2010 Annual Coalbed Methane Regional Groundwater Monitoring Report: Powder River Basin, Montana

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Executive Summary

This report presents groundwater data collected through September 2010 from within the northern portion of the Powder River Basin and a brief discussion of all monitoring data with an emphasis on data collected during 2010. This annual report is presented on the water year, which is October through September. Data collected during the water year will be referred to as the 2010 data. This is the eighth year in which the Montana coalbed-methane (CBM) regional groundwater monitoring network has been fully active. The network was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to determine actual groundwater impacts and recovery, to help present factual data, and to provide data and interpretations to aid environmental analyses and permitting decisions. The current monitoring network consists of a combination of pre-existing monitoring wells installed during the late 1970s and early 1980s in response to actual and potential coal mining, recently installed monitoring wells specific to CBM impacts, domestic wells, stock wells, and springs.

The first commercial production of CBM in Montana in April, 1999, was from the CX field near Decker. This field is operated by Fidelity Exploration and Production Company. Montana currently has 824 CBM wells that produced methane, water, or both during 2010, 61 wells less than 2009. A total of 9.99 million mscf (1 mscf = 1000 standard cubic feet) of CBM was produced in Montana during 2010, 92% of which came from the CX field. The other 8% of the methane was produced from the Dietz, Coal Creek, and Waddle Creek fields. The new field, Coal Coulee, which produced gas last year from one well, did not have any water or gas production this year.

Coalbed methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping groundwater from coal aquifers allows methane to desorb. Groundwater is typically pumped at a rate and scale that reduces water pressure (head) to a few feet above the top of each coal seam over large areas. The extraction and subsequent management of CBM production water has raised concerns about potential loss of stock and domestic water supplies due to groundwater drawdown, and impacts to surface-water quality and soils from water management practices.

Methane-producing coalbeds in the Powder River Basin of Montana contain water that is dominated by sodium and bicarbonate. Sodium adsorption ratios (SAR) are generally between 40 and 60, and total dissolved solids concentrations between 1,000 and 2,000 mg/L. Sulfate concentrations in production water are very low. This production water is typically of acceptable quality for domestic and livestock use; however, its high SAR makes it undesirable for direct application to soils.

During 2010, Montana Bureau of Mines and Geology (MBMG) regularly measured water levels in the network of monitoring wells covering much of the Powder River Basin in Montana, with a focus on areas with current CBM activity or areas predicted to have high CBM potential. Fidelity Exploration and Production Company (Fidelity) and Pinnacle Gas Resources, Inc. (Pinnacle) also provided water level measurements in monitoring wells and during 24-hour shut-in tests of selected wells. Fidelity supplied water level measurements collected by themselves at the Decker and Spring Creek mines. Fidelity reported 51 water level measurements from 33 wells, the majority completed in the Anderson/Dietz coal zone. Spring Creek mine reported 75 water level measurements from 22 wells. Decker reported 21 water levels from 9 wells. Pinnacle supplied 47 water level measurements from as many wells: 7 from the Anderson/Dietz coal zone, 5 from the Canyon coal, 10 from the Cook coal, 18 from the Wall coal, and 7 from the Flowers-Goodale coal. These water levels were used to help create plates 2, 3, 4, and 5. The Dietz and Canyon coalbeds are primarily used in discussions in this report because of the greater density and coverage of monitoring wells completed in those coalbeds. Hydrostatic heads in the Dietz coal have been lowered as much as 150 feet or more within areas of production. The potentiometric surface in the Canyon coal has been lowered more than 600 feet. After 10 years of CBM production, the 20-foot drawdown contours for both the Dietz and Canyon coals extend approximately 1.0 to 1.5 miles beyond the boundary of the CX field. These distances, while similar, are somewhat less than originally predicted in the Montana CBM environmental impact statement (U.S. Department of the Interior, Bureau of Land Management, 2003). The radius of the 20-foot drawdown contour will increase if the duration and magnitude of CBM production increases; however, there has been little change in this radius since 2004 (Wheaton and others, 2005).

Initial computer modeling efforts and reviews of current data from nearby coal mines that were conducted near the beginning of CBM production in Montana, projected drawdown of 20 feet would eventually reach as far as 4 miles beyond the edges of large production fields. The amount of drawdown decreases with distance from the producing fields, and drawdown of 10 feet was predicted to reach as far as 5 to 10 miles beyond production fields after 20 years (Wheaton and Metesh, 2002). After over 10 years of production the 20 foot drawdown contour generally does not extend beyond 2 miles outside the CBM fields. Faults tend to act as barriers to groundwater flow and drawdown has not been identified to migrate across fault planes where measured in monitoring wells; however, recent computer modeling of the Ash Creek mine area shows that the hydraulic conductivity of faults can vary significantly along their length from impermeable to permeable. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, but it may take decades to return to their original water levels. The extent of drawdown and rates of recovery will mainly be determined by the rate, intensity, and continuity of CBM development, site-specific aquifer characteristics, including the extent of faulting and proximity to recharge areas, as well as other significant groundwater withdrawals in the area such as coal mining. Since 2004, recovery due to discontinuation or reduction in CBM production has been measured at four wells near the Montana–Wyoming state line in the far western part of the study area. Drawdown in these wells ranged from 19 to 152 feet. Estimates based on current rates of recovery, indicate that baseline water levels will be reached in approximately 30 years; however, that projection is based on recovery rates in fields where there is still some CBM production. The recovery rates may increase as more CBM wells are taken out of production.

Projections are important for evaluating potential future impacts. However, inventories of existing resources and long-term monitoring are necessary to test the accuracy of these models and determine the actual magnitude and duration of impacts. After 138 months of CBM production it continues to be apparent that these monitoring data and interpretations are key to making informed development decisions and for determining the causes of observed changes in groundwater availability.

List of abbreviations

above mean sea level (amsl); barrels (bbls); coalbed methane (CBM); gallons per minute (GPM); million cubic feet (MMCF); Montana Board of Oil and Gas Conservation (MBOGC); Montana Bureau of Mines and Geology (MBMG); Million British Thermal Units (MMBtu); Montana Ground Water Information Center (GWIC); Powder River Basin (PRB); sodium adsorption ratio (SAR); specific storage (Ss); specific yield (Sy); storativity (S); total dissolved solids (TDS); Tritium Units (TU); United States Department of the Interior, Bureau of Land Management (BLM); United States Geological Survey (USGS); Wyoming Oil and Gas Conservation Commission (WOGCC)

Introduction

Coalbed methane (CBM) is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping groundwater from coal aquifers allows methane to desorb. Groundwater is typically pumped at a rate and scale that reduces water pressure (head) to a few feet above the top of each representative coal seam over large areas. The extraction and subsequent management of CBM production water has raised concerns about potential loss of stock and domestic water supplies due to groundwater drawdown and impacts to surface-water quality and soils from water management practices. The reduction of hydrostatic pressure in coal aquifers during coalbed-methane production may affect yield from wells and discharge rates of springs that obtain their water from the developed coal seams. The magnitude, geographic extent, and duration of this drawdown are the primary focus of the regional monitoring program.

Streams in the Montana portion of the Powder River Basin (PRB) have formed valleys that cut through the entire coal-bearing Tongue River Member of the Fort Union Formation. Coal seams exposed along valley walls allow groundwater seepage to form springs and allow methane to naturally leak to the atmosphere. Groundwater monitoring wells completed in a coalbed occasionally release methane under static water-level conditions. It is interpreted that these wells are completed in an area of the coalbed where methane adsorption sites are saturated and additional methane migrates to the lower pressure of the well bore.

Coalbed methane production is an important industry in Montana. The benefits from CBM production include tax revenue, increased employment, secondary economic effects on local economies, and potential royalty payments to landowners (Blend, 2002). To date, the CBM industry has contributed over $45 million dollars to the state of Montana through taxes and royalties (1999: $7,472, 2000: $588,676, 2001: $2,061,469, 2002: $2,029,626, 2003: $2,531,687, 2004: $4,071,391, 2005: $7,738,367, 2006: $5,896,658, 2007: $5,482,386, 2008: $8,429,811, 2009: $3,221,266, 2010: $3,212,740) (Personal communication Mike Keller, Fidelity and Terry Webster, Pinnacle, March 2011). The spot Henry Hub price of natural gas has varied greatly in dollars per MMBtu (million British Thermal Units). It reached a peak in 2005 of over $15/MMBtu and currently stands just below $4.00/MMBtu (www.energystox.com).

This report presents groundwater data and interpretations from within the northern portion of the PRB undergoing CBM development. This is the eighth year in which the Montana regional CBM groundwater monitoring network has been active. This program was initiated to document baseline hydrogeologic conditions in current and prospective CBM areas in southeastern Montana, to quantify groundwater impacts and lack of impacts, to record groundwater recovery, and to provide data and interpretations for use in environmental and permitting decisions. Additional background is presented in Wheaton and Donato (2004). This and future reports released each year will present data collected in the water year (October through September).

This report includes: (1) a description of groundwater conditions outside of CBM production areas, which provides an overview of normal variations, helps improve our understanding of the groundwater regime in southeastern Montana, and provides water quality information for planning CBM projects; and, (2) a description of groundwater conditions within and near CBM fields that show actual impacts from CBM production. The area covered by the CBM regional groundwater monitoring network is shown in Figure 1 and Plate 1.

All hydrogeologic monitoring data collected under the CBM regional monitoring program (including the data presented in this report) are available from the Montana Bureau of Mines and Geology 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 well head. 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 web page (http://www.bogc.dnrc.mt.gov/default.asp), and the Wyoming Oil and Gas Conservation Commission (WOGCC) web page (http://wogcc.state.wy.us/).

A total of 824 CBM wells produced water, gas, or both in Montana during 2010, a decrease of 61 wells since 2009. Fidelity Exploration and Production (Fidelity) has been producing from the CX Field near Decker, Montana (Plate 1) since April 1999. Based on data from the MBOGC web page, the CX Field now includes 713 wells actively producing gas or water or both during 2010. Pinnacle Gas Resources, Inc. (Pinnacle) began production in the Coal Creek Field during April 2005 and in the Dietz Field during January 2006. During 2010, 28 wells are listed as producing water, methane, or both in the Coal Creek Field and 82 wells are listed as producing in the Dietz field.

Coalbed methane is produced in many fields in the Wyoming portion of the PRB. For the purposes of this report, only that activity in the two townships nearest the Montana - Wyoming state line is considered (townships 57N and 58N). This covers a distance of about 9 miles from the state line (Plate 1). The Prairie Dog Creek Field (1,185 active wells during 2010) in Wyoming is adjacent to the CX field in Montana. The Hanging Woman Creek Field (246 active wells during 2010) is near the center of the PRB along the state line. The Powder River area (an informal name used in this report) is on the eastern edge of the PRB in Wyoming and included 529 active wells during 2010 (Plate 1).

Hydrogeologic data were collected by MBMG at 239 wells, 14 springs, and 2 streams during 2010 water year. Of those monitored sites, 17 wells, 8 springs, and 1 stream are located within the boundary of the Ashland Ranger District of the Custer National Forest. Six monitoring wells, located on the Northern Cheyenne Reservation, are monitored by tribal employees and the

United States Geological Survey (USGS). Collected data are stored in GWIC. Three new monitoring wells were installed in 2010: SL09-BA,-PC, and –CC in the Brewster-Arnold, Pawnee and Cache coals, respectively. These three wells were installed as a part of this monitoring program along the state line east of the Powder River (see State Line Drilling section). 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 2010 are listed in Appendix C. All data are available electronically from GWIC (http://mbmggwic.mtech.edu/). The locations of all monitoring sites are shown in Plate 1.

Acknowledgments

The landowners and coalbed-methane producers who are allowing monitoring access are gratefully acknowledged for their cooperation in this project. Funding for the current and much of the previous work has been provided by the U.S. Department of the Interior, Bureau of Land Management (BLM), and the Montana Department of Natural Resources and Conservation with the support of the Big Horn Conservation District. The USDA Forest Service provides funding in support of monitoring on the Ashland Ranger District on the Custer National Forest. The Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal and coalbed methane hydrogeology work. The statewide Ground-Water Assessment Program, operated by the Montana Bureau of Mines and Geology (MBMG), monitors several wells and springs in the Powder River Basin, and those data are incorporated in this work. Clay Schwartz and Simon Bierbach, of MBMG in Billings, monitor these wells and provide additional assistance to the regional program. Data are also collected by the Northern Cheyenne Tribe with the United States Geological Survey. Technical discussions and reviews by the BLM, USFS and cooperating groups continue to be invaluable.

Location, description, and general hydrogeology of the area

The study area is that part of the PRB bounded by the Montana–Wyoming line on the south, roughly the Powder River on the east, the Wolf Mountains on the west, and extending north to near the town of Ashland (Figure 1 and Plate 1). This is the Montana portion of the PRB believed to have high to medium potential for CBM development (Van Voast and Thale, 2001). Methane production data and locations are included for that portion of the PRB in Wyoming that is adjacent to the Montana–Wyoming state line (townships 57N and 58N).

The PRB is classified as a semi-arid climate because it receives, on average, less than 15 inches of precipitation per year based on data from Fort Howes, Badger Peak, Bradshaw Creek, and Moorhead meteorological stations (Plate 1). Typically, in the PRB, May and June are the wettest months and November through March the driest. The average high temperature is 89ºF in July and August and the average low temperature is 32 ºF in December and January (Western Regional Climate Center, 2009).

Geologic setting

The PRB is a structural and hydrogeologic basin in southeast Montana and northeast Wyoming. Exposed formations include the Tertiary Fort Union Formation and overlying Wasatch Formation. Both formations consist of sandstone, siltstone, shale, and coal units. The Fort Union Formation is divided, from top to bottom, into the Tongue River, Lebo Shale, and Tullock members. The coalbeds in the Tongue River Member are the primary targets for CBM development in Montana. The geologic and structural relationships above the Lebo Shale are shown in the cross section on Plate 1. The cross section is based on MBMG monitoring wells and published well logs and correlations (Culbertson, 1987; Culbertson and Klett, 1979a,1979b; Lopez, 2006; McLellan, 1991; McLellan and others, 1990). Generally, the zones between and including the Anderson and Knobloch coal seams are considered the most likely prospects for CBM in southeastern Montana (Van Voast and Thale, 2001).
However, methane is currently being produced from outside this zone. Groundwater monitoring wells are completed in numerous coalbeds as well as the overlying and underlying sandstone units.

A generalized stratigraphic column showing relative stratigraphic positions of the major coalbeds is presented in Figure 2. Not all coal seams shown in Figure 2 are present across the entire basin. The coal from the Anderson and Dietz coalbeds is mined near Decker. Lithologic units on Figure 2 are marked to indicate intervals that are monitored as part of the regional network, intervals that are the source units for monitored springs, and the coal units that are presently producing CBM in Montana or Wyoming. Coal stratigraphic nomenclature varies by agency or company. Table 1 shows the correlations between several different naming conventions.

The axis of the PRB 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.

Table 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

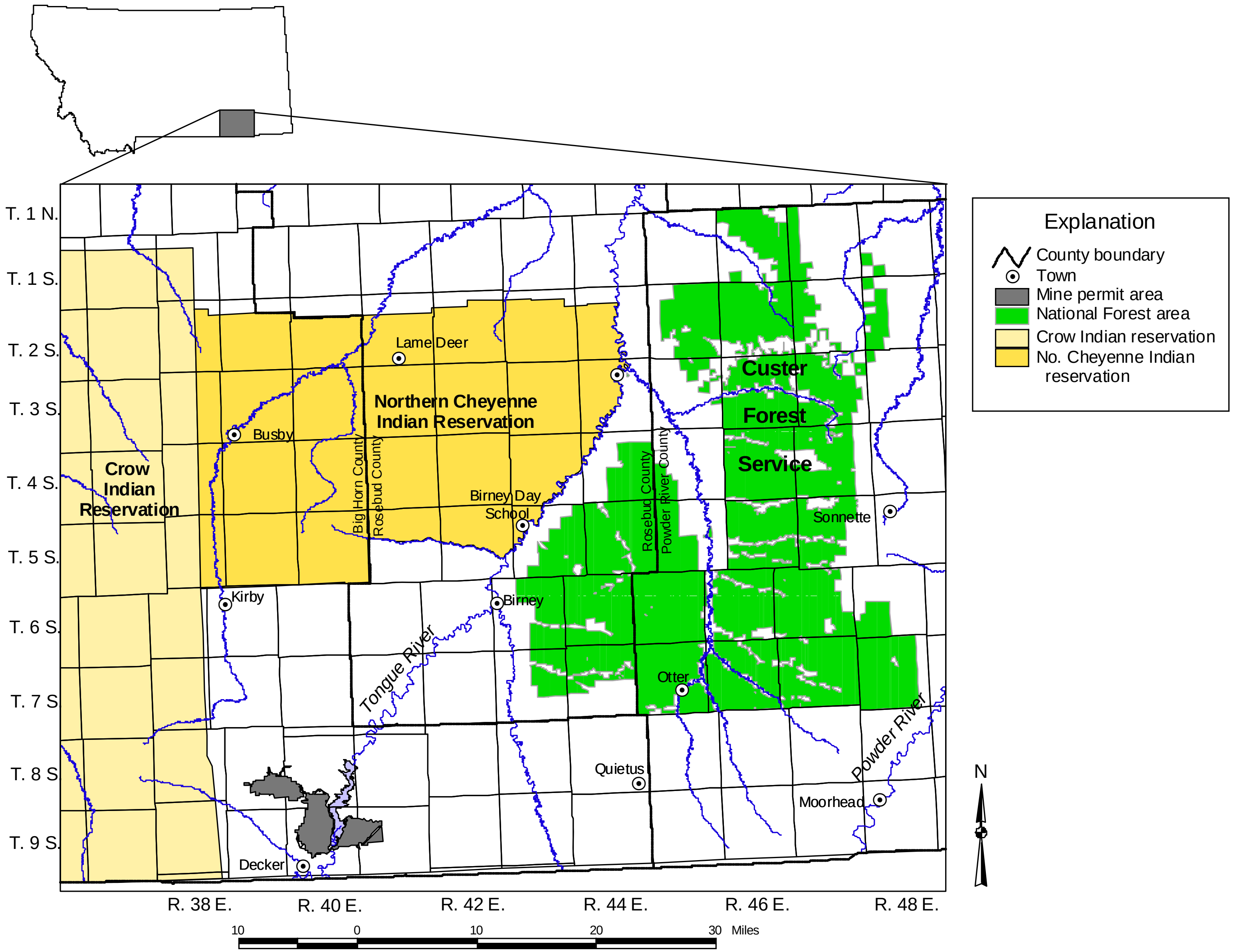


Figure 1. Location of study area.

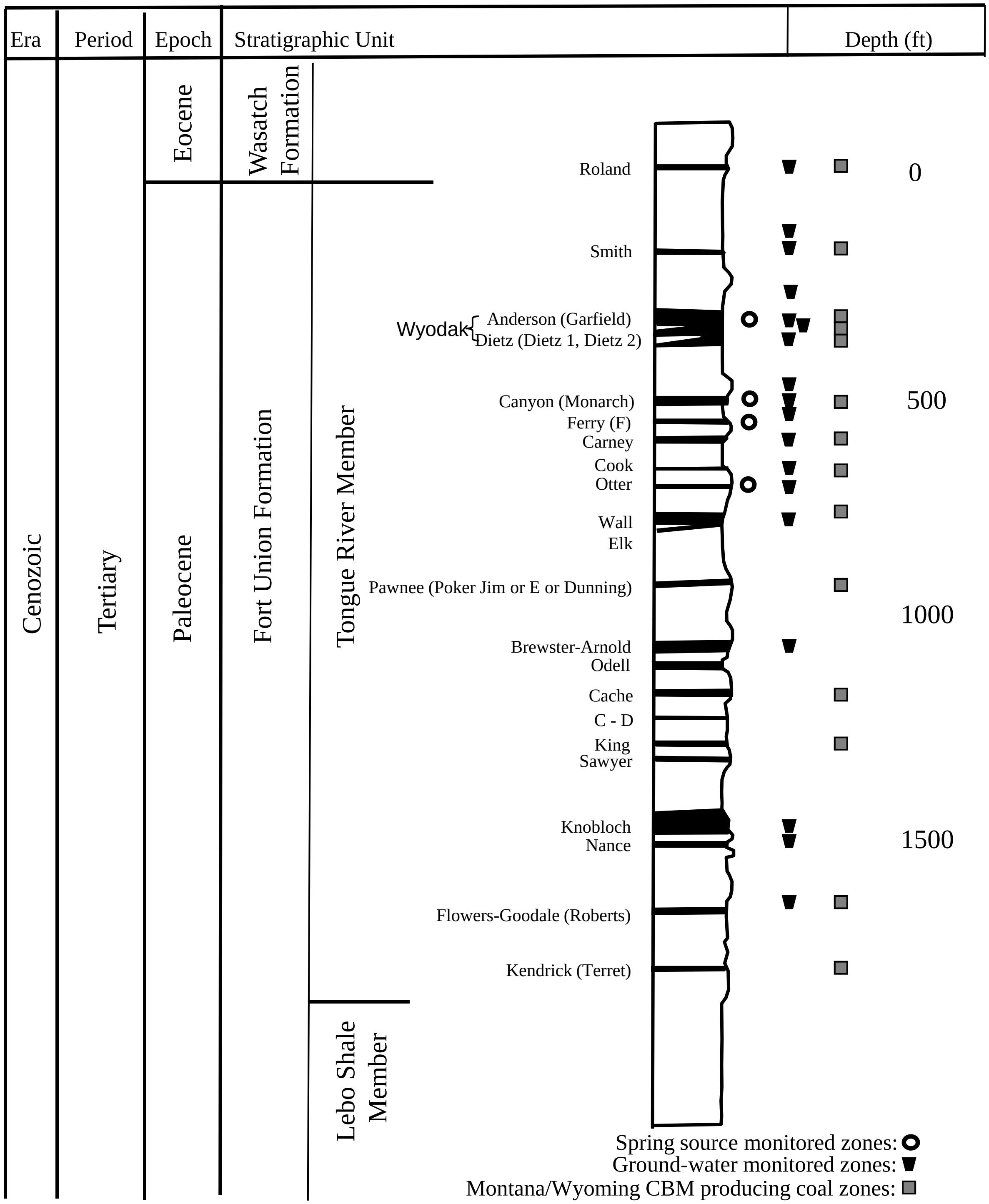


Figure 2. Many coal beds have been mapped within the Tongue River Member of the Fort Union Formation in southeastern Montana. The general relative positions of selected coal beds are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Most coals do not exist across the entire area and the interburden thickness varies considerably. The indicated depths are only approximations. Sources: Culbertson, 1987; Fort Union Coal Assessment Team, 1999; Law and others, 1979; Matson and Blumer, 1973; McLellan, 1991; McLellan and Beiwick, 1988; McLellan and others, 1990; and various U. S. Geological Survey coal resource maps prepared by the Colorado School of Mines Research Institute (1979a,b,c,d,e,f,g).

Hydrogeologic setting

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^-.

Recharge occurs as precipitation on clinker-capped ridges and outcrops and, in a few locations, stream-flow infiltration. Near recharge areas the local bedrock flow systems follow topography. These local flow systems either discharge to alluvial aquifers, form springs at bedrock outcrops, or seep vertically into deeper regional flow systems. Some seepage between aquifers occurs; however, seepage is limited due to the low permeability of the numerous shale layers. Aquifers that are local flow systems near recharge areas will be part of the regional flow system if they continue a sufficient distance and to great enough depth. The definition is not precise and the transition is gradual: not correlated with a specific length of flow path or depth.

The regional bedrock flow systems are recharged near the perimeter of the PRB in areas where aquifers crop out and by vertical leakage from the overlying local flow systems. Regionally, groundwater flows from Wyoming northward into Montana and towards the Yellowstone River. Groundwater in regional flow systems will either leave the PRB as deep groundwater flow or discharge as springs to streams or to alluvium. Hundreds of springs originating in the Tongue River Member of the Fort Union Formation have been inventoried and mapped in the project area (Kennelly and Donato, 2001; Donato and Wheaton, 2004a, 2004b; and Wheaton and others, 2008). The Tongue River Member is a shale-dominated unit, with relatively thin permeable layers (coal, sandstones, and fractured carbonaceous shale). This stratigraphic setting produces spring discharge from both local and regional groundwater flow systems; and demonstrates the general lack of vertical migration between units. An unknown, but likely significant, percentage of the groundwater in the Tongue River Member aquifers discharge to springs and to streams above the base of the unit.

The coal-bearing Tongue River Member is bounded on the bottom by the Lebo Shale aquitard (Figure 2 and Plate 1). Due to the low vertical permeability of the Lebo Shale, most groundwater that is remaining in lower units of the Tongue River Member at its contact with the Lebo Shale is forced to discharge to springs and streams along the contact between the two units, which is south of the Yellowstone River. There may be some vertical seepage into the underlying Tullock Member. Contact springs at the base of the Tongue River Member add baseflow to streams. In terms of coalbed-methane development, the Lebo Shale effectively limits the potential for impacts from reduced hydrostatic pressure and management of produced water to only those units lying stratigraphically above this aquitard.

Water levels in shallow aquifers respond to seasonal variations in precipitation. Deeper aquifers show little if any measurable seasonal changes in water level except for long periods of low or high precipitation. Water level differences between aquifers can suggest downward gradients (hydraulic head is lower in wells in deep aquifers than those in shallower aquifers) or upward gradients (hydraulic head is higher in wells in deeper aquifers than those in shallower aquifers). Most areas in the PRB show downward gradients. Areas of recharge have strong downward gradients. Upward gradients indicate proximity to discharge areas.

Aquifers are recharged by precipitation and shallow groundwater levels reflect both short- and long-term precipitation patterns. Precipitation data for the Moorhead station in the southeast part of the study area along the Powder River, near the Montana–Wyoming state line, indicate average total annual precipitation is 11.85 inches, based on records from 1970 through the end of 2010 (Western Regional Climate Center, 2010). During the water year 2010, Moorhead received 16.59 inches of precipitation, which is 4.74 inches higher than the average annual precipitation (Figure 3). Long-term precipitation trends that may affect groundwater levels are illustrated by the departure from average bar-graph (blue columns) in Figure 3. The early 2000s marked a period of average-to-low precipitation, while precipitation has generally been above average from 2005 to 2010.

Aquifer characteristics

Storativity (S) is the ability of an aquifer to store and release water per unit surface area per unit change in head. In a confined aquifer, the storativity is the product of the specific storage (S_s) and the aquifer thickness (Fetter, 1994). Specific storage (S_s) is the volume of water released from a unit volume of aquifer per unit change in pressure head. Water stored or released due to specific storage results from changes in pressure within the aquifer, which causes the aquifer's mineral skeleton and the water itself to expand and contract. The aquifer pore space is still completely saturated. Specific yield (S_y) is the volume of water that can be drained from the pore spaces per unit volume of material under the force of gravity. Within unconfined aquifers, the primary means of water release to wells is from specific yield as pore spaces are dewatered, while the effects of specific storage are negligible. Within confined aquifers (such as coalbeds in the PRB) storativity, not specific yield, is the primary means of water release (Fetter, 1994).

Davis (1984) reported values of specific yield for unconfined coal aquifers in the PRB on the order of 0.003 to 0.03, based on effective porosity measurements. For these values, between 0.003 and 0.03 cubic feet of water would be released by completely draining 1 cubic foot of a coalbed aquifer. Typical values for specific storage for a confined coalbed aquifer are much less, on the order of 0.00006 (Wheaton and Metesh, 2002). In this case, reducing the hydrostatic pressure of a confined coalbed by 1 foot would release 0.00006 cubic feet of water from 1 cubic foot of material. The two examples of water released are basically comparable, as each represents a 1-foot change in water level. The difference in the quantities of water released is a function of how the water is released. Removal of water during CBM production typically reduces the hydrostatic pressure (S_s) rather than draining the pores (S_y).

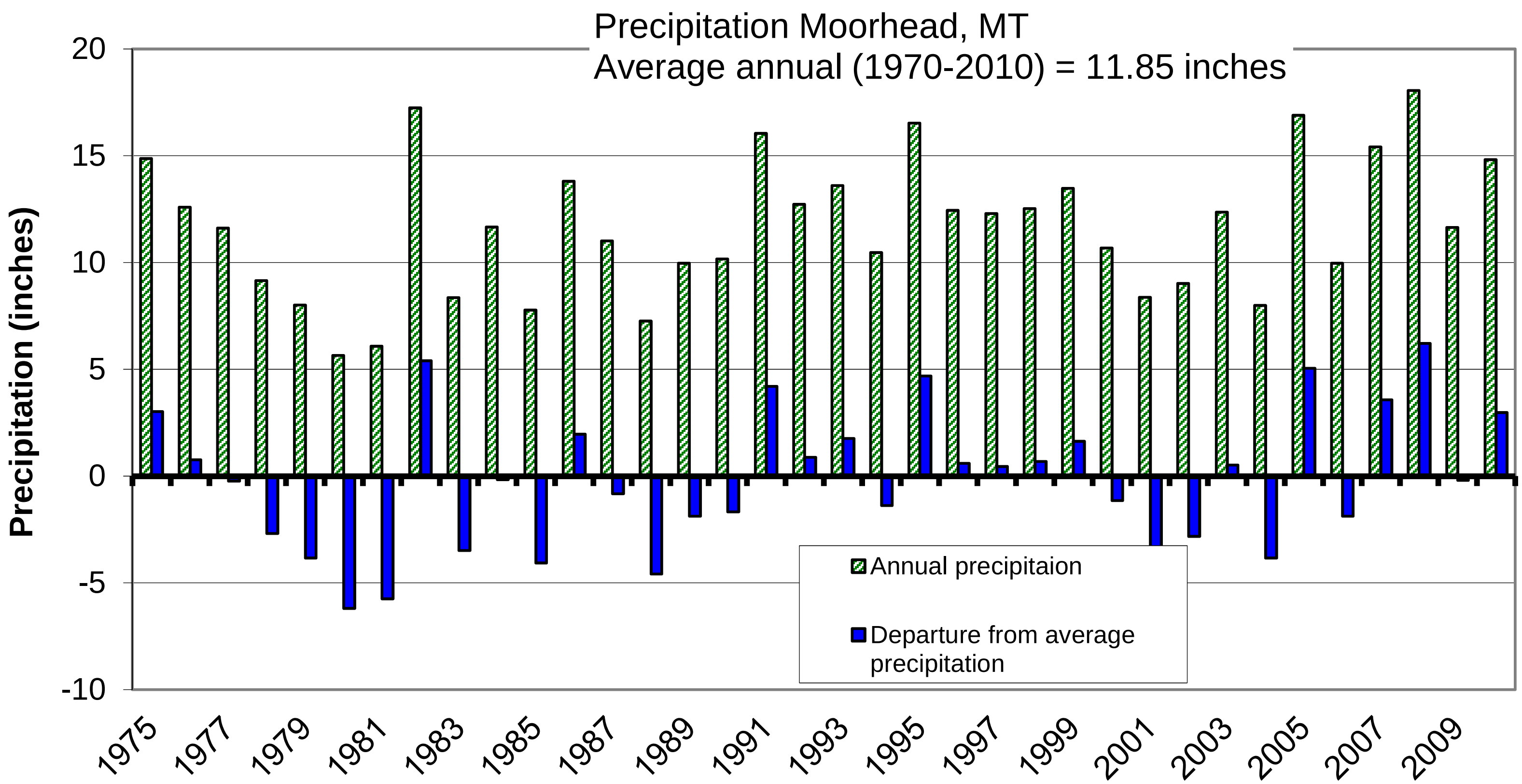


Figure 3. Annual precipitation (striped bar graph) at Moorhead MT. Departure from average precipitation (solid bar graph) provides a perspective on the long-term moisture trends that may effect ground-water recharge.

Coalbeds in the PRB are generally separated from other aquifers by shale units. Due to these confining shale units, water-level drawdown in response to CBM production, in most areas, is expected to be limited to the coal aquifers and not migrate vertically to impact overlying or underlying aquifers. At a few selected locations, overburden and underburden aquifers are monitored and generally verify this concept.

In southeastern Montana, faults in the Fort Union Formation are typically no-flow boundaries that limit the aerial extent of drawdown (Van Voast and Reiten, 1988). A series of monitoring wells were installed south of the east Decker mine in the early 1970's to document this effect (Van Voast and Hedges, 1975). These wells continue to be monitored, and they demonstrate that this fault limits groundwater flow. However, long term monitoring at other sites have demonstrated that fault systems can also allow slow leaking across the fault. These different boundary conditions are possibly due to fault offset thickness. If the offset is less than the thickness of the coal seam, the aquifer may still be hydrologically connected. If the offset is greater than the thickness of the coalbed, the aquifer may encounter a no-flow boundary. Some faults in this area are scissor faults, which allow communication along and around the end of the fault in some locations and are barriers to flow in other locations (see Ash Creek Mine groundwater model section)

Groundwater chemistry

Groundwater quality in the Powder River Basin has been extensively documented. The general chemical characteristics of groundwater in different parts of the flow systems and an overview of baseline water quality across the PRB are briefly discussed in Wheaton and Donato (2004). In the PRB, coalbed methane exists only in reduced (oxygen poor) zones where the water quality is characterized by high concentrations of Na^+ and HCO_3^-, and low concentrations of Ca^{2+}, Mg^{2+}, and SO_4^{2-} (Van Voast, 2003). Groundwater quality in coal seams is not expected to change in response to CBM production. Infiltration of produced water may, however, cause changes in shallow groundwater quality. To document possible changes, water-quality data are collected semi-annually in shallow aquifers.

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 Table 2. The number of samples from individual coals ranged from 1 to 26. 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).

Table 2. Water quality summary for coalbed aquifers in the Powder River Basin of Montana

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

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

BD indicates lowest readings were below detection

Groundwater conditions outside of potential coalbed methane influence

Bedrock-aquifer water levels and water quality

Groundwater levels (the potentiometric surface) and inferred groundwater flow directions in the Dietz and Canyon coal beds, as interpreted from the available data, are shown on Plates 2 and 3, respectively. Near the outcrop areas, topography exerts a strong control on flow patterns. Groundwater flows generally from south to north, with some recharge occurring in Montana along the western outcrop areas in the Wolf Mountains and in the east near the Powder River. Other regional bedrock aquifers in the Tongue River Member should have similar flow patterns relative to their outcrops. Groundwater discharges to outcrops, springs, domestic wells, stock wells and CBM wells.

Three new wells were installed as a part of this project by the MBMG east of the Powder River along the state line in Township 9S, Range 48E, Section 34. These wells are completed in the Brewster-Arnold, Pawnee, and Cache coals. These wells will initially be monitored on a monthly basis, or until their characteristics determine whether more or less frequent monitoring is required.

Hydrographs and geologic cross sections for selected monitoring sites that are outside of potential coalbed-methane impacts are presented in Figures 4 through 12. At monitoring site CBM 03-12, data from 1974 through 2010 from an overburden sandstone and the Canyon coal indicate a downward gradient (Figure 4). These wells are located in the eastern part of the study area near Bear Creek, and show no response to CBM production. They do, however, show a decline in water levels that is likely related to the long-term precipitation trends. At site CBM 03-11, the Anderson and Dietz coals also show a downward gradient (Figure 5). This site is in the south-central portion of the monitoring area, near the Anderson coal outcrop, and also reflects baseline conditions.

Monitoring site CBM 02-8 is west of the Tongue River near the outcrop of the Knobloch coal, where hydrostatic pressures in the Knobloch coal and Knobloch overburden have been reduced by natural discharge to nearby outcrops in Coal Creek and along the Tongue River (Figure 6). Water levels in wells completed in the underlying Flowers-Goodale coal and overburden are higher than those measured in the Knobloch overburden and coal. The upward gradient suggests that this is near a discharge area for the Flowers-Goodale units. 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 CBM 02-8DS is completed in the “D” channel sandstone overlying the Flowers-Goodale coal. This channel sandstone has been identified as a possible location for re-injecting CBM produced water (Lopez and Heath, 2007). Yield from this well, measured during drilling, is approximately 35 gpm.

At monitoring site CBM 02-1, near the community of Kirby, just east of Rosebud Creek, a downward gradient exists between the Brewster-Arnold coal, a local unnamed coal and the

Knobloch coal (Figure 7). Water-level data from the Brewster-Arnold coal and the local coal demonstrate a slight annual cycle, with lowest levels in late summer or early fall, indicating a relationship with precipitation patterns. The deeper Knobloch coal does not reflect a seasonal pattern and is most likely part of the regional flow systems.

At monitoring site WO-1, along Otter Creek, an upward vertical gradient exists, indicating proximity to a groundwater discharge zone (Figures 8, 9, and 10). Several landowners have flowing wells in this area, owing to this upward gradient. The shallow sandstone (WO-3) is directly discharging to the Otter Creek alluvium that provides baseflow for the creek. The deeper units (WO-1 and WO-2) are likely confined, and therefore are flowing towards their outcrop/subcrop areas.

Several monitoring wells on the southern border of the Northern Cheyenne Reservation (Plate 1) are being monitored for influences of CBM production. These wells were installed and are monitored in a cooperative effort between the Northern Cheyenne Nation and the USGS. Monitoring wells NC02-1 through NC02-6 (GWIC ID numbers 223238, 223240, 223242, 223243, 223236, and 223237; USGS ID numbers 05S40E31BDCC01, 05S42E14ADDC02, 05S41E17ADBD01, 05S40E13ADAB01, 05S42E16CCAB01, and 05S41E14BDCD01) monitor the water levels of the Wall (2), Flowers-Goodale, Pawnee, and Knobloch (2) coal beds. These wells are monitored periodically and as of the last measurements, none of these wells have shown any significant changes in water level since monitoring began in 2002. Water level data for these wells are available on the Montana Bureau of Mines and Geology GWIC web-site and the USGS NWIS website (http://nwis.waterdata.usgs.gov/).

Alluvial-aquifer water levels and water quality

Water levels in the Otter Creek alluvium are lower than those in the underlying bedrock aquifers at site WO-8. The upward vertical gradient described above indicates the bedrock aquifer will discharge into the alluvium where the two units are in contact (Figures 8, 9, and 10). Based on the upward hydrologic gradient at this site, the Otter Creek alluvium receives discharge from bedrock aquifers. Recharge to the alluvium also occurs as precipitation infiltrates locally and possibly by loss from Otter Creek during periods of high flow. Alluvial water levels at this site vary seasonally. Otter Creek appears to transition between a gaining and losing stream in this area depending on the exact location along the stream and the seasonal alluvial groundwater level.

Water levels in Rosebud Creek alluvium also vary with precipitation trends. The geologic cross section shown in Figure 11 crosses Rosebud Creek and a tributary. As shown in Figure 11, groundwater flows toward, and provides baseflow to, Rosebud Creek (it is a gaining stream). Data, particularly those from the continuous recorders at the site, show the relationships between meteorological conditions, groundwater levels, and surface-water flow (Figure 12). Groundwater levels show typical annual responses with the highest levels occurring during late winter and early spring and the lowest levels occurring during late summer and fall (Figure 12A). Flow data in Figure 12B for Rosebud Creek are from the U.S. Geological Survey gauging station near Kirby (station number 06295113) and are available from the website:

http://waterdata.usgs.gov/mt/nwis/uv?06295113. Stream flows correlate well with precipitation events.

