2014 Annual Coalbed-Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

MBMG Open-File Report 658

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Cover and back photos: John Wheaton, MBMG, 2004.

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ABSTRACT

A regional groundwater monitoring network has been active in the Montana portion of the Powder River Basin for 12 yr. In this annual report, we present data collected through September 2014, with an emphasis on data collected during Water Year 2014 (October 2013–September 2014). 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 2014. This is 204 fewer wells than 2013 and 575 fewer than 2012. These wells produced a total of 487 mmscf (1 mmscf = 1,000,000 standard cubic feet) of CBM in 2014. Forty percent came from the Coal Creek field; 54 percent was from the Dietz field, and 6 percent was from the Waddle Creek field. This is the first year since 1999 that the CX field had no CBM-related production or activity.

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 operator of the Spring Creek coal mine provided their water-level monitoring data. Monitoring well density and coverage data 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 15 yr 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 limiting drawdown (Wheaton and others, 2005; Wheaton and Metesh, 2002). Faults tend to act as barriers to groundwater flow, and, where measured in monitoring wells, drawdown has not been observed to migrate across fault planes. However, 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 in the area, such as coal mining. Since 2004, the MBMG has documented water-level recovery due to discontinuation or reduction in CBM production in wells near the Montana–Wyoming state line in the far western part of the study area. Drawdown in these wells ranged from 19 to 152 ft. The amount of time required for water levels to recover to near-baseline conditions is difficult to estimate based on current recovery curves in the CX

field. Initial recovery rates were as expected and could have resulted in full recovery in 30 to 100 yr; however, observations during the past 5 yr indicate recovery has stagnated. Further recovery may only be seen 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 that 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 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. Reducing water pressure by pumping groundwater from coalbeds 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 concerns about potential loss of stock and domestic water supplies due to water-level drawdown that may reduce yields from wells and discharge from springs. Other concerns include the management of the produced water because of potential impacts to surface-water quality and soils. The Montana regional monitoring program provides data and interpretations that help governmental agencies and the public address the magnitude, extent, and duration of CBM-caused drawdown 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 gas prices. The spot Henry Hub price for natural gas was more than $15/MMBtu in 2005, but in January 2015 was $3.00/MMBtu (http://www.eia.gov/naturalgas/weekly/).

This is the twelfth 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 area covered by the Montana regional CBM groundwater monitoring network is shown in figure 1 and plate 1.

All hydrogeologic data collected under the Montana regional CBM groundwater monitoring program 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 222 wells, 14 springs, and 5 streams during the 2014 water year. Of those monitored sites, 25 wells and 9 springs are located within the Ashland Ranger District of the

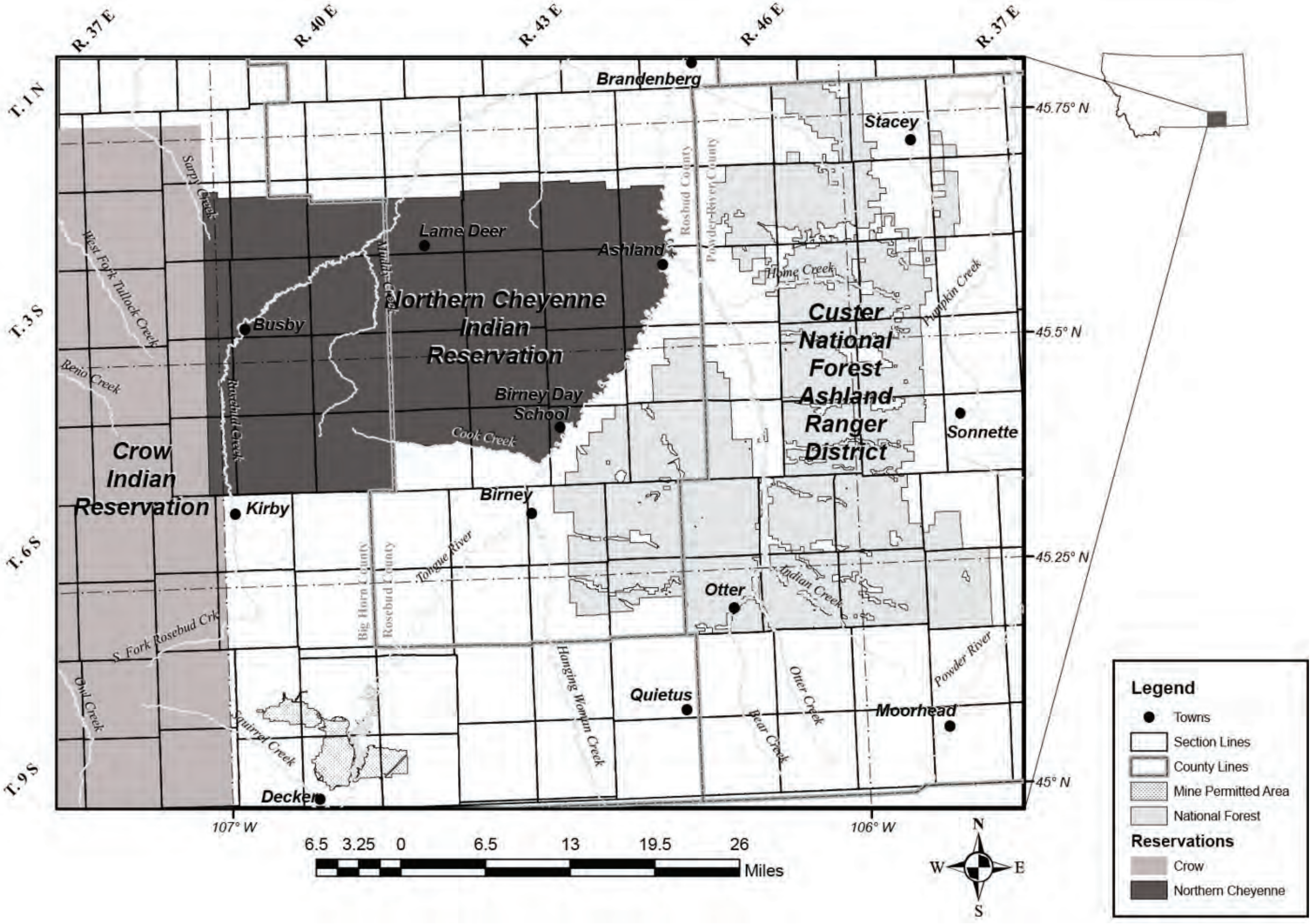


Figure 1. The Montana regional CBM monitoring network covers the area considered to have medium to high potential for CBM development in the Powder River Basin. This area extends from the Wolf Mountains in the west to the Powder River in the east, and from the MT–WY state line north to Ashland.

Custer National Forest. Six monitoring wells, located on the Northern Cheyenne Reservation, are monitored by tribal employees and the United States Geological Survey (USGS). The Spring Creek mine supplied 82 water levels for 21 monitoring wells (plates 2–5). Descriptions of all wells included in the regular monitoring program and the most recent data are listed in appendix A. Site descriptions for monitored springs and the most recent flow data are listed in appendix B. Water-quality data collected during the 2014 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 on plate 1.

ACKNOWLEDGMENTS

The landowners, coalbed-methane producers, and coalmine operators who allowed monitoring access or provided monitoring data are gratefully acknowledged for their cooperation. Funding for the current and much of the previous work has been provided by the U.S. Department of the Interior, Bureau of Land Management (BLM). The USDA Forest Service (USFS) provides funding to support monitoring and water-quality sampling on the Ashland Ranger District in the Custer National Forest. The Montana Department of Natural Resources and Conservation and the Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal and coalbed methane hydrogeology work. The Coalbed Methane Protection Program has supported the publication of informational fliers for CBM education. The statewide Ground Water Assessment Program, operated by the MBMG, monitors several wells and springs in the Powder River Basin, and those data are incorporated in this work. Technical discussions and reviews by the BLM, USFS, and cooperating groups continue to be invaluable.

LOCATION, DESCRIPTION, AND GENERAL HYDROGEOLOGY OF THE AREA

The study area is 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 reaction to climatic periods of below- or above-average precipitation, but 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 from this station indicate that average annual precipitation is 12.08 in (1970–2014; Western Regional Climate Center, 2015). During the calendar year 2014, the Moorhead station received 11.57 in of precipitation (black circles in fig. 2), 0.51 in less than the average annual precipitation. Long-term precipitation trends that may affect groundwater levels are illustrated by the departure from average (black squares in fig. 2). The early 2000s marked a period of average to below-average precipitation, while precipitation was generally above average from 2005 to 2011.

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

In southeastern Montana, faults in the Fort Union Formation are typically barriers to flow that limit the areal extent of drawdown (Van Voast and Reiten, 1988). A series of monitoring wells were installed along a fault south of the East Decker mine in the early 1970s to document this effect (Van Voast and Hedges, 1975). These wells continue to be monitored, and measurements demonstrate that this fault limits groundwater flow. However, long-term water-level monitoring at other sites demonstrates that some fault systems do allow some cross-fault leakage. A computer model of the area around the Ash Creek Mine (Meredith and others, 2010) showed that groundwater flow must be occurring around the ends of scissor faults.

In the Powder River Basin, coalbed methane exists only in reduced (oxygen-poor) zones where water quality is characterized by high concentrations of Na^+ and HCO_3^-, and low concentrations of Ca^{2+}, Mg^{2+}, and SO_42^- (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 shallow groundwater quality. To assess possible changes, water-quality data are collected semi-annually from some shallow aquifers.

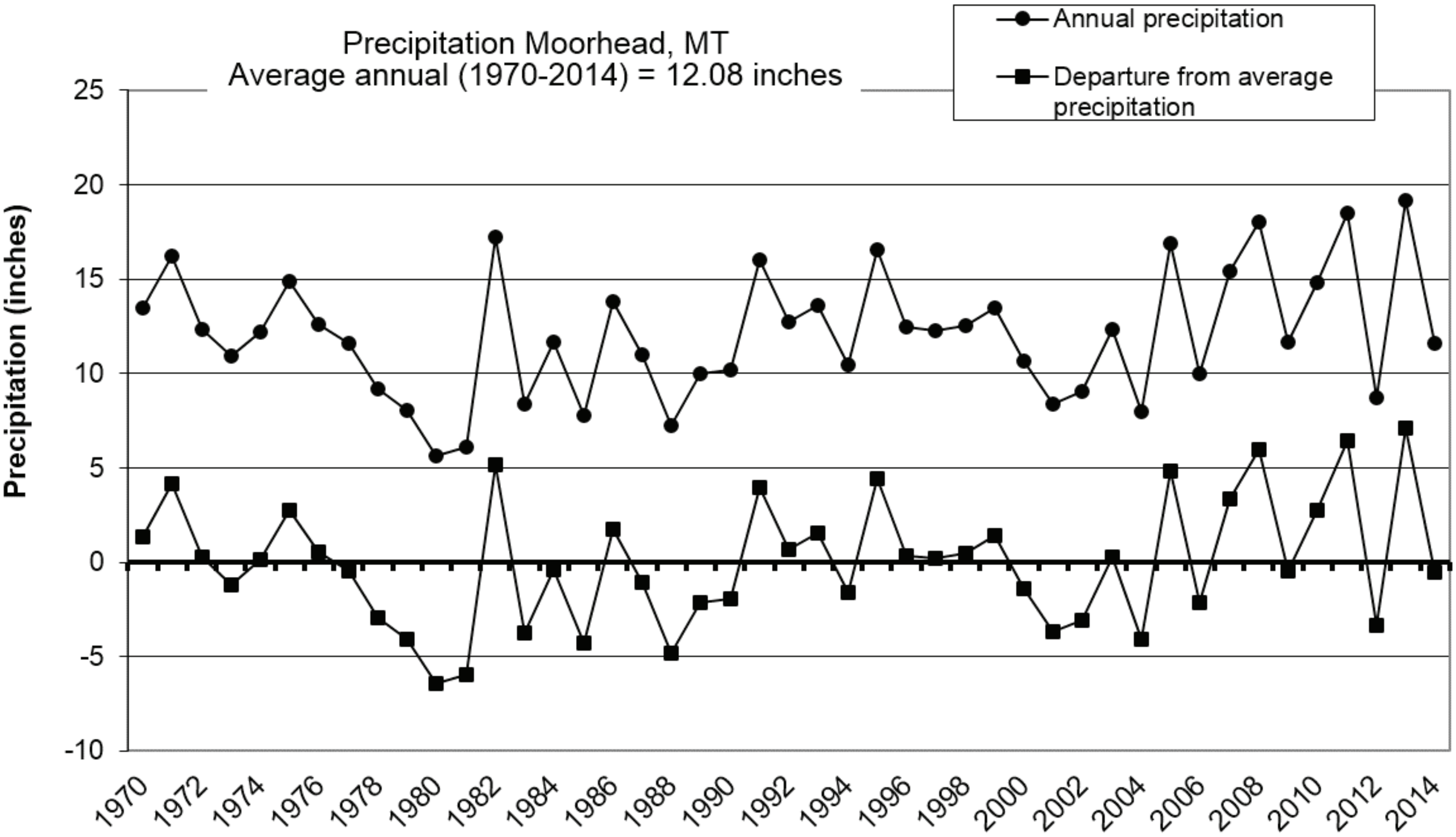


Figure 2. Annual precipitation (circles on line graph) at Moorhead, MT. Departure from average precipitation (squares on line graph) provides a perspective on the long-term moisture trends that may effect groundwater recharge.

GROUNDWATER CONDITIONS OUTSIDE OF CURRENT CBM INFLUENCE

BEDROCK- AND ALLUVIAL-AQUIFER WATER LEVELS AND WATER QUALITY

Groundwater levels (the potentiometric surface) and inferred groundwater flow directions in the Dietz and Canyon 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 vertically downward over geologic time 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 12 yr 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, all aquifers responded with higher potentiometric surfaces. The shallowest coalbed, the Brewster–Arnold, experienced only a slight upward water-level perturbation and quickly returned to more typical seasonal responses. 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. After rising 4 ft from 2011 to 2012, water levels in the Knobloch coal fell by only 1 ft before again rising 0.5 ft in 2014.

Alluvial water levels, such as at monitoring site WO (fig. 4) along Otter Creek, and RBC along Rosebud Creek, respond to local, recent precipitation. The flow in Otter Creek varies along its length, at times disappearing into the alluvium altogether, transitioning between a gaining and losing stream; the transition's exact location depends on the seasonal alluvial groundwater level. 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.

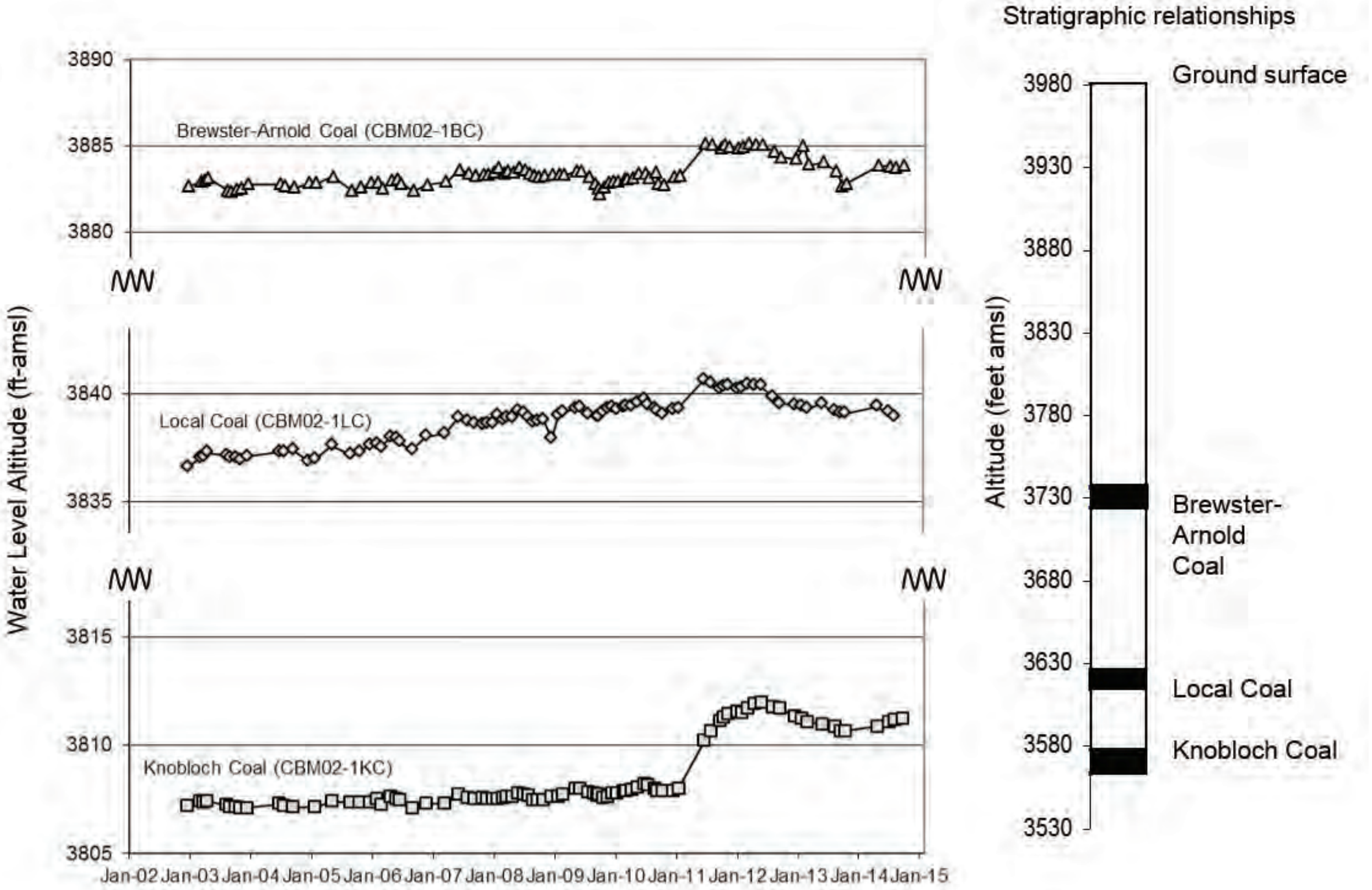


Figure 3. A downward hydrostatic gradient is evident between the Brewster–Arnold coal, Local Coal, and Knobloch coal at the CBM02-1 site. This monitoring site is near the town of Kirby, just east of Rosebud Creek. Water-level data from the Brewster–Arnold coal and the Local Coal demonstrate a slight 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.

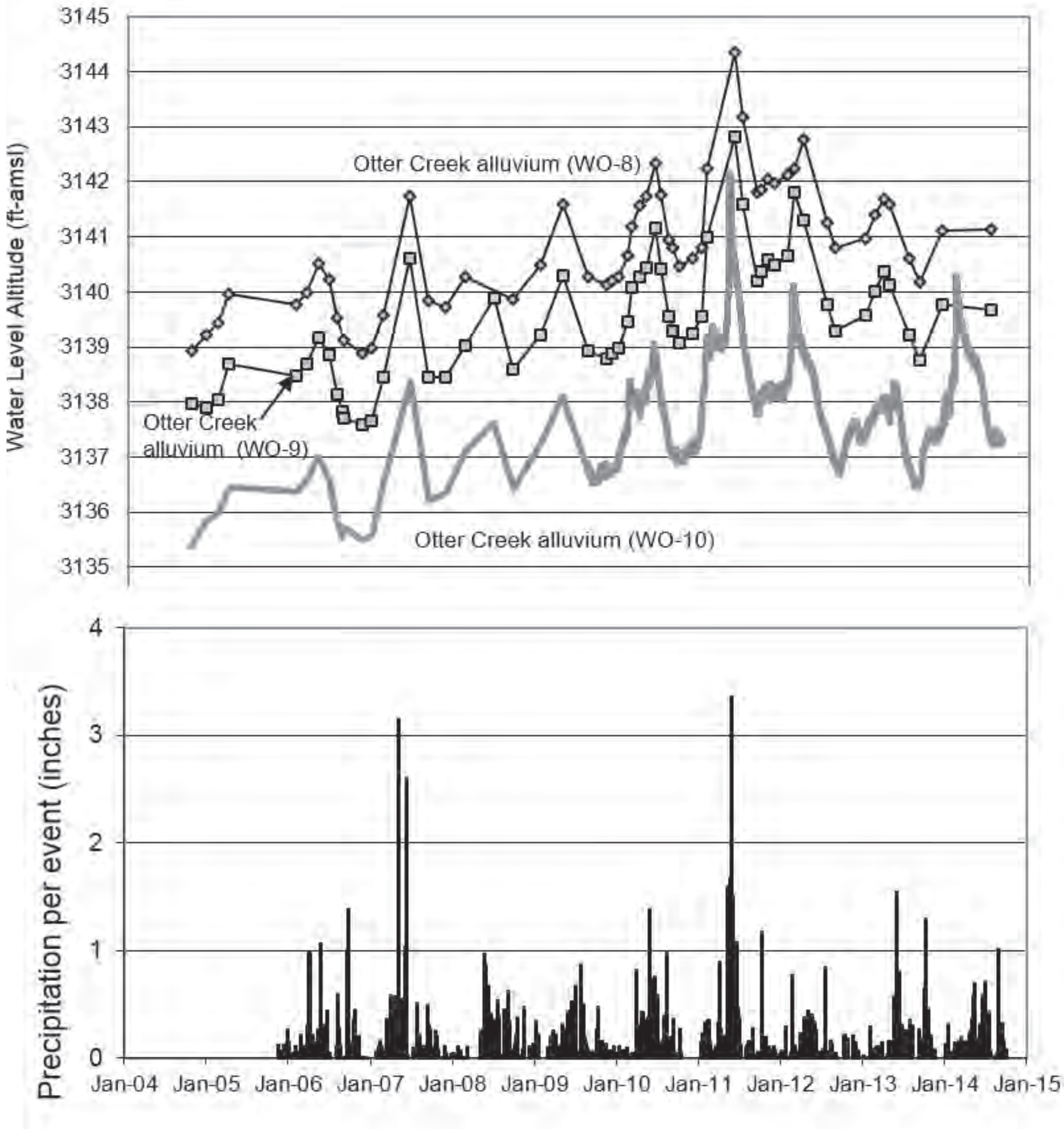


Figure 4. Seasonal water-level change in the alluvium at the Otter Creek site closely follows the precipitation recorded at the Poker Jim weather station (shown as the total rain in inches per event in the lower graph).

SPRING AND STREAM FLOW AND WATER QUALITY

Flow rates and specific conductivity data were collected at 14 springs and one stream within the project area, but outside the influence of CBM production during 2014. The locations of monitored springs and the streams are shown in plate 1, site data are in appendix B, and water-chemistry data for selected springs are in appendix C. Additional information about springs is in the National Forest Synoptic Sampling section.

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 1.5 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.

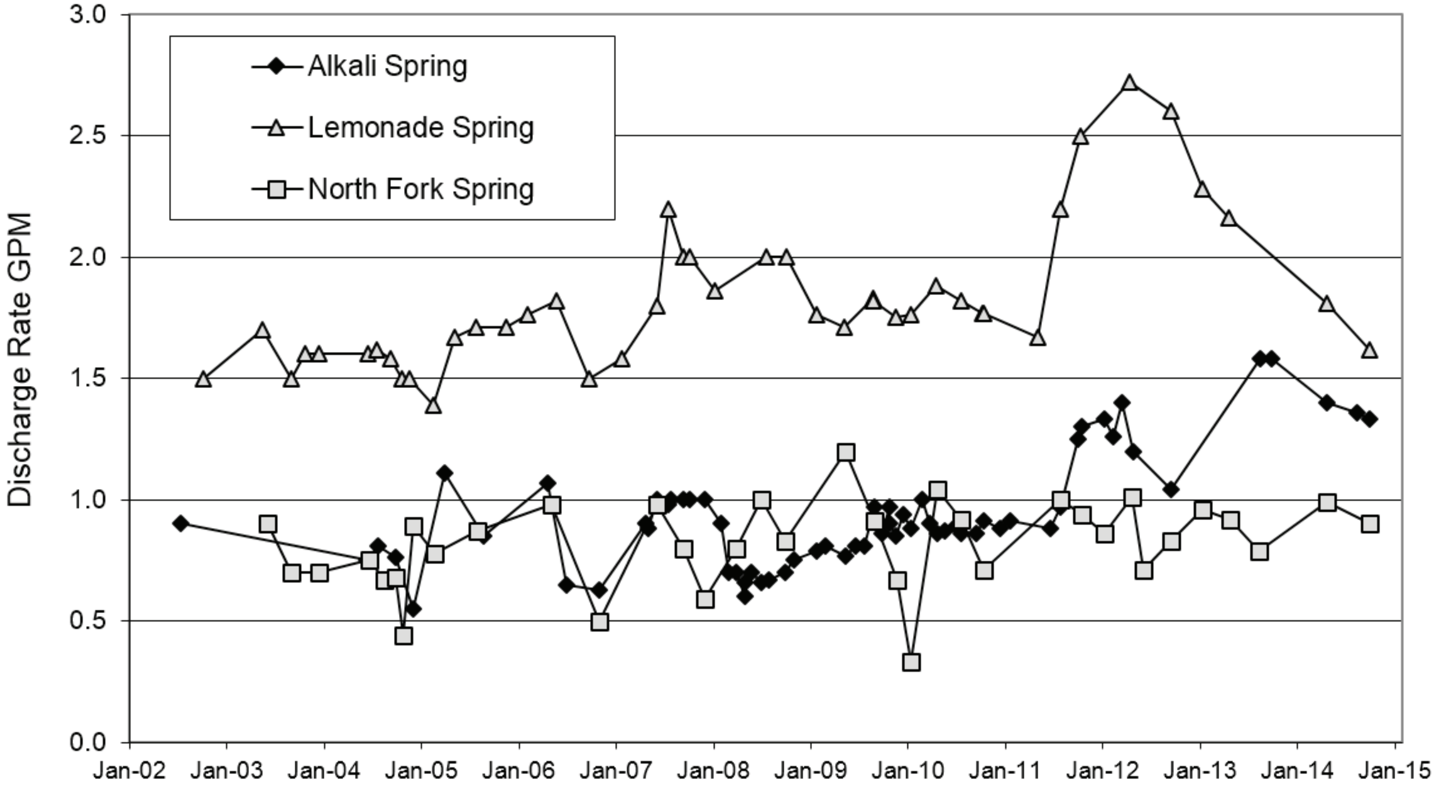


Figure 5. Discharge from Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.94 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.82 gpm. Lemonade Spring appears to be locally recharged by the Ferry coalbed. The spring has an average discharge rate of 1.82 gpm.

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.

Produced-water volume data for water year 2014 were retrieved for Montana (MBOGC, 2015) and Wyoming (WOGCC, 2014) and are summarized in table 1. A total of 90 Montana wells produced methane and/or water at some point during 2014. The 90 wells produced 3.8 million barrels (bbls) of water (492 acre-ft) during water year 2014, 61 percent less than in 2013. In the same time period, 768 wells in the two tiers of Wyoming townships nearest Montana (57 N. and 58 N.) produced 47 million bbls (6,005 acre-ft) of water, 23 percent less than in 2013. The total amount of water co-produced with CBM in the Powder River Basin in all of Wyoming during water year 2014 was approximately 263 million bbls or 33,850 acre-ft.

Coalbed methane permitted wells in Montana are summarized by county and field in table 2. The number of producing wells in table 2 differs from that in table 1 because table 1 includes all wells that were active at any time in water year 2014, rather than just those active in November 2014. As of November 2014, there were 1,029 shut-in or abandoned CBM wells in Montana; all of the remaining production is in Big Horn County (table 2).

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) 2014	Annual + total water production in Bbls *1,000 (acre-ft)							
				2014	2013	2012	2011	2010	2009	2008	2007
Montana	Coal Creek	33	194,355	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)	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	55	262,606	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	29,657	0 (0)	0 (0)	15.6 (2.0)	92.4 (12)	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**90**	**486,618**	**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	220	4,604,042	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	113	1,113,519	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	435	4,989,205	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	**768**	**10,706,766**	**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)**

Note. 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.

Table 2. Summary of Montana Board of Oil and Gas Conservation Listings of Coalbed Methane Permitted Wells by County and Field.

County	Field or POD	Well Status	Mar. 2008	Oct. 2008	Nov. 2009	Nov. 2010	Oct. 2011	Oct. 2012	Oct. 2013	Nov. 2014
Big Horn	Coal Creek	Permit/Spudded	9	7	4	5	5	0	0	0
		Expired Permit	0	0	2	2	2	6	6	6
		Producing	**13**	**26**	**23**	**20**	**14**	**17**	**18**	**20**
		Shut In/Abandoned	49	35	39	44	50	46	45	45
	CX	Permit/Spudded	44	44	9	0	0	0	0	0
		Expired Permit	231	251	288	288	288	288	288	288
		Producing	**741**	**705**	**676**	**623**	**508**	**275**	**10**	**2**
		Shut In/Abandoned	110	168	212	270	385	619	875	879
		Water Well, Released	0	0	0	0	0	2	11	12
	Dietz	Permitted Injection Well	1	1	1	1	1	0	0	0
		Permit/Spudded	1	0	0	0	0	0	0	0
		Expired Permit	42	42	42	42	42	42	42	42
		Producing	**96**	**92**	**36**	**61**	**55**	**38**	**34**	**45**
		Shut In/Abandoned	10	5	61	45	51	59	63	61
	Other (Deer Creek, Four Mile, Forks Ranch, Waddle Creek, Wildcat BH)	Permit/Spudded	34	56	35	36	35	0	0	0
		Expired Permit	38	49	67	67	68	103	103	103
		Producing	**2**	**2**	**3**	**1**	**1**	**2**	**1**	**2**
		Shut In/Abandoned	21	27	29	24	24	30	28	21
		Water Well, Released	0	1	1	1	1	1	4	3
Other Counties Carbon, Custer, Gallatin, Powder River, Rosebud		Permit/Spudded	124	2	2	2	2	1	1	0
		Expired Permit	35	157	157	157	157	158	158	158
		Producing	**2**	**2**	**3**	**2**	**1**	**0**	**0**	**0**
		Shut In/Abandoned	15	14	16	19	21	21	21	23
		Water Well, Released	0	0	0	1	1	1	1	1

Note. Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ accessed Nov. 24, 2014.

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 producing wells in Montana are mirrored by changes in Wyoming (figs. 6A, 6B).

