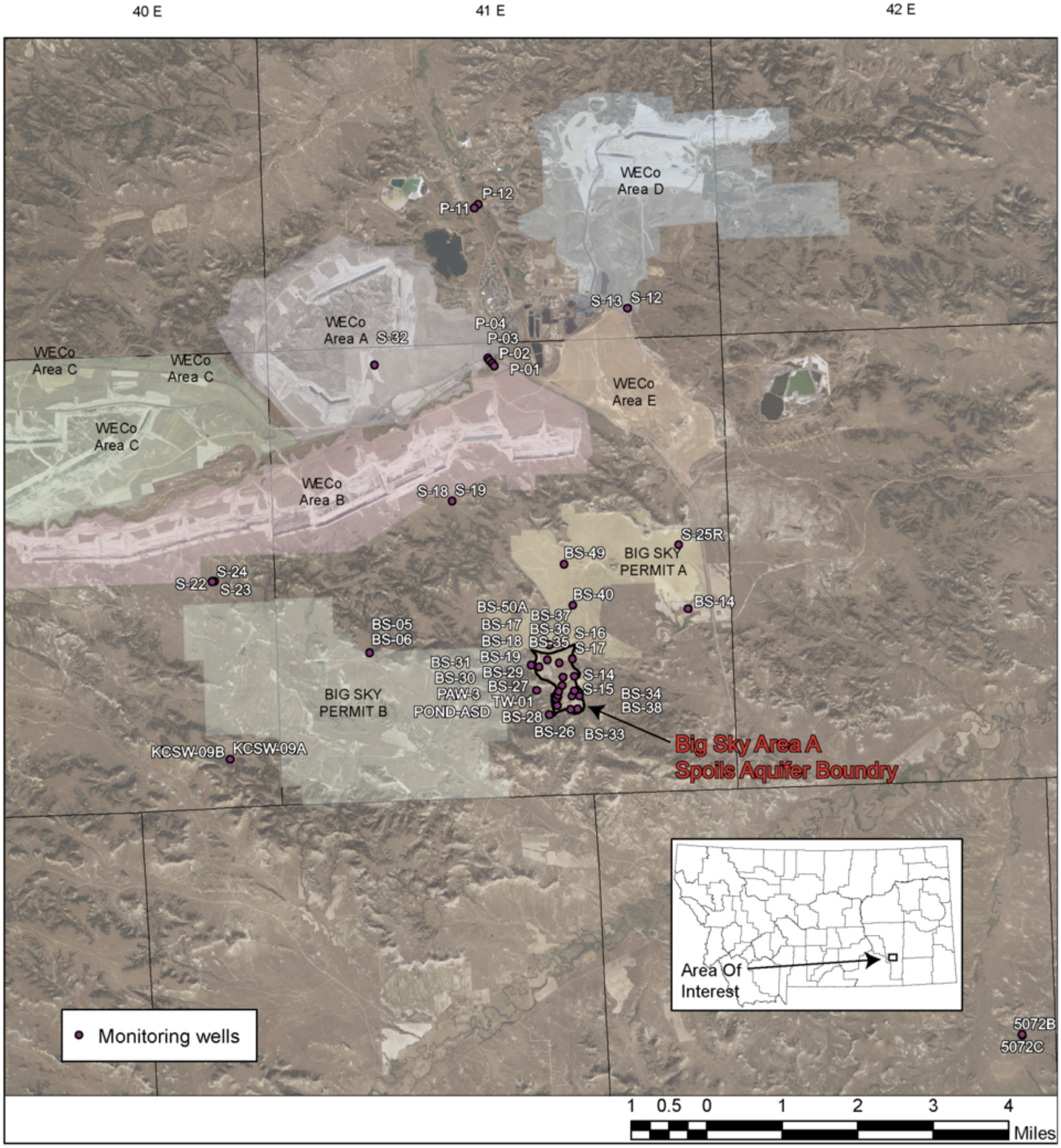


Figure 27. Monitoring wells in the Colstrip area.

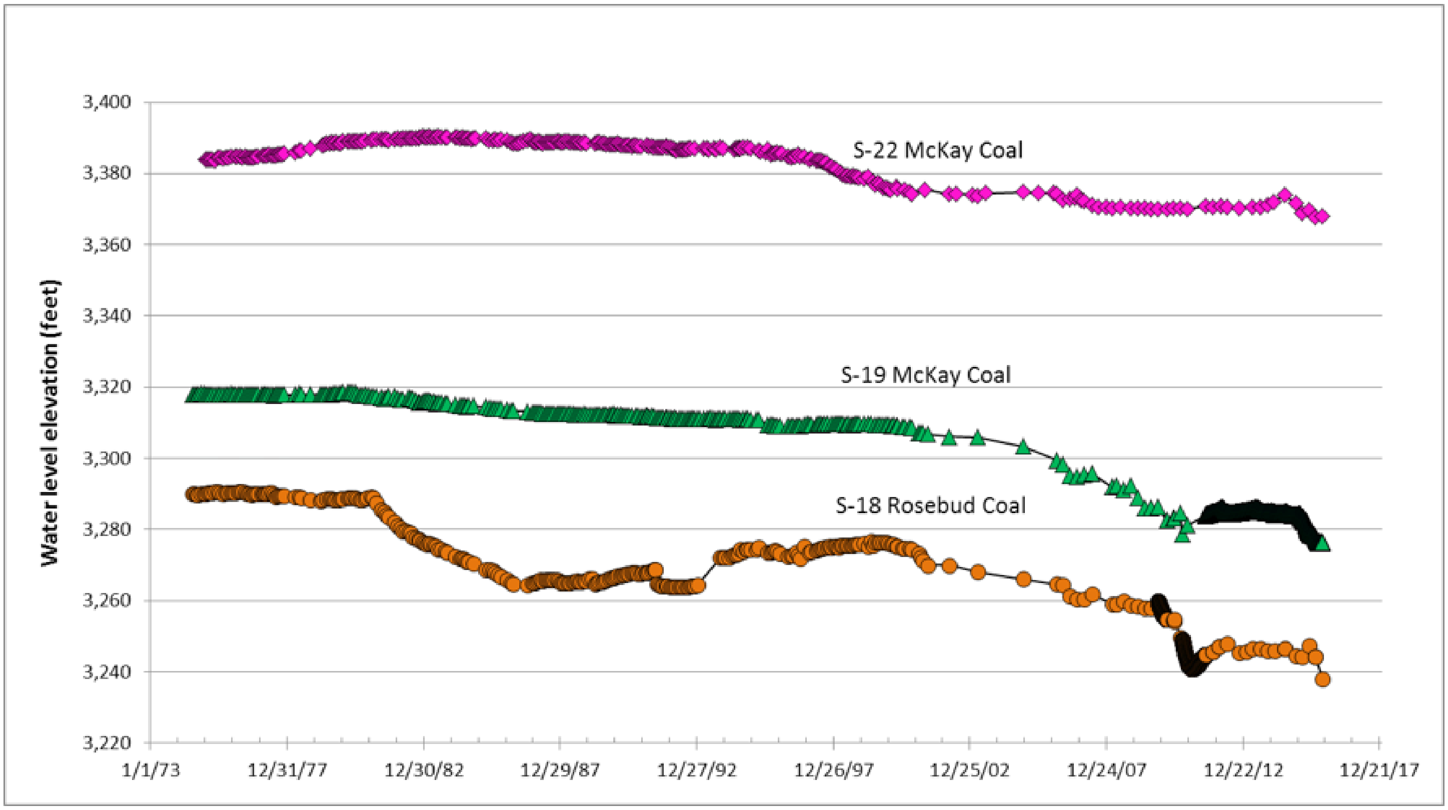


Figure 28. Water levels in coal aquifers decline in response to active coal pit dewatering.

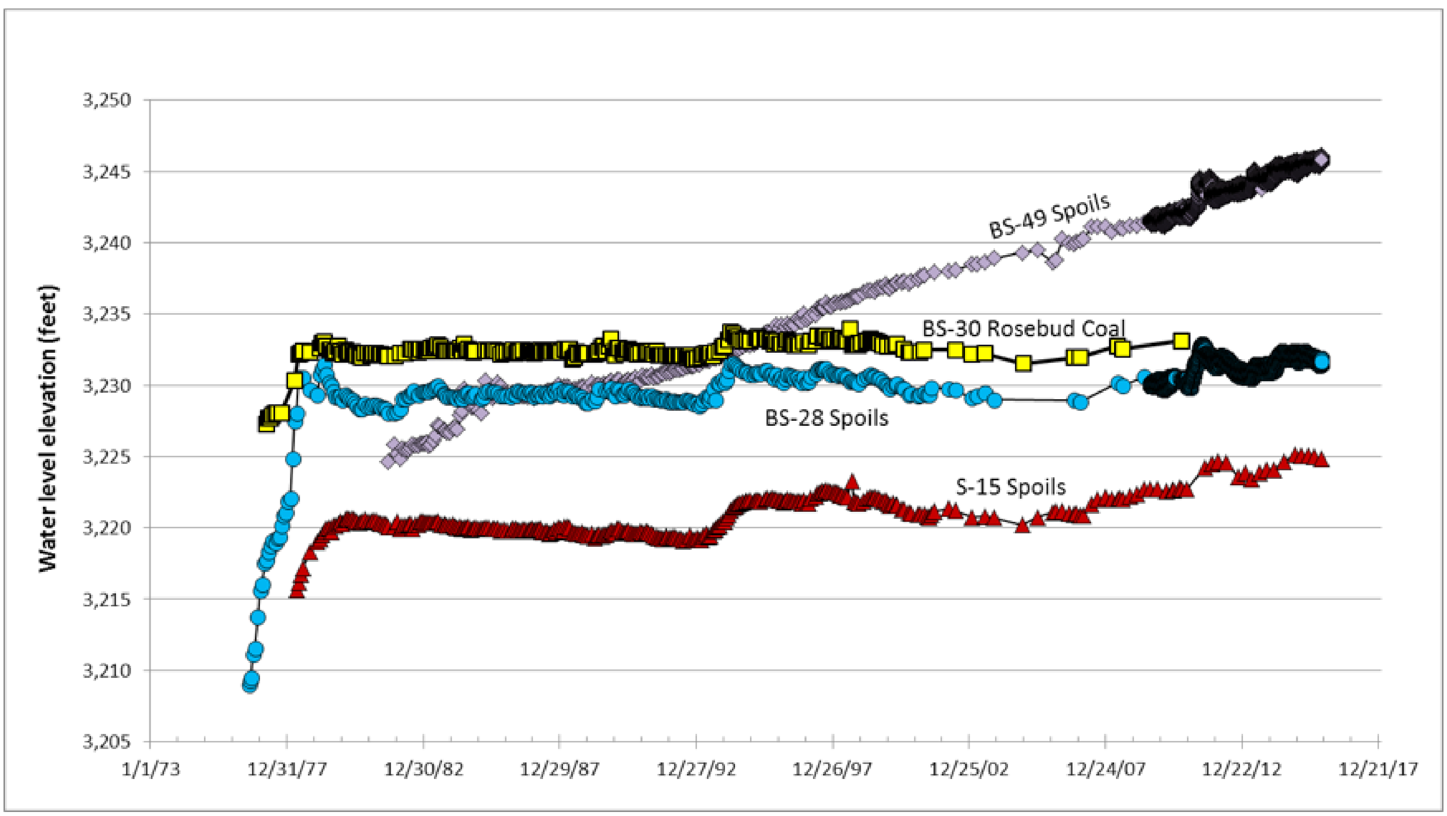


Figure 29. Water levels in spoils aquifers respond to mine reclamation in the Big Sky area.

Water Quality

Bedrock water quality near the Big Sky mine is typically Ca-Mg-SO_4 type, with a total dissolved solids (TDS) range of 438 to 4,406 mg/L and an average of 2,375 mg/L. Groundwater salinity, measured as total dissolved solids, is a good indicator of impact from mining and ultimate recovery of water quality. The area with the longest record of water-quality monitoring since mine reclamation is in the southern portion of the Big Sky Mine near the final pit impoundment, Pond A (fig. 27). In the 1970s, groundwater in the newly formed spoils aquifer had TDS that ranged from 2,800 to 6,000 mg/L (fig. 30A). Groundwater flows from approximately west, from Pond A, to east–northeast. The highest concentration of 6,000 mg/L occurs north of the Pond A area near another spoils region to the northwest. The lowest TDS water is near Pond A and reflects bedrock recharge and precipitation recharging through Pond A.

Twenty years later, in the 1990s (fig. 30B), groundwater monitoring shows the TDS load being flushed from the flow system. The area that had groundwater with TDS greater than 5,000 mg/L now has TDS of 3,800 to 4,600 mg/L. In 2010 and 2011, the highest concentration remains in the same central-eastern part, almost unchanged at 4,600 mg/L (fig. 30C), but TDS in areas to the north and west have again dropped.

Spoils water chemistry is primarily controlled by the composition of the spoils. During mining, the overburden is broken by the blasting and equipment handling when removed and placed in the pits. The fractured material has large surface areas from which soluble salts will be dissolved. Breaking the bedrock into cobble-sized fragments also changes the skeletal material of the aquifer. Shale layers that were aquitards become grains within the new spoils flow system, and the unsaturated, weathered overburden layers are incorporated into the saturated flow system. All three of these changes alter the mineral species available to react with groundwater as well as the quantity of available minerals. The duration of high-TDS water depends on the available minerals, the chemistry of the groundwater, and the quantity of water flowing through the system. Published estimates of the volume of water required to bring salinity down to pre-mining levels (Van Voast and Reiten, 1988) underestimated the required flushing volume and time. That estimate assumed no vertical recharge from the spoils surface, an assumption that, given the current groundwater conditions, may not be valid.

POWDER RIVER WATERSHED GROUNDWATER MONITORING BY THE COALBED METHANE PROTECTION PROGRAM

The Montana Legislature adopted the Coal Bed Methane Protection Act (CBMPA) in 2001 (§ 76-15-901 MCA through § 76-15-905 MCA) for the purpose of compensating private landowners and water rights holders for certain damages attributed to CBM development and production. The CBMPA assigned administrative authority over the Program to the local Conservation Districts (CDs) that may be adversely affected

For a claim of CBM-related damages to be accepted by the Program, the cause of the damages must be shown to be “more likely than not” caused by CBM-related activities. In order to evaluate the cause of lowered water levels and increased methane in groundwater found in the Powder River watershed, field inventories and samples have been collected at domestic and stock wells. Sampling emphasis was on water wells within the MBMG monitoring boundary (plate 1) where landowners indicated declining flow or increased gas levels. Additional sampling was completed at nearby wells. Water samples were analyzed for inorganic constituents and methane to provide data to evaluate current and potential future CBMPA claims (CBMPP, 2014). Laboratory analysis for inorganic constituents and methane was completed by Montana Bureau of Mines and Geology Analytical Laboratory, Butte; Pace Analytical, Billings; and Energy Laboratories, Billings. Data were entered into the Montana Ground Water Information Center (GWIC) database. Isotopes of oxygen and hydrogen were analyzed in samples collected in 2015 to potentially aid in identifying recharge sources. Isotope analysis was completed by the Stable Isotope Laboratory at the University of Wyoming, Laramie.

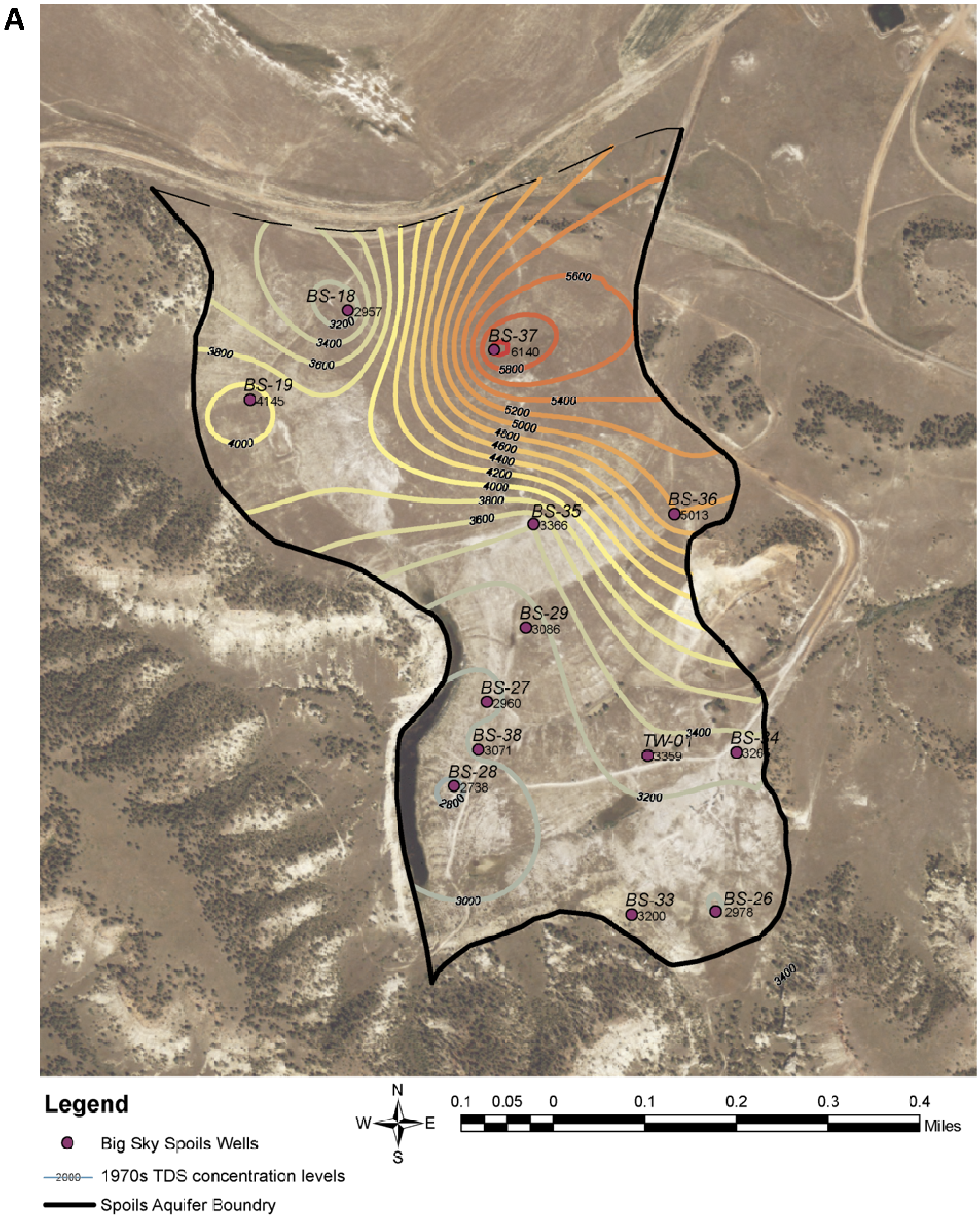


Figure 30. (A) 1970s spoils aquifer salinity. Salinity in the spoils aquifer has improved over the 30 years since re-saturation, but not to the extent predicted by VanVoast and Reiten (1988).

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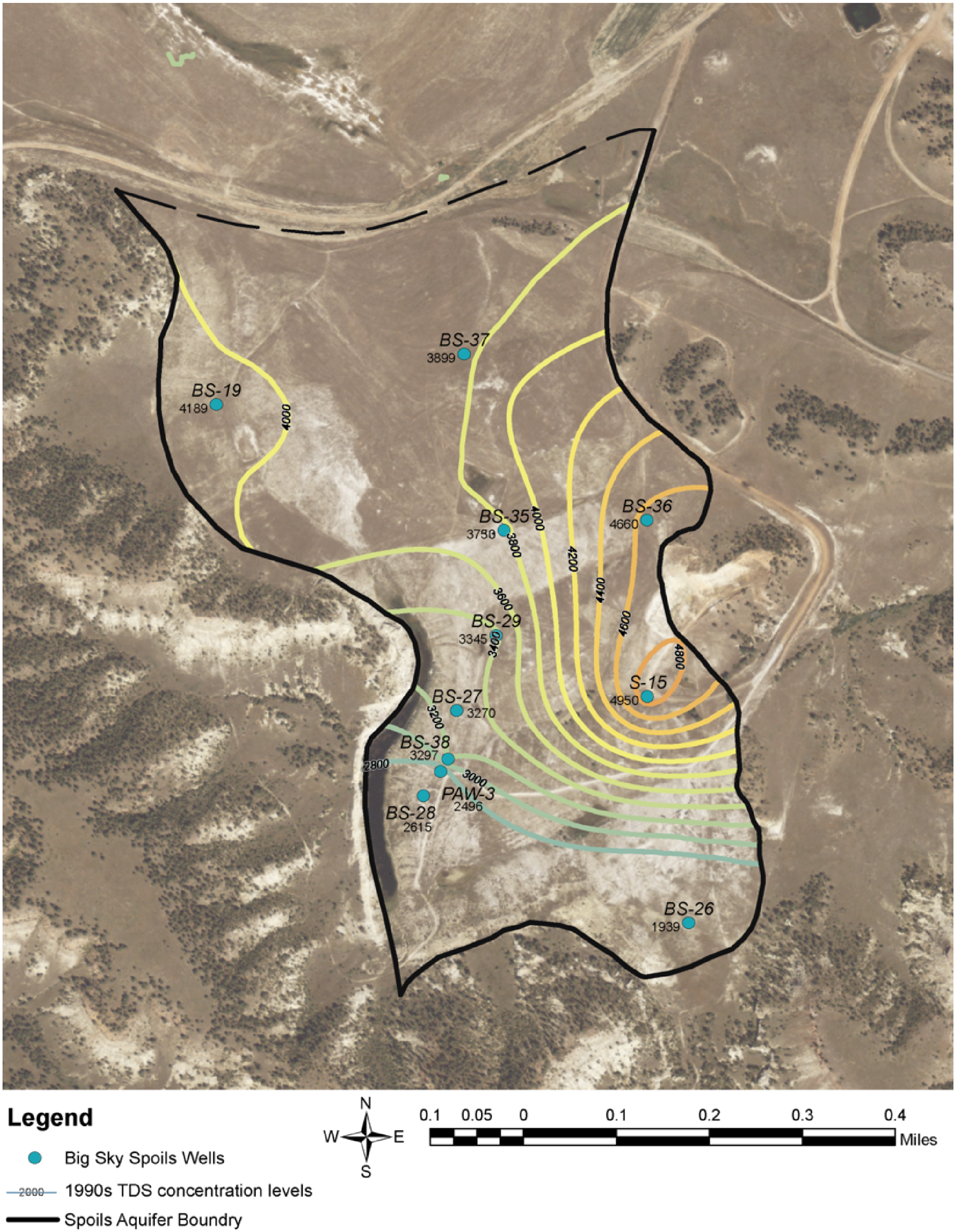

Figure 30 (continued). (B) 1990s spoils aquifer salinity. Salinity in the spoils aquifer has improved over the 30 years since re-saturation, but not to the extent predicted by VanVoast and Reiten (1988).

C

Figure 30 (continued). (C) 2010s spoils aquifer salinity. Salinity in the spoils aquifer has improved over the 30 years since re-saturation, but not to the extent predicted by VanVoast and Reiten (1988).