The Rosebud alluvial groundwater levels show typical diurnal cycles. The summer months are typically periods of high transpiration as grasses and alfalfa use large amounts of water during the daylight hours and very little at night. As air temperatures increase in the morning, plant water consumption increases, lowering the water table. In the evening, as the air temperature decreases, plant stress on the water table decreases and the groundwater level recovers. This diurnal cycling causes the high frequency oscillations in water levels from June to the end of August. The overall downward trend of the water table during the growing season indicates transpiration exceeds recharge rates during this hot, dry time.

Detailed precipitation data for the Rosebud Creek site (Figure 12B; Rosebud Meteorological Station data available on the MBMG GWIC website), illustrates how quickly alluvial groundwater levels respond to precipitation events. Increased in-stream flow as this site usually lag behind heavy rain events by 6- to 18-hours.

Water-quality samples were collected in September 2009 and May 2010 from one alluvial well (RBC-2) outside areas of potential coalbed-methane influence (appendix C). This well is completed in alluvium of Rosebud Creek. Similar to previous years, concentrations of TDS were 544 and 556 mg/L and SAR values were both 0.8. The Rosebud Creek alluvium water chemistry is dominated by calcium, magnesium, and bicarbonate. The data are available on GWIC.

Spring and stream flow and water quality

Flow rates and specific conductivity data were collected at 15 springs and two streams within the project area during 2010. These springs and streams are located outside the current area of potential CBM impacts. The locations of monitored springs and the streams are shown on Plate 1, site data are in appendix B, and water chemistry in appendix C. Data collected from these sites during 2010 are available in the GWIC database. Springs are discharge points for groundwater flow systems. Local recharge occurs on ridge tops and hillsides adjacent to springs. Regional recharge originates at more distant locations such as outcrop areas along the edges of the Powder River Basin and flows beneath valleys between the recharge area and the discharge area. If a spring is topographically isolated from the regional flow systems by a valley, is at higher elevations, or is at the base of clinker zones on ridges, the spring is assumed to be local in origin. Springs located low on hillsides or along the floors of major valleys such as Otter Creek may represent regional flow systems or a combination of local and regional recharge. A survey of springs within the northern PRB showed that most springs probably obtain their water from local flow systems (Wheaton and others, 2008). Springs are identified by a local name or, where absent, the GWIC number is used.

In the southern portion of the Custer National Forest Ashland Ranger District along Otter Creek, Alkali Spring discharges at rates of between 0.5 and 1 gpm. The discharge rate at this spring shows some seasonal influence (Figure 13). Evidence suggests that Alkali Spring is a mixture of regional and local flow systems. Evidence for regional flow systems includes a tritium analysis in 2007 that indicated a tritium-dead (old) system. However, the seasonally dependent discharge rate and seasonally dependent water quality (Meredith and others, 2009) indicate a local source of water. Based on stratigraphic relationships and the regional nature of the spring, it appears that the Otter coal supplies some of the water to this spring (Wheaton et al., 2008).

In contrast, the North Fork Spring, in the southeastern portion of the Ashland Ranger District, is located in a topographically high area. The North Fork Spring shows moderate seasonal influence in discharge rates which are typically less than 1 gpm (Figure 13). This spring is associated with an isolated portion of the Canyon coal and likely represents local groundwater recharge.

Lemonade Spring, located east of the town of Ashland along U.S. Highway 212, probably receives a combination of regional flow and local recharge. This spring is associated with the Ferry coalbed and average discharge at this spring is 1.7 gpm, showing moderate seasonal variations (Figure 13). There has been a slight increase in flow rate since monitoring began in 2003. This may be caused by long-term precipitation patterns.

The East Fork Hanging Woman Creek weir site is located on the Ashland Ranger District boundary, east of Birney. The site consists of a 90^{o} v-notch weir with a stage recorder. During winter months the creek freezes and there is no measurable flow. The maximum flow rates over the period of record was 1,100 gpm (2.45 cubic feet per second [CFS]) during March, 2007 (snow melt) and 1,000 gpm (2.23 CFS) in June, 2007 (Figure 14). Typical summer flows are generally less than 150 gpm (0.33 CFS). Flow in East Fork Hanging Woman Creek responds quickly to precipitation events, and is sensitive to antecedent soil-moisture conditions and available storage capacity in upstream constructed reservoirs. Heavy rain events in spring 2007 resulted in a large increase in surface flow in the creek, however, the 3.28 inches of rain over the period of May 22-24, 2008 (measured at the Poker Jim meteorological station located near the headwater area for the creek) did not result in similar increases because of the lack of antecedent soil moisture and low stage conditions in up stream reservoirs.

Water-quality samples were collected in Fall 2009 and Spring 2010 from four springs and one creek: Three Mile Spring, Chipmunk Spring, and East Fork Hanging Woman Creek weir outside the area influenced by CBM production and Upper and Lower Anderson Springs within the current CBM producing area (Appendix C). Three Mile Spring is located near a clinker recharge area and the water has the lowest TDS and SAR values of all measured springs (271 mg/L and 0.8, respectively).

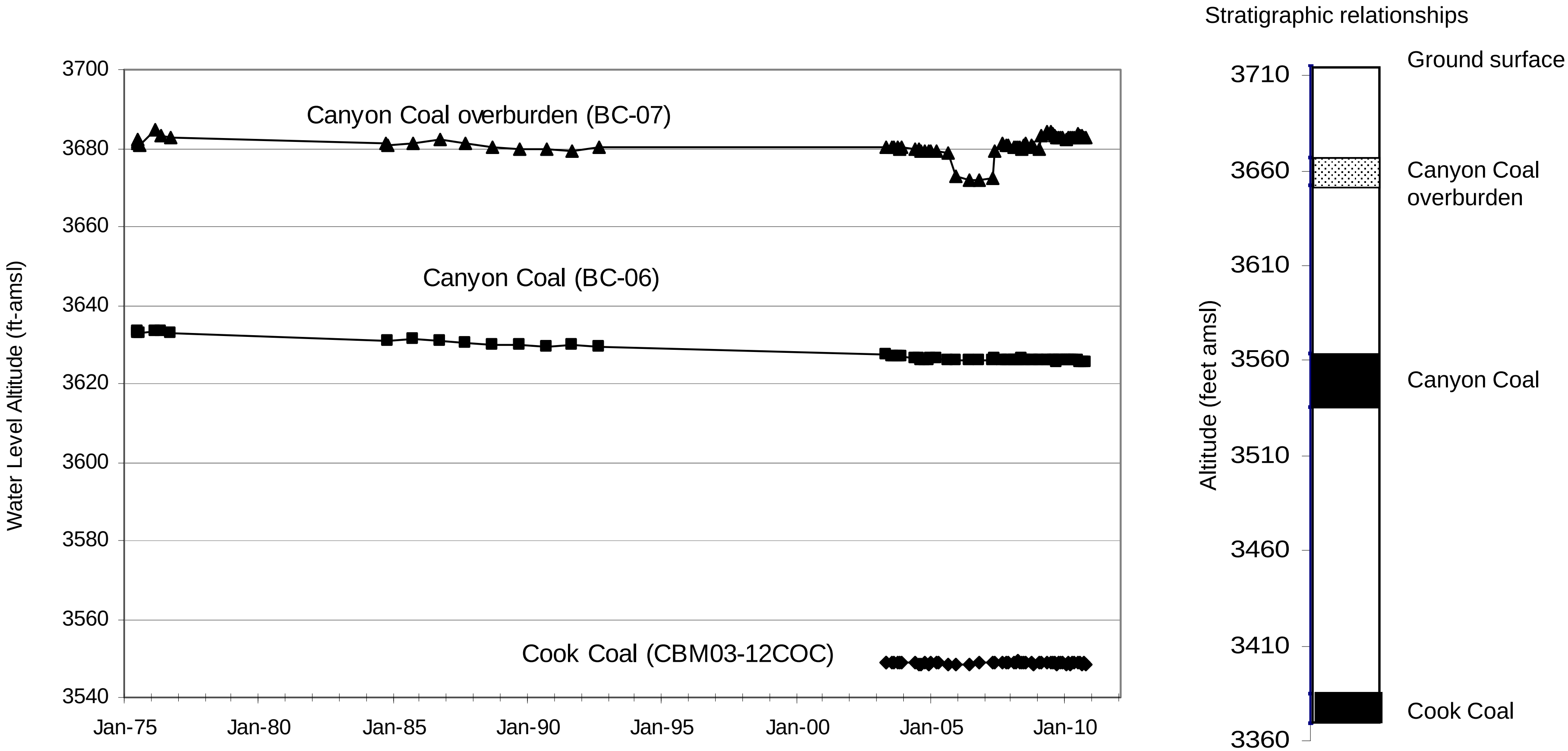


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07), and Canyon coal (BC-06), likely relates to precipitation patterns shown on Figure 2. The 5 years of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence.

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

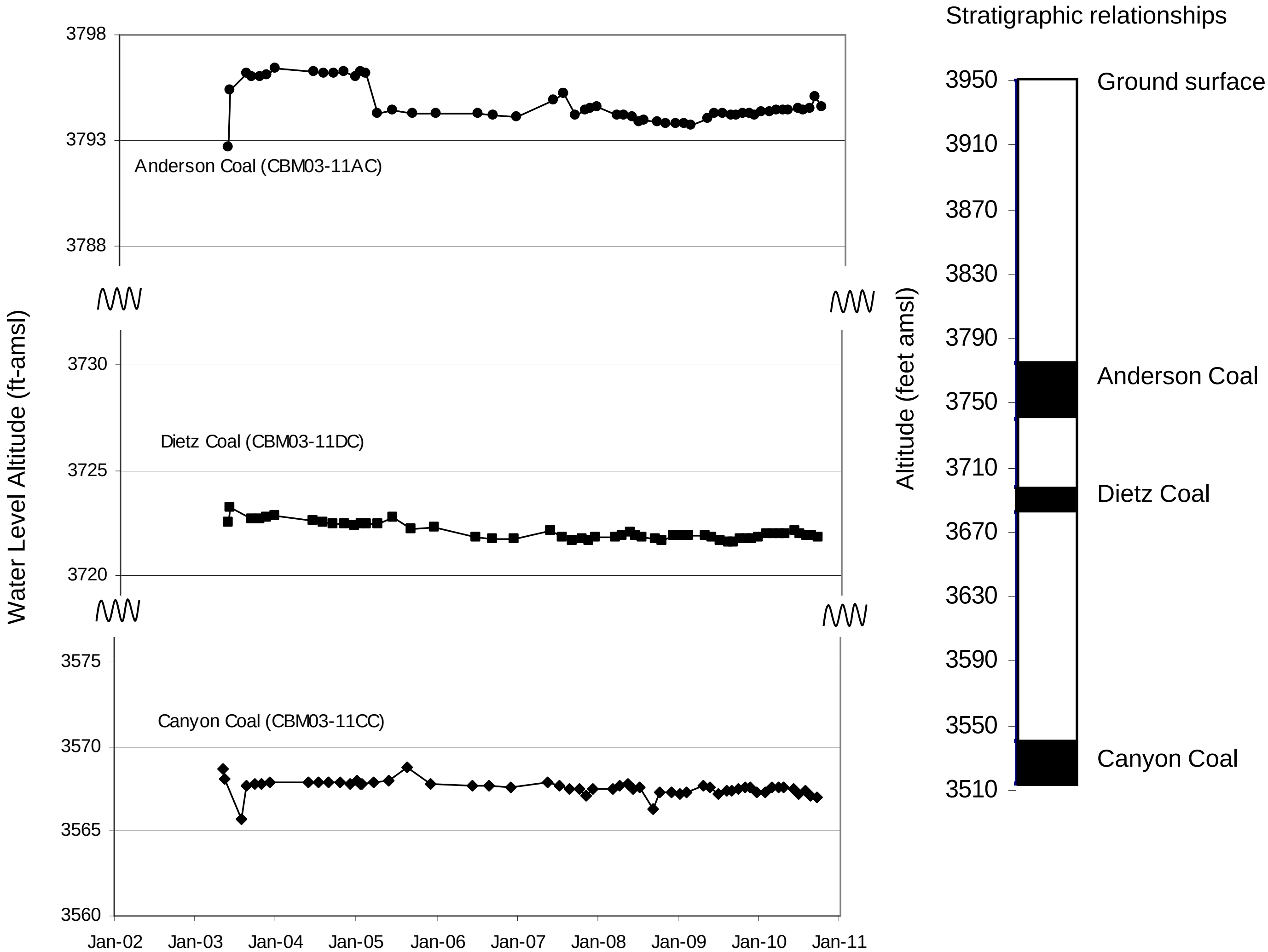


Figure 5 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

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

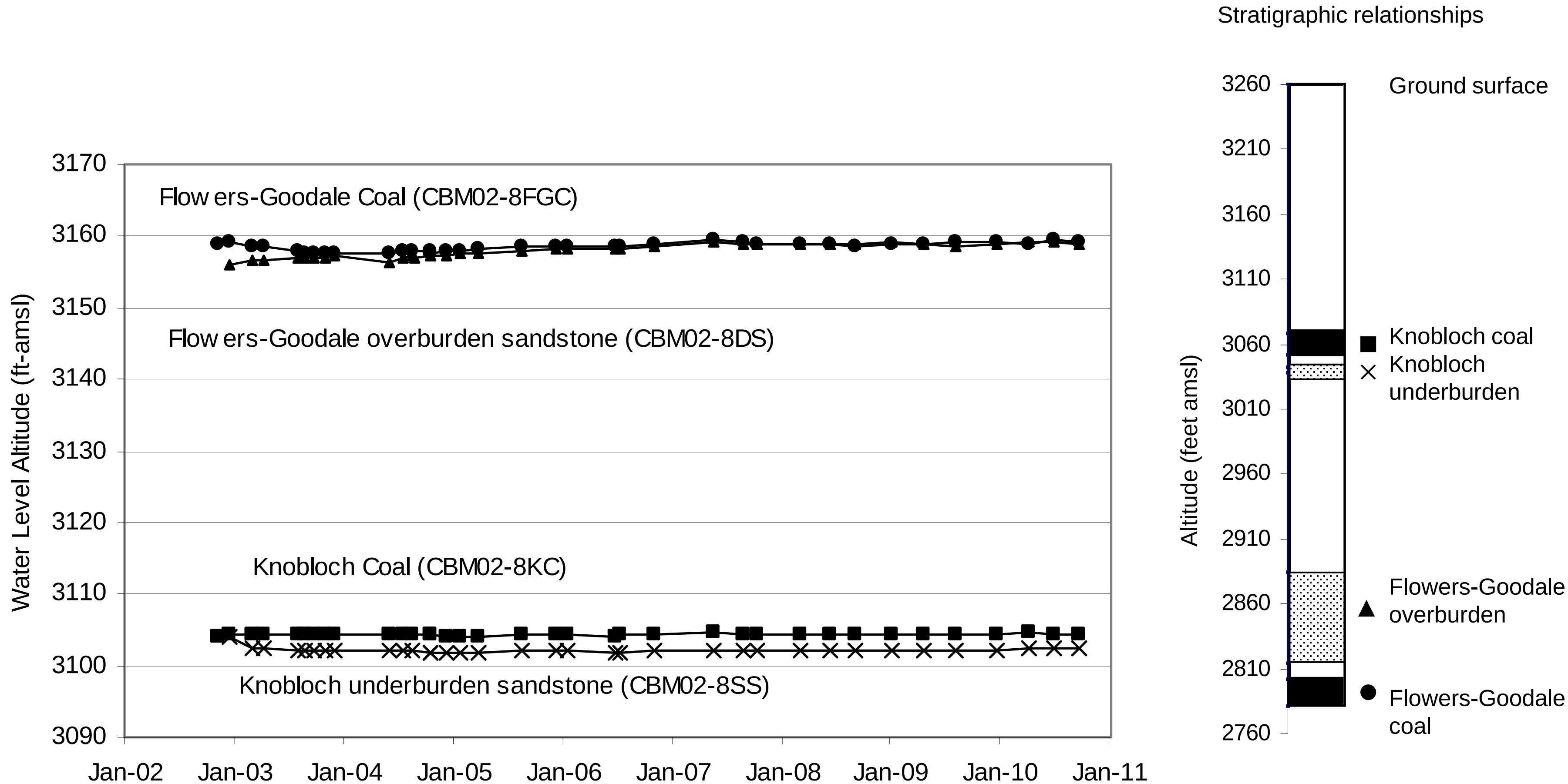


Figure 6. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site.

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

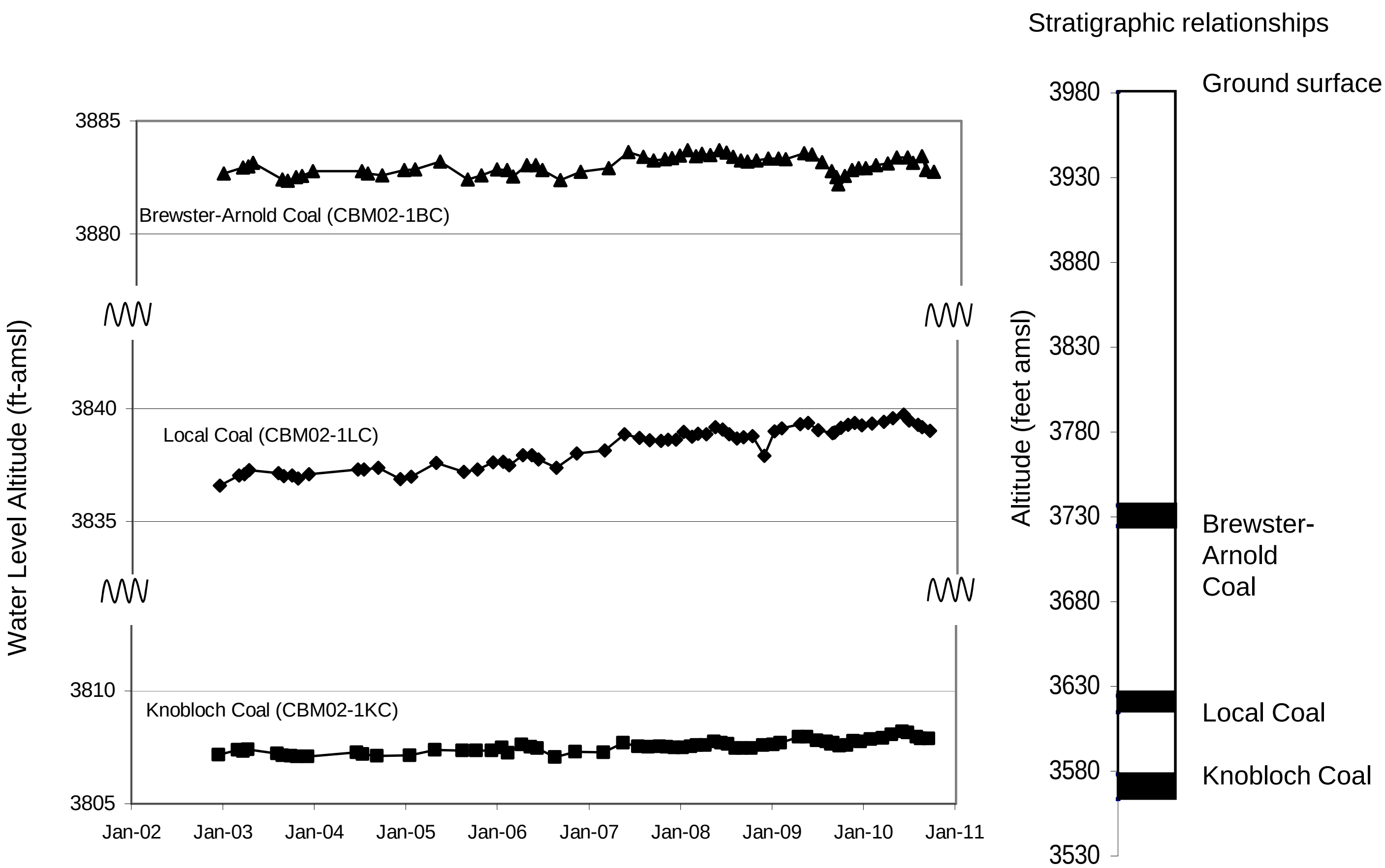


Figure 7. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site.

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

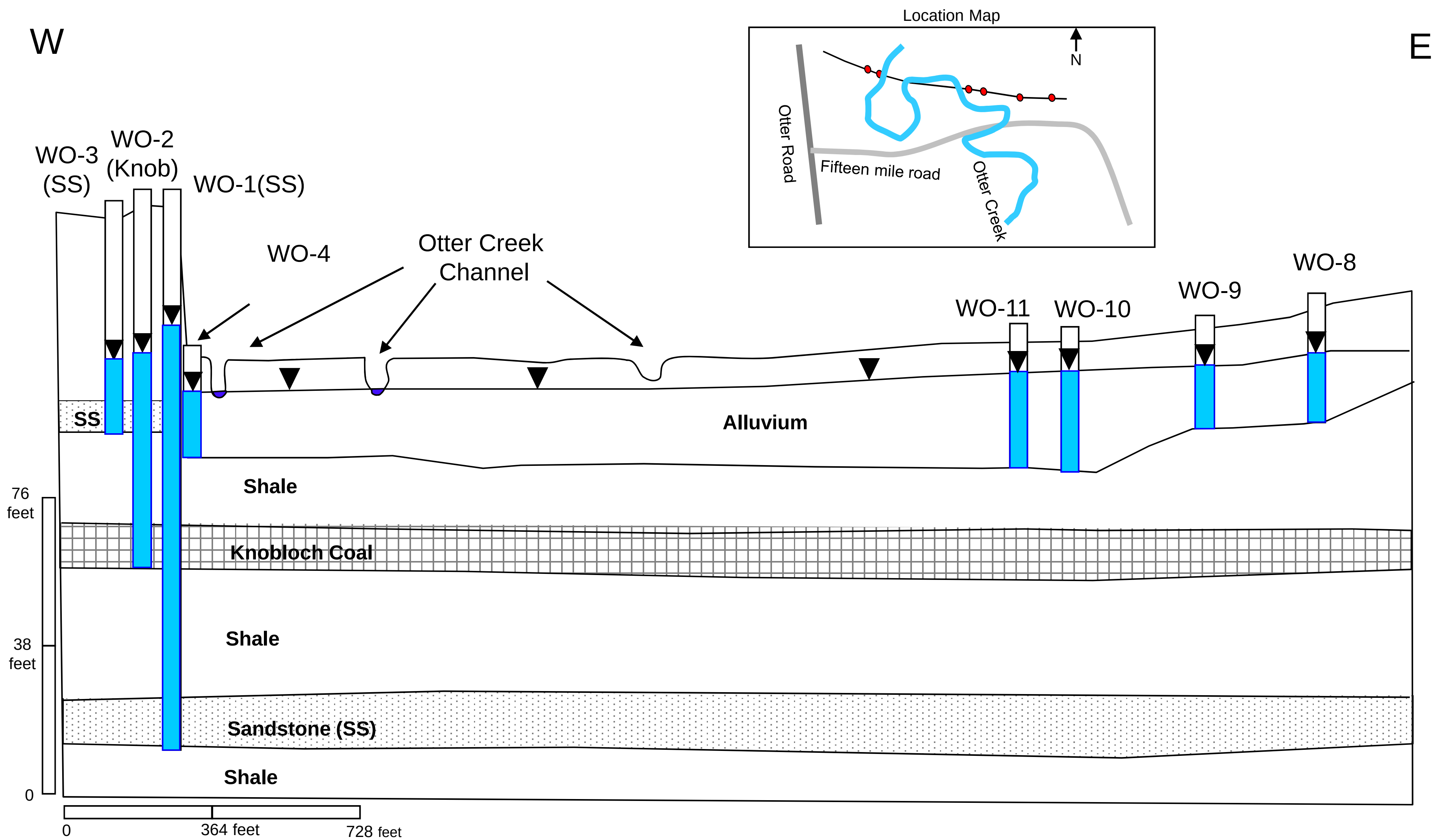


Figure 8. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in February, 2007. Vertical exaggeration is 9.6:1.

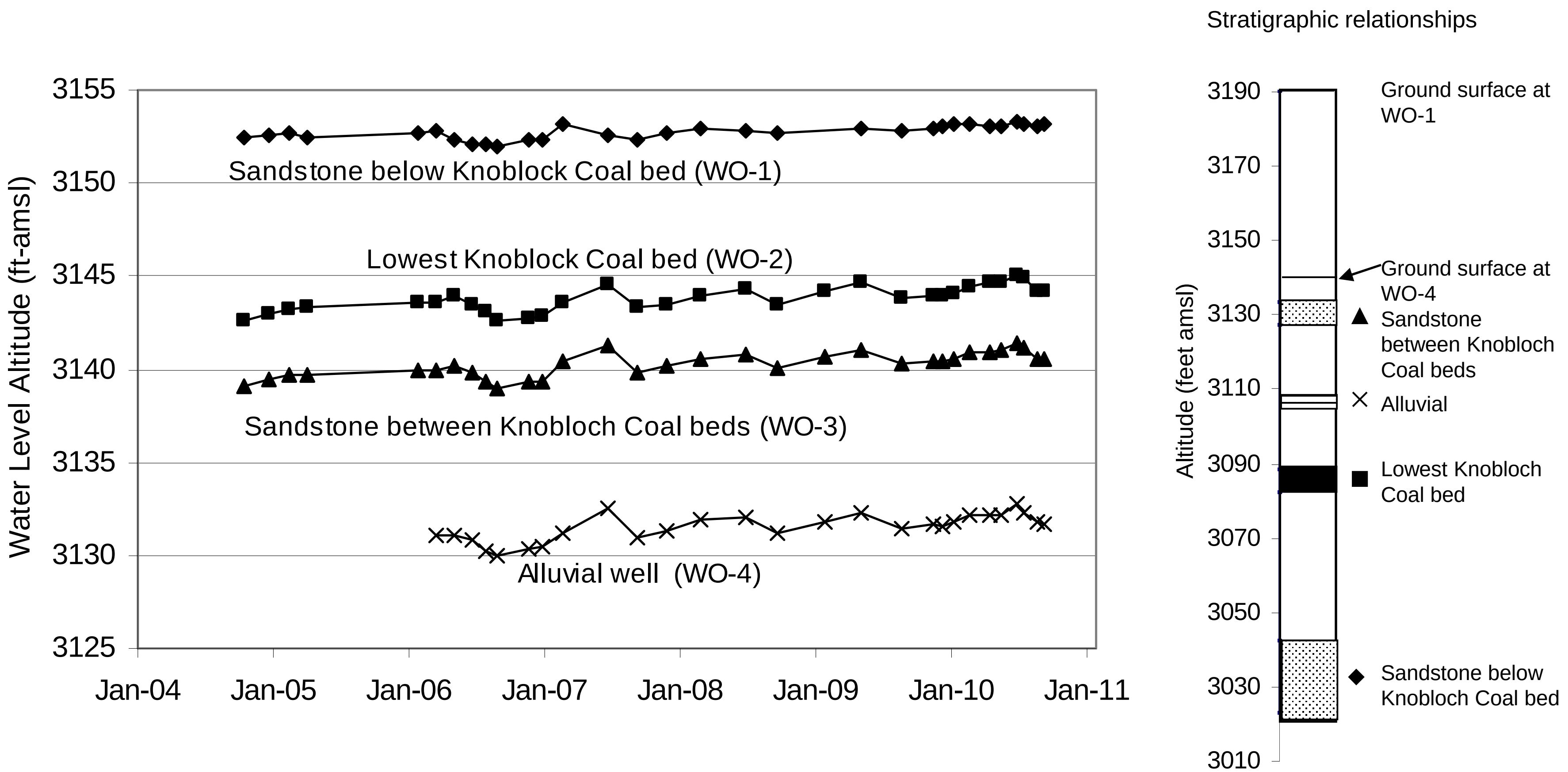


Figure 9. Bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. The alluvial well appears to show the general seasonal water year cycle.

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

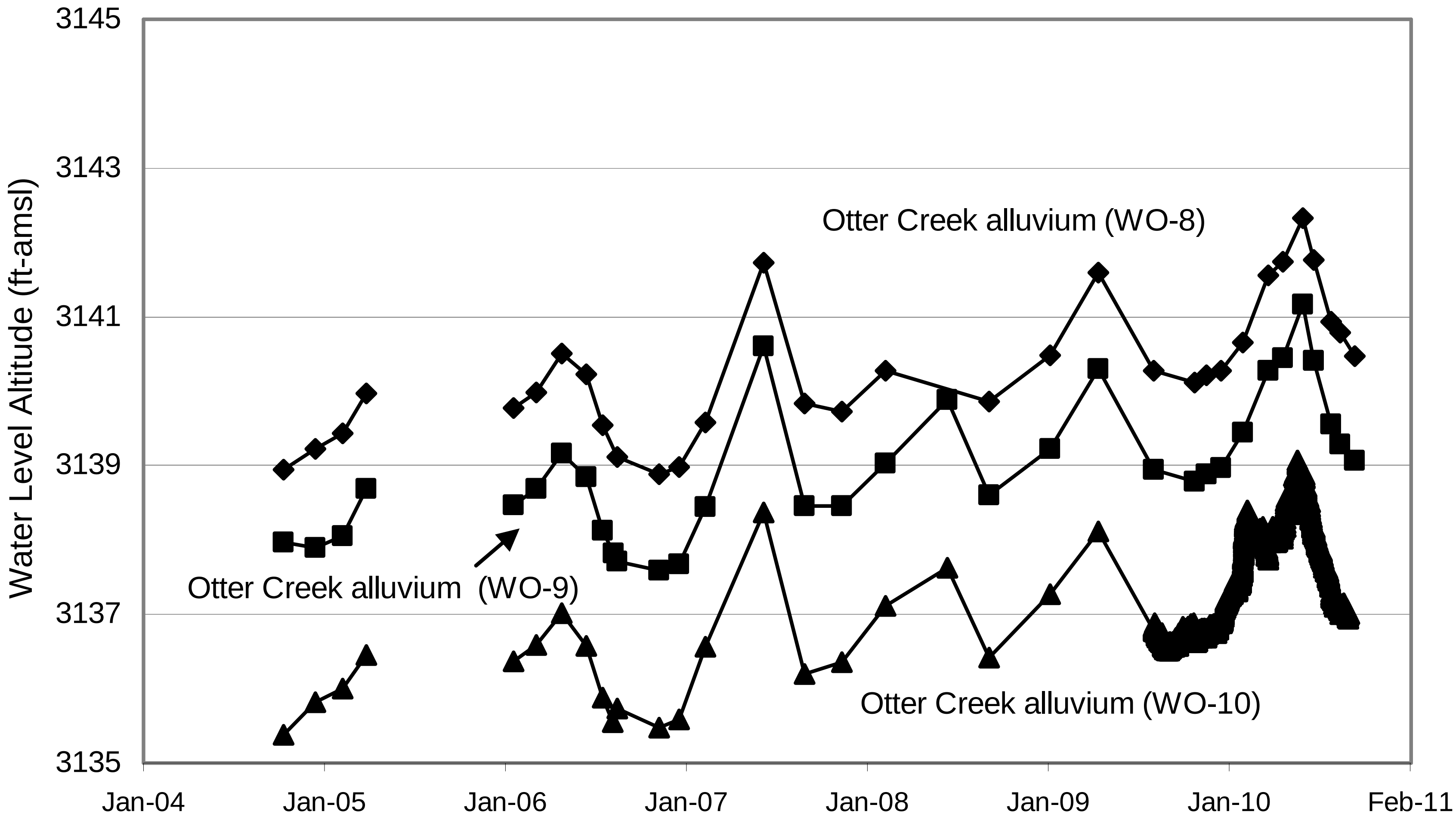


Figure 10. Water-level trends in the alluvium at the Otter Creek site probably relate to weather patterns. The alluvial aquifer appears to receive recharge from the bedrock aquifers in the area, based on the upward vertical gradient Indicated by WO-1,WO-2, and WO-3.

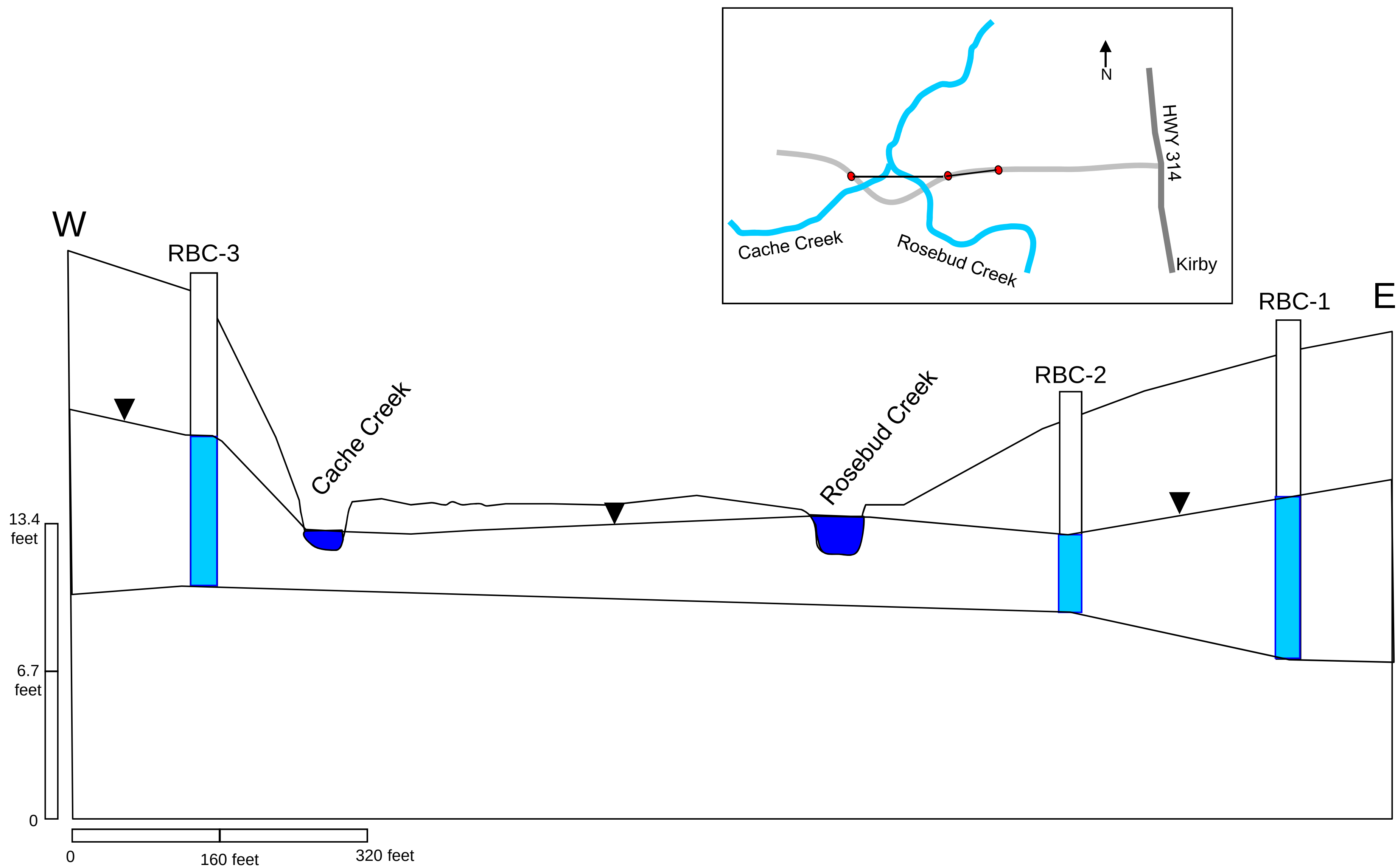


Figure 11. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The creek may gain or lose water depending on the groundwater elevation. The water levels at RBC-2 shows a correlation with the diurnal effect from the surrounding alfalfa plants. Water levels for this cross section were taken in September 2010. Vertical exaggeration is 23.9:1.

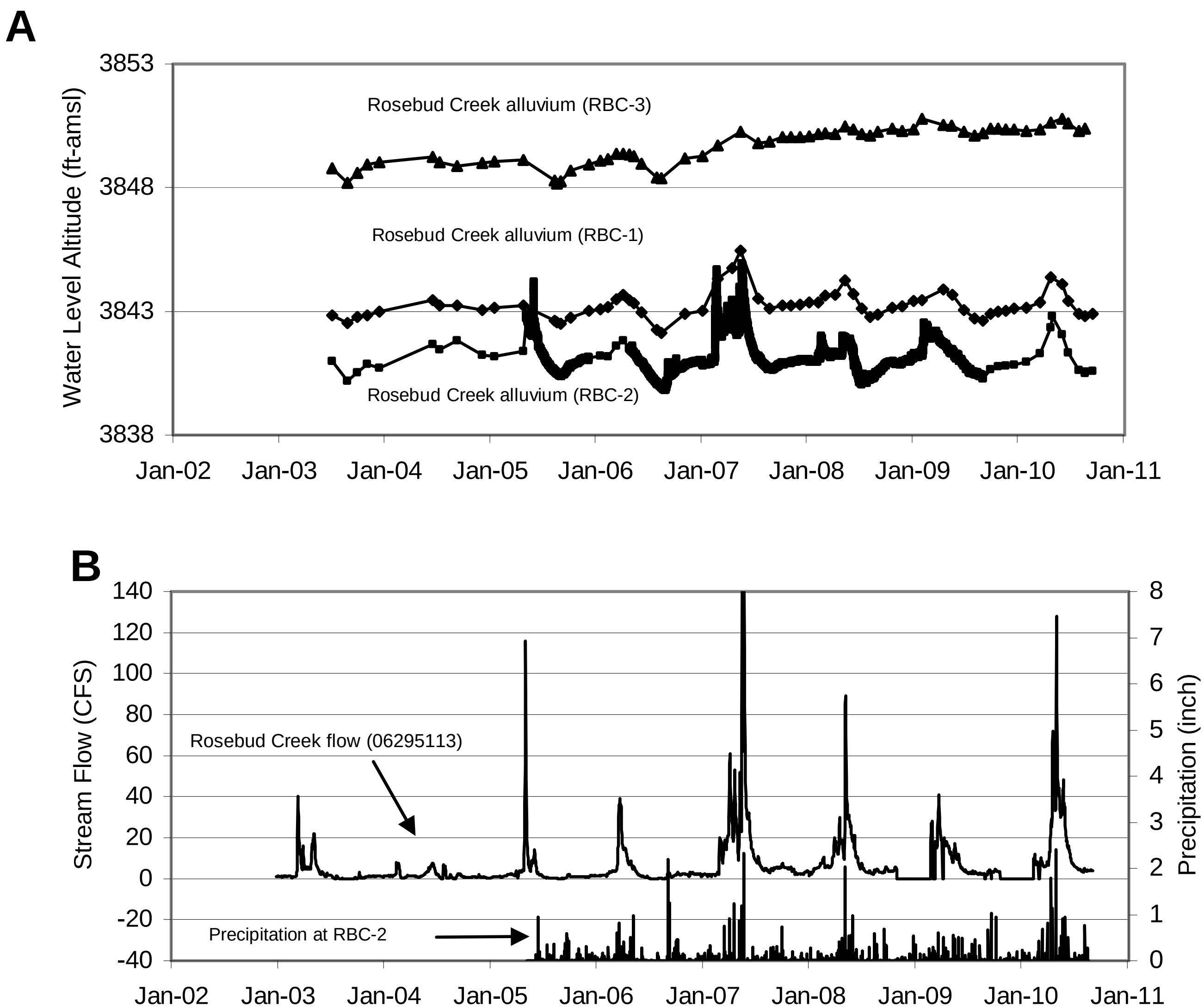


Figure 12. A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. B) Rosebud Creek stream flow follows precipitation trends.