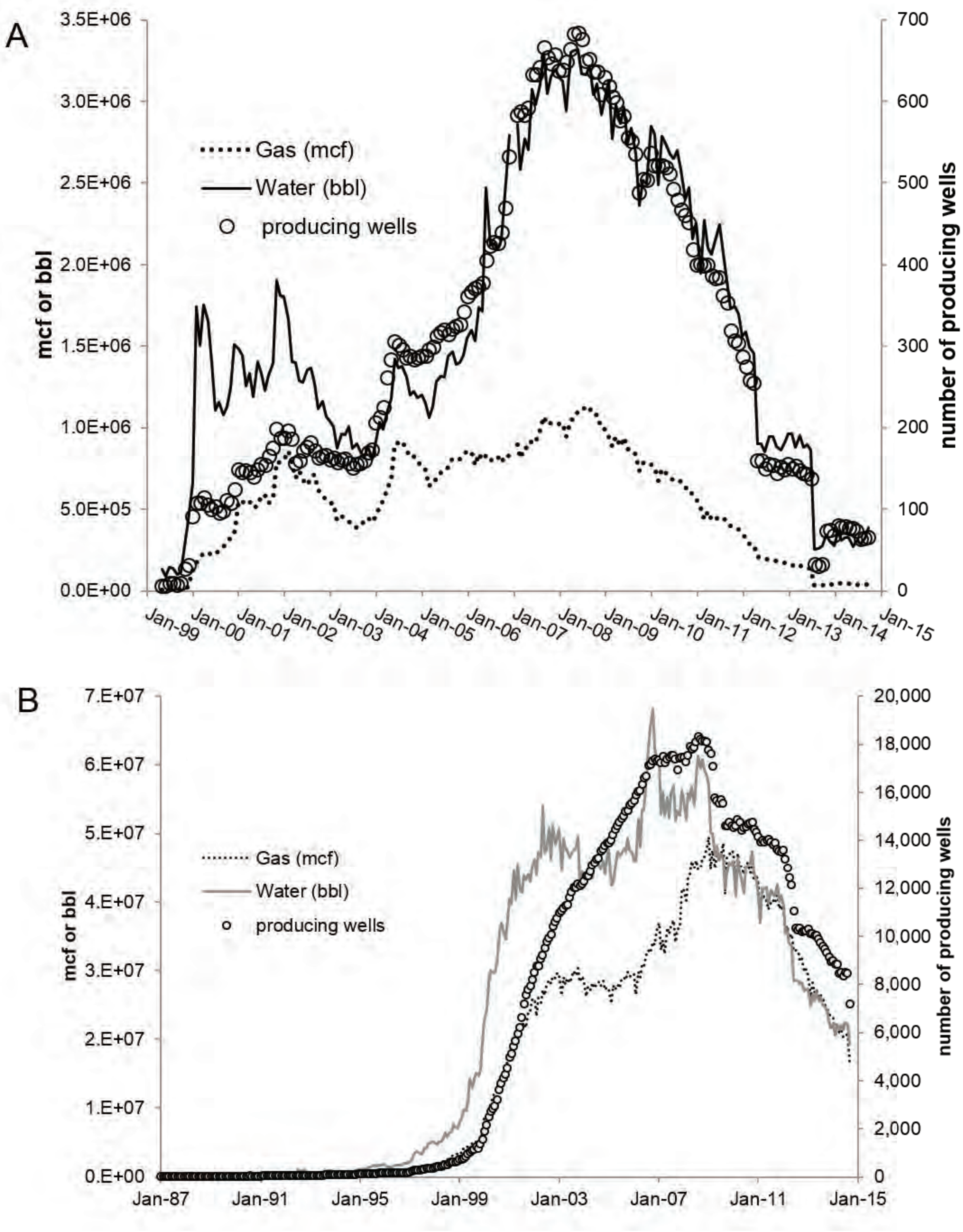


Figure 6. Monthly totals of water and gas produced from Montana (A) and Wyoming (B) CBM wells in the Powder River Basin and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production.The total number of producing wells and the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

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, 2015). During 2014, there were no producing CBM wells in the CX field. This is the first year since CBM production began in Montana, 1999, 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 yr; however, observations during the past 5 yr indicate recovery has slowed or stagnated. Drawdown in Wyoming may have migrated around the ends of faults or through connected zones in scissor faults, and further recovery in Montana wells may only occur when water levels in Wyoming recover (see 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 (plate 1) were retrieved from the MBOGC website (MBOGC, 2015). The Coal Creek field northeast of the Tongue River Reservoir first produced gas in April 2005. During 2014, a total of 33 CBM wells (plate 1, table 1) produced water or gas from the Wall and Flowers–Goodale coalbeds (appendix D). Total water production for the 12-mo period was 2.5 million bbls (322 acre-ft).

The Dietz field east of the reservoir first produced gas in November 2005. During 2014, a total of 55 CBM wells (plate 1, table 1) produced water or gas from the Dietz, Canyon, Carney, and Wall coalbeds (appendix D). The total water production for the 12-mo period was 1.3 million bbls (171 acre-ft).

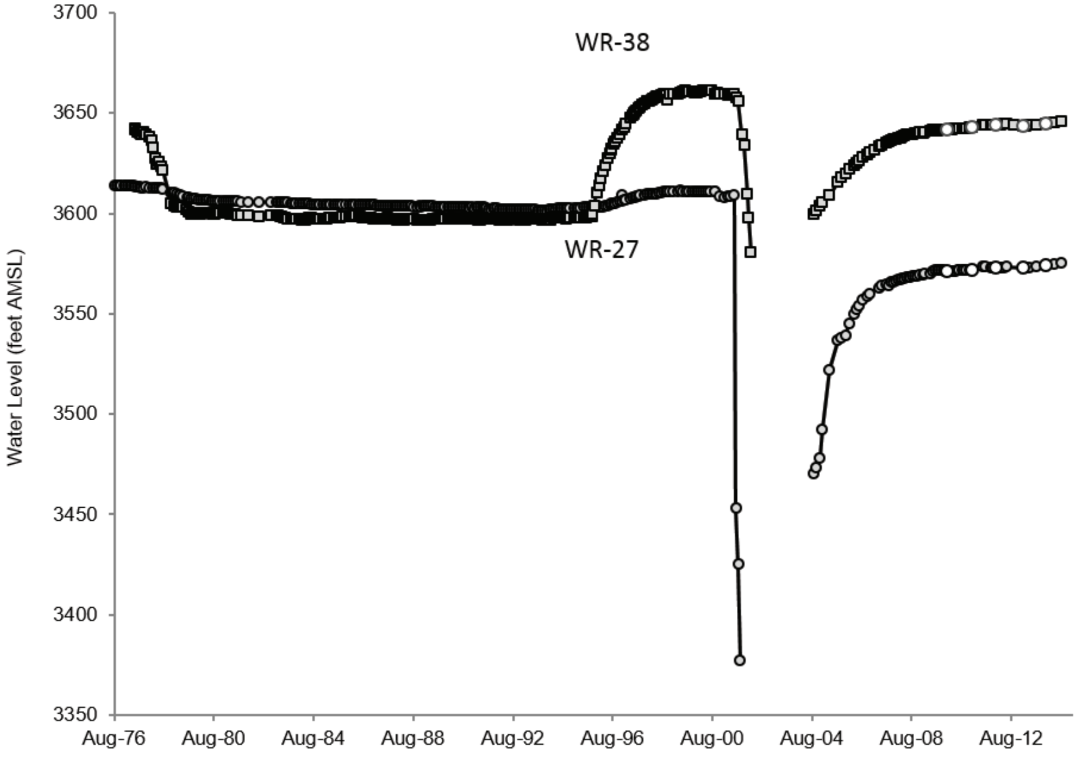


Figure 7. Water-level records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production. The recovery water levels are flattening; however, they have not reached baseline conditions. Water levels for January 2010, 2011, 2012, 2013, and 2014 are labeled.

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.

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 within the Dietz coalbed interpreted to be specific to CBM production (plate 4), typically reaches about 1 mi beyond the active field boundaries, but has reached as much as ~1.5 mi in some areas. For the Canyon coalbed, the extent of CBM-related drawdown appears similar to that in the Dietz coalbed; 20 ft of drawdown extends about 1 mi beyond the field boundaries (plate 5).

Drawdown was predicted to reach 20 ft at 2 mi from development after 10 yr 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 yr in any specific area (U.S. Department of the Interior, Bureau of Land Management, 2008). Measured drawdown is less than that predicted primarily because of restrained CBM development, shorter than anticipated production duration, faults that isolate drawdown, and 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 be-

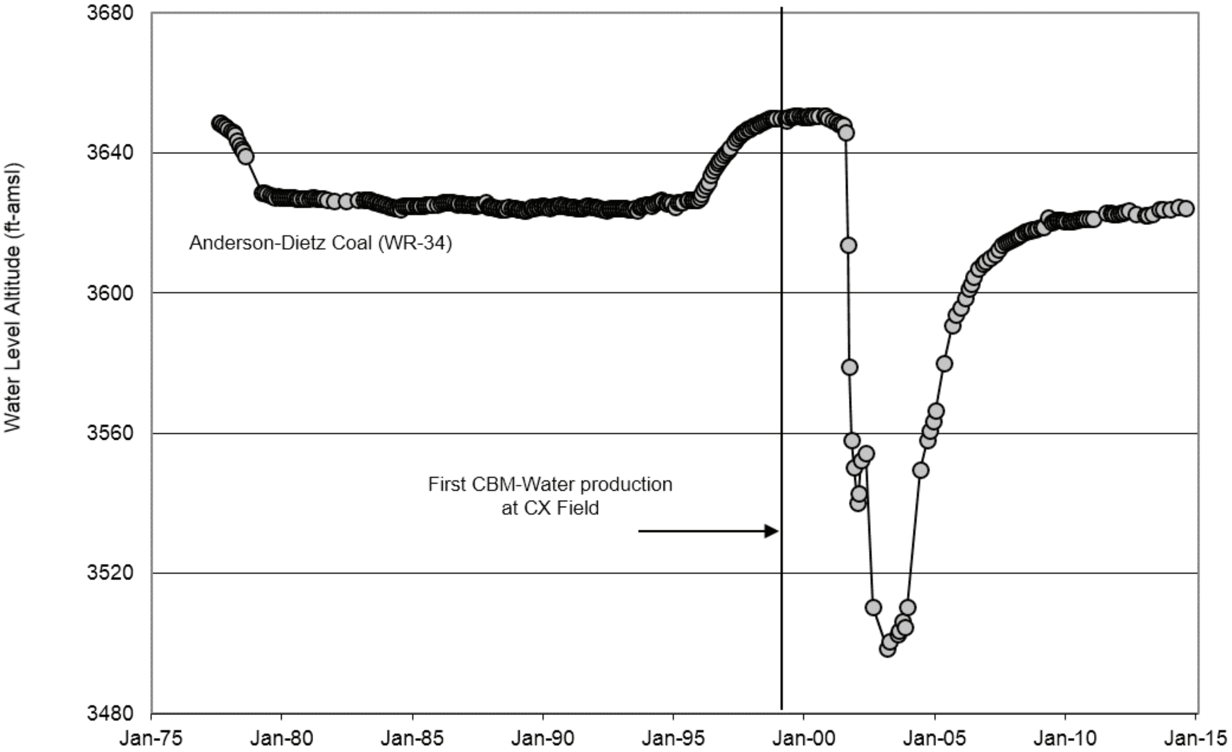


Figure 8. Water levels in the combined Anderson–Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed-methane production. The water-level recovery that began in 2003 is in response to decreased production in the CX field.

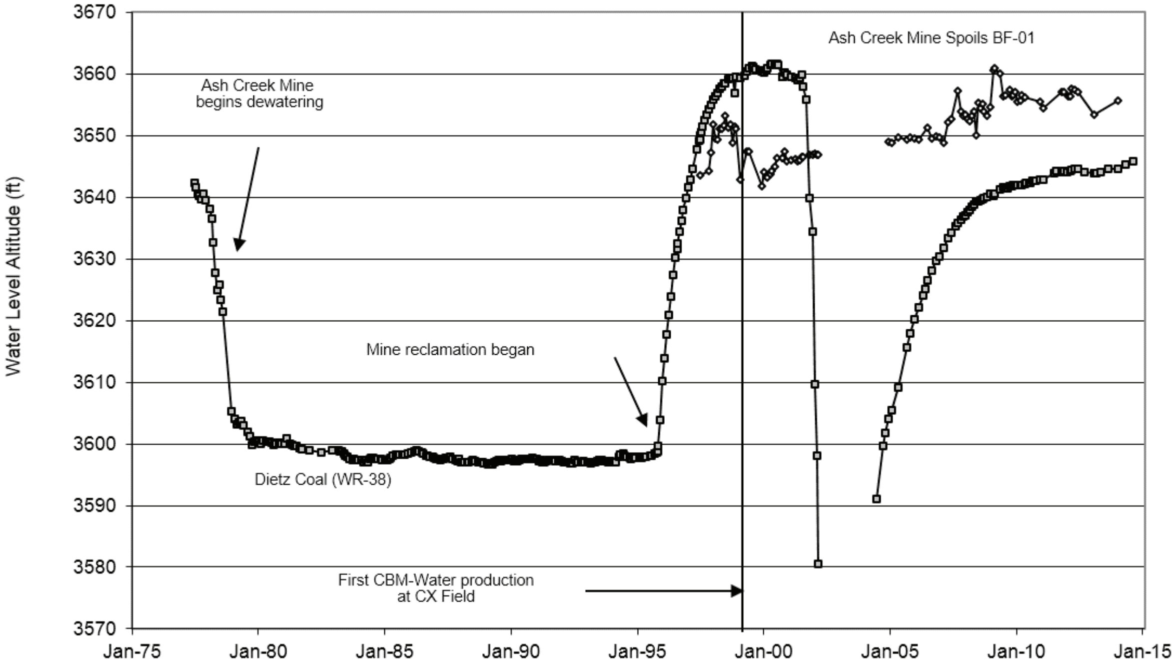


Figure 9. Water levels in the Dietz coal (well WR-38) decreased by at least 80 ft in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping, which illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses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

low 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 (see section Water Level Drawdown in Wyoming Fields).

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 yr. However, there has been no response to East Decker mine pit 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 areas north of the fault. 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 do respond slightly to coal mining north of the fault, and also to CBM production south of the fault. 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-term precipitation patterns. The water level in the Roland coal, stratigraphically above the CBM production zones and on the other side of the fault, dropped about 8 ft during 2005, began to recover in early 2006,

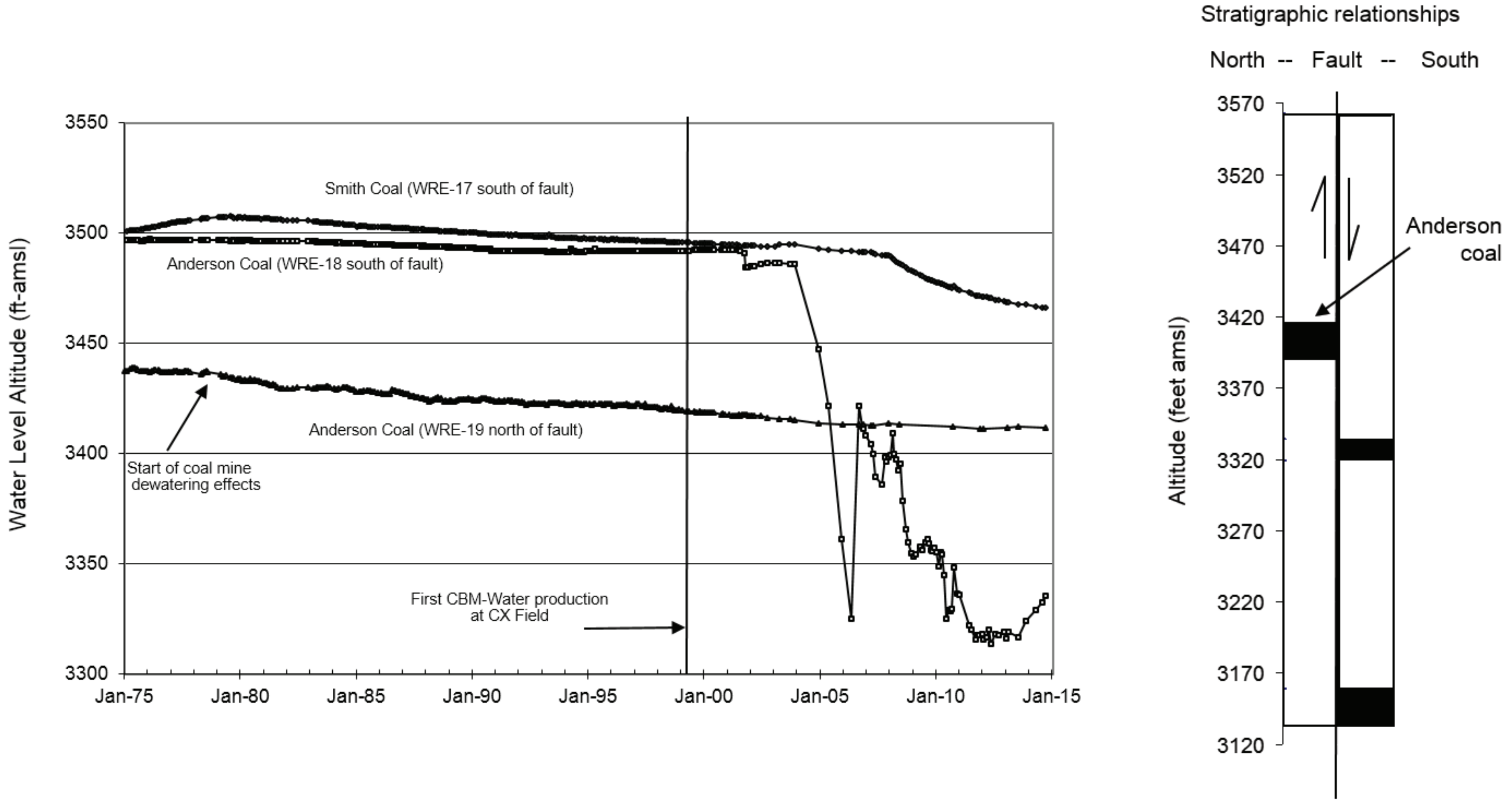


Figure 10. Drawdown from either coal mining or coalbed-methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970s, and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980s. The pressure 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 began 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.

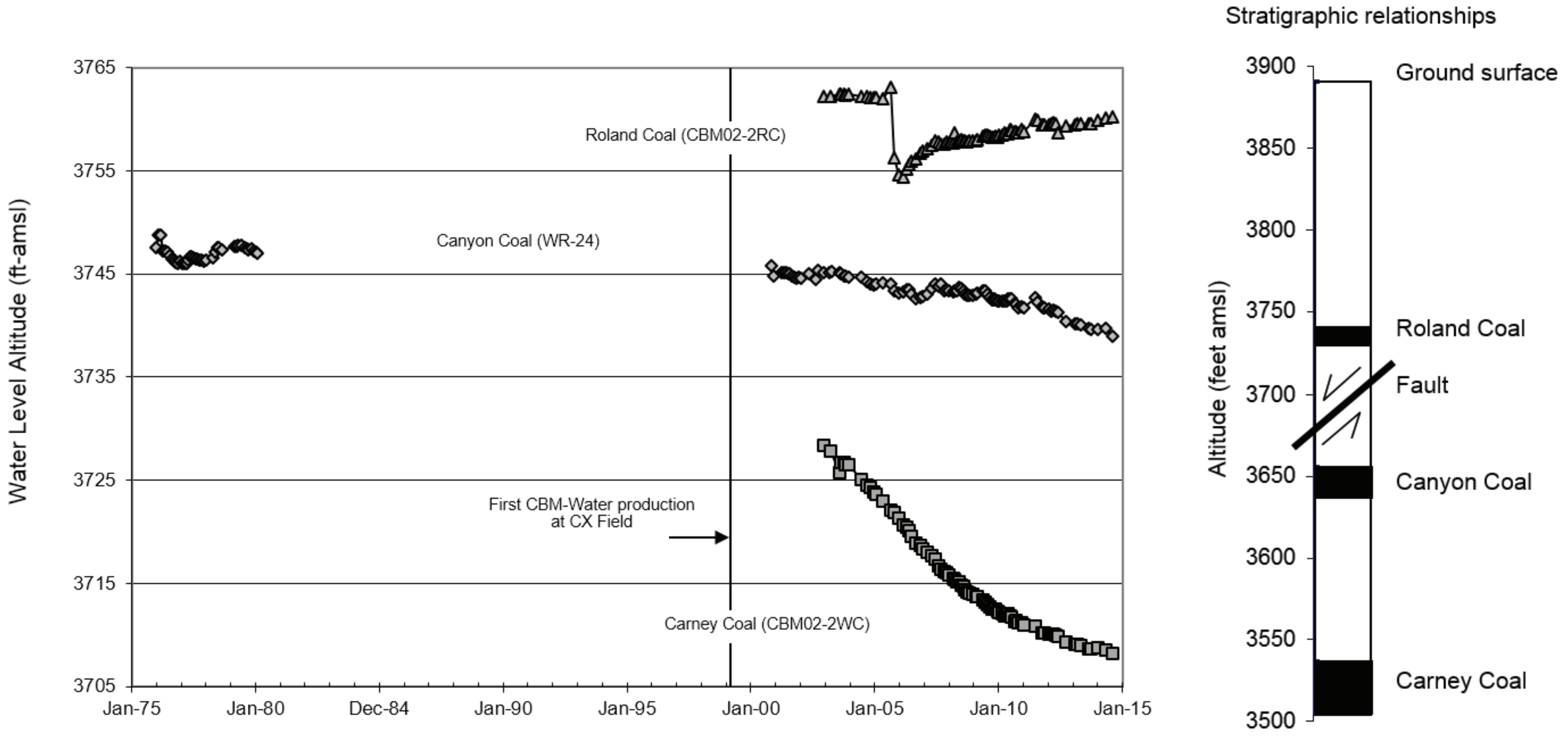


Figure 11. The decrease in water levels in the Canyon coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM-related drawdown since well installation. 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.

and continues. 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 rate of 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 still recovering but are still approximately 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 the 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 (personal communication Mathew Nordberg, MT DNRC, December 11, 2014). Average reservoir stage during this time has been about 3,420 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 the water year 2014 was 3,423 ft amsl, which is approximately the same as the historical average. The increased storage elevation steepens the gradient 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 seeks to identify this influence (Meredith and others, 2010). Well WRE-13 is one of the potential sample sites for 2015.

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 deeper 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 CBM02-4 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 that time water levels 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. Water-level declines in the overlying sandstone aquifer (CBM02-4SS1; fig. 15) indicated slow vertical leakage into the drawn-down Wall coal aquifer.

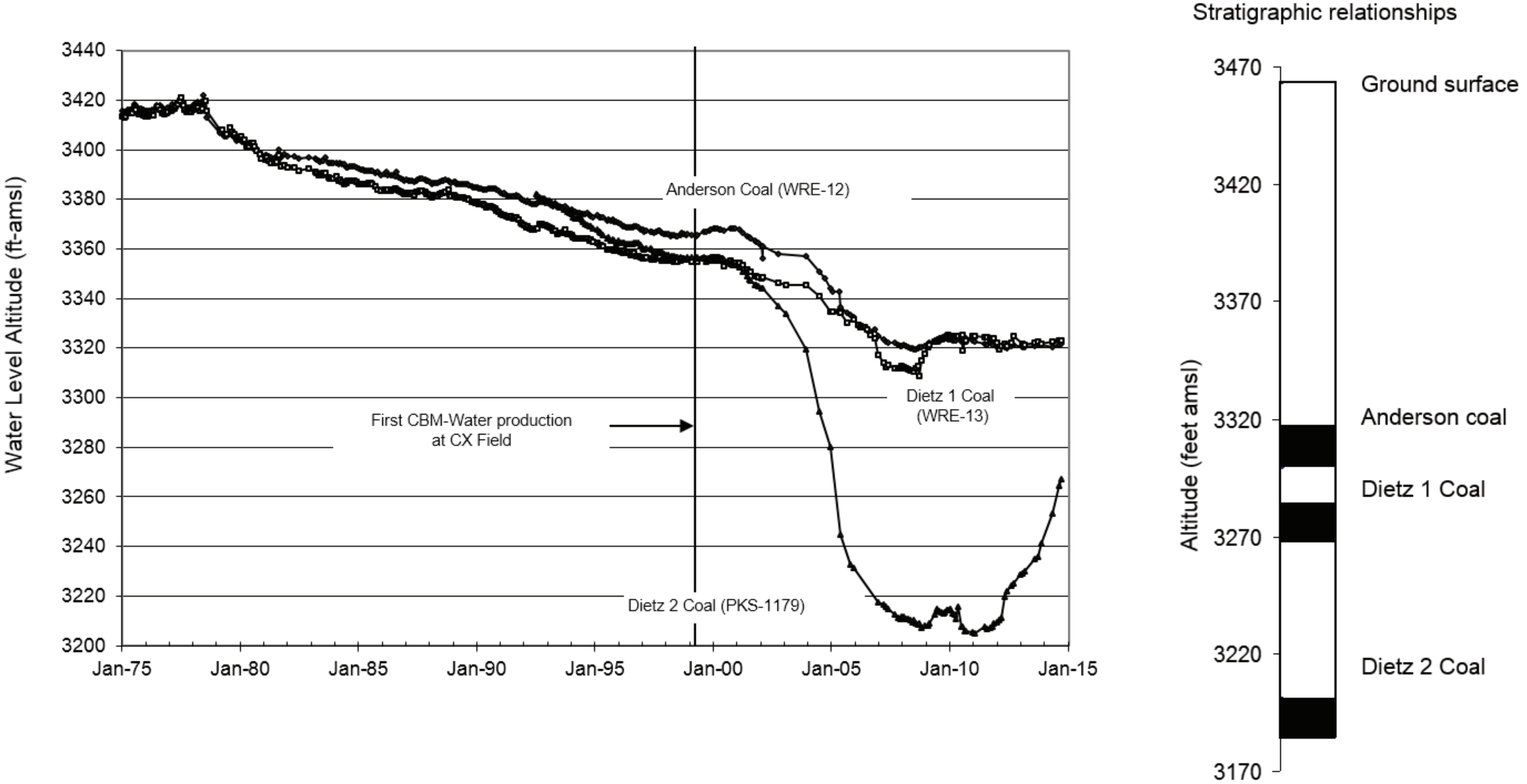


Figure 12. CBM production requires drawdown to near the top of the producing zone; this is the case for wells WRE-12, WRE-13, and PKS-1179. The three coal seams have water-level elevations just above their tops. Well PKS-1179 has been recovering.

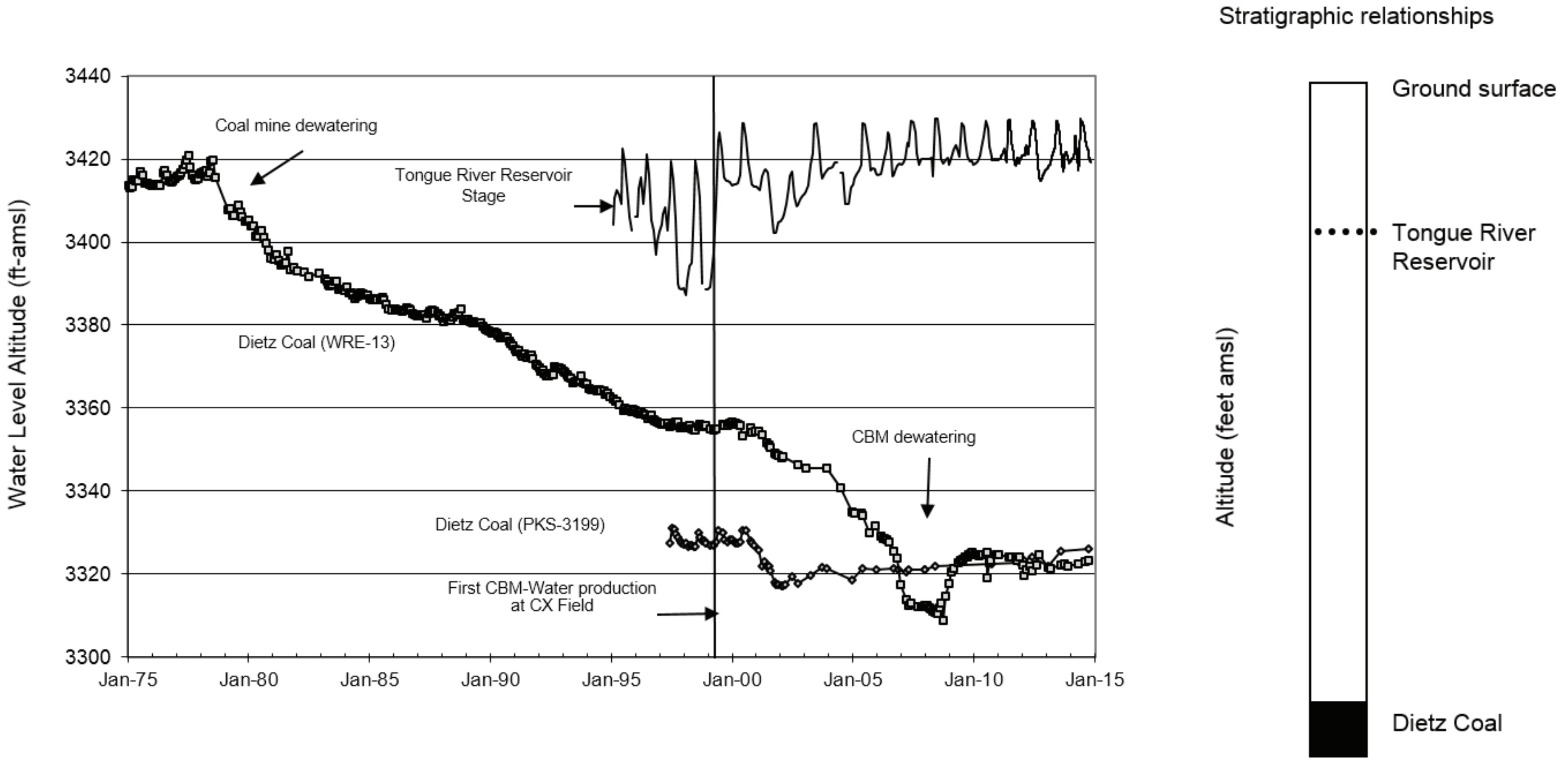


Figure 13. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Anderson–Dietz coal (WRE-13 and PKS-3199) prior to mining and CBM production. Since 1979, coal mining and CBM influences dominate the hydrographs. Note the vertical scales of the stratigraphic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

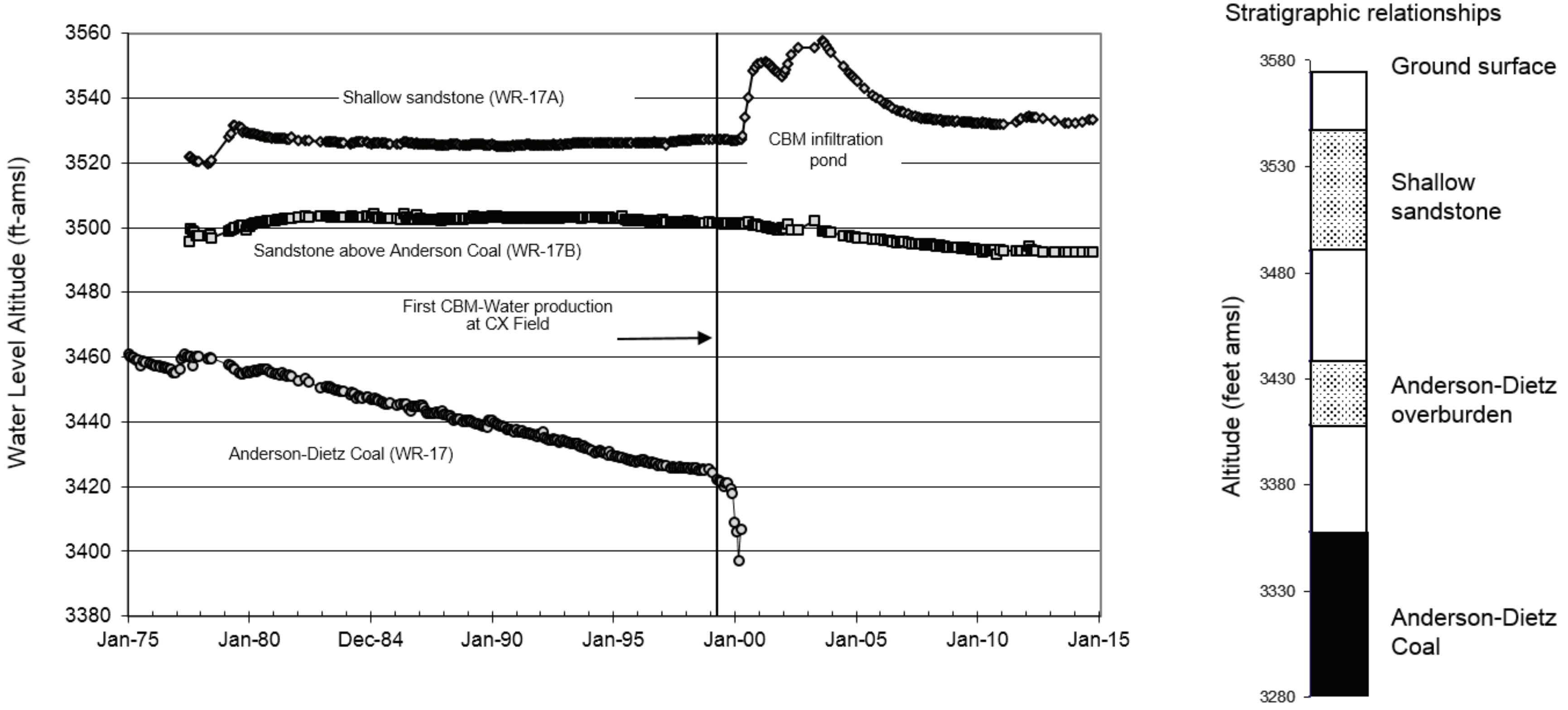


Figure 14. The water table rise in 1999 at WR-17A is in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water; therefore, the water level in this aquifer dropped. Recently, water levels have shown a slight increase. Water-level trends in the Anderson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

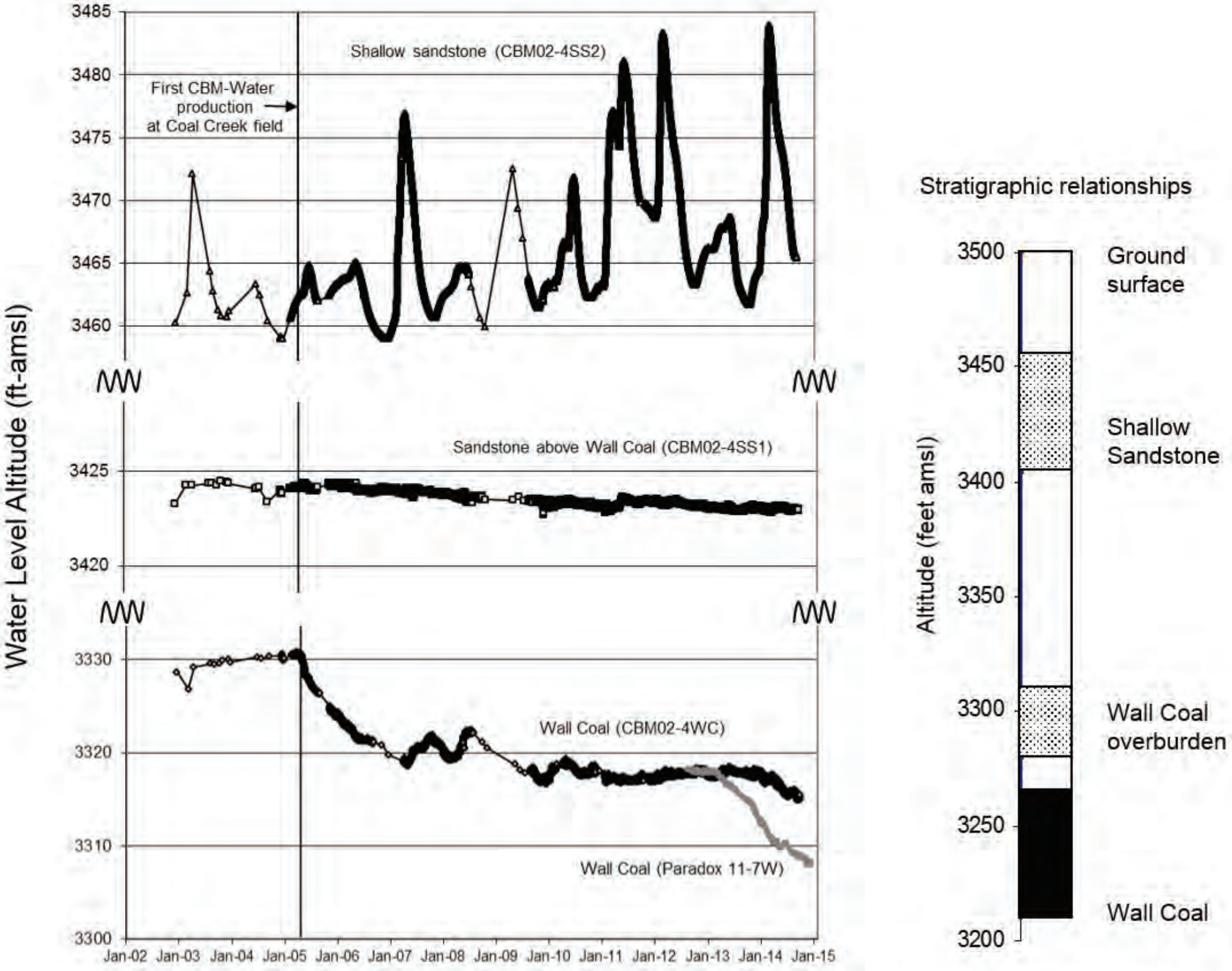


Figure 15. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal (CBM02-4WC and Paradox 11-7W) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in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

Water quality. Upper and Lower Anderson springs, within the current CBM producing area, were sampled in November 2013 and May 2014 (appendix C). Both springs discharge from the Anderson coalbed. The chemistry of Lower Anderson spring water is relatively constant, with TDS concentrations of 1,555 and 1,525 mg/L and SAR values of 3.26 and 3.11 for the two sample dates, respectively. Upper Anderson Spring is more variable. TDS values were 3,941 and 4,234 mg/L and SAR values were 9.42 and 6.35 for the two sample dates, respectively. The water-quality and flow rate changes in Upper Anderson Spring indicate a significant component of local recharge. None of the monitored springs within the area influenced by CBM development have shown impacts that can be distinguished from natural variability.