Program coordinators visited 191 water wells as part of the CBMPP and entered the data into the GWIC database; 139 of these wells are in Powder River County. Field visits to wells in Powder River County showed several previously flowing water wells have stopped flowing or have reduced flow rates (fig. 31). Flowing wells along the Powder River show a pattern of declining flows extending approximately 10 mi north of the Wyoming line into Montana. CBM development in Wyoming (plate 1) is one possible cause of reduced water levels; however, collapse in well casing or a build-up of excessive sediment in the well could cause similar issues. CBMPP Coordinators relied on landowner descriptions of the timing and nature of the reduced flow to narrow down possible causes. Typically, according to landowner accounts, the wells in question have been in gradual decline for the past 5 to 7 years. The gradual decline in water level is not consistent with casing collapse, but is what would be expected from water-level drawdown. Additionally, the timing of drawdown is coincident with CBM production in Wyoming. Long-term climatic trends can also create water-level changes. However, the MBMG statewide monitoring program (GWAAMON) does not indicate drought-related impacts in any deep wells in this area. Lastly, an increase in the number of domestic and stock production wells in the aquifer could lower water levels. MBMG records (GWIC, 2015) show negligible change in stock wells within a mile of the wells in question in CBMPP claims.

Increased methane concentrations follow a pattern similar to declining gpm in wells (fig. 31). The U.S. Department of the Interior, Office of Surface Mining, suggests that when the level of methane gas in the water is less than 10 mg/L, no immediate action is necessary, but monitoring and investigation is recommended at 10 to 28 mg/L, and immediate action is recommended above 28 mg/L, the lower explosive level (Eltschlager and others, 2001). The highest measured methane concentration was 31 mg/L. Several water sources for homes exceeded methane concentrations of 20 mg/L. Water droplets propelled by gas were observed blowing from the water well outflow pipe across a stock tank, though measured methane concentrations were not exceptionally high (1–9 mg/L).

Problems encountered while sampling include:

- Accessing wells: In some cases landowners cut and later repaired PVC pipelines so water samples could be taken at wells. Some wells and electrical lines were in flooded pits and could not be safely measured. In some cases there was no access to the well casing, which prevented measuring of static or pumping water levels.

- Well logs: Additional time to purge casing water volume prior to testing was required where well logs were missing. Some well logs previously unrecorded in GWIC were provided by private landowners and others were found in BLM Range Allotment files.

- Methane samples: Methane concentrations from replicate samples were variable. More consistent methane values were obtained from wells that could be sampled from fully occupied water columns than from those where water trickled out of pipes or from wells spouting water and gas.

SUMMARY AND 2016 MONITORING PLAN

Coalbed-methane production continues east of the Tongue River Reservoir in Montana; however, the number of producing wells has been greatly reduced in recent years. The CBM plan of development that encompasses much of the area between Hanging Woman Creek and the Powder River in ranges 8 and 9 south has not yet been developed. Timing of development depends upon a number of factors including economic forces and industry priorities. This year CBM development in Wyoming took a sudden dip when most of the wells along the state line were shut-in in June. The only remaining Wyoming CBM production near Montana is along the Powder River.

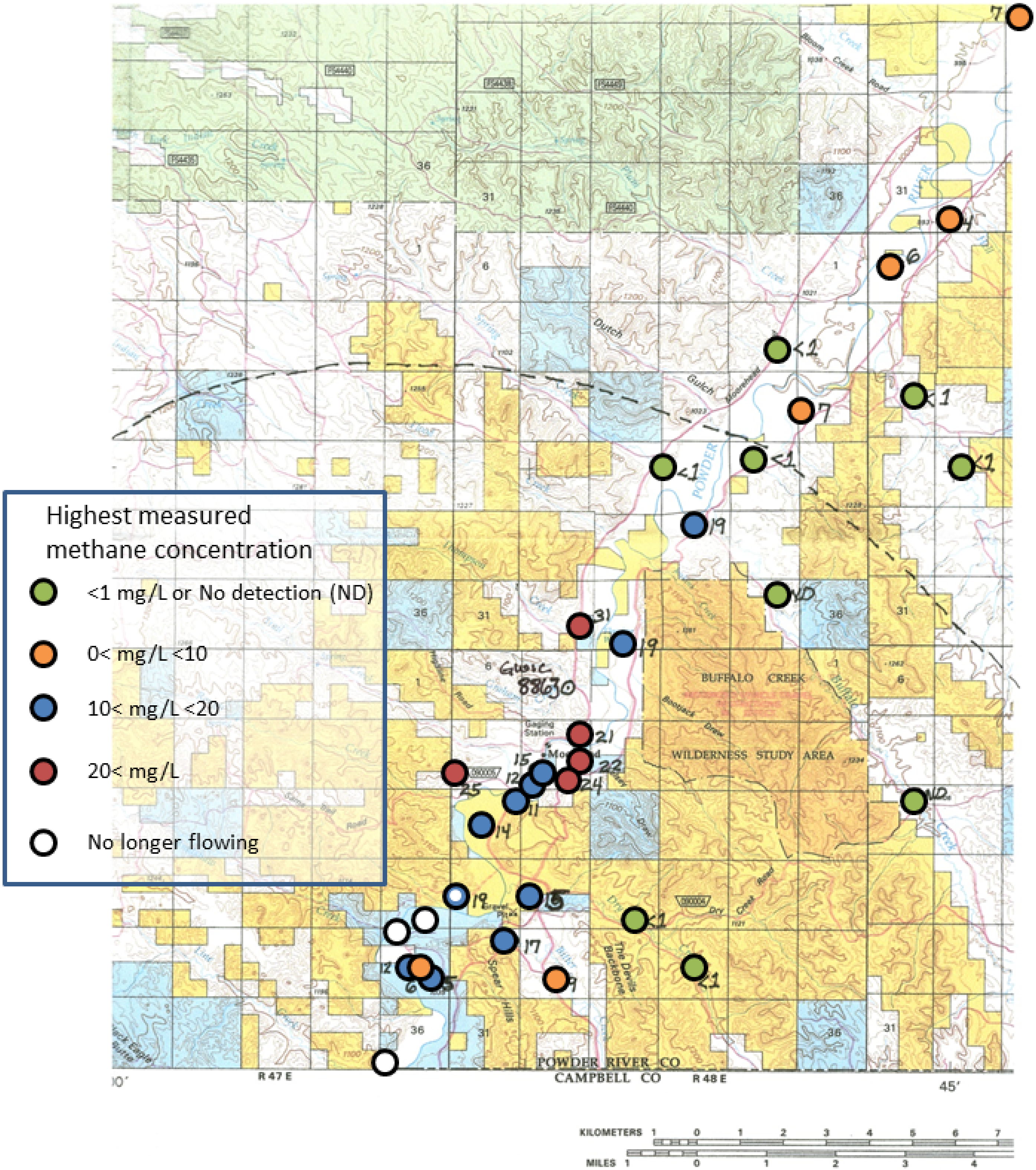

Figure 31. Methane concentrations in groundwater can cause problems for groundwater users near the state line along the Powder River. Accurately measuring methane concentrations is difficult. The dashed line represents a 10-mi radius from the nearest producing CBM wells in Wyoming.

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 typically responds to precipitation and variable climate. Within the area of influence, groundwater levels were drawn down, as required for CBM production, and are recovering in areas where CBM production has decreased.

Within active CBM fields, the water level in produced coalbeds is drawn down to near the top of the coal, and a drawdown of up to 20 ft in coalbeds can reach 1 to 1.5 mi from 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).

Faults in the study area generally act as barriers to groundwater flow, and the monitoring network has documented only 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 drawdown in overburden aquifers.

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 rate and location of recharge. Water-level recovery curves suggest that full recovery will depend upon infrequent recharge events during times of high precipitation. The regional flow system cannot provide recharge while it is being intercepted by CBM development in Wyoming.

Monitoring plans for water year 2016 are included in appendices A and B and shown in plate 1. During water year 2016, monitoring sites located within approximately 6 mi of existing or proposed development will be monitored quarterly. At distances greater than 6 mi, monitoring will occur quarterly or semi-annually—depending on distance to production and amount of background data. Meteorological stations currently deployed at SL-3, RBC-2, and near Poker Jim Butte will be maintained. Water-quality samples will be collected semi-annually from selected alluvial sites and occasionally from selected bedrock wells. Monitoring priorities will be adjusted as new areas of production are proposed or developed.

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APPENDIX A

Site details for water year 2015 and monitoring plan for water year 2016

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract
7573	WO-15	45.5186	-106.1855	3022	04S	45E	4	BDDB
7574	WO-16	45.5158	-106.1861	3040	04S	45E	4	CAAC
7755	77-26 O-22	45.4352	-106.1839	3284	05S	45E	4	ABCC
7770	WO-8	45.3922	-106.1411	3155	05S	45E	23	ABCA
7772	WO-9	45.3925	-106.1419	3150	05S	45E	23	ABCA
7775	WO-10	45.3925	-106.1430	3145	05S	45E	23	ABCB
7776	WO-5	45.3922	-106.1386	3160	05S	45E	23	ABDA
7777	WO-6	45.3922	-106.1386	3160	05S	45E	23	ABDA
7778	WO-7	45.3922	-106.1386	3160	05S	45E	23	ABDA
7780	WO-1	45.3947	-106.1494	3190	05S	45E	23	BBAA
7781	WO-2	45.3947	-106.1494	3188	05S	45E	23	BBAA
7782	WO-3	45.3947	-106.1494	3186	05S	45E	23	BBAA
7783	WO-4	45.3941	-106.1486	3140	05S	45E	23	BBAA
7903	HWC-86-9	45.2965	-106.5030	3170	06S	43E	19	DACD
7905	HWC-86-7	45.2956	-106.5040	3143	06S	43E	19	DDBA
7906	HWC-86-8	45.2961	-106.5030	3170	06S	43E	19	DDBA
8074	WR-21	45.0877	-106.9808	3890	08S	39E	32	DBBC
8101	HWC-86-2	45.1350	-106.4827	3460	08S	43E	17	DDCA
8103	HWC-86-5	45.1341	-106.4822	3455	08S	43E	17	DDDC
8107	HWC-01 * DITCH WELL O-2 TR-26	45.1254	-106.4827	3530	08S	43E	20	DDDD
8110	HC-01 O-4	45.1313	-106.4750	3455	08S	43E	21	BBDA
8118	HC-24 O-10	45.1297	-106.4747	3490	08S	43E	21	BDBB
8140	FC-01	45.1025	-106.5166	3735	08S	43E	31	BBDA
8141	FC-02	45.1025	-106.5166	3735	08S	43E	31	BBDA
8191	BC-06 O-42	45.1355	-106.2121	3715	08S	45E	16	DBCB
8192	BC-07 O-43	45.1355	-106.2121	3715	08S	45E	16	DBCB
8347	WR-23	45.0922	-106.9905	3960	09S	38E	1	AADC
8368	SH-391	45.0412	-107.0330	3987	09S	38E	22	DADC
8371	SH-388	45.0391	-107.0205	3975	09S	38E	23	CDAD
8372	SH-396	45.0490	-107.0088	3939	09S	38E	24	BBBC
8377	SH-394	45.0329	-107.0075	3909	09S	38E	25	BCBA
8379	SH-422	45.0261	-107.0061	3917	09S	38E	25	CBDC
8387	SH-395	45.0359	-107.0180	3900	09S	38E	26	ABAB
8412	WR-58	45.0408	-106.9122	3631	09S	39E	14	DDBD
8413	WR-58D	45.0394	-106.9138	3627	09S	39E	14	DDCC
8417	WR-19	45.0525	-106.9505	3835	09S	39E	16	AABA
8419	WR-20	45.0525	-106.9505	3835	09S	39E	16	AABA
8428	WR-54A	45.0147	-106.8902	3631	09S	39E	25	DADB
8430	WR-53A	45.0122	-106.8888	3608	09S	39E	25	DDAA
8436	WR-24	45.0202	-106.9877	3777	09S	39E	29	BBDD
8441	WR-33	45.0067	-106.9760	3732	09S	39E	32	ACAA
8444	WR-27	45.0009	-106.9590	3672	09S	39E	33	DBBD
8446	WR-45	44.9962	-106.9538	3638	09S	39E	33	DDCC
8447	WR-44	44.9962	-106.9528	3637	09S	39E	33	DDCD
8451	WR-42	44.9962	-106.9509	3637	09S	39E	33	DDDD
8456	WRN-10	45.0733	-106.8094	3433	09S	40E	3	DABA
8461	WRN-15	45.0638	-106.8275	3500	09S	40E	9	AADD
8471	DS-05A	45.0555	-106.8338	3506	09S	40E	9	DCAB
8479	DS-05B	45.0555	-106.8338	3506	09S	40E	9	DCAB
8500	WRE-09	45.0397	-106.7741	3511	09S	40E	13	DCBC
8501	WRE-10	45.0383	-106.7741	3519	09S	40E	13	DCCB
8504	WRE-11	45.0383	-106.7736	3509	09S	40E	13	DCCD

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract
8574	DS-02A	45.0416	-106.8166	3430	09S	40E	15	DBCC
8584	DS-02B	45.0416	-106.8166	3430	09S	40E	15	DBCC
8590	DS-02C	45.0416	-106.8166	3430	09S	40E	15	DBCC
8650	WR-55	45.0302	-106.8874	3591	09S	40E	19	CBBD
8651	WR-55A	45.0302	-106.8863	3591	09S	40E	19	CBBD
8687	WRE-12	45.0307	-106.8050	3463	09S	40E	23	BCCD
8692	WRE-13	45.0308	-106.8050	3463	09S	40E	23	BCCD
8698	WRE-16	45.0351	-106.7690	3551	09S	40E	24	AACB
8706	WR-17B	45.0227	-106.8656	3575	09S	40E	29	BBAC
8708	WR-51	45.0186	-106.8622	3541	09S	40E	29	BDCB
8709	WR-51A	45.0186	-106.8622	3541	09S	40E	29	BDCB
8710	WR-52B	45.0147	-106.8627	3519	09S	40E	29	CACB
8721	WRE-27	45.0586	-106.7391	3524	09S	41E	8	CABC
8723	WRE-28	45.0586	-106.7391	3525	09S	41E	8	CABC
8726	WRE-29	45.0586	-106.7411	3523	09S	41E	8	CBAD
8754	CC-01	45.0872	-106.4655	3525	09S	43E	4	ABDD
8757	CC-04	45.0874	-106.4659	3511	09S	43E	4	ABDD
8758	CC-03	45.0864	-106.4654	3521	09S	43E	4	ACAA
8777	HWC-38 USGS OBS WELL	45.0719	-106.4028	3586	09S	43E	12	ADBB
8778	HWC-17	45.0575	-106.4142	3610	09S	43E	13	BCAA
8779	HWC-07	45.0536	-106.4094	3595	09S	43E	13	CAAA
8782	HWC-15	45.0412	-106.4468	3600	09S	43E	22	ACCA
8796	HWC-29B	45.0697	-106.3974	3620	09S	44E	7	BBCC
8835	AMAX NO. 110	45.0699	-106.1153	3965	09S	46E	8	BACC
8846	UOP-09 KB-33 O-35	45.0720	-106.0578	3929	09S	46E	11	BBBA
8847	UOP-10 KB-34 O-36	45.0720	-106.0578	3930	09S	46E	11	BBBA
8863	FULTON RANCH-TRAILER * TRAILER	45.0807	-105.8634	3380	09S	48E	5	ACDD
8888	HWC-86-13	45.0020	-106.4262	3640	10S	43E	2	ABCA
94661	LISCOM BUTTE WELL	45.7782	-106.0329	3275	01S	46E	3	DBAA
94666	COYOTE WELL * WINDMILL WELL	45.7524	-106.0511	3294	01S	46E	16	AACC
100472	EAST FORK WELL	45.5935	-106.1648	3210	03S	45E	10	BACB
103155	PADGET CREEK PIPELINE WELL	45.3939	-106.2940	3385	05S	44E	22	BBBD
105007	TOOLEY CREEK WELL * TOOLEY	45.2153	-106.2703	3755	07S	45E	19	CAAA
121669	WRE-18	45.0335	-106.7690	3573	09S	40E	24	AACD
122766	WR-59	45.0050	-106.8526	3470	09S	40E	32	ACAD
122767	WRE-20	45.0369	-106.7716	3519	09S	40E	24	ABAB
122769	WR-38	44.9939	-106.9660	3693	54N	84W	23	BBCB
122770	WR-39	44.9957	-106.9555	3666	58N	84W	23	ABBC
123795	WRE-25	45.0683	-106.7333	3549	09S	41E	5	DCCA
123796	WR-17A	45.0227	-106.8656	3574	09S	40E	29	BBAC
123797	WRE-19	45.0369	-106.7736	3520	09S	40E	24	ABBA
123798	WRN-11	45.0733	-106.8094	3437	09S	40E	3	DABA
127605	WR-54	45.0147	-106.8902	3630	09S	39E	25	DADB
130475	WRE-24	45.0688	-106.7333	3552	09S	41E	5	DCCA
130476	WR-31	45.0163	-106.9863	3895	09S	39E	29	CBAA
132716	WR-48	44.9939	-106.9660	3694	58N	84W	23	BBCB
132903	WR-58A	45.0406	-106.9125	3631	09S	39E	14	DDBD
132907	WR-53	45.0129	-106.8900	3607	09S	39E	25	DDAA
132908	WR-30	45.0165	-106.9874	3895	09S	39E	29	CBAB
132909	WR-34	45.0027	-106.9700	3772	09S	39E	33	CBBB
132910	WRE-02	45.0712	-106.7758	3457	09S	40E	1	DBCC
132958	WRE-21	45.0376	-106.7726	3529	09S	40E	24	ABAB

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GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract
132959	WRE-17	45.0341	-106.7683	3562	09S	40E	24	AACD
132960	WR-52C	45.0157	-106.8625	3530	09S	40E	29	CABC
132961	WR-52D	45.0157	-106.8612	3529	09S	40E	29	CABD
132965	WRE-23	45.0694	-106.7335	3557	09S	41E	5	DCBD
132973	PKS-1179	45.0314	-106.8040	3458	09S	40E	23	CBBB
144969	LOHOF PIPELINE WELL 7(PL-1W)	45.2354	-106.3074	3876	07S	44E	14	ABD
157879	5072B * 5072B	45.7393	-106.4910	3160	01S	42E	24	ACBB
157882	5072C * 5072C	45.7394	-106.4911	3160	01S	42E	24	ACBB
157883	5080B * 5080B	45.7199	-106.5132	3260	01S	42E	26	DCBA
157884	5080C * 5080C	45.7200	-106.5132	3260	01S	42E	26	DCBA
161749	BF-01	44.9897	-106.9667	3680	58N	84W	22	ACCC
166351	PKS-3204-79	45.1067	-106.8299	3500	08S	40E	28	ADA
166358	PKS-3203-79	45.1068	-106.8302	3500	08S	40E	28	ADA
166359	PKS-3202	45.0451	-106.7981	3438	09S	40E	14	CAA
166362	PKS-3201	45.0437	-106.7971	3438	09S	40E	14	CAA
166370	PKS-3200	45.0440	-106.7969	3438	09S	40E	14	CAA
166388	PKS-3199	45.0443	-106.7966	3439	09S	40E	14	CAA
166389	PKS-3198	45.0446	-106.7964	3440	09S	40E	14	CAA
166761	WR-29R	45.0456	-106.8151	3461	09S	40E	15	ACCD
183559	BRIDGE ARTESIAN IP-11	45.4114	-106.4555	3085	05S	43E	8	CDCB
183560	ALLUVIAL-CORRAL	45.4387	-106.4211	3035	05S	43E	4	AAAB
183563	FULTON RANCH -RIVER	45.0637	-105.8715	3360	09S	48E	8	CABC
183564	WHITETAIL RANGER STATION	45.6404	-105.9764	4045	02S	47E	19	CDCA
183565	SKINNER GULCH PIPELINE WELL	45.4275	-105.9177	3730	05S	47E	3	BCCD
184222	SH-624	45.0725	-107.0917	4645	09S	38E	7	DADB
184223	SH-625	45.1133	-107.0522	4187	08S	38E	28	DADB
184224	SH-625A	45.1133	-107.0522	4187	08S	38E	28	DADB
184225	SH-634	45.1422	-107.0728	4481	08S	38E	17	DADD
184226	SH-634A	45.1425	-107.0730	4481	08S	38E	17	DADD
186195	WR-41	44.9962	-106.9498	3643	09S	39E	34	CCCC
189743	HWC-29A	45.0697	-106.3974	3619	09S	44E	7	BBCC
189802	HWC-37	45.0719	-106.4028	3578	09S	43E	12	ADBB
189838	HWC-39 AL-46	45.0710	-106.4015	3591	09S	43E	12	ADBD
190902	HWC-10	45.0444	-106.4695	3615	09S	43E	21	BADA
190904	HWC-11	45.0444	-106.4696	3610	09S	43E	21	BADA
191139	20-LW (DIAMOND CROSS)	45.3391	-106.7801	3940	06S	40E	1	CDDC
191155	(DIAMOND CROSS) 22-BA	45.3484	-106.6954	3530	06S	41E	3	BADD
191163	(DIAMOND CROSS) 28-W	45.3197	-106.7256	3715	06S	41E	16	BBCC
191169	32-LW	45.2943	-106.7076	3530	06S	41E	21	DDDC
191634	M75-23	45.0966	-106.2011	3780	08S	45E	34	BDBC
192874	YA-109	45.0465	-107.0530	3830	09S	38E	22	DADC
198465	HWC-06	45.0536	-106.4092	3595	09S	43E	13	CAAA
198489	HWC-86-15	45.0025	-106.4235	3630	10S	43E	2	AABC
203646	CBM02-1KC	45.3186	-106.9671	3980	06S	39E	16	DBCA
203655	CBM02-1BC	45.3186	-106.9671	3984	06S	39E	16	DBCA
203658	CBM02-1LC	45.3186	-106.9671	3982	06S	39E	16	DBCA
203669	CBM02-2WC	45.0207	-106.9884	3792	09S	39E	29	BBDC
203670	CBM02-2RC	45.0185	-106.9889	3890	09S	39E	29	BCBD
203676	CBM02-3CC	45.1392	-106.9608	3920	08S	39E	16	BAAA
203678	CBM02-3DC	45.1391	-106.9607	3920	08S	39E	16	BAAA
203680	CBM02-4WC	45.1798	-106.7802	3500	07S	40E	36	CDDC
203681	CBM02-4SS1	45.1798	-106.7803	3500	07S	40E	36	CDDC