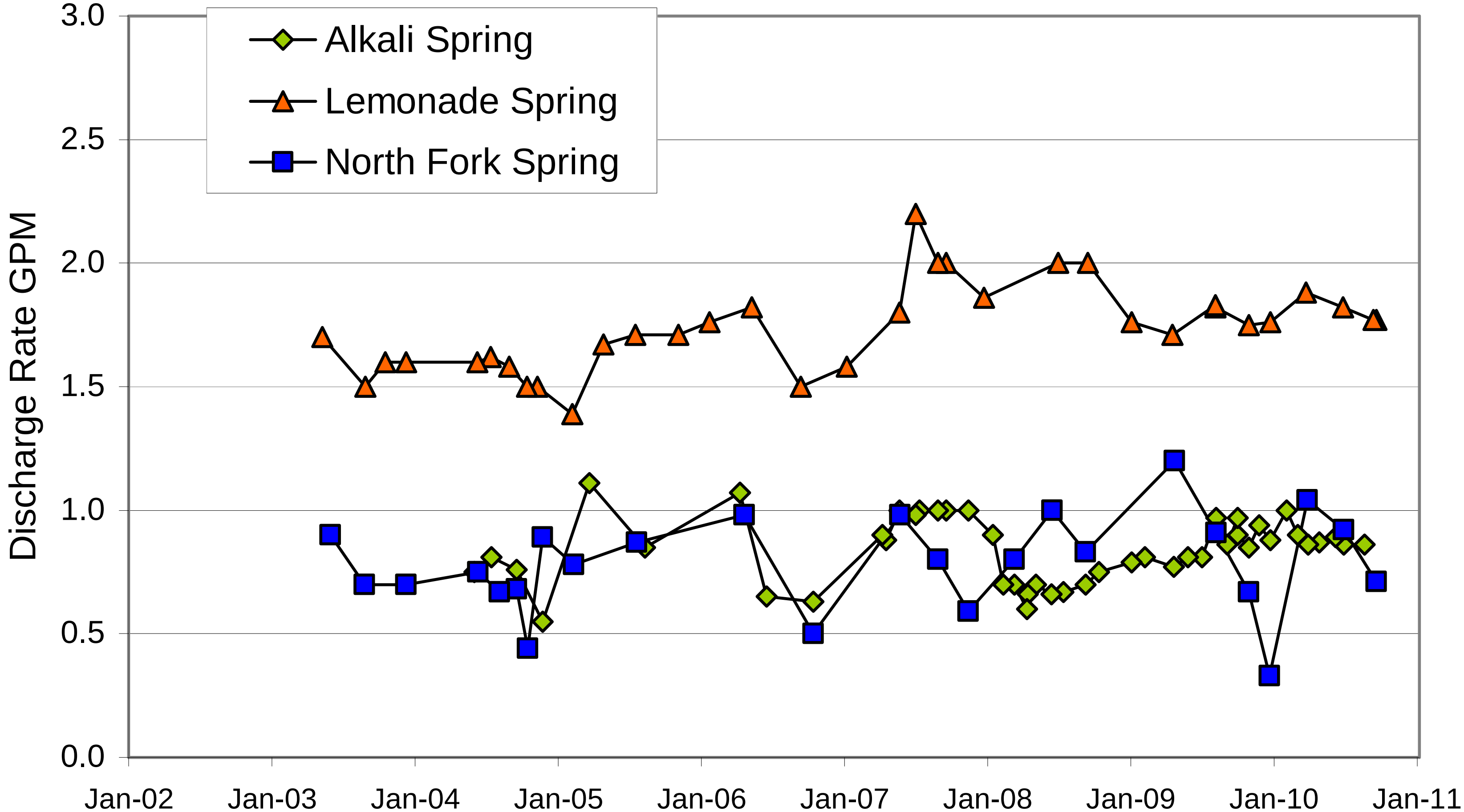
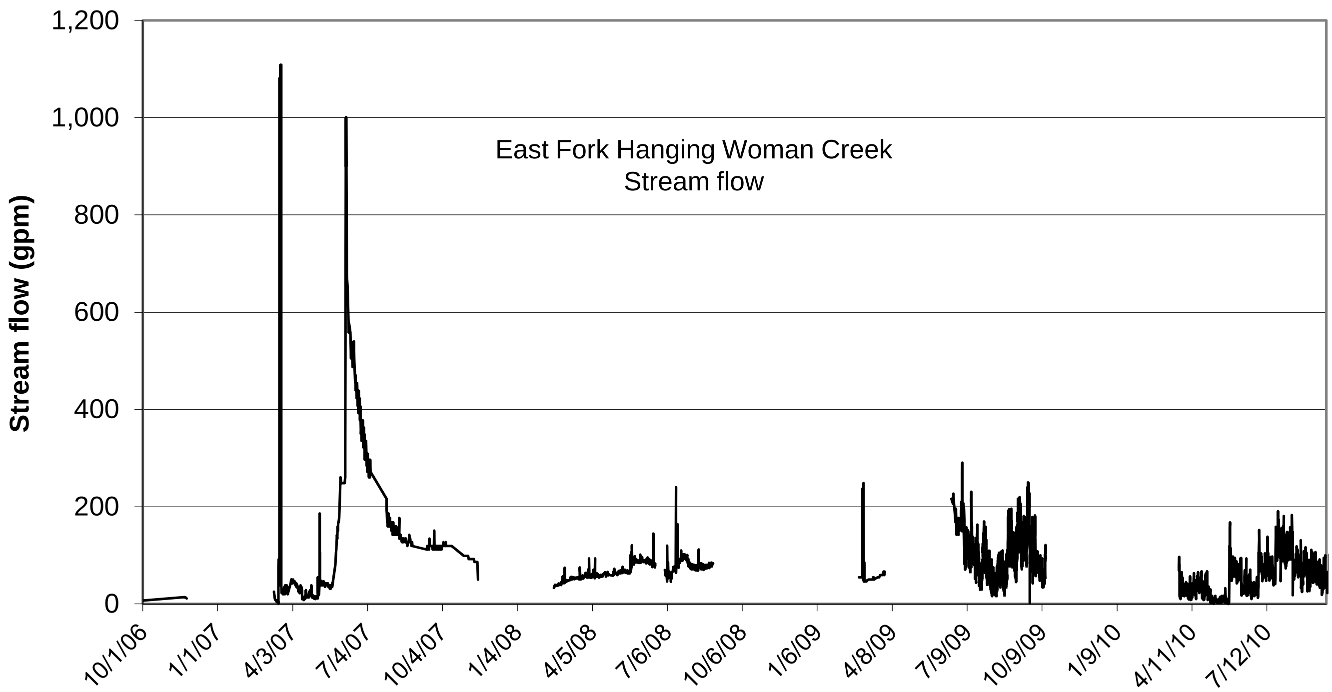


Figure 13. Alkali Spring appears to be a combination of local and regional recharge associated with the Otter coal aquifer. The average discharge rate is 0.84 gpm. North Fork Spring appears to be locally recharged by the Canyon coal aquifer. The average discharge rate is 0.79 gpm. Lemonade Spring appears to be locally recharged by the Ferry coal bed. The spring has an average discharge rate of 1.73 gpm.



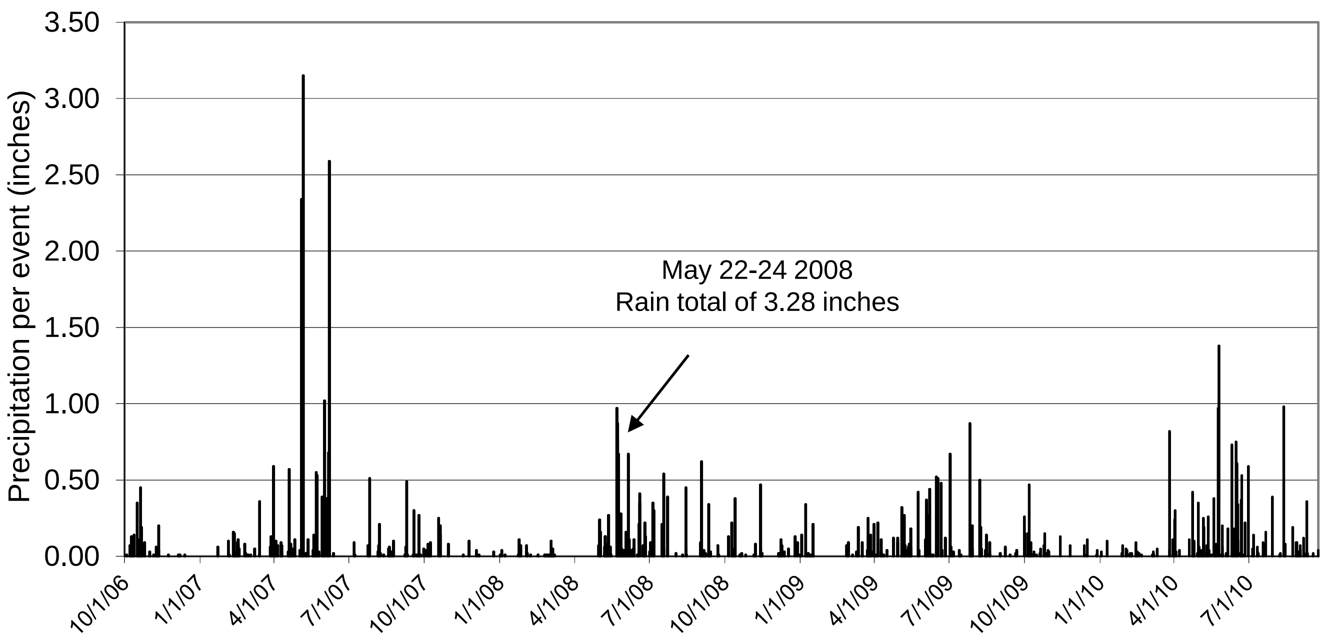


Figure 14. Stream flow at the East Fork Hanging Woman Creek weir correlates with precipitation events recorded at the Poker Jim meteorological station. Precipitation is shown as the total rain in inches per event in the lower graph. A precipitation event is defined as continuous precipitation with no more than 3 continuous hours of no precipitation.

Groundwater conditions within areas of coalbed methane production and influence

Contiguous areas of wells classified as producing CBM on the MBOGC web page cover an area of approximately 50 square miles (Plate 1). Roughly one-half of the area is west of the Tongue River and one-half is east of the river. Coalbed methane permitted wells are summarized by county and field in Table 3. A total of 1,711 coalbed methane wells have been permitted in Montana as of November 23, 2010, an increase of 5 permits over last year. Of these wells, 402 are shut-in, abandoned, or plugged and abandoned (P&A on Table 3), 707 are producing and the rest are either permitted, spud, or expired. Counties experiencing CBM production or permitting for CBM production include Big Horn, Powder River, Carbon, Custer, Gallatin, and Rosebud; however, only Big Horn and Rosebud have producing wells.

Produced-water data for 2010 were retrieved for Montana (MBOGC, 2010) and Wyoming (WOGCC, 2010) and are summarized in Table 4. A total of 824 wells produced methane and/or water in Montana during 2010 (this number differs from the Table 3 either because producers have not updated the well status or because of the time difference between the data downloads of October 1st and November 23rd). These wells produced a total of 33.5 million barrels (bbls) of water (4,323 acre-feet). In Wyoming during 2010, 87 million barrels of water (11,154 acre-feet) were produced from the 1,960 wells in the two townships nearest Montana (57N and 58N). The total amount of water co-produced with CBM in the Powder River Basin in *all* of Wyoming from October 2009 to September 2010 was approximately 534 million bbls or 68,800 acre-feet.

Table 3. Summary of Montana Board of Oil and Gas Conservation Listings of Coalbed Methane Permitted Wells by County.

County	Field or POD (Operators)	Well Status	Mar. 2008	Oct. 2008	Nov. 2009	Nov.2 010
Big Horn	Coal Creek	Permit to Drill	7	6	4	5
		Expired Permit	0	0	2	2
		Spudded	2	1	0	0
		Producing	13	26	23	20
		Shut In	49	35	39	44
	CX	Permit to Drill	27	44	3	0
		Expired Permit	228	226	280	288
		Expired, Not Released	3	25	8	0
		Spudded	17	0	6	0
		Producing	741	705	676	623
		Shut In	77	129	172	231
		Temporarily Abandoned	2	8	9	8
		Abandoned - Unapproved	29	29	29	14
		P&A - Approved	2	2	2	17
	Deer Creek Fee POD	Permit to Drill	32	21	10	10
		Expired Permit	0	0	11	22
		Expired, Not Released	0	11	11	0
		Shut In	1	1	1	1
	Dietz	Permitted Injection Well	1	1	1	1
		Expired Permit	0	0	35	42
		Expired, Not Released	42	42	7	0
		Spudded	1	0	0	0
		Producing	96	92	36	61
		Shut In	10	5	61	45
	Forks Ranch - State	Permit to Drill	n/a	16	8	8
		Expired Permit	n/a	0	5	7
		Expired, Not Released	n/a	0	2	0
		Shut In	n/a	0	1	1
	Waddle Creek - State	Permit to Drill	n/a	16	16	16
		Producing	n/a	0	0	1
	Wildcat Big Horn	Permit to Drill	0	1	1	2
		Expired Permit	36	36	36	37
		Expired, Not Released	2	2	2	1
		Spudded	2	2	0	0
		Producing	2	2	3	0
		Shut In	19	25	26	21
		Temporarily Abandoned	1	1	1	1
		Water Well, Released	0	1	1	1
Carbon	Wildcat Carbon	Expired Permit	1	1	1	1
		P&A - Approved	3	2	2	3
Custer	Wildcat Custer	Producing	1	1	0	0
		P&A - Approved	0	0	1	1
Gallatin	Wildcat Gallatin	Expired, Not Released	1	1	0	0
		Expired Permit	0	0	1	1
Powder River	Castle Rock	Permit to Drill	121	0	0	0
		Expired Permit	7	128	128	128
		Shut In	6	0	0	6
		P&A - Approved	1	0	0	1
	Wildcat Powder River	Permit to Drill	1	0	0	0
		Expired Permit	25	26	26	26
		Producing	1	1	1	0
		Shut In	3	9	8	5
		P&A - Approved	1	2	3	1
		Water Well, Released	0	0	0	1
Rosebud	Hosford	Permit to Drill	n/a	n/a	n/a	1
	Kirby, East	Shut In	n/a	n/a	n/a	1
	Wildcat Rosebud, N	Expired Permit	1	1	1	1
		Spudded	1	2	0	0
		Permit to Drill	1	0	2	1
		Producing	0	0	2	2
		Shut In	1	1	2	1

Source: Montana Board of Oil and Gas Conservation online database: http://bogc.dnrc.mt.gov/ accessed 11/23/2010

Table 4. Annual summary for all wells in Montana and northern Wyoming (townships 57N and 58N) reporting either gas or water production during 2010.

	Field	Well Count	Gas (MCF) 2009	Annual+ total water production in **Bbls *1,000** (acre-feet)			
				2010	2009	2008	2007
Montana	Coal Creek	28	176,110	2,262 (292)	2,055 (265)	1,782 (230)	2,389 (308)
Montana	CX	713	9,229,692	29,310 (3,778)	31,625 (4,176)	35,414 (4,565)	34,686 (4,471)
Montana	Dietz	82	550,280	1,817 (234)	1,790 (231)	2,837 (366)	2,159 (278)
Montana	Waddle Creek	1	32,263	151 (20)	151 (20)	89 (11)	0 (0)
	MT Combined	**824**	**9,988,345**	**33,540 (4,323)**	**35,621 (4,591)**	**40,121 (5,171)**	**39,234 (5,057)**
Wyoming	Prairie Dog Creek	1,185	32,024,043	35,938 (4,632)	45,052 (5,807)	56,947 (7,340)	51,259 (6,607)
Wyoming	Hanging Woman Creek	246	3,226,444	15,641 (2,016)	19,269 (2,484)	24,589 (3,169)	22,342 (2,880)
Wyoming	Near Powder River	529	7,787,257	34,957 (4,506)	40,233 (5,186)	45,396 (5,851)	38,187 (4,922)
	WY Combined	**1,960**	**43,037,744**	**86,535 (11,154)**	**104,554 (13,477)**	**126,932 (16,361)**	**111,788 (14,409)**

Montana source: MBOGC web page (http://bogc.dnrc.mt.gov/default.asp)

Wyoming source: WOGCC web page (http://wogcc.state.wy.us/)

+Totals reflect production during the water year for 2010, 2009, 2008 and calendar year 2007

Estimated average discharge rates per well are used to predict aquifer drawdown and water-management impacts from CBM development. The Montana CBM environmental impact statement (U.S. Department of the Interior Bureau of Land Management, 2008) and the technical hydrogeology report associated with that analysis (ALL Consulting, 2001) included an estimation of the average water production rates per CBM well. The trendline for the estimated water production rate for individual wells is shown as a dashed line on Figure 15. This trend is re-evaluated here based on 137 months (the longest producing well) of available production reports. The monthly average water-production rates for CBM wells in Montana are plotted in gallons per minute against normalized months in Figure 15.

The early production data (normalized months 1 through 6) appear to reflect the effects of infrastructure construction and well development, not hydrologic response. Similarly, the average values for normalized months over 130 are not believed to be indicative of typical CBM well production because less than 20 wells have been producing 130 months or longer. The amount of water initially produced, on average, from each CBM well is less than was expected (Figure 15). However, predicted water production rates are between the 80th and 90th percentile of actual production. The predicted and observed rates become similar after approximately 6 years. Between 6 and 10 years of production, the actual rate of CBM water production levels out and exceeds the anticipated rate. After 10 years the rate of water production begins to rise again. Wells that have been producing over 10 years are in the older CBM fields in Montana where wells are being shut-in. This means the remaining wells have to produce more water to keep the coal groundwater drawn-down. The area between the anticipated and actual production lines in Figure 15 prior to month 72 represents the amount of water that was anticipated, but never produced (see figure 18). This lower quantity of CBM production water decreases the amount of water that must be included in water-management plans and decreases the anticipated stress on the aquifers. The difference between the anticipated and actual production after month 72 represents the water produced in excess of the predicted production. However, because there are relatively few wells that have produced over 6 years, the actual production is still significantly less than anticipated.

Gas production for an average well in the PRB increases sharply in the well's first 5 months of active production and is then relatively stable from 5 to 35 months of production (Figure 16). The peak production for an average well occurs in its second year at around 2,500 MCF/month. After 35 months of production, the gas produced slowly decreases throughout the life of the well. The range of production in wells varies greatly as illustrated by the 90th percentile of production; however, the 80th and 90th average percentiles also follow the same pattern of production.

Gas and water production rates from individual wells vary by location within the basin. Figures 17A and 17B illustrate the role local geology plays in field productivity. In figures 17A and 17B, each point represents an individual CBM well, the size of the point is proportional to the amount of gas or water the well has produced over its operating life, and the color of the point corresponds to the number of months a well has been in production. These figures allow field productivity to be generally compared based on age. Northern fields, especially those near the Tongue River, tend to produce more water without producing significant amounts of gas; however, the same northern field is a good example of the well-to-well variation that can be found within one field. Three wells produced much more gas than the surrounding wells. The wells in the field to the east of the reservoir have all produced a similar amount of water; however, the amount of gas has varied quite a bit. This variability may be caused by the coal that the CBM wells are completed in or by fractures creating isolated pockets in the aquifer that drawdown more efficiently.

Total water and gas production since the initiation of CBM production in April, 1999 is presented on Figure 18A. Water production climbed more steeply than gas production from 2006 to today. The dashed line on Figure 18A represents the water that would have been produced if the rate of water production used in the EIS had been correct. The total amount of water produced has been 160 million barrels less than was predicted. Since mid-2008, wells that produce relatively large amounts of water compared to the amount of gas produced have been shut-in which causes the slope of the monthly gas production to be more similar to the slope of the monthly water production (Figure 18B). The rate of water production per month decreases in the years immediately following years where few new wells were installed (e.g. 2003, 2008). When wells are taken off-line the water production quickly reflects this drop (e.g. 2009, 2010). As the price of methane drops, more wells are taken out of production, such as since mid-2008 (Figure 18B).

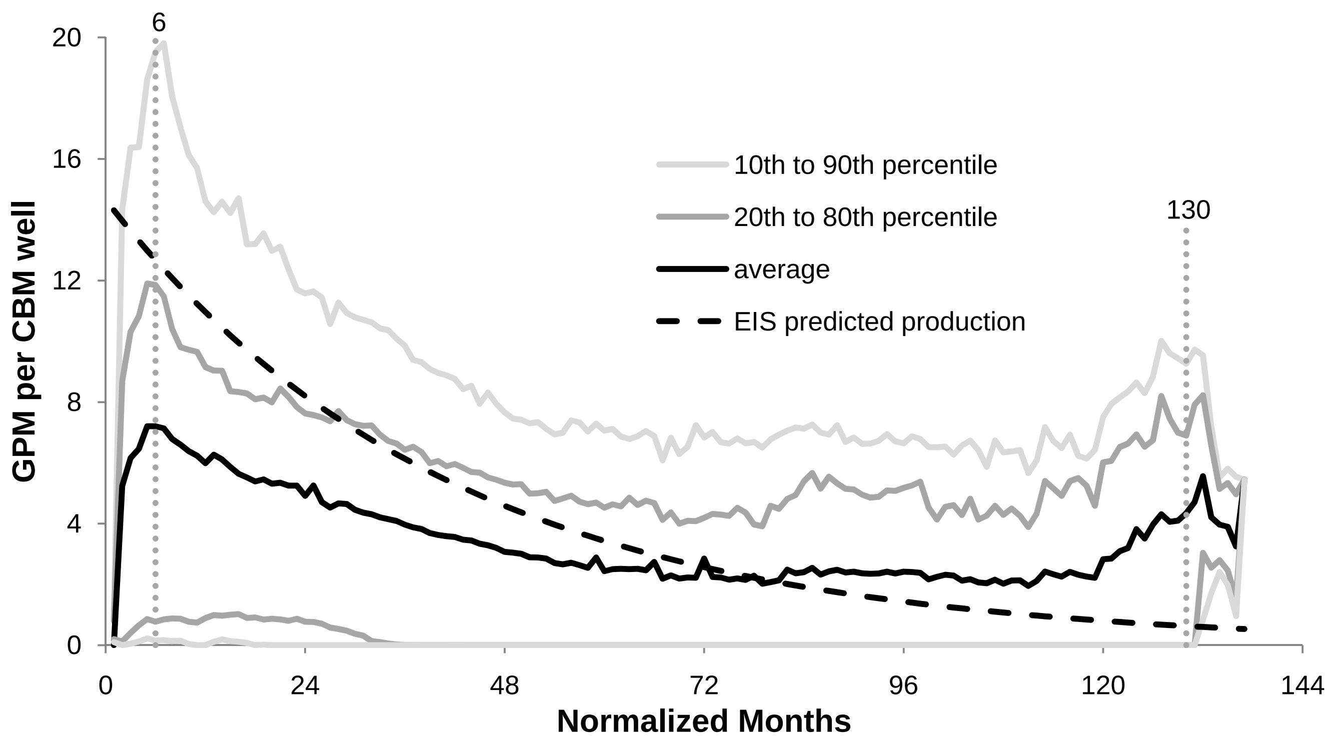


Figure 15. Normalized CBM produced water in gallons per minute (GPM) in the Montana portion of the Powder River Basin (data from the MT BOGC website). The actual average production (solid black line) falls below the EIS predicted production (dashed line: y=14.661 e^(-0.0242x); US BLM, 2003) for the first 6 years of production. Trends from 1 to 6 months and over 130 are not considered to be representative of hydrogeologic responses to CBM production.

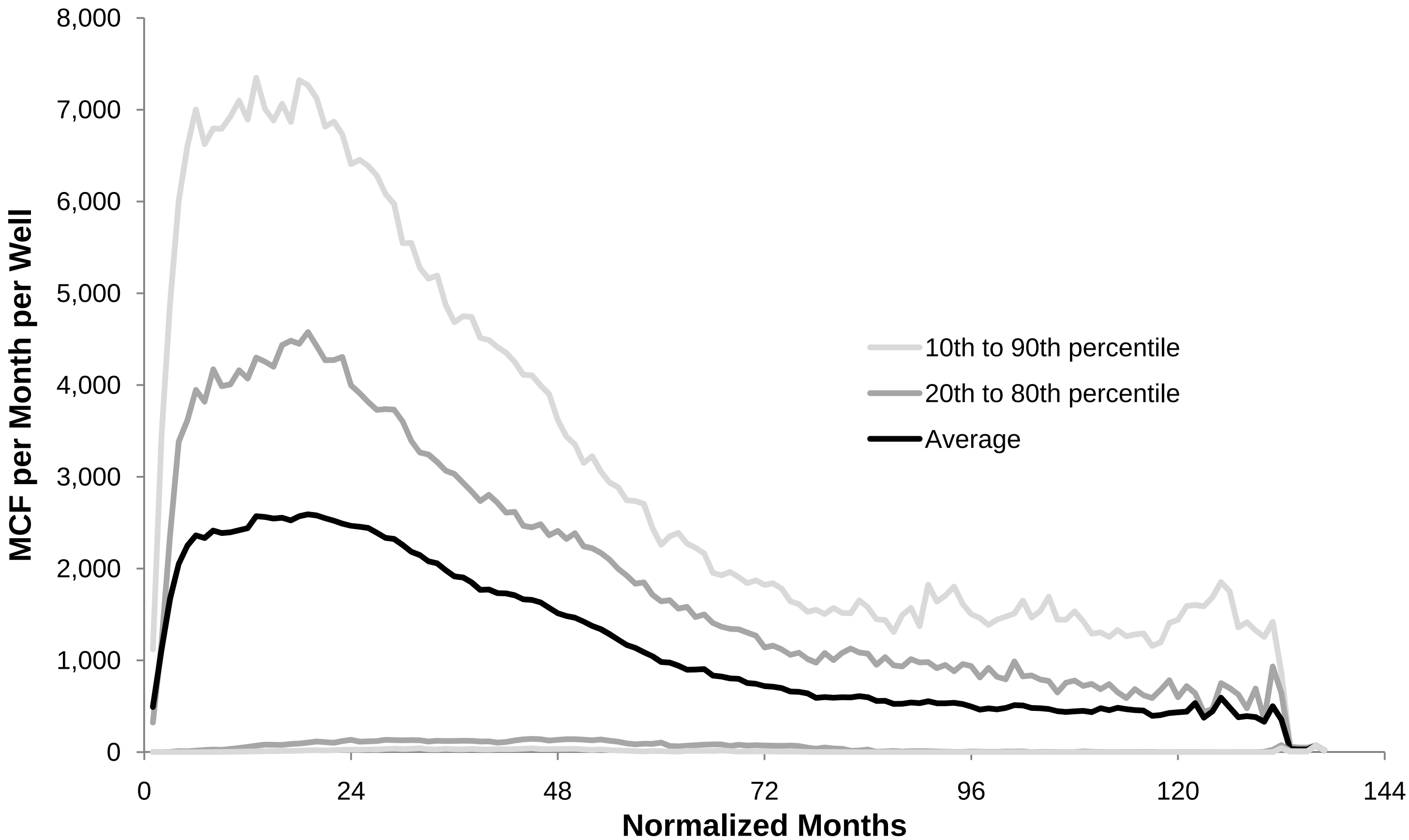


Figure 16. Normalized gas production (MCF) per month for individual CBM wells in the Montana portion of the Powder River Basin (data from MT BOGC web site). The solid black line represents the average gas production per well per month.

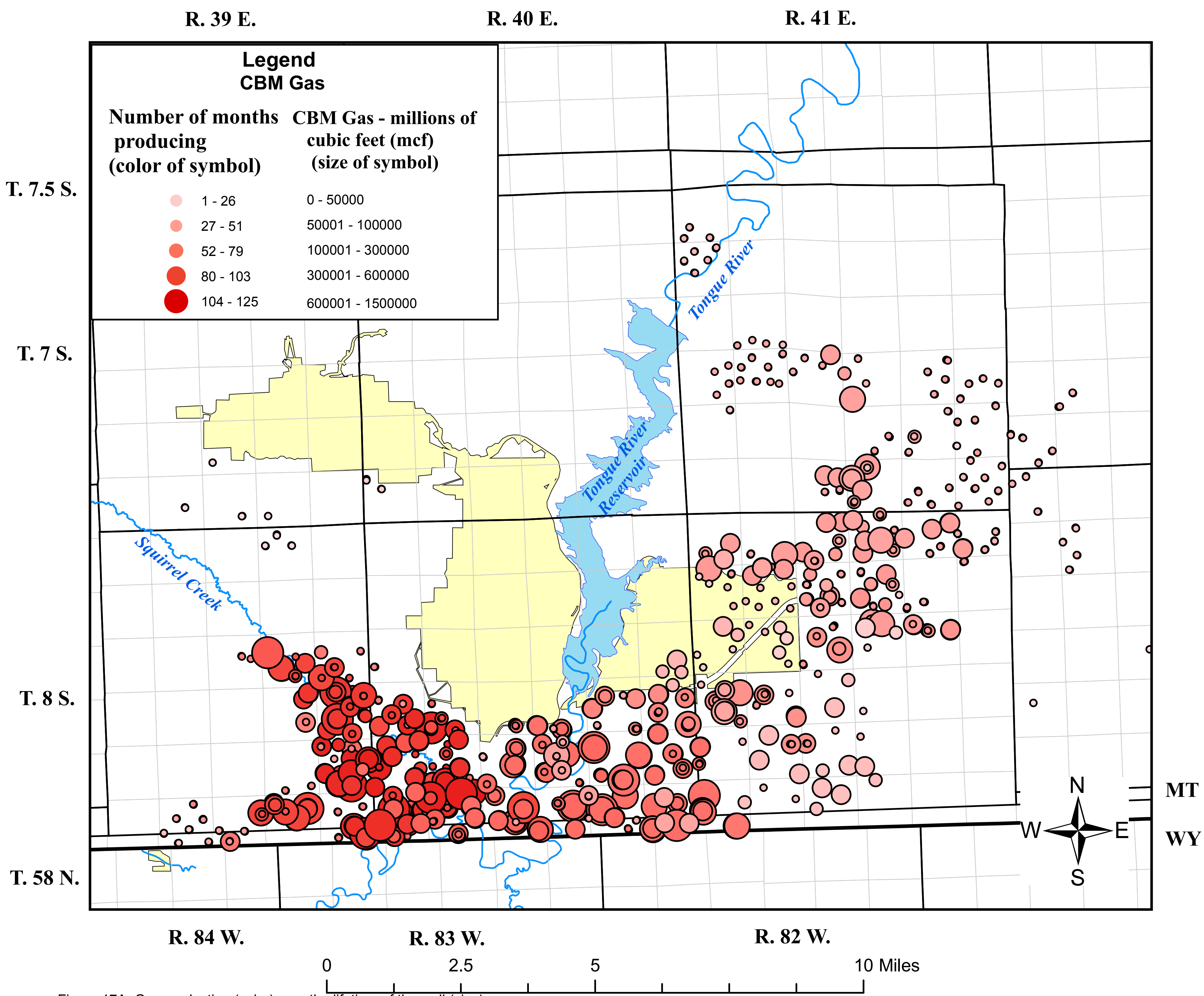


Figure 17A. Gas production (color) over the lifetime of the well (size).

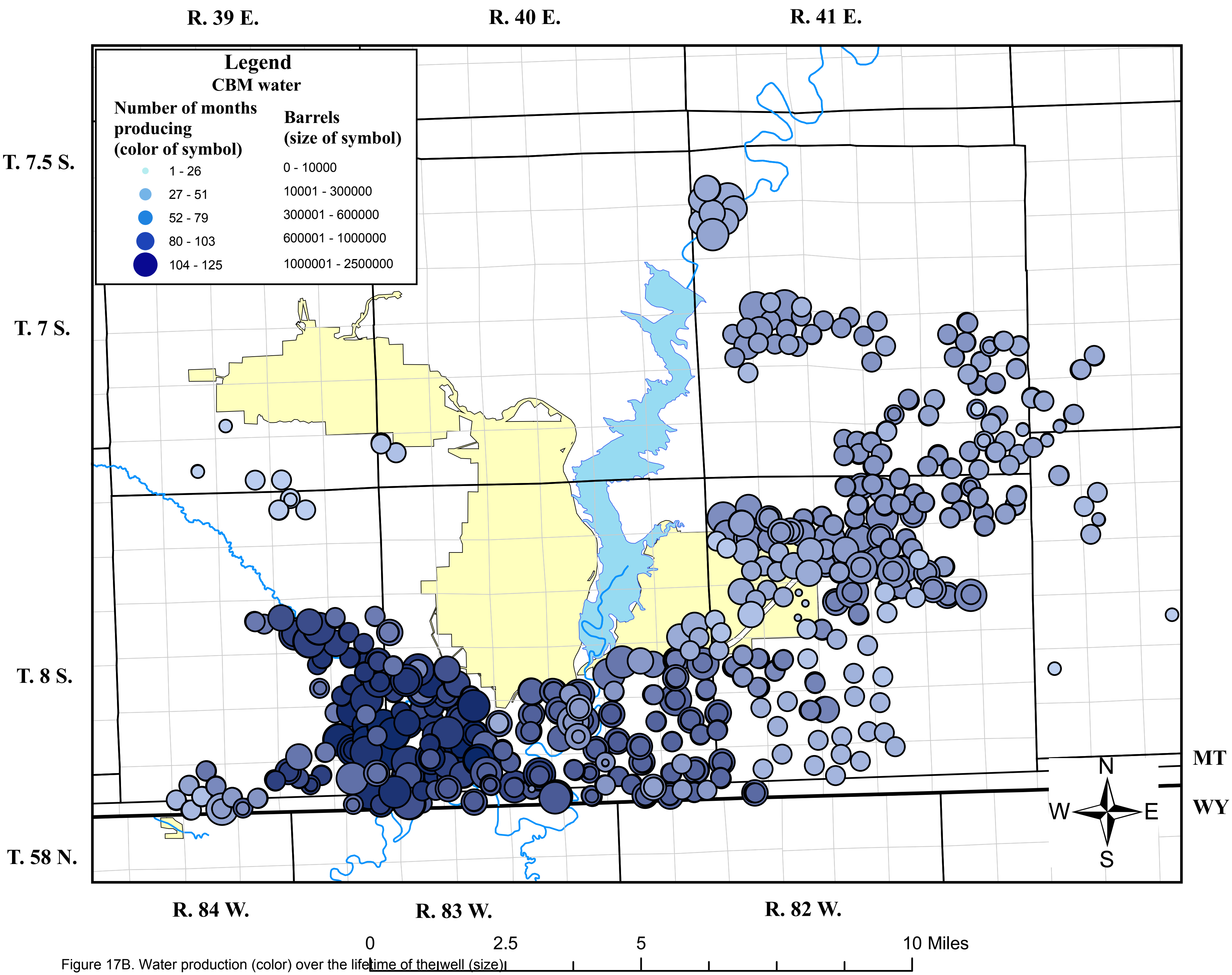
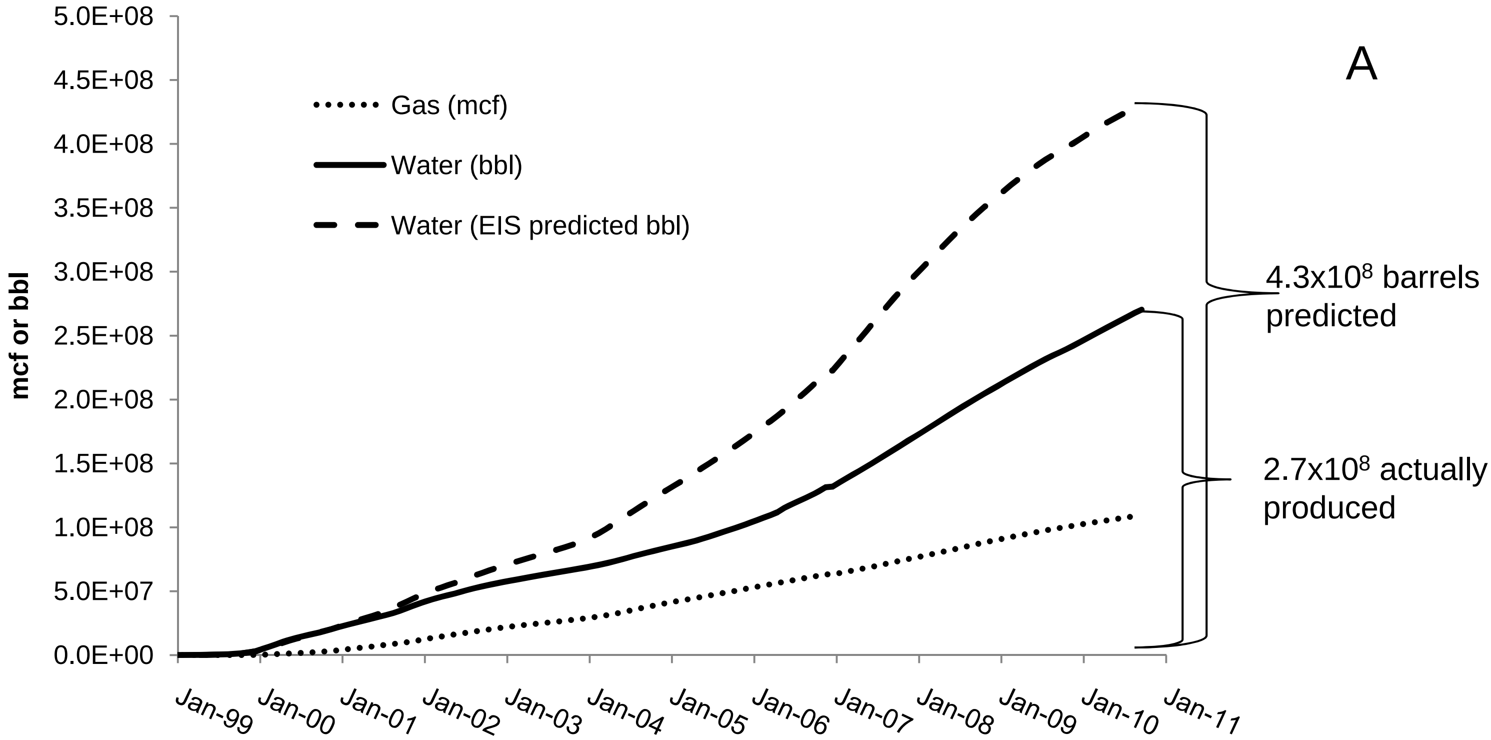


Figure 17B. Water production (color) over the lifetime of the well (size)



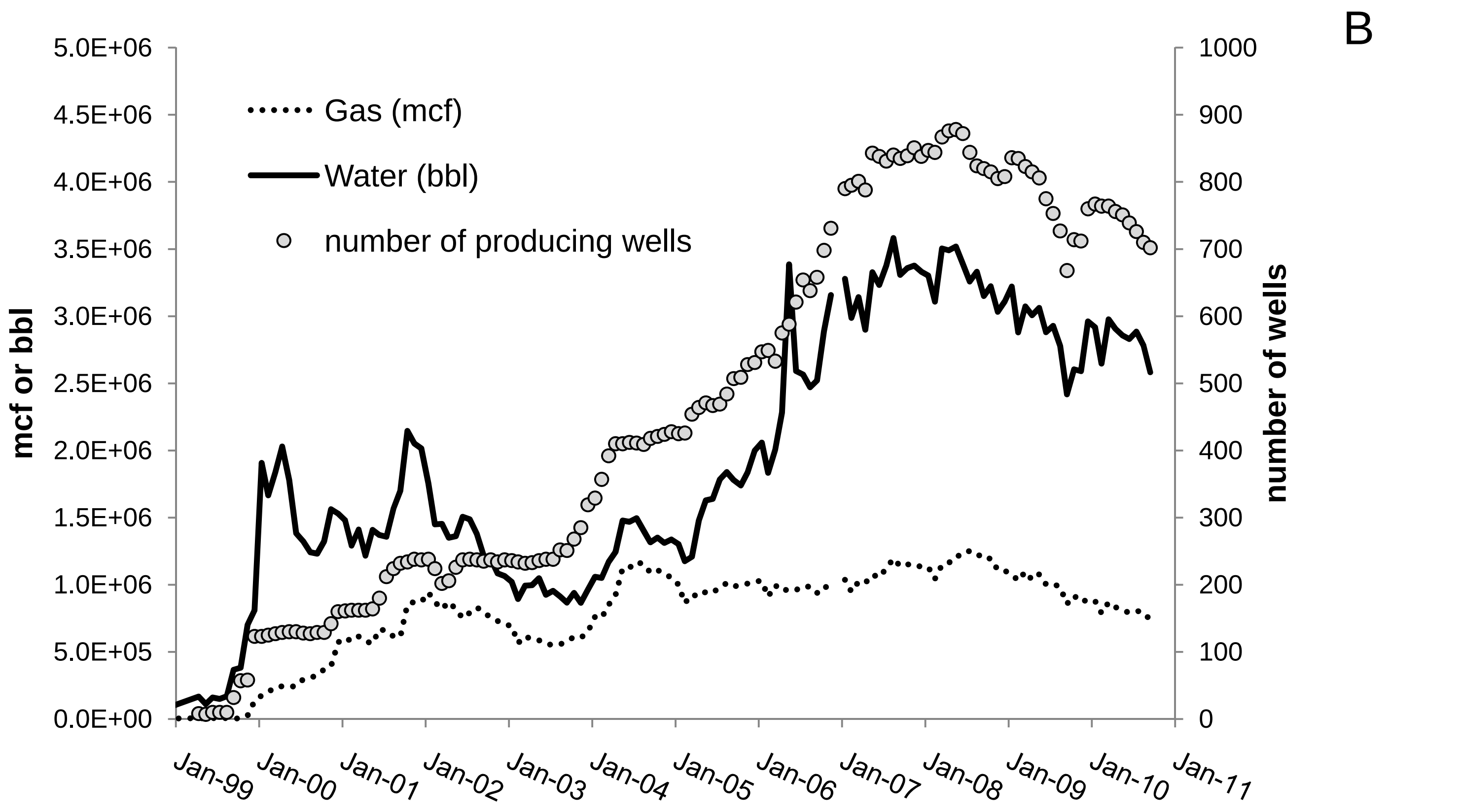


Figure 18A. Total water and gas produced in Montana since CBM production began in the spring of 1999. The dashed line indicates the amount of water that was predicted to be produced based on the EIS rate and the actual number of wells and months produced. This predicted amount exceeds the actual produced water by 160 million barrels.