Tongue River Alluvial-Aquifer Water Levels and Water Quality

Water-quality samples were collected in October 2013 and June 2014 (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

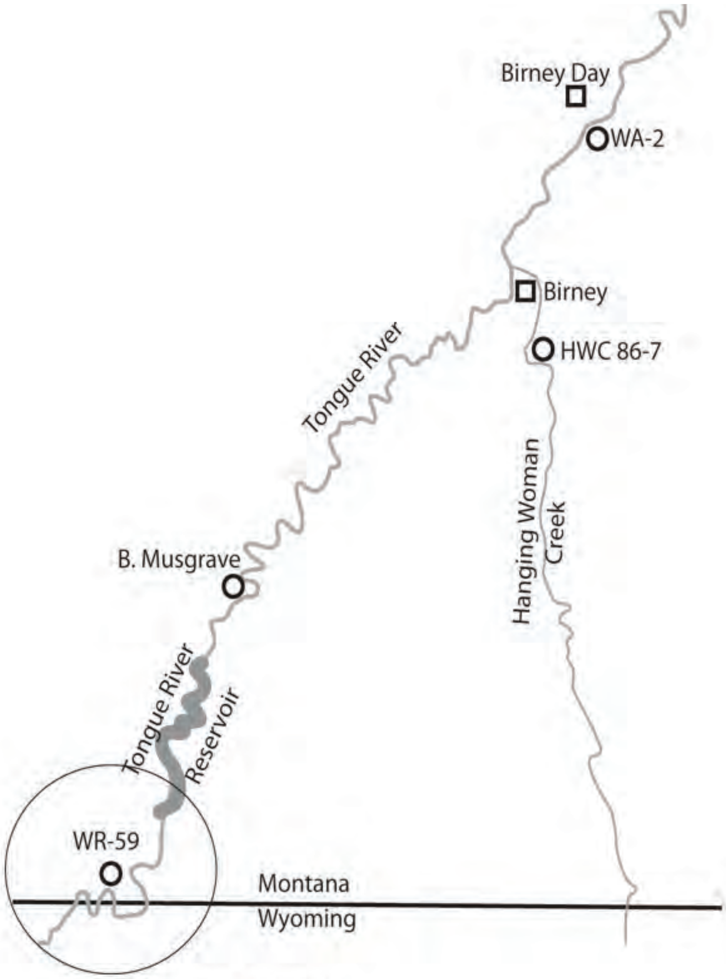
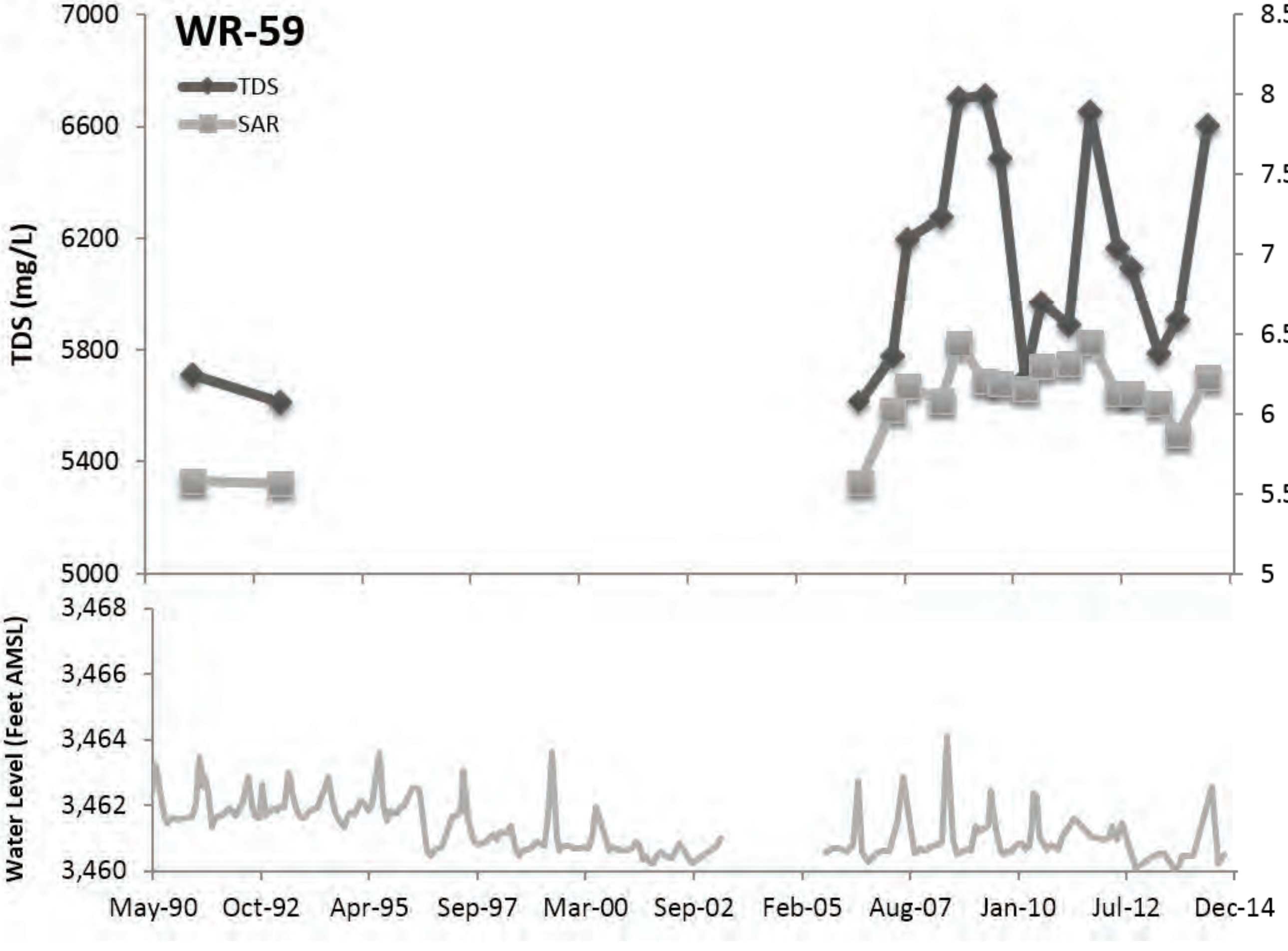


Figure 16. TDS, SAR, and water-level / stream discharge for well WR-59 near the Squirrel Creek–Tongue River confluence and for the Tongue River at the state line.



approximately the same time period (fig. 16). However, continued monitoring from 2009 through 2014 illustrates the variable nature of the groundwater 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 perturbations in groundwater chemistry 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 October 2013 and June 2014. Since sampling began in 1987, TDS and SAR in the alluvial groundwater have generally increased, but have been falling for the last 2 yr. Future monitoring will be required to determine if the elevated values represent an impact to the aquifer or a temporary perturbation. 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 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). During 2014, 220 CBM wells produced methane and/or water in the Prairie Dog Creek field, a decrease of 80 wells from 2013. Cumulative water production for 2014 was 14.5 million bbls (table 1). Monthly water production in the field peaked in mid-2002 at nearly 7 million bbls per month; however, since August 2008 water production has fallen steadily and by fall of 2014 was about 1 million bbls per month (fig. 18). Gas production rose fairly consistently until early 2008 but has fallen steadily since (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). During 2014, 113 CBM wells produced methane and/or water in the Hanging Woman Creek field, a decrease of 15 wells from 2013. Total water production for the 12-mo period was 6.4 million bbls (table 1). Water production began to climb in November 2004, and peaked in September 2007 at 2.5 million bbls/mo (fig. 18). Since that time, water production has fallen to less than 0.5 million bbls per month. Throughout the life of this field, gas production has been relative to production from nearby fields.

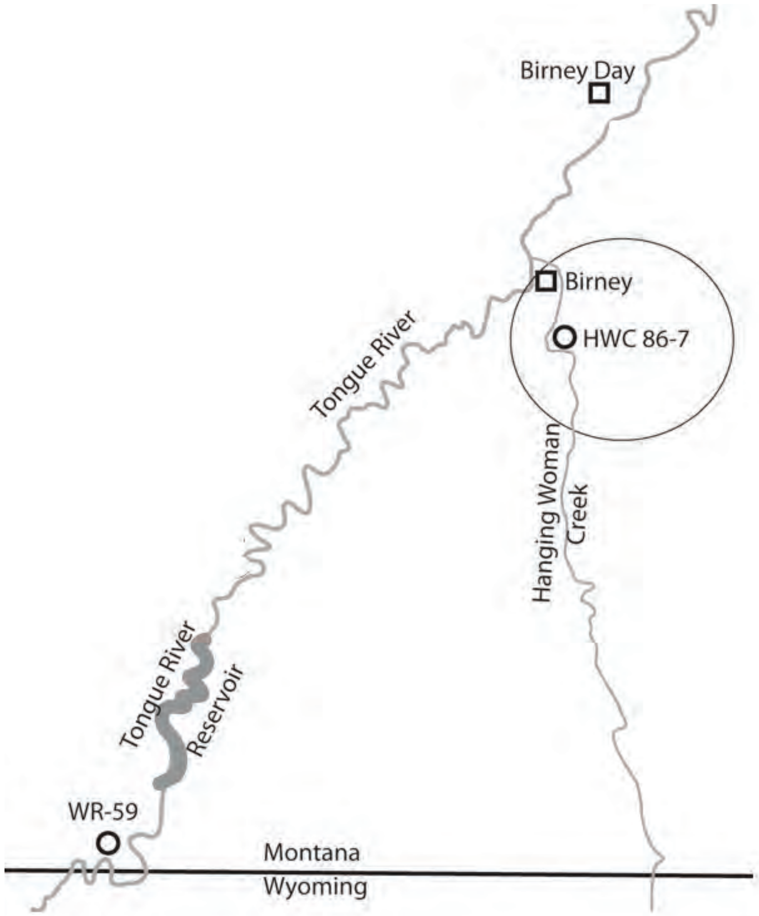
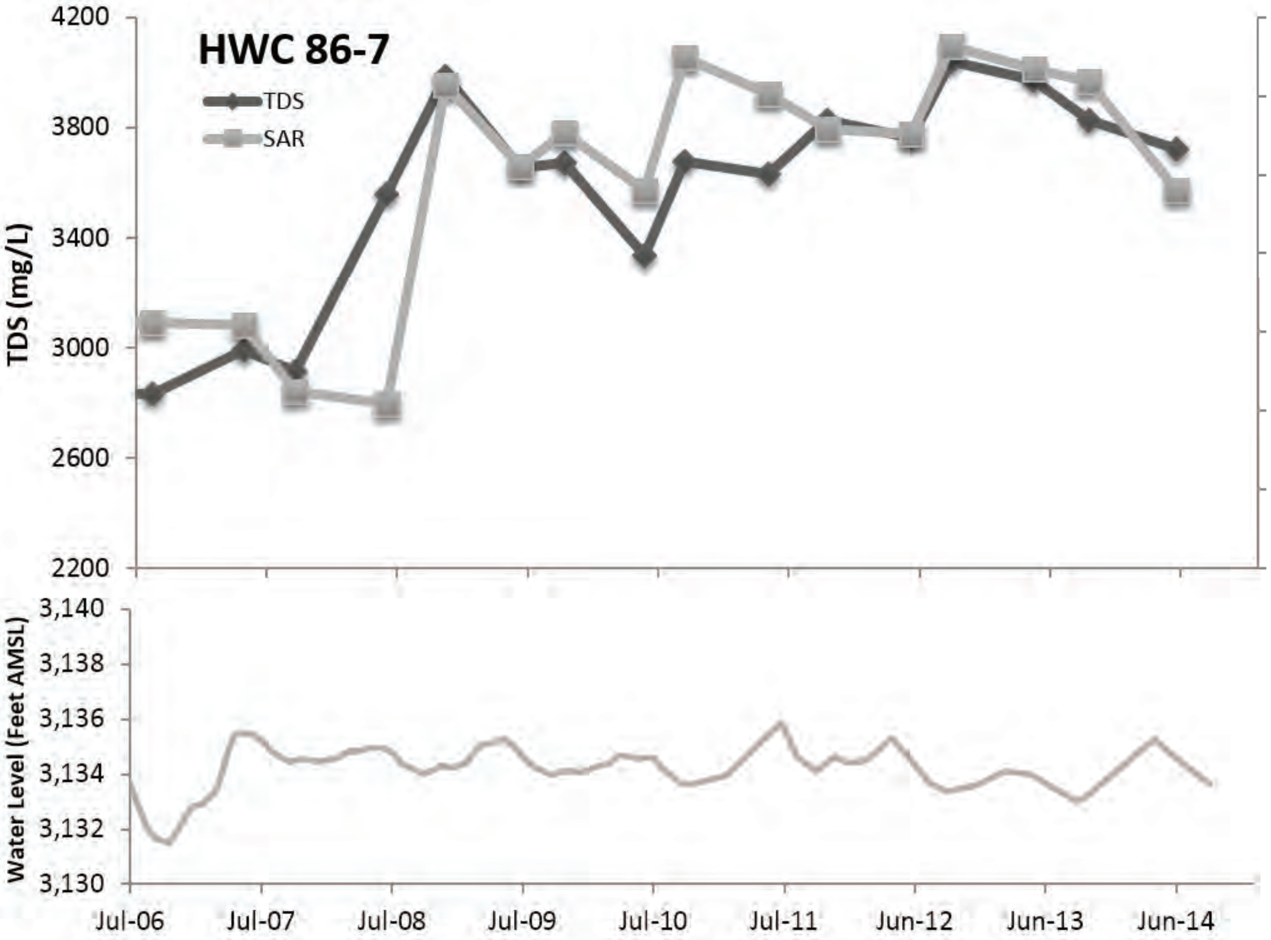
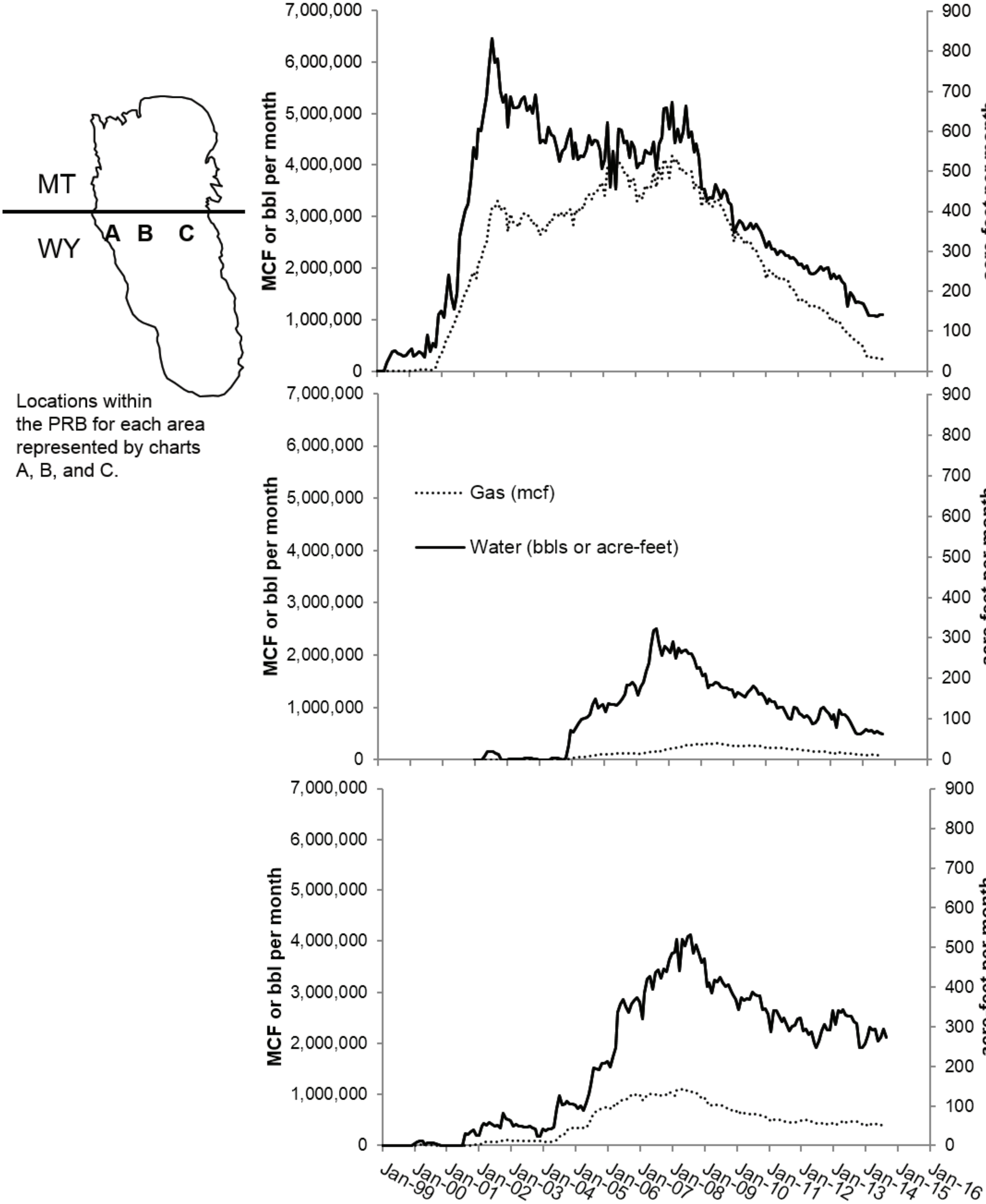


Figure 17. TDS, SAR, and water level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.





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

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 due to Hanging Woman Creek gas field production is monitored primarily by state line sites SL-3, SL-4, and SL-5 (plate 1). Site SL-3 is located about 1 mi north of the nearest Wyoming CBM well. Monitoring wells at SL-3 include wells completed in the alluvium of North Fork Waddle Creek, an overburden sandstone, and the Smith, Anderson, and Canyon 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, but beginning in January 2012 has been fairly consistently 10 ft higher than its lowest altitude. 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 140 ft due to CBM production since monitoring began in May 2005.

Monitoring well site SL-4 is located about 1 mi north of the nearest CBM well in the Hanging Woman Creek gas field (plate 1). Monitoring wells at this site are completed in the alluvium and in the Smith and Anderson coalbeds (fig. 21). The water level in the Anderson coalbed responds to CBM production in Wyoming and is currently 76 ft lower than when monitoring began (fig. 22). The water level in the Smith coalbed has also dropped slightly; the high-frequency oscillations are characteristic of pumping in nearby wells for stock watering or cistern filling. However, since 2013 the response to pumping has stopped, indicating the nearby well(s) is no longer used and water levels have begun to recover. This supports the hypothesis that drawdown was related to local uses (Meredith and Kuzara, 2013). This monitoring well is located approximately 150 ft from the Forks Ranch Headquarters well, which was completed in the Smith coalbed in June 2006.

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 seal in the Canyon coal well causing communication along the well bore between the Canyon and the higher-pressure Anderson coals. 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, well API 49-033-26223, 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-10 and E-11).

Water-quality results for samples collected from alluvial wells HWC 86-13 and HWC 86-15 during October 2013 and June 2014 (appendix C) reported TDS concentrations from 6,257 to 8,361 mg/L and SAR values from 9.97 to 10.8. Sodium and sulfate dominate the alluvial water chemistry. The groundwater salinity has a natural variation of approximately 1,000 mg/L (GWIC, 2015). Water-quality samples were also collected on North Fork Waddle Creek at SL-3Q during November 2013 (appendix C). TDS and SAR concentrations have varied little since sampling began in 2005; in the November 2013 sample TDS was 3,985 mg/L and SAR was 5.4. The water chemistry is dominated by a balance of cations (calcium, magnesium, and sodium in nearly equal parts) and sulfate. There appears to be no discernible effect from CBM development in the alluvial aquifer at SL-3Q. Because this monitoring site has a long history of sample analyses and little variability in chemistry, the frequency of sampling has been reduced (GWIC, 2015).

Gas Fields near Powder River

Methane and water production. Near the Powder River (plate 1), CBM is being produced from the combined Anderson and Dietz (Wyodak), Canyon, Cook, Wall, Pawnee, and Cache coalbeds (appendix D). During water

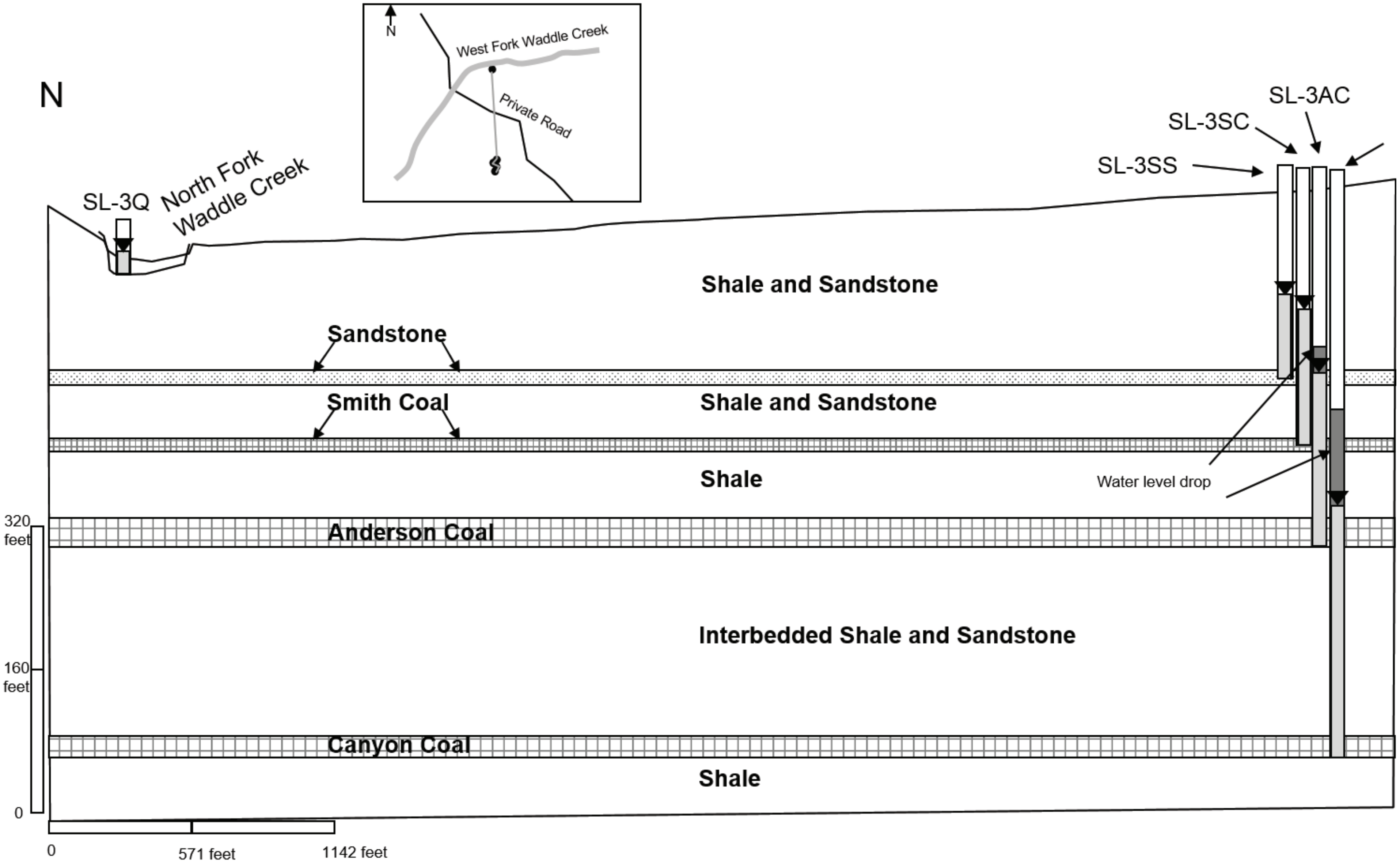


Figure 19. Geologic cross section for alluvium, an overburden sandstone: Smith, Anderson, and Canyon coalbeds located at T. 9 S., R. 42 E., sec. 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2014. The water 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 about140 ft since well installation. The wells are located roughly 1 mi north from the nearest CBM field. Vertical exaggeration is 3.6:1.

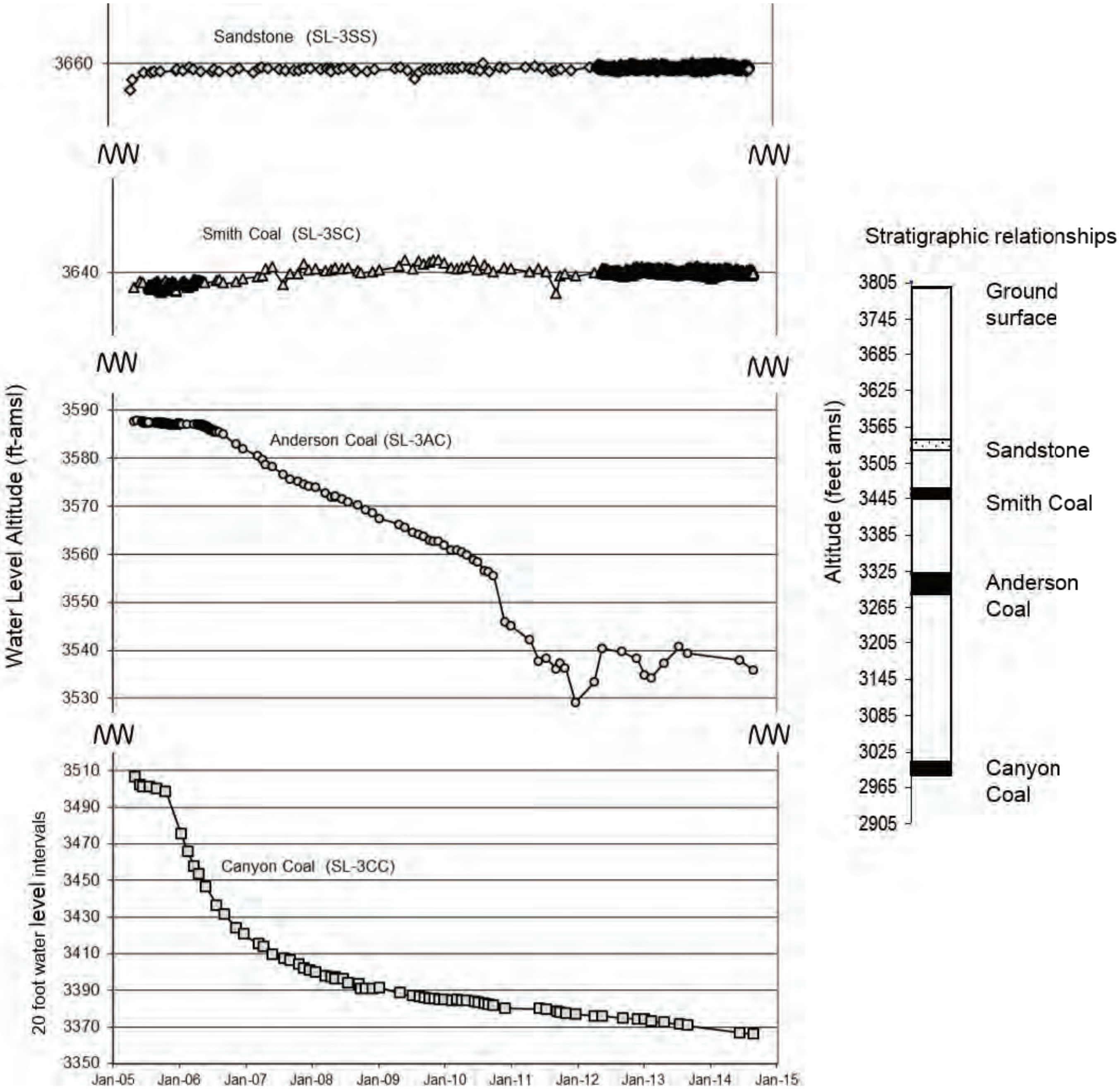


Figure 20. Water levels in the overburden sandstone (SL-3SS) and Smith (SL-3SC) coals are not responding to CBM development. The water level in the Canyon coal dropped about 140 ft in response to CBM production. The water levels in the Anderson coal had a maximum drop of about 58 ft in response to CBM production. However, water levels are rising in response to nearby CBM wells being shut-in. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.The Y axis scale is broken to show better hydrograph detail.