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GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract
203690	CBM02-4SS2	45.1798	-106.7803	3500	07S	40E	36	CDDC
203693	CBM02-7CC	45.1801	-106.8906	3900	08S	39E	1	AAAA
203695	CBM02-7SS	45.1799	-106.8906	3900	08S	39E	1	AAAA
203697	CBM02-8KC	45.3689	-106.5473	3262	05S	42E	28	DDAC
203699	CBM02-8SS	45.3688	-106.5472	3262	05S	42E	28	DDAC
203700	CBM02-8DS	45.3687	-106.5470	3261	05S	42E	28	DDAC
203701	CBM02-8FG	45.3688	-106.5471	3261	05S	42E	28	DDAC
203703	CBM03-10AC	45.1141	-106.6045	4130	08S	42E	29	ADAD
203704	CBM03-10SS	45.1141	-106.6045	4130	08S	42E	29	ADAD
203705	CBM03-11AC	45.1793	-106.3632	3950	08S	44E	5	BBBB
203707	CBM03-11DC	45.1793	-106.3641	3950	08S	44E	5	BBBB
203708	CBM03-11CC	45.1793	-106.3647	3950	08S	44E	5	BBBB
203709	CBM03-12COC	45.1352	-106.2121	3715	08S	45E	16	DBCB
203710	CBM03-13OC	45.0722	-106.0572	3931	09S	46E	11	BBBA
205082	SPRING CREEK PIPELINE WELL	45.3883	-105.9538	3630	05S	47E	20	ACAC
207064	RBC-1	45.3327	-106.9836	3855	06S	39E	8	CAAA
207066	RBC-2	45.3327	-106.9844	3849	06S	39E	8	CAAA
207068	RBC-3	45.3331	-106.9868	3860	06S	39E	8	BDCD
207075	YA-114	45.0463	-107.0543	4000	09S	38E	21	ADBD
207076	YA-105	45.0465	-107.0527	4015	09S	38E	21	ACAC
207080	TA-100	45.0478	-107.0090	3900	09S	38E	23	BBCC
207081	TA-101	45.0481	-107.0090	3910	09S	38E	24	BBCC
207083	TA-102	45.0484	-107.0076	3910	09S	38E	24	BBCB
207096	IB-2	45.3930	-106.4372	3192	05S	43E	21	BBDB
207097	MK-4	45.3919	-106.4363	3195	05S	43E	21	BBDC
207098	NM-4	45.3916	-106.4361	3195	05S	43E	21	BCAB
207099	WL-2	45.3918	-106.4358	3188	05S	43E	21	BBDC
207101	OC-28	45.4717	-106.1928	3171	04S	45E	21	CCBD
207143	HC-01 O-4	45.1314	-106.4750	3457	08S	43E	21	BBDA
210094	WO-14	45.5183	-106.1849	3010	04S	45E	4	BDDB
214096	HWCQ-2 (DIAMOND CROSS)	45.1913	-106.5010	3340	07S	43E	32	
214097	HWCQ-1 (DIAMOND CROSS)	45.1912	-106.5010	3340	07S	43E	32	
214354	WA-7	45.3933	-106.4347	3179	05S	43E	21	BABC
215085	WO-11	45.3927	-106.1433	3145	05S	45E	23	
219125	SL-2AC	45.0276	-106.6358	3925	09S	42E	30	BDAC
219136	SL-3Q	45.0161	-106.5386	3725	09S	42E	36	BBAD
219138	SL-3SC	45.0080	-106.5313	3805	09S	42E	36	DBCB
219139	SL-3AC	45.0079	-106.5313	3805	09S	42E	36	DBCB
219140	SL-3CC	45.0082	-106.5313	3805	09S	42E	36	DBCB
219141	SL-4SC	45.0031	-106.4243	3640	10S	43E	2	ABAA
219169	SL-4AC	45.0031	-106.4244	3640	10S	43E	2	ABAA
219617	SL-3SS	45.0079	-106.5313	3805	09S	42E	36	DBCB
219927	SL-5AC	45.0119	-106.2714	3810	09S	44E	36	ABBD
219929	SL-5DC	45.0119	-106.2714	3810	09S	44E	36	ABBD
220062	SL-6AC	45.0148	-106.1514	4220	09S	45E	36	ABBB
220064	SL-6CC	45.0148	-106.1513	4220	09S	45E	36	ABBB
220069	SL-7CC	45.0147	-106.0392	4173	09S	46E	36	BBBB
220076	SL-5CC	45.0119	-106.2715	3810	09S	44E	36	ABBD
220385	SL-2CC	45.0273	-106.6360	3920	09S	42E	30	BCBC
220851	SL-8-1Q	45.0176	-105.8998	3397	09S	47E	25	DDDB
220857	SL-8-2Q	45.0182	-105.9052	3394	09S	47E	25	DCDB
220859	SL-8-3Q	45.0177	-105.9028	3398	09S	47E	25	DDCB

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract
221592	IP-22	45.0177	-105.9003	3395	09S	47E	25	DDBD
223236	NC02-5	45.3986	-106.5603	3400	05S	42E	16	CCAB
223237	NC02-6	45.4022	-106.6397	3510	05S	41E	14	BDCD
223238	NC02-1	45.3608	-106.8464	4440	05S	40E	31	BDCC
223240	NC02-2	45.4030	-106.5044	3220	05S	42E	14	ADDC
223242	NC02-3	45.4044	-106.6917	3740	05S	41E	17	ADBD
223243	NC02-4 WALL COAL WELL	45.4080	-106.7311	3940	05S	40E	13	ADAB
223687	SITE RBC-4	45.3332	-106.9863	3841	06S	39E	8	
223695	MOORHEAD CAMPGROUND	45.0542	-105.8773	3400	09S	48E	17	BCBB
223801	SL-5ALQ	45.0129	-106.2579	3810	09S	45E	31	BBA
223890	TAYLOR CREEK PIPELINE WELL	45.2213	-105.9928	3910	07S	47E	21	BBCC
223952	WA-2	45.4032	-106.4566	3069	05S	43E	17	BCDD
227246	DH 76-102D	45.0798	-106.1862	3811	09S	45E	3	ADCC
228592	MUSGRAVE BILL ALLUVIAL	45.1639	-106.7319	3335	08S	41E	5	ACDB
251797	GC09-KC	45.4376	-106.3919		05S	43E	2	BAB
251798	GC09-FG	45.4376	-106.3919		05S	43E	2	BAB
251799	GC09-TC	45.4376	-106.3919		05S	43E	2	BAB
259676	SL-9OC	45.0068	-105.8175	3640	09S	48E	34	DAA
259683	SL-9BA	45.0068	-105.8175	3640	09S	48E	34	DAA
259684	SL-9PC	45.0068	-105.8175	3640	09S	48E	34	DAA
276654	10MILE-KC1	45.4400	-106.0946	3268	04S	46E	31	DAAC
277326	SL-8KC	45.0164	-105.9037	3394	09S	47E	25	DCDA
277327	SL-8BA	45.0164	-105.9037	3395	09S	47E	25	DCDA

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2016 SWL monitoring plan	2016 QW sample collection	2016 Possible QW samples
73	12/7/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
61	12/10/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
216.8		125KNCB	7/18/2002	10/2/2014	Quarterly		
34	11/14/1979	110ALVM	10/13/2004	8/14/2014	Quarterly		
45	11/15/1979	110ALVM	10/13/2004	8/14/2014	Quarterly		
43	11/27/1979	110ALVM	10/13/2004	10/2/2014	Quarterly		
192	11/8/1979	125KNUB	10/13/2004	8/14/2014	Quarterly		
82	11/8/1979	125LKCB	10/13/2004	10/6/2014	Quarterly		
40	11/9/1979	110ALVM	10/13/2004	10/6/2014	Quarterly		
172	11/2/1979	125KNUB	10/13/2004	10/6/2014	Quarterly		
112	11/6/1979	125LKCB	10/13/2004	10/7/2014	Quarterly		
66	11/6/1979	125KNOB	10/13/2004	10/6/2014	Quarterly		
31.5	11/7/1979	110ALVM	3/14/2006	8/14/2014	Quarterly		
44		110ALVM	10/8/1986	9/30/2014	Quarterly		
71		110ALVM	10/5/1986	9/30/2014	Quarterly	Semi-Annual	
67		110ALVM	10/8/1986	9/30/2014	Quarterly		
206	8/20/1975	125D1D2	9/18/1975	8/13/2014	Quarterly		X
50	9/29/1986	110ALVM	6/8/2004	10/1/2014	Quarterly		
40	9/30/1986	110ALVM	6/8/2004	10/1/2014	Quarterly		
232	5/8/1974	125CNCB	6/4/1974	10/1/2014	Quarterly		
19.7		110ALVM	4/18/2003	1/27/2009	Quarterly		
150	12/29/1980	125CNOB	7/22/2003	1/31/2013	Semi-Annual		
133		125ANCB	6/16/1981	5/1/2014	Quarterly		
260		125DICB	6/16/1981	5/1/2014	Quarterly		
188		125CNCB	7/1/1975	4/30/2014	Quarterly		
66		125CNOB	6/30/1975	4/30/2014	Quarterly		
322	8/28/1975	125D1D2	12/1/1975	8/13/2014	Quarterly		
175	9/27/1972	125D1D2	9/26/1972	8/14/2014	Quarterly		
190	9/28/1972	125DICB	9/25/1972	8/14/2014	Quarterly		
280		125AND2	10/21/1972	8/13/2014	Quarterly		
242		125DICB	10/5/1972	8/14/2014	Quarterly		
187		125DICB	6/7/1973	4/28/2014	Semi-Annual		
299		125DICB	10/7/1972	8/14/2014	Quarterly		
55	8/23/1977	110ALVM	9/28/1977	10/1/2014	Quarterly		
27	8/25/1977	110ALVM	10/2/2001	10/1/2014	Quarterly		
305	8/14/1975	125D1D2	9/18/1975	10/1/2014	Quarterly		X
166	8/18/1975	125ANCB	9/18/1975	10/1/2014	Quarterly		X
211	8/30/1977	125ADOB	9/28/1977	10/1/2014	Quarterly		
187	8/29/1977	125ADOB	3/28/1979	10/1/2014	Quarterly		
146		125CNCB	12/29/1975	8/14/2014	Quarterly		
165	6/6/1977	125ADKC	6/22/1977	8/14/2014	Quarterly		
363	1/21/1976	125AND2	2/3/1976	8/14/2014	Quarterly		
64	6/21/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
64	6/21/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
66		110ALVM	6/18/2004	8/14/2014	Quarterly		
79	12/5/1974	125D2CB	1/6/1975	9/25/2014	Quarterly		
140	12/5/1974	125D2CB	1/7/1975	10/8/2014	Quarterly		X
166	5/21/1976	125D2CB	6/21/1976	10/8/2014	Quarterly		X
140	5/24/1976	111SPBK	6/21/1976	10/8/2014	Quarterly		
232	11/1/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
183	11/1/1974	125DICB	12/11/1974	10/8/2014	Quarterly		
127	11/15/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2016 SWL monitoring plan	2016 QW sample collection	2016 Possible QW samples
150	5/20/1976	125D2CB	6/21/1976	10/8/2014	Quarterly		X
74	5/20/1976	111SPBK	6/21/1976	10/8/2014	Quarterly		
65		111SPBK	6/21/1976	10/8/2014	Quarterly		
288	8/16/1977	125AND2	9/28/1977	8/13/2014	Quarterly		
72	8/17/1977	125ADOB	9/28/1977	8/13/2014	Quarterly		
172	11/18/1974	125ANCB	12/4/1974	9/25/2014	Quarterly		X
206	11/18/1974	125DICB	12/4/1974	9/25/2014	Quarterly		
458	11/18/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		
160	6/28/1977	125ADOB	7/6/1977	10/1/2014	Quarterly		
344	6/29/1977	125AND2	7/6/1977	8/13/2014	Quarterly		
187	7/12/1977	125ADOB	9/27/1977	8/13/2014	Quarterly		
55	7/14/1977	110ALVM	9/27/1977	10/2/2014	Quarterly		
77	10/28/1974	125ANCB	12/11/1974	10/8/2014	Quarterly		
153	10/28/1974	125D1CB	12/11/1974	10/8/2014	Quarterly		
217	10/29/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
28	12/12/1979	110ALVM	5/29/1980	4/29/2014	Quarterly		
25	12/18/1979	110ALVM	2/28/1980	4/29/2014	Quarterly		
34.5	12/13/1979	110ALVM	2/28/1980	4/29/2014	Quarterly		
40.5	6/15/1977	110ALVM	11/16/1977	9/24/2014	Quarterly		
82	8/10/1976	125ANCB	9/21/1976	9/24/2014	Quarterly		
66	7/16/1975	125ANCB	8/5/1975	9/24/2014	Quarterly		
129	8/4/1976	125ANCB	9/21/1976	9/24/2014	Quarterly		
92	5/14/1977	125ANCB	5/14/1977	9/24/2014	Quarterly		
240		125DICB	9/19/1975	7/9/2014	Quarterly		
261.5	6/13/2002	125CNCB	7/23/1983	9/26/2013	Quarterly		
207.3		125CNOB	7/23/1983	9/26/2013	Quarterly		
410	12/2/1958	125TGRV	7/31/1979	10/8/2014	Quarterly		
53	10/8/1986	110ALVM	10/1/2002	10/1/2014	Quarterly	Semi-Annual	
135	7/11/1946	125TGRV	6/30/2000	9/30/2014	Quarterly		
190	9/27/1963	125TGRV	6/30/2000	9/30/2014	Quarterly		
193	4/1/1961	125KNUB	6/29/2000	10/13/2014	Quarterly		
135	4/30/1981	125TGRV	2/3/2006	8/13/2013	Quarterly		
110	11/5/1978	125CNOB	11/5/1978	10/1/2014	Quarterly		
445	11/4/1974	125ANCB	12/4/1974	10/8/2014	Quarterly		
34	8/31/1977	110ALVM	9/27/1977	10/1/2014	Quarterly	Semi-Annual	
120	12/11/1974	125ANCB	1/9/1975	10/8/2014	Quarterly		
286	6/14/1977	125D1D2	6/24/1977	8/14/2014	Quarterly		
312	6/14/1977	125AND2	8/2/1977	8/14/2014	Quarterly		
114.5	10/29/1974	125ANCB	12/11/1974	10/8/2014	Quarterly		
88	6/17/1977	125ADOB	7/6/1977	10/2/2014	Quarterly		
140	11/18/1974	125ANCB	12/4/1974	10/8/2014	Quarterly		
50	12/5/1974	125ADKC	1/6/1975	9/25/2014	Quarterly		
384	8/15/1977	125AND2	9/28/1977	10/1/2014	Quarterly		
154	10/29/1994	125D1CB	12/11/1974	10/8/2014	Quarterly		
316	6/2/1977	125ANCB	6/22/1977	8/14/2014	Quarterly		
167	6/24/1977	125ANCB	7/6/1977	8/14/2014	Quarterly		
24	8/24/1977	110ALVM	9/28/1977	10/1/2014	Quarterly		
384	8/11/1977	125AND2	9/28/1977	10/1/2014	Quarterly		
428	6/1/1977	125D1D2	6/22/1977	8/14/2014	Quarterly		
522	6/7/1977	125AND2	8/2/1977	8/14/2014	Quarterly		
79		110ALVM	1/7/1975	10/8/2014	Quarterly		
130	12/1/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2016 SWL monitoring plan	2016 QW sample collection	2016 Possible QW samples
250	11/18/1974	125SMCB	12/4/1974	10/8/2014	Quarterly		
62	7/14/1977	110ALVM	10/2/2001	10/1/2014	Quarterly		
40	7/15/1977	110ALVM	9/27/1977	10/1/2014	Quarterly		
240	11/4/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
282	6/3/1992	125D2CB	7/7/1992	9/25/2014	Quarterly		
225	5/25/1992	125TGRV	2/3/2006	10/1/2014	Quarterly		
86	9/12/1996	125RBCB	9/19/1996	7/1/2014	Quarterly		
68	9/12/1996	125RBOB	9/19/1996	7/1/2014	Quarterly		
88.5	9/11/1996	125KNCB	10/2/1996	7/1/2014	Quarterly		
46	9/11/1996	125KNOB	9/20/1996	7/1/2014	Quarterly		
125	4/30/1996	111SPBK	6/25/1997	1/9/2014	Quarterly		
82	4/4/1997	125ADKB	6/5/1997	9/25/2014	Quarterly		
201	4/3/1997	125CNCB	6/5/1997	9/25/2014	Quarterly		
60	3/5/1997	110ALVM	6/5/1997	10/8/2014	Quarterly		
390	3/5/1997	125CNCB	6/5/1997	10/8/2014	Quarterly		
242	2/28/1997	125D2CB	6/5/1997	10/8/2014	Quarterly		
165	2/27/1997	125D1CB	6/5/1997	10/8/2014	Quarterly		
112	2/25/1997	125ANCB	6/5/1997	10/8/2014	Quarterly		
72	10/23/1997	125ADKC	12/3/1987	9/25/2014	Quarterly		
540	1/1/1947	125FGUB	7/3/2000	10/7/2014	Quarterly		
20		111ALVM	7/3/2000	10/7/2014	Quarterly		
30		111ALVM	6/28/2000	10/8/2014	Quarterly		
60		125TGRV	6/30/2000	9/30/2014	Quarterly		
167		125PWUB	6/29/2000	10/2/2014	Quarterly		
435.1		125ADCB	6/23/1976	8/14/2014	Quarterly		
187	6/24/1976	125DICB	8/13/1974	8/13/2014	Quarterly		
91	6/24/1976	125ANCB	6/23/1976	8/13/2014	Quarterly		
348	8/9/1976	125DICB	8/9/1976	8/13/2014	Semi-Annual		
159	8/9/1976	125ANCB	8/9/1976	8/13/2014	Semi-Annual		
40	6/20/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
98	5/13/1977		9/27/1977	9/24/2014	Quarterly		
32	6/14/1977	110ALVM	11/16/1977	9/24/2014	Quarterly		
39	6/16/1977	110ALVM	9/10/2001	9/24/2014	Quarterly		
229	7/22/1975	125DICB	8/5/1975	9/24/2014	Quarterly		
135	7/28/1975	125ANCB	8/5/1975	9/24/2014	Quarterly		
253		125WACB	7/7/1979	9/23/2014	Quarterly		
262		125BACB	6/5/1979	4/24/2012	Quarterly		
144		125WACB	8/15/1978	9/23/2014	Quarterly		
51		125WACB	6/27/1979	9/23/2014	Quarterly		
247		125CNCB	12/11/2001	11/20/2013	Quarterly		
43.8		110ALVM	10/12/2001	8/14/2014	Quarterly		
184	7/15/1975	125DICB	8/5/1975	9/24/2014	Quarterly		
62.52	10/8/1986	110ALVM	10/1/2002	10/1/2014	Quarterly	Semi-Annual	
417	10/4/2002	125KNCB	12/18/2002	9/25/2014	Quarterly		
255.5	10/8/2002	125BACB	12/18/2002	9/25/2014	Quarterly		
366	10/8/2002	125LOCB	12/18/2002	9/25/2014	Quarterly		
290	9/11/2002	125CRCB	12/18/2002	8/14/2014	Quarterly		
159	9/14/2002	125RLCB	12/18/2002	8/14/2014	Quarterly		
376.4	10/24/2002	125CNCB	3/7/2003	9/25/2014	Quarterly		
235	10/24/2002	125DICB	12/18/2002	9/25/2014	Quarterly		
291	10/18/2002	125WACB	12/18/2002	9/30/2014	Quarterly		
221	10/19/2002	125WAOB	12/18/2002	9/30/2014	Quarterly		

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Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2016 SWL monitoring plan	2016 QW sample collection	2016 Possible QW samples
96.6	10/20/2002	125CNUB	12/18/2002	9/30/2014	Quarterly		
263.4	9/27/2002	125CNCB	9/28/2002	9/25/2014	Quarterly		
190.3	9/28/2002	125CNOB	9/29/2002	9/25/2014	Quarterly		
208	11/8/2002	125KNCB	11/12/2002	9/23/2014	Quarterly		
224	11/11/2002	125KNUB	12/18/2002	9/23/2014	Quarterly		
446	11/13/2002	125FGOB	12/18/2002	9/23/2014	Quarterly		
480.4	11/11/2002	125FGCB	11/13/2002	9/23/2014	Quarterly		
560	4/21/2003	125ANCB	6/23/2003	9/25/2014	Quarterly		X
462	4/23/2003	125ADOB	4/29/2003	9/25/2014	Quarterly		X
211	4/28/2003	125ANCB	5/14/2003	9/24/2013	Quarterly		
271	5/7/2003	125DICB	5/14/2003	9/24/2013	Quarterly		
438	5/7/2003	125CNCB	5/14/2003	9/24/2013	Quarterly		
351	5/16/2003	125CKCB	5/16/2003	4/30/2014	Quarterly		
500	5/22/2003	125OTCB	5/23/2003	9/26/2013	Quarterly		
50		125TGRV	1/26/2006	10/2/2014	Quarterly		
26.77	7/9/2003	110ALVM	7/10/2003	9/23/2014	Quarterly		
16.9	7/9/2003	110ALVM	7/10/2003	9/23/2014	Quarterly		
24.55		110ALVM	7/11/2003	9/23/2014	Quarterly		
		110ALVM	8/10/2003	8/14/2014	Quarterly		
		110ALVM	8/28/2003	8/14/2014	Quarterly		
		110ALVM	8/10/2003	8/13/2014	Quarterly		
		110ALVM	8/10/2003	8/13/2014	Quarterly		
		110ALVM	8/10/2003	8/13/2014	Quarterly		
245		125KNUB	10/19/2003	9/23/2014	Quarterly		
188		125KNCB	10/19/2003	9/23/2014	Quarterly		
294		125NACB	6/16/2004	9/23/2014	Quarterly		
199		125KNCB	10/19/2003	9/23/2014	Quarterly		
236		125KNCB	12/14/2003	10/2/2014	Quarterly		
19.7		110ALVM	4/18/2003	1/31/2013	Semi-Annual		
72	12/6/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
19	9/10/2004	110ALVM	9/16/2004	11/19/2013	Quarterly		
19.5	9/10/2004	110ALVM	9/16/2004	11/19/2013	Quarterly		
59		110ALVM	7/23/2004	9/23/2014	Quarterly		
40	11/28/1979	110ALVM	10/13/2004	10/2/2014	Quarterly		
671	5/25/2005	125ANCB	6/21/2005	9/23/2014	Quarterly		
40	4/7/2005	110ALVM	5/20/2005	9/24/2014	Quarterly		
358	4/29/2005	125SMCB	5/3/2005	9/24/2014	Quarterly		
523	4/12/2005	125ANCB	5/3/2005	9/24/2014	Quarterly		
817	4/18/2005	125CNCB	5/3/2005	9/24/2014	Quarterly		
120.4	4/7/2005	125SMCB	4/12/2005	9/24/2014	Quarterly		
279	4/1/2005	125ANCB	4/4/2005	9/24/2014	Quarterly		
278	4/26/2005	125SMOB	5/3/2005	9/24/2014	Quarterly		
223	6/6/2005	125ANCB	6/22/2005	9/24/2014	Quarterly		
322	6/3/2005	125DICB	6/24/2005	9/24/2014	Quarterly		
492	6/23/2005	125ANCB	7/6/2005	9/24/2014	Quarterly		
685	6/17/2005	125CNCB	7/5/2005	6/23/2011	Gas Danger		
515	7/8/2005	125CNCB	7/14/2005	4/20/2010	Gas Danger		
430.5	6/10/2005	125CNCB	7/5/2005	9/24/2014	Quarterly		
1301	8/22/1999	125CNCB	7/23/2005	9/23/2014	Quarterly		
19	8/26/2005	110ALVM	8/28/2005	9/24/2014	Quarterly		
13.8	8/26/2005	110ALVM	8/28/2005	10/8/2014	Quarterly	Semi-Annual	
19	8/26/2005	110ALVM	8/28/2005	9/24/2014	Quarterly		

Appendix A. Site details and 2016 monitoring schedule for groundwater monitoring wells

Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2016 SWL monitoring plan	2016 QW sample collection	2016 Possible QW samples
			7/17/2007	1/19/2011	Quarterly		
376		125KNCB	12/11/2002	11/6/2013			
360		125KNCB	12/11/2002	11/3/2013			
680.5		125WACB	12/10/2002	6/6/2005			
420		125FGCB	12/11/2002	5/6/2014			
353			12/11/2002	5/6/2014			
380		125WACB	12/11/2002	11/6/2013			
5.05			8/25/2005	9/23/2014	Quarterly		
1000			4/19/2010	4/24/2014	Quarterly		
35		110ALVM	9/16/2005	9/24/2014	Quarterly		
150		125TGRV	1/26/2006	4/24/2014	Quarterly		
37.8	8/16/1978	110ALVM	8/17/2006	9/23/2014	Quarterly		
144		125DICB	5/5/2006	9/26/2013	Quarterly		
21.5		111ALVM	9/7/2006	9/30/2014	Quarterly	Semi-Annual	
165.5		125KNCB	3/25/2010	12/23/2014	Quarterly		
400		125FGCB	3/25/2010	12/23/2014	Quarterly		
534		125TTCB	3/25/2010	12/23/2014	Quarterly		
378	10/23/2010	125ODCB	7/19/2011	9/24/2014	Quarterly		
291	10/26/2010	125BACB	7/19/2011	9/24/2014	Quarterly		
169	10/28/2010	125PWCB	7/19/2011	9/24/2014	Quarterly		
71	9/25/2013		9/26/2013	8/14/2014	Quarterly		
423	7/16/2013		9/26/2013	9/24/2014	Quarterly		
115	7/17/2013		9/26/2013	9/24/2014	Quarterly		