Figure 18B. Monthly totals of water and gas produced from Montana CBM wells and total number of producing CBM wells. Water production decreases when few new wells are installed or wells are taken out of production.

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 web page (2010). During 2010, a total of 713 CBM wells produced either water, gas, or both in the CX field. Production is from the Smith, Anderson (D1), Dietz 1 (D2), Dietz 2 (D3), Canyon (Monarch), Carney, Wall, King, and Flowers-Goodale coalbeds (Table 4; Figure 2). The total water production for the year was 29.3 million barrels (3,778 acre-feet; 2,340 gpm). Along the western edge of the Fidelity project area near the Montana–Wyoming state line, some wells are no longer being used (as indicated by red well symbols on Plate 1) and others are being pumped at a reduced rate as the methane-production rates in this area have declined. Similarly, across the state line in Wyoming, CBM wells are also being shut-in. Water levels begin to recover in areas where CBM water production rates have decreased as seen in wells WR-27 and WR-38 (Figure 19), among others.

Coal Creek and Dietz gas fields. Data from CBM production wells in the Coal Creek field and Dietz field (Plate 1) were retrieved from the Montana Board of Oil and Gas Conservation web page (2010). Pinnacle Gas Resources, Inc. first produced water from CBM wells in the Coal Creek field north of the Tongue River Reservoir in April 2005 and from the Dietz field northeast of the reservoir in November 2005. During 2010, a total of 28 CBM wells produced water in the Coal Creek field (Table 4). Gas production was from the Wall and Flowers-Goodale coalbeds (Figure 2). The total water production for the 12-month period was 2.3 million barrels (292 acre-feet; 181 gpm). A total of 82 CBM wells produced water in the Dietz field during 2010 (Plate 1, Table 4). Production is from the Dietz, Canyon, Carney, and Wall coalbeds (Figure 2). The total water production for the 12-month period was 1.8 million barrels (234 acre-feet; 145 gpm).

Bedrock-aquifer water levels and water quality

Groundwater trends in areas of bedrock aquifers that are susceptible to CBM impacts in and adjacent to the CX field are presented in Figures 21 through 29. Groundwater levels in this area respond to a combination of influences from precipitation patterns, coal mining, and CBM production. Both coal mining and CBM production have created large areas of lowered groundwater levels in the coal beds.

The potentiometric surface for the Dietz coal aquifer is shown in Plate 2, and is based on data provided by the CBM industry, coal mine operators, and data collected by the MBMG as part of the regional monitoring program. Drawdown within the Dietz coal that is interpreted to be specific to CBM production is shown on Plate 4. The locations of active CBM wells at any specific time are not available, so some generalizations are necessary in interpreting Plate 4. It does appear that drawdown of at least 20 feet has reached a typical distance of about 1 mile beyond the active field in most areas and has reached 1.5 miles in some areas. For the Canyon coal, the potentiometric surface is shown on Plate 3 and drawdown related to CBM production is shown on Plate 5. Based on the available data, drawdown within the Canyon coal appears similar to that in the Dietz; 20 feet of drawdown reaches about 1 mile beyond the field boundaries.

Drawdown was expected to reach 20 feet at a distance of 2 miles after 10 years of CBM production (Wheaton and Metesh, 2002) and a maximum distance of 4 to 5 miles if production continued for 20 years in any specific area (U.S. Department of the Interior, Bureau of Land Management, 2008). While similar, current measured drawdown is less than expected. This is primarily due to CBM development rates and production duration being less than anticipated and faults isolating drawdown. Additionally, aquifer properties are not well constrained (0.4 to 1.5 meters/day; Van Voast and Reiten, 1988) and the model could be sensitive to these values.

Water Levels. Hydrostatic pressure in the combined Anderson and Dietz coal in well WR-34 near the Ash Creek mine declined about 21 feet between 1977 and 1979 due to mine dewatering (Figure 20). The Ash Creek mine pit reached a maximum size of about 5 acres. Pit dewatering maintained a reduced water level until reclamation and recovery began in 1995. Water levels returned to near-baseline conditions in 1998. Between 2001 and 2003 groundwater levels at this site were lowered to about 150 feet below baseline conditions by CBM production. The greater magnitude of drawdown at this monitoring well due to CBM development is primarily due to the proximity to the area affected by CBM production. Since March 2003, the water levels have recovered to within 29 feet of baseline conditions. This represents 81% recovery during a period of 7.5 years. The recovery rate has stalled in the last year with only 3 inches of recovery occurring in the last 12 months. Overall, the recovery appears to be due to a reduction in the pumping rates and the number of producing CBM wells in this area; however, not all wells are shut-in and the water level appears to be reaching an equilibrium with the remaining pumping wells.

Groundwater level responses due to the Ash Creek mine pit dewatering are also evident at well WR-38 (Figure 21). The water level in this well dropped at least 80 feet in response to CBM production. In response to decreased pumping from CBM wells in this area, the water levels in WR-38 have now recovered to within 19 feet of baseline conditions, or a water-level recovery of about 76%. Well BF-01 is completed in the Ash Creek mine spoils. Although the mine pit created a water-level response in the adjacent coal aquifer, the water level in the spoils did not respond to CBM production. The spoils aquifer is probably unconfined and the lack of a measurable response is not surprising due to the much greater storage capacity of an unconfined system.

Monitoring wells installed in the Fort Union Formation show that the monitored fault sections in this area are often no-flow boundaries (Van Voast and Hedges, 1975; Van Voast and Reiten, 1988). Dewatering of the East Decker mine pit, which is less than 1 mile north of a monitored fault, has lowered water levels in the Anderson coal (WRE-19) and overburden aquifers for over 25 years on the north side of the fault (Figure 22) but there was no response to mine pit dewatering south of the fault (WRE-18). Current monitoring of CBM-production-related drawdown south of the fault shows the opposite response as water levels in the Anderson coal (WRE-18) south of the fault have been lowered significantly without a similar decrease in water levels north of the fault (WRE-19). WRE-18 lowest recorded water level was over 170 feet below baseline which occurred in May 2006 and June 2010. The isolated drawdown effects indicate that the fault acts as a barrier to flow within the Anderson coalbed. South of the fault (WRE-17) the Smith coal responds slightly to both coal mining north of the fault and CBM production south of the fault. Reduced pressure from coal mining may have migrated around the end of the fault or the reduced pressure from CBM production from the Anderson coal has lowered the pressure in overlying aquifers.

Near the western edge of the CX field, but isolated by faults from nearby active CBM wells, water levels in the Carney coal (CBM 02-2WC) have been responding to CBM-related drawdown since the well was installed in 2003. Water levels in this well are now 17.2 feet lower than the first measurement (Figure 23). It appears that the drawdown observed at this site results from drawdown that is channelized along a SW-NE trending fault block from CBM wells to the northeast approximately 3.5 miles away on Squirrel Creek. The water level in the Canyon coal (WR-24) at this site has decreased somewhat, which may be a response to CBM production or may be due to long-term precipitation patterns. The water level in the Roland coal (CBM 02-2RC), stratigraphically above the CBM production zones and on the other side of the fault, dropped about 8 feet during 2005, began to recover in early 2006 but has not yet reached previous water levels. The cause of the water-level changes in the Roland coal is not apparent and is unlikely to be related to CBM development. The type of response is much different than that measured in the other coal aquifers at this site.

Near the East Decker mine, coal mining and CBM production has lowered water levels in the Anderson, Dietz 1, and Dietz 2 coals (wells WRE-12, WRE-13, PKS-1179, respectively) (Figure 24). The rate of water level drawdown increased, particularly in the Dietz 2 coal, in response to CBM production in the area. Most likely due to reduced CBM activity in the area, water levels in three coal aquifers recovered slightly in 2008; however, water levels have leveled off or dropped in 2010. During CBM production, water levels are lowered to the top of the aquifer so deeper coals experience more drawdown than do shallower coals.

Changes in stage in the Tongue River Reservoir affect water levels in aquifers that are connected to it such as the Dietz coal, which crops out beneath the reservoir. Water levels in the Dietz coal south of the reservoir show annual responses to the reservoir stage levels, but the water levels are more strongly influenced by mining and CBM production (Figure 25). Since January, 1995 the stage in the reservoir has ranged between a low of 3,387 and a high of 3,430 feet above mean sea level (amsl) (DNRC, 2010). Average reservoir stage during this time has been about 3,415 feet amsl, which is higher than the Dietz potentiometric surface and it is likely that some water has always seeped from the Tongue River Reservoir to the coal seam. The average stage during the water year 2010 was 3422 feet amsl, which is higher than the historical average because goals for reservoir storage have increased recently. This creates a greater gradient between the head of the reservoir, which is increasing, and the Dietz coal, which is decreasing due to CBM production, and will most likely result in more water seeping into the coal from the surface. Ultimately, however, the amount of the increased seepage related to CBM production will be limited by faulting (Plate 2).

The water level in the Anderson coal monitored in the Squirrel Creek watershed (WR-17; Figure 26) was lowered 37 feet by coal mine dewatering and had been lowered 30 feet from CBM production until monitoring ended. Water levels are no longer collected from this Anderson coal well because of a methane hazard. Declining water levels (10 feet since the year 2000) in Anderson overburden at this site show either a possible correlation with precipitation patterns or migration of water from CBM production in underlying coalbeds, however this aquifer is separated from the

Anderson coal by over 50 feet of shale, siltstone, and coal. The shallow, unconfined aquifer (WR-17A) shows a rapid rise following the start of CBM production. This rise, totaling about 30 feet, is interpreted to be a response to a, now unused, infiltration CBM holding pond. Since use of the pond was discontinued, the water table has returned to near baseline. The deeper overburden aquifer (WR-17B) at this site shows no response to the holding pond.

Monitoring well site CBM02-7 is located about 6 miles northwest of Pinnacle's Coal Creek Field (Plate 1). No response in water levels due to CBM production has been measured in either the overburden sandstone or Canyon coal at this site (Figure 27). Similarly, two miles west of the Tongue River and about 4 miles north of the Tongue River Dam, there has been no response to CBM production in the overlying sandstone aquifer (Figure 28).

Well CBM02-4WC monitors the Wall Coal where water levels were lowered about 12 feet from April 2005 to May 2007 in response to water production in Pinnacle's Coal Creek and Dietz areas (Figure 28). The nearest shut-in CBM wells range from about 1.75 to 2.5 miles from site CBM02-4, while the nearest producing wells are over 4 miles away. CBM production in the immediate area was discontinued in March 2007 and the water level recovered through October 2007. Since that time water levels have fluctuated in response to water pumped intermittently from wells along the Tongue River (2.5 miles away) which are completed in the Wall coal (Figure 29). High frequency drawdown and recovery is captured only when real-time water-level data loggers are installed. It is currently difficult to attribute all drawdown to production from the Pinnacle wells in part because the water-level data logger failed from July 2008 to August 2009, which was an active period of water use from the wells along the Tongue River. However, Pinnacle has not pumped these wells since January 2010, yet drawdown was recorded from April 2010 to July 2010. The water level has recovered slightly from July to October 2010 (Figure 29). Since 2007, five new bedrock domestic and stock wells have been installed in the surrounding townships but they are all reported to be completed in sandstone or sandstone with small lenses of coal. It is unlikely that additional domestic and stock wells in the area are causing the drawdown seen in monitoring well CBM02-4WC. Further monitoring is required to determine the distance/drawdown relationship between the production from the Wall coal along the Tongue River and the MBMG monitoring well.

Water Quality. Water-quality samples were collected from Upper and Lower Anderson Springs in October 2009 and May 2010. Water quality is quite different between the two: Upper Anderson had TDS concentrations of 3752 and 3778 mg/L and SAR values of 8.8 and 9.5, while Lower Anderson had TDS concentrations of 1381 and 1524 mg/L and SAR values of 3.0 and 3.1. These springs discharge from the Anderson coalbed. No significant water quality changes have occurred from previous samples.

Six deep wells were sampled in July 2010: HWC-01, WR-24, WR-27, WR-38, WRE-13, and CBM02-7CC. Wells HWC-01, CBM02-7CC and WR-24 are being used for a Master's thesis out of Montana State University's Microbiology department. The research focuses on isolating the methanogenic microbial community that is responsible for the creation of coalbed methane and finding ways to increase the rate of methane creation. As a part of our commitment to periodically revisiting monitoring wells for sampling and to assist in this emerging research field, these wells were chosen for our summer sampling trip. All three wells are completed in the Canyon coal and samples collected previously from these wells indicated that they show a sulfate gradient from high (which would indicate an aquifer without methanogenesis activity) to low (which is a characteristic of a methanogen rich community). The most recent samples also show this gradient. Well WR-24 has a sulfate concentration of 1050 mg/L, well CBM02-7CC has a sulfate concentration of 259.6 mg/L and well HWC-01 has an undetectable (<12.5 mg/L) sulfate concentration. Interestingly, well HWC-01, sampled 6 times from 1974 to 2010, has decreased in sulfate concentration with time from 290 mg/L to undetectable. This progression matches the theory of how the bacterial community evolves from sulfate reducing to methanogenic.

Wells WR-27 and WR-38, completed in the Anderson/Dietz and Dietz 1 and 2 combined coals, were chosen for sampling because they show water level recovery from slowed CBM production in the area (see Figure 19). It is unclear as to whether this water level recovery originates from redistribution of aquifer water or from primary recharge. Well WR-27 was sampled three times in years that represent times when the aquifer was at baseline conditions (1976), actively dewatered for the Ash Creek mine (1991), and during recovery from CBM production (2010). Well WR-38 has been sampled 6 times that represent times when the aquifer was being drawndown for the Ash Creek Mine (1977), actively dewatered for the mine (1991, 1993), recovering from mine dewatering (1996, 1997), and recovering from CBM production (2010). With one exception from well WR-38 collected while it was recovering from coal mining in 1997, there has not been a significant change in water quality in either of these wells. This indicates that, at least initially, water level recovery is coming from aquifer redistribution and/or that recharge pathways are not significantly shortened (Figure 30).

Well WRE-13, completed in the Dietz coal, was chosen for sampling this year because it shows the influence of the Tongue River Reservoir in addition to CBM and mine related drawdown. It was unclear as to whether the influence on the water level in well WRE-13 from the reservoir was from pressure or from direct infiltration of Tongue River surface water. Displaying the available water chemistry analyses on a Piper Diagram illustrates that there has not been a change in water chemistry since sampling began in 1975 – all samples are dominated strongly by sodium and bicarbonate. The groundwater in the Dietz coal has a very different composition from the Tongue River (USGS, 2010), which is calcium-magnesium and bicarbonate-sulfate dominated (Figure 30). The water level responses in the groundwater appear to be related to the pressure changes in the reservoir, rather than direct infiltration of the river water.

Tongue River alluvial-aquifer water levels and water quality

Water levels in the Squirrel Creek alluvium show annual variations that are typical for shallow water table aquifers (Figure 31). The overall trend in water levels in WR-58 from 1999 to 2007 was declining in response to drought conditions, however the water levels have returned to normal. Farther downstream, in the CBM production area (WR-52D), the water levels in the alluvium were stable until 2000 when levels increased by approximately four feet. Since that time water levels have gradually returned to baseline and are currently at their original levels. This rise and subsequent fall may be in response to CBM production water seepage from nearby infiltration ponds which were in use from 1999 to 2002.

Water-quality samples were collected in October 2009 and May 2010 (appendix C) from the Squirrel Creek alluvium (well WR-59) near the Squirrel Creek – Tongue River Confluence. The TDS concentrations increased from 5,710 mg/L in June 1991 to 6,709 mg/L in June, 2009, an increase of 17%. The SAR value increased from 5.6 to 6.4 over approximately the same time period (Figure 32). These peaks have been followed by slightly lower SAR values and TDS values similar to samples taken from 1991 through 2007. The Tongue River TDS and SAR values have not shown similar trends. The river chemistry varies seasonally; the TDS and SAR tend to drop as flow rate increases (Figure 32). The relationship between river discharge rate and Specific Conductance (SC) is discussed in more detail by Osborne and others. (2010). The alluvial groundwater chemistry is dominated by sodium, magnesium, and sulfate.

Further downstream along the Tongue River, a domestic well north of the Tongue River reservoir is regularly sampled (B. Musgrave's property) and was sampled most recently in October, 2009 and June, 2010 (appendix C). The TDS concentration varies by as much as 60%, however, total concentrations are very low. This variability could be natural or controlled by dam releases. Groundwater levels appear to mimic the discharge of the Tongue River at this site, but neither water level nor river discharge rate appears to be closely linked to TDS. The upward trend in TDS from September 2006 to October 2008 (747 to 1074 mg/L) has been mirrored in the upward trend from June, 2009 (775 mg/L) to June, 2010 (1126.81), which serves to reiterate the importance of regular monitoring. SAR is extremely low (Figure 33). The alluvial groundwater chemistry is dominated by calcium and bicarbonate.

Near the town of Birney, Hanging Woman Creek enters the Tongue River. Approximately 20 miles from the state line and near the confluence, well HWC86-7 is completed in the Hanging Woman Creek alluvium. This well was sampled in October 2009 and May 2010. The TDS was 3,671 mg/L and 3,338 and SAR was 8.3 and 7.9, respectively. Since sampling began in 1987, the TDS and SAR have generally increased; however, future monitoring will be required to determine if these values represent a trend or natural variation. Since water quality monitoring sites closer to CBM development have not shown an effect it seems unlikely that these changes are related to CBM development (Figure 34).

Even further downstream, water-quality samples were collected from alluvial monitoring well WA-2 near Birney Day Village in October, 2009 and May, 2010 (appendix C). The TDS concentration of the Tongue River alluvial water in this area has been relatively steady from August, 2006 to May, 2010. The SAR values have varied more, from 20 in August, 2006 to 23 in May, 2008. Alluvial groundwater levels mimic the river discharge in this area (Figure 35). The water chemistry is dominated by sodium and bicarbonate.

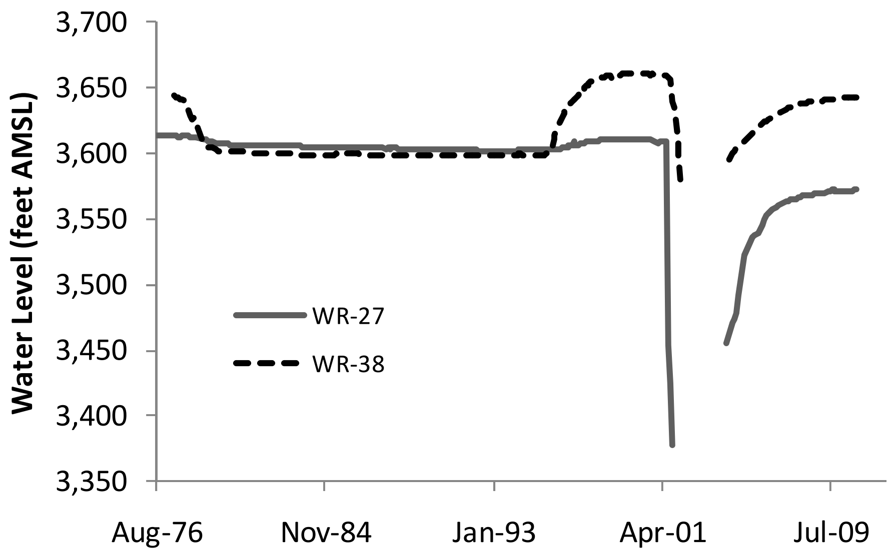


Figure 19. Water levels records for wells WR-27 and WR-38 show drawdown and recovery from dewatering from Ash Creek Mine and from CBM production.

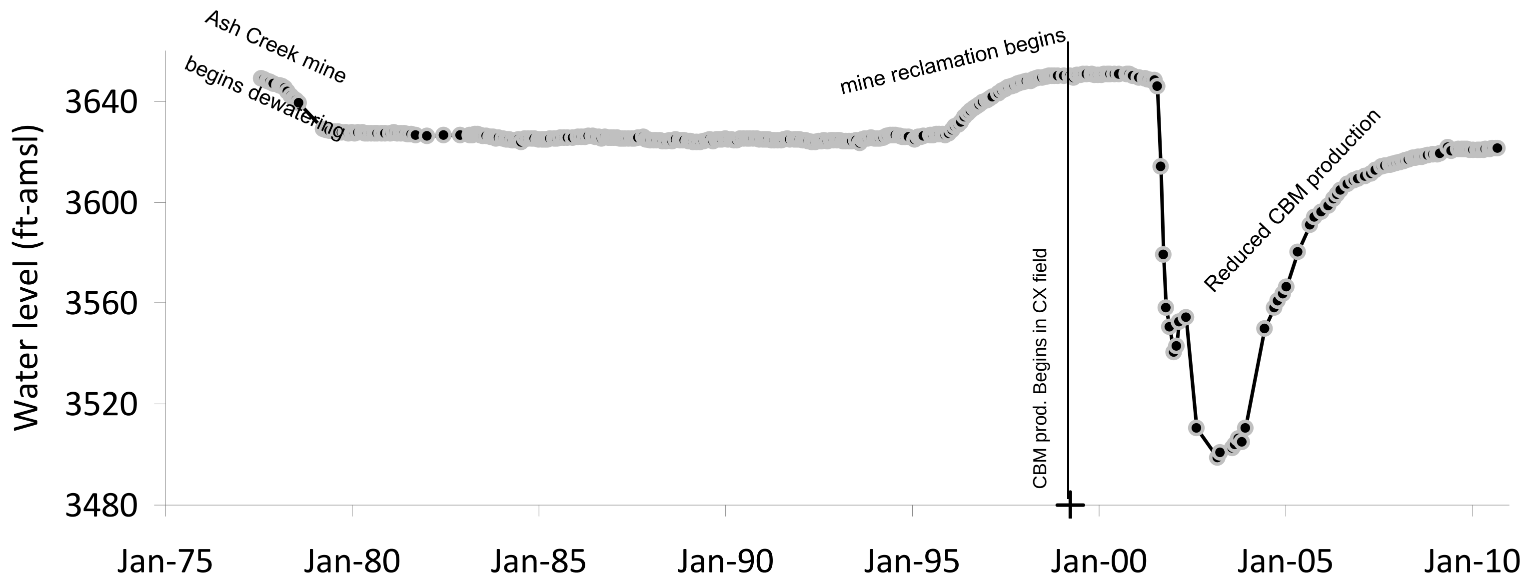


Figure 20. Water levels in the combined Anderson-Dietz coal (WR-34) in the Young Creek area respond to both coal mining and coalbed methane production. The water level recovered starting in 2003 in response to water production decreases in this portion of the CX field.

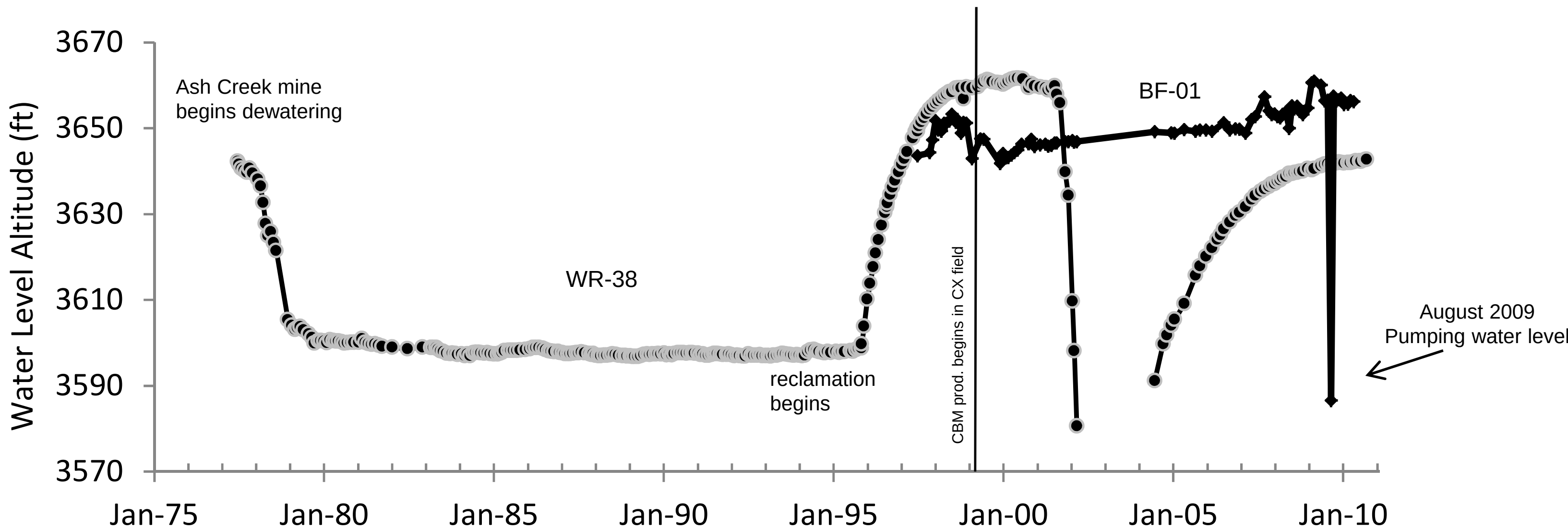
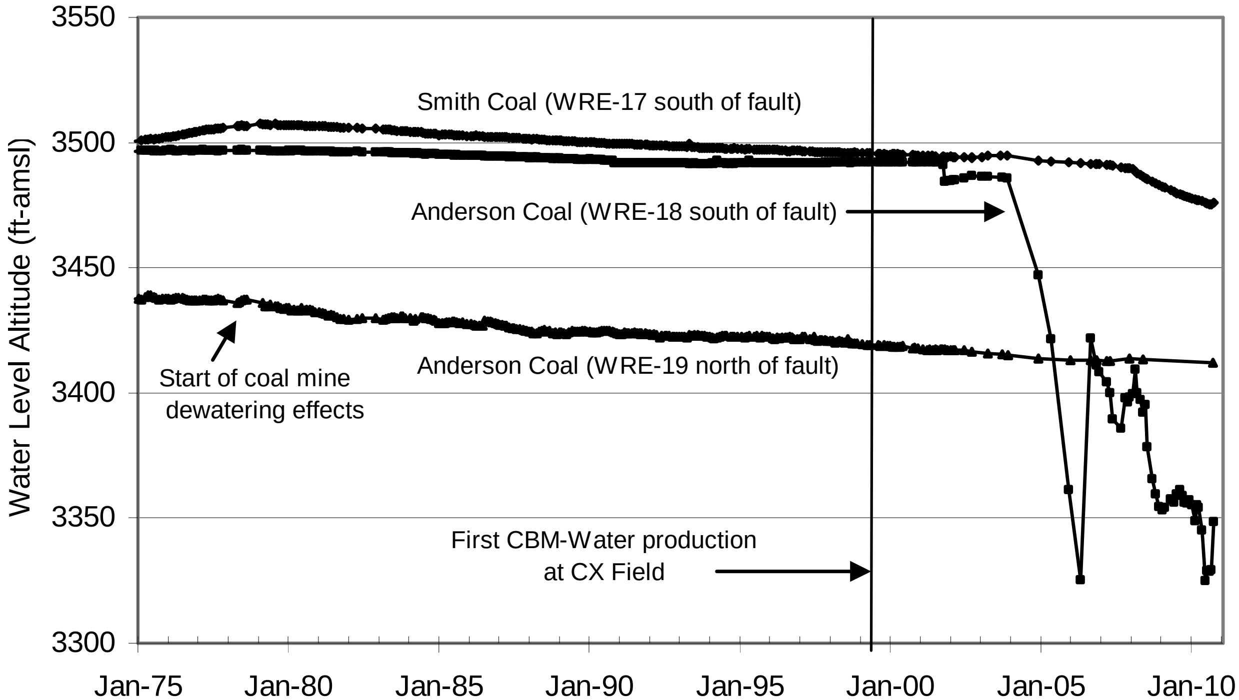


Figure 21. Water levels in the Dietz coal (well WR-38) decreased by 80 feet in response to CBM production. In contrast, water levels in the mine spoils (well BF-01) show no response to CBM pumping. This illustrates the difference between confined (WR-38) and unconfined (BF-01) aquifer responses to drawdown. Please note: August 2009 water level in BF-01 is a pumping level.



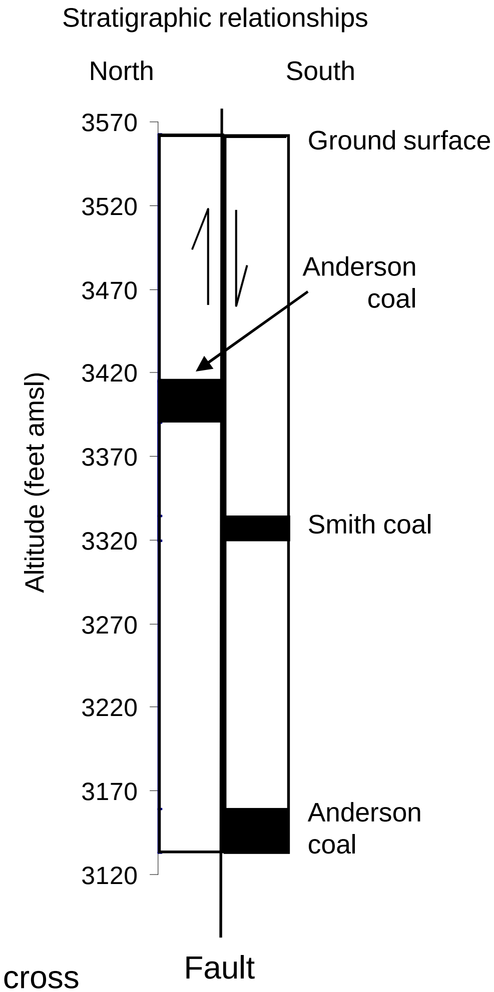


Figure 22. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured south of the fault at WRE-17 (Smith coal) since the mid-1980's. The pressure reduction has probably migrated around the end of the fault. Coalbed methane production south of the fault is apparent in WRE-18 but not north of the fault in WRE-19.

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

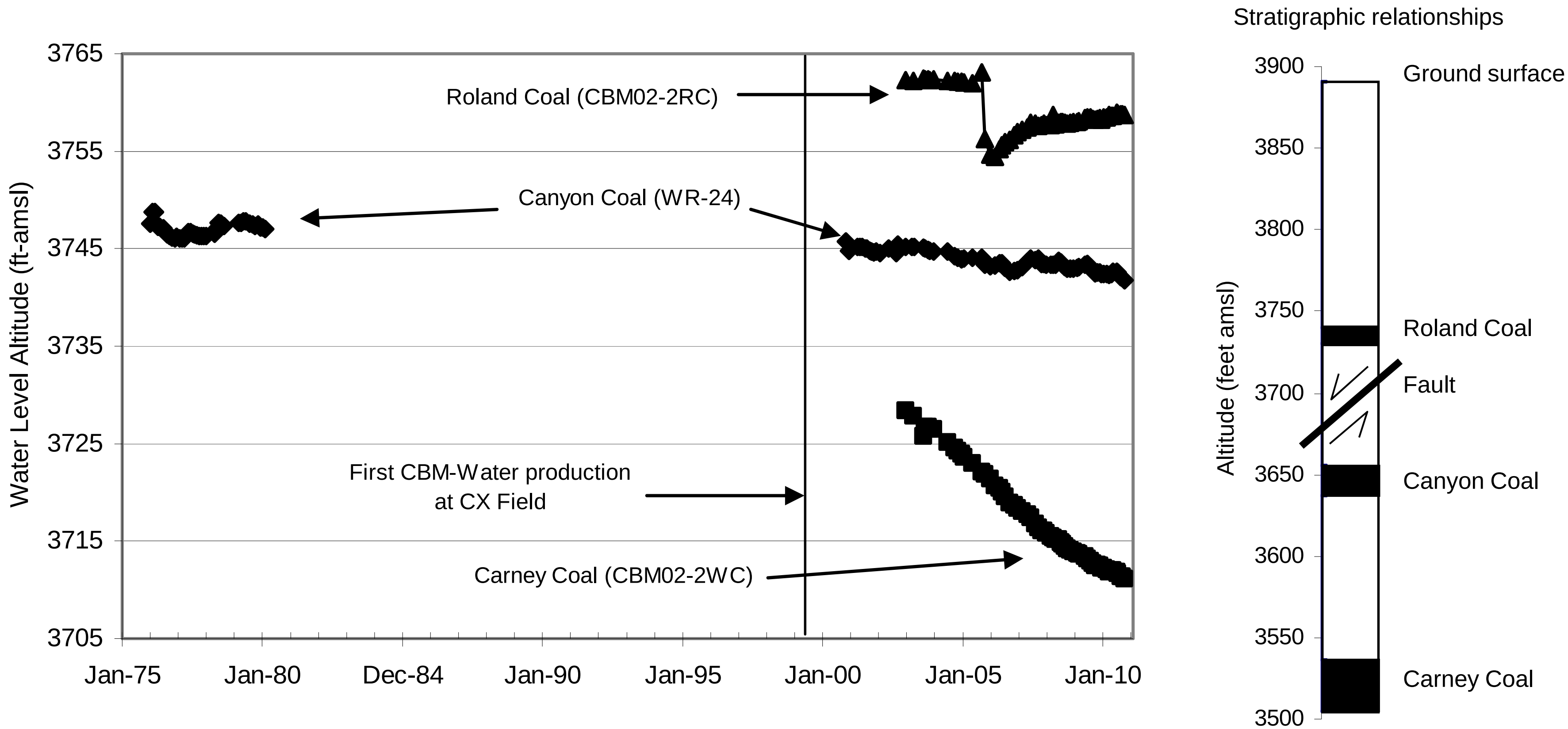


Figure 23. The decrease in water levels in the Canyon Coal may be related to migration of drawdown from CBM production from underlying coalbeds or may be related to long-term precipitation patterns. The short period of record for the Carney coal has responded to CBM related drawdown since its installation. The Roland Coal has not been developed for CBM production and the cause of water-level decline is not apparent at this time but is unlikely to be a response to CBM activities.