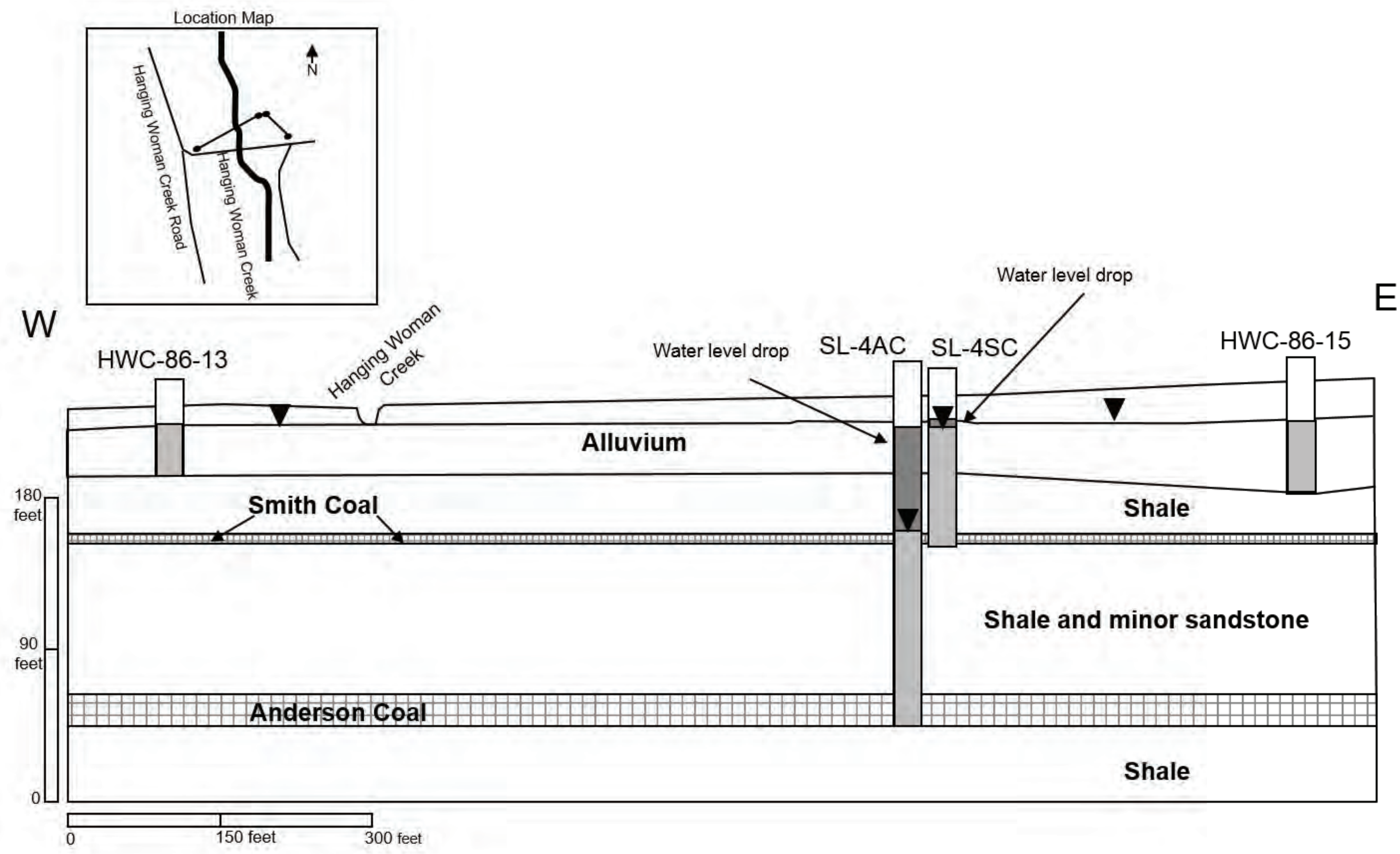


Figure 21. Geological cross section for the alluvium and bedrock wells near the Montana/Wyoming state line on Hanging Woman Creek located in T. 10 S., R. 43 E., sec. 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson coal and Smith coal have lowered in response to CBM production. The Anderson has lowered by about 76 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 2014. Vertical exaggeration is 7:1.

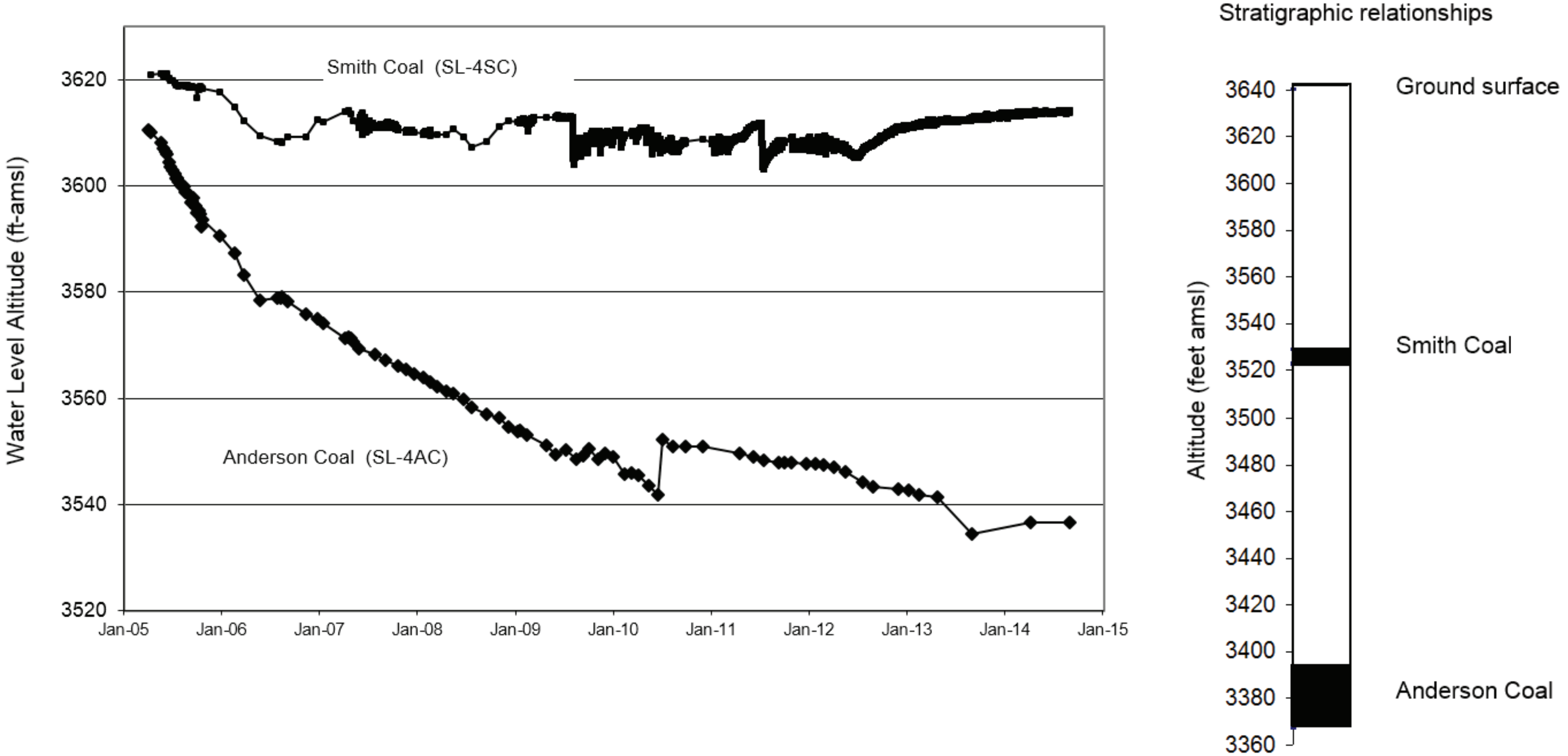


Figure 22. The SL-4 site is located about 1 mi north of the nearest CBM field. Water levels in the Anderson coal appear to have lowered about 76 ft from April 2005 to September 2013 in response to CBM development; however, it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft, presumably due to activities in the nearby CBM field. Water levels in the Smith coal have decreased 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.

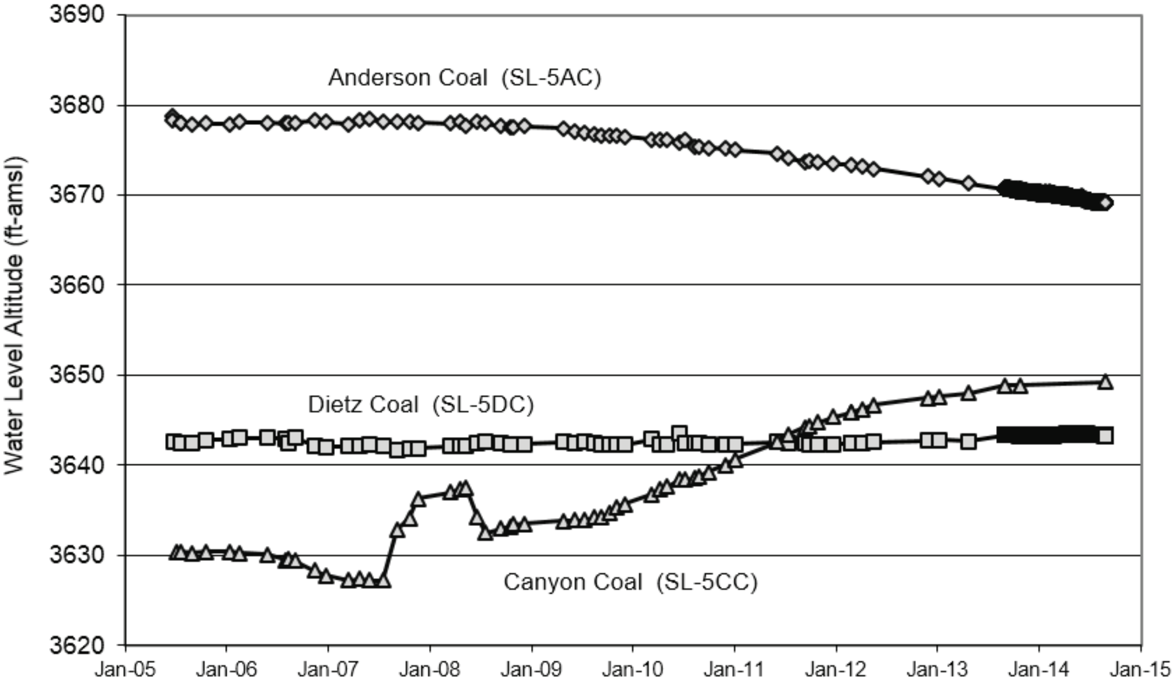


Figure 23. The increasing water level in the Canyon and decreasing water level in the Anderson may be a result of a failed seal in the neat cement in the Canyon coal well causing communication along the well bore. Alternatively, it may be that a nearby well has allowed the two aquifers to communicate.

year 2014, 435 wells produced methane and/or water, a decrease of 28 wells since 2013. The cumulative water production for the 12-mo period was 25.7 million bbls. Water production in these fields increased steadily from January 2004 through July 2008, peaking at just over 4 million bbls per month. As of September 2014, water production is approximately 2.5 million bbls per month. Gas production also peaked in 2008 (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 down-hole packer/pressure transducer equipped with a direct read cable below the frost line to acquire water-level measurements. With less than 1 yr of data it is difficult to determine trends; however, water pressure in the Knobloch coalbed has fallen while the Brewster–Arnold coalbed groundwater level has remained fairly constant (fig. 25). The nearest producing CBM wells (58. N, 75 W., sec. 20) are completed in the Wall and Pawnee coalbeds. One well is completed in the Canyon, Cook, Wall, and Pawnee coalbeds. However, naming conventions change across the state line, so it is difficult to tell where the nearest producing wells are 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 that of 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.

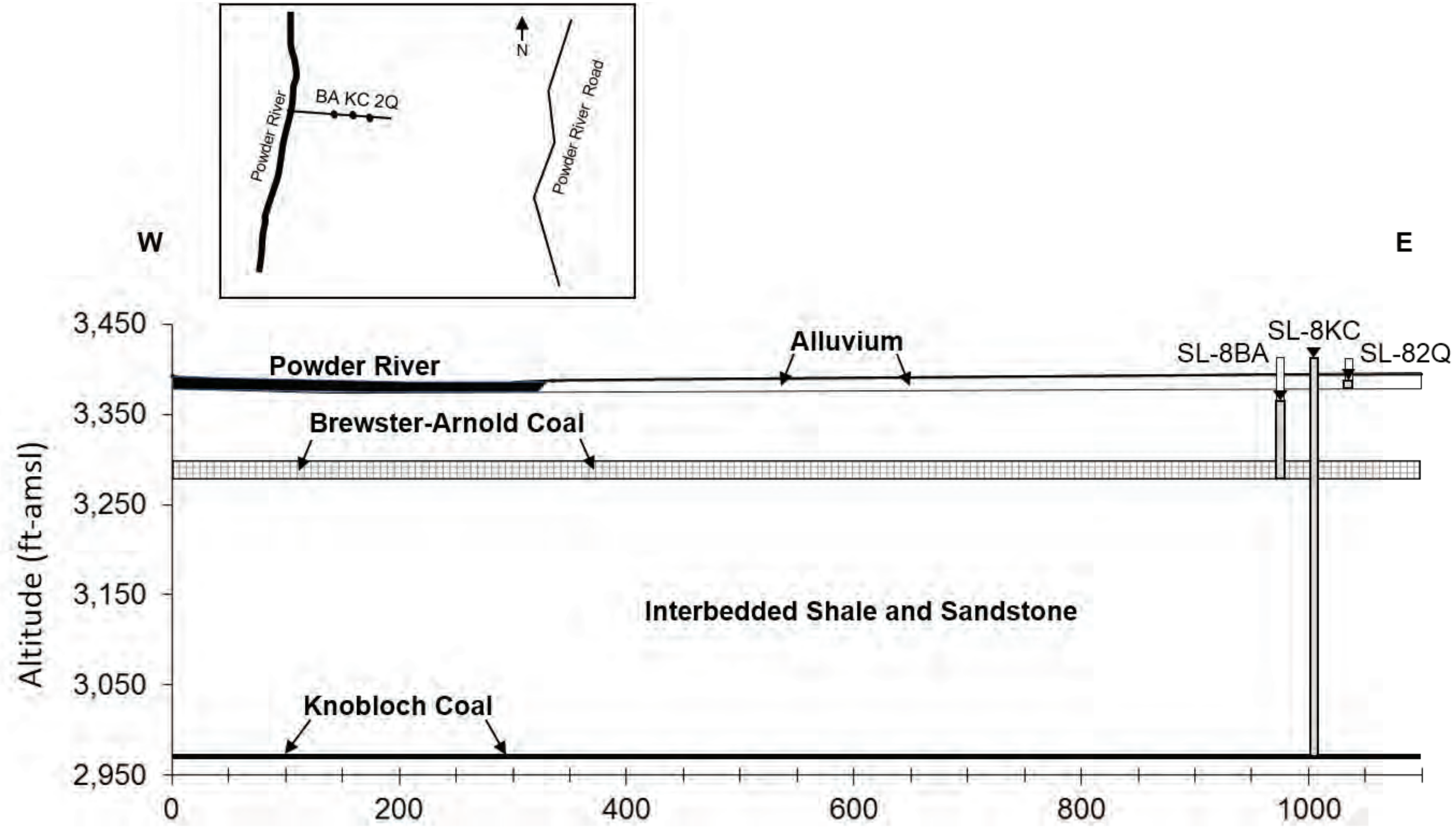


Figure 24. Cross section of the alluvial and coal aquifers south of Moorhead near the Powder River located in T. 09 S., R. 47 E., sec. 25. Groundwater in the alluvium appears to flow parallel to the river valley. An upward groundwater gradient exists between the Knobloch coal and the Brewster–Arnold 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 2014.

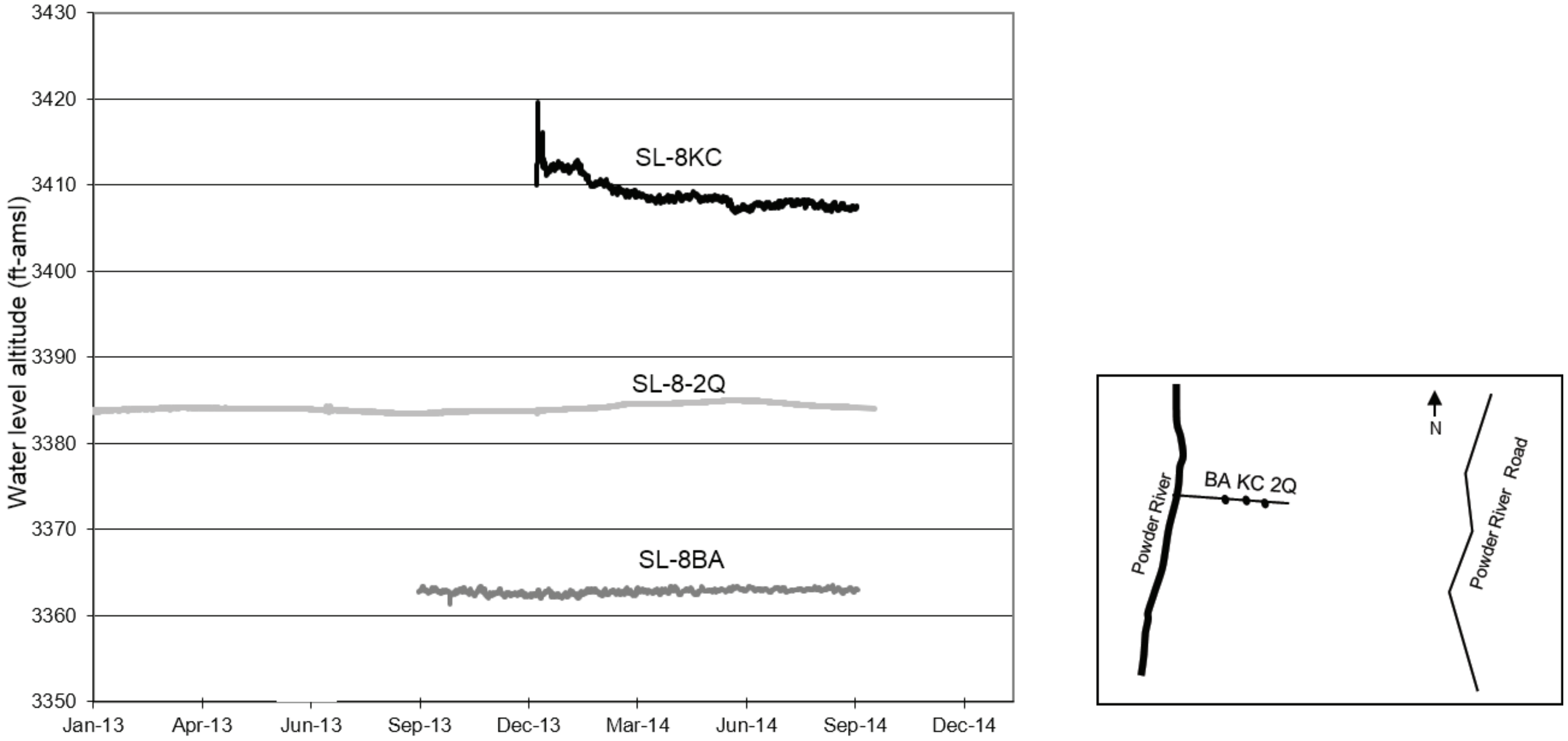


Figure 25. Groundwater flow in the alluvial aquifer at SL-82Q is roughly parallel to that of the Powder River. The groundwater level in the Knobloch coal has an upward gradient toward the alluvial aquifer. The cross section for this site is displayed in figure 24.

Water-quality samples were collected from SL-8-2Q in October 2013 and July 2014 (appendix C). TDS concentrations were 2,556 and 3,679 mg/L and SAR values 4.6 and 5.0, respectively. The water chemistry is dominated by calcium, sodium, and sulfate. An additional Powder River alluvial well, Fulton Ranch River well, was sampled in July 2014. This well is approximately 5 mi north of the SL-8 monitoring site. The TDS of the sampled groundwater was 1,411 mg/L and the SAR was 2.6.

WATER-LEVEL DRAWDOWN IN WYOMING FIELDS

The lack of continued water-level recovery in monitoring wells along the state line suggests that water levels in Montana are being influenced by ongoing CBM production in Wyoming. The northeast-trending faults, which are generally taken to be barriers to flow, stand between the CBM development in Wyoming and the monitoring wells in Montana. However, we have monitoring wells in Montana that show migration of drawdown around the end of faults. We also have demonstrated a gradient of transmissivity along scissor faults in Montana (Meredith and others, 2010). Despite the presence of faults, the development in Wyoming may still be influencing recovery in Montana. In 2013, The Wyoming State Geological Survey published water monitoring results from BLM-monitored wells in the Wyoming part of the Powder River Basin (Stafford and Wittke, 2013). Wyoming monitoring sites Lower Prairie Dog, Remington Creek, Leiter, South Coal, and Palo roughly correspond to Montana monitoring sites WR-27, SL-3, SL-4, and SL-9 (fig. 26). Of the monitored aquifers in Wyoming, the eastern fields do not show drawdown; however, measurements may not include baseline values. Water levels in monitored coals in Wyoming's Lower Prairie Dog Creek and Remington Creek (which corresponds to the field we refer to as Montana's Hanging Woman Creek), are still drawn down (fig. 27). Lower Prairie Dog Creek monitors the Anderson coalbed aquifer and two overlying sandstone aquifers. Water levels in the Anderson coalbed are still approximately 400 ft below the initial water-level measurements (fig. 27). The Remington Creek monitoring site has wells completed in the Anderson, Canyon, and Cook coalbeds and an overlying sandstone. Water levels in the monitored coals appear to be drawn down, but baseline information is not available so total drawdown cannot be determined.

Northeast-trending faults limit groundwater recharge from the west along the state line in Montana; therefore, recharge is likely coming from the south. However, as long as Wyoming CBM fields maintain lowered water levels for CBM production, further water-level recovery in Montana fields will be limited.

NATIONAL FOREST SYNOPTIC SAMPLING

For approximately 10 yr, major National Forest springs have been visited quarterly. During visits, the MBMG measured the flow, salinity, temperature and pH of the springs discharge. The MBMG also collected water–quality samples at two to four springs per year. Sampling goals were to collect at least two samples from every spring at high and low discharge points in the year. Additionally, one-time tritium isotope samples were collected from a few springs (see the 2007 version of this report for results and interpretation). Results from the quarterly monitoring and sample collection are presented in this and previous reports.

A change in funding structure has caused MBMG and USFS to reevaluate the monitoring approach in the Ashland Ranger District, Gallatin-Custer National Forest. Quarterly monitoring will be discontinued and a synoptic sample set was collected from well and spring sites on the Ashland Ranger District in late September and early October of 2014 (table 3). By collecting samples near the low-flow point in the hydrograph, we hope to present a complete picture of the groundwater conditions in the forest. This sample set will be repeated in 2015. A full discussion of the groundwater chemistry on the National Forest will be presented in a 2016 stand-alone report.

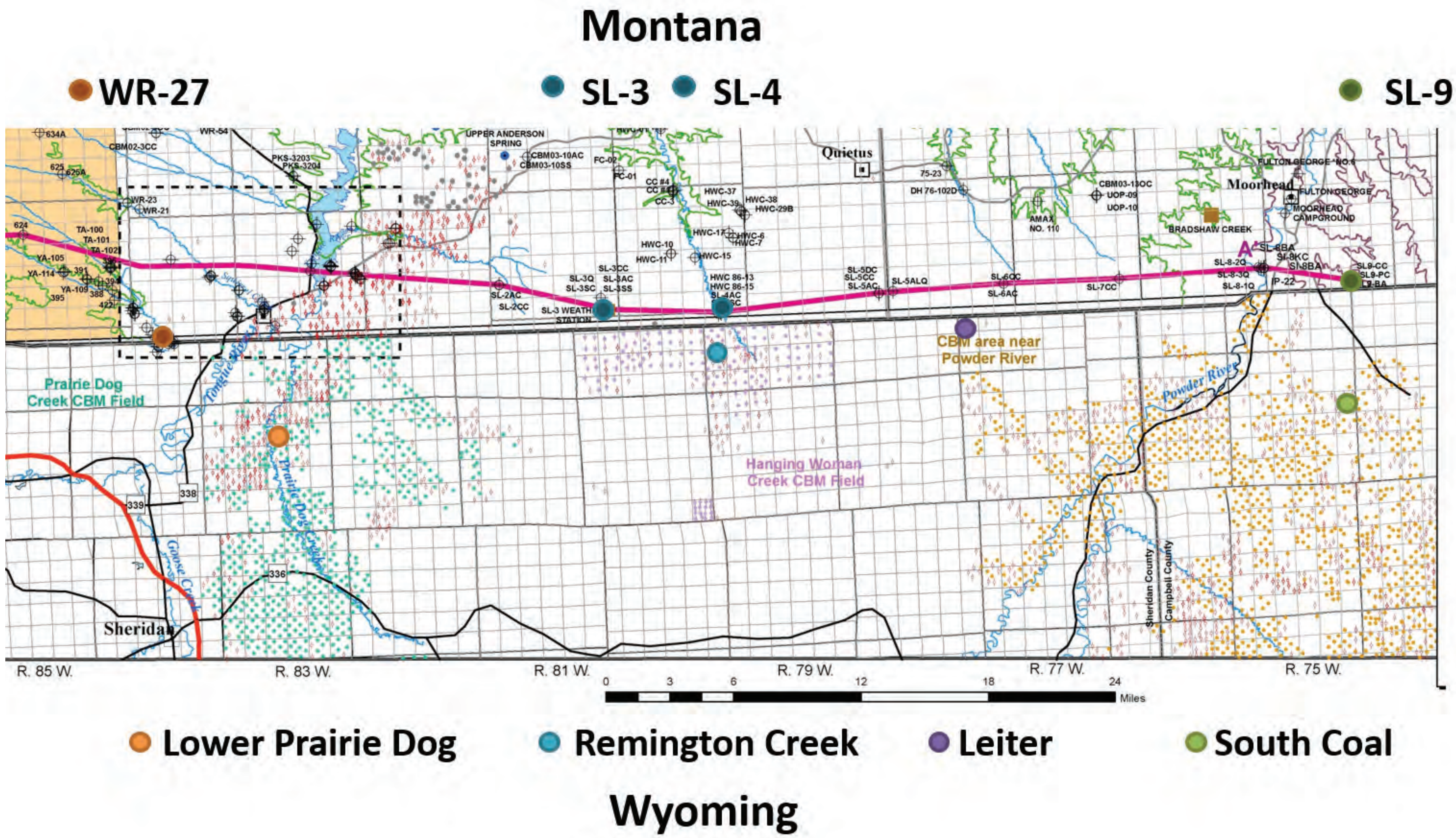


Figure 26. Monitoring well sites in Wyoming that correspond to MBMG monitoring sites in Montana include the Lower Prairie Dog, Remington Creek, Leiter, and South coal sites.

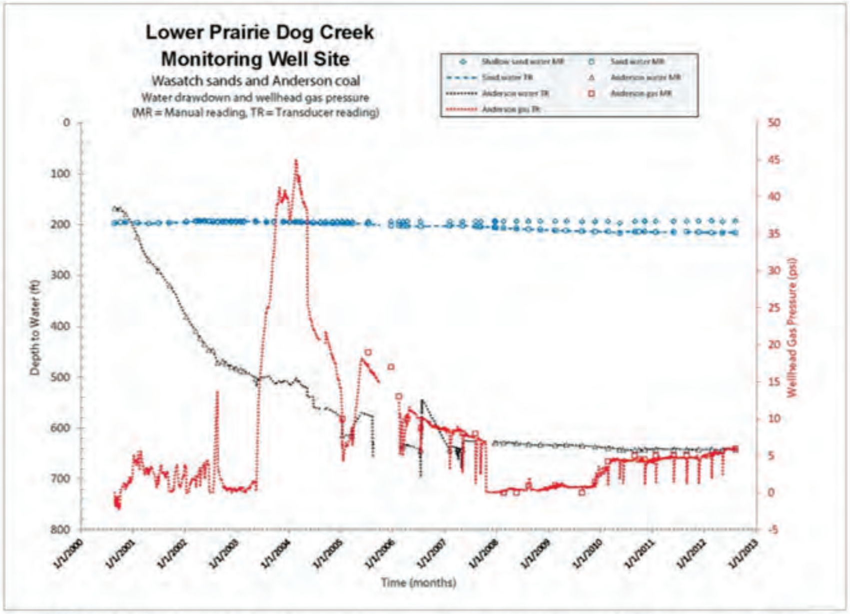


Figure A.155. Graph showing the manual and transducer recorded measurements for water levels and gas pressure for the monitored zones at the Lower Prairie Dog monitoring wellsite location.

Figure 27. Figures from Stafford and Wittke (2013) show coal aquifer water levels in the Prairie Dog Creek and Remington Creek CBM fields (referred to as Hanging Woman Creek field in this text) are still drawn down in Wyoming.

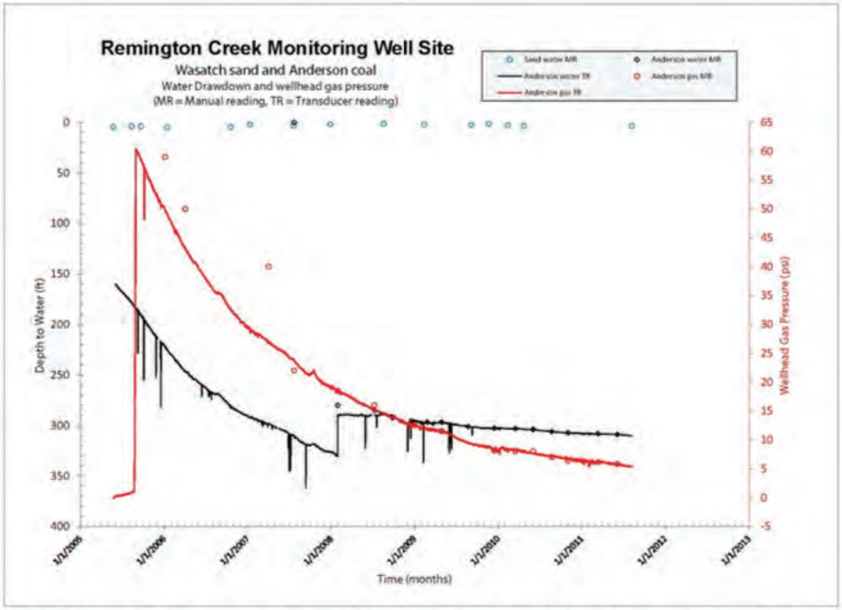


Figure A.194. Graph showing the manual and transducer recorded measurements for water levels and gas pressure for the monitored zones at the Remington Creek monitoring wellsite location.

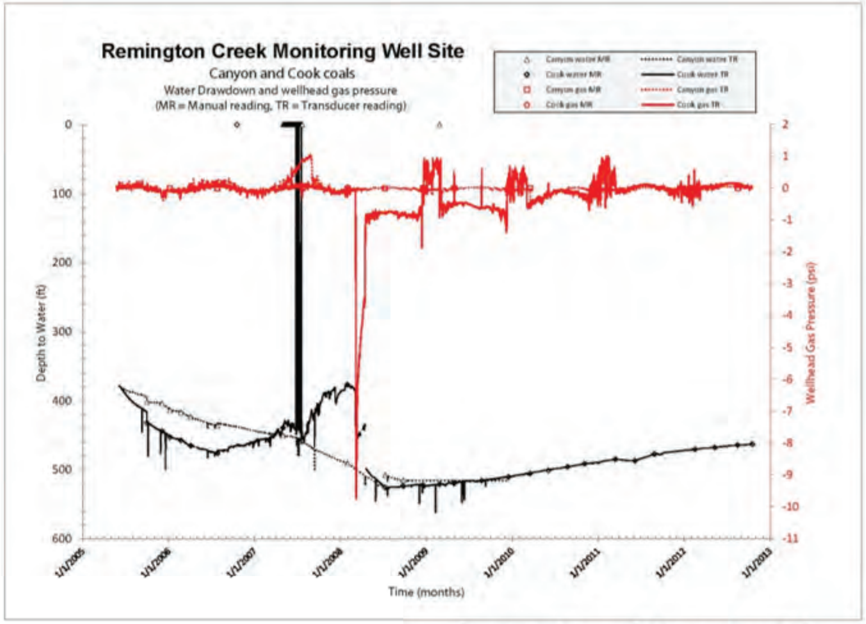


Figure A.195. Graph showing the manual and transducer recorded measurements for water levels and gas pressure for the monitored zones at the Remington Creek monitoring wellsite location.