APPENDIX B

Site details and discharge data for water year 2015 and
monitoring plan for springs and streams for water year 2016

Appendix B. Site details and water year 2016 monitoring plan for springs

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
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	2016 planned flow monitoring	2016 planned QW sample collection
197247		Anderson	Regional	3690	1.4	5/4/2015	Quarterly	
228591		Dietz	Local	3620	3.9	8/14/2015	Quarterly	
228776				3920	0.5	9/30/2015	Quarterly	Semi-Annual
240578		Anderson	Regional & Local	3665	0.4	9/30/2015	Quarterly	Semi-Annual

APPENDIX C

Groundwater-quality data collected in 2014 and 2015

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Site Name	Sampled in 2014/2015	Latitude	Longitude	Township	Range	Section	Track	County	Site Type	Aquifer
Sites currently outside areas of potential CMB influence	199568	Hedum Spring		45.2823	-106.0710	06S	46E	26	CDBA	Powder River	Spring	
	7780	WO1		45.3947	-106.1503	05S	45E	23	BBAA	Powder River	Well	125LKCB
	7781	WO2		45.3947	-106.1504	05S	45E	23	BBAA	Powder River	Well	125LKCB
	7782	WO3		45.3946	-106.1504	05S	45E	23	BBAA	Powder River	Well	125KNOB
	7777	WO6		45.3922	-106.1394	05S	45E	23	ABDA	Powder River	Well	125LKCB
	7778	WO7		45.3922	-106.1395	05S	45E	23	ABDA	Powder River	Well	110ALVM
	7775	WO10		45.3926	-106.1440	05S	45E	23	ABCB	Powder River	Well	110ALVM
Sites within current areas of potential CBM influence	8101	HWC862		45.1350	-106.4827	08S	43E	17	DDCA	Big Horn	Well	110ALVM
	8710	WR52B		45.0147	-106.8627	09S	40E	29	CACB	Big Horn	Well	110ALVM
	123796	WR17A		45.0227	-106.8656	09S	40E	29	BBAC	Big Horn	well	125ADOB
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S	43E	19	DDBA	Rosebud	Well	110ALVM
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S	43E	2	ABCA	Big Horn	Well	110ALVM
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S	43E	2	AABC	Big Horn	Well	110ALVM
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09E	47E	25	DCDB	Powder River	Well	110ALVM
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S	40E	32	ACAD	Big Horn	Well	110ALVM
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261	08S	42E	30	ADAA	Big Horn	Spring	125TGRV
	240578	Lower Anderson Creek Spring	Semi-annual	45.1373	-106.6913	08S	41E	15	ABBB	Big Horn	Spring	
	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319	08S	41E	5	ACDB	Big Horn	Well	111ALVM

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Site Name	Sampled in 2014/2015	Latitude	Longitude	Township	Range	Section	Track	County	Site Type	Aquifer
Samples collected on the Ashland Ranger District	7589	Newell Pipeline Well		45.4727	-106.2148	04S	45E	19	DADD	Powder River	WELL	125KNCB
	183564	Whitetail Ranger Station		45.6403	-105.9765	02S	47E	19	CDCA	Powder River	WELL	125TGRV
	198766	Lemonade Spring		45.5454	-105.9263	03S	47E	28	ACAA	Powder River	SPRING	125TGRV
	205010	North Fork Spring		45.2994	-105.8742	06S	48E	20	BDCA	Powder River	SPRING	125TGRV
	199572	Dead Man Spring		45.2902	-105.8750	06S	48E	29	BABB	Powder River	SPRING	125TGRV
	205011	Joe Anderson Spring		45.2714	-105.9554	06S	47E	34	CABA	Powder River	SPRING	125TGRV
	205041	School House Spring		45.1944	-106.0081	07S	47E	32	BABA	Powder River	SPRING	125TGRV
	199568	Hedum Spring		45.2822	-106.0717	06S	46E	26	CDBA	Powder River	SPRING	125TGRV
	205049	chipmunk Spring		45.2119	-106.3618	07S	44E	21	CCBB	Powder River	SPRING	125TGRV
	144969	Lohof Pipeline Well 7		45.2354	-106.3082	07S	44E	14	ABD	Rosebud	WELL	125TGRV
	197452	Alkali Spring		45.1914	-106.1507	07S	46E	31	BACD	Powder River	SPRING	125TGRV
	205082	Spring Creek Pipeline Well		45.3882	-105.9545	05S	47E	20	ACAC	Powder River	WELL	125TGRV
	197607	Upper Fifteen Mile Spring		45.3914	-105.9384	05S	47E	21	DCDC	Powder River	SPRING	125TGRV
	7777	WO-6		45.3922	-106.1394	05S	45E	23	ABDA	Powder River	WELL	125LKCB
	7778	WO-7		45.3922	-106.1395	05S	45E	23	ABDA	Powder River	WELL	110ALVM
	7782	WO-3		45.3946	-106.1504	05S	45E	23	BBAA	Powder River	WELL	125KNOB
	7781	WO-2		45.3947	-106.1504	05S	45E	23	BBAA	Powder River	WELL	125LKCB
	7780	WO-1		45.3947	-106.1503	05S	45E	23	BBAA	Powder River	WELL	125KNUB
	7775	WO-10		45.3926	-106.1440	05S	45E	23	ABCB	Powder River	WELL	110ALVM
	205004	Hagen -2 Spring		45.3449	-106.2694	06S	45E	6	ACDC	Powder River	SPRING	125FRUN
	197247	South Fork Harris Creek Spring		45.1642	-106.6053	08S	42E	5	DDDB	Big Horn	SPRING	125FRUN

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Depth (ft)	Comp Date	Sample Date	TDS (mg/l)	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)
Sites currently outside areas of potential CMB influence	199568			10/1/14 16:30	3388.5	2.2	9.6	7.5	3893.0	227.4	399.0	235.1	45.4
	7780	172.0	11/2/79	10/6/14 14:45	554.1	43.3	12.7	8.7	911.6	1.7	0.3	232.4	1.2
	7781	112.0	11/6/79	10/7/14 8:25	658.5	41.7	12.0	8.0	1084.4	2.3	0.5	268.7	1.3
	7782	66.0	11/6/79	10/6/14 15:05	3579.6	9.5	12.3	7.1	4641.2	175.6	175.3	741.1	15.5
	7777	82.0	11/8/79	10/6/14 12:00	1773.5	15.2	11.5	8.2	2597.7	36.6	37.1	547.0	5.5
	7778	40.0	11/9/79	10/6/14 12:01	3214.7	7.3	10.5	7.3	3940.8	148.2	218.0	594.8	15.6
	7775	43.0	11/27/79	10/2/14 13:22	4211.6	6.8	9.2	7.4	4767.6	162.4	328.4	656.0	23.0
Sites within current areas of potential CBM influence	8101	50.0	9/29/86	10/1/14 16:25	2945.0	7.6	10.5	7.6	3516.5	144.2	170.6	567.7	12.7
	8710	55.0	7/14/77	10/2/14 9:56	5645.7	6.8	10.0	7.5	6053.8	249.0	475.1	796.0	24.1
	123796	88.0	6/17/77	10/2/14 11:30	3681.4	23.2	12.2	7.8	4860.2	43.7	84.1	1135.6	12.1
	7905	71		9/30/14 18:03	3837.0	8.9	9.7	7.6	4473.6	165.6	223.2	744.8	21.2
				5/4/15 11:54	3844.2	8.5	10.4	7.5	4924.7	173.9	236.2	729.1	24.6
	8888	53	10/8/86	10/1/2014 19:00	6461.7	10.9	9.7	7.3	7044.1	374.4	325.9	1200.1	11.2
				5/5/2015 15:45	6284.6	10.6	10.4	7.2	7430.9	381.5	336.2	1175.0	13.8
	198489	62.52	10/8/86	10/1/2014 17:58	8434.5	11.0	10.4	7.2	8705.1	510.5	483.5	1439.1	11.5
				5/5/2015 17:00	8200.2	10.6	10.7	7.1	9208.1	519.0	506.5	1414.4	13.4
	220857	13.8	8/26/05	10/8/14 17:45	3396.3	4.8	13.4	7.4	3992.6	444.9	127.9	445.6	8.8
				5/11/15 16:52	2083.5	3.8	8.2	7.4	2777.5	279.9	85.1	280.4	6.8
	122766	34	8/31/77	10/1/14 14:46	6093.0	6.0	11.8	7.4	6343.1	273.4	575.7	763.1	29.9
				5/5/15 11:58	5761.2	5.6	8.9	7.3	6657.7	265.2	580.0	712.9	29.4
	228776			9/25/14 15:00	3917.8	8.0	16.1	7.3	4488.5	157.2	266.3	710.9	8.9
				5/4/15 17:10	4012.5	6.9	9.4	7.2	5072.7	176.3	317.2	665.4	10.0
	240578			9/25/14 15:30	1578.7	3.1	17.8	7.2	1991.6	114.5	137.9	205.8	8.9
				5/4/15 15:39	1486.9	2.9	12.7	7.2	2104.8	107.8	133.5	190.7	9.9
	228592	21.5		9/30/14 16:01	1239.2	1.6	12.9	7.2	1619.1	153.2	100.6	106.9	4.4
				5/13/15 11:25	879.1	1.5	10.8	7.6	1234.8	108.2	76.2	82.2	4.0

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Depth (ft)	Comp Date	Sample Date	TDS (mg/l)	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)
Samples collected on the Ashland Ranger District	7589	325	4/20/58	10/6/2014 10:41	800.98	45.77	18.40	8.56	1297.99	2.25	1.07	332.65	1.63
				9/23/2015 13:32	777.07	43.73	21.40	8.42	1336.06	2.13	0.99	308.27	1.57
	183564	60.0		9/30/14 9:52	427.3	0.4	9.0	7.1	707.5	50.0	59.7	17.4	7.6
				9/22/15 9:54	431.0	0.4	8.9	7.0	752.1	52.9	60.1	16.7	7.9
	198766			9/30/14 12:09	1763.6	2.5	10.7	7.0	2224.1	159.1	149.0	185.6	8.3
				9/22/15 11:00	1658.7	2.6	11.2	6.9	2354.1	159.3	140.9	187.9	8.6
	205010			9/30/14 15:35	3076.0	6.4	10.4	7.3	3785.5	221.6	171.4	523.1	9.0
				9/22/15 12:35	2997.6	6.1	12.1	7.0	3977.1	227.2	167.8	495.6	10.0
	199572			9/30/14 14:50	2768.0	5.6	11.4	7.2	3431.4	204.4	166.3	447.3	8.3
				9/22/15 13:40	2653.4	5.6	16.0	7.1	3595.1	198.6	155.7	437.2	8.0
	205011			9/30/14 16:55	466.0	0.4	12.0	7.9	752.3	73.0	53.1	19.3	4.5
				9/22/15 14:30	466.2	0.4	13.8	7.8	791.2	73.0	52.2	18.5	5.4
	205041			9/30/14 18:00	2178.9	4.2	11.0	7.2	3026.2	167.0	182.8	326.6	9.5
				9/22/15 15:40	2229.9	4.1	12.6	7.0	3064.0	163.8	173.6	314.0	10.4
	199568			9/22/15 17:50	3487.6	2.2	11.3	7.2	4239.2	239.0	415.4	242.8	46.6
	205049			10/1/14 10:00	3198.0	9.0	10.9	7.6	4006.4	114.7	190.5	678.6	13.1
				9/23/15 8:30	3059.6	9.2	12.7	7.4	4110.0	106.9	171.9	662.3	11.1
	144969	225.0	5/25/92	10/1/14 10:55	1323.4	8.7	11.7	7.7	1954.8	47.7	49.8	358.3	8.2
				9/23/15 10:15	1306.1	8.1	12.0	7.5	2055.6	47.7	50.2	334.6	8.7
	197452			10/1/14 13:58	2118.4	9.3	11.2	7.6	2954.5	62.3	110.2	528.6	8.8
				9/23/15 11:40	2092.0	9.0	12.4	7.4	3147.1	59.7	108.5	504.3	8.8
	205082	50.0		10/2/14 10:38	1990.6	6.3	15.9	7.7	2633.6	94.8	128.3	401.9	7.3
				9/23/15 17:00	1883.9	5.8	17.6	7.5	2713.3	88.3	121.0	354.8	7.8
	197607			10/2/14 10:05	1785.4	5.0	13.6	7.3	2478.4	114.7	133.7	332.4	9.8
				9/23/15 18:00	1741.3	5.0	16.8	7.1	2615.6	108.1	129.4	323.5	9.8
	7777	82.0	11/8/79	9/24/15 7:16	1822.4	14.4	10.7	8.1	2788.4	38.7	39.9	536.2	6.2
	7778	40.0	11/9/79	9/24/15 7:18	3210.3	6.9	10.2	7.2	4328.9	152.0	223.2	569.8	16.0
	7782	66.0	11/6/79	9/24/15 9:46	3805.9	11.0	12.9	7.1	5426.3	181.4	157.1	837.3	15.1
	7781	112.0	11/6/79	9/24/15 9:50	657.1	41.8	12.8	8.4	1148.1	2.3	0.5	265.7	1.5
	7780	172.0	11/2/79	9/24/15 9:51	538.7	42.5	13.1	8.5	933.9	1.6	0.3	222.2	1.3
	7775	43.0	11/27/79	9/23/15 14:55	4111.5	7.0	10.1	7.6	5634.3	160.7	330.1	673.5	23.9
	205004			10/7/14 12:00	689.2	1.3		7.8	1058.9	83.3	61.7	65.5	5.8
				9/24/15 16:00	651.0	1.3	18.6	8.0	1086.7	79.9	60.3	64.0	6.3
	197247			5/4/15 14:25	3130.4	8.1	10.1	7.2	4065.8	150.6	178.8	622.6	12.8