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

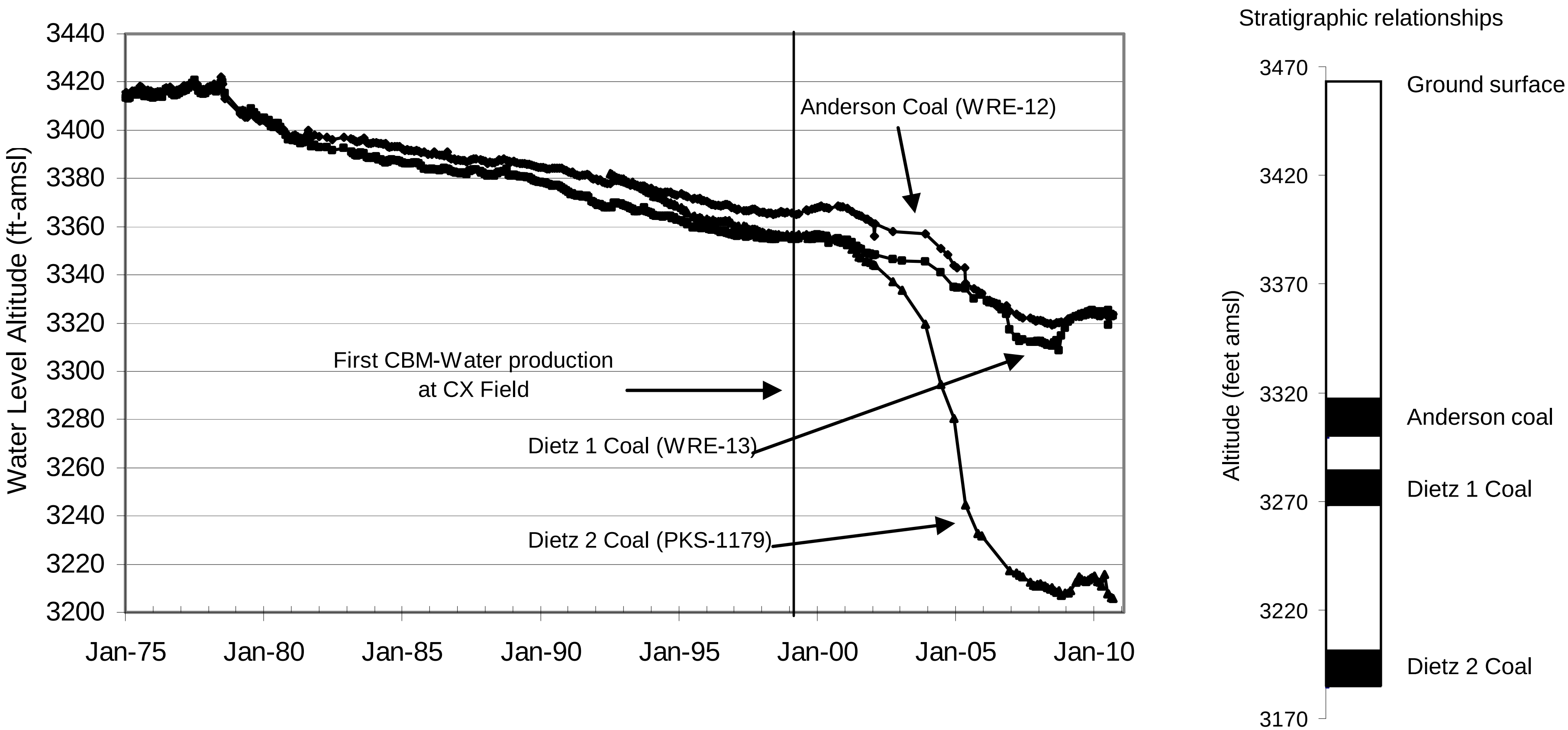


Figure 24. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

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

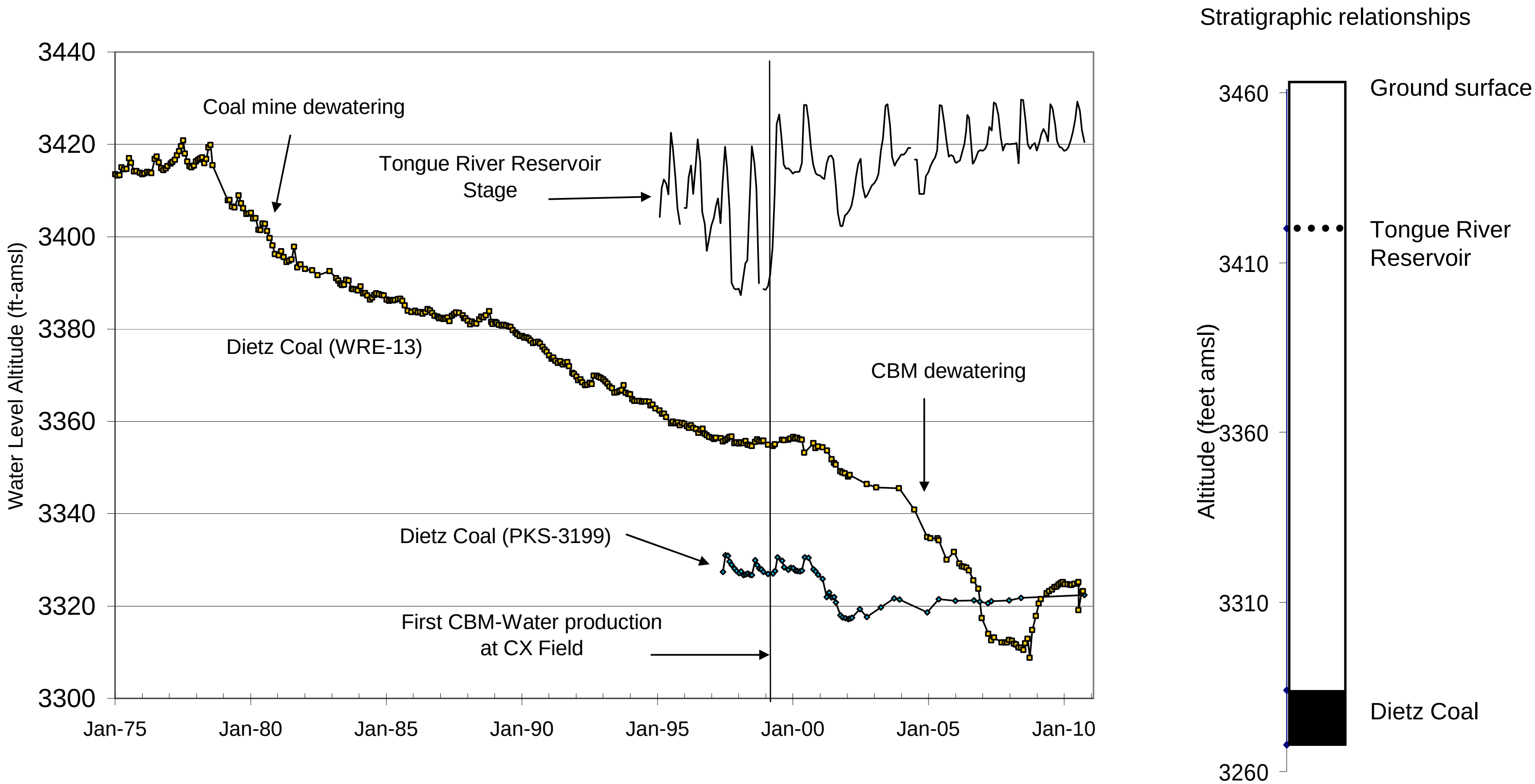


Figure 25. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present. Fluctuations may be related to pressure or water movement.

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

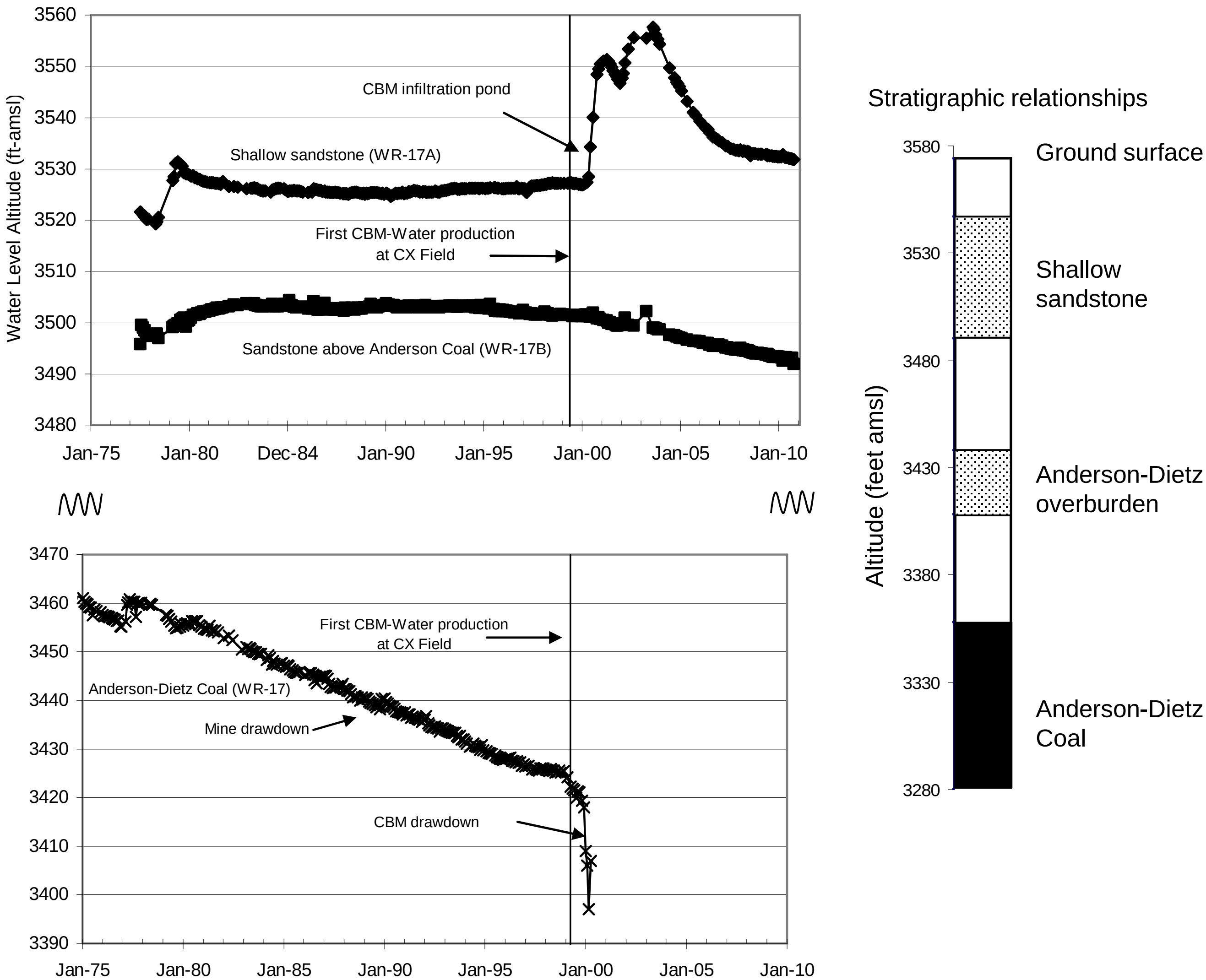


Figure 26. The rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The pond is no longer used for impounding CBM water, therefore the water level in this aquifer is now dropping. Water-level trends in the Anderson overburden (WR-17B) in the Squirrel Creek area may relate to precipitation patterns or to migration of water drawdown from CBM production in underlying coalbeds. Water levels in the Anderson coal (WR-17) were drawn-down first by coal mining and subsequently by CBM production. Water levels are no longer measured because of the volume of methane gas released from the well.

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

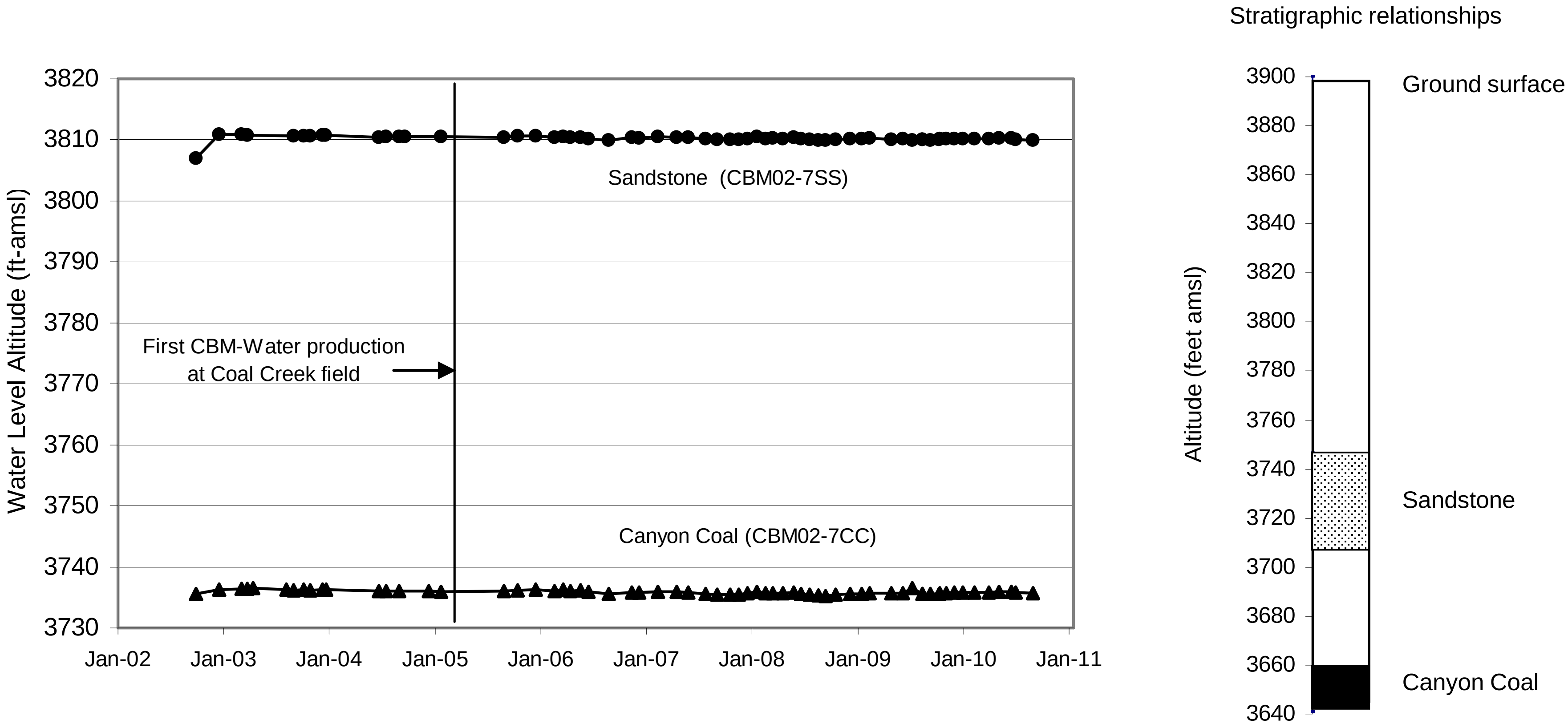


Figure 27. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

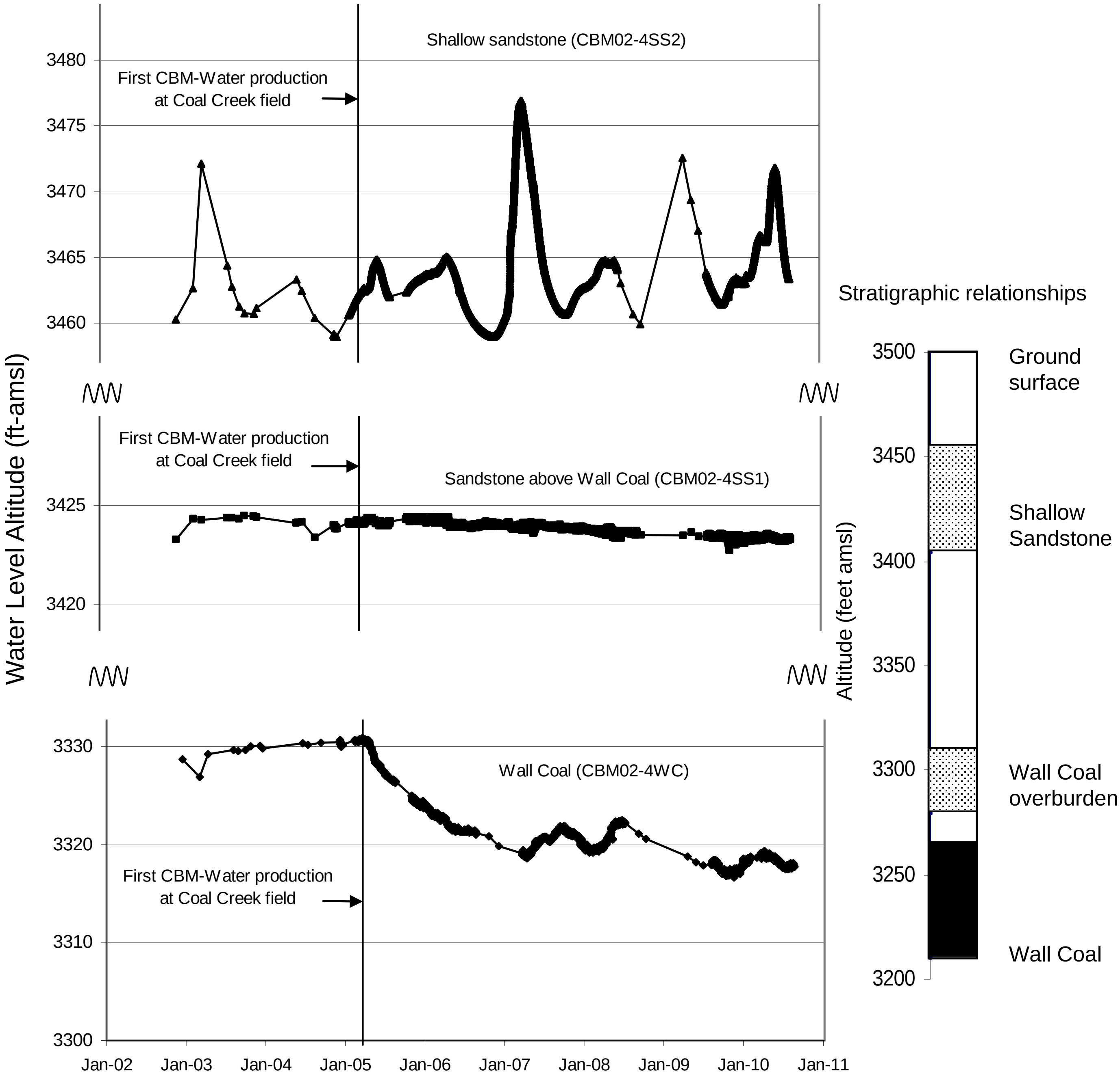


Figure 28. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal (CBM02-4WC) are in response to CBM production. The Wall overburden (CBM02-4SS1) has a slight decline in water level that might be related to meteorological patterns. The shallow sandstone (CBM02-4SS1) water level trend is likely related to meteorological patterns.

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

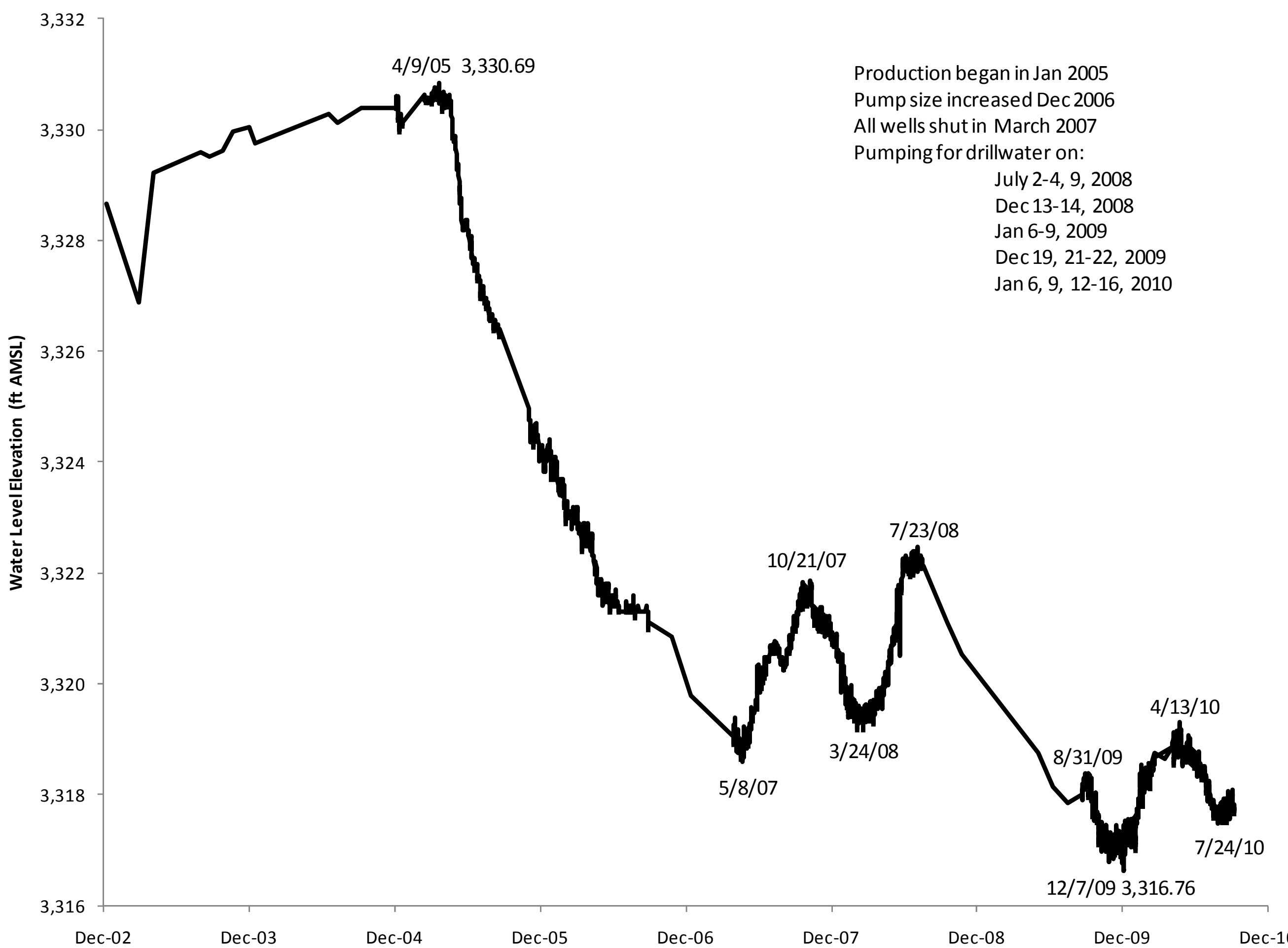


Figure 29. Drawdown in the Wall coal at the MBMG monitoring site CBM02-4WC is related to production from currently un-used CBM wells completed in the Wall coal along the Tongue River approximately 2.5 miles away. The CBM wells were used as water wells through 2009 but have not been used since early 2010.

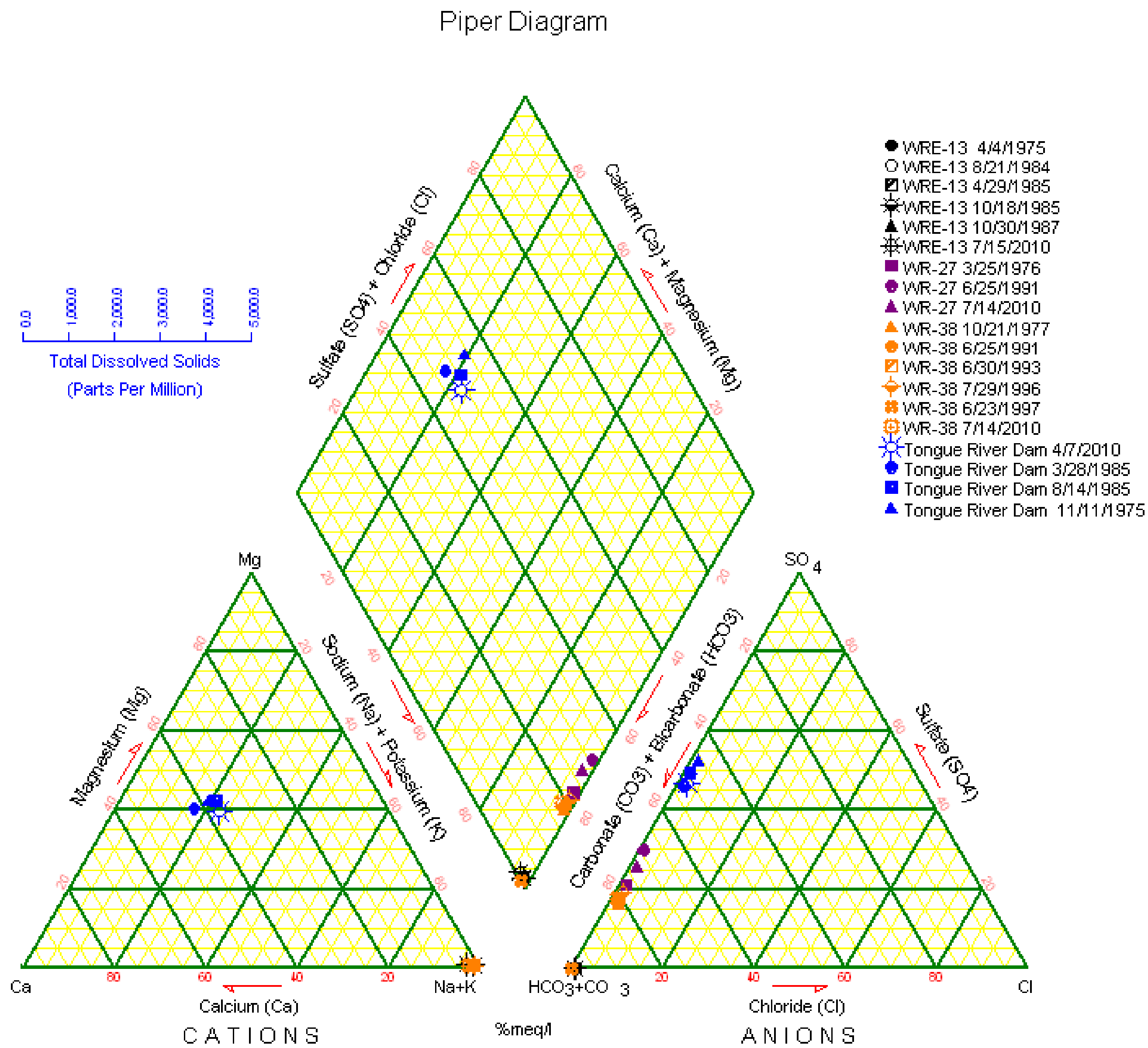


Figure 30. Water chemistry analyses measured prior to CBM development are very similar to recent samples. This indicates that there has not been a significant change in water recharge sources in the intervening time. Although well WRE-13 (purple) shows the influence of the Tongue River Reservoir (blue), the water chemistry is very dissimilar.

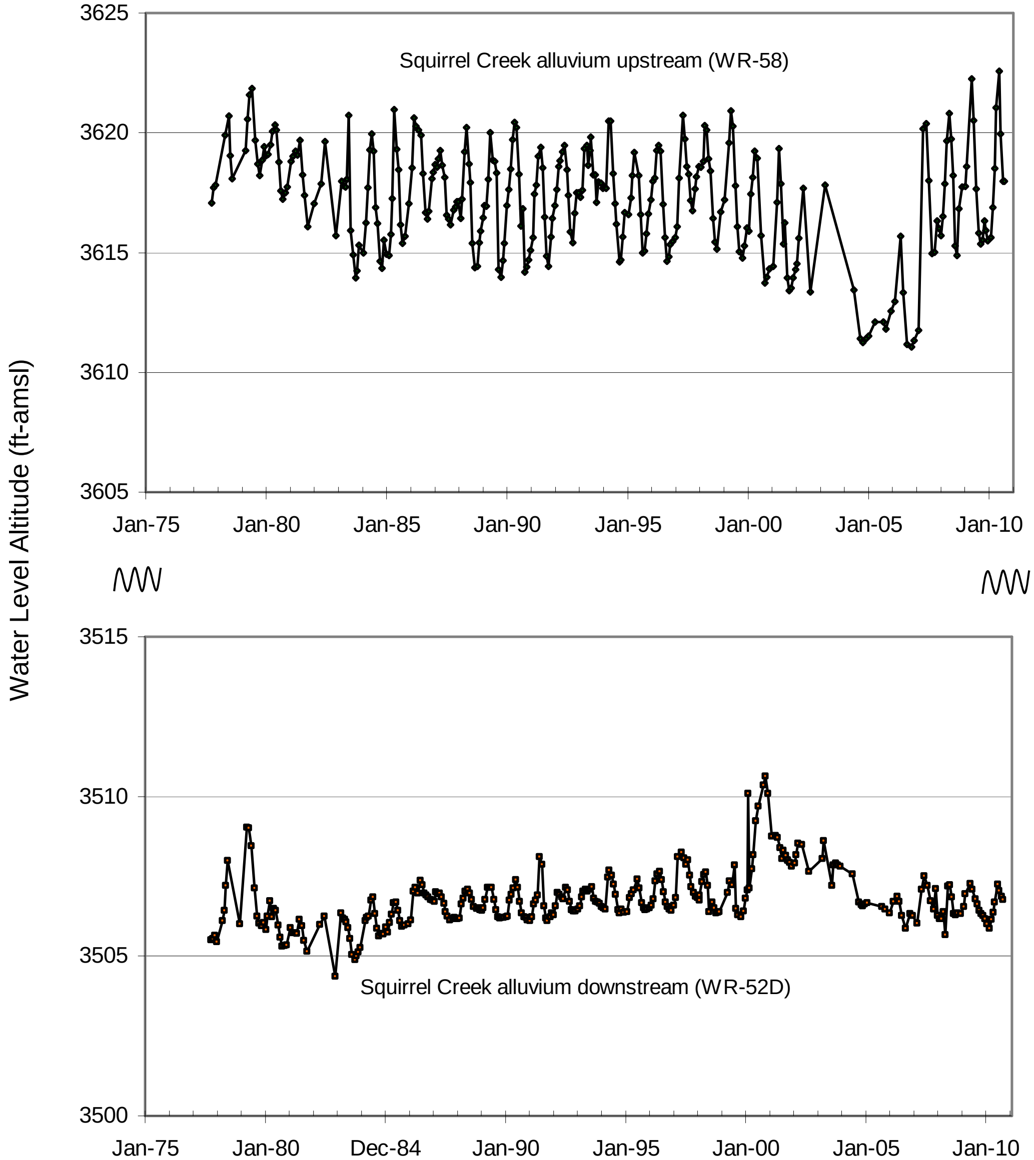


Figure 31. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall during 2004 likely relates to infiltration ponds located in between these sites. The water levels are now indistinguishable from pre-CBM levels (WR-52D).

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

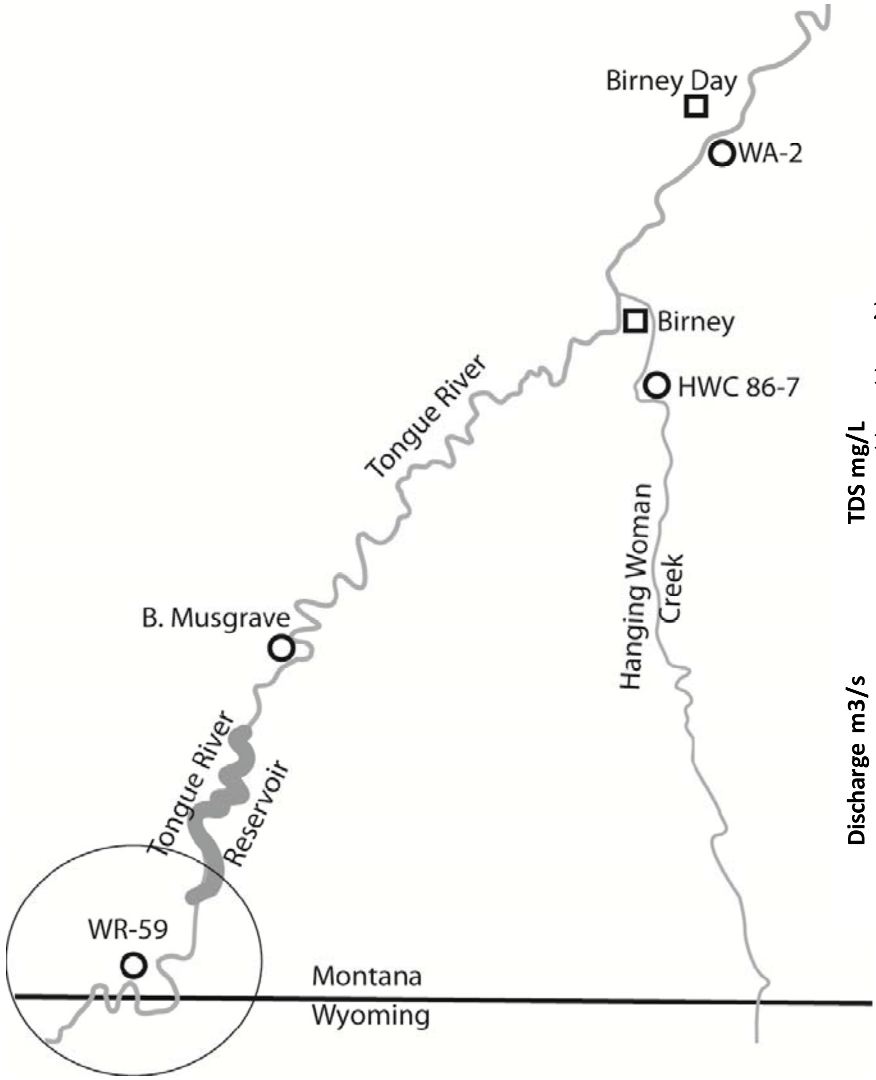
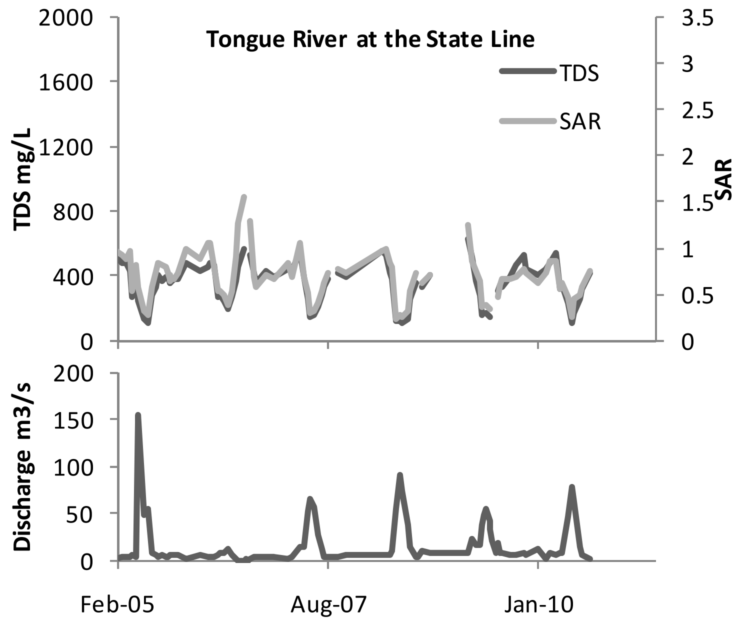


Figure 32. TDS, SAR and Water Level / Stream Discharge for well WR-59 near the Squirrel Creek-Tongue River confluence and for the Tongue River at the state line.



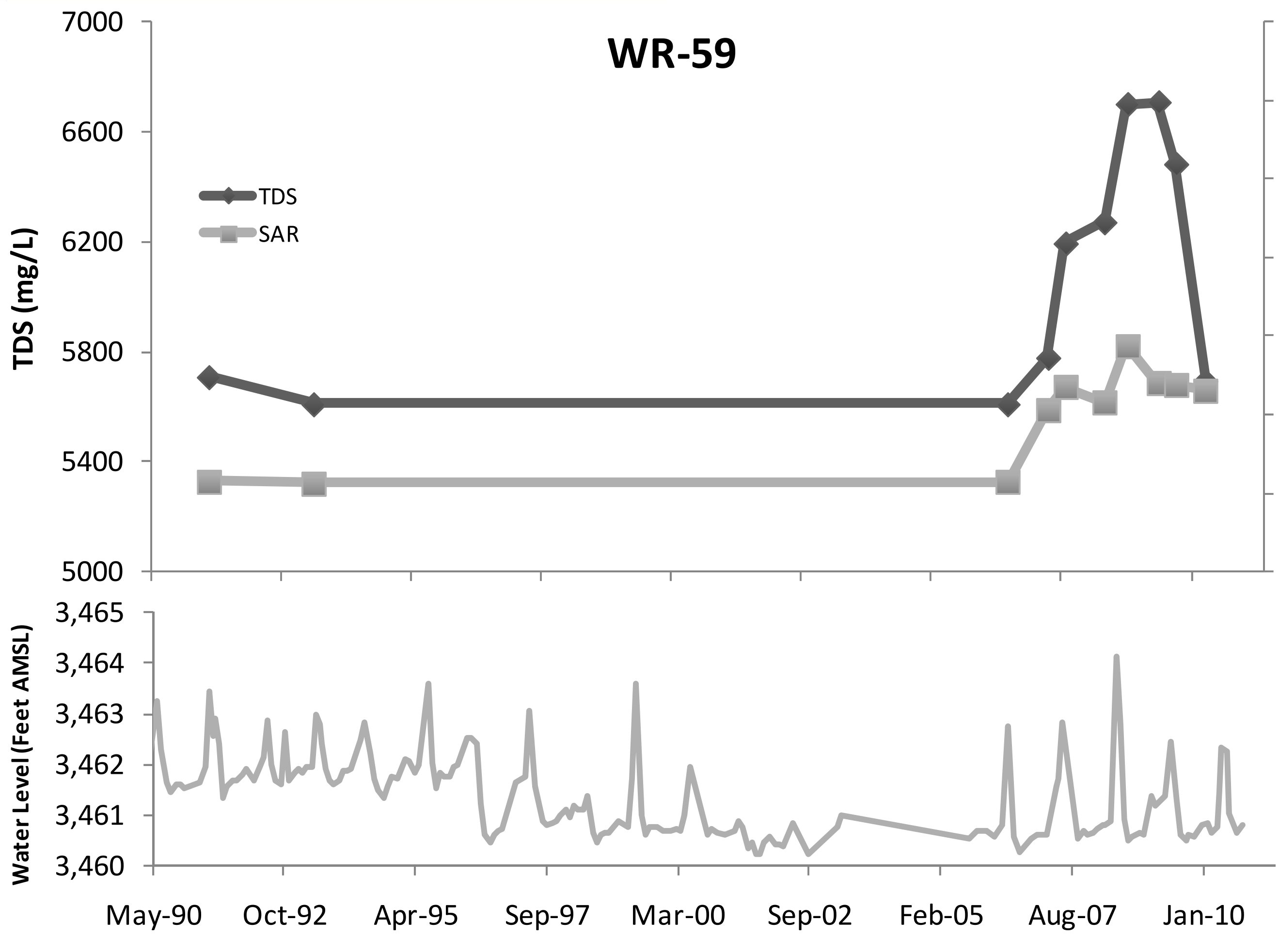
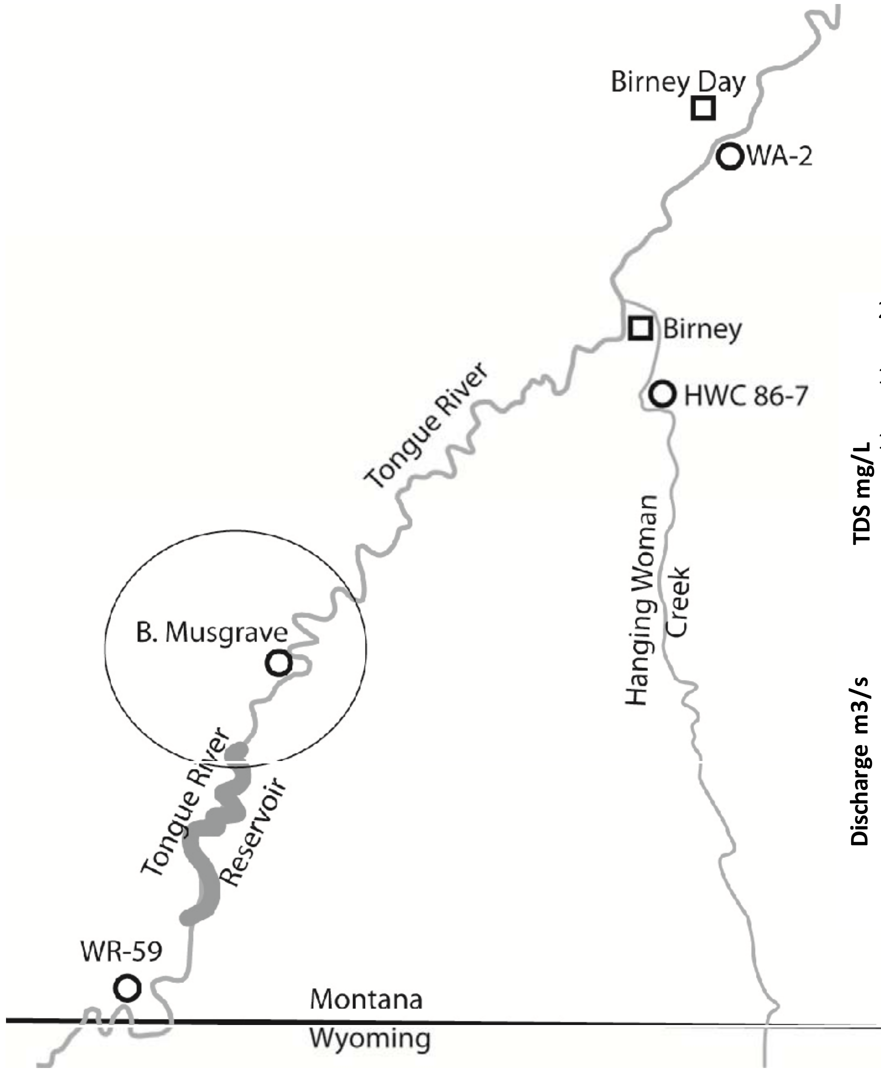
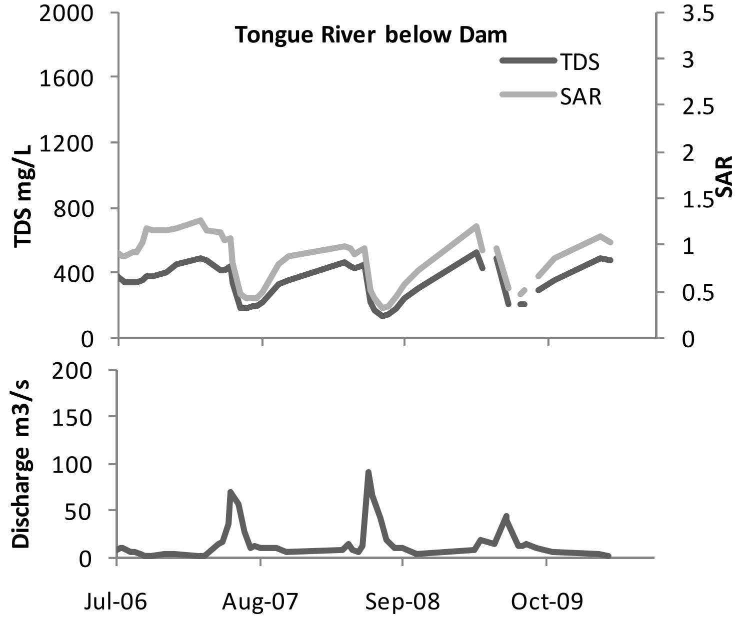
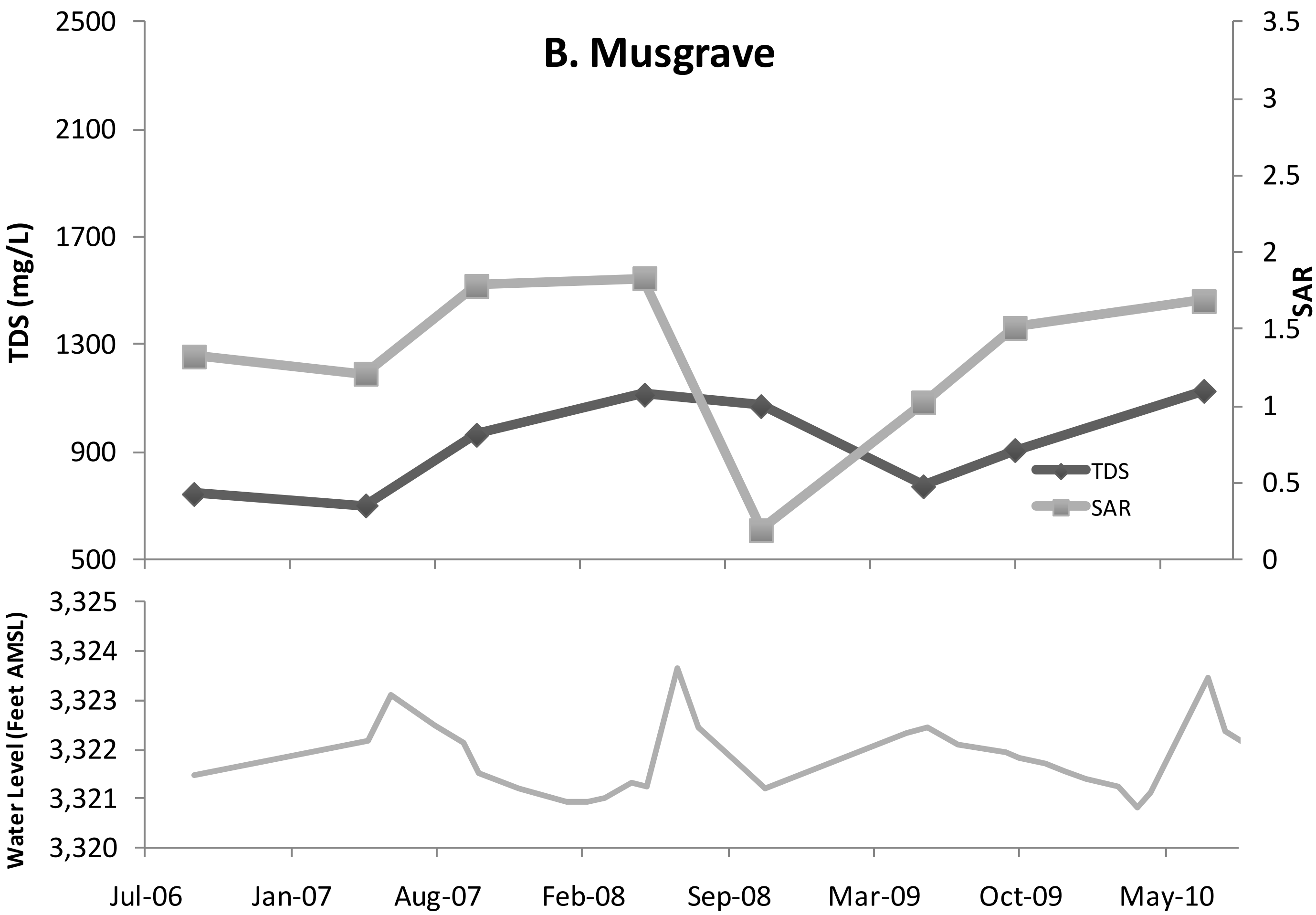