SUMMARY AND 2015 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. In contrast, the State of Montana has approved a new CBM plan of development that encompasses much of the area between Hanging Woman Creek and the Powder River in ranges 8 and 9 south. Depending upon a number of factors including economic forces and industry priorities, CBM development could expand into that area within the next several years.

The MBMG regional groundwater monitoring network documents baseline conditions outside current production areas, changes to groundwater systems within CBM's current area of influence, and the current extent of drawdown within the monitored aquifers. Outside the area of CBM production influence, groundwater typically responds to precipitation and variable climate. Within the area of influence, groundwater levels are drawn down as required for CBM production.

Within CBM fields, the water level in produced coalbeds is drawn down to near the top of the coal, and 14-plus yr of CBM production has caused drawdown of up to 20 ft in coalbeds 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 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.

Table 3. Synoptic Sampling

GWIC ID	Site Name	Site Type	Sample Date
183564	Whitetail Cabin	stock well	9/30/2014
144969	Lohoff Qtr Circle V	pipeline well	10/1/2014
205082	Spring Creek	pipeline well	10/2/2014
7589	Newell Creek	pipeline well	10/6/2014
7775	WO-10	monitoring well	10/2/2014
7777	WO-6	monitoring well	10/6/2014
7778	WO-7	monitoring well	10/6/2014
7780	WO-1	monitoring well	10/6/2014
7781	WO-2	monitoring well	10/7/2014
7782	WO-3	monitoring well	10/6/2014
198766	Lemonade Spring	spring	9/30/2014
205010	North Fork Spring	spring	9/30/2014
199572	Deadman Spring	spring	9/30/2014
205011	Joe Anderson Spring	spring	9/30/2014
205041	School House Spring	spring	9/30/2014
197452	Alkali Spring	spring	10/1/2014
205049	Chipmunk Spring	spring	10/1/2014
199568	Hedum Spring	spring	10/1/2014
197607	Upper 15 Mile Creek	spring	10/2/2014
205004	Hagen-2 Spring	spring	10/7/2014

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.

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

Monitoring plans for water year 2015 are included in appendices A and B and shown in plate 6. During water year 2015, 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 2014 and Monitoring Plan for Water Year 2015

Appendix A. Site details and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract	Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2015 SWL monitoring plan	2015 QW sample collection	2015 Possible QW samples
7573	WO-15	45.5186	-106.1855	3022	04S	45E	4	BDDB	73	12/7/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
7574	WO-16	45.5158	-106.1861	3040	04S	45E	4	CAAC	61	12/10/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
7755	77-26 O-22	45.4352	-106.1839	3284	05S	45E	4	ABCC	216.8		125KNCB	7/18/2002	10/2/2014	Quarterly		
7770	WO-8	45.3922	-106.1411	3155	05S	45E	23	ABCA	34	11/14/1979	110ALVM	10/13/2004	8/14/2014	Quarterly		
7772	WO-9	45.3925	-106.1419	3150	05S	45E	23	ABCA	45	11/15/1979	110ALVM	10/13/2004	8/14/2014	Quarterly		
7775	WO-10	45.3925	-106.1430	3145	05S	45E	23	ABCB	43	11/27/1979	110ALVM	10/13/2004	10/2/2014	Quarterly		
7776	WO-5	45.3922	-106.1386	3160	05S	45E	23	ABDA	192	11/8/1979	125KNUB	10/13/2004	8/14/2014	Quarterly		
7777	WO-6	45.3922	-106.1386	3160	05S	45E	23	ABDA	82	11/8/1979	125LKCB	10/13/2004	10/6/2014	Quarterly		
7778	WO-7	45.3922	-106.1386	3160	05S	45E	23	ABDA	40	11/9/1979	110ALVM	10/13/2004	10/6/2014	Quarterly		
7780	WO-1	45.3947	-106.1494	3190	05S	45E	23	BBAA	172	11/2/1979	125KNUB	10/13/2004	10/6/2014	Quarterly		
7781	WO-2	45.3947	-106.1494	3188	05S	45E	23	BBAA	112	11/6/1979	125LKCB	10/13/2004	10/7/2014	Quarterly		
7782	WO-3	45.3947	-106.1494	3186	05S	45E	23	BBAA	66	11/6/1979	125KNOB	10/13/2004	10/6/2014	Quarterly		
7783	WO-4	45.3941	-106.1486	3140	05S	45E	23	BBAA	31.5	11/7/1979	110ALVM	3/14/2006	8/14/2014	Quarterly		
7903	* HWC-86-9	45.2965	-106.5030	3170	06S	43E	19	DACD	44		110ALVM	10/8/1986	9/30/2014	Quarterly		
7905	HWC-86-7	45.2956	-106.5040	3143	06S	43E	19	DDBA	71		110ALVM	10/5/1986	9/30/2014	Quarterly	Semi-Annual	
7906	HWC-86-8	45.2961	-106.5030	3170	06S	43E	19	DDBA	67		110ALVM	10/8/1986	9/30/2014	Quarterly		
8074	WR-21	45.0877	-106.9808	3890	08S	39E	32	DBBC	206	8/20/1975	125D1D2	9/18/1975	8/13/2014	Quarterly		X
8101	HWC-86-2	45.1350	-106.4827	3460	08S	43E	17	DDCA	50	9/29/1986	110ALVM	6/8/2004	10/1/2014	Quarterly		
8103	HWC-86-5	45.1341	-106.4822	3455	08S	43E	17	DDDC	40	9/30/1986	110ALVM	6/8/2004	10/1/2014	Quarterly		
8107	HWC-01 * DITCH WELL O-2 TR-26	45.1254	-106.4827	3530	08S	43E	20	DDDD	232	5/8/1974	125CNCB	6/4/1974	10/1/2014	Quarterly		
8110	HC-01 O-4	45.1313	-106.4750	3455	08S	43E	21	BBDA	19.7		110ALVM	4/18/2003	1/27/2009	Quarterly		
8118	* HC-24 O-10	45.1297	-106.4747	3490	08S	43E	21	BDBB	150	12/29/1980	125CNOB	7/22/2003	1/31/2013	Semi-Annual		
8140	FC-01	45.1025	-106.5166	3735	08S	43E	31	BBDA	133		125ANCB	6/16/1981	5/1/2014	Quarterly		
8141	FC-02	45.1025	-106.5166	3735	08S	43E	31	BBDA	260		125DICB	6/16/1981	5/1/2014	Quarterly		
8191	BC-06 O-42	45.1355	-106.2121	3715	08S	45E	16	DBCB	188		125CNCB	7/1/1975	4/30/2014	Quarterly		
8192	BC-07 O-43	45.1355	-106.2121	3715	08S	45E	16	DBCB	66		125CNOB	6/30/1975	4/30/2014	Quarterly		
8347	WR-23	45.0922	-106.9905	3960	09S	38E	1	AADC	322	8/28/1975	125D1D2	12/1/1975	8/13/2014	Quarterly		
8368	SH-391	45.0412	-107.0330	3987	09S	38E	22	DADC	175	9/27/1972	125D1D2	9/26/1972	8/14/2014	Quarterly		
8371	SH-388	45.0391	-107.0205	3975	09S	38E	23	CDAD	190	9/28/1972	125DICB	9/25/1972	8/14/2014	Quarterly		
8372	SH-396	45.0490	-107.0088	3939	09S	38E	24	BBBC	280		125AND2	10/21/1972	8/13/2014	Quarterly		
8377	SH-394	45.0329	-107.0075	3909	09S	38E	25	BCBA	242		125DICB	10/5/1972	8/14/2014	Quarterly		
8379	SH-422	45.0261	-107.0061	3917	09S	38E	25	CBDC	187		125DICB	6/7/1973	4/28/2014	Semi-Annual		
8387	SH-395	45.0359	-107.0180	3900	09S	38E	26	ABAB	299		125DICB	10/7/1972	8/14/2014	Quarterly		
8412	WR-58	45.0408	-106.9122	3631	09S	39E	14	DDBD	55	8/23/1977	110ALVM	9/28/1977	10/1/2014	Quarterly		
8413	WR-58D	45.0394	-106.9138	3627	09S	39E	14	DDCC	27	8/25/1977	110ALVM	10/2/2001	10/1/2014	Quarterly		
8417	WR-19	45.0525	-106.9505	3835	09S	39E	16	AABA	305	8/14/1975	125D1D2	9/18/1975	10/1/2014	Quarterly		X
8419	WR-20	45.0525	-106.9505	3835	09S	39E	16	AABA	166	8/18/1975	125ANCB	9/18/1975	10/1/2014	Quarterly		X
8428	WR-54A	45.0147	-106.8902	3631	09S	39E	25	DADB	211	8/30/1977	125ADOB	9/28/1977	10/1/2014	Quarterly		
8430	WR-53A	45.0122	-106.8888	3608	09S	39E	25	DDAA	187	8/29/1977	125ADOB	3/28/1979	10/1/2014	Quarterly		
8436	WR-24	45.0202	-106.9877	3777	09S	39E	29	BBDD	146		125CNCB	12/29/1975	8/14/2014	Quarterly		
8441	WR-33	45.0067	-106.9760	3732	09S	39E	32	ACAA	165	6/6/1977	125ADKC	6/22/1977	8/14/2014	Quarterly		
8444	WR-27	45.0009	-106.9590	3672	09S	39E	33	DBBD	363	1/21/1976	125AND2	2/3/1976	8/14/2014	Quarterly		
8446	WR-45	44.9962	-106.9538	3638	09S	39E	33	DDCC	64	6/21/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
8447	WR-44	44.9962	-106.9528	3637	09S	39E	33	DDCD	64	6/21/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
8451	WR-42	44.9962	-106.9509	3637	09S	39E	33	DDDD	66		110ALVM	6/18/2004	8/14/2014	Quarterly		
8456	WRN-10	45.0733	-106.8094	3433	09S	40E	3	DABA	79	12/5/1974	125D2CB	1/6/1975	9/25/2014	Quarterly		
8461	WRN-15	45.0638	-106.8275	3500	09S	40E	9	AADD	140	12/5/1974	125D2CB	1/7/1975	10/8/2014	Quarterly		X
8471	DS-05A	45.0555	-106.8338	3506	09S	40E	9	DCAB	166	5/21/1976	125D2CB	6/21/1976	10/8/2014	Quarterly		X
8479	DS-05B	45.0555	-106.8338	3506	09S	40E	9	DCAB	140	5/24/1976	111SPBK	6/21/1976	10/8/2014	Quarterly		
8500	WRE-09	45.0397	-106.7741	3511	09S	40E	13	DCBC	232	11/1/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
8501	WRE-10	45.0383	-106.7741	3519	09S	40E	13	DCCB	183	11/1/1974	125DICB	12/11/1974	10/8/2014	Quarterly		
8504	WRE-11	45.0383	-106.7736	3509	09S	40E	13	DCCD	127	11/15/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		
8574	DS-02A	45.0416	-106.8166	3430	09S	40E	15	DBCC	150	5/20/1976	125D2CB	6/21/1976	10/8/2014	Quarterly		X
8584	DS-02B	45.0416	-106.8166	3430	09S	40E	15	DBCC	74	5/20/1976	111SPBK	6/21/1976	10/8/2014	Quarterly		
8590	DS-02C	45.0416	-106.8166	3430	09S	40E	15	DBCC	65		111SPBK	6/21/1976	10/8/2014	Quarterly		

Appendix A. Site details and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract	Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2015 SWL monitoring plan	2015 QW sample collection	2015 Possible QW samples
8650	WR-55	45.0302	-106.8874	3591	09S	40E	19	CBBD	288	8/16/1977	125AND2	9/28/1977	8/13/2014	Quarterly		
8651	WR-55A	45.0302	-106.8863	3591	09S	40E	19	CBBD	72	8/17/1977	125ADOB	9/28/1977	8/13/2014	Quarterly		
8687	WRE-12	45.0307	-106.8050	3463	09S	40E	23	BCCD	172	11/18/1974	125ANCB	12/4/1974	9/25/2014	Quarterly		X
8692	WRE-13	45.0308	-106.8050	3463	09S	40E	23	BCCD	206	11/18/1974	125DICB	12/4/1974	9/25/2014	Quarterly		
8698	WRE-16	45.0351	-106.7690	3551	09S	40E	24	AACB	458	11/18/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		
8706	WR-17B	45.0227	-106.8656	3575	09S	40E	29	BBAC	160	6/28/1977	125ADOB	7/6/1977	10/1/2014	Quarterly		
8708	WR-51	45.0186	-106.8622	3541	09S	40E	29	BDCB	344	6/29/1977	125AND2	7/6/1977	8/13/2014	Quarterly		
8709	WR-51A	45.0186	-106.8622	3541	09S	40E	29	BDCB	187	7/12/1977	125ADOB	9/27/1977	8/13/2014	Quarterly		
8710	WR-52B	45.0147	-106.8627	3519	09S	40E	29	CACB	55	7/14/1977	110ALVM	9/27/1977	10/2/2014	Quarterly		
8721	WRE-27	45.0586	-106.7391	3524	09S	41E	8	CABC	77	10/28/1974	125ANCB	12/11/1974	10/8/2014	Quarterly		
8723	WRE-28	45.0586	-106.7391	3525	09S	41E	8	CABC	153	10/28/1974	125D1CB	12/11/1974	10/8/2014	Quarterly		
8726	WRE-29	45.0586	-106.7411	3523	09S	41E	8	CBAD	217	10/29/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
8754	CC-01	45.0872	-106.4655	3525	09S	43E	4	ABDD	28	12/12/1979	110ALVM	5/29/1980	4/29/2014	Quarterly		
8757	CC-04	45.0874	-106.4659	3511	09S	43E	4	ABDD	25	12/18/1979	110ALVM	2/28/1980	4/29/2014	Quarterly		
8758	* CC-03	45.0864	-106.4654	3521	09S	43E	4	ACAA	34.5	12/13/1979	110ALVM	2/28/1980	4/29/2014	Quarterly		
8777	HWC-38 USGS OBS WELL	45.0719	-106.4028	3586	09S	43E	12	ADBB	40.5	6/15/1977	110ALVM	11/16/1977	9/24/2014	Quarterly		
8778	HWC-17	45.0575	-106.4142	3610	09S	43E	13	BCAA	82	8/10/1976	125ANCB	9/21/1976	9/24/2014	Quarterly		
8779	HWC-07	45.0536	-106.4094	3595	09S	43E	13	CAAA	66	7/16/1975	125ANCB	8/5/1975	9/24/2014	Quarterly		
8782	HWC-15	45.0412	-106.4468	3600	09S	43E	22	ACCA	129	8/4/1976	125ANCB	9/21/1976	9/24/2014	Quarterly		
8796	HWC-29B	45.0697	-106.3974	3620	09S	44E	7	BBCC	92	5/14/1977	125ANCB	5/14/1977	9/24/2014	Quarterly		
8835	AMAX NO. 110	45.0699	-106.1153	3965	09S	46E	8	BACC	240		125DICB	9/19/1975	7/9/2014	Quarterly		
8846	UOP-09 KB-33 O-35	45.0720	-106.0578	3929	09S	46E	11	BBBA	261.5	6/13/2002	125CNCB	7/23/1983	9/26/2013	Quarterly		
8847	UOP-10 KB-34 O-36	45.0720	-106.0578	3930	09S	46E	11	BBBA	207.3		125CNOB	7/23/1983	9/26/2013	Quarterly		
8863	FULTON RANCH-TRAILER * TRAILER	45.0807	-105.8634	3380	09S	48E	5	ACDD	410	12/2/1958	125TGRV	7/31/1979	10/8/2014	Quarterly		
8888	HWC-86-13	45.0020	-106.4262	3640	10S	43E	2	ABCA	53	10/8/1986	110ALVM	10/1/2002	10/1/2014	Quarterly	Semi-Annual	
94661	LISCOM BUTTE WELL	45.7782	-106.0329	3275	01S	46E	3	DBAA	135	7/11/1946	125TGRV	6/30/2000	9/30/2014	Quarterly		
94666	COYOTE WELL * WINDMILL WELL	45.7524	-106.0511	3294	01S	46E	16	AACC	190	9/27/1963	125TGRV	6/30/2000	9/30/2014	Quarterly		
100472	EAST FORK WELL	45.5935	-106.1648	3210	03S	45E	10	BACB	193	4/1/1961	125KNUB	6/29/2000	10/13/2014	Quarterly		
103155	PADGET CREEK PIPELINE WELL	45.3939	-106.2940	3385	05S	44E	22	BBBD	135	4/30/1981	125TGRV	2/3/2006	8/13/2013	Quarterly		
105007	TOOLEY CREEK WELL * TOOLEY	45.2153	-106.2703	3755	07S	45E	19	CAAA	110	11/5/1978	125CNOB	11/5/1978	10/1/2014	Quarterly		
121669	WRE-18	45.0335	-106.7690	3573	09S	40E	24	AACD	445	11/4/1974	125ANCB	12/4/1974	10/8/2014	Quarterly		
122766	WR-59	45.0050	-106.8526	3470	09S	40E	32	ACAD	34	8/31/1977	110ALVM	9/27/1977	10/1/2014	Quarterly	Semi-Annual	
122767	WRE-20	45.0369	-106.7716	3519	09S	40E	24	ABAB	120	12/11/1974	125ANCB	1/9/1975	10/8/2014	Quarterly		
122769	WR-38	44.9939	-106.9660	3693	54N	84W	23	BBCB	286	6/14/1977	125D1D2	6/24/1977	8/14/2014	Quarterly		
122770	WR-39	44.9957	-106.9555	3666	58N	84W	23	ABBC	312	6/14/1977	125AND2	8/2/1977	8/14/2014	Quarterly		
123795	WRE-25	45.0683	-106.7333	3549	09S	41E	5	DCCA	114.5	10/29/1974	125ANCB	12/11/1974	10/8/2014	Quarterly		
123796	WR-17A	45.0227	-106.8656	3574	09S	40E	29	BBAC	88	6/17/1977	125ADOB	7/6/1977	10/2/2014	Quarterly		
123797	WRE-19	45.0369	-106.7736	3520	09S	40E	24	ABBA	140	11/18/1974	125ANCB	12/4/1974	10/8/2014	Quarterly		
123798	WRN-11	45.0733	-106.8094	3437	09S	40E	3	DABA	50	12/5/1974	125ADKC	1/6/1975	9/25/2014	Quarterly		
127605	WR-54	45.0147	-106.8902	3630	09S	39E	25	DADB	384	8/15/1977	125AND2	9/28/1977	10/1/2014	Quarterly		
130475	WRE-24	45.0688	-106.7333	3552	09S	41E	5	DCCA	154	10/29/1994	125D1CB	12/11/1974	10/8/2014	Quarterly		
130476	WR-31	45.0163	-106.9863	3895	09S	39E	29	CBAA	316	6/2/1977	125ANCB	6/22/1977	8/14/2014	Quarterly		
132716	WR-48	44.9939	-106.9660	3694	58N	84W	23	BBCB	167	6/24/1977	125ANCB	7/6/1977	8/14/2014	Quarterly		
132903	WR-58A	45.0406	-106.9125	3631	09S	39E	14	DDBD	24	8/24/1977	110ALVM	9/28/1977	10/1/2014	Quarterly		
132907	WR-53	45.0129	-106.8900	3607	09S	39E	25	DDAA	384	8/11/1977	125AND2	9/28/1977	10/1/2014	Quarterly		
132908	WR-30	45.0165	-106.9874	3895	09S	39E	29	CBAB	428	6/1/1977	125D1D2	6/22/1977	8/14/2014	Quarterly		
132909	WR-34	45.0027	-106.9700	3772	09S	39E	33	CBBB	522	6/7/1977	125AND2	8/2/1977	8/14/2014	Quarterly		
132910	WRE-02	45.0712	-106.7758	3457	09S	40E	1	DBCC	79		110ALVM	1/7/1975	10/8/2014	Quarterly		
132958	WRE-21	45.0376	-106.7726	3529	09S	40E	24	ABAB	130	12/1/1974	125ANCB	12/10/1974	10/8/2014	Quarterly		
132959	WRE-17	45.0341	-106.7683	3562	09S	40E	24	AACD	250	11/18/1974	125SMCB	12/4/1974	10/8/2014	Quarterly		
132960	WR-52C	45.0157	-106.8625	3530	09S	40E	29	CABC	62	7/14/1977	110ALVM	10/2/2001	10/1/2014	Quarterly		
132961	WR-52D	45.0157	-106.8612	3529	09S	40E	29	CABD	40	7/15/1977	110ALVM	9/27/1977	10/1/2014	Quarterly		
132965	WRE-23	45.0694	-106.7335	3557	09S	41E	5	DCBD	240	11/4/1974	125D2CB	12/11/1974	10/8/2014	Quarterly		
132973	PKS-1179	45.0314	-106.8040	3458	09S	40E	23	CBBB	282	6/3/1992	125D2CB	7/7/1992	9/25/2014	Quarterly		
144969	LOHOF PIPELINE WELL 7(PL-1W)	45.2354	-106.3074	3876	07S	44E	14	ABD	225	5/25/1992	125TGRV	2/3/2006	10/1/2014	Quarterly		

Appendix A. Site details and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract	Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2015 SWL monitoring plan	2015 QW sample collection	2015 Possible QW samples
157879	5072B * 5072B	45.7393	-106.4910	3160	01S	42E	24	ACBB	86	9/12/1996	125RBCB	9/19/1996	7/1/2014	Quarterly		
157882	5072C * 5072C	45.7394	-106.4911	3160	01S	42E	24	ACBB	68	9/12/1996	125RBOB	9/19/1996	7/1/2014	Quarterly		
157883	5080B * 5080B	45.7199	-106.5132	3260	01S	42E	26	DCBA	88.5	9/11/1996	125KNCB	10/2/1996	7/1/2014	Quarterly		
157884	5080C * 5080C	45.7200	-106.5132	3260	01S	42E	26	DCBA	46	9/11/1996	125KNOB	9/20/1996	7/1/2014	Quarterly		
161749	BF-01	44.9897	-106.9667	3680	58N	84W	22	ACCC	125	4/30/1996	111SPBK	6/25/1997	1/9/2014	Quarterly		
166351	PKS-3204-79	45.1067	-106.8299	3500	08S	40E	28	ADA	82	4/4/1997	125ADKB	6/5/1997	9/25/2014	Quarterly		
166358	PKS-3203-79	45.1068	-106.8302	3500	08S	40E	28	ADA	201	4/3/1997	125CNCB	6/5/1997	9/25/2014	Quarterly		
166359	PKS-3202	45.0451	-106.7981	3438	09S	40E	14	CAA	60	3/5/1997	110ALVM	6/5/1997	10/8/2014	Quarterly		
166362	PKS-3201	45.0437	-106.7971	3438	09S	40E	14	CAA	390	3/5/1997	125CNCB	6/5/1997	10/8/2014	Quarterly		
166370	PKS-3200	45.0440	-106.7969	3438	09S	40E	14	CAA	242	2/28/1997	125D2CB	6/5/1997	10/8/2014	Quarterly		
166388	PKS-3199	45.0443	-106.7966	3439	09S	40E	14	CAA	165	2/27/1997	125D1CB	6/5/1997	10/8/2014	Quarterly		
166389	PKS-3198	45.0446	-106.7964	3440	09S	40E	14	CAA	112	2/25/1997	125ANCB	6/5/1997	10/8/2014	Quarterly		
166761	WR-29R	45.0456	-106.8151	3461	09S	40E	15	ACCD	72	10/23/1997	125ADKC	12/3/1987	9/25/2014	Quarterly		
183559	BRIDGE ARTESIAN IP-11	45.4114	-106.4555	3085	05S	43E	8	CDCB	540	1/1/1947	125FGUB	7/3/2000	10/7/2014	Quarterly		
183560	ALLUVIAL-CORRAL	45.4387	-106.4211	3035	05S	43E	4	AAAB	20		111ALVM	7/3/2000	10/7/2014	Quarterly		
183563	FULTON RANCH -RIVER	45.0637	-105.8715	3360	09S	48E	8	CABC	30		111ALVM	6/28/2000	10/8/2014	Quarterly		
183564	WHITETAIL RANGER STATION	45.6404	-105.9764	4045	02S	47E	19	CDCA	60		125TGRV	6/30/2000	9/30/2014	Quarterly		
183565	SKINNER GULCH PIPELINE WELL	45.4275	-105.9177	3730	05S	47E	3	BCCD	167		125PWUB	6/29/2000	10/2/2014	Quarterly		
184222	SH-624	45.0725	-107.0917	4645	09S	38E	7	DADB	435.1		125ADCB	6/23/1976	8/14/2014	Quarterly		
184223	SH-625	45.1133	-107.0522	4187	08S	38E	28	DADB	187	6/24/1976	125DICB	8/13/1974	8/13/2014	Quarterly		
184224	SH-625A	45.1133	-107.0522	4187	08S	38E	28	DADB	91	6/24/1976	125ANCB	6/23/1976	8/13/2014	Quarterly		
184225	SH-634	45.1422	-107.0728	4481	08S	38E	17	DADD	348	8/9/1976	125DICB	8/9/1976	8/13/2014	Semi-Annual		
184226	SH-634A	45.1425	-107.0730	4481	08S	38E	17	DADD	159	8/9/1976	125ANCB	8/9/1976	8/13/2014	Semi-Annual		
186195	WR-41	44.9962	-106.9498	3643	09S	39E	34	CCCC	40	6/20/1977	110ALVM	6/22/1977	8/14/2014	Quarterly		
189743	HWC-29A	45.0697	-106.3974	3619	09S	44E	7	BBCC	98	5/13/1977		9/27/1977	9/24/2014	Quarterly		
189802	HWC-37	45.0719	-106.4028	3578	09S	43E	12	ADBB	32	6/14/1977	110ALVM	11/16/1977	9/24/2014	Quarterly		
189838	HWC-39 AL-46	45.0710	-106.4015	3591	09S	43E	12	ADBD	39	6/16/1977	110ALVM	9/10/2001	9/24/2014	Quarterly		
190902	HWC-10	45.0444	-106.4695	3615	09S	43E	21	BADA	229	7/22/1975	125DICB	8/5/1975	9/24/2014	Quarterly		
190904	HWC-11	45.0444	-106.4696	3610	09S	43E	21	BADA	135	7/28/1975	125ANCB	8/5/1975	9/24/2014	Quarterly		
191139	20-LW (DIAMOND CROSS)	45.3391	-106.7801	3940	06S	40E	1	CDDC	253		125WACB	7/7/1979	9/23/2014	Quarterly		
191155	(DIAMOND CROSS) 22-BA	45.3484	-106.6954	3530	06S	41E	3	BADD	262		125BACB	6/5/1979	4/24/2012	Quarterly		
191163	(DIAMOND CROSS) 28-W	45.3197	-106.7256	3715	06S	41E	16	BBCC	144		125WACB	8/15/1978	9/23/2014	Quarterly		
191169	32-LW	45.2943	-106.7076	3530	06S	41E	21	DDDC	51		125WACB	6/27/1979	9/23/2014	Quarterly		
191634	M75-23	45.0966	-106.2011	3780	08S	45E	34	BDBC	247		125CNCB	12/11/2001	11/20/2013	Quarterly		
192874	YA-109	45.0465	-107.0530	3830	09S	38E	22	DADC	43.8		110ALVM	10/12/2001	8/14/2014	Quarterly		
198465	HWC-06	45.0536	-106.4092	3595	09S	43E	13	CAAA	184	7/15/1975	125DICB	8/5/1975	9/24/2014	Quarterly		
198489	HWC-86-15	45.0025	-106.4235	3630	10S	43E	2	AABC	62.52	10/8/1986	110ALVM	10/1/2002	10/1/2014	Quarterly	Semi-Annual	
203646	CBM02-1KC	45.3186	-106.9671	3980	06S	39E	16	DBCA	417	10/4/2002	125KNCB	12/18/2002	9/25/2014	Quarterly		
203655	CBM02-1BC	45.3186	-106.9671	3984	06S	39E	16	DBCA	255.5	10/8/2002	125BACB	12/18/2002	9/25/2014	Quarterly		
203658	CBM02-1LC	45.3186	-106.9671	3982	06S	39E	16	DBCA	366	10/8/2002	125LOCB	12/18/2002	9/25/2014	Quarterly		
203669	CBM02-2WC	45.0207	-106.9884	3792	09S	39E	29	BBDC	290	9/11/2002	125CRCB	12/18/2002	8/14/2014	Quarterly		
203670	CBM02-2RC	45.0185	-106.9889	3890	09S	39E	29	BCBD	159	9/14/2002	125RLCB	12/18/2002	8/14/2014	Quarterly		
203676	CBM02-3CC	45.1392	-106.9608	3920	08S	39E	16	BAAA	376.4	10/24/2002	125CNCB	3/7/2003	9/25/2014	Quarterly		
203678	CBM02-3DC	45.1391	-106.9607	3920	08S	39E	16	BAAA	235	10/24/2002	125DICB	12/18/2002	9/25/2014	Quarterly		
203680	CBM02-4WC	45.1798	-106.7802	3500	07S	40E	36	CDDC	291	10/18/2002	125WACB	12/18/2002	9/30/2014	Quarterly		
203681	CBM02-4SS1	45.1798	-106.7803	3500	07S	40E	36	CDDC	221	10/19/2002	125WAOB	12/18/2002	9/30/2014	Quarterly		
203690	CBM02-4SS2	45.1798	-106.7803	3500	07S	40E	36	CDDC	96.6	10/20/2002	125CNUB	12/18/2002	9/30/2014	Quarterly		
203693	CBM02-7CC	45.1801	-106.8906	3900	08S	39E	1	AAAA	263.4	9/27/2002	125CNCB	9/28/2002	9/25/2014	Quarterly		
203695	CBM02-7SS	45.1799	-106.8906	3900	08S	39E	1	AAAA	190.3	9/28/2002	125CNOB	9/29/2002	9/25/2014	Quarterly		
203697	CBM02-8KC	45.3689	-106.5473	3262	05S	42E	28	DDAC	208	11/8/2002	125KNCB	11/12/2002	9/23/2014	Quarterly		
203699	CBM02-8SS	45.3688	-106.5472	3262	05S	42E	28	DDAC	224	11/11/2002	125KNUB	12/18/2002	9/23/2014	Quarterly		
203700	CBM02-8DS	45.3687	-106.5470	3261	05S	42E	28	DDAC	446	11/13/2002	125FGOB	12/18/2002	9/23/2014	Quarterly		
203701	CBM02-8FG	45.3688	-106.5471	3261	05S	42E	28	DDAC	480.4	11/11/2002	125FGCB	11/13/2002	9/23/2014	Quarterly		
203703	CBM03-10AC	45.1141	-106.6045	4130	08S	42E	29	ADAD	560	4/21/2003	125ANCB	6/23/2003	9/25/2014	Quarterly		X
203704	CBM03-10SS	45.1141	-106.6045	4130	08S	42E	29	ADAD	462	4/23/2003	125ADOB	4/29/2003	9/25/2014	Quarterly		X