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)	Cl (mg/l)	NO3-N (mg/l)	F (mg/l)	OPO4-P (mg/l)	Ag (ug/l)
Sites currently outside areas of potential CMB influence	199568	<0.150 U	<0.020 U	23.95	811.61	0.00	2040.00	7.03	9.86	1.17	<0.100 U	<1.000 U
	7780	<0.015 U	<0.002 U	7.28	601.35	1.08	<0.500 U	13.36	0.030 J	2.24	0.040 J	<0.100 U
	7781	<0.038 U	<0.005 U	6.97	727.90	0.00	0.820 J	16.98	<0.010 U	2.92	0.030 J	<0.250 U
	7782	5.62	0.104 J	9.20	1065.43	0.00	1909.00	22.98	<0.050 U	0.91	<0.100 U	<1.000 U
	7777	<0.038 U	<0.005 U	9.86	894.57	0.00	683.10	11.99	0.05	1.51	<0.020 U	<0.250 U
	7778	<0.150 U	0.038 J	12.17	872.45	0.00	1781.00	13.71	0.41	0.53	<0.100 U	<1.000 U
	7775	5.34	0.96	25.67	901.14	0.00	2548.00	17.13	<0.050 U	1.02	<0.100 U	<1.000 U
Sites within current areas of potential CBM influence	8101	<0.075 U	0.034 J	18.79	716.67	0.00	1658.00	18.10	0.250 J	0.91	<0.100 U	<0.500 U
	8710	3.84	1.59	30.09	800.53	0.00	3655.00	15.12	<0.050 U	0.82	<0.100 U	<1.000 U
	123796	<0.150 U	0.070 J	7.70	1329.19	5.49	1666.00	31.85	40.23	0.43	<0.100 U	<1.000 U
	7905	0.425 J	0.90	21.85	928.34	0.00	2177.00	24.21	<0.050 U	1.23	<0.100 U	<1.000 U
		0.717 J	0.94	22.62	946.20	0.00	2165.00	24.49	<0.050 U	1.24	<0.100 U	<1.000 U
	8888	5.40	1.72	13.93	893.77	0.00	4076.00	11.89	<0.050 U	0.69	<0.100 U	<1.000 U
		6.13	1.89	13.48	886.70	0.00	3908.00	11.46	<0.050 U	0.68	<0.100 U	<1.000 U
	198489	7.90	1.96	15.12	943.08	0.00	5481.00	17.89	<0.050 U	0.59	<0.100 U	<1.000 U
		8.54	2.11	14.28	921.05	0.00	5250.00	17.55	<0.050 U	0.63	<0.100 U	<1.000 U
	220857	0.266 J	1.34	19.93	611.56	0.00	1787.00	258.70	<0.050 U	0.39	<0.100 U	<1.000 U
		<0.075 U	0.49	16.85	467.73	0.00	1036.00	148.20	<0.010 U	0.34	<0.020 U	<0.500 U
	122766	6.11	0.92	22.86	754.69	0.00	4025.00	23.42	<0.050 U	0.74	<0.100 U	<1.000 U
		6.57	0.92	20.67	742.86	0.00	3756.00	22.18	<0.050 U	0.77	<0.100 U	<1.000 U
	228776	0.462 J	0.164 J	10.34	904.48	0.00	2298.00	20.03	<0.050 U	0.53	0.170 J	<1.000 U
		<0.150 U	0.101 J	8.77	878.52	0.00	2379.00	21.55	<0.050 U	0.63	<0.100 U	<1.000 U
	240578	<0.038 U	<0.005 U	16.57	706.84	0.00	734.60	11.44	0.07	0.030 J	<0.020 U	<0.250 U
		<0.038 U	<0.005 U	16.64	661.16	0.00	690.10	10.97	<0.010 U	0.73	<0.020 U	<0.250 U
	228592	0.20	0.046 J	20.96	545.35	0.00	553.80	31.40	0.13	0.34	<0.020 U	<0.250 U
		0.068 J	0.015 J	18.84	510.96	0.00	322.40	15.82	0.09	0.32	<0.020 U	<0.250 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)	Cl (mg/l)	NO3-N (mg/l)	F (mg/l)	OPO4-P (mg/l)	Ag (ug/l)
Samples collected on the Ashland Ranger District	7589	<0.038 U	<0.005 U	8.59	790.62	0.00	4.17	57.31	<0.010 U	2.79	0.020 J	<0.250 U
		<0.038 U	0.007 J	8.90	751.15	16.53	2.66	61.93	<0.010 U	2.64	0.020 J	<0.250 U
	183564	<0.038 U	0.006 J	16.62	460.30	0.00	43.39	3.74	0.030 J	1.73	<0.020 U	<0.250 U
		<0.015 U	0.007 J	17.29	467.40	0.00	39.53	3.55	0.06	1.66	<0.020 U	<0.100 U
	198766	0.15	0.026 J	12.92	818.51	0.00	839.60	5.29	0.06	0.29	<0.020 U	<0.100 U
		0.111 J	0.033 J	13.48	821.23	0.00	739.20	5.44	<0.010 U	0.31	<0.020 U	<0.250 U
	205010	1.67	0.224 J	11.39	947.54	0.00	1666.00	5.00	<0.050 U	0.34	<0.100 U	<1.000 U
		1.79	0.314 J	13.54	940.66	0.00	1611.00	6.36	<0.050 U	0.40	<0.100 U	<1.000 U
	199572	<0.075 U	0.068 J	11.16	903.59	0.00	1478.00	8.20	0.230 J	0.40	<0.100 U	<0.500 U
		0.152 J	0.152 J	11.44	937.66	0.00	1371.00	8.67	0.40	0.62	<0.100 U	<0.500 U
	205011	0.033 J	0.06	18.48	485.29	0.00	51.60	7.69	0.030 J	0.43	<0.020 U	<0.100 U
		0.031 J	0.050 J	19.18	479.06	0.00	54.63	6.51	0.09	0.46	<0.020 U	<0.100 U
	205041	0.46	0.162 J	15.01	866.72	0.00	1040.00	8.57	0.150 J	0.58	<0.100 U	<0.500 U
		0.47	0.28	15.73	868.25	0.00	1114.00	10.42	0.12	0.63	<0.020 U	<0.500 U
	199568	<0.150 U	<0.020 U	24.32	855.11	0.00	2078.00	8.18	11.36	1.28	<0.100 U	<1.000 U
	205049	<0.150 U	<0.020 U	13.75	1041.18	0.00	1641.00	31.97	0.40	1.45	<0.100 U	<1.000 U
		<0.150 U	<0.020 U	13.46	1042.58	0.00	1547.00	31.77	0.42	1.56	<0.100 U	<1.000 U
	144969	0.26	0.017 J	10.46	828.26	0.00	431.20	9.89	0.05	0.83	<0.020 U	<0.250 U
		0.34	0.027 J	11.31	851.18	0.00	422.90	9.91	<0.010 U	0.83	<0.020 U	<0.250 U
	197452	0.124 J	0.028 J	9.23	1169.06	0.00	797.50	23.06	0.16	1.74	<0.020 U	<0.500 U
		0.189 J	0.049 J	9.86	1189.16	0.00	788.90	24.40	0.23	1.69	<0.020 U	<0.500 U
	205082	<0.075 U	<0.010 U	9.15	746.43	0.00	974.30	7.74	0.30	0.41	<0.020 U	<0.500 U
		<0.038 U	0.012 J	9.01	733.56	0.00	933.40	7.62	0.32	0.41	<0.020 U	<0.250 U
	197607	<0.038 U	0.005 J	12.11	1216.18	0.00	577.90	4.78	0.23	0.77	<0.020 U	<0.250 U
		0.088 J	0.012 J	12.31	1178.88	0.00	571.90	4.90	0.24	0.71	<0.020 U	<0.250 U
	7777	<0.038 U	0.005 J	10.60	970.41	0.00	699.70	12.22	<0.010 U	1.42	<0.020 U	<0.250 U
	7778	<0.150 U	0.058 J	12.71	860.62	0.00	1794.00	15.52	0.57	0.53	<0.100 U	<1.000 U
	7782	6.41	0.169 J	9.78	1029.86	0.00	2065.00	25.94	<0.050 U	0.61	<0.100 U	<1.000 U
	7781	<0.015 U	0.006 J	7.16	700.88	13.29	0.570 J	17.84	<0.010 U	2.81	0.030 J	<0.100 U
	7780	<0.015 U	0.003 J	7.51	562.22	14.22	0.520 J	12.85	<0.010 U	1.96	0.040 J	<0.100 U
	7775	5.69	0.91	26.93	921.19	0.00	2416.00	18.31	<0.050 U	0.90	<0.100 U	3.630 J
	205004	<0.038 U	0.045 J	17.85	594.83	0.00	152.90	8.23	0.050 J	1.05	<0.020 U	<0.250 U
		0.035 J	0.07	18.09	569.94	0.00	133.40	7.52	0.07	1.05	<0.020 U	<0.100 U
	197247	0.266 J	0.282 J	13.61	947.70	0.00	1670.00	13.04	<0.050 U	1.00	<0.100 U	<1.000 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)
Sites currently outside areas of potential CMB influence	199568	<20.000 U	10.94	615.01	20.49	<1.000 U	<50.000 U	<1.000 U	<1.000 U	7.96	<5.000 U	377.63	17.53	<1.000 U	<0.600 U
	7780	22.31	<0.100 U	100.77	60.00	<0.100 U	77.00	<0.100 U	<0.100 U	<0.100 U	<0.500 U	19.04	1.12	<0.100 U	<0.060 U
	7781	<5.000 U	<0.250 U	106.35	96.50	<0.250 U	127.00	<0.250 U	<0.250 U	<0.250 U	1.260 J	22.890 J	0.590 J	<0.250 U	<0.150 U
	7782	<20.000 U	<1.000 U	692.48	14.99	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	274.98	<1.000 U	<1.000 U	<0.600 U
	7777	<5.000 U	<0.250 U	140.86	24.19	<0.250 U	54.00	<0.250 U	<0.250 U	<0.250 U	<1.250 U	71.50	<0.250 U	<0.250 U	<0.150 U
	7778	<20.000 U	<1.000 U	479.28	11.88	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	170.54	<1.000 U	<1.000 U	<0.600 U
	7775	<20.000 U	2.390 J	411.53	17.60	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	5.160 J	142.33	5.35	<1.000 U	<0.600 U
Sites within current areas of potential CBM influence	8101	<10.000 U	<0.500 U	272.65	9.49	<0.500 U	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<2.500 U	138.79	2.360 J	<0.500 U	<0.300 U
	8710	<20.000 U	2.370 J	179.73	11.85	<1.000 U	<50.000 U	<1.000 U	2.440 J	<1.000 U	<5.000 U	230.89	3.980 J	2.930 J	<0.600 U
	123796	<20.000 U	<1.000 U	19.450 J	13.76	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	342.97	7.51	7.05	<0.600 U
	7905	<20.000 U	<1.000 U	304.86	22.31	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	133.60	6.40	2.540 J	<0.600 U
		<20.000 U	<1.000 U	315.42	26.05	<1.000 U	<50.000 U	<1.000 U	<1.000 U	3.810 J	<5.000 U	148.14	10.07	<1.000 U	<0.600 U
	8888	<20.000 U	2.280 J	163.94	6.93	<1.000 U	<50.000 U	<1.000 U	2.560 J	<1.000 U	<5.000 U	191.96	<1.000 U	3.310 J	<0.600 U
		<20.000 U	2.190 J	181.78	7.50	<1.000 U	<50.000 U	<1.000 U	2.860 J	3.760 J	<5.000 U	209.11	2.580 J	<1.000 U	<0.600 U
	198489	<20.000 U	2.860 J	182.36	6.04	<1.000 U	<50.000 U	<1.000 U	3.080 J	<1.000 U	<5.000 U	222.79	<1.000 U	4.800 J	<0.600 U
		<20.000 U	2.840 J	201.59	6.82	<1.000 U	<50.000 U	<1.000 U	3.410 J	3.800 J	<5.000 U	253.49	2.280 J	<1.000 U	<0.600 U
	220857	<20.000 U	2.380 J	127.60	29.04	<1.000 U	366.00	<1.000 U	<1.000 U	<1.000 U	<5.000 U	40.660 J	5.93	<1.000 U	<0.600 U
		<10.000 U	1.420 J	89.51	15.10	<0.500 U	165.00	<0.500 U	1.010 J	1.750 J	<2.500 U	32.080 J	2.73	<0.500 U	<0.300 U
	122766	<20.000 U	2.750 J	258.77	13.70	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	276.89	3.450 J	2.450 J	<0.600 U
		<20.000 U	2.720 J	222.17	13.77	<1.000 U	<50.000 U	<1.000 U	<1.000 U	2.950 J	<5.000 U	282.13	5.65	<1.000 U	<0.600 U
	228776	<20.000 U	<1.000 U	82.45	8.13	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	16.890 J	264.67	<1.000 U	<1.000 U	<0.600 U
		<20.000 U	<1.000 U	105.12	7.28	<1.000 U	<50.000 U	<1.000 U	<1.000 U	3.930 J	<5.000 U	307.14	4.410 J	<1.000 U	<0.600 U
	240578	<5.000 U	<0.250 U	214.29	17.64	<0.250 U	53.00	<0.250 U	<0.250 U	<0.250 U	3.110 J	174.73	<0.250 U	0.510 J	<0.150 U
		<5.000 U	<0.250 U	217.74	16.31	<0.250 U	82.00	<0.250 U	<0.250 U	3.03	<1.250 U	182.55	0.590 J	<0.250 U	<0.150 U
	228592	<5.000 U	<0.250 U	73.38	54.64	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	14.23	25.56	0.750 J	1.72	0.750 J
		<5.000 U	<0.250 U	74.50	35.74	<0.250 U	<10.000 U	<0.250 U	<0.250 U	2.07	13.99	21.590 J	1.67	<0.250 U	<0.150 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)
Samples collected on the Ashland Ranger District	7589	<5.000 U	<0.250 U	117.91	118.25	<0.250 U	291.00	<0.250 U	<0.250 U	<0.250 U	<1.250 U	19.440 J	0.790 J	<0.250 U	<0.150 U
		<5.000 U	<0.250 U	113.90	103.41	<0.250 U	427.00	<0.250 U	<0.250 U	<0.250 U	<1.250 U	23.070 J	1.53	<0.250 U	<0.150 U
	183564	6.320 J	0.600 J	228.82	95.74	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	1.330 J	56.01	4.56	0.760 J	<0.150 U
		<2.000 U	0.59	202.81	106.77	<0.100 U	<10.000 U	<0.100 U	0.210 J	<0.100 U	1.320 J	77.44	5.35	0.290 J	<0.060 U
	198766	<2.000 U	0.61	235.40	18.86	<0.100 U	<10.000 U	<0.100 U	0.430 J	<0.100 U	<0.500 U	112.99	0.210 J	0.71	<0.060 U
		81.33	0.780 J	239.00	17.77	<0.250 U	<10.000 U	<0.250 U	0.660 J	<0.250 U	<1.250 U	157.86	0.780 J	1.080 J	<0.150 U
	205010	<20.000 U	<1.000 U	107.07	11.80	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	148.17	<1.000 U	<1.000 U	<0.600 U
		<20.000 U	<1.000 U	107.26	13.90	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	206.35	<1.000 U	<1.000 U	104.55
	199572	<10.000 U	<0.500 U	120.48	14.33	<0.500 U	<50.000 U	<0.500 U	<0.500 U	<0.500 U	2.830 J	144.64	<0.500 U	<0.500 U	<0.300 U
		<10.000 U	<0.500 U	117.22	16.02	<0.500 U	<50.000 U	<0.500 U	1.130 J	<0.500 U	<2.500 U	206.04	<0.500 U	3.82	<0.300 U
	205011	<2.000 U	0.59	34.87	204.95	<0.100 U	<10.000 U	<0.100 U	0.230 J	<0.100 U	<0.500 U	32.31	0.410 J	0.63	<0.060 U
		<2.000 U	0.61	38.70	211.65	<0.100 U	<10.000 U	<0.100 U	0.330 J	<0.100 U	<0.500 U	49.92	0.58	1.28	<0.060 U
	205041	<10.000 U	<0.500 U	232.17	12.50	<0.500 U	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<2.500 U	169.11	<0.500 U	1.260 J	<0.300 U
		<10.000 U	<0.500 U	218.21	13.81	<0.500 U	250.00	<0.500 U	1.380 J	<0.500 U	<2.500 U	218.43	1.360 J	1.580 J	<0.300 U
	199568	<20.000 U	10.22	656.05	19.39	<1.000 U	<50.000 U	<1.000 U	<1.000 U	9.24	<5.000 U	542.55	22.36	<1.000 U	<0.600 U
	205049	<20.000 U	<1.000 U	375.57	16.87	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	167.34	<1.000 U	<1.000 U	<0.600 U
		<20.000 U	<1.000 U	370.94	15.05	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	216.26	3.260 J	<1.000 U	<0.600 U
	144969	<5.000 U	<0.250 U	206.31	10.73	<0.250 U	64.00	<0.250 U	<0.250 U	<0.250 U	<1.250 U	159.76	<0.250 U	<0.250 U	<0.150 U
		<5.000 U	<0.250 U	206.01	10.75	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	<1.250 U	198.37	0.540 J	<0.250 U	<0.150 U
	197452	<10.000 U	<0.500 U	210.22	10.99	<0.500 U	121.00	<0.500 U	<0.500 U	<0.500 U	<2.500 U	150.58	<0.500 U	<0.500 U	<0.300 U
		<10.000 U	<0.500 U	209.46	12.15	<0.500 U	173.00	<0.500 U	<0.500 U	<0.500 U	<2.500 U	215.82	<0.500 U	<0.500 U	<0.300 U
	205082	<10.000 U	<0.500 U	176.09	11.96	<0.500 U	<10.000 U	<0.500 U	<0.500 U	<0.500 U	4.150 J	142.73	1.020 J	<0.500 U	<0.300 U
		<5.000 U	<0.250 U	178.44	13.74	<0.250 U	202.00	<0.250 U	<0.250 U	<0.250 U	7.81	198.95	1.61	1.240 J	<0.150 U
	197607	<5.000 U	<0.250 U	457.00	15.84	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	<1.250 U	173.01	<0.250 U	0.690 J	<0.150 U
		<5.000 U	<0.250 U	490.82	16.64	<0.250 U	<10.000 U	<0.250 U	<0.250 U	<0.250 U	<1.250 U	230.73	<0.250 U	0.830 J	<0.150 U
	7777	<5.000 U	<0.250 U	144.74	22.16	<0.250 U	92.00	<0.250 U	<0.250 U	2.02	<1.250 U	99.82	<0.250 U	<0.250 U	<0.150 U
	7778	<20.000 U	<1.000 U	471.15	13.70	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	233.66	<1.000 U	<1.000 U	<0.600 U
	7782	<20.000 U	<1.000 U	462.48	11.98	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	347.89	<1.000 U	<1.000 U	<0.600 U
	7781	4.400 J	<0.100 U	99.01	93.79	<0.100 U	163.00	<0.100 U	<0.100 U	<0.100 U	<0.500 U	29.59	0.84	<0.100 U	<0.060 U
	7780	<2.000 U	<0.100 U	108.98	60.23	<0.100 U	227.00	<0.100 U	<0.100 U	<0.100 U	<0.500 U	25.14	1.25	<0.100 U	<0.060 U
	7775	<20.000 U	2.590 J	399.01	16.39	<1.000 U	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	200.01	7.55	<1.000 U	<0.600 U
	205004	<5.000 U	0.850 J	152.82	57.38	<0.250 U	58.00	<0.250 U	0.640 J	<0.250 U	1.290 J	71.65	1.59	1.050 J	<0.150 U
		<2.000 U	1.55	175.90	55.04	<0.100 U	199.00	<0.100 U	2.02	<0.100 U	0.680 J	110.08	2.35	1.37	0.40
	197247	<20.000 U	<1.000 U	172.04	16.97	<1.000 U	<50.000 U	<1.000 U	<1.000 U	4.250 J	<5.000 U	277.50	2.480 J	<1.000 U	<0.600 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)	U (ug/l)	V (ug/l)	Zn (ug/l)	Zr (ug/l)	Ce (ug/l)	Cs (ug/l)	Ga (ug/l)	La (ug/l)	Nb (ug/l)	Nd (ug/l)
Sites currently outside areas of potential CMB influence	199568	<1.000 U	21.93	<1.000 U	3122.86	250.45	<1.000 U	27.94	114.17	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	7780	<0.100 U	<0.100 U	0.260 J	62.48	1.09	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.100 U	<0.100 U	<0.100 U	2.07	<0.100 U	<0.100 U	<0.100 U
	7781	<0.250 U	<0.250 U	<0.250 U	100.20	1.51	<0.250 U	<0.250 U	<0.250 U	<1.250 U	<0.250 U	<0.250 U	<0.250 U	3.44	<0.250 U	<0.250 U	<0.250 U
	7782	<1.000 U	<1.000 U	<1.000 U	6134.59	216.61	<1.000 U	<1.000 U	<1.000 U	13.370 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	7777	<0.250 U	<0.250 U	1.130 J	1325.55	60.29	<0.250 U	<0.250 U	<0.250 U	<1.250 U	<0.250 U	<0.250 U	<0.250 U	0.770 J	<0.250 U	<0.250 U	<0.250 U
	7778	<1.000 U	<1.000 U	<1.000 U	3478.07	202.88	<1.000 U	9.06	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.740 J	<1.000 U
	7775	<1.000 U	<1.000 U	<1.000 U	2878.83	238.60	<1.000 U	12.14	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	3.250 J	<1.000 U
Sites within current areas of potential CBM influence	8101	<0.500 U	<0.500 U	<0.500 U	1899.10	174.54	<0.500 U	15.86	<0.500 U	3.130 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
	8710	<1.000 U	<1.000 U	<1.000 U	4821.12	353.32	<1.000 U	25.06	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	123796	<1.000 U	37.17	<1.000 U	5125.44	116.36	<1.000 U	11.81	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	7905	<1.000 U	<1.000 U	<1.000 U	2368.24	221.61	<1.000 U	11.87	<1.000 U	<5.000 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	<1.000 U	2828.97	221.57	<1.000 U	13.60	<1.000 U	5.850 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	8888	<1.000 U	<1.000 U	<1.000 U	5034.00	463.06	<1.000 U	16.14	<1.000 U	<5.000 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	<1.000 U	5643.02	476.11	<1.000 U	18.12	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	198489	<1.000 U	<1.000 U	<1.000 U	6765.73	611.88	<1.000 U	34.23	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.710 J	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	7653.74	640.85	<1.000 U	40.50	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	220857	<1.000 U	<1.000 U	<1.000 U	2884.27	445.39	<1.000 U	29.64	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
		<0.500 U	<0.500 U	<0.500 U	1866.69	256.13	<0.500 U	17.18	1.710 J	<2.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
	122766	<1.000 U	<1.000 U	<1.000 U	5082.10	398.92	<1.000 U	26.97	<1.000 U	7.620 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	5447.05	374.04	<1.000 U	28.94	<1.000 U	7.220 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	228776	<1.000 U	<1.000 U	<1.000 U	3916.09	216.67	<1.000 U	6.35	<1.000 U	68.98	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	4980.58	246.63	<1.000 U	8.89	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	240578	<0.250 U	<0.250 U	<0.250 U	2463.74	101.44	<0.250 U	<0.250 U	1.120 J	4.990 J	<0.250 U	<0.250 U	<0.250 U	0.570 J	<0.250 U	0.870 J	<0.250 U
		<0.250 U	<0.250 U	<0.250 U	2647.55	109.48	<0.250 U	<0.250 U	1.77	2.280 J	<0.250 U	<0.250 U	<0.250 U	0.640 J	<0.250 U	<0.250 U	<0.250 U
	228592	<0.250 U	<0.250 U	<0.250 U	745.03	121.90	<0.250 U	9.17	0.520 J	22.97	<0.250 U	<0.250 U	<0.250 U	1.75	<0.250 U	<0.250 U	<0.250 U
		<0.250 U	<0.250 U	<0.250 U	604.16	100.17	<0.250 U	8.22	1.160 J	17.77	<0.250 U	<0.250 U	<0.250 U	1.35	<0.250 U	<0.250 U	<0.250 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)	U (ug/l)	V (ug/l)	Zn (ug/l)	Zr (ug/l)	Ce (ug/l)	Cs (ug/l)	Ga (ug/l)	La (ug/l)	Nb (ug/l)	Nd (ug/l)
Samples collected on the Ashland Ranger District	7589	<0.250 U	<0.250 U	0.780 J	116.20	1.69	<0.250 U	<0.250 U	<0.250 U	<1.250 U	<0.250 U	<0.250 U	<0.250 U	4.11	<0.250 U	0.540 J	<0.250 U
		<0.250 U	<0.250 U	3.11	135.09	1.82	<0.250 U	<0.250 U	<0.250 U	<1.250 U	<0.250 U	<0.250 U	<0.250 U	7.04	<0.250 U	<0.250 U	<0.250 U
	183564	<0.250 U	<0.250 U	<0.250 U	1331.85	31.28	<0.250 U	1.63	3.05	4.740 J	<0.250 U	<0.250 U	<0.250 U	3.36	<0.250 U	<0.250 U	<0.250 U
		<0.100 U	0.54	0.180 J	1429.36	24.90	<0.100 U	3.55	9.64	1.480 J	<0.100 U	<0.100 U	<0.100 U	7.03	<0.100 U	<0.100 U	<0.100 U
	198766	<0.100 U	<0.100 U	<0.100 U	2514.58	128.47	<0.100 U	3.30	<0.100 U	3.49	<0.100 U	<0.100 U	<0.100 U	0.52	<0.100 U	<0.100 U	<0.100 U
		<0.250 U	<0.250 U	<0.250 U	2557.83	98.89	<0.250 U	4.60	0.620 J	6.00	<0.250 U	<0.250 U	<0.250 U	1.030 J	<0.250 U	<0.250 U	<0.250 U
	205010	<1.000 U	<1.000 U	<1.000 U	4046.12	230.06	<1.000 U	<1.000 U	<1.000 U	6.010 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
		<1.000 U	<1.000 U	<1.000 U	4286.76	197.17	<1.000 U	<1.000 U	<1.000 U	34.36	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	199572	<0.500 U	<0.500 U	<0.500 U	3988.87	200.07	<0.500 U	1.280 J	<0.500 U	7.820 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
		<0.500 U	<0.500 U	<0.500 U	4040.35	185.40	<0.500 U	2.450 J	1.610 J	<2.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
	205011	<0.100 U	<0.100 U	<0.100 U	607.87	45.42	<0.100 U	0.53	<0.100 U	0.710 J	<0.100 U	<0.100 U	<0.100 U	6.77	<0.100 U	0.360 J	<0.100 U
		<0.100 U	<0.100 U	<0.100 U	648.18	41.53	<0.100 U	1.17	0.480 J	<0.500 U	<0.100 U	<0.100 U	<0.100 U	14.23	<0.100 U	<0.100 U	<0.100 U
	205041	<0.500 U	<0.500 U	<0.500 U	2364.39	165.57	<0.500 U	3.79	<0.500 U	<2.500 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	<0.500 U	<0.500 U	2347.82	114.49	<0.500 U	4.71	<0.500 U	<2.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
	199568	<1.000 U	4.800 J	1.140 J	3125.22	187.08	<1.000 U	47.98	293.40	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	205049	<1.000 U	<1.000 U	<1.000 U	2494.37	165.60	<1.000 U	11.37	<1.000 U	<5.000 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	<1.000 U	2424.85	461.16	<1.000 U	17.49	2.040 J	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	144969	<0.250 U	<0.250 U	<0.250 U	1358.86	50.52	<0.250 U	<0.250 U	<0.250 U	4.200 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	<0.250 U	1402.35	41.47	<0.250 U	<0.250 U	<0.250 U	5.32	<0.250 U	<0.250 U	<0.250 U	0.610 J	<0.250 U	<0.250 U	<0.250 U
	197452	<0.500 U	<0.500 U	<0.500 U	1282.85	83.40	<0.500 U	<0.500 U	<0.500 U	2.880 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	1.570 J	<0.500 U
		<0.500 U	<0.500 U	<0.500 U	1403.23	304.48	<0.500 U	1.540 J	1.060 J	<2.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
	205082	<0.500 U	<0.500 U	<0.500 U	1749.08	113.20	<0.500 U	6.04	<0.500 U	3.630 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U
		<0.250 U	1.34	<0.250 U	1874.97	86.85	<0.250 U	11.49	1.210 J	1.260 J	<0.250 U	<0.250 U	<0.250 U	0.820 J	<0.250 U	<0.250 U	<0.250 U
	197607	<0.250 U	<0.250 U	<0.250 U	1860.85	98.53	<0.250 U	4.95	<0.250 U	4.760 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	0.930 J	2020.84	88.09	<0.250 U	10.38	1.35	4.730 J	<0.250 U	<0.250 U	<0.250 U	1.010 J	<0.250 U	<0.250 U	<0.250 U
	7777	<0.250 U	<0.250 U	0.370 J	1456.69	121.52	<0.250 U	<0.250 U	<0.250 U	<1.250 U	<0.250 U	<0.250 U	<0.250 U	1.32	<0.250 U	<0.250 U	<0.250 U
	7778	<1.000 U	<1.000 U	<1.000 U	3946.62	515.25	<1.000 U	17.90	2.800 J	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	7782	<1.000 U	<1.000 U	<1.000 U	6603.56	682.43	<1.000 U	<1.000 U	<1.000 U	6.350 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	7781	<0.100 U	<0.100 U	0.320 J	106.89	8.12	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.100 U	<0.100 U	<0.100 U	6.22	<0.100 U	<0.100 U	<0.100 U
	7780	<0.100 U	<0.100 U	0.400 J	65.02	1.33	<0.100 U	<0.100 U	<0.100 U	<0.500 U	<0.100 U	<0.100 U	<0.100 U	4.12	<0.100 U	<0.100 U	<0.100 U
	7775	<1.000 U	<1.000 U	<1.000 U	2879.54	657.67	<1.000 U	20.59	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U
	205004	<0.250 U	<0.250 U	7.43	1520.89	60.00	<0.250 U	3.35	<0.250 U	5.96	<0.250 U	<0.250 U	<0.250 U	1.97	<0.250 U	0.850 J	<0.250 U
		<0.100 U	0.400 J	3.20	1640.46	47.45	<0.100 U	6.44	0.69	5.10	<0.100 U	<0.100 U	<0.100 U	3.72	<0.100 U	<0.100 U	<0.100 U
	197247	<1.000 U	<1.000 U	<1.000 U	3862.43	191.86	<1.000 U	2.650 J	<1.000 U	<5.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Pd (ug/l)	Pr (ug/l)
Sites currently outside areas of potential CMB influence	199568	3.260 J	<1.000 U
	7780	<0.100 U	<0.100 U
	7781	<0.250 U	<0.250 U
	7782	6.35	<1.000 U
	7777	1.38	<0.250 U
	7778	3.630 J	<1.000 U
	7775	3.050 J	<1.000 U
Sites within current areas of potential CBM influence	8101	1.850 J	<0.500 U
	8710	4.950 J	<1.000 U
	123796	5.09	<1.000 U
	7905	2.520 J	<1.000 U
		2.640 J	<1.000 U
	8888	5.04	<1.000 U
		5.04	<1.000 U
	198489	6.73	<1.000 U
		7.05	<1.000 U
	220857	3.070 J	<1.000 U
		1.710 J	<0.500 U
	122766	5.20	<1.000 U
		5.06	<1.000 U
	228776	4.230 J	<1.000 U
		5.09	<1.000 U
	240578	2.49	<0.250 U
		2.44	<0.250 U
	228592	0.820 J	<0.250 U
		0.570 J	<0.250 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Pd (ug/l)	Pr (ug/l)
Samples collected on the Ashland Ranger District	7589	<0.250 U	<0.250 U
		<0.250 U	<0.250 U
	183564	1.42	<0.250 U
		1.10	<0.100 U
	198766	2.66	<0.100 U
		2.07	<0.250 U
	205010	4.450 J	<1.000 U
		3.810 J	<1.000 U
	199572	4.11	<0.500 U
		3.65	<0.500 U
	205011	0.85	<0.100 U
		0.55	<0.100 U
	205041	2.66	<0.500 U
		1.720 J	<0.500 U
	199568	2.280 J	<1.000 U
	205049	2.560 J	<1.000 U
		2.190 J	<1.000 U
	144969	1.38	<0.250 U
		1.48	<0.250 U
	197452	1.410 J	<0.500 U
		1.480 J	<0.500 U
	205082	1.730 J	<0.500 U
		1.64	<0.250 U
	197607	1.91	<0.250 U
		1.87	<0.250 U
	7777	1.33	<0.250 U
	7778	3.440 J	<1.000 U
	7782	4.820 J	<1.000 U
	7781	<0.100 U	<0.100 U
	7780	<0.100 U	<0.100 U
	7775	2.230 J	<1.000 U
	205004	1.62	<0.250 U
		1.43	<0.100 U
	197247	3.510 J	<1.000 U