Figure 33. TDS, SAR and Water Level/Stream Discharge for a well at B. Musgrave's residence and the Tongue River north of the Tongue River Reservoir dam.







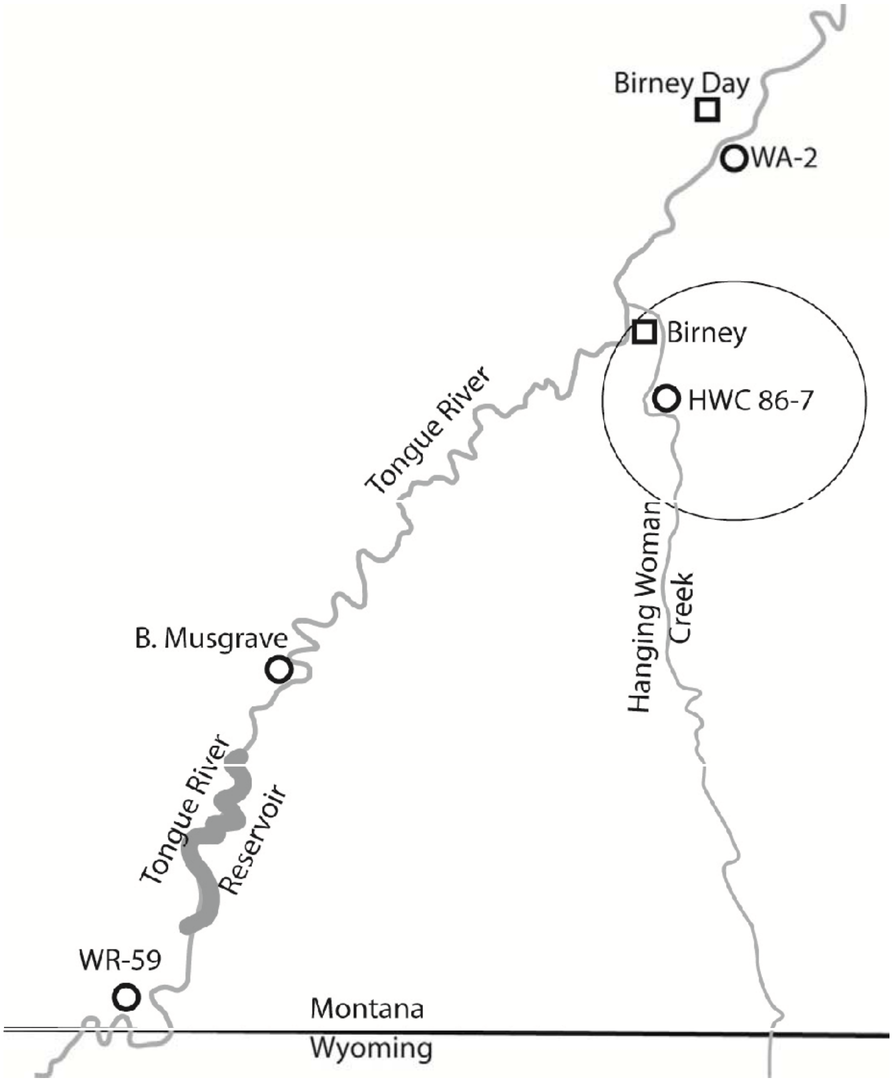


Figure 34. TDS, SAR and Water Level for well HWC 86-7 in the alluvium of Hanging Woman Creek, a tributary to the Tongue River.

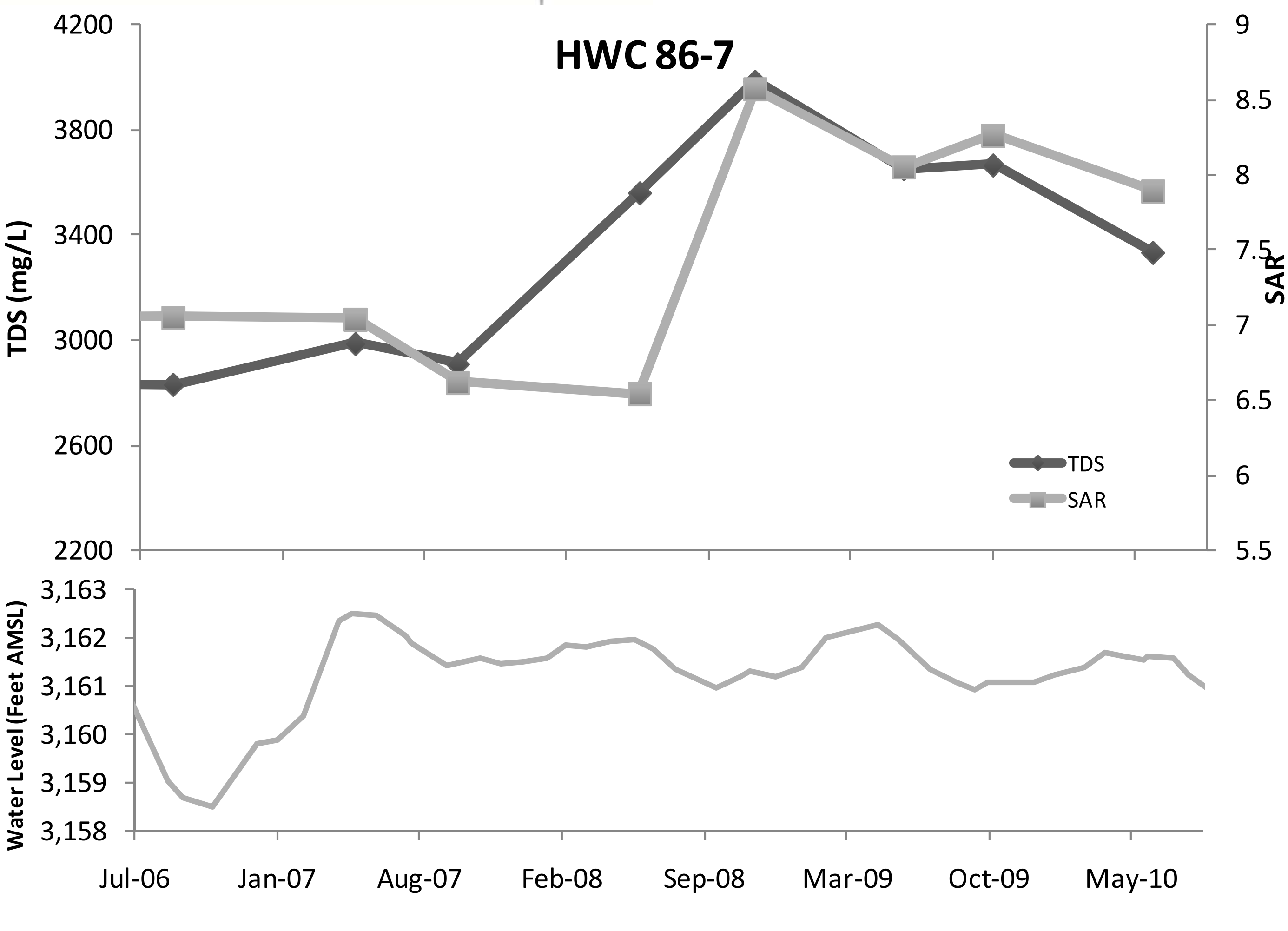
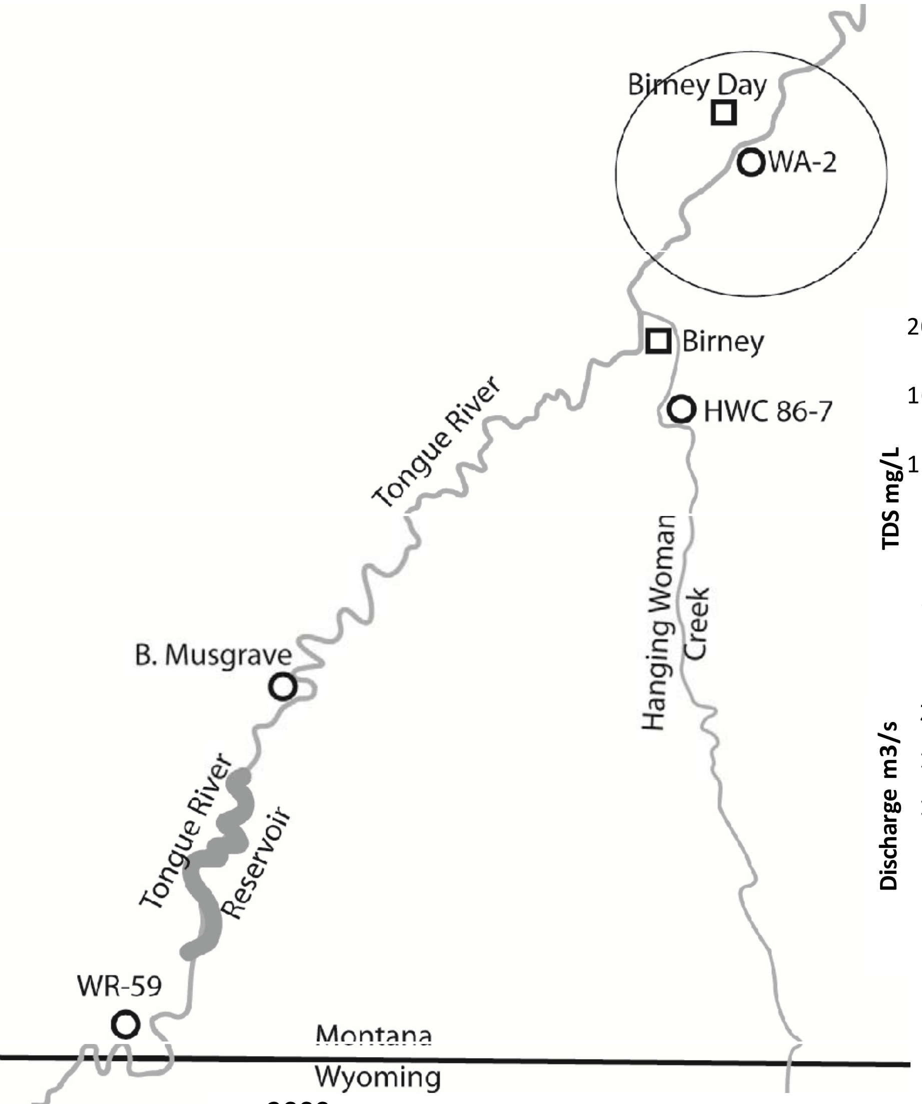
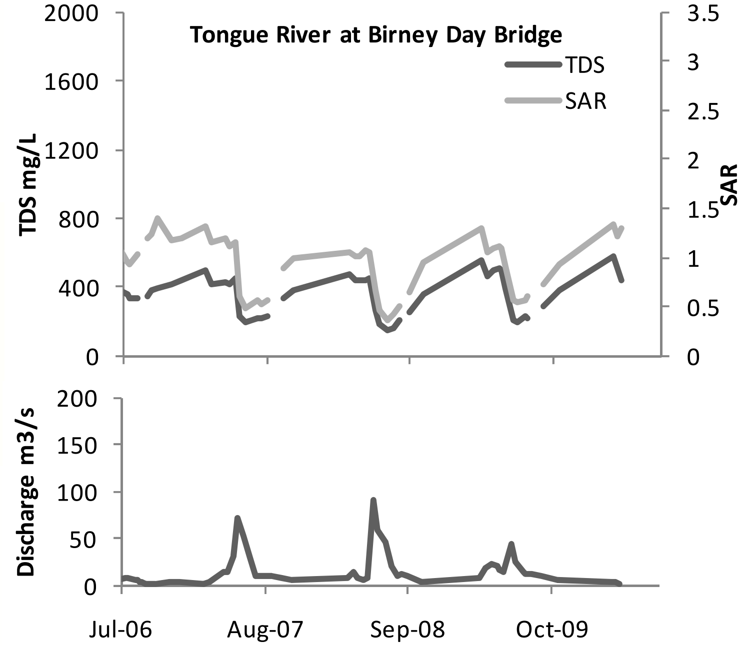
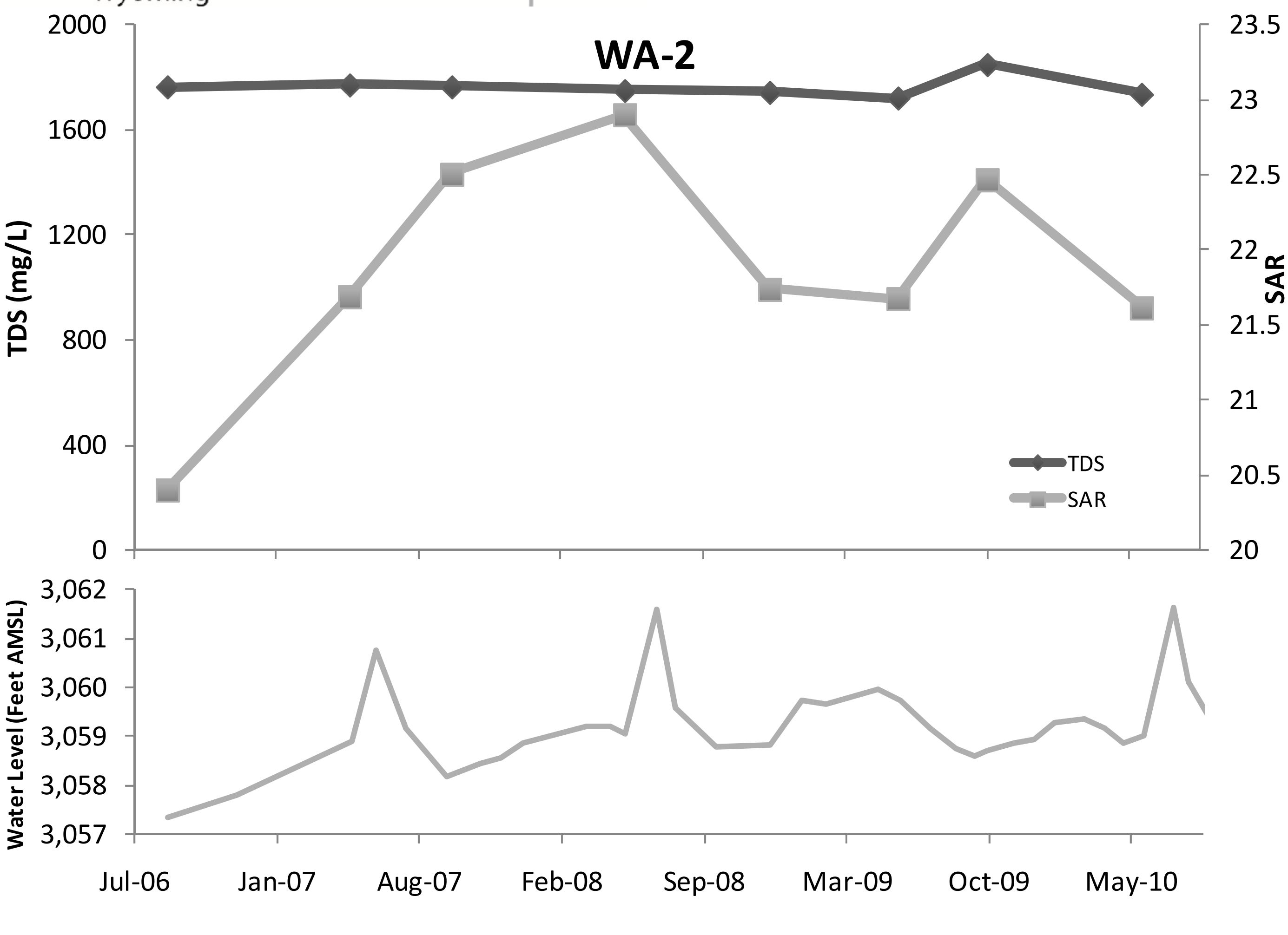


Figure 35. TDS, SAR and Water Level / Stream Discharge for well WA-2 in the alluvium of the Tongue River and the Tongue River at Birney Day Bridge.







Wyoming CBM fields near the Montana border

Data for CBM wells in Wyoming are available from the Wyoming Oil and Gas Conservation Commission website (http://wogcc.state.wy.us/). For this report, only those wells in Wyoming townships 57N and 58N were considered (Plate 1). Water production data were downloaded for CBM wells located in these townships. For the purpose of this report the CBM producing areas near the state line are referred to as the Prairie Dog and Hanging Woman fields and the area near Powder River (Plate 1).

Prairie Dog Creek gas field

Methane and water production. The Prairie Dog Creek Field is located in Wyoming south of the CX field in Montana. Methane is produced from the Roland, Smith, Anderson, Dietz, Canyon, Carney, Cook, King, and Flowers-Goodale (Roberts) coalbeds (Figure 2). During 2010, a total of 1,185 CBM wells produced methane and/or water in the Prairie Dog Creek Field. Cumulative water production for the year was 35.9 million barrels (Figure 36). Per-month water production in the field peaked in mid-2002. For the next five years the water production fluctuated between 500 and 600 acre-feet per month; however, since August 2008 the water production has fallen steadily and water production is currently less than 400 acre-feet per month. Gas production rose fairly consistently until early-2008, after which the gas production has fallen steadily (Figure 36).

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

Hanging Woman Creek gas field

Methane and water production. During November 2004, St. Mary Land and Exploration (St. Mary, previously Nance Petroleum) began pumping water from CBM wells in the Hanging Woman Creek watershed, directly south of the Montana–Wyoming state line (Plate 1). CBM production in this field is from the Roland, Anderson, Dietz, Canyon, Cook, Brewster-Arnold, Knobloch, Flowers-Goodale (Roberts), and Kendrick coalbeds (Figure 2). During 2010, a total of 246 CBM wells produced methane and/or water in the Hanging Woman Creek Field. The total water production for the 12-month period was 15.6 million barrels. Water production began to climb in November of 2004 reaching a peak in September of 2007 with 319 acre-feet per month (2.5 million barrels; Figure 36). Since that time, water production fell to less than 200 acre-feet per month and has remained fairly constant at that rate for the last year. Gas production has been low throughout the life of the field.

Bedrock-aquifer water levels. Drawdown due to production from the Hanging Woman Creek gas field is monitored primarily by state line sites SL-3, SL-4 and SL-5. Site SL-3 is located about 1 mile north of the nearest Wyoming CBM well. Monitoring wells at SL-3 include wells completed in the alluvium of North Fork Waddle Creek, an overburden sandstone, and Smith, Anderson, and

Canyon coals (Figure 37). Water levels in the alluvium, sandstone overburden, and Smith coal are not responding to CBM production. The water level in the Anderson coal has dropped about 31 feet, and water level in the Canyon coal has dropped about 125 feet (Figure 38).

Monitoring well site SL-4 is located about 1 mile north of the nearest CBM well in the Hanging Woman Creek gas field. Monitoring wells at this site are completed in the alluvium, and the Smith and Anderson coalbeds (Figure 39). The water level in the Anderson coal was lowered 70 feet at this site in response to CBM production before recovering 9 feet (Figure 40). This quick recovery may be in response to decreased development in Wyoming. The water level in the Smith coal has also dropped slightly (11 feet); the installed data logger shows high frequency oscillations characteristic of pumping in nearby wells completed in the same aquifer for stock watering or cistern filling (Figure 40 inset). Water-level drawdown, therefore, may be related to domestic use rather than CBM production. This monitoring well is located approximately 150 feet from the Forks Ranch Headquarters well.

Monitoring well site SL-5 is located approximately 4 miles to the northeast from the nearest CBM development in Wyoming. Drawdown in the Anderson coal has been less than 4 feet at this site. There is no noticeable change in the Dietz coal aquifer water level. The Canyon coal water level has risen over 10 feet since monitoring began in July, 2005 (Figure 41). There are a number of factors that could cause the water level to rise. The rise may be a response to climatic changes; however, aquifers over 400 feet below the surface, such as the Canyon coal in this location, are usually insulated from all but the most long-term climatic patterns. The increase may be related to lower CBM production rates in the Canyon coal in nearby areas; however, monitoring in other Canyon coal wells do not show a similar response. Produced water disposal by injection may account for the water level rise, but it is unlikely that a CBM producer would inject into the same coal zone that is being dewatered for methane extraction elsewhere. Another possibility is the water level rise may be related to the dissolution of migrated methane gas from CBM fields in Wyoming into the well water column. If this were the case, then, when the sealed cap was opened and gas allowed to escape, the water level should start to drop slowly. This may be missed by hand water-level measurements. Migration of gas to this site implies that the methane production fields in Wyoming are, perhaps, losing some of the product they hope to recover.

Alluvial-aquifer water levels and water quality. Based on water-level trends and lithology, the Hanging Woman Creek alluvium near the state line appears to be effectively isolated from the Anderson and Smith coalbeds (Figures 38 and 42). Changes in water levels in the alluvium reflect water table response to seasonal weather patterns (Figure 42). Alluvial water-level changes at SL-3Q (Figure 43) also appear to be in response to seasonal weather patterns and not to CBM production.

Water-quality samples were collected from wells HWC 86-13 and HWC 86-15 during October 2009 and May 2010 (appendix C). For the two sampling events, the TDS concentrations in the alluvial water range from 6,352 to 8,040 mg/L and SAR values range from 10.6 to 10.9. The water chemistry in the alluvium is dominated by sodium and sulfate. There is a natural variation of approximately 1000 mg/L in both these wells since sampling began in 1987. Water-quality samples were collected on North Fork Waddle Creek at SL-3Q during October 2009 and June 2010 (appendix C). TDS and SAR concentrations have not varied much since sampling began in 2005 and during these sampling events were 3,406 and 3,422 mg/L and 5.3 and 5.0, respectively. The water chemistry is dominated by sodium and sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site.

Gas fields near Powder River

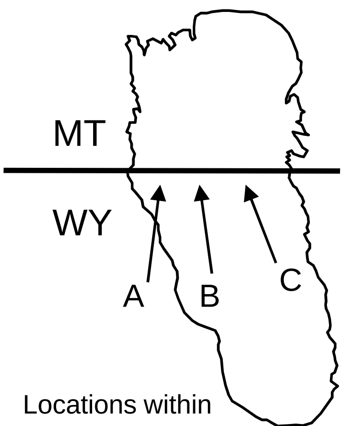
Methane and water production. Near the Powder River (Plate 1), CBM is being produced from the combined Anderson and Dietz (Wyodak), Canyon, Cook, Wall, Pawnee, and Cache coalbeds (Figure 2). During 2010, a total of 529 wells produced methane and/or water in this area. The cumulative production for the 12-month period was 35.0 million barrels of water. Water production in the fields near the Powder River increased steadily from January 2004 through July 2008, and peaked at just over 500 acre-feet per month. Current water production as of September 2010 is just less than 400 acre-feet per month (3,000 gpm) (Figure 36).

Bedrock-aquifer water levels. Monitoring well SL-7CC is completed in the Canyon coal and located less than 1 mile north of the state line near the Wyoming CBM production in this area. Water levels are not currently monitored in this well due to the volume of gas released when the well is opened. The free gas release from this well was documented during 2005 and is discussed in the 2005 annual monitoring report (Wheaton and others, 2006). This gas migration was occurring prior to CBM development in this area, so at least some portion of the venting is due to naturally occurring free-phase gas.

Two monitoring wells at site SL-6 are located 6 miles west of SL-7CC. Well SL-6CC is completed in the Canyon coal and releases gas similar to the conditions described for SL-7CC. For this safety reason, water levels are not currently measured at this well. Well SL-6AC is completed in the Anderson coal and no CBM-related change in water levels have been noted in this well.

Alluvial-aquifer water levels and water quality. South of Moorhead, Montana groundwater flow through the Powder River alluvium is roughly parallel to the river flow (Figures 44 and 45). This site is located on a large meander of the river, and the river likely loses flow to the alluvium on the up-gradient end of the meander and gains at the lower end. A stock well at this location is flowing under artesian pressure, indicating an upward gradient with depth. This well is likely producing from a sandstone unit 500 to 586 feet below ground surface (MBMG file date). Water levels in alluvial monitoring wells at this site do not indicate responses to CBM production or CBM water management in Wyoming.

Water-quality samples were collected from wells SL-8-2Q and SL-8-3Q in October 2009 and May 2010 (appendix C). TDS concentrations ranged from 1,961 to 2,605 mg/L and SAR values ranged from 3.2 to 4.7. The water chemistry is dominated by calcium, sodium, and sulfate. The TDS and SAR values are higher in the well closest to the Powder River (Figure 44) but no CBM impacts are apparent. There are also insufficient data to identify seasonality trends.



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

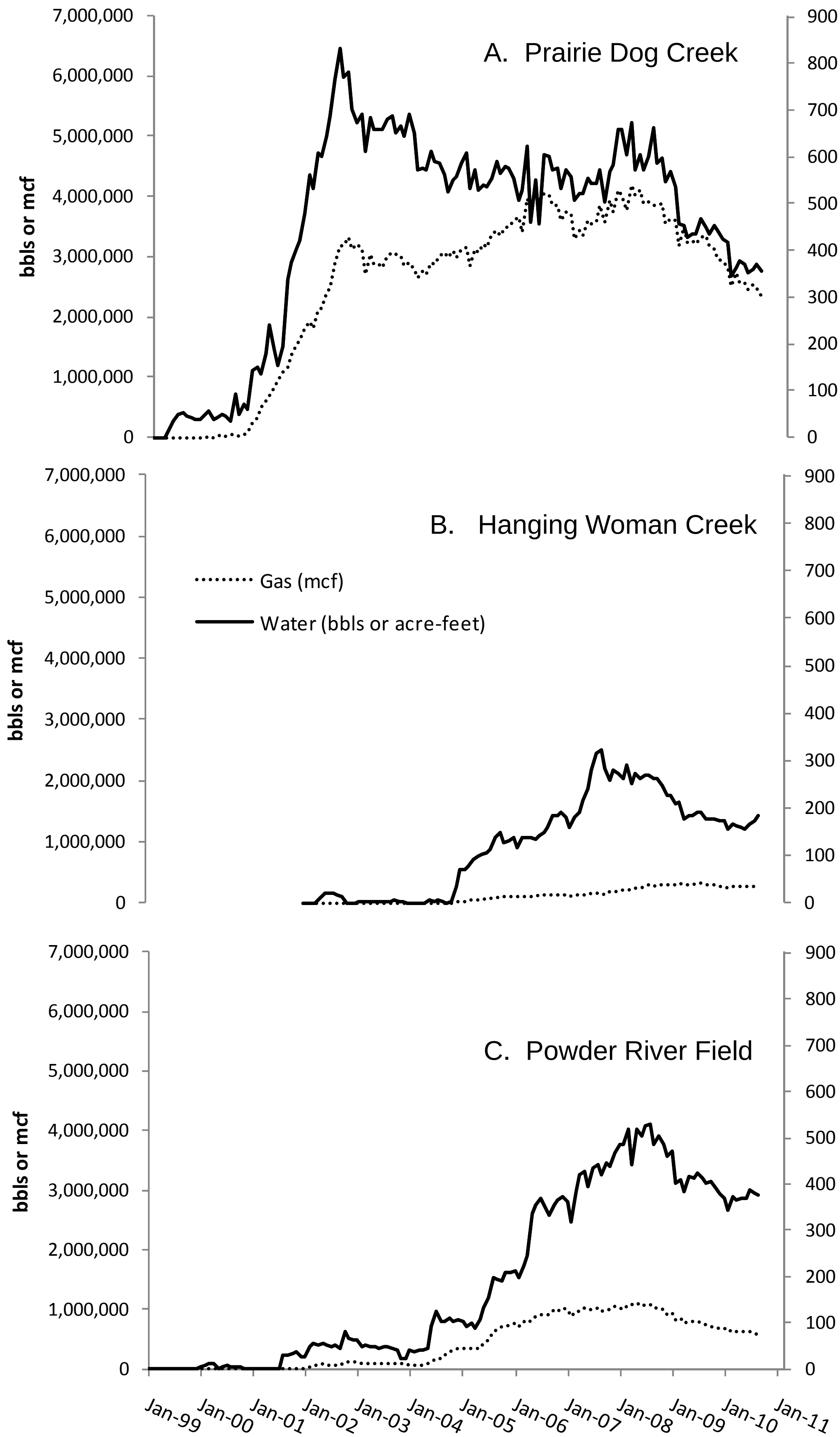


Figure 36. Total water (solid line) and gas (dashed line) produced per month in Wyoming CBM fields. Wyoming development is increasing to the east by the Powder River.

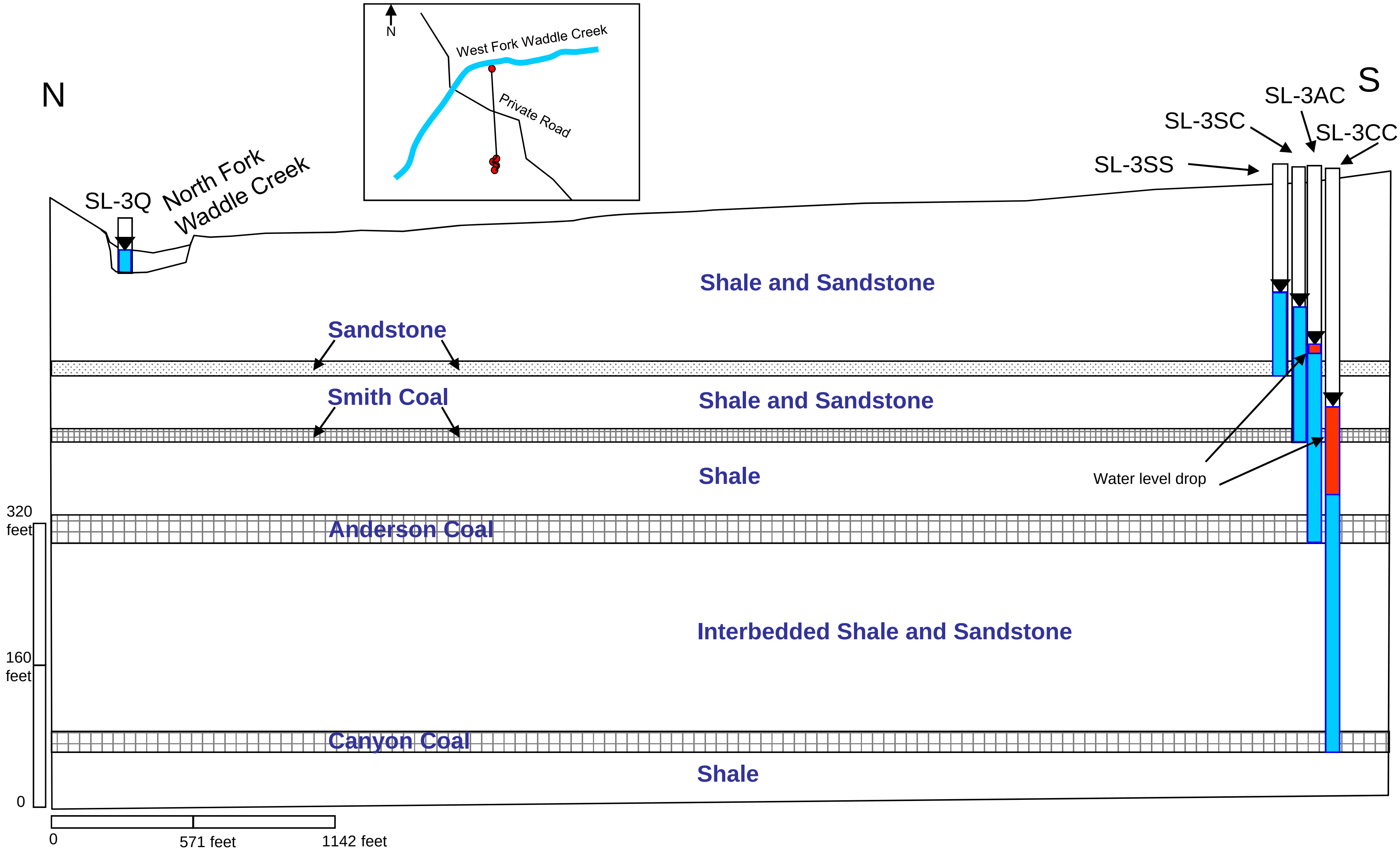


Figure 37. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coal beds located at T9S R42E section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in September 2010. The water level in the Anderson Coal has lowered about 31 feet and the Canyon coal has lowered about 118 feet since well installation. The wells are located roughly 1 mile north from nearest CMB field. Vertical exaggeration is 3.6:1.