Appendix A. Site details and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Latitude	Longitude	Land altitude (feet)	Town-ship	Range	Sect	Tract	Well total depth (feet)	Date Completed	Aquifer	First SW date	Most recent SWL date	2015 SWL monitoring plan	2015 QW sample collection	2015 Possible QW samples
203705	CBM03-11AC	45.1793	-106.3632	3950	08S	44E	5	BBBB	211	4/28/2003	125ANCB	5/14/2003	9/24/2013	Quarterly		
203707	CBM03-11DC	45.1793	-106.3641	3950	08S	44E	5	BBBB	271	5/7/2003	125DICB	5/14/2003	9/24/2013	Quarterly		
203708	CBM03-11CC	45.1793	-106.3647	3950	08S	44E	5	BBBB	438	5/7/2003	125CNCB	5/14/2003	9/24/2013	Quarterly		
203709	CBM03-12COC	45.1352	-106.2121	3715	08S	45E	16	DBCB	351	5/16/2003	125CKCB	5/16/2003	4/30/2014	Quarterly		
203710	CBM03-13OC	45.0722	-106.0572	3931	09S	46E	11	BBBA	500	5/22/2003	125OTCB	5/23/2003	9/26/2013	Quarterly		
205082	SPRING CREEK PIPELINE WELL	45.3883	-105.9538	3630	05S	47E	20	ACAC	50		125TGRV	1/26/2006	10/2/2014	Quarterly		
207064	RBC-1	45.3327	-106.9836	3855	06S	39E	8	CAAA	26.77	7/9/2003	110ALVM	7/10/2003	9/23/2014	Quarterly		
207066	RBC-2	45.3327	-106.9844	3849	06S	39E	8	CAAA	16.9	7/9/2003	110ALVM	7/10/2003	9/23/2014	Quarterly		
207068	RBC-3	45.3331	-106.9868	3860	06S	39E	8	BDCD	24.55		110ALVM	7/11/2003	9/23/2014	Quarterly		
207075	YA-114	45.0463	-107.0543	4000	09S	38E	21	ADBD			110ALVM	8/10/2003	8/14/2014	Quarterly		
207076	YA-105	45.0465	-107.0527	4015	09S	38E	21	ACAC			110ALVM	8/28/2003	8/14/2014	Quarterly		
207080	TA-100	45.0478	-107.0090	3900	09S	38E	23	BBCC			110ALVM	8/10/2003	8/13/2014	Quarterly		
207081	TA-101	45.0481	-107.0090	3910	09S	38E	24	BBCC			110ALVM	8/10/2003	8/13/2014	Quarterly		
207083	TA-102	45.0484	-107.0076	3910	09S	38E	24	BBCB			110ALVM	8/10/2003	8/13/2014	Quarterly		
207096	IB-2	45.3930	-106.4372	3192	05S	43E	21	BBDB	245		125KNUB	10/19/2003	9/23/2014	Quarterly		
207097	MK-4	45.3919	-106.4363	3195	05S	43E	21	BBDC	188		125KNCB	10/19/2003	9/23/2014	Quarterly		
207098	NM-4	45.3916	-106.4361	3195	05S	43E	21	BCAB	294		125NACB	6/16/2004	9/23/2014	Quarterly		
207099	WL-2	45.3918	-106.4358	3188	05S	43E	21	BBDC	199		125KNCB	10/19/2003	9/23/2014	Quarterly		
207101	OC-28	45.4717	-106.1928	3171	04S	45E	21	CCBD	236		125KNCB	12/14/2003	10/2/2014	Quarterly		
207143	HC-01 O-4	45.1314	-106.4750	3457	08S	43E	21	BBDA	19.7		110ALVM	4/18/2003	1/31/2013	Semi-Annual		
210094	WO-14	45.5183	-106.1849	3010	04S	45E	4	BDDB	72	12/6/1979	110ALVM	4/9/2003	1/8/2014	Quarterly		
214096	HWCQ-2 (DIAMOND CROSS)	45.1913	-106.5010	3340	07S	43E	32		19	9/10/2004	110ALVM	9/16/2004	11/19/2013	Quarterly		
214097	HWCQ-1 (DIAMOND CROSS)	45.1912	-106.5010	3340	07S	43E	32		19.5	9/10/2004	110ALVM	9/16/2004	11/19/2013	Quarterly		
214354	WA-7	45.3933	-106.4347	3179	05S	43E	21	BABC	59		110ALVM	7/23/2004	9/23/2014	Quarterly		
215085	WO-11	45.3927	-106.1433	3145	05S	45E	23		40	11/28/1979	110ALVM	10/13/2004	10/2/2014	Quarterly		
219125	SL-2AC	45.0276	-106.6358	3925	09S	42E	30	BDAC	671	5/25/2005	125ANCB	6/21/2005	9/23/2014	Quarterly		
219136	SL-3Q	45.0161	-106.5386	3725	09S	42E	36	BBAD	40	4/7/2005	110ALVM	5/20/2005	9/24/2014	Quarterly		
219138	SL-3SC	45.0080	-106.5313	3805	09S	42E	36	DBCB	358	4/29/2005	125SMCB	5/3/2005	9/24/2014	Quarterly		
219139	SL-3AC	45.0079	-106.5313	3805	09S	42E	36	DBCB	523	4/12/2005	125ANCB	5/3/2005	9/24/2014	Quarterly		
219140	SL-3CC	45.0082	-106.5313	3805	09S	42E	36	DBCB	817	4/18/2005	125CNCB	5/3/2005	9/24/2014	Quarterly		
219141	SL-4SC	45.0031	-106.4243	3640	10S	43E	2	ABAA	120.4	4/7/2005	125SMCB	4/12/2005	9/24/2014	Quarterly		
219169	SL-4AC	45.0031	-106.4244	3640	10S	43E	2	ABAA	279	4/1/2005	125ANCB	4/4/2005	9/24/2014	Quarterly		
219617	SL-3SS	45.0079	-106.5313	3805	09S	42E	36	DBCB	278	4/26/2005	125SMOB	5/3/2005	9/24/2014	Quarterly		
219927	SL-5AC	45.0119	-106.2714	3810	09S	44E	36	ABBD	223	6/6/2005	125ANCB	6/22/2005	9/24/2014	Quarterly		
219929	SL-5DC	45.0119	-106.2714	3810	09S	44E	36	ABBD	322	6/3/2005	125DICB	6/24/2005	9/24/2014	Quarterly		
220062	SL-6AC	45.0148	-106.1514	4220	09S	45E	36	ABBB	492	6/23/2005	125ANCB	7/6/2005	9/24/2014	Quarterly		
220064	SL-6CC	45.0148	-106.1513	4220	09S	45E	36	ABBB	685	6/17/2005	125CNCB	7/5/2005	6/23/2011	Gas Danger		
220069	SL-7CC	45.0147	-106.0392	4173	09S	46E	36	BBBB	515	7/8/2005	125CNCB	7/14/2005	4/20/2010	Gas Danger		
220076	SL-5CC	45.0119	-106.2715	3810	09S	44E	36	ABBD	430.5	6/10/2005	125CNCB	7/5/2005	9/24/2014	Quarterly		
220385	SL-2CC	45.0273	-106.6360	3920	09S	42E	30	BCBC	1301	8/22/1999	125CNCB	7/23/2005	9/23/2014	Quarterly		
220851	SL-8-1Q	45.0176	-105.8998	3397	09S	47E	25	DDDB	19	8/26/2005	110ALVM	8/28/2005	9/24/2014	Quarterly		
220857	SL-8-2Q	45.0182	-105.9052	3394	09S	47E	25	DCDB	13.8	8/26/2005	110ALVM	8/28/2005	10/8/2014	Quarterly	Semi-Annual	
220859	SL-8-3Q	45.0177	-105.9028	3398	09S	47E	25	DDCB	19	8/26/2005	110ALVM	8/28/2005	9/24/2014	Quarterly		
221592	IP-22	45.0177	-105.9003	3395	09S	47E	25	DDBD				7/17/2007	1/19/2011	Quarterly		
223236	NC02-5	45.3986	-106.5603	3400	05S	42E	16	CCAB	376		125KNCB	12/11/2002	11/6/2013			
223237	NC02-6	45.4022	-106.6397	3510	05S	41E	14	BDCD	360		125KNCB	12/11/2002	11/3/2013			
223238	NC02-1	45.3608	-106.8464	4440	05S	40E	31	BDCC	680.5		125WACB	12/10/2002	6/6/2005			
223240	NC02-2	45.4030	-106.5044	3220	05S	42E	14	ADDC	420		125FGCB	12/11/2002	5/6/2014			
223242	NC02-3	45.4044	-106.6917	3740	05S	41E	17	ADBD	353			12/11/2002	5/6/2014			
223243	NC02-4 WALL COAL WELL	45.4080	-106.7311	3940	05S	40E	13	ADAB	380		125WACB	12/11/2002	11/6/2013			
223687	SITE RBC-4	45.3332	-106.9863	3841	06S	39E	8		5.05			8/25/2005	9/23/2014	Quarterly		
223695	MOORHEAD CAMPGROUND	45.0542	-105.8773	3400	09S	48E	17	BCBB	1000			4/19/2010	4/24/2014	Quarterly		
223801	SL-5ALQ	45.0129	-106.2579	3810	09S	45E	31	BBA	35		110ALVM	9/16/2005	9/24/2014	Quarterly		
223890	TAYLOR CREEK PIPELINE WELL	45.2213	-105.9928	3910	07S	47E	21	BBCC	150		125TGRV	1/26/2006	4/24/2014	Quarterly		
223952	WA-2	45.4032	-106.4566	3069	05S	43E	17	BCDD	37.8	8/16/1978	110ALVM	8/17/2006	9/23/2014	Quarterly		

Appendix A. Site details and 2014 monitoring schedule for groundwater monitoring wells

GWIC ID	**Site Name**	**Latitude**	**Longitude**	**Land altitude (feet)**	**Town-ship**	**Range**	**Sect**	**Tract**	**Well total depth (feet)**	**Date Completed**	**Aquifer**	**First SW date**	**Most recent SWL date**	**2015 SWL monitoring plan**	**2015 QW sample collection**	**2015 Possible QW samples**
227246	DH 76-102D	45.0798	-106.1862	3811	09S	45E	3	ADCC	144		125DICB	5/5/2006	9/26/2013	Quarterly		
228592	MUSGRAVE BILL ALLUVIAL	45.1639	-106.7319	3335	08S	41E	5	ACDB	21.5		111ALVM	9/7/2006	9/30/2014	Quarterly	Semi-Annual	
251797	GC09-KC	45.4376	-106.3919		05S	43E	2	BAB	165.5		125KNCB	3/25/2010	12/23/2014	Quarterly		
251798	GC09-FG	45.4376	-106.3919		05S	43E	2	BAB	400		125FGCB	3/25/2010	12/23/2014	Quarterly		
251799	GC09-TC	45.4376	-106.3919		05S	43E	2	BAB	534		125TTCB	3/25/2010	12/23/2014	Quarterly		
259676	SL-9OC	45.0068	-105.8175	3640	09S	48E	34	DAA	378	10/23/2010	125ODCB	7/19/2011	9/24/2014	Quarterly		
259683	SL-9BA	45.0068	-105.8175	3640	09S	48E	34	DAA	291	10/26/2010	125BACB	7/19/2011	9/24/2014	Quarterly		
259684	SL-9PC	45.0068	-105.8175	3640	09S	48E	34	DAA	169	10/28/2010	125PWCB	7/19/2011	9/24/2014	Quarterly		
276654	10MILE-KC1	45.4400	-106.0946	3268	04S	46E	31	DAAC	71	9/25/2013		9/26/2013	8/14/2014	Quarterly		
277326	SL-8KC	45.0164	-105.9037	3394	09S	47E	25	DCDA	423	7/16/2013		9/26/2013	9/24/2014	Quarterly		
277327	SL-8BA	45.0164	-105.9037	3395	09S	47E	25	DCDA	115	7/17/2013		9/26/2013	9/24/2014	Quarterly		

Appendix B

Site Details, Discharge Data for Water Year 2014, and Monitoring Plan for Springs and Streams for Water Year 2015

Appendix B. Site details and water year 2015 monitoring plan for springs and streams

GWIC ID	Site name	Longitude	Latitude	Township	Range	Section	Tract	County
197247	South Fork Harris Creek Spring	-106.60530	45.16420	08S	42E	5	DDDB	Big Horn
197452	Alkali Spring	-106.15010	45.19140	07S	46E	31	BACD	Powder River
197607	Upper Fifteen Mile Spring	-105.93720	45.39200	05S	47E	16	DCDC	Powder River
198766	Lemonade Spring	-105.92550	45.54550	03S	47E	28	ACAA	Powder River
199568	Hedum Spring	-106.07100	45.28230	06S	46E	26	CDBA	Powder River
199572	Deadman Spring	-105.87430	45.29030	06S	48E	29	BABB	Powder River
205004	Hagen 2 Spring	-106.26880	45.34500	06S	45E	6	ACDC	Powder River
205010	North Fork Spring	-105.87360	45.29960	06S	48E	20	BDCA	Powder River
205011	Joe Anderson Spring	-105.95470	45.27150	06S	47E	34	CABA	Powder River
205041	School House Spring	-106.00810	45.19440	07S	47E	32	BABA	Powder River
205049	Chipmunk Spring	-106.36110	45.21200	07S	44E	21	CCBB	Rosebud
228591	Three Mile Spring	-106.79584	45.16904	07S	40E	35	BDAC	Big Horn
228776	Upper Anderson Spring	-106.62610	45.11550	08S	42E	30	ADAA	Big Horn
240578	Lower Anderson Spring	-106.69128	45.13732	08S	41E	15	ABBB	Big Horn

GWIC ID	Spring source lithology	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Average spring yield (gpm)	Most recent yield date	2015 planned flow monitoring	2015 planned QW sample collection
197247		Anderson	Regional	3690	0.0	11/19/2013	Quarterly	One time
197452	Coal	Otter	Local	3470	1.3	10/1/2014	Discontinued	
197607	Colluvium	Cook	Local	3805	0.8	10/2/2014	Discontinued	
198766		Ferry	Local	3660	1.6	9/30/2014	Discontinued	
199568	Sandstone	Cook	Local	3680	2.4	10/1/2014	Discontinued	
199572	Sandstone	Canyon	Local	3940	1.1	9/30/2014	Discontinued	
205004	Clinker	Anderson/Dietz	Local	3890	0.5	10/7/2014	Discontinued	
205010		Canyon	Local	3960	0.9	9/30/2014	Discontinued	
205011		Anderson	Local	4050	15.0	9/30/2014	Discontinued	
205041	Sandstone	Canyon	Local	3735	1.5	9/30/2014	Discontinued	
205049	Sandstone	Dietz	Local	3670	1.1	10/1/2014	Discontinued	
228591		Dietz	Local	3620	10.9	9/30/2014	Quarterly	One time
228776				3920	0.2	9/25/2014	Quarterly	Semi-Annual
240578		Anderson	Regional & Local	3665	0.6	9/25/2014	Quarterly	Semi-Annual

Appendix C

Groundwater Quality Data Collected in 2013 and 2014

Appendix C. Groundwater quality data collected in 2013-2014

	Gwic Id	Site Name	Sampled in 2013/2014	Latitude	Longitude	Location (TRS)	County	Site Type	Aquifer	Depth (ft)	Comp Date
Sites currently outside areas of potential CBM influence	207066	Well RBC-2	Semi-annual	45.3327	-106.9844	06S 39E 8 CAAA	Big Horn	Well	110ALVM	16.9	7/9/2003
	251797	Well GC09-KC	Periodic	45.4376	-106.3919	05S 43E 2 BAB	Rosebud	Well	125KNCB		
	203697	Well CBM02-8KC	Periodic	45.3689	-106.5473	05S 42E 28 DDAC	Rosebud	Well	125KNCB	208	11/8/2002
	7781	WO-2		45.3947	-106.1494	05S 45E 23 BBAA	Powder River	WELL	125LKCB	112	11/6/1979
	199568	Hedum Spring		45.2823	-106.0710	06S 46E 26 CDBA	Powder River	Spring			
	203655	CBM02-1BC		45.3186	-106.9671	06S 39E 16 DBCA	Big Horn	Well	125BACB	255.5	10/8/2002
	276654	10Mile-KC1		45.4400	-106.0946	04S 46E 31 DAAC	Powder River	Well		71	9/25/2013
Sites within current areas of potential CBM influence	223952	WA-2	Semi-annual	45.4032	-106.4566	05S 43E 17 BCDD	Rosebud	Well	110ALVM	37.8	8/16/1978
	7905	Well HWC-86-7	Semi-annual	45.2958	-106.5033	16S 43E 19 DDBA	Rosebud	Well	110ALVM	71	
	8888	Well HWC-86-13	Semi-annual	45.0020	-106.4262	10S 43E 2 ABCA	Big Horn	Well	110ALVM	53	10/8/1986
	198489	Well HWC-86-15	Semi-annual	45.0025	-106.4235	10S 43E 2 AABC	Big Horn	Well	110ALVM	62.52	10/8/1986
	219136	Well SL-3Q	Semi-annual	45.0161	-106.5386	09S 42E 36 BBAD	Big Horn	Well	110ALVM	40	4/7/2005
	220857	Well SL-8-2Q	Semi-annual	45.0182	-105.9052	09S 47E 25 DCDB	Powder River	Well	110ALVM	13.8	8/26/2005
	122766	Well WR-59	Semi-annual	45.0050	-106.8526	09S 40E 32 ACAD	Big Horn	Well	110ALVM	34	8/31/1977
	228776	Upper Anderson Creek Spring	Semi-annual	45.1155	-106.6261	08S 42E 30 ADAA	Big Horn	Spring	125TGRV		
	240578	Lower Anderson Creek Spring	Semi-annual	45.1373	-106.6913	08S 41E 15 ABBB	Big Horn	Spring			
	228592	Musgrave Bill Alluvial	Semi-annual	45.1639	-106.7319	08S 41E 5 ACDB	Big Horn	Well	111ALVM	21.5	
	190904	Well HWC-11	Periodic	45.0444	-106.4696	09S 43E 21 BADA	Big Horn	Well	125ANCB	135	7/28/1975
	8107	HWC-01		45.1254	-106.4827	08S 43E 20 DDDD	Big Horn	Well	125CNCB	232	5/8/1974
	183563	Fulton Ranch River		45.0637	-105.8715	09S 48E 08 CABC	Powder River	Well	111ALVM	30	
	277326	SL-8KC		45.0164	-105.9037	09S 47E 25 DCDA	Powder River	Well		423	7/16/2013
	277327	SL-8BA		45.0164	-105.9037	09S 47E 25 DCDA	Powder River	Well		115	7/17/2013
	259683	SL-9BA		45.0068	-105.8175	09S 48E 34 DAA	Powder River	Well	125BACB	291	10/26/2010
	8782	Well HWC-15	Periodic	45.0412	-106.4468	09S 43E 22ACCA	Big Horn	Well	125ANCB	129	8/4/1976
Stream samples	7910	Otter Creek	One time	45.2922	-106.1472	06S 46E 30 BAAD	Powder River	Stream			
	223687	RBC-4	One time	45.3332	-106.9863	06S 39E 08	Big Horn	Stream			
	259296	Otter Creek at Bear Creek	One time	45.2252	-106.1680	07S 45E 13	Powder River	Stream			
	259300	Otter Creek at 15 Mile Road	One time	45.3914	-106.1440	05S 45E 23	Powder River	Stream			
	259302	Otter Creek at 10 Mile Road	One time	45.4302	-106.1443	05S 45E 02	Powder River	Stream			
	259304	Otter Creek	One time	45.5213	-106.1852	04S 45E 04	Powder River	Stream			
	259306	Otter Creek	One time	45.5879	-106.2550	03S 45E 11	Powder River	Stream			

Appendix C. Groundwater quality data collected in 2013-2014

	Gwic Id	Sample Date	TDS (mg/L)	SAR	Water Temp	Lab pH	Lab SC	Ca (mg/L)	Mg (mg/L	Na (mg/L)	K (mg/L	Fe (mg/L)	Mn (mg/L)	SiO_2 (mg/L)
Sites currently outside areas of potential CBM influence	207066	10/15/2013 14:51	564.8	0.8	11	7.99	916.99	64.78	66.12	39.2	9.93	<0.015 U	0.165	26.58
	251797	10/17/2013 16:52	3748.3	8.0	11.3	7.34	4720	207.34	195.56	665.93	15.23	1.516	0.114 J	12.87
	203697	12/17/2013 14:11	1025.3	79.1	14.5	8.28	1643.53	1.2	0.62	427.84	2.24	0.045 J	<0.005 U	7.44
	7781	10/16/2013 13:49	631.3	40.0	12.2	8.64	993.38	2.34	0.52	259.8	1.57	<0.015 U	0.004 J	6.85
	199568	11/20/2013 14:40	3456.9	2.4	6.3	7.33	4430	235.96	408.47	257.75	47.57	<0.150 U	<0.020 U	24.57
	203655	10/15/2013 14:27	752.2	51.4	15	8.53	1168.65	1.74	0.68	315.8	1.94	<0.038 U	0.010 J	7.33
	276654	10/16/2013 16:26	3163.9	6.4			4020	159.98	206.61	517.06	14.4	0.421 J	0.262 J	21.37
Sites within current areas of potential CBM influence	223952	12/17/2013 16:20	1822.1	21.6	10.7	7.49	2999.19	25.22	27.46	658.41	6.35	0.081 J	<0.010 U	9.72
	7905	6/18/2014 14:24	3721.7	7.9	9.6	7.43	4494.67	171.57	228.15	675.47	22.94	0.82	0.879	20.77
		10/16/2013 18:13	3825.1	8.6	10.8	7.34	4840	168.18	230.64	730.86	24.42	0.507 J	1.022	21.32
	8888	6/18/2014 17:40	6257.4	10.1	10.2	7.06	6742.95	376.05	336.06	1114.62	13.06	6.976	1.918	12.28
		10/16/2013 11:28	8361.4	10.6	10.46	7.13	8700	485.84	483.16	1374.63	14.95	8.332	2.086	13.8
	198489	6/18/2014 18:05	8107.4	10.0	10.4	7.02	8196.61	513.59	498.29	1322.64	14.02	9.24	2.108	13.88
		10/16/2013 11:42	6532.9	10.8	10.5	7.05	7290	359.46	325.35	1174.77	13.47	6.569	1.978	13.5
	219136	11/19/2013 16:58	3985.3	5.4	8.3	7.18	4810	331.74	253.76	535.45	5.82	1.83	0.536	9.98
	220857	7/9/2014 18:35	3679.5	5.0	10.9	7.16	4108.28	470.63	139.58	478.73	5.77	0.171 J	0.367 J	19.09
		10/22/2013 18:00	2556.2	4.6	13.7	7.41	3469.53	329.33	94.83	371.75	7.88	<0.075 U	0.88	18.08
	122766	6/19/2014 10:40	6602.5	6.2	9.6	7.35	6227.23	275.76	645.85	829.08	37.31	4.852	0.822	18.92
		10/17/2013 10:06	5906.6	5.9	12.2	7.19	6520	255.08	550.35	726.57	32.39	6.563	0.882	22.21
	228776	5/1/2014 15:10	3846.0	6.3	7.9	7.04	4760	165.02	310.64	600.21	7.59	<0.150 U	0.085 J	8.23
		11/19/2013 14:54	3941.1	9.4	8.4	7.31	5230	152.41	247.45	810.07	9.9	1.245	0.068 J	9.64
	240578	5/1/2014 15:43	1525.6	3.1			2260	104.91	131.73	203.21	8.31	<0.038 U	<0.005 U	16.16
		11/19/2013 14:21	1555.6	3.3	10.7	7.12	2364.14	109.99	137.11	217.41	8.92	<0.038 U	<0.005 U	16.08
	228592	6/19/2014 14:02	1724.4	2.3	10.1	7.25	2124.25	188.73	137.54	167.48	5.75	0.052 J	0.040 J	18.47
		10/17/2013 11:22	750.9	1.2	12.4	3.35	1191.73	98.13	62.97	62.17	4.52	0.056 J	0.088 J	19.72
	190904	10/17/2012	1810.2	49.0	11.70	8.07	2494.20	8.90	5.30	748.00	5.59	<0.075 U	<0.010 U	9.27
	8107	10/15/2013 19:29	1564.8	67.7	13.2	8.09	2376.21	3.73	2.04	655.33	4.71	<0.038 U	<0.005 U	8.42
	183563	7/9/2014 17:15	1411.4	2.6	10.9	7.58	1817.46	156.08	92.5	166.07	19.22	0.131 J	0.518	16.82
	277326	10/21/2013 18:06	804.6	37.4			1318.42	3.61	1.31	325.57	2.47	<0.038 U	<0.005 U	7.25
	277327	10/22/2013 18:11	1280.4	39.6			1986.37	7.45	4.08	542.49	3.58	0.048 J	0.022 J	6.86
	259683	10/23/2013 16:48	727.8	32.0	13.7	8.77	1124.23	4.02	1.78	305.59	3.34	<0.038 U	<0.005 U	5.6
	8782	10/17/2012	1371.7	49.7	11.50	7.92	1810.40	4.96	3.42	586.55	4.30	0.046 J	<0.005 U	8.52
Stream samples	7910	11/6/2013 14:15	2632.6	5.0	3.1	8.36	3495.53	137.77	221.01	404.43	18.21	<0.075 U	0.093 J	12.37
	223687	12/18/2013 10:24	597.0	0.5	1.3	8.01	999.56	78.03	72.04	26.91	7.43	<0.015 U	0.024 J	18.46
	259296	11/6/2013 13:00	3121.8	5.7	3.9	7.89	3970	185.23	215.9	484.39	17.79	<0.150 U	0.056 J	20.17
	259300	11/6/2013 14:55	2799.9	5.0	3.8	8.47	3701.66	124.48	234.88	409.79	18.38	<0.075 U	0.166 J	9.65
	259302	11/6/2013 15:40	2771.7	4.9	3.3	8.63	3746.77	123.75	234.28	401.19	18.71	<0.075 U	0.041 J	6.41
	259304	11/6/2013 16:45	2757.6	5.4	2.7	8.58	3730	110.82	240.25	438.71	18.83	<0.150 U	<0.020 U	2.13
	259306	11/6/2013 17:29	2092.8	5.3	4.2	8.86	3342.43	89.21	183.26	384.07	17.97	<0.075 U	0.029 J	7.19

Appendix C. Groundwater quality data collected in 2013-2014

	Gwic Id	HCO$_3$ (mg/L)	CO$_3$ (mg/L)	SO$_4$ (mg/L)	Cl (mg/L)	NO$_3$-N (mg/L)	F (mg/L)	OPO$_4$-P (mg/L)	Ag (µg/L)	Al (µg/L)	As (µg/L)	B (µg/L)	Ba (µg/L)	Be (µg/L)
Sites currently outside areas of potential CBM influence	207066	551.87	0	80.89	3.78	0.06	0.62	0.040 J	<0.100 U	<2.000 U	1.76	110.43	79.28	<0.100 U
	251797	752.42	0	2264	14.34	<0.050 U	0.89	<0.100 U	<1.000 U	<20.000 U	<1.000 U	385.28	14.94	<1.000 U
	203697	1148.48	0	1.780 J	10.1	<0.010 U	10.88	0.12	<0.250 U	<5.000 U	<0.250 U	269.63	123.7	<0.250 U
	7781	679.19	4.89	1.500 J	17.49	<0.010 U	2.58	0.11	<0.100 U	<2.000 U	<0.100 U	104.81	93.16	<0.100 U
	199568	815.18	0	2061	7.97	9.53	1.13	<0.100 U	<1.000 U	<20.000 U	12.99	491.62	20.49	<1.000 U
	203655	847.53	0	1.320 J	3.49	<0.010 U	4.29	0.12	<0.250 U	<5.000 U	<0.250 U	33.71	120.88	<0.250 U
	276654	628.11	0	1923	12.14	<0.050 U	0.72	<0.100 U	<1.000 U	<20.000 U	<1.000 U	621.81	16.81	<1.000 U
Sites within current areas of potential CBM influence	223952	1640.55	0	210.3	74.38	<0.010 U	3.33	0.070 J	<0.500 U	<10.000 U	<0.500 U	213.55	24.93	<0.500 U
	7905	951.77	0	2106	24.72	<0.050 U	1.24	<0.100 U	<1.000 U	<20.000 U	<1.000 U	375.15	24.98	<1.000 U
		916.46	0	2171	25.86	<0.050 U	1.22	<0.100 U	<1.000 U	<20.000 U	<1.000 U	358.14	21.99	<1.000 U
	8888	911.57	0	3934	11.84	<0.050 U	0.57	<0.100 U	<1.000 U	<20.000 U	<1.000 U	225.14	7.46	<1.000 U
		894.16	0	5520	16.91	<0.050 U	0.68	0.210 J	<1.000 U	<20.000 U	2.990 J	233.19	7.1	<1.000 U
	198489	938.81	0	5252	18.01	<0.050 U	0.5	<0.100 U	<1.000 U	<20.000 U	<1.000 U	245.59	6.44	<1.000 U
		869.03	0	4196	11.66	<0.050 U	0.72	<0.100 U	<1.000 U	<20.000 U	2.260 J	209.16	6.54	<1.000 U
	219136	496.99	0	2589	11	<0.050 U	0.57	<0.100 U	<1.000 U	<20.000 U	<1.000 U	38.4	7.33	<1.000 U
	220857	563.44	0	2022	265.6	<0.050 U	0.37	<0.100 U	<1.000 U	<20.000 U	<1.000 U	114.97	16.62	<1.000 U
		539.52	0	1294	171.8	<0.050 U	0.66	<0.100 U	<0.500 U	<10.000 U	2.26	146.86	20.75	<0.500 U
	122766	753.17	0	4394	24.16	0.230 J	0.67	<0.100 U	<1.000 U	<20.000 U	<1.000 U	284.23	13.85	<1.000 U
		723.37	0	3933	22.02	<0.050 U	0.81	<0.100 U	<1.000 U	<20.000 U	3.310 J	280.42	12.02	<1.000 U
	228776	765.68	0	2353	23.32	0.26	0.59	<0.100 U	<1.000 U	<20.000 U	<1.000 U	140.34	8.98	<1.000 U
		981.12	0	2207	19.49	<0.050 U	0.71	<0.100 U	<1.000 U	<20.000 U	<1.000 U	45.16	6.28	<1.000 U
	240578	676.11	0	715.9	11.52	0.010 J	0.85	<0.020 U	<0.250 U	<5.000 U	<0.250 U	242.4	16.68	<0.250 U
		672.87	0	723.5	10.43	<0.010 U	0.65	<0.020 U	<0.250 U	<5.000 U	<0.250 U	167.17	17.05	<0.250 U
	228592	527.83	0	899.9	47.1	<0.010 U	0.34	<0.020 U	<0.250 U	30.58	<0.250 U	72.96	72.06	<0.250 U
		436.34	0	270.9	17.13	<0.010 U	0.35	<0.020 U	<0.250 U	<5.000 U	<0.250 U	80.08	37.03	<0.250 U
	190904	1764.20	0.00	144.00	18.46	<0.010 U	1.82	0.12	<0.500 U	3.040 J	<0.500 U	79.97	525.44	<0.500 U
	8107	1754.36	0	1.420 J	22.76	<0.010 U	3.65	0.26	<0.250 U	<5.000 U	<0.250 U	85.88	373.06	<0.250 U
	183563	503.38	0	697.5	12.51	0.51	0.3	<0.020 U	<0.250 U	<5.000 U	<0.250 U	168.71	38.77	<0.250 U
	277326	852	9.21	2.120 J	35.43	<0.010 U	1.47	0.060 J	<0.250 U	<5.000 U	<0.250 U	133.5	190.09	<0.250 U
	277327	1376.39	0	7.54	27.98	<0.010 U	1.83	0.050 J	<0.250 U	<5.000 U	<0.250 U	145.06	318.57	<0.250 U
	259683	751.12	17.18	8.84	10.1	<0.010 U	1.05	0.040 J	<0.250 U	<5.000 U	<0.250 U	85.92	60.97	<0.250 U
	8782	1510.69	0.00	0.850 J	17.13	<0.010 U	1.76	0.12	<0.250 U	<1.000 U	<0.250 U	77.13	326.83	<0.250 U
Stream samples	7910	632.51	4.08	1506	17.09	<0.050 U	0.74	<0.100 U	<0.500 U	<10.000 U	<0.500 U	298.91	19.95	<0.500 U
	223687	483.32	0	153.4	4.3	0.19	0.47	<0.020 U	<0.100 U	<2.000 U	0.6	59.92	87.67	<0.100 U
	259296	659.31	0	1852	20.42	1.35	0.71	<0.100 U	<1.000 U	<20.000 U	<1.000 U	298.39	15.2	<1.000 U
	259300	676.62	13.33	1637	18.06	0.3	0.78	<0.100 U	<0.500 U	<10.000 U	1.220 J	306.07	15.36	<0.500 U
	259302	650.61	20.51	1627	18.43	<0.050 U	0.77	<0.100 U	<0.500 U	<10.000 U	1.110 J	305.26	15.38	<0.500 U
	259304	677.05	8.43	1586	18.48	<0.050 U	0.74	<0.100 U	<1.000 U	<20.000 U	<1.000 U	335.26	12.04	<1.000 U
	259306	634.35	28.05	1066	3.14	0.62	1.12	<0.100 U	<0.500 U	<10.000 U	1.040 J	414.25	20.4	<0.500 U