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Rb (ug/l)	Th (ug/l)	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Total N as N (mg/l)	Sum Dissolved Constituents (mg/l)	Hardness (mg/l)	Alkalinity	Procedure
Sites currently outside areas of potential CMB influence	199568	39.81	<1.000 U	<1.000 U	<0.050 U	9.68	10.50	3800.47	2210.33	665.98	DISSOLVED
	7780	1.07	<0.100 U	0.230 J	<0.010 U	<0.200 U	<1.000 U	858.99	5.44	494.59	DISSOLVED
	7781	1.33	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1027.83	7.88	597.08	DISSOLVED
	7782	8.62	<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.87	4119.96	1160.22	873.48	DISSOLVED
	7777	3.63	<0.250 U	<0.250 U	<0.010 U	<0.200 U	1.14	2227.62	243.83	734.05	DISSOLVED
	7778	4.380 J	<1.000 U	<1.000 U	<0.050 U	0.43	<1.000 U	3657.18	1267.26	715.19	DISSOLVED
	7775	16.58	<1.000 U	<1.000 U	<0.050 U	<0.200 U	1.05	4668.75	1757.07	738.97	DISSOLVED
Sites within current areas of potential CBM influence	8101	7.17	<0.500 U	<0.500 U	<0.050 U	<0.200 U	<1.000 U	3308.79	1062.28	588.06	DISSOLVED
	8710	25.57	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	6052.16	2577.45	656.96	DISSOLVED
	123796	12.38	<1.000 U	2.020 J	<0.050 U	35.65	40.80	4355.76	455.13	1098.35	DISSOLVED
	7905	12.17	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	4307.83	1332.32	761.12	DISSOLVED
		15.21	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	4324.15	1406.60	775.88	DISSOLVED
	8888	5.43	<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.69	6915.30	2276.28	733.23	DISSOLVED
		6.18	<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.48	6734.69	2336.38	727.49	DISSOLVED
	198489	4.860 J	<1.000 U	<1.000 U	<0.050 U	<0.200 U	1.76	8912.96	3264.66	773.42	DISSOLVED
		5.63	<1.000 U	<1.000 U	0.25	<0.200 U	1.81	8667.53	3380.84	755.38	DISSOLVED
	220857	<1.000 U	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	3706.82	1637.45	501.94	DISSOLVED
		<0.500 U	<0.500 U	<0.500 U	<0.010 U	<0.200 U	<1.000 U	2320.99	1049.19	383.84	DISSOLVED
	122766	27.33	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	6476.09	3052.16	619.23	DISSOLVED
		25.55	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	6138.21	3049.53	609.39	DISSOLVED
	228776	6.77	<1.000 U	<1.000 U	<0.050 U	<0.200 U	4.98	4376.52	1488.45	741.43	DISSOLVED
		6.74	<1.000 U	2.210 J	<0.050 U	<0.200 U	3.82	4458.50	1745.78	720.93	DISSOLVED
	240578	5.87	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1937.43	853.59	579.86	DISSOLVED
		6.31	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1822.27	818.57	542.13	DISSOLVED
	228592	5.41	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1515.78	796.40	446.99	DISSOLVED
		4.64	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1138.42	583.81	419.11	DISSOLVED

Appendix C. Groundwater quality data collected in 2014-2015

	Gwic Id	Rb (ug/l)	Th (ug/l)	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Total N as N (mg/l)	Sum Dissolved Constituents (mg/l)	Hardness (mg/l)	Alkalinity	Procedure
Samples collected on the Ashland Ranger District	7589	1.56	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	1202.32	10.02	648.76	DISSOLVED
		3.03	<0.250 U	0.650 J	<0.010 U	<0.200 U	<1.000 U	1158.12	9.39	644.30	DISSOLVED
	183564	7.57	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	660.67	370.50	377.28	DISSOLVED
		16.18	<0.100 U	0.370 J	<0.010 U	<0.200 U	<1.000 U	667.99	379.47	383.02	DISSOLVED
	198766	2.69	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	2179.14	1010.66	671.72	DISSOLVED
		5.43	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	2075.28	977.74	673.36	DISSOLVED
	205010	6.96	<1.000 U	<1.000 U	<0.050 U	<0.200 U	3.08	3557.05	1258.96	777.52	DISSOLVED
		15.00	<1.000 U	<1.000 U	<0.050 U	<0.200 U	3.05	3475.01	1257.85	771.78	DISSOLVED
	199572	6.69	<0.500 U	<0.500 U	<0.050 U	0.25	2.03	3226.70	1194.88	741.43	DISSOLVED
		14.32	<0.500 U	<0.500 U	0.25	0.35	2.07	3129.31	1136.81	769.32	DISSOLVED
	205011	0.75	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	712.06	400.66	397.78	DISSOLVED
		1.66	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	709.20	397.17	392.86	DISSOLVED
	205041	6.25	<0.500 U	<0.500 U	<0.050 U	<0.200 U	2.40	2618.80	1169.44	711.09	DISSOLVED
		12.22	<0.500 U	<0.500 U	0.040 J	<0.200 U	1.51	2670.33	1123.29	711.91	DISSOLVED
	199568	83.34	<1.000 U	2.190 J	<0.050 U	10.10	11.70	3921.37	2306.45	701.25	DISSOLVED
	205049	8.20	<1.000 U	<1.000 U	<0.050 U	0.40	<1.000 U	3726.17	1070.45	853.80	DISSOLVED
		16.20	<1.000 U	<1.000 U	<0.050 U	0.31	<1.000 U	3588.78	974.39	855.44	DISSOLVED
	144969	9.88	<0.250 U	<0.250 U	<0.010 U	<0.200 U	4.19	1743.48	324.08	679.10	DISSOLVED
		19.31	<0.250 U	<0.250 U	<0.010 U	<0.200 U	4.17	1737.86	325.59	697.97	DISSOLVED
	197452	4.42	<0.500 U	<0.500 U	<0.010 U	<0.200 U	<1.000 U	2711.49	609.09	958.78	DISSOLVED
		9.72	<0.500 U	<0.500 U	<0.010 U	<0.200 U	1.02	2695.28	595.92	975.18	DISSOLVED
	205082	3.50	<0.500 U	<0.500 U	<0.010 U	0.31	<1.000 U	2369.09	764.84	611.85	DISSOLVED
		7.72	<0.250 U	<0.250 U	0.06	0.26	<1.000 U	2256.29	718.52	602.01	DISSOLVED
	197607	5.17	<0.250 U	<0.250 U	<0.010 U	0.24	<1.000 U	2402.35	836.56	997.33	DISSOLVED
		12.02	<0.250 U	<0.250 U	<0.010 U	0.22	<1.000 U	2339.53	802.64	966.98	DISSOLVED
	7777	7.48	<0.250 U	<0.250 U	<0.010 U	<0.200 U	1.49	2314.59	260.77	795.57	DISSOLVED
	7778	10.14	<1.000 U	<1.000 U	<0.050 U	0.43	<1.000 U	3647.14	1298.00	706.17	DISSOLVED
	7782	17.03	<1.000 U	<1.000 U	0.28	<0.200 U	2.89	4328.47	1099.44	844.78	DISSOLVED
	7781	2.55	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	1012.76	7.69	596.62	DISSOLVED
	7780	2.22	<0.100 U	0.360 J	<0.010 U	<0.200 U	<1.000 U	823.87	5.17	484.29	DISSOLVED
	7775	32.10	<1.000 U	<1.000 U	0.31	<0.200 U	1.17	4578.80	1760.02	755.38	DISSOLVED
	205004	2.91	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	991.06	462.13	488.00	DISSOLVED
		7.00	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	940.19	447.70	467.50	DISSOLVED
	197247	7.65	<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.06	3611.41	1112.01	777.52	DISSOLVED

APPENDIX D

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

Appendix D

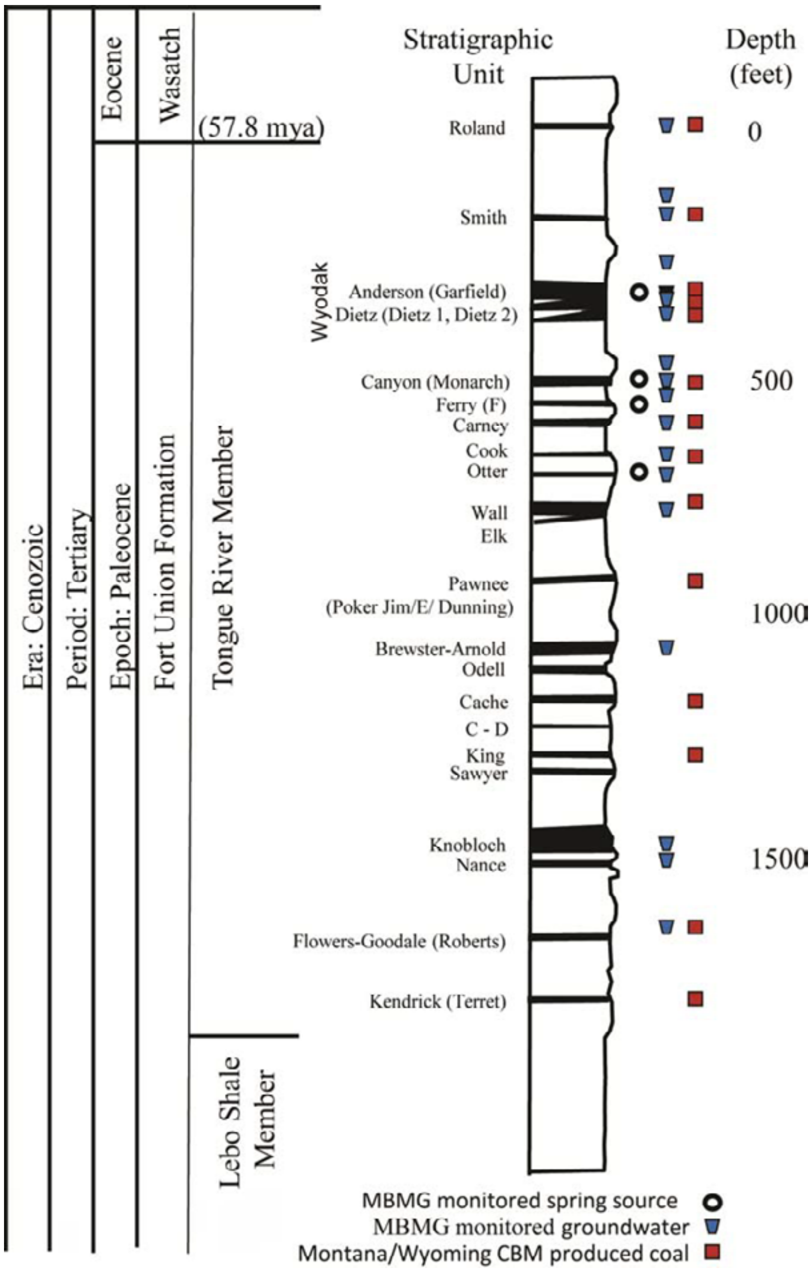
Geology and Hydrogeology of the Tongue River Member of the Fort Union Formation

The axis of the Powder River Basin in Montana coincides roughly with the Tongue River. Geologic dip is toward the west on the eastern side of the axis and toward the east on the western side. The base of the Tongue River Member is deepest in the central part of the study area nearest the basin axis (Lopez, 2006). East of the axis, groundwater recharge generally occurs along outcrop areas and natural flow is generally toward the west and north, eventually discharging along outcrops or seeping into deeper aquifers. West of the basin axis, recharge occurs in the topographically high areas in Wyoming and on the Crow Indian Reservation. Groundwater flows to the east, toward the Tongue River. Near the Tongue River Reservoir it is interrupted by coal mines and coalbed-methane production. Generally, the zones between and including the Anderson and Knobloch coals are considered the most likely prospects for CBM in southeastern Montana (Van Voast and Thale, 2001); 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

Appendix D-2

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

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

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

BD indicates lowest readings were below detection

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 D-3

APPENDIX E

Hydrographs from wells outside of current CBM impacts

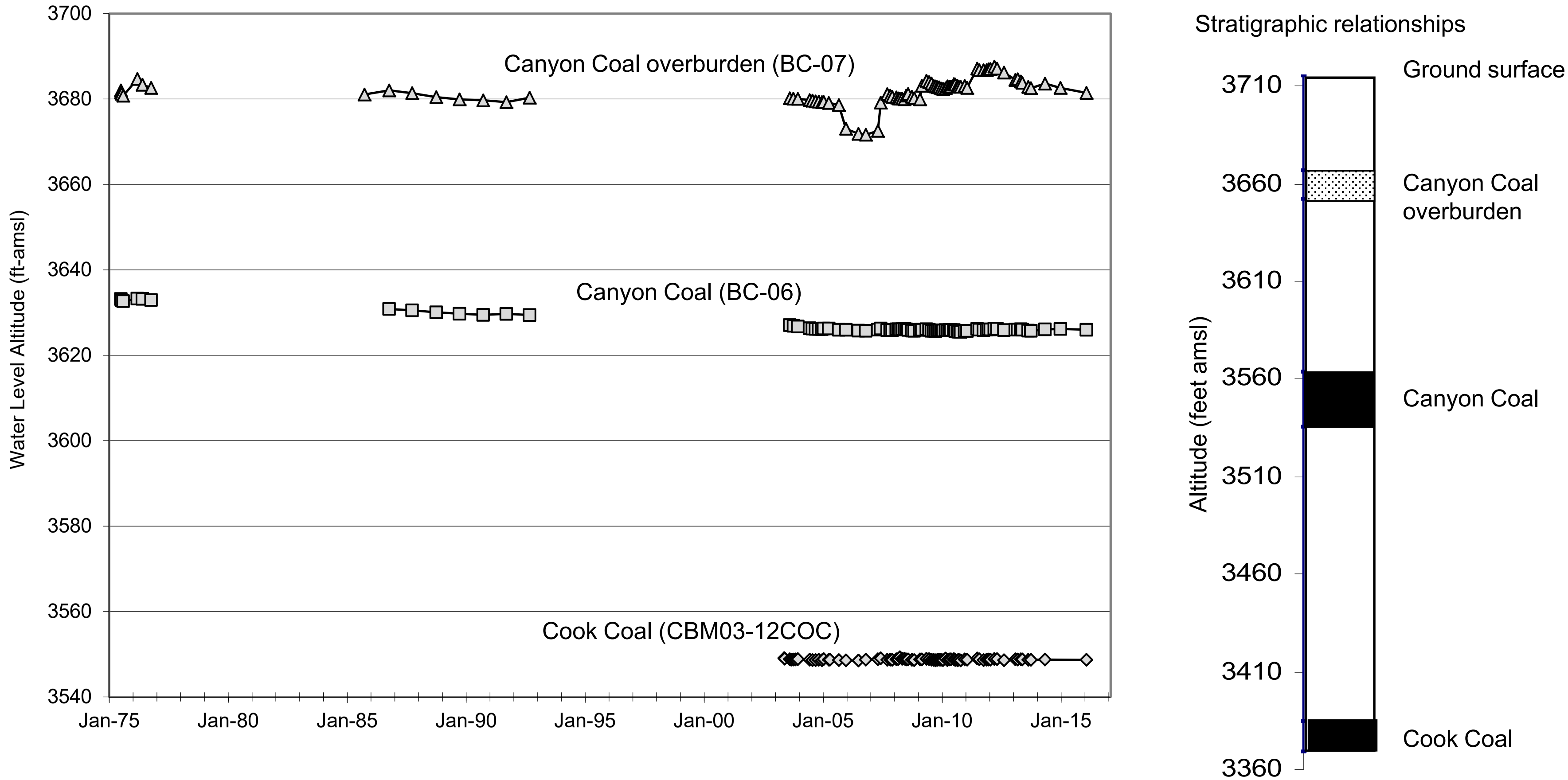


Figure E-1. Monitoring site CBM03-12 has been measured since 1974. There is a downward gradient at this site. The long-term decrease in water levels in the overburden sandstone (BC-07) and Canyon coal (BC-06), began long before the introduction of CBM and likely relate to long-term precipitation patterns (Figure 2). The 13 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.

Appendix E-1

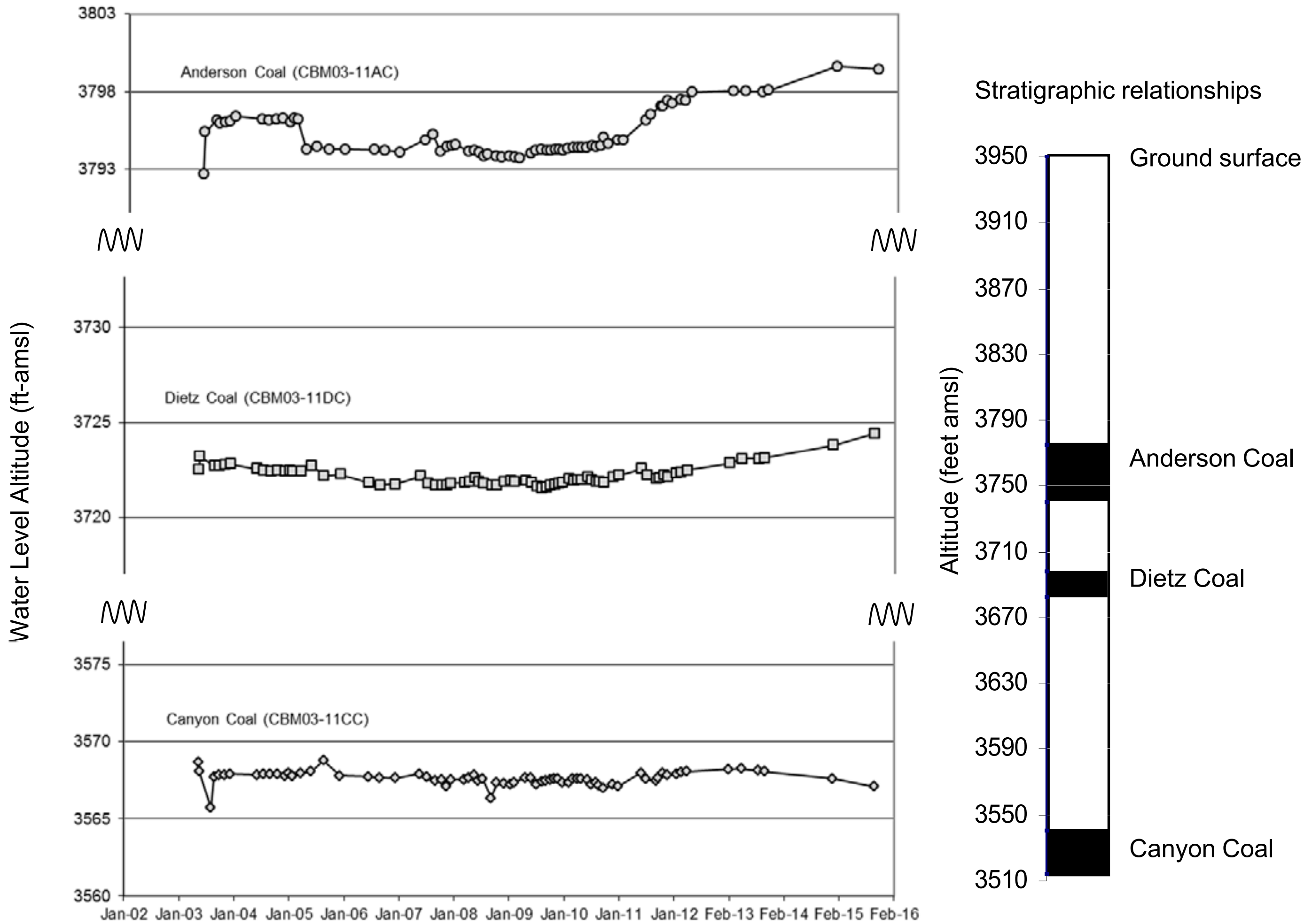


Figure E-2 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site. This site is near the Anderson coal outcrop.

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

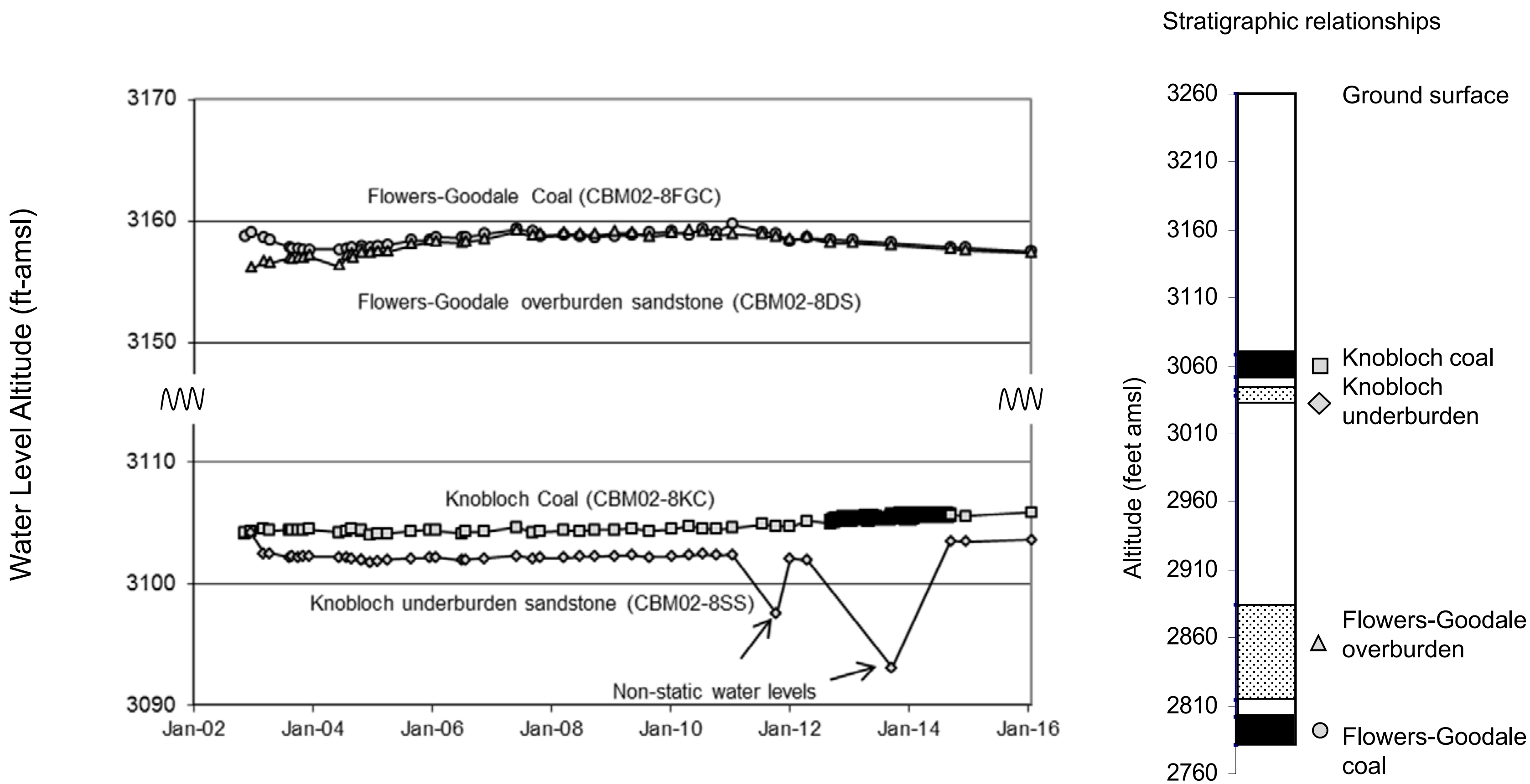


Figure E-3. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. The hydrostatic pressure in the Knobloch coal have been reduced by natural discharge to nearby outcrops. This upward gradient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