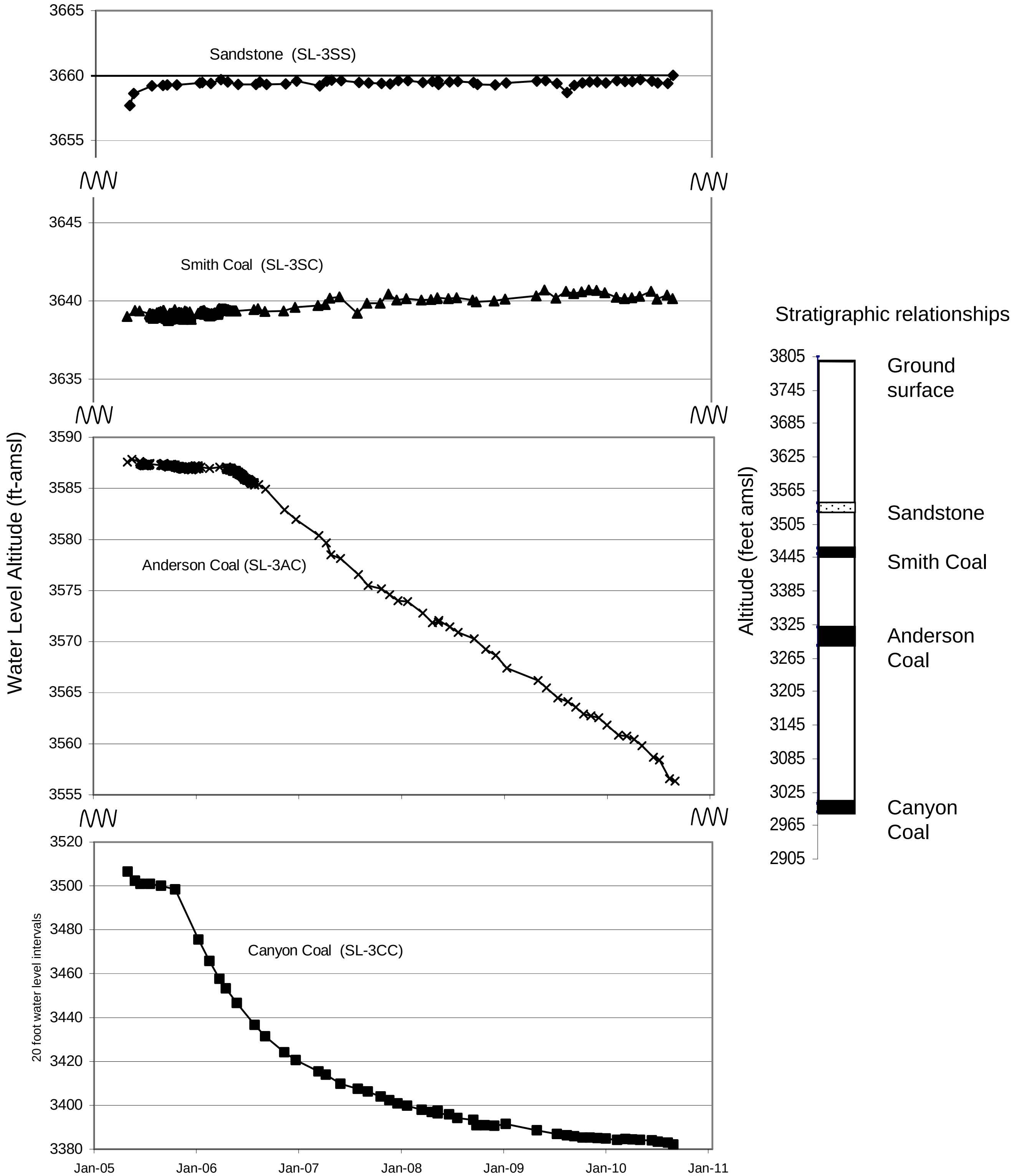


Figure 38. Water levels in the overburden sandstone and Smith coals are not responding to CBM development. However the water level in the Anderson and Canyon Coal have dropped about 31 and 119 feet respectively in response to CBM production.

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

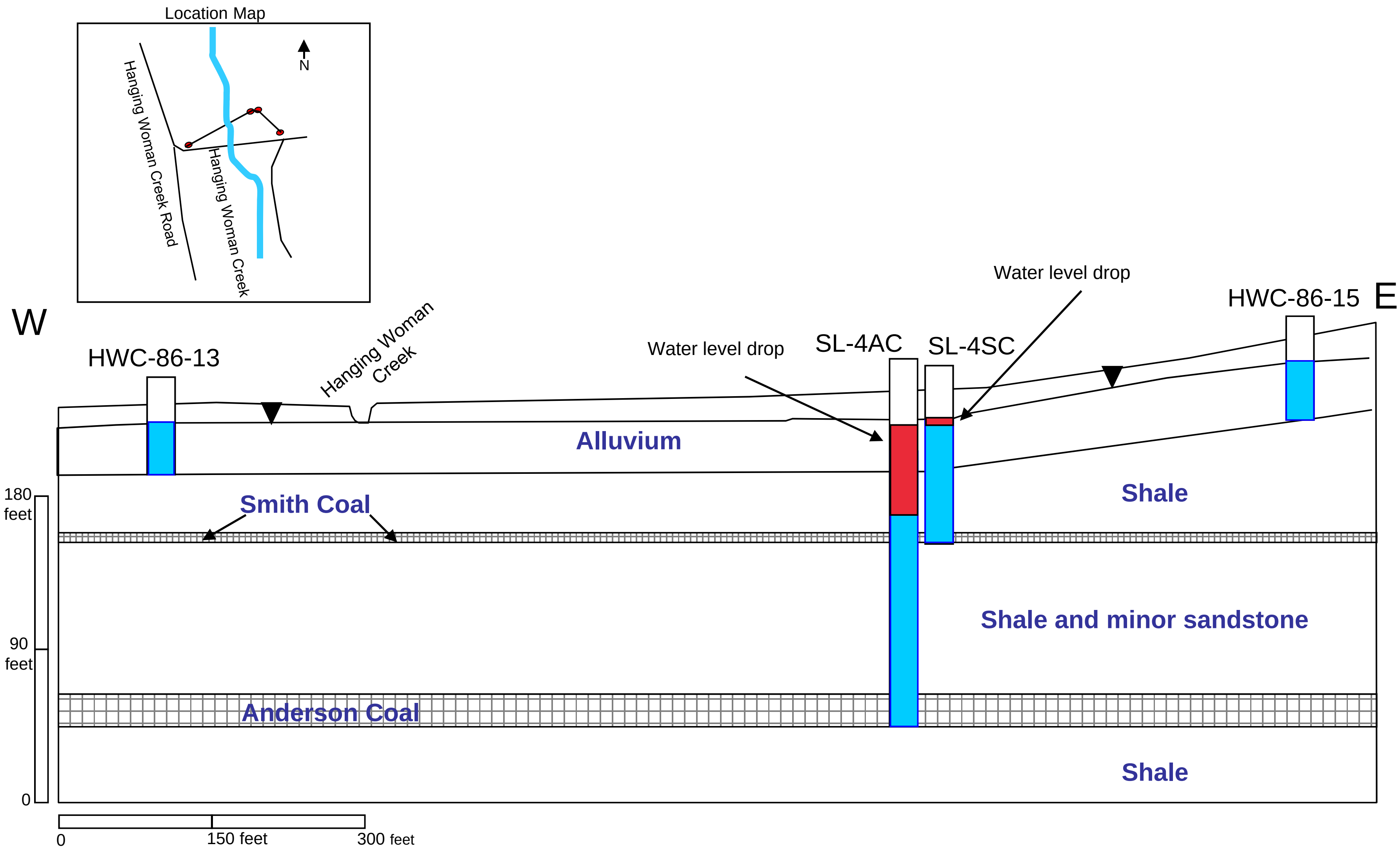


Figure 39. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 69 ft and the Smith has lowered about 13 ft since well instillation (shown in cross section). These wells are located roughly 1 mile north of the nearest CBM field. Water levels for the cross section were taken in August 2010. Vertical exaggeration is 7:1.

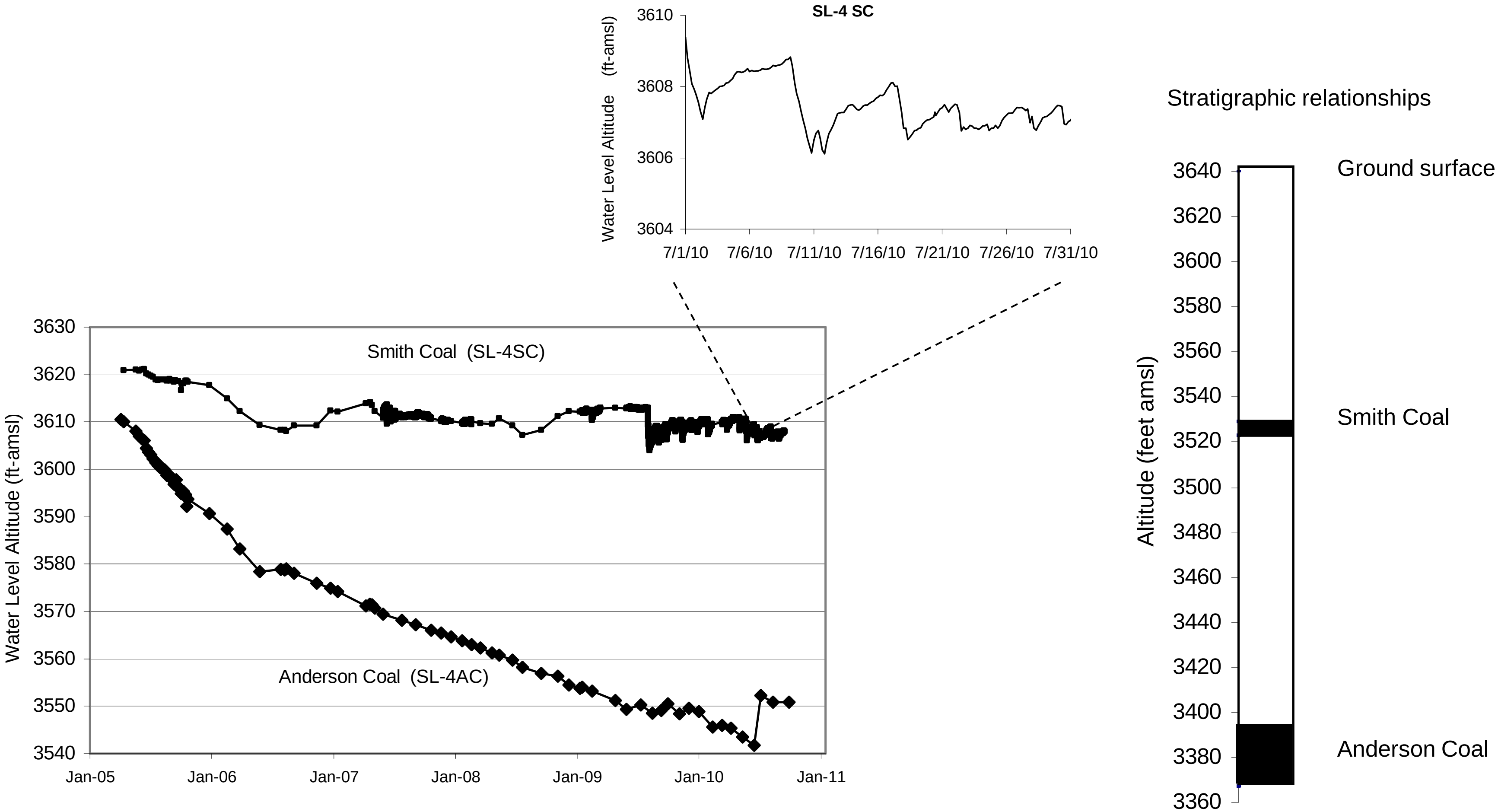


Figure 40. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels appear to have lowered about 69 feet from April 2005 to June 2010 in response to CBM development; however it is unclear if true baseline was obtained prior to impacts occurring. In July 2010 the water levels rose over 9 ft, this is presumably due to activities in the nearby CMB field. Water levels in the Smith Coal have decreased, but a clear relationship to CBM has not been established. Water production from CBM wells in this field began during November, 2004. The Smith Coal well (SL-4SC) shows an aquifer response from the pumping of a private well located about 150 ft from the monitor well (inset graph).

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

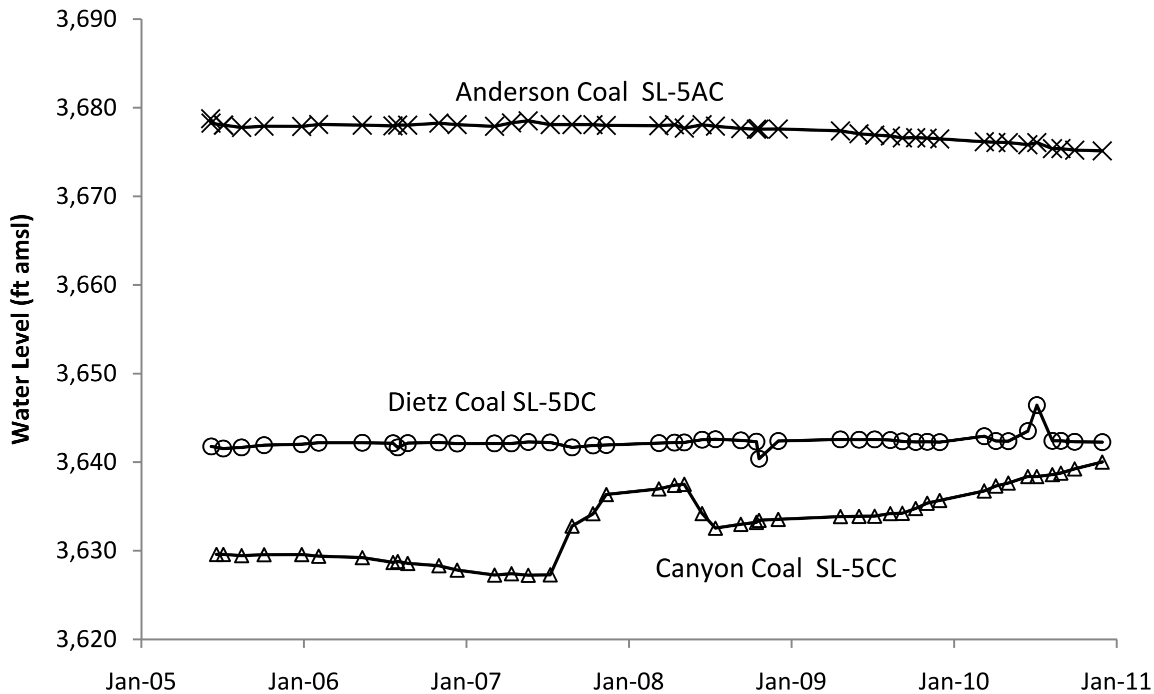


Figure 41. Coalbed methane development in the Anderson coal is causing a slight decline in water level in the Anderson coal at the SL-5 site. The Canyon coal has increased 10 feet since monitoring began in July 2005. The nearest CBM development is approximately 4 miles away in Wyoming.

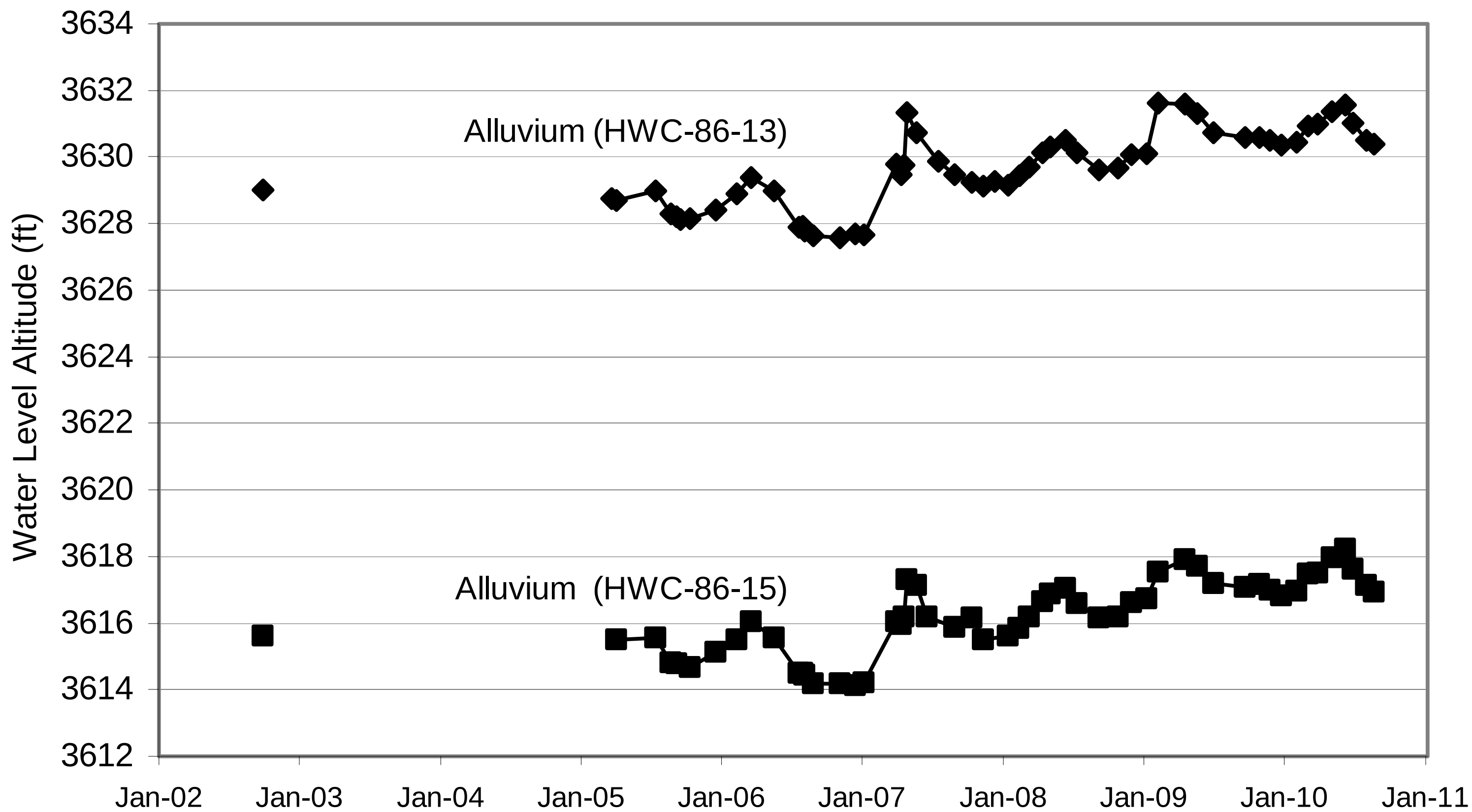


Figure 42. The water level in the Hanging Woman Creek alluvial aquifer near the Montana – Wyoming state line reflects water table response to meteorological pattern. Refer to figure 39 for site location.

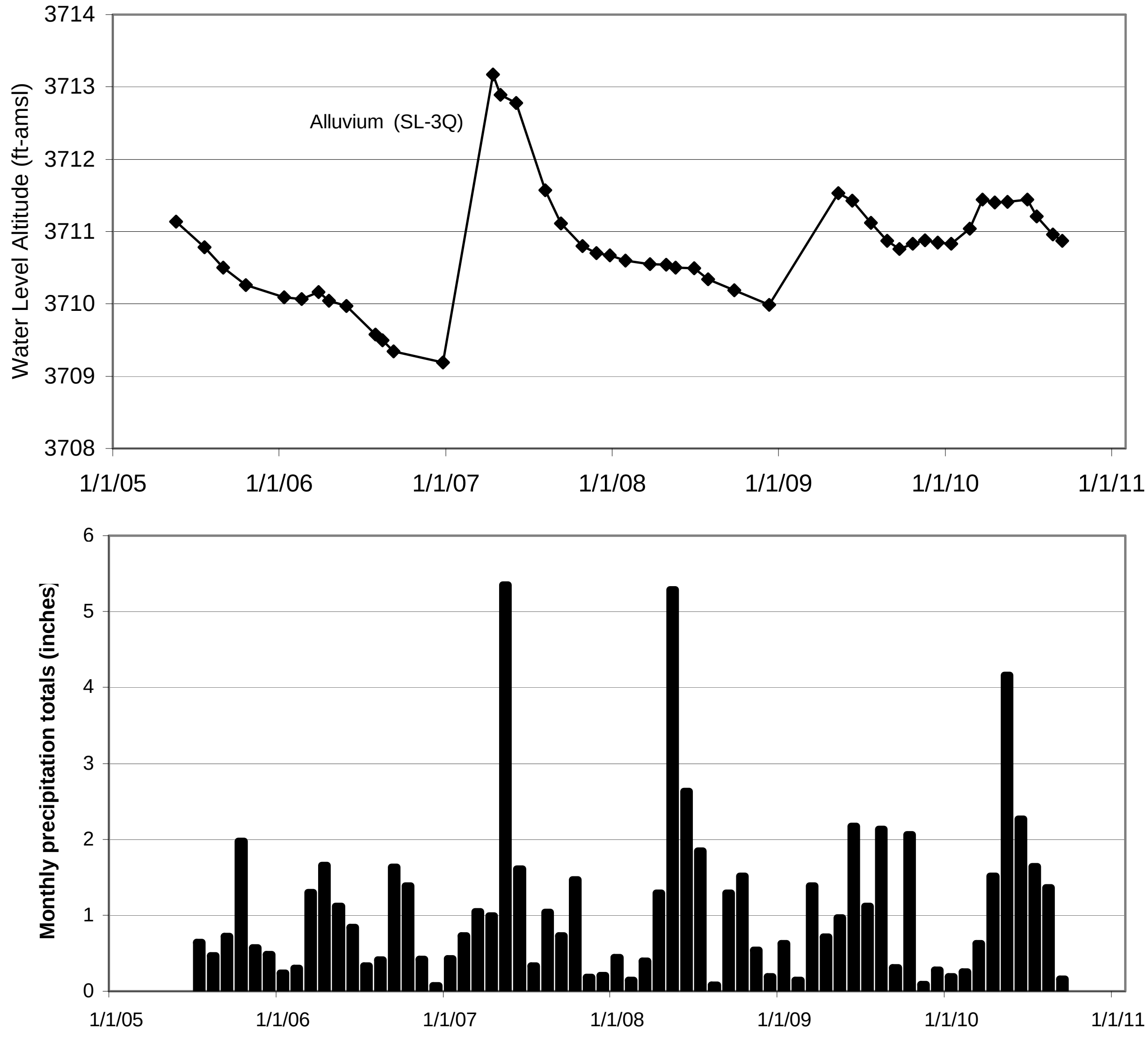


Figure 43. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production. Refer to figure 37 for site location. Monthly precipitation totals in inches is displayed on the lower graph.

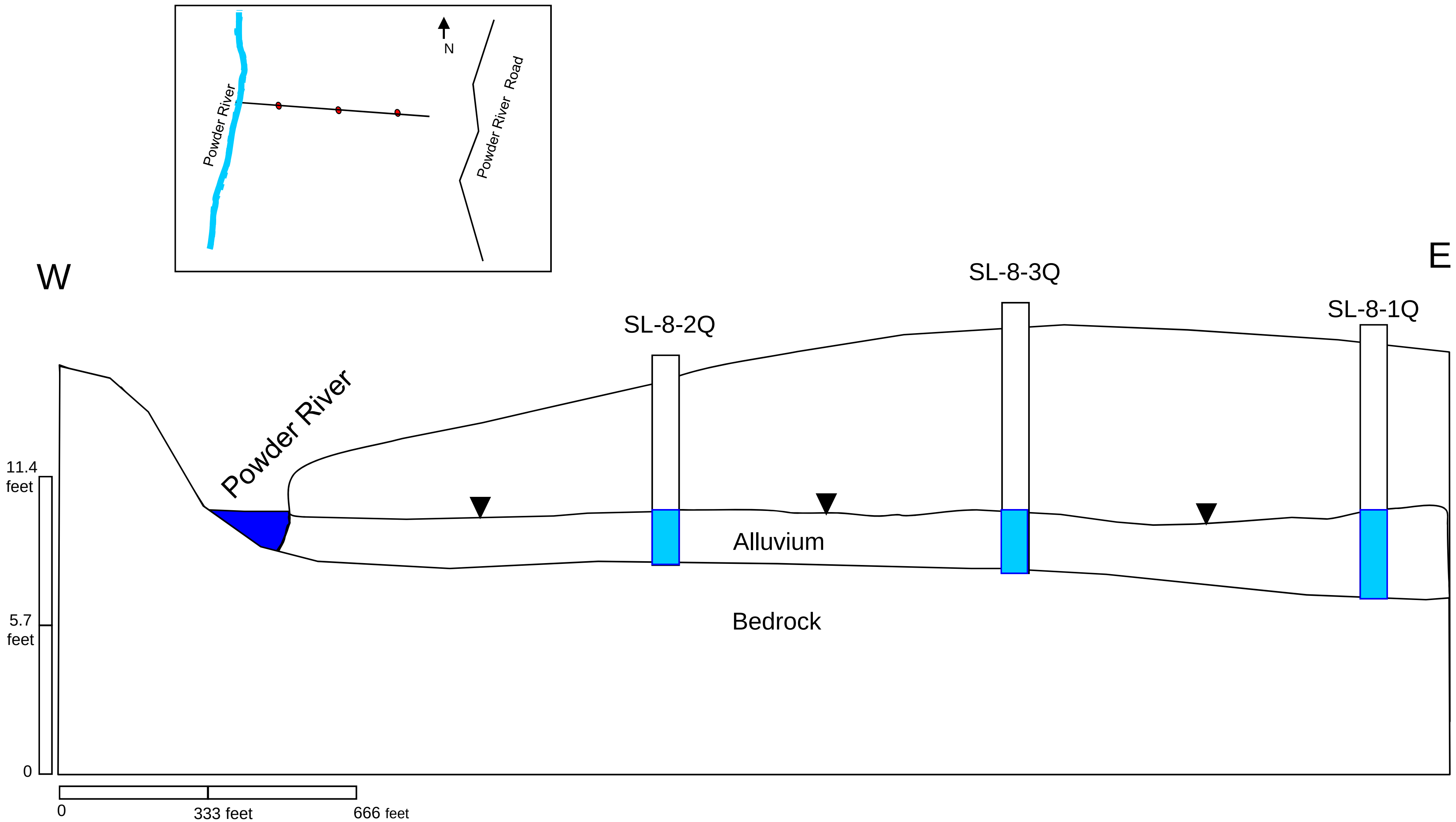


Figure 44. Cross section of alluvial wells south of Moorhead near the Powder River located in T09S R47E section 25. Groundwater in the alluvium appear to flow parallel to the river. Water levels for this cross section were taken in September 2010. Vertical exaggeration is 58:1.

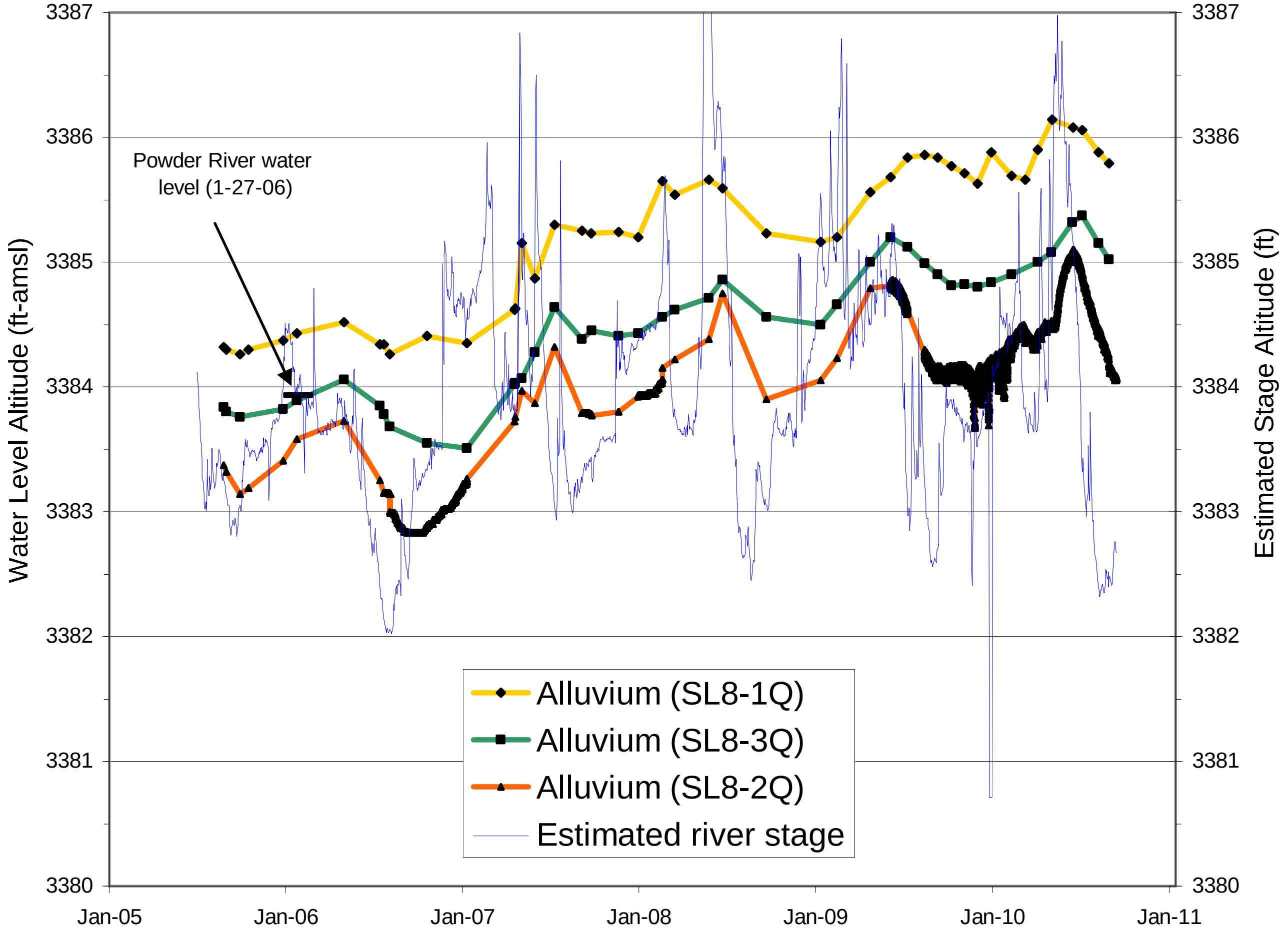


Figure 45. Ground-water flow in the alluvial aquifer at SL-8 is generally toward the Powder River. The ground water-level trends follow river stage trends. The river alternates between gaining (summer) and losing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gaging station (USGS data) and the surveyed river water-level altitude at SL-8 on 1/27/06.

State line drilling program

Previous state line drilling efforts included seven sites along the Montana-Wyoming border approximately every six miles from Range 42E to 47E. The eastern-most State Line site, SL-8, on the Powder River, only includes alluvial wells, so coal aquifer monitoring was limited to Range 46E and west. Wyoming CBM production, however, extends approximately 12 miles east of the Powder River. Wyoming CBM in this area is produced from the Canyon, Cook, Wall, Pawnee, and Cache coal beds (WOGCC, 2010).

During 2010, additional wells were installed in Range 48E (T9S, 48E, S34) to monitor for drawdown in coal aquifers being developed for CBM in Wyoming east of the Powder River. Three wells were installed between October 20th to October 28th, 2010 in the Pawnee, Brewster-Arnold and Odell/Cache coals. Detailed information about well construction and completion can be found on the MBMG website for these wells under the GWIC ID numbers 259676, 259683, and 259684. The deepest well was drilled to 480 feet and was logged without casing with a natural gamma logger (Figure 46). The gamma logger detects the presence of natural levels of gamma radiation, which works well to distinguish between different geologic zones in the Fort Union formation. Coal has very little gamma radiation causing the trace to move to the left (zero), shale has high amounts causing the trace to move to the right, and sandstone has an intermediate amount of radiation. Several small coals were in evidence on the log in addition to the drill cuttings; the largest coal in this area is a 15 foot thick coal which has been correlated to the Brewster-Arnold coal bed.

Coal correlations and the nomenclature attributed to the coals were derived primarily from seven nearby wells in Montana and four wells in Wyoming (Figure 47A and 47B; Culbertson, 1987; McLellan, 1991; McLellan and Biewick, 1988; Molnia and Pierce, 1992; NCRDS, 2010). These nearby wells were installed primarily for coal and oil/gas exploration. The coal logs illustrate that the coal naming convention appears to change in Wyoming. What is called the Wall, Pawnee and Brewster-Arnold coal beds on the Montana side of the border is called the Cook, Wall, and Pawnee coal beds, respectively in Wyoming. The Wyoming Oil and Gas Conservation Commission reports production from the Canyon, Cook, Wall and Pawnee coals south of this monitoring site in Wyoming (WOGCC, 2010). However, based on the naming conventions, production is most likely from the Wall, Pawnee and Brewster-Arnold coals, according to Montana naming conventions. The three monitoring wells were completed in coals based on the Wyoming production and the available coals in the area (the upper coals, the Canyon, Cook and most of the Wall, have been eroded away in this valley). Water level drawdown in these coals, if it occurs, will verify that these coals have been correlated correctly.

All but the shallowest coals (the Wall coal and an un-named coal above the Wall coal) were saturated with water. The deepest well, completed in the Cache coal, produced approximately 2 GPM of water during development with air. The well completed in the Brewster-Arnold coal bed, the thickest coal in this part of the Powder River Basin, and produced 4.6 GPM of water during development with air. This well was also completed in the Pawnee coal bed and produced water at a rate less than ½ GPM during development.

Future drilling priorities include installing wells into coal aquifers at the SL-8 site on the Powder River and adding two deeper wells at the SL-4 site, along Hanging Woman Creek, which currently has wells in the two shallowest coals.

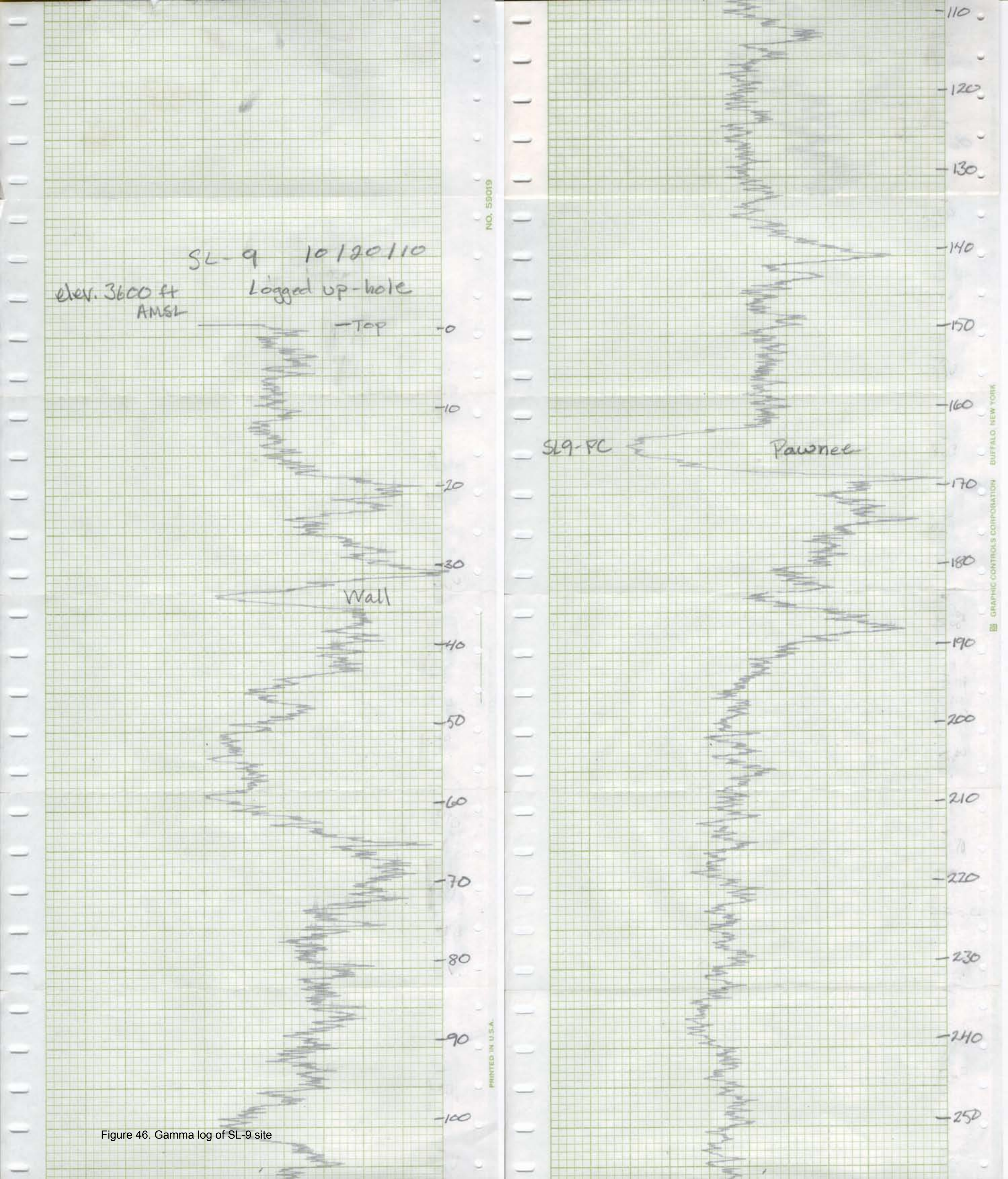


Figure 46. Gamma log of SL-9 site

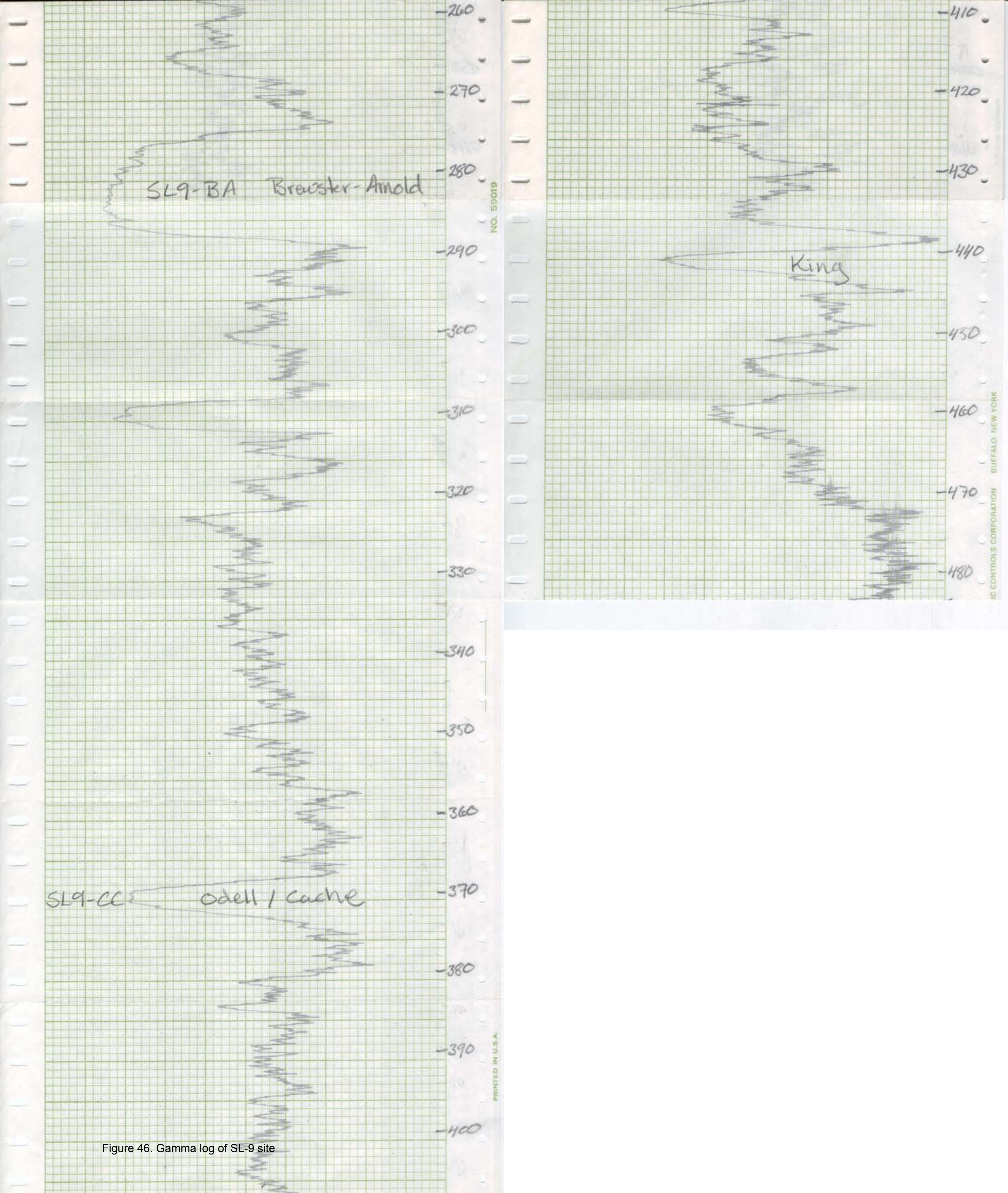
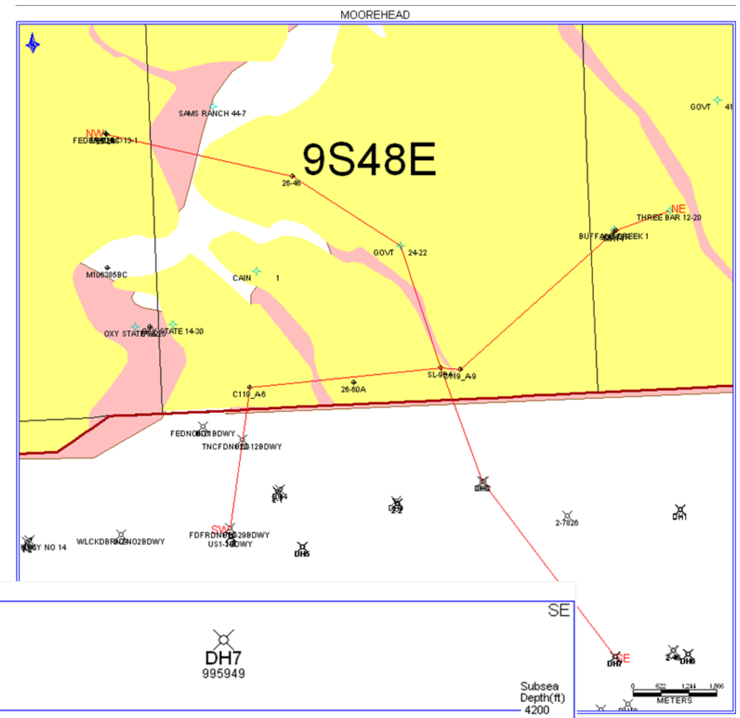


Figure 46. Gamma log of SL-9 site

Figure 47A. Cross section showing MBMG coal correlations from northwest to southeast (inset map). Naming conventions change in Wyoming.