Appendix C. Groundwater quality data collected in 2013-2014

	Gwic Id	Br (µg/L)	Cd (µg/L)	Co (µg/L)	Cr (µg/L)	Cu (µg/L)	Li (µg/L)	Mo (µg/L)	Ni (µg/L)	Pb (µg/L)	Sb (µg/L)	Se (µg/L)	Sn (µg/L)	Sr (µg/L)	Ti (µg/L)
Sites currently outside areas of potential CBM influence	207066	59	<0.100 U	<0.100 U	<0.100 U	<0.040 U	41.45	2.67	1.13	<0.060 U	<0.100 U	<0.100 U	<0.100 U	1095.23	0.6
	251797	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<0.400 U	168.64	<1.000 U	5.56	<0.600 U	<1.000 U	<1.000 U	<1.000 U	8015.36	20.46
	203697	98	<0.250 U	<0.250 U	<0.250 U	<1.250 U	27.22	1.010 J	0.630 J	<0.150 U	<0.250 U	<0.250 U	<0.250 U	151.84	<0.250 U
	7781	134	<0.100 U	<0.100 U	<0.100 U	<0.040 U	20.6	0.69	<0.100 U	<0.060 U	<0.100 U	0.340 J	<0.100 U	115.83	<0.100 U
	199568	<50.000 U	<1.000 U	<1.000 U	4.560 J	<5.000 U	270.46	20.47	3.670 J	<0.600 U	<1.000 U	27.09	<1.000 U	3594.92	11.72
	203655	<10.000 U	<0.250 U	<0.250 U	1.44	<0.100 U	43.64	<0.250 U	<0.250 U	<0.150 U	<0.250 U	<0.250 U	1.100 J	139.09	<0.250 U
	276654	<50.000 U	<1.000 U	<1.000 U	<1.000 U	5.470 J	167.82	<1.000 U	3.430 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	4940.97	17.64
Sites within current areas of potential CBM influence	223952	341	<0.500 U	<0.500 U	<0.500 U	<2.500 U	67.12	<0.500 U	<0.500 U	1.62	<0.500 U	<0.500 U	<0.500 U	1634.37	1.120 J
	7905	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	133.53	10.44	<1.000 U	<0.600 U	<1.000 U	<1.000 U		2943.33	27.49
		<50.000 U	<1.000 U	<1.000 U	<1.000 U	<0.400 U	137.93	6.82	5.28	<0.600 U	<1.000 U	<1.000 U	<1.000 U	2856.52	21.25
	8888	<50.000 U	<1.000 U	2.660 J	<1.000 U	<5.000 U	198.03	2.440 J	4.380 J	<0.600 U	<1.000 U	2.200 J		5941.51	49.21
		<50.000 U	<1.000 U	2.830 J	<1.000 U	<0.400 U	223.16	<1.000 U	12.39	<0.600 U	<1.000 U	<1.000 U	<1.000 U	7738.88	48.51
	198489	<50.000 U	<1.000 U	3.000 J	<1.000 U	<5.000 U	236.79	3.170 J	5.53	<0.600 U	<1.000 U	3.030 J		7982.07	66.93
		<50.000 U	<1.000 U	2.360 J	<1.000 U	<0.400 U	172.48	<1.000 U	8.92	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5606.02	35.05
	219136	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	66.500 J	<1.000 U	4.820 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5482.44	13.39
	220857	248.000 J	<1.000 U	<1.000 U	<1.000 U	<5.000 U	42.300 J	<1.000 U	<1.000 U	<0.600 U	<1.000 U	2.080 J		3036.43	33.51
		<50.000 U	<0.500 U	<0.500 U	<0.500 U	<0.200 U	31.750 J	4.18	4.91	<0.300 U	<0.500 U	<0.500 U	<0.500 U	2117.69	11.39
	122766	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	274.95	4.350 J	<1.000 U	<0.600 U	<1.000 U	2.810 J		5941.51	49.17
		<50.000 U	<1.000 U	<1.000 U	<1.000 U	<0.400 U	262.35	3.420 J	5.85	<0.600 U	<1.000 U	<1.000 U	<1.000 U	5505.22	34.43
	228776	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	279.05	<1.000 U	<1.000 U	<0.600 U	<1.000 U	7.5	<1.000 U	4434.23	18.63
		<50.000 U	<1.000 U	<1.000 U	<1.000 U	<5.000 U	190.31	<1.000 U	2.160 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	4943.19	11.89
	240578	108	<0.250 U	<0.250 U	<0.250 U	<1.250 U	194.17	<0.250 U	1.32	<0.150 U	<0.250 U	<0.250 U	<0.250 U	2643.75	6.12
		90	<0.250 U	<0.250 U	<0.250 U	<1.250 U	117.41	<0.250 U	1.79	<0.150 U	<0.250 U	<0.250 U	<0.250 U	2711.71	3.84
	228592	<10.000 U	<0.250 U	<0.250 U	<0.250 U	21.09	25.69	0.940 J	1.67	0.660 J	<0.250 U	1.160 J		1145.94	9.26
		<10.000 U	<0.250 U	<0.250 U	<0.250 U	8.97	21.000 J	1.010 J	2.2	<0.150 U	<0.250 U	<0.250 U	<0.250 U	569.28	2.58
	190904	161.00	<0.500 U	<0.500 U	<0.500 U	8.87	123.40	<0.500 U	<0.500 U	<0.200 U	<0.500 U	<0.500 U	<0.500 U	440.30	1.490 J
	8107	195	<0.250 U	<0.250 U	<0.250 U	<0.100 U	124.44	<0.250 U	<0.250 U	<0.150 U	<0.250 U	0.620 J	<0.250 U	319.23	<0.250 U
	183563	47.000 J	<0.250 U	0.700 J	<0.250 U	<1.250 U	72.15	2.92	1.42	<0.150 U	<0.250 U	1.44		1713.7	11.54
	277326	189	<0.250 U	<0.250 U	1.160 J	<0.100 U	30.5	1.110 J	1.85	<0.150 U	<0.250 U	0.730 J	<0.250 U	141.49	<0.250 U
	277327	158	<0.250 U	<0.250 U	<0.250 U	<0.100 U	50.12	<0.250 U	<0.250 U	<0.150 U	<0.250 U	<0.250 U	<0.250 U	233.83	<0.250 U
	259683	99	<0.250 U	<0.250 U	0.910 J	1.310 J	37.49	2.3	0.730 J	0.540 J	<0.250 U	<0.250 U	2.82	105.85	<0.250 U
	8782	169.00	<0.250 U	<0.250 U	<0.250 U	8.01	81.96	<0.250 U	<0.250 U	<0.100 U	<0.250 U	0.610 J	<0.250 U	267.51	<0.250 U
Stream samples	7910	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<0.200 U	125.25	3	2.380 J	<0.300 U	<0.500 U	<0.500 U	<0.500 U	1846.81	14.15
	223687	<10.000 U	<0.100 U	<0.100 U	<0.100 U	2.29	28.15	1.71	1.29	<0.060 U	<0.100 U	0.5	<0.100 U	1014.19	0.72
	259296	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<0.400 U	113	2.890 J	3.280 J	<0.600 U	<1.000 U	2.970 J	<1.000 U	2320.04	14.44
	259300	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<0.200 U	124.77	3.68	3.42	<0.300 U	<0.500 U	<0.500 U	<0.500 U	1988.78	14.93
	259302	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<0.200 U	119.72	3.97	3.71	<0.300 U	<0.500 U	<0.500 U	<0.500 U	1911.48	14.44
	259304	<50.000 U	<1.000 U	<1.000 U	<1.000 U	<0.400 U	106.11	3.710 J	3.670 J	<0.600 U	<1.000 U	<1.000 U	<1.000 U	1842.79	14.13
	259306	<50.000 U	<0.500 U	<0.500 U	<0.500 U	<0.200 U	109.55	4.19	3.16	<0.300 U	<0.500 U	1.240 J	<0.500 U	1791.98	12.38

	Gwic Id	Tl (µg/L)	U (µg/L)	V (µg/L)	Zn (µg/L)	Zr (µg/L)	Ce (µg/L)	Cs (µg/L)	Ga (µg/L)	La (µg/L)	Nb (µg/L)	Nd (µg/L)	Pd (µg/L)	Pr (µg/L)	Rb (µg/L)
Sites currently outside areas of potential CBM influence	207066	<0.100 U	1.08	1.97	0.550 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.470 J	<0.100 U	16.38
	251797	<1.000 U	<1.000 U	<1.000 U	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	3.010 J	<1.000 U	13.32
	203697	<0.250 U	<0.250 U	<0.250 U	1.870 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	2.34
	7781	<0.100 U	<0.100 U	<0.100 U	0.740 J	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	1.68
	199568	<1.000 U	25.43	68.82	<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	47.52
	203655	<0.250 U	<0.250 U	<0.250 U	1.140 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	2.33
	276654	<1.000 U	<1.000 U	<1.000 U	15.000 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.060 J	<1.000 U	11.34
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.500 U	<0.500 U	5.170 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	7.2
	7905	<1.000 U		<1.000 U	9.150 J										
		<1.000 U	13.73	<1.000 U	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	15.54
	8888	<1.000 U		<1.000 U	6.230 J										
		<1.000 U	39.19	<1.000 U	<0.500 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	3.740 J	<1.000 U	6.74
	198489	<1.000 U		<1.000 U	<5.000 U										
		<1.000 U	18.78	<1.000 U	4.420 J	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	<1.000 U	2.130 J	<1.000 U	6.57
	219136	<1.000 U	3.020 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	2.640 J	<1.000 U	2.840 J
	220857	<1.000 U		<1.000 U	<5.000 U										
		<0.500 U	25.02	<0.500 U	2.600 J	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	1.490 J	<0.500 U	3.53
	122766	<1.000 U		<1.000 U	<5.000 U										
		<1.000 U	26.69	<1.000 U	4.570 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	32.95
	228776	<1.000 U	9.88	<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	5.52
		<1.000 U	<1.000 U	<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	3.030 J	<1.000 U	9.29
	240578	<0.250 U	<0.250 U	0.890 J	4.240 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	0.840 J	<0.250 U	6.7
		<0.250 U	<0.250 U	0.600 J	3.360 J	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	1.3	<0.250 U	6.82
	228592	<0.250 U		<0.250 U	20.18										
		<0.250 U	6.26	<0.250 U	14.45	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	6.07
	190904	<0.500 U	<0.500 U	<0.500 U	<1.000 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	<0.500 U	4.59
	8107	<0.250 U	<0.250 U	<0.250 U	<0.130 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	5.42
	183563	<0.250 U		<0.250 U	80.85										
	277326	<0.250 U	<0.250 U	0.860 J	1.020 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	3.55
	277327	<0.250 U	<0.250 U	<0.250 U	7.98	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	3.75
	259683	<0.250 U	<0.250 U	<0.250 U	4.360 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	5.86
	8782	<0.250 U	<0.250 U	<0.250 U	8.73	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	<0.250 U	3.62
Stream samples	7910	<0.500 U	10.15	1.050 J	<0.250 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	9.66
	223687	<0.100 U	2.67	0.350 J	3.14	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	<0.100 U	0.490 J	<0.100 U	6.33
	259296	<1.000 U	11.91	<1.000 U	5.830 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	11.64
	259300	<0.500 U	9.34	<0.500 U	<0.250 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	8.76
	259302	<0.500 U	9.23	1.180 J	<0.250 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	8.38
	259304	<1.000 U	8.23	<1.000 U	48.16	<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	8.11
	259306	<0.500 U	6.52	1.640 J	<0.250 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	9.52

Appendix C. Groundwater quality data collected in 2013-2014

	Gwic Id	Th (µg/L)	W (µg/L)	NO$_2$-N (mg/l)	NO^{3+}NO$_2^{-}$N (mg/L)	Total N as N (mg/L)	Dissolved Inorganic Carbon (mg/L)	Sum Dissolved Constituents (mg/L)	Hardness (mg/L)	Alkalinity	Procedure
Sites currently outside areas of potential CBM influence	207066	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	52.1	844.90	433.91	452.73	DISSOLVED
	251797	<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.94	41	4129.90	1322.65	616.77	DISSOLVED
	203697	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	74.21	1607.82	5.55	941.56	DISSOLVED
	7781	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	58.9	975.86	7.98	565.24	DISSOLVED
	199568	<1.000 U	<1.000 U	<0.050 U	10.1	10.1	77.7	3870.43	2270.45	668.44	DISSOLVED
	203655	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	9.3	1182.42	7.14	695.51	DISSOLVED
	276654	<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U	69.1	3482.59	1249.88	515.07	DISSOLVED
Sites within current areas of potential CBM influence	223952	<0.500 U	<0.500 U	<0.010 U	<0.200 U	1.81	129.36	2654.68	176.00	1345.90	DISSOLVED
	7905			<0.050 U	<0.200 U	<1.000 U		4204.72	1367.48	780.80	DISSOLVED
		<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U		4289.82	1369.26	751.28	DISSOLVED
	8888			<0.050 U				6720.11	2322.22	748.00	DISSOLVED
		<1.000 U	<1.000 U	<0.050 U	<0.200 U	1.83	11	8815.00	3201.83	733.23	DISSOLVED
	198489			<0.050 U	3.72	5.79		8583.88	3333.40	770.14	DISSOLVED
		<1.000 U	<1.000 U	<0.050 U	<0.200 U	2.47		6973.81	2236.71	712.73	DISSOLVED
	219136	<1.000 U	<1.000 U	<0.050 U	<0.200 U	1.25	40.8	4237.50	1872.83	407.63	DISSOLVED
	220857			<0.050 U	<0.200 U	<1.000 U		3965.21	1749.67	461.76	DISSOLVED
		<0.500 U	<0.500 U	<0.050 U	<0.200 U	<1.000 U		2830.16	1212.66	442.89	DISSOLVED
	122766			<0.050 U	<0.200 U	<1.000 U		6984.61	3346.89	617.59	DISSOLVED
		<1.000 U	<1.000 U	<0.050 U	<0.200 U	<1.000 U		6273.43	2902.18	592.98	DISSOLVED
	228776	<1.000 U	<1.000 U	<0.050 U	0.47	2.89		4234.66	1690.65	628.25	DISSOLVED
		<1.000 U	<1.000 U	<0.050 U	<0.200 U	5.78	51.4	4438.86	1399.07	804.59	DISSOLVED
	240578	<0.250 U	<0.250 U	<0.010 U	0.24	<1.000 U		1868.64	804.16	554.44	DISSOLVED
		<0.250 U	<0.250 U	<0.010 U	1.05	1.05	38.3	1897.10	838.99	551.98	DISSOLVED
	228592			<0.010 U	<0.200 U	<1.000 U		1992.34	1037.37	433.05	DISSOLVED
		<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	24.2	972.12	504.22	357.59	DISSOLVED
	190904	<0.500 U	<0.500 U	<0.010 U	0.27	4.15	374.00	2705.21	44.04	1446.78	DISSOLVED
	8107	<0.250 U	<0.250 U	<0.010 U	<0.200 U	2.1	108	2454.77	17.71	1438.58	DISSOLVED
	183563			<0.010 U	0.54	<1.000 U		1666.66	770.46	412.55	DISSOLVED
	277326	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	79	1236.92	14.41	713.80	DISSOLVED
	277327	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	138	1978.54	35.40	1128.56	DISSOLVED
	259683	<0.250 U	<0.250 U	<0.010 U	<0.200 U	<1.000 U	30.5	1108.80	17.36	644.30	DISSOLVED
	8782	<0.250 U	<0.250 U	<0.010 U	0.27	1.76	319.00	2138.40	26.46	1239.28	DISSOLVED
Stream samples	7910	<0.500 U	<0.500 U	<0.050 U	3.91	4.78	37.2	2953.78	1253.69	525.84	DISSOLVED
	223687	<0.100 U	<0.100 U	<0.010 U	<0.200 U	<1.000 U	52.09	842.08	491.36	396.14	DISSOLVED
	259296	<1.000 U	<1.000 U	<0.050 U	5.18	5.68	70.7	3456.13	1351.16	540.49	DISSOLVED
	259300	<0.500 U	<0.500 U	<0.050 U	<0.200 U	<1.000 U	67.7	3143.36	1277.59	576.94	DISSOLVED
	259302	<0.500 U	<0.500 U	<0.050 U	<0.200 U	<1.000 U	56	3102.03	1273.30	568.96	DISSOLVED
	259304	<1.000 U	<1.000 U	<0.050 U	3.61	4.22	65.8	3101.12	1265.59	568.60	DISSOLVED
	259306	<0.500 U	<0.500 U	<0.050 U	<0.200 U	<1.000 U	68.4	2414.47	977.06	566.69	DISSOLVED

Appendix D

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

Appendix D

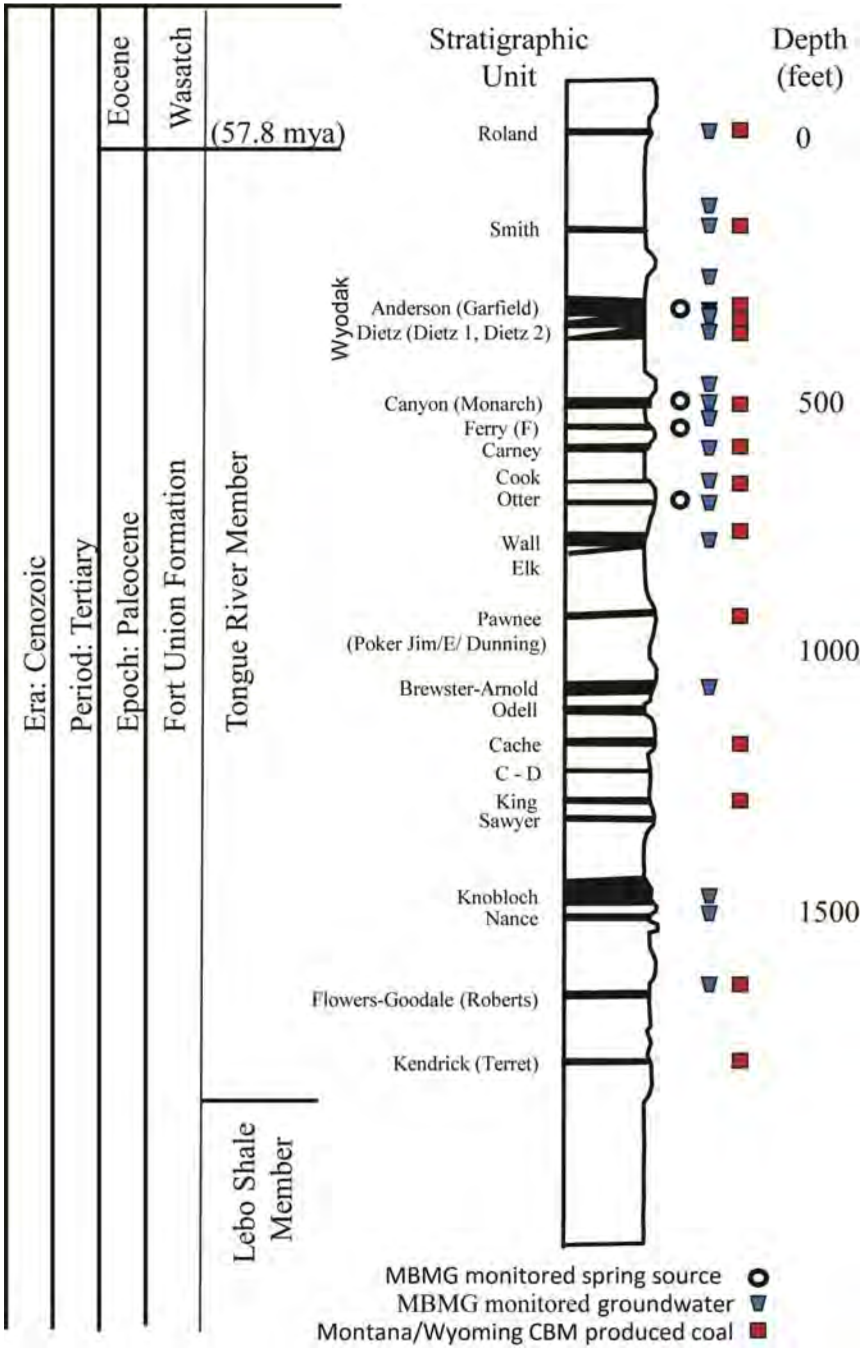
Geology and Hydrogeology of the Tongue River Member of the Fort Union Formation

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 Montana.

The coal-bearing Tongue River Member is bounded on the bottom by the Lebo Shale aquitard (fig. 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 ridgetops 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 coalbeds shown are present across the entire basin. Many coalbeds have been mapped within the Tongue River Member of the Fort Union Formation in southeastern Montana. The general relative positions of selected coalbeds are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Most coals do not exist across the entire area and the interburden thickness varies considerably. The indicated depths are only approximations. Sources: Culbertson, 1987; Fort Union Coal Assessment Team, 1999; Law and others, 1979; Matson and Blumer, 1973; McLellan, 1991; McLellan and Beiwick, 1988; McLellan and others, 1990; and various U.S. Geological Survey coal resource maps prepared by the Colorado School of Mines Research Institute (1979a,b,c,d,e,f,g).

Table D-1

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

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

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

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

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

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

BD indicates lowest readings were below detection

Water-quality samples are collected from monitoring wells as part of the regional groundwater monitoring program and have been collected during previous projects in southeastern Montana. Water-quality data are available in GWIC for 147 samples collected from monitoring wells completed in coal aquifers in southeastern Montana. In cases where more than one water-quality measurement was reported from an individual well, only the most recent sample was chosen for inclusion in the statistical analysis. Summary statistics for individual coals are presented in the adjoining table. The number of samples from individual coals ranged from 1 to 26 (parenthetical numbers next to the coal name). The variability of pH within coals is very low but between coals is significant, ranging from 7.44 (Rosebud) to 8.23 (Anderson–Dietz 1,2). However, within individual coalbeds TDS, SAR, sodium, bicarbonate, and sulfate concentrations varied greatly. In one half of the monitored coalbeds, the lowest sulfate measurements were below detection; however, overall high sulfate concentrations were found in Rosebud, Flowers–Goodale and Dietz 1 coals. The Rosebud coal is not a source of CBM. Low sulfate concentrations in coalbed water indicate reducing conditions and can be an important tool for CBM exploration (Van Voast, 2003).

Appendix E

Hydrographs from Wells outside of Current CBM Impacts

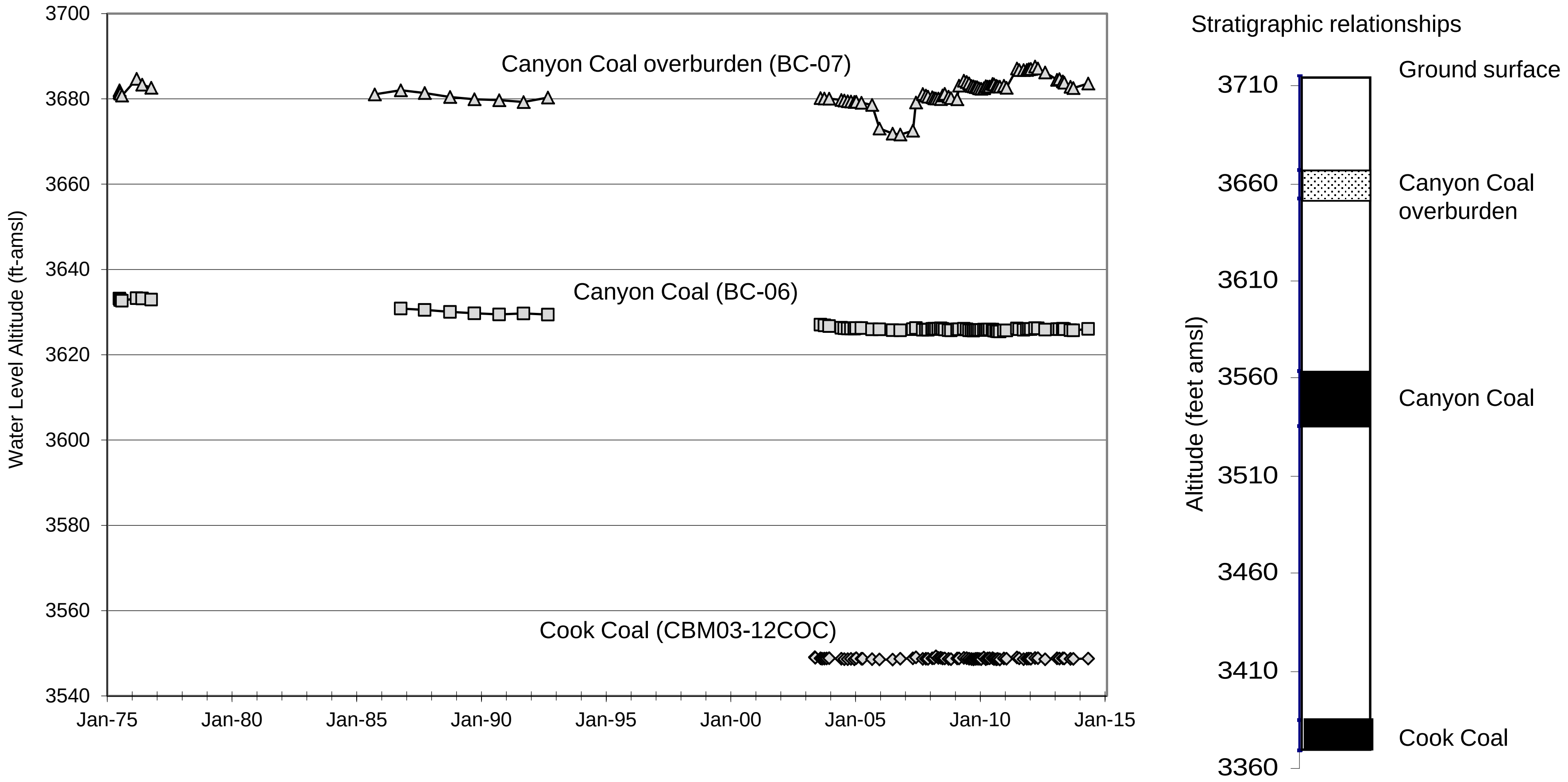


Figure E-1. Monitoring site CBM03-12 has been measured since 1974. There is a downward gradient at this site. The long-term decrease in water levels in the overburden sandstone (BC-07) and Canyon coal (BC-06) began long before the introduction of CBM and likely relate to long-term precipitation patterns (fig. 2). The 11 years of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence. Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

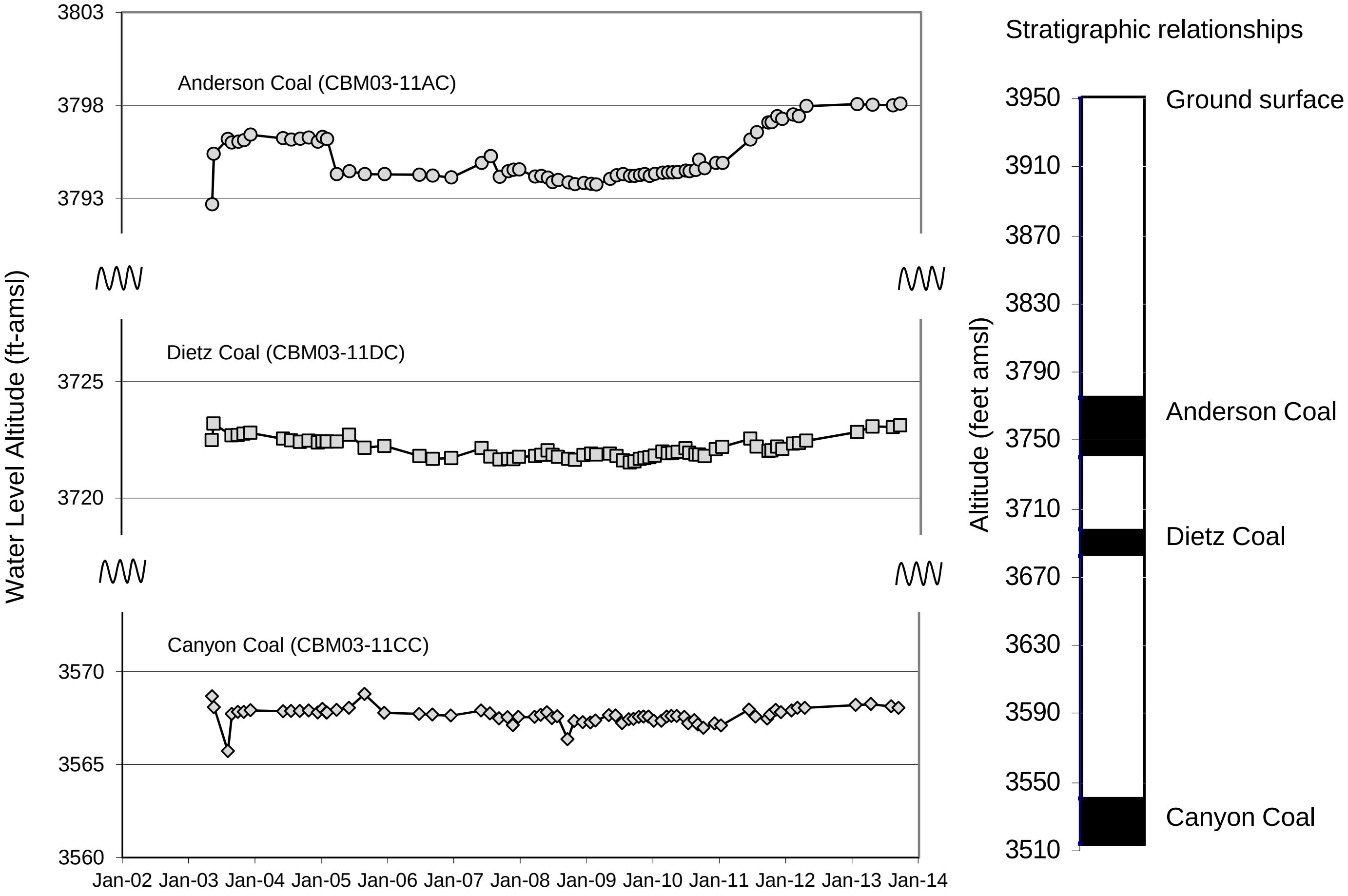


Figure E-2. A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.This site is near the Anderson coal outcrop. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.

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

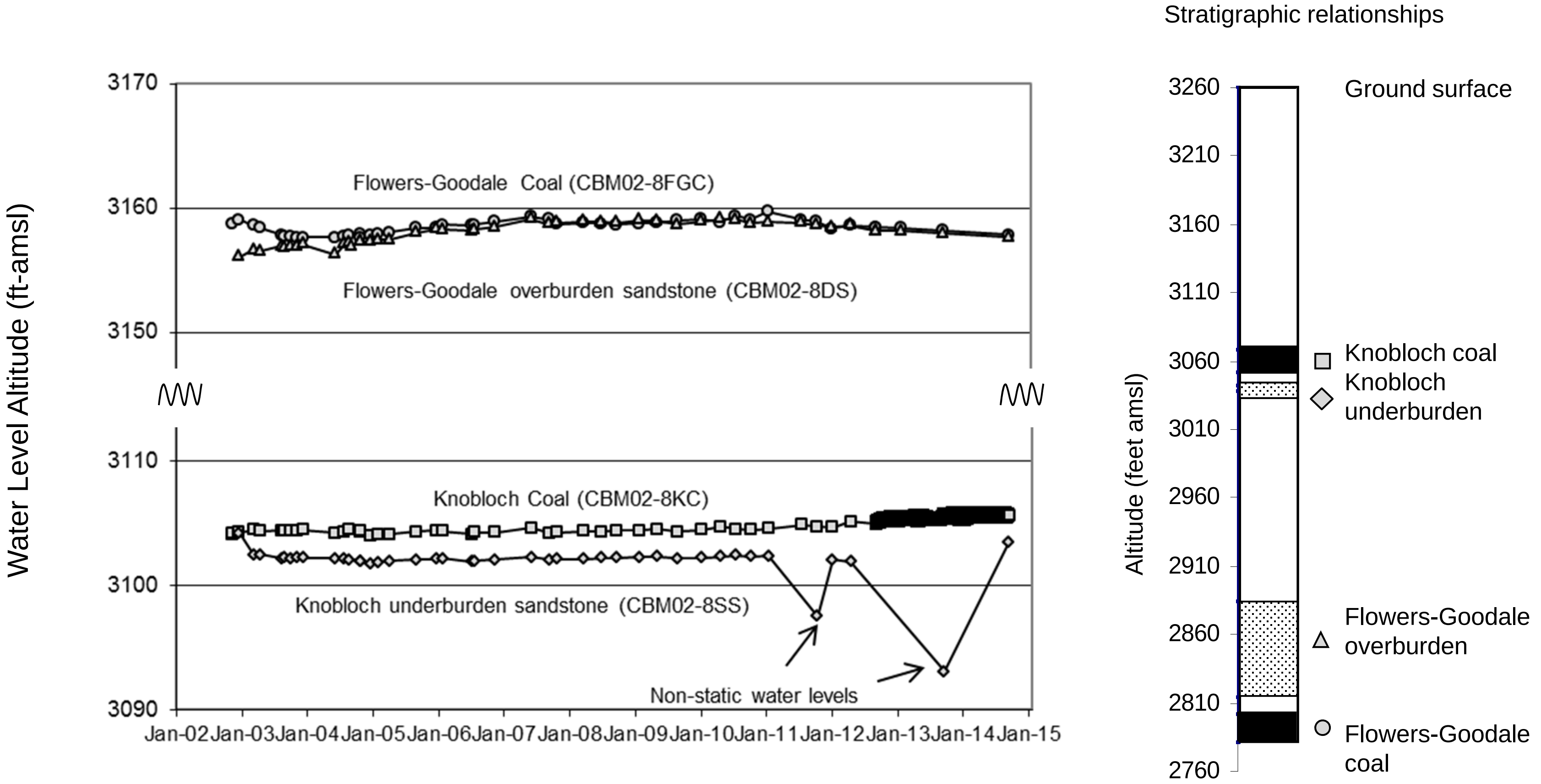


Figure E-3. Water levels in wells completed in the stratigraphically deeper Flowers–Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site. The hydrostatic pressure in the Knobloch coal has been reduced by natural discharge to nearby outcrops. This upward gradient suggests that this is a discharge area for the Flowers–Goodale coal. Flowing wells near Birney, including the town water supply well, also reflect this upward gradient. These deep wells flow at ground surface due to the high hydrostatic pressure at depth and the relatively low land surface near the Tongue River. Well CBM02-8DS is completed in the “D” channel sandstone overlying the Flowers–Goodale coal. This channel sand has been identified as a possible location for injecting CBM produced water (Lopez and Heath, 2007). Yield from this well, measured during drilling, is approximately 35 gpm. Note: The vertical scales of the stratigraphic relationship and the hydrograph are different.