Appendix E-3

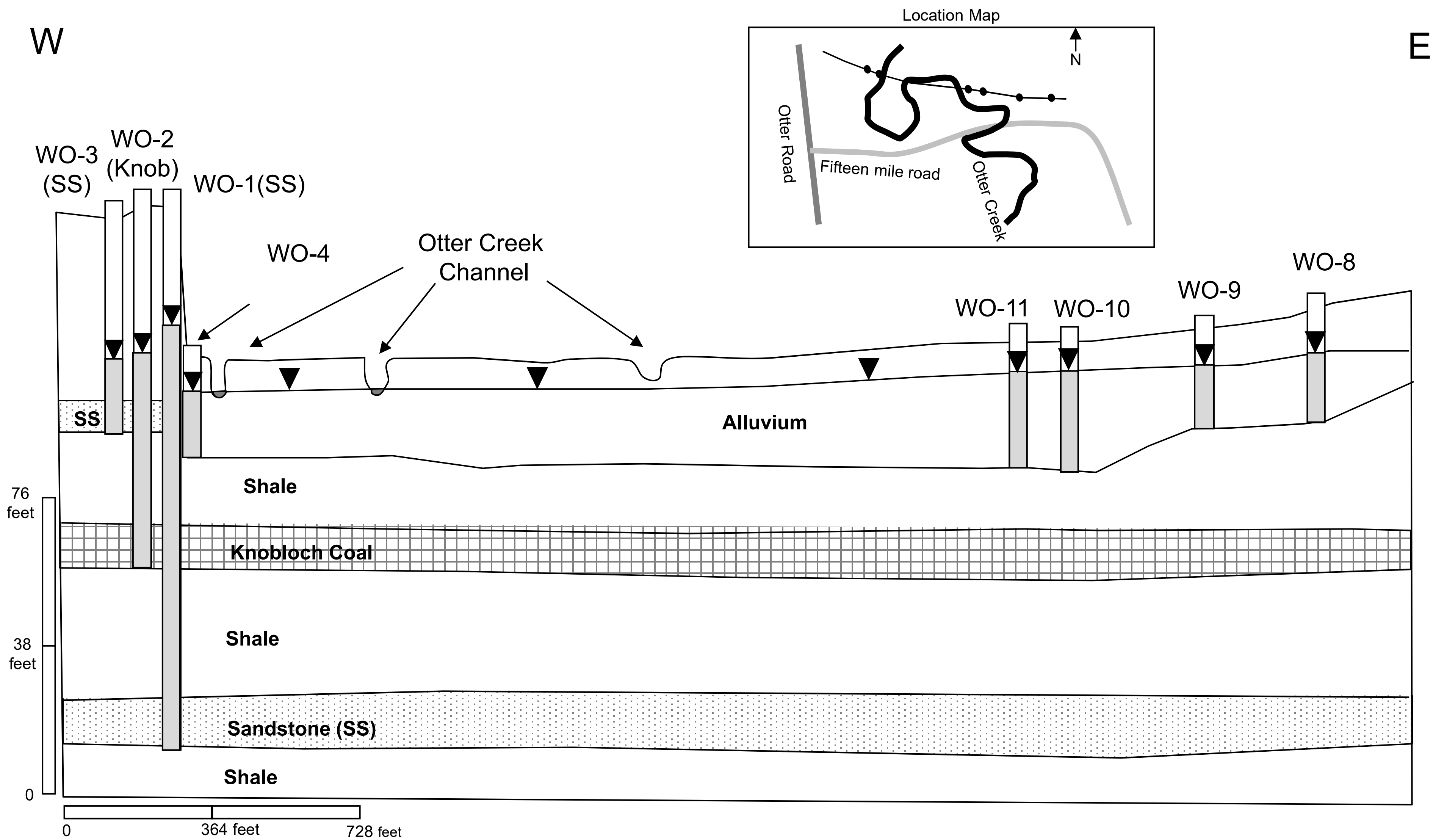


Figure E-4. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in September, 2015. Vertical exaggeration is 9.6:1. Hydrographs for these wells are presented in Figures 4 and E-5.

Appendix E-4

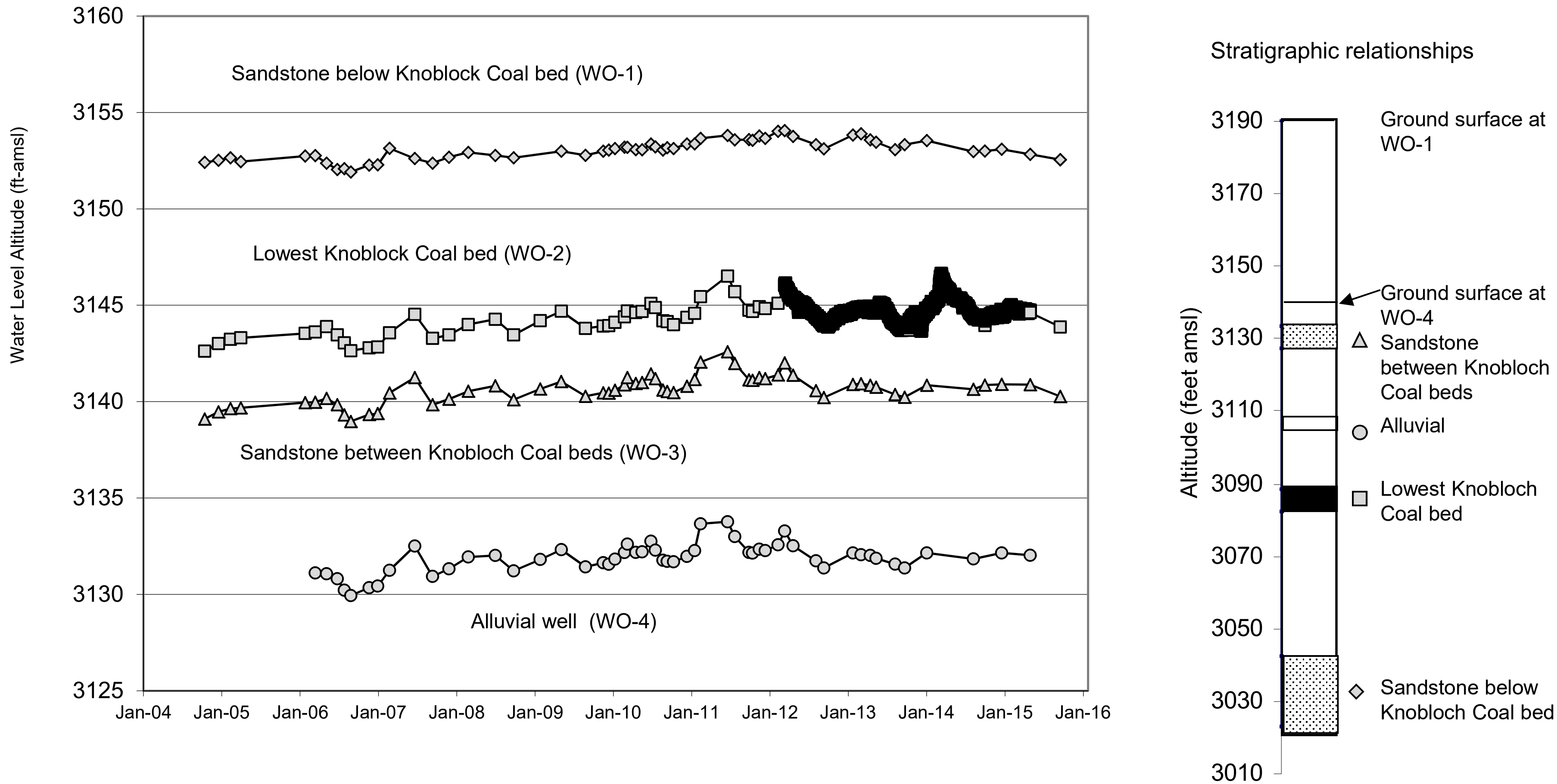


Figure E-5. At monitoring site WO, bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. This upward gradient indicates that the bedrock aquifer will discharge into the alluvium where the two units are in contact. The alluvial well appears to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

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

Appendix E-5

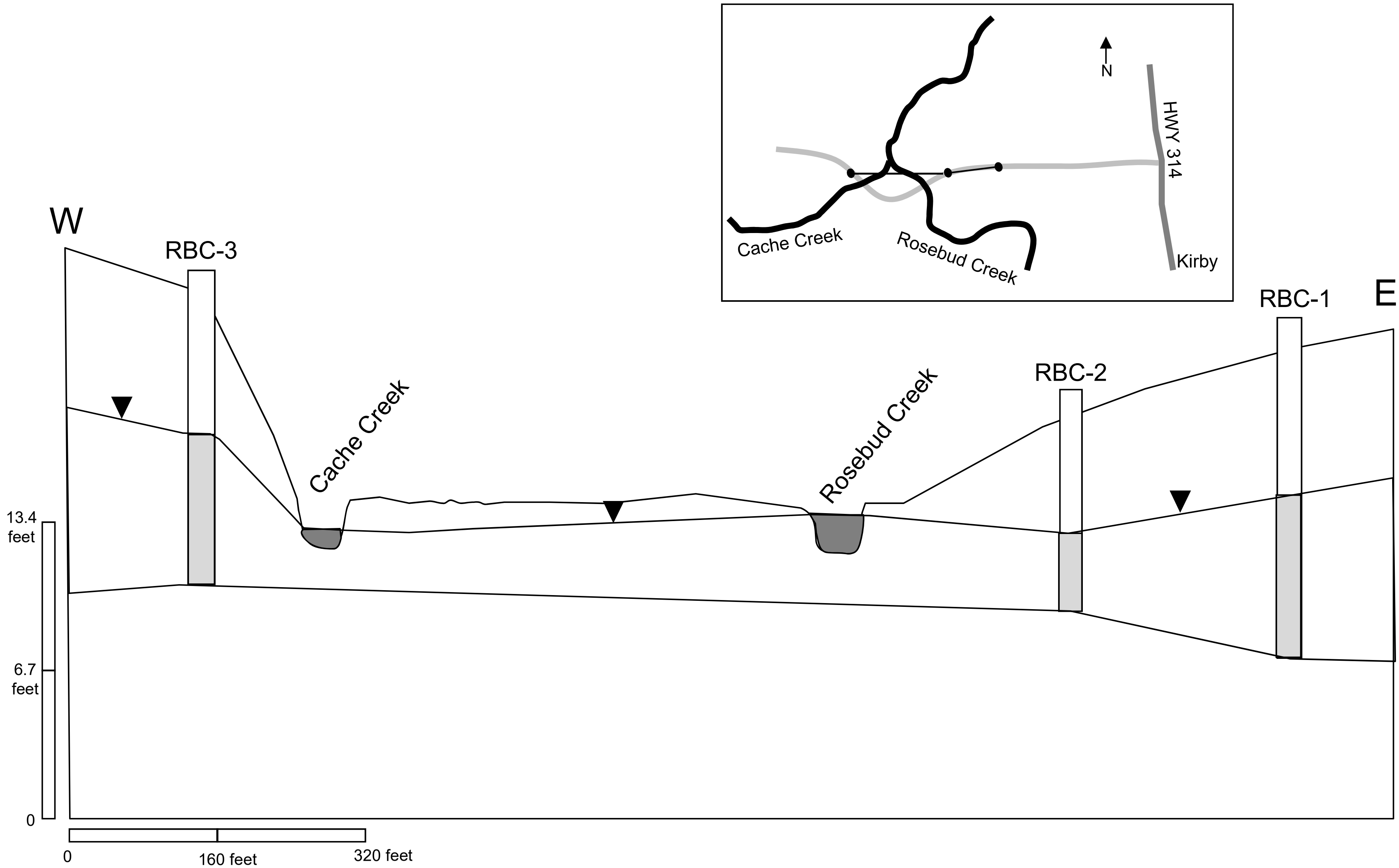
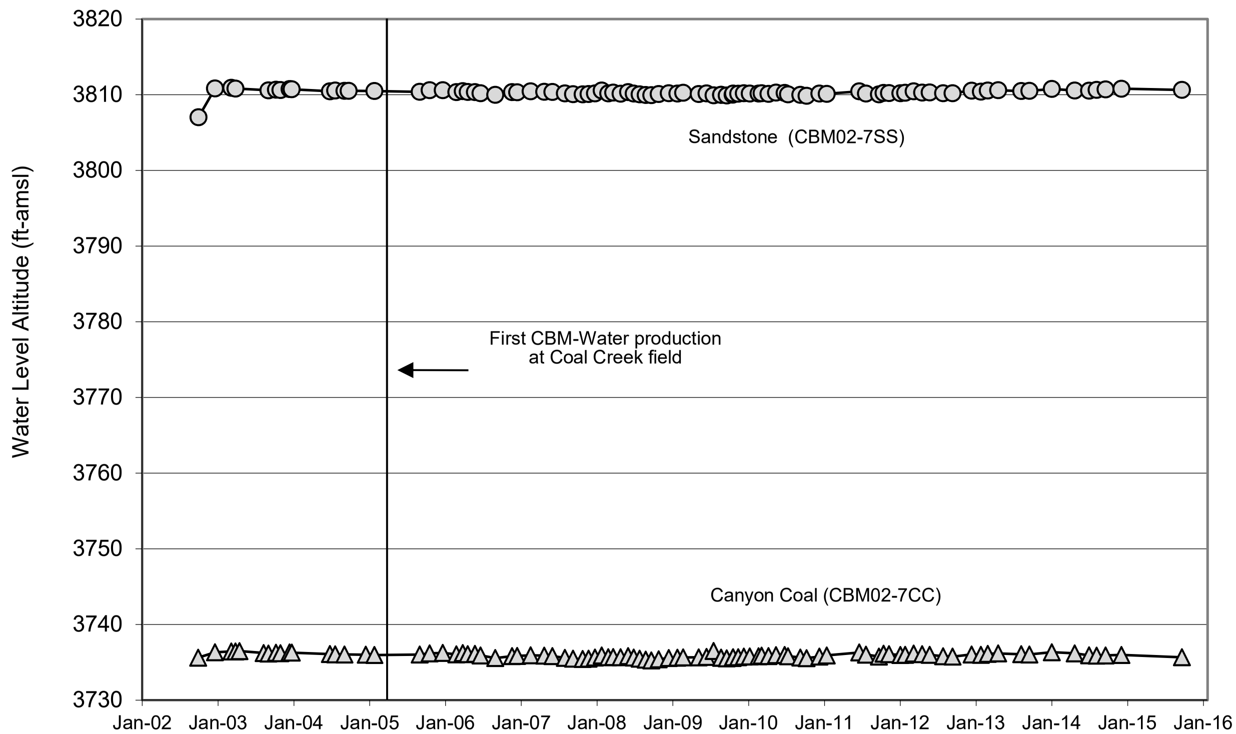


Figure E-6. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water depending 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 2015. Vertical exaggeration is 23.9:1. Hydrographs associated with this site are shown in Figure E-7.

Appendix E-6



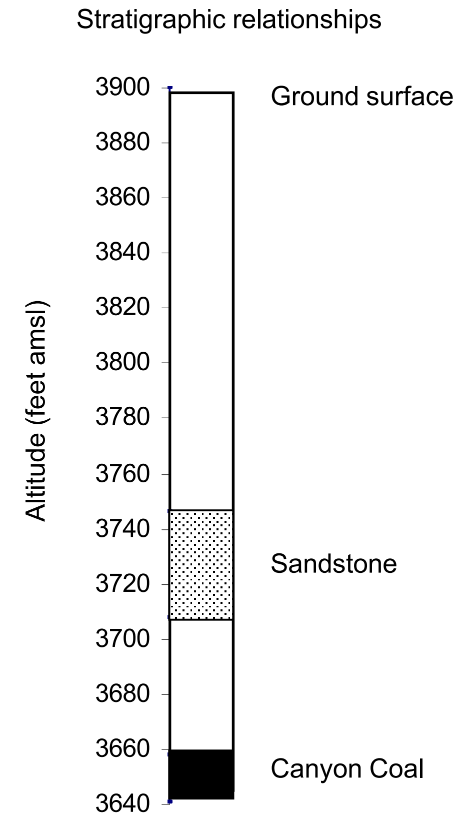


Figure E-7. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

Appendix E-7

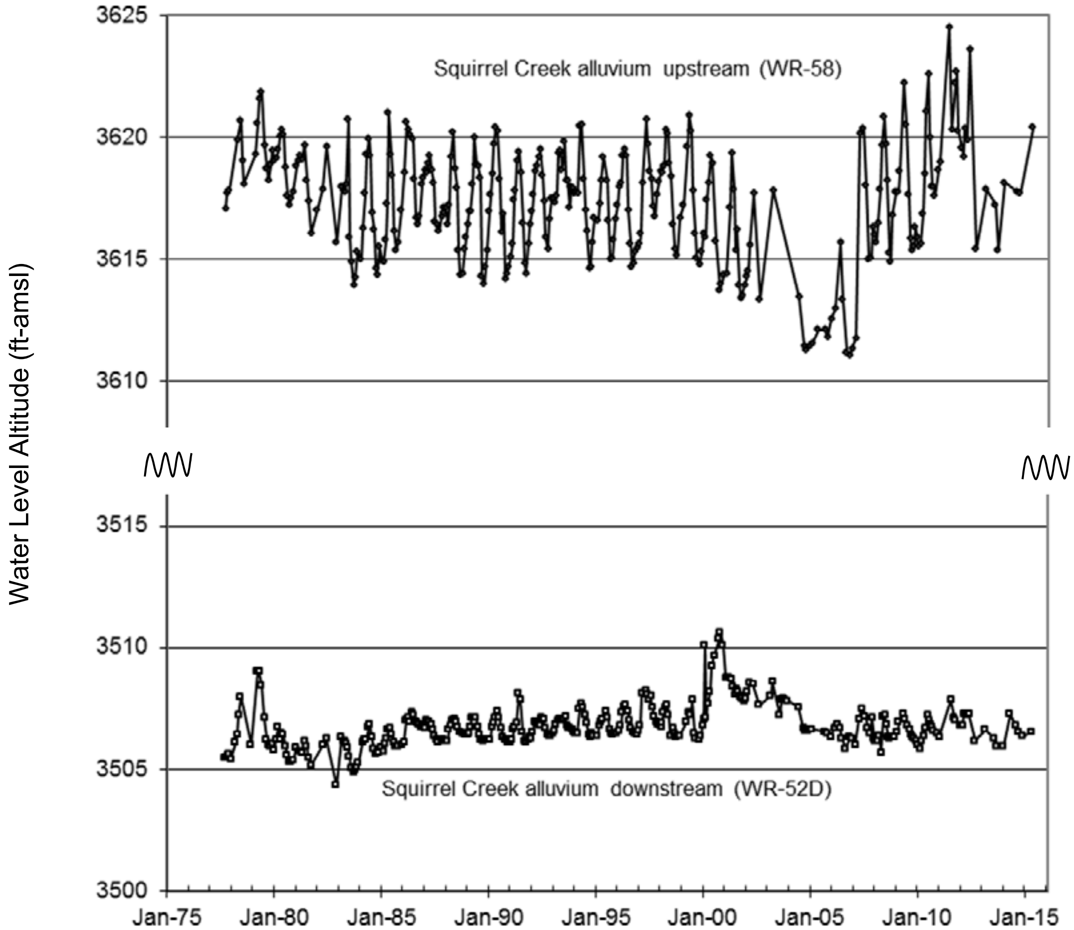


Figure E-8. These alluvial wells are within the area influenced by CBM production; however, they no longer show impacts from the nearby infiltration pond. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production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

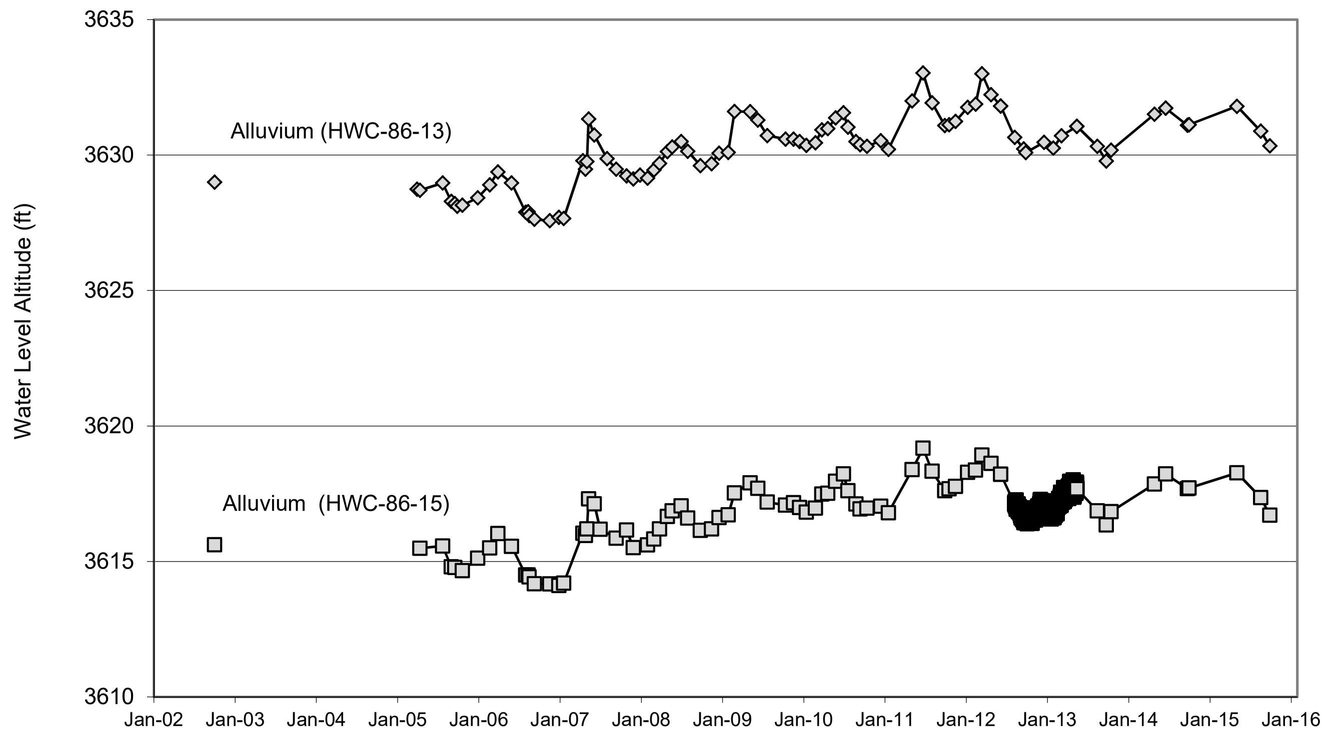


Figure E-9. The water level in the Hanging Woman Creek alluvial aquifer near the Montana – Wyoming state line reflects water table response to meteorological patterns. Shown on plate 1.

Appendix E-9

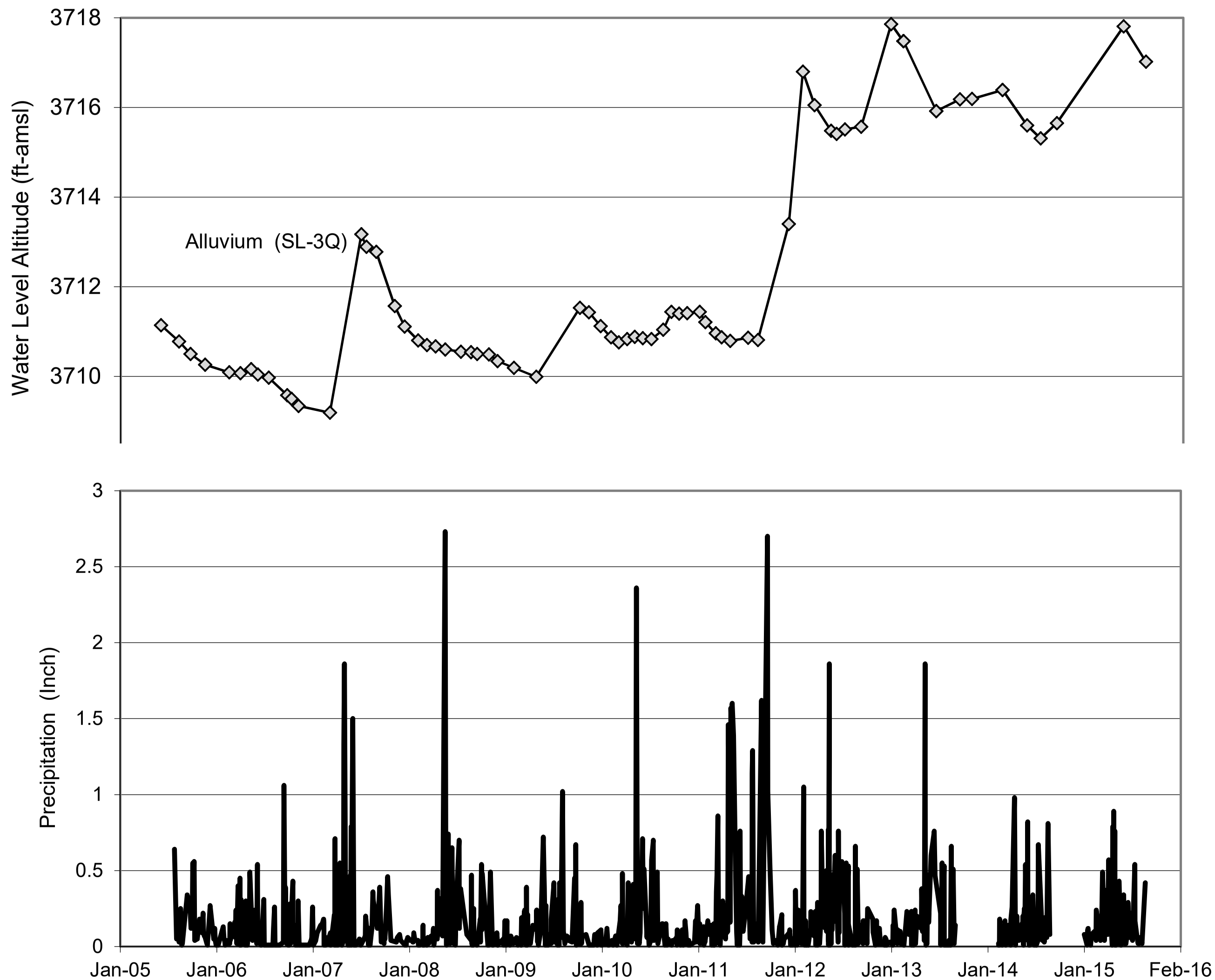
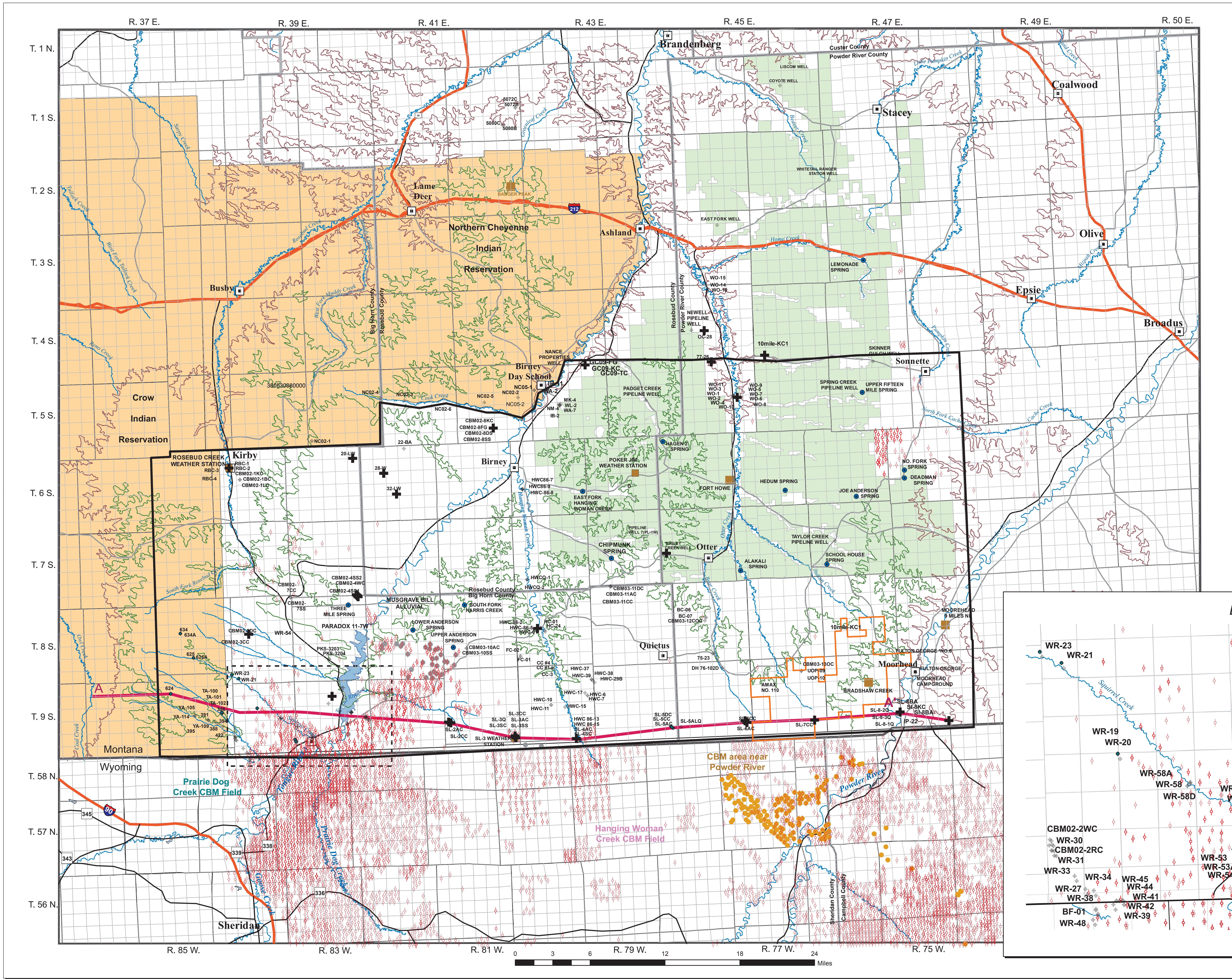


Figure E-10. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to plate 1. Precipitation at the SL-3 weather station is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation.

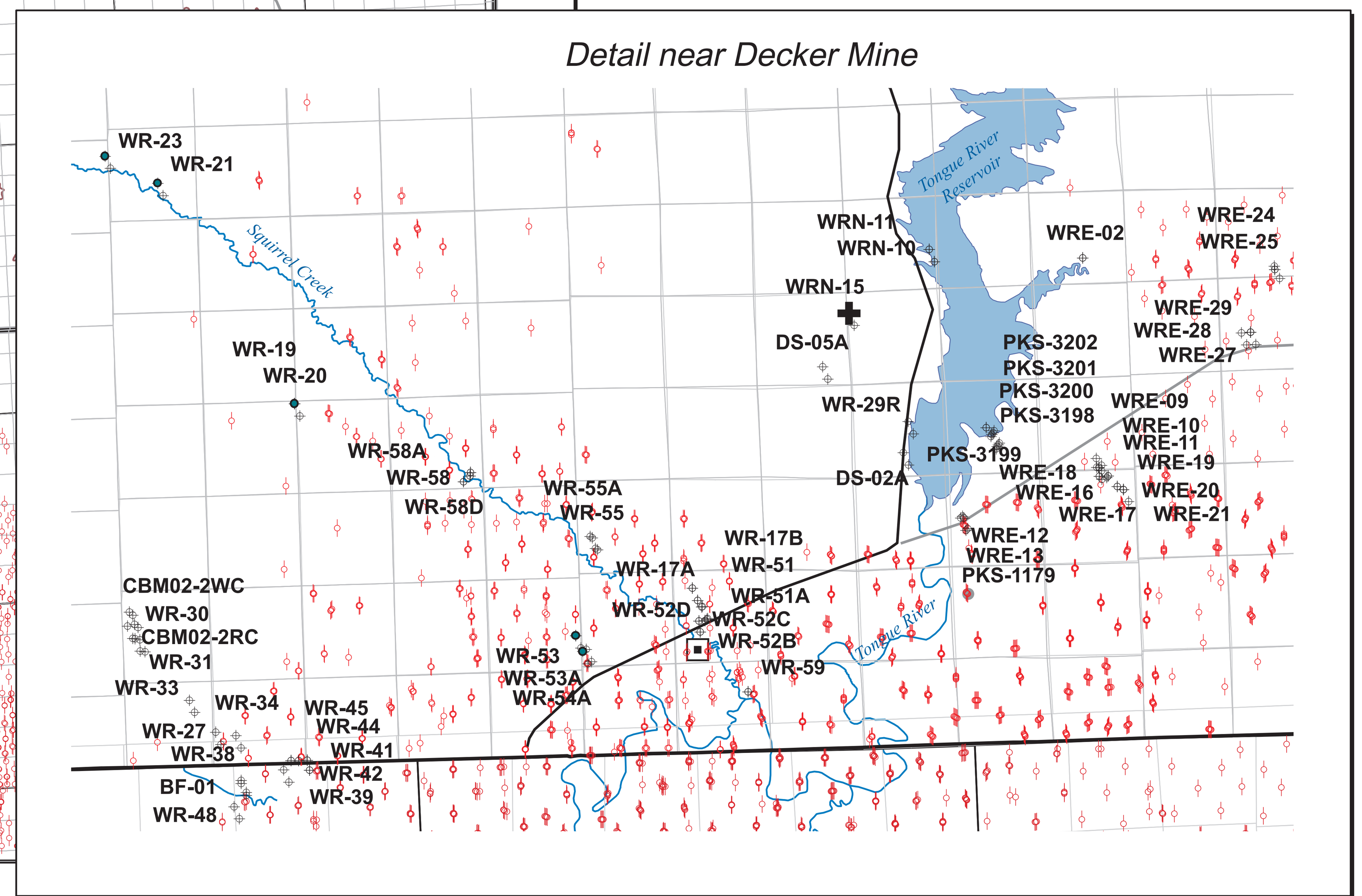
Appendix E-10

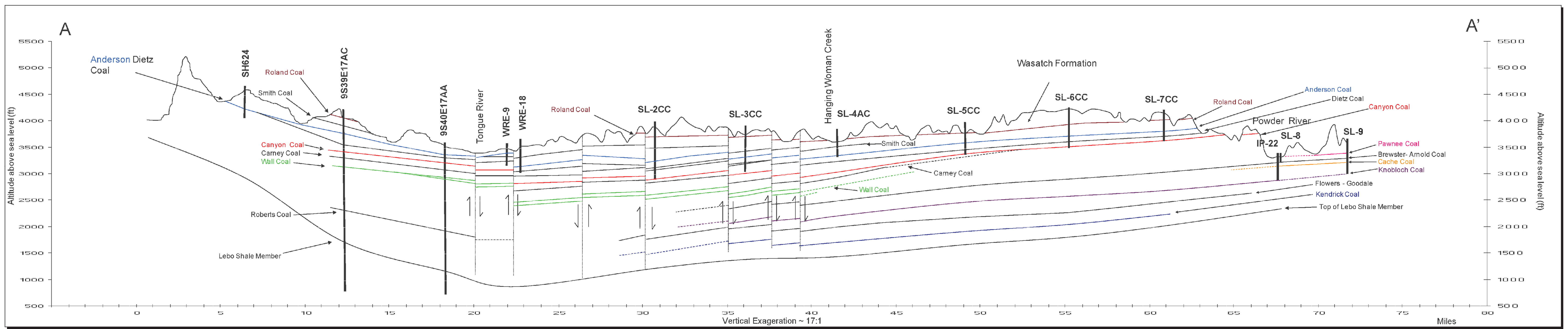
Plate 1. Locations of 2015 monitoring sites, and Anderson and Knobloch coal outcrops.



Explanation

- Monitor wells
- Monitor springs
- CBM production well, Montana
- Shut-in CBM well
- Prairie Dog Creek field producing CBM well
- Data logger location
- Proposed CBM development
- Quarterly Monitoring Boundary
- Outline of Decker Mine Inset map
- A - A' Geologic cross-section
- Anderson coal outcrop
- Knobloch coal outcrop
- Weather station, black border if operated by MBMG
- Towns
- Local roads
- Secondary roads
- US Route
- County boundary
- Custer National Forest
- Indian reservation lands





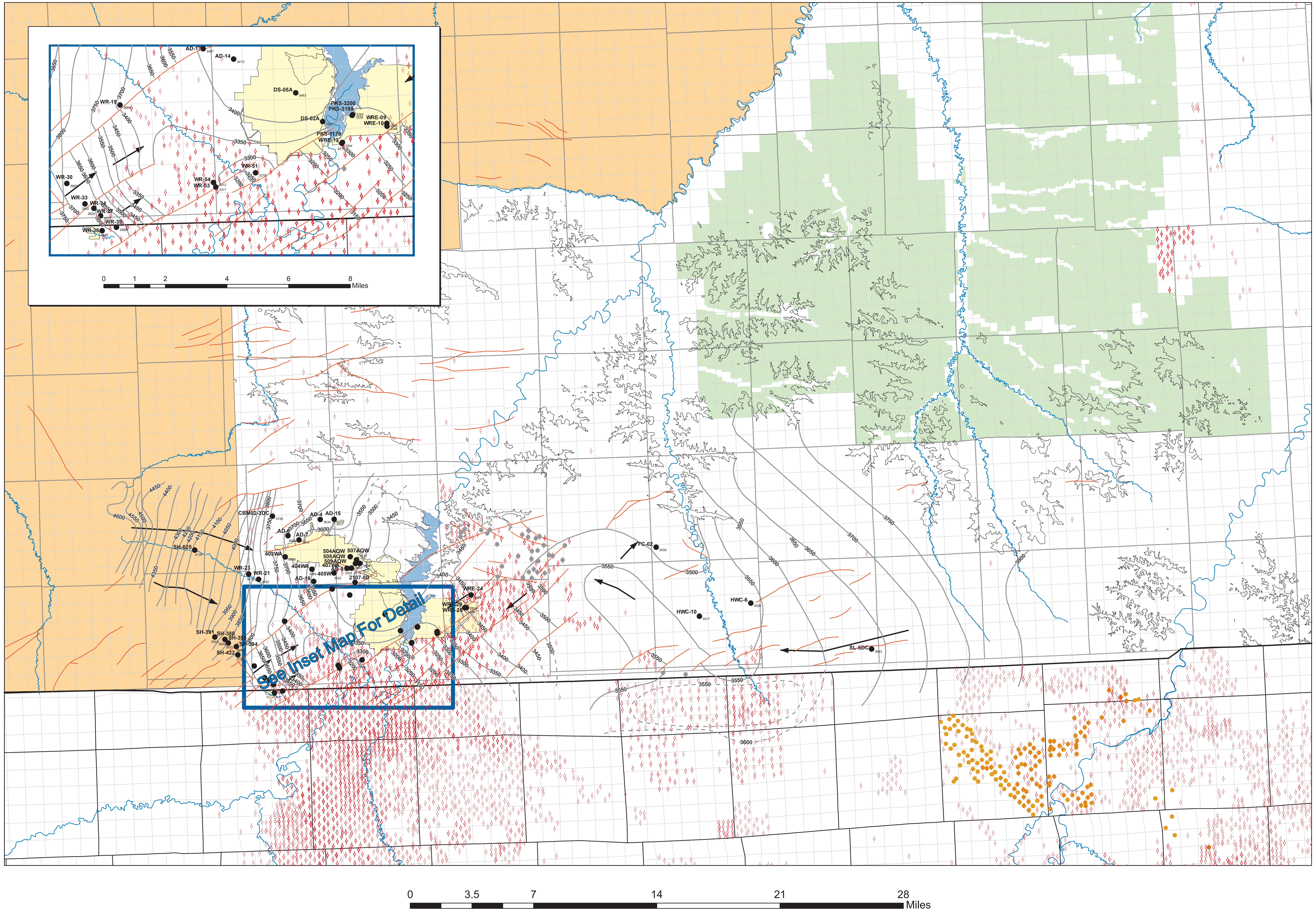


Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2015.

Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, 2009. Squirrel Creek area modified from Hedges and others, 1998), 50-ft contour intervals
- Approximate direction of ground-water flow
- HWC-6 / 3528 — MBMG Monitor well name, water-level altitude (ft) for water year 2015. (D1-Dietz 1, D2-Dietz 2)
- Dietz coal outcrop
- Fault, MBMG geological data, CX coal field area modified using data from Fidelity
- Mine area, includes active, permitted and reclaimed
- CBM production well with production records during water year 2015.
- CBM production well was listed as shut-in at the end of water year 2015.
- Powder River field CBM well
- Indian Reservation land
- National Forest, (Ashland Ranger District)

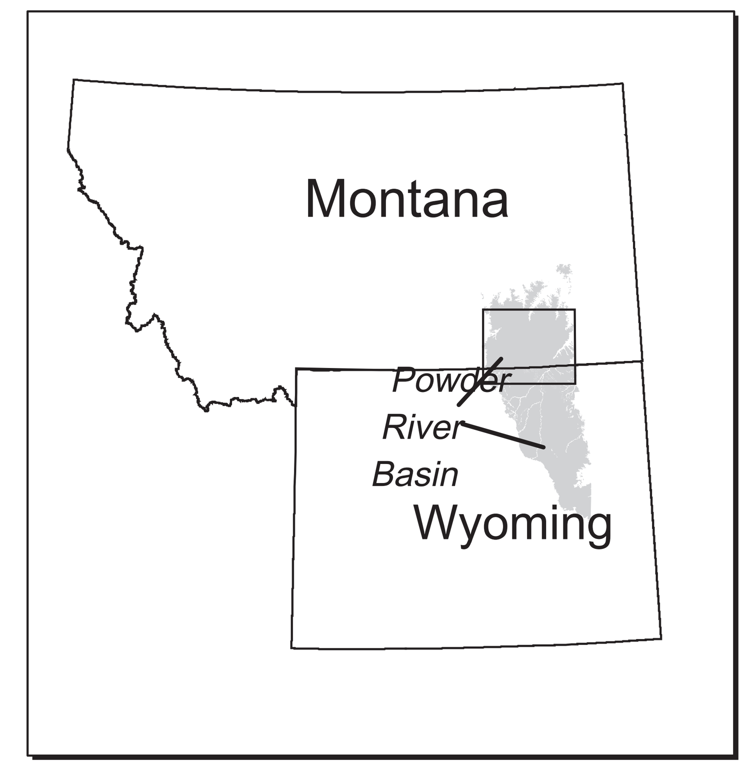
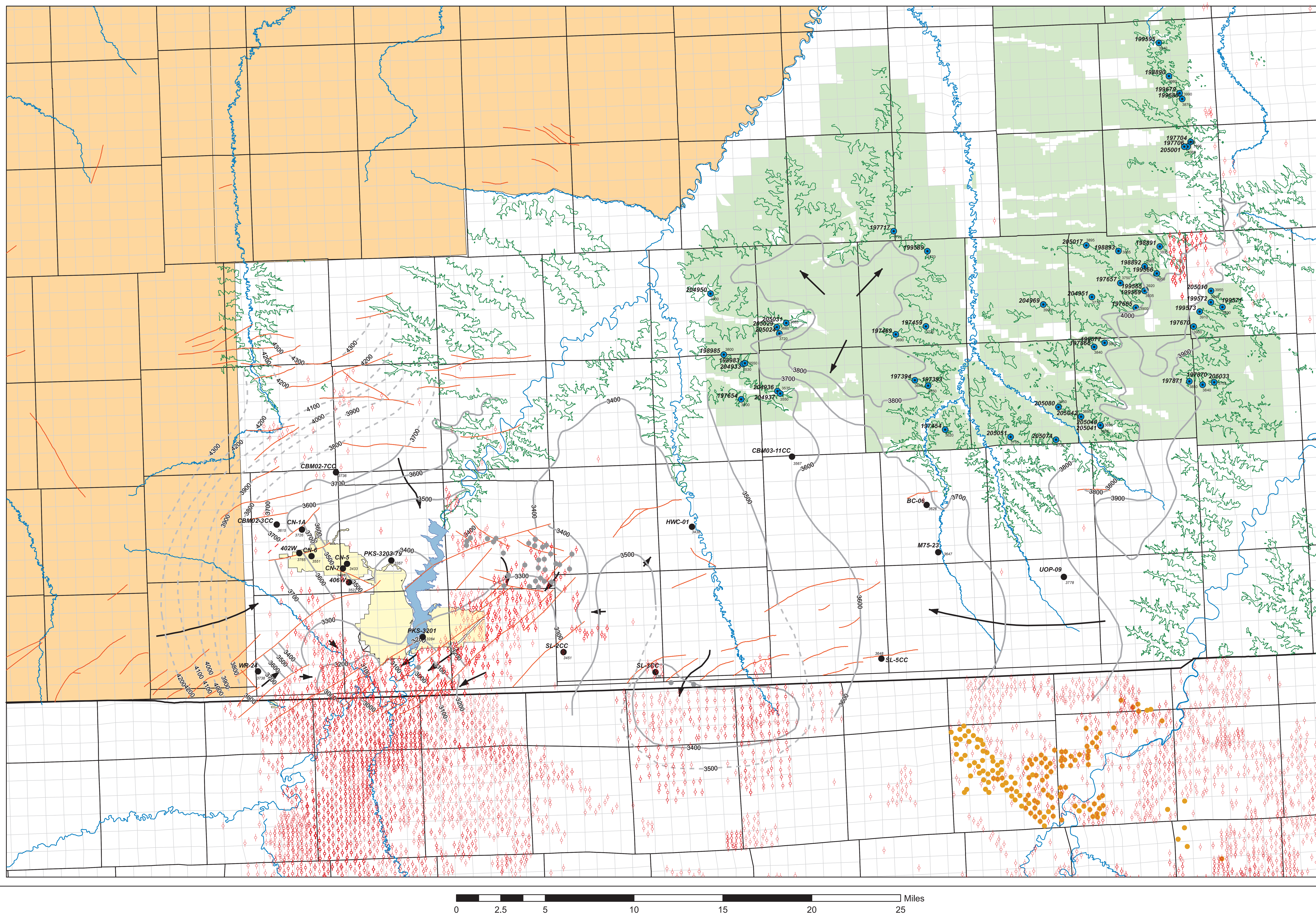


Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2015.



Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, water year 2015), 100-ft contour intervals
- Approximate direction of ground-water flow
- WR-24 3740 — Monitor well name, water-level altitude (ft) for last data in water year 2015.
- 199595 3940 — Spring with Canyon coal (GWIC identifier number and elevation)
- Canyon coal outcrop
- Fault, MBMG geological data, CX coal field area modified using data from Fidelity
- Mine area, includes active, permitted and reclaimed
- CBM production well in Montana with production records during water year 2015.
- CBM production well was listed as shut-in at the end at the end of water year 2015.
- Powder River field CBM well
- Indian Reservation land
- National Forest, (Ashland Ranger District)