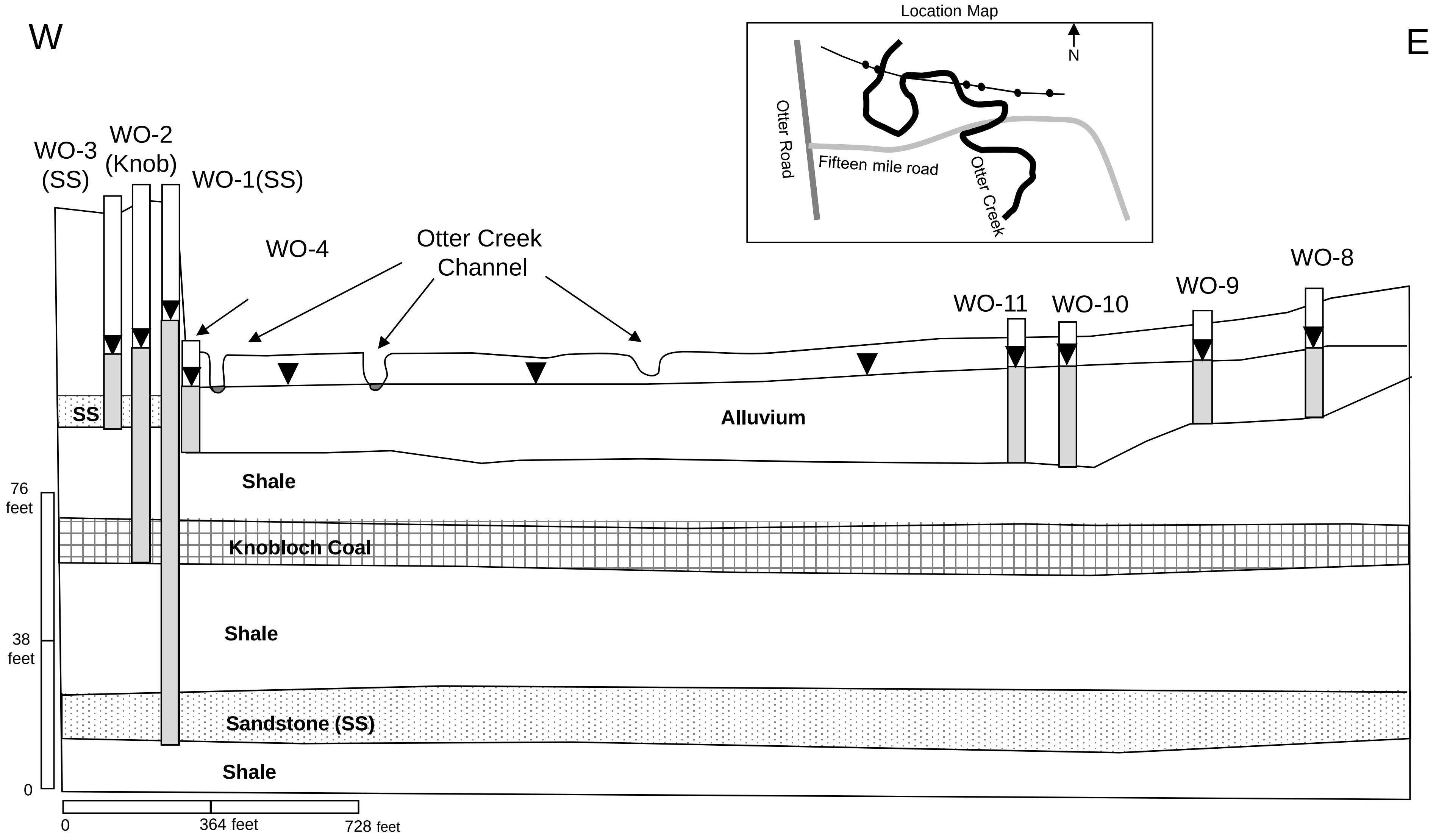


Figure E-4. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T. 05 S., R. 45 E., sec 23. Water levels in the alluvium are lower than in the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in August, 2014. Vertical exaggeration is 9.6:1. Hydrographs for these wells are presented in figures 4 and E-5.

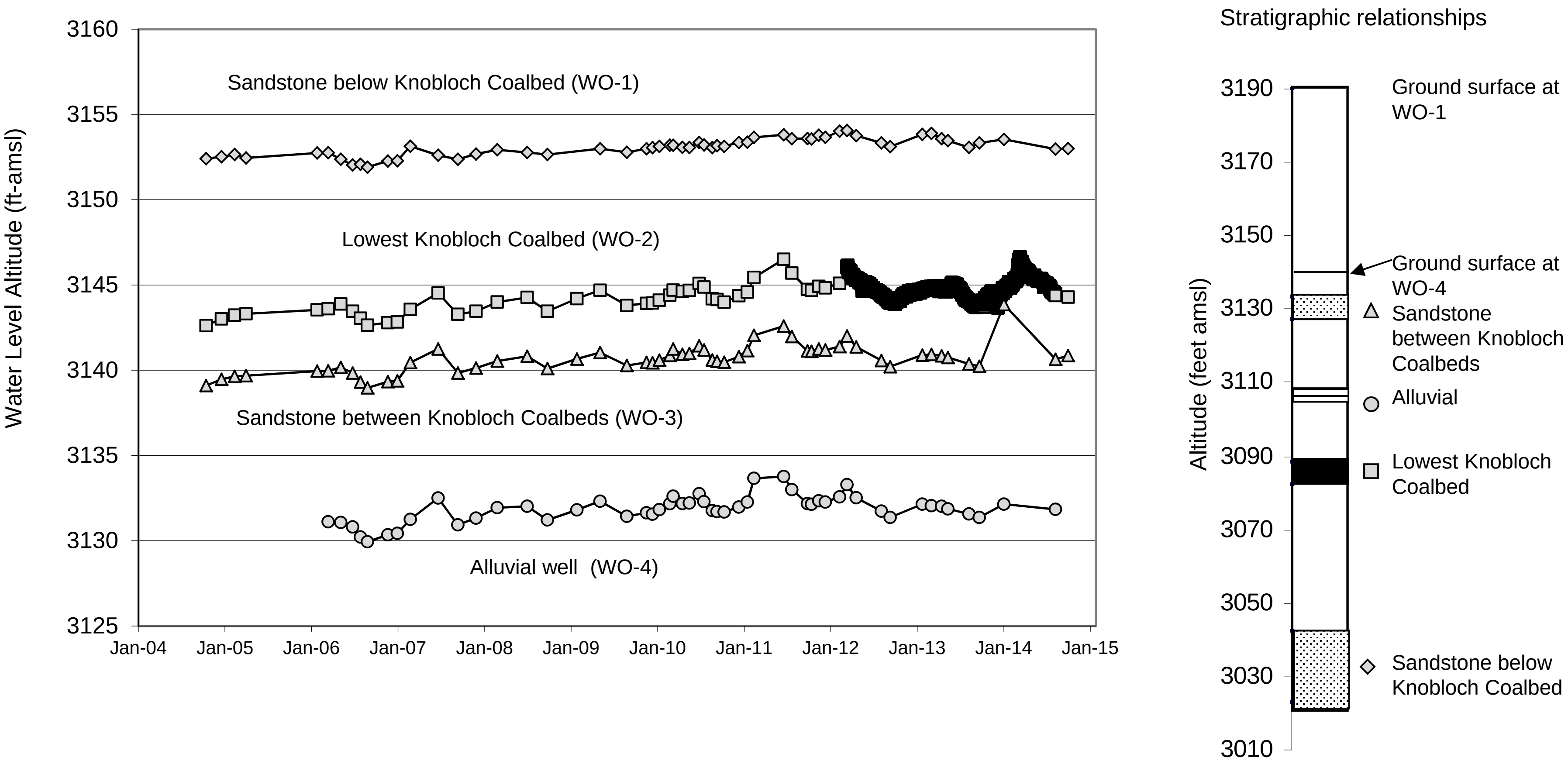


Figure E-5. At monitoring site WO, bedrock aquifers at the Otter Creek area have an upward vertical gradient; flowing wells are common in the area. This upward gradient indicates that the bedrock aquifer will discharge into the alluvium where the two units are in contact. The alluvial well appears to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

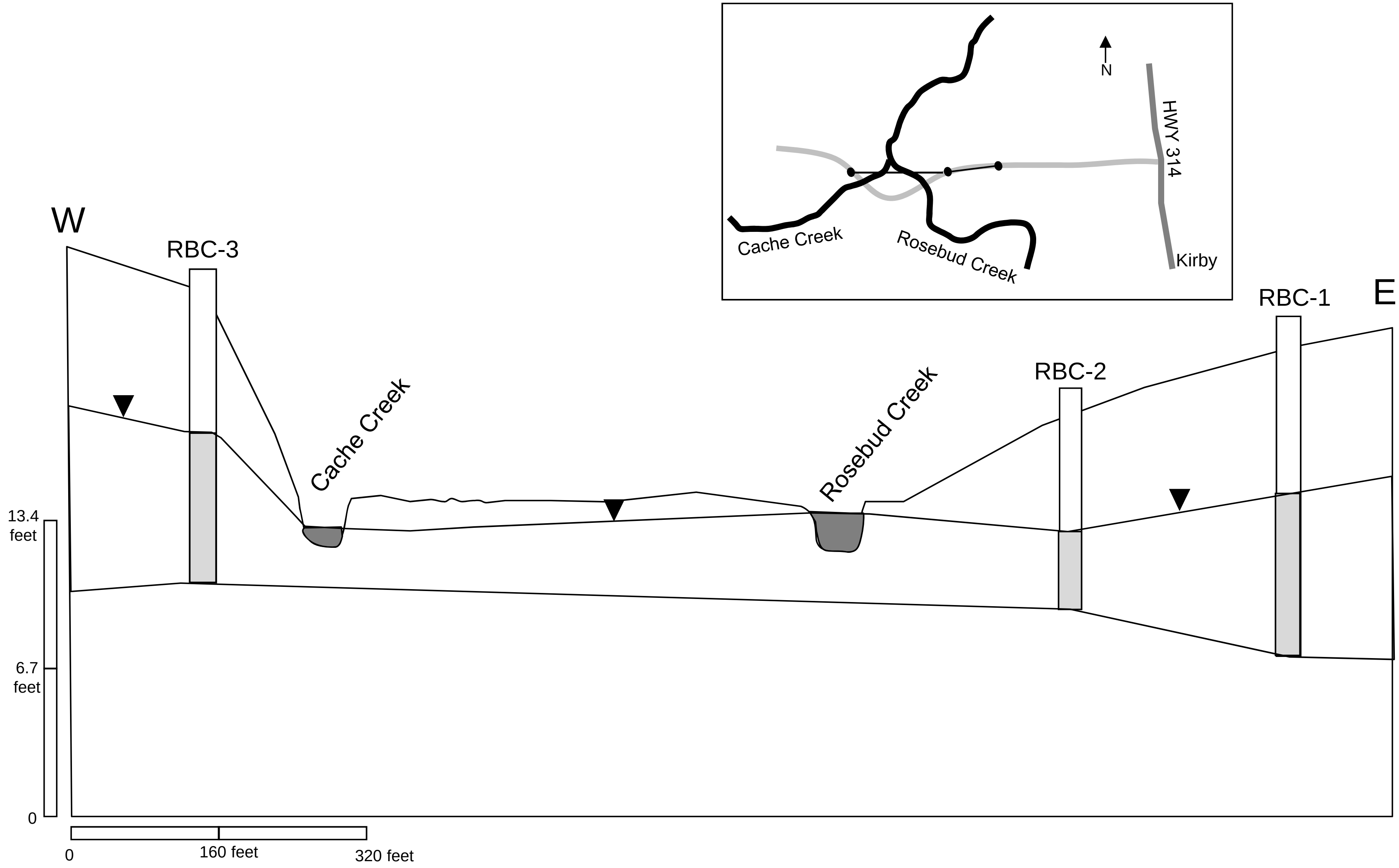


Figure E-6. Cross section of the Rosebud Creek site located in T. 06 S., R. 39 E., section 8. Water levels in this alluvial aquifer and surface-water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water 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 2014. Vertical exaggeration is 23.9:1. Hydrographs associated with this site are shown in figure E-7.

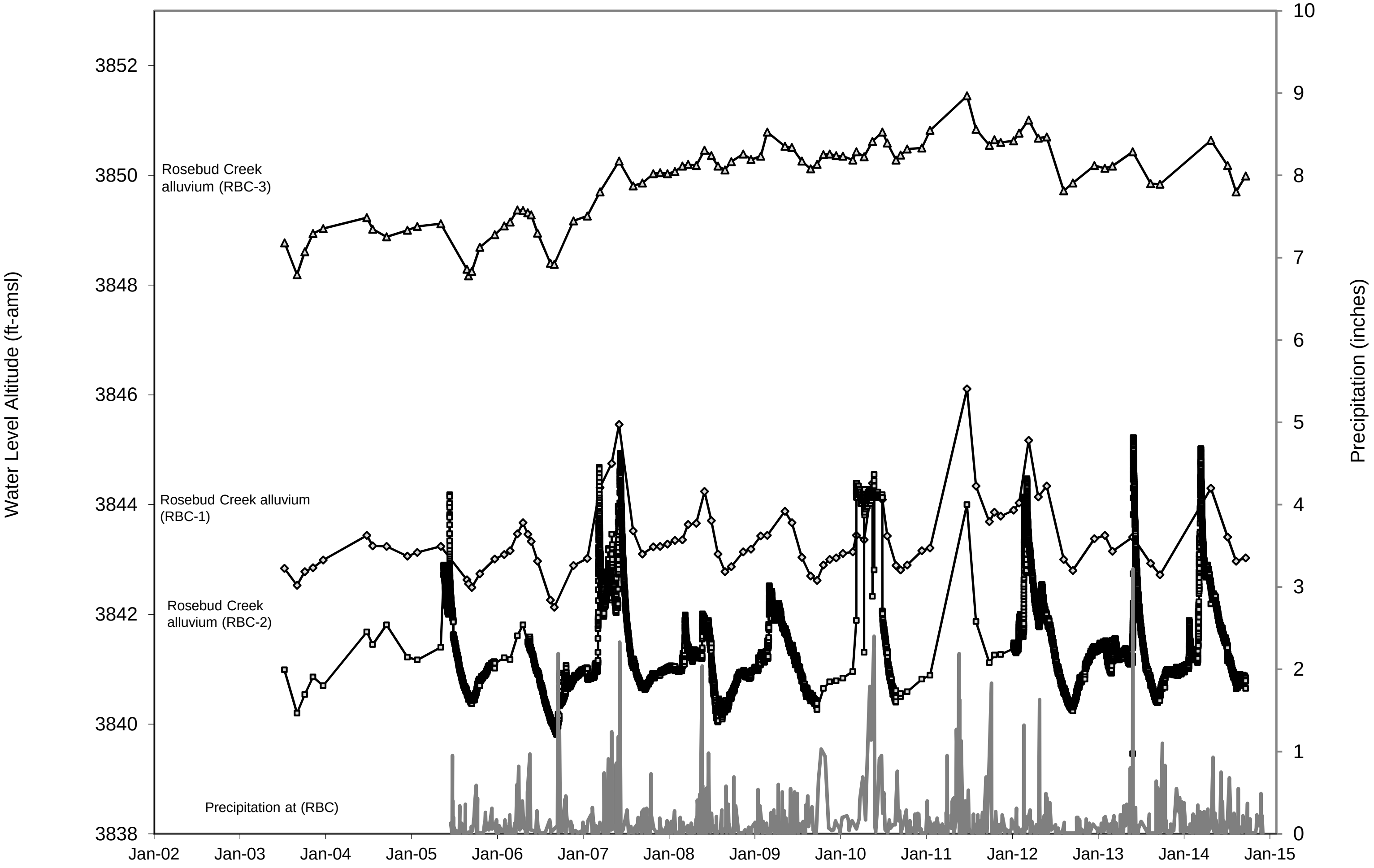


Figure E-7. Groundwater levels are typically high during wet times of the year at the Rosebud Creek alluvium site. Wells RBC-1 and RBC-2 show a strong correlation with precipitation. Precipitation is shown as the total rain in inches per event and a precipitation event is defined as continuous precipitation 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).

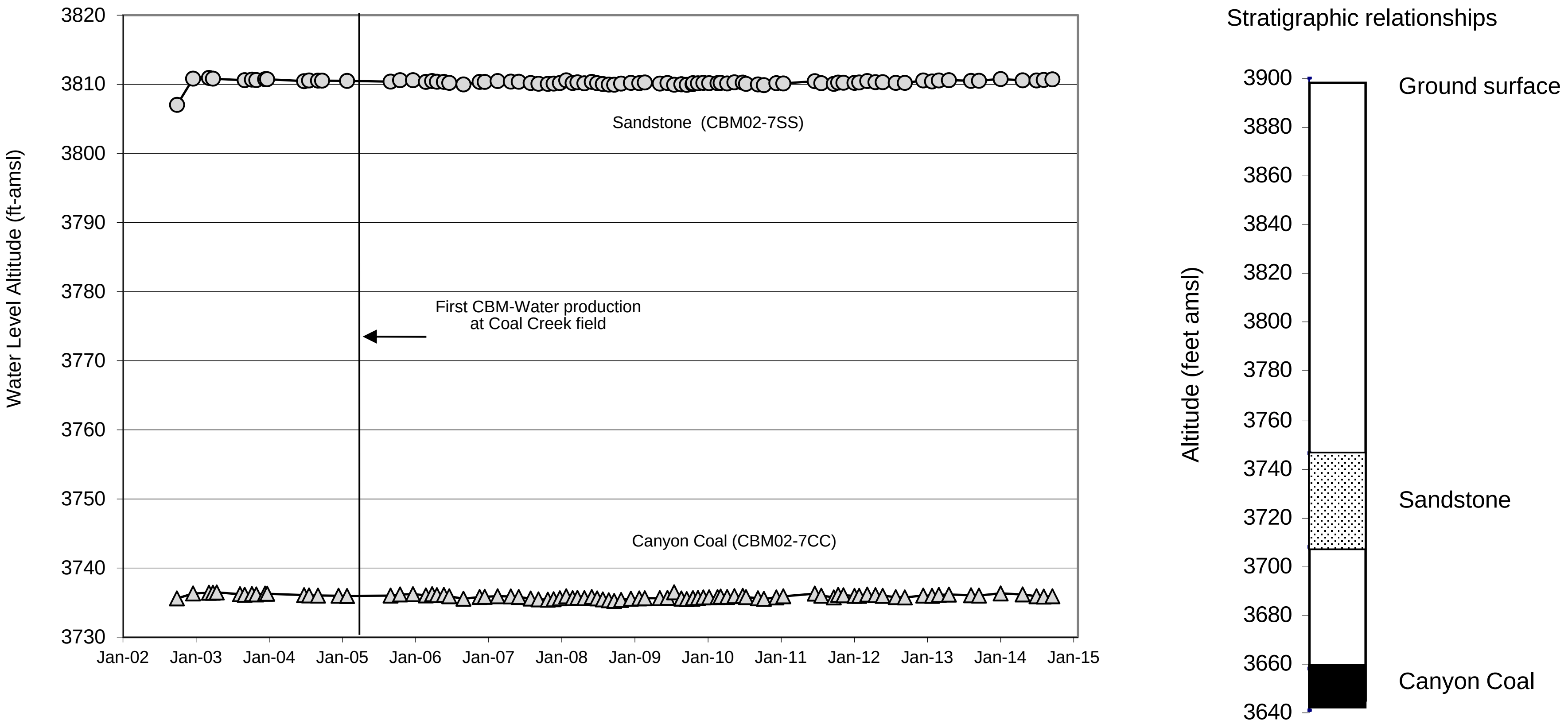


Figure E-8. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field. Note the vertical scales of the stratigraphic relationship and the hydrograph are different.

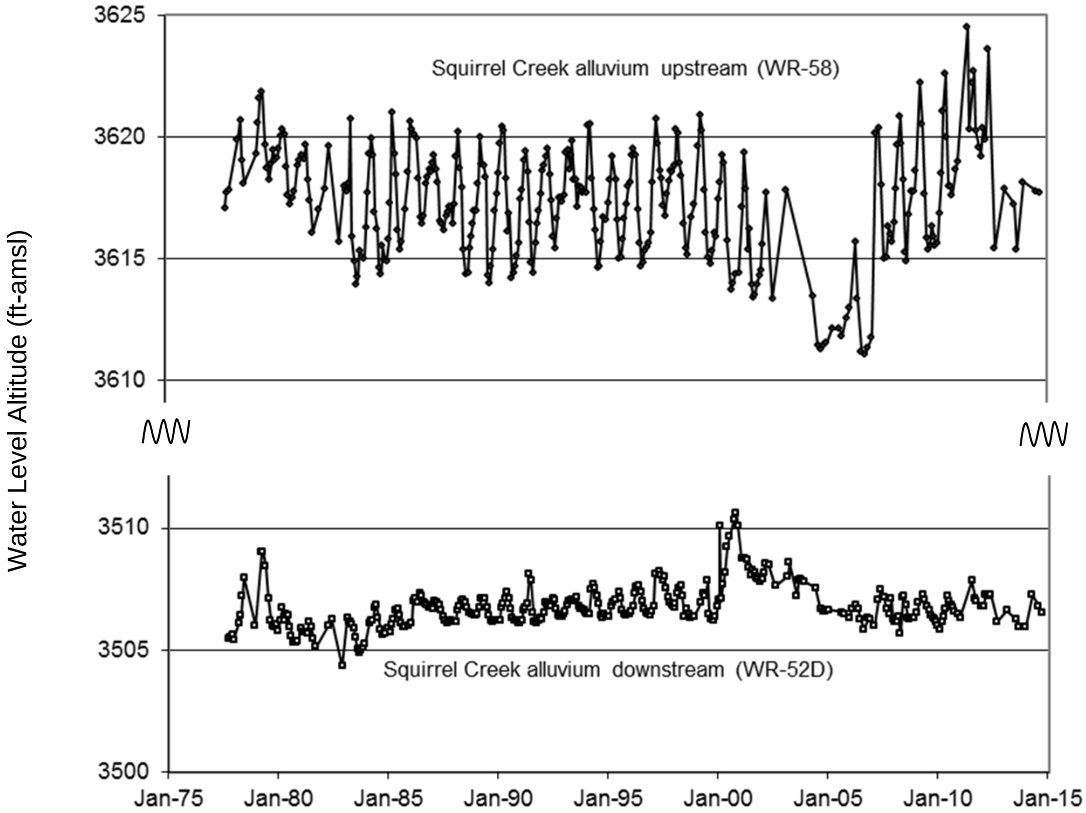


Figure E-9. These alluvial wells are within the area influenced by CBM production; however, they no longer show impacts from the nearby infiltration pond. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production, 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 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.

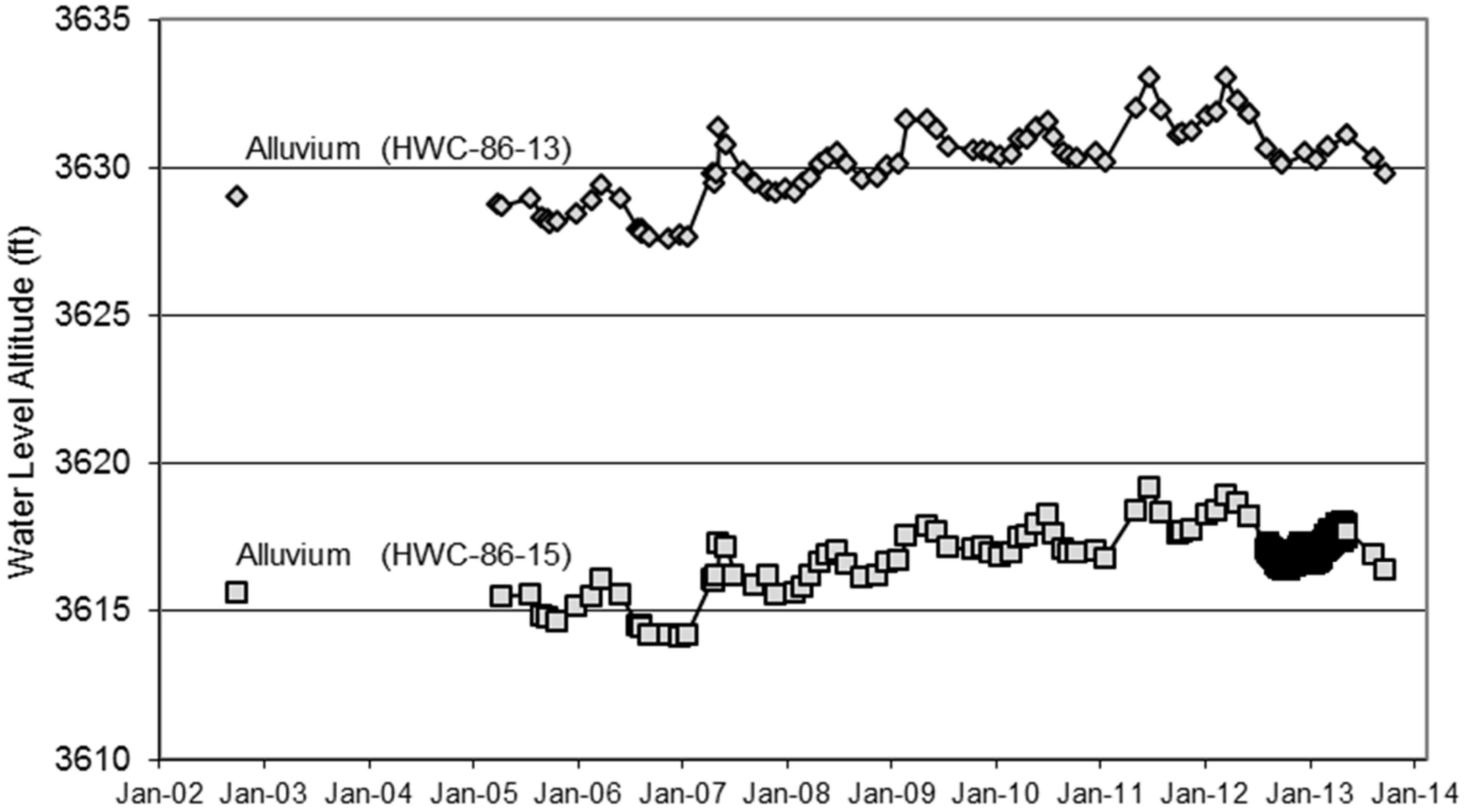


Figure E-10. The water level in the Hanging Woman Creek alluvial aquifer near the Montana–Wyoming state line reflects water table response to meteorological patterns. Shown on plate 1.

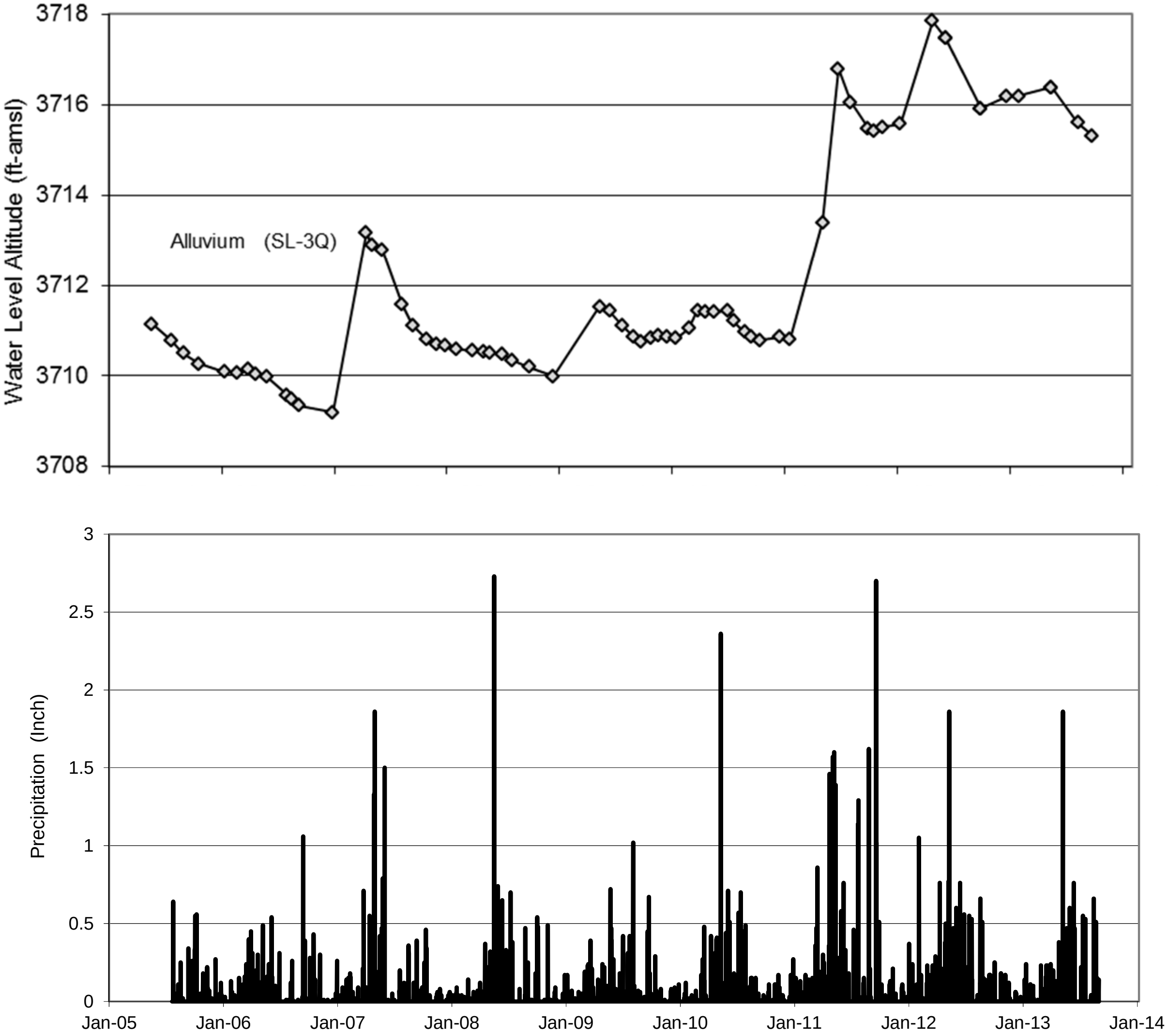


Figure E-11. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to plate 1. Precipitation at the SL-3 weather station is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation.

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