NW ⟺ SE



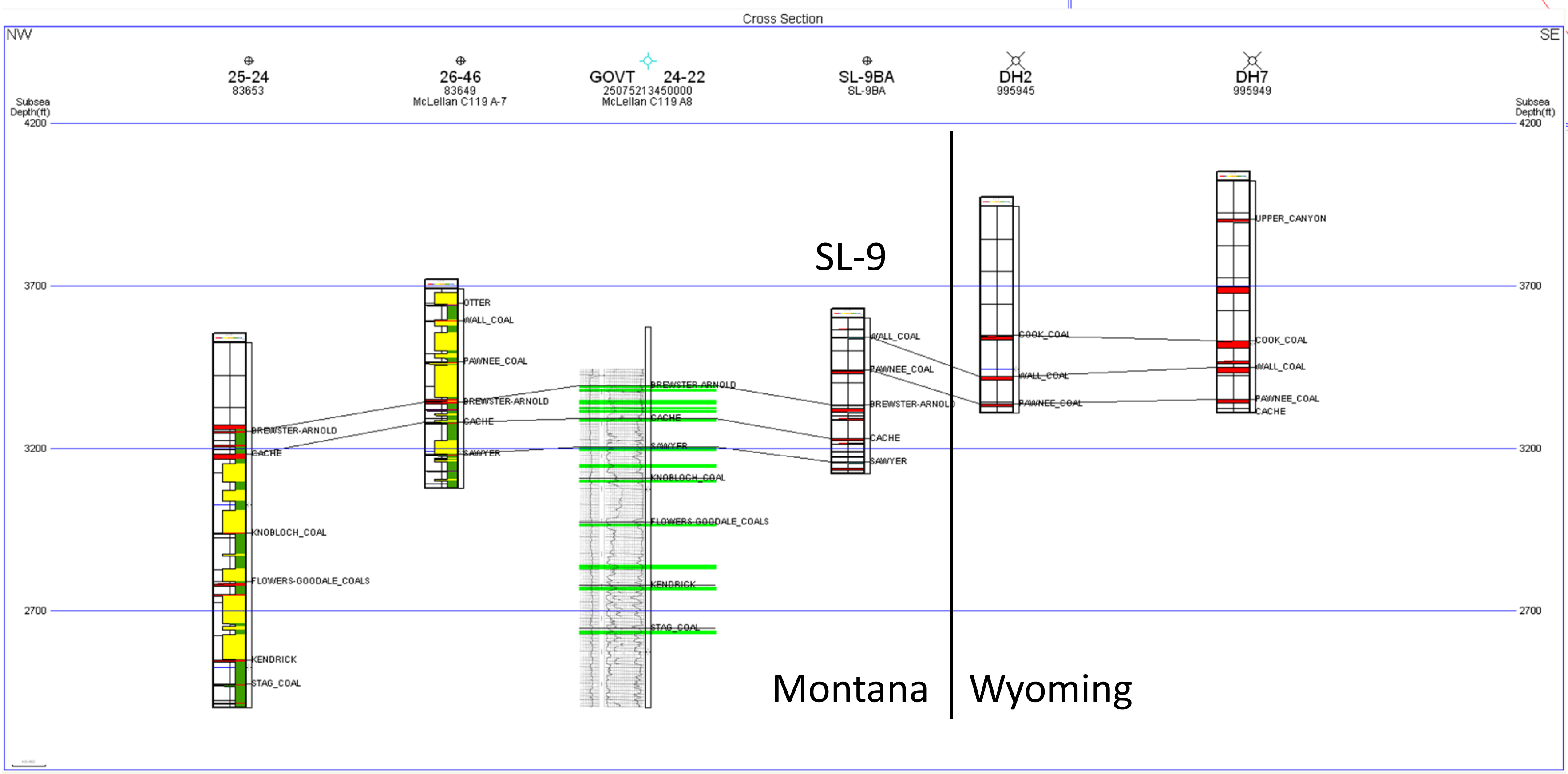
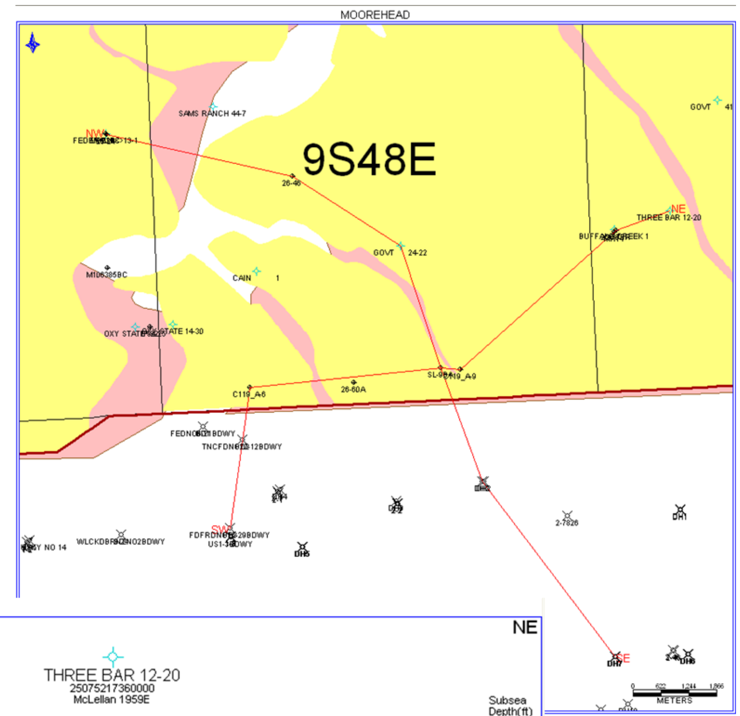
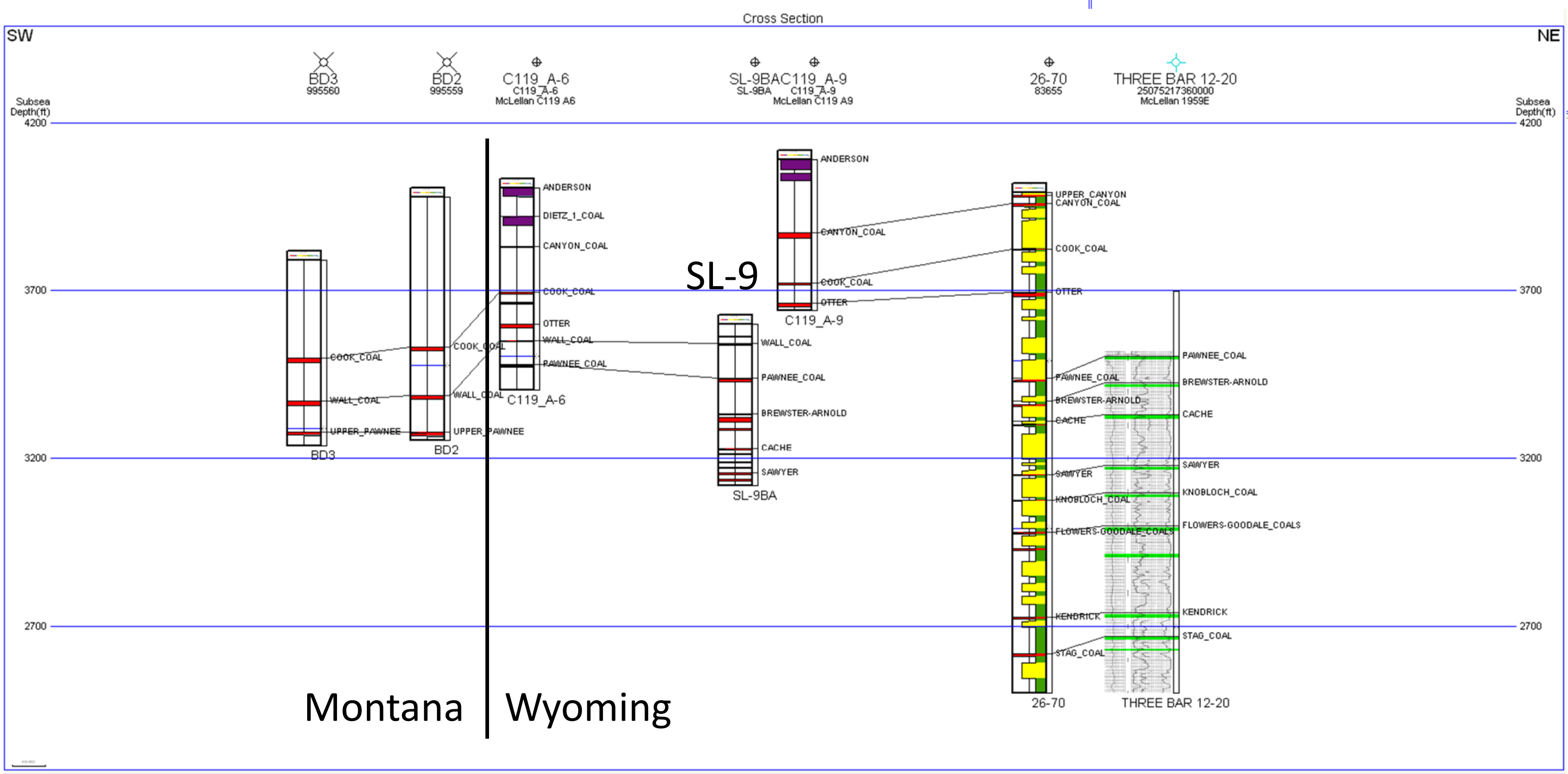


Figure 47B. Cross section showing MBMG coal correlations from southwest to northeast (inset map). Naming conventions change in Wyoming.

SW ⟷ NE





Nutrient evaluation of CBM produced water

Numerous ongoing studies are searching to find ways to extend and expand production of methane from coalbeds. Most studies focus on methods to increase the population of methanogenic bacteria or rate of methane production through increasing food sources or availability. These studies are generally undertaken by adding a suite of nutrients to bacteria cultures and measuring the methane produced. In order to support these efforts toward sustainable coalbed methane fields, the MBMG initiated a small study to look at coalbed methane produced water collected directly from individual CBM wellheads. These water samples were analyzed for 4 nutrients that may be limiting production of methane. The nutrients were chosen by looking at existing coal aquifer water samples available in GWIC and choosing nutrients that are often found to be below detection through normal analysis. The nutrients chosen for study were nitrogen, iron, manganese, and phosphate (Table 5). The nitrogen species that is commonly analyzed is nitrate (NO_3^-), however discussions with MSU microbiologists lead to choosing ammonia as a more probable nutrient source.

Table 5. Four nutrients that may be limiting in methane production.

	Fe	Mn	NO_3^-*	PO_4^{3-}**
Maximum (ppm)	1.4	0.352	18.7	0.69
Minimum (ppm)	0.006	0.001	0.01	0.052
Non-detect (#)	22	24	73	129
% non-detect	15%	16%	49%	87%

*nitrogen as nitrate; ** phosphate in the form of orthophosphate
Data source: MBMG GWIC database water quality of PRB coal aquifer water samples

Funding through the Montana Tech seed grant program allowed the purchase of a handheld, field colorimeter to analyze CBM produced water for the four chosen nutrients. Additionally, the funding covered duplicate analysis by the MBMG analytical laboratory to verify the quality of the colorimeter results. Wells were chosen from among Fidelity's wells in Montana to represent a variety of wells that produced both high and low levels of gas and water. Selected wells are single completion (that is they produce only from one coal zone) in the Dietz 1 or Dietz combined coal and have been producing at least 4 years to limit the effects of development on the analysis. Of the original 34 requested wells, Fidelity reported that 14 were either no longer producing water, were broken, or were inaccessible due to muddy roads. The remaining 20 wells were sampled between July 27th and 29th, 2010, and colorimeter measurements were made the evening following sampling. Samples for analysis by the MBMG analytical laboratory were shipped to Butte immediately upon return to Billings.

Well location and completion information and the chemical analyses for the 20 sampled wells are available in Appendix D. The duplicate analyses were compared to verify the accuracy of the colorimeter data. The colorimeter was calibrated in the laboratory just prior to sample collection using laboratory standards for the four analytes in the low concentrations expected to be found in the field. The MBMG laboratory was not able to measure manganese concentrations in 17 of the 20 samples, whereas the colorimeter reported values for all but 7 samples. This may be due to the delay in processing the samples by the MBMG laboratory which had to be done after all samples were collected and shipped to Butte. A similar problem was encountered with the ammonia analyses which, if not performed within a 3 to 4 hours of collection, tended to be non-detectable by the colorimeter. The MBMG laboratory, instead of analyzing for ammonia, measured nitrate, Kjeldahl nitrogen, and total nitrogen. A comparison between iron and phosphate concentrations measured by colorimeter and the MBMG analytical laboratory (Figure 48) illustrates that, while the measurements may be related (r^2 values of 0.46 and 0.57 respectively), the colorimeter regularly reported values ½ (for iron) to 1/3 (for phosphate) lower than reported by the MBMG laboratory. However, Figure 48 and the linear regression lines were generated by excluding 2 iron measurements and 4 phosphate values that were visually determined to be outliers. These points will be included in further analysis. Despite the lack of a close relationship between the two measurement methods, the general trends (higher to lower values) holds for both methods and rather than the absolute magnitude, further analyses will concentrate on the relative concentration of each analyte.

Each of the four nutrients (nitrogen was analyzed using the total nitrogen measured by the MBMG laboratory, otherwise the colorimeter results are displayed) was compared to the average amount of gas produced by the measured well between 18 and 24 months of production (Figure 49). Months of production was defined as total months a well produced either water or gas. This did not always correlate to the individual well's peak performance, but does serve as an indicator of how productive a well is. There was no correlation between a well's gas production and the concentration of nutrients except in the case of nitrogen. Displayed on Figure 49 is total nitrogen concentration, but the trend was the same for nitrate and total Kjeldahl nitrogen. The general positive correlation between nitrogen concentration and gas production also holds true for the amount of gas produced by each well during July, 2010, the month the water samples were collected (Figure 50).

Displaying the nutrient and gas production in map form in ArcGIS (Figures 51 and 52) helps illustrate the variability in nutrient concentrations even between wells that are geographically close together. Similar to Figure 49, the map display of nutrients shows little correlation between the concentration of the nutrient, displayed as a color range, and the average amount of gas produced between the 18th and 24th month of the wells producing life, displayed as circle size in Figures 51 and 52. However, in the case of total nitrogen, the concentration does appear to correlate to average gas produced. This correlation does not necessarily imply causation; however, preliminary work being done by researchers at Montana State University indicates that the addition of nitrogen to a methanogenic community generally increases the rate of methane production (personal communication Elliot Barnhart, January 2011). These two lines of evidence may indicate that nitrogen contributes to limiting gas production from wells. Increasing available nitrogen to the microbes may help increase gas production from individual CBM wells.

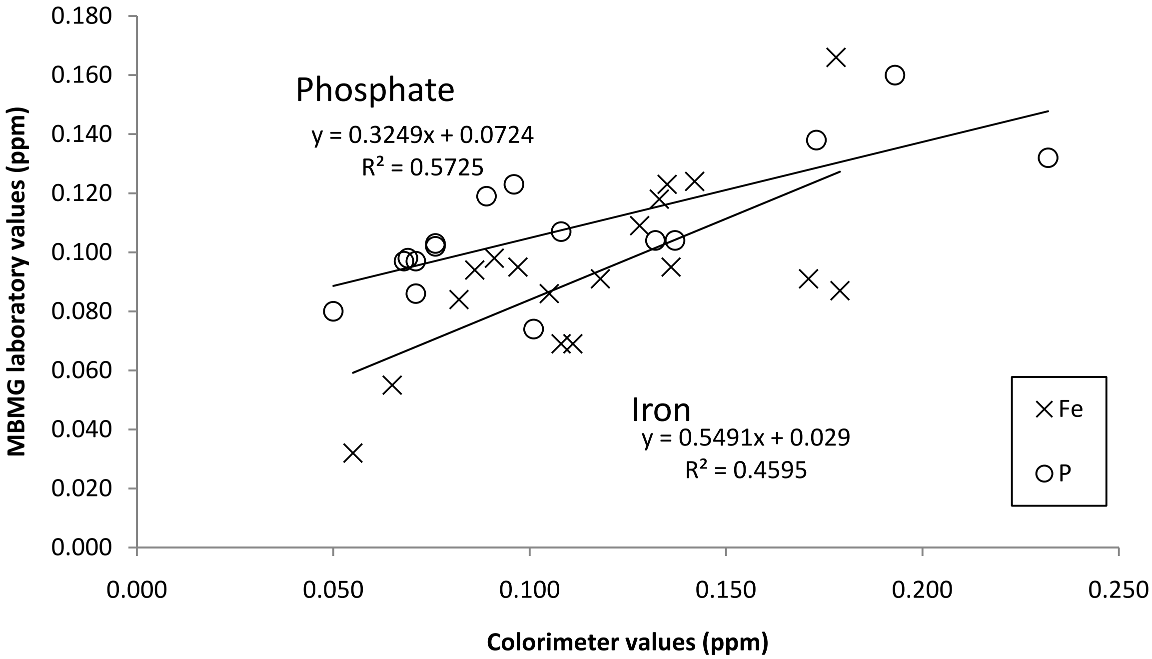


Figure 48. A comparison between the colorimeter and MBMG analytical laboratory values for iron and phosphate show that, while related (R^2=0.46 and 0.57 respectively), the colorimeter reports values of 1/2 (iron) to 1/3 (phosphate) those reported by the MBMG analytical laboratory. The data and regression lines do not reflect 2 measured iron values and 4 measured phosphate values that were visually determined to be possible outliers.

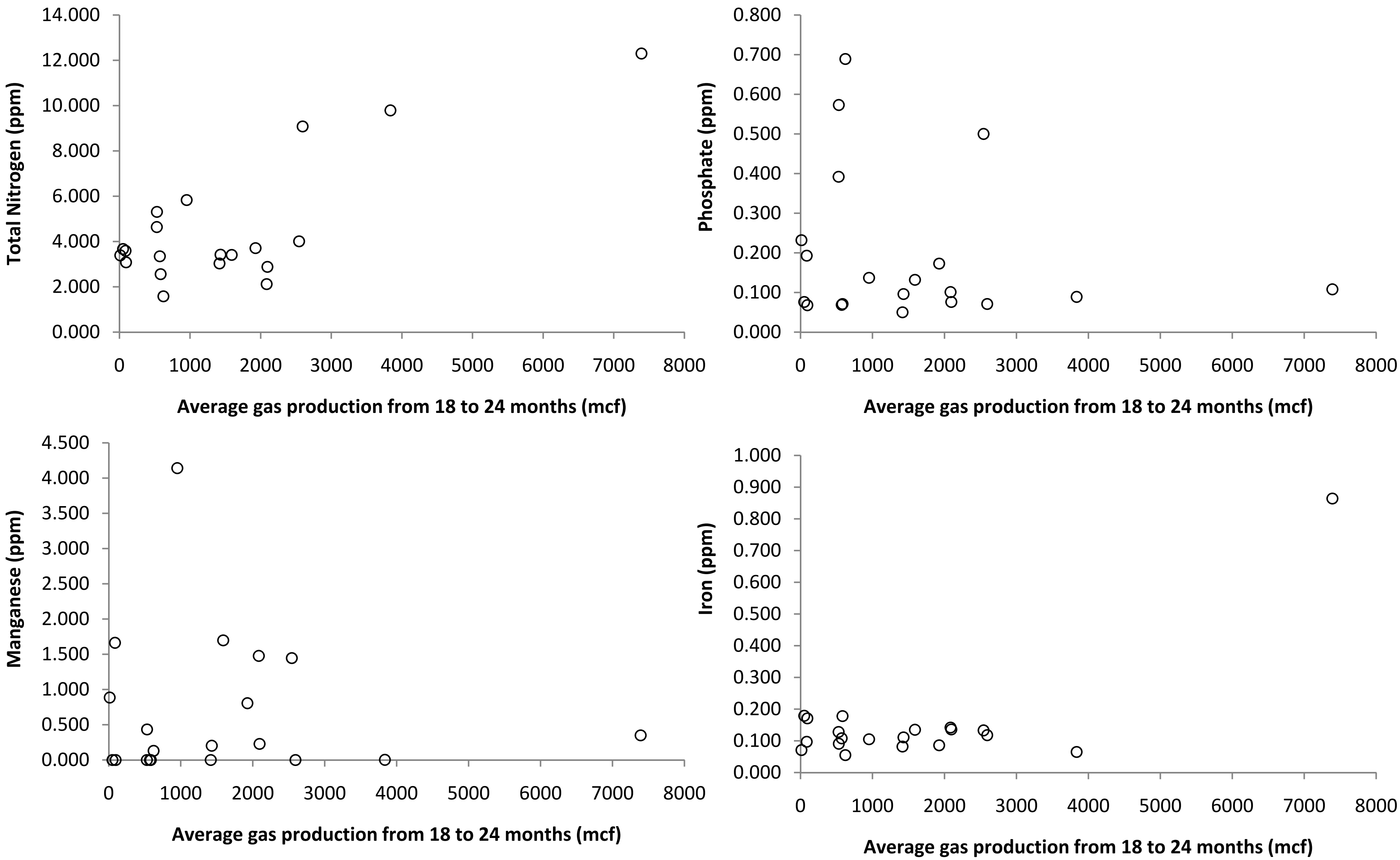


Figure 49. There is no correlation between nutrient concentration and the average amount of gas produced from 18 to 24 months of water and/or gas production (the average time frame for individual wells to reach their peak gas production) except in the case of total nitrogen.

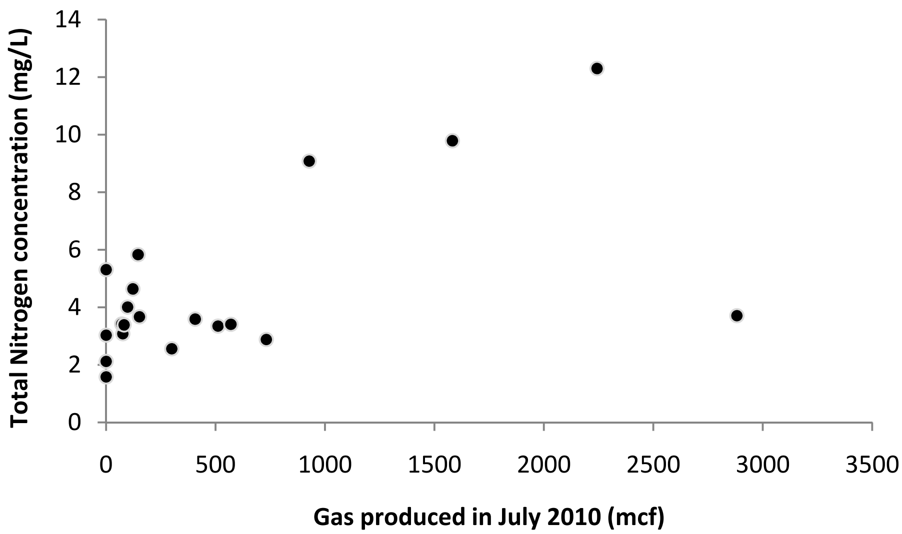


Figure 50. The positive correlation between total nitrogen concentration and gas production generally holds true for the gas produced during July, 2010 – the month the water samples were collected.

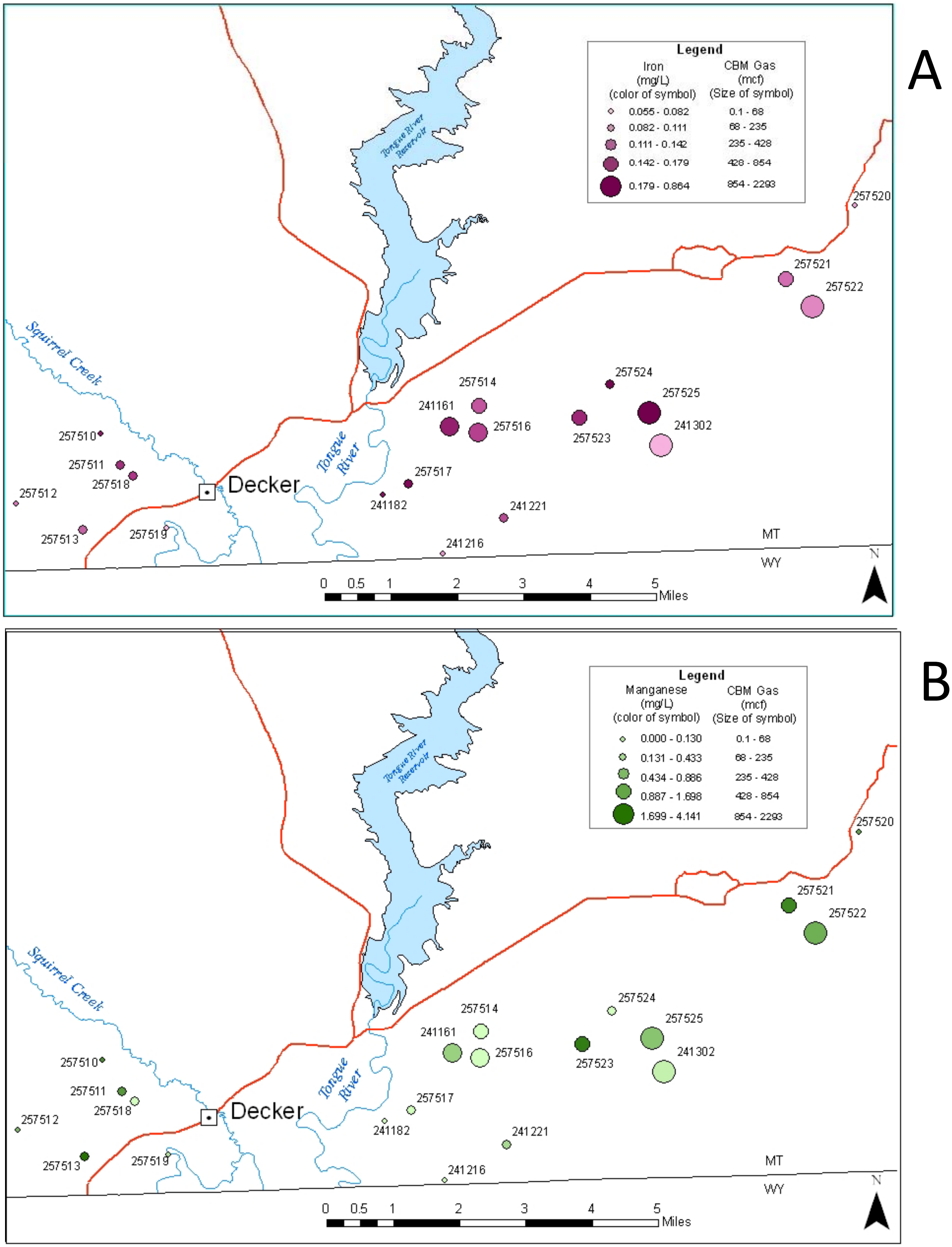


Figure 51. Map display of nutrient concentrations for iron (A) and manganese (B) . Concentration is depicted by color range and the average gas produced from 18 to 24 months by the size of circle.

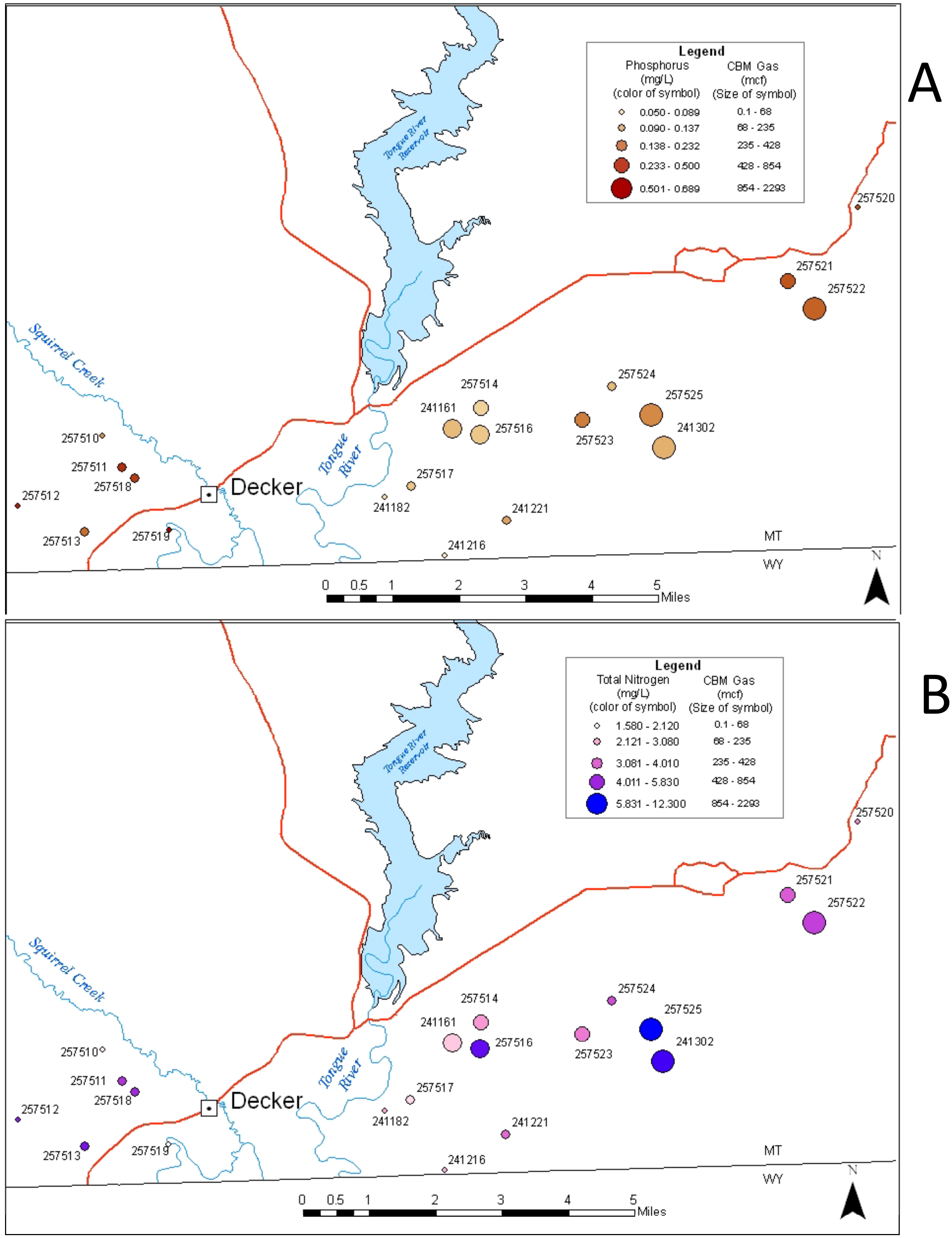


Figure 52. Map display of nutrient concentrations for phosphorus (A) and total nitrogen(B) . Concentration is depicted by color range and the average gas produced from 18 to 24 months by the size of circle.

Groundwater flow model of the Ash Creek – West Decker Mine Area

Purpose and Site Description of the Model

A simple, steady-state model was constructed which illuminated the limitations in the completeness and usefulness of existing data for use in more complex, comprehensive models. The comprehensive models would be used to predict the impact and interaction of coal strip mining and CBM development on groundwater levels and stream flow in this portion of the Powder River basin. Evaluated data include groundwater level monitoring, stream flow, and recharge estimates along with published aquifer parameters.

The extensive coal deposits in the Fort Union formation of the Tongue River basin extend from northeastern Wyoming into southeastern Montana in the Powder River Basin (Wyoming State Geological Survey, 2008). Surface coal mining and the associated dewatering began at the Decker mine in 1972 and at the nearby Ash Creek mine in 1976. The Ash Creek mine only produced coal for a short time but dewatering continued until the end of 1995. The target coal for production at both mines was, and is, the Anderson-Deitz coal. In addition to the laterally continuous coal bed aquifers, sandstone aquifers in the Tertiary Wasatch Formation and the Tongue River member of the Fort Union Formation are also used for domestic and stock purposes throughout this area (Thompson, et al., 1981; Wyoming State Geological Survey, 2008). These aquifers have been extensively monitored prior to and during surface mine dewatering and continue to be monitored as CBM production expands.

The groundwater flow model was constructed for the area from southwest of Ash Creek mine to northeast of Decker mine to model the aquifer drawdown in response to mine dewatering. The more comprehensive model will be calibrated against the recent recorded drop in water levels with the onset of CBM production in the area then will be tested as a predictive tool. The model area includes approximately 91 square miles extending from the recharge area in Sheridan County, Wyoming to the discharge area along the Tongue River and at Tongue River Reservoir near Decker, Montana (Figure 53).

Model Description

Statigraphy Modeling

Stratigraphy modeling was accomplished using the borehole and grid modules in the software package Groundwater Modeling Systems, Aquaveo,LLC GMS 7.1.2. Borehole stratigraphy data recorded in well logs for area wells were used to define the thicknesses and elevations of the Anderson-Deitz coal bed aquifer and the siltstone/shale overburden. Well logs from monitoring and water wells recorded with Montana Ground Water Information Center (GWIC: mbmggwic.mtech.edu) and oil and gas well logs were used in this process. The borehole stratigraphy in Wyoming was estimated using the interactive web site provided by the University of Wyoming (2010, ims.wrds.uwyo.edu/prb/viewer.htm). Surface elevations were entered as a scatter point set digitized from USGS 1:24,000 topographic maps. Model surface elevations were interpolated from the digitized scatter point elevations (Figure 54). Borehole contacts were converted to scatter point sets representing the elevations of the bottom and top of the Anderson-

Deitz coal bed. The scatter point sets were interpolated to 2D grids to visualize the surface and to image the aquifer thickness.

MODFLOW Grid

The conceptual model approach in GMS 7.1.2 was used to build the MODFLOW grid. USGS 7.5 minute quad images (Bar V Ranch, Pearl School, Decker, Tongue River, Monarch, Acme, and Bar N Draw) were used as model base maps. Aerial photos (NAIP, 2009) were also downloaded from the Montana geographic database NRIS (2010) and used to verify map positions of wells. The grid was rotated to align the cells with the predominant direction of the northeast trending faults and the apparent groundwater flow. The grid was set to represent an area 92,000 feet long and 52,000 feet wide. A cell size of 500 feet by 500 feet was selected. Boundary arcs were used to define the active area of the grid resulting in 10,201 active cells in each layer. The top layer of the two layer grid represents the overburden and the second layer represents the combined Anderson-Deitz coal (Figure 55). In most of the model area, the Anderson, Deitz-1, and Deitz-2 are separated by variable amounts of interburden (Hedges, et al., 1980). Interpolations of the top of the Anderson to the bottom of the Deitz were used to define layer 2 thereby modeling the Anderson-Deitz coal as a single hydrologic unit for simplicity.

Boundary Conditions

Previous studies suggest the recharge area for the Anderson-Deitz coal bed aquifer to be the area southwest of Ash Creek mine where the coal beds outcrop and in some areas have burned forming large areas of clinker (Hedges et al., 1980; Van Voast and Hedges, 1975). The University of Wyoming interactive website was used to define the boundary of the coal beds in the recharge area (http://ims.wrds.uwyo.edu/prb/viewer.htm). General head boundaries (GHB) were used along the southwest and northwest sides of the model. Head elevations were set to keep the coal bed (layer 2) saturated. The node elevations used to define the heads along the boundary arcs were adjusted in the early stages of model calibration to achieve saturation along the boundary. The southeastern boundary was modeled using the river package with an arc representing the Tongue River extending from the model southwest boundary to the Tongue River Reservoir. The boundary of the Tongue River to the northern boundary was set as a GHB (Figure 56). Some of the coal beds once outcropped north of Decker and have been burned resulting in clinker. These large areas of clinker are presented in the Colorado School of Mines Coal Resource Occurrence maps (Colorado School of Mines, 1979). The lower beds of the Anderson-Deitz extend beneath the reservoir near Decker Mine; Davis (1984) surmised that groundwater from these beds discharge to the reservoir. Drains were included in the model to represent groundwater discharge to streams.

Role of Area Faults

About 14 northeast-trending faults cross the model area and some have been documented to act as hydrologic barriers (Hedges, et al., 1980; Van Voast and Hedges, 1975; Van Voast and Reiten, 1988). A GIS coverage of the fault locations as mapped by Fidelity (Wheaton, et al., 2008) was used as a starting point for positioning the fault barrier arcs in GMS. The faults were modeled using the flow barrier package. Stratigraphy data interpolated from boreholes logs were used to document the amount of offset and direction for each fault (Figure 57). The offset of the Anderson-Dietz coal bed along a given fault can range from completely off-set at one end to no off-set at the other end. This type of scissor fault results in variable restriction to groundwater flow. The barrier conductance factor in the barrier package was adjusted as part of calibration to model the variable restriction to groundwater flow.

Steady-State Model Calibration

The steady-state model was calibrated to the water levels reported for August 2^{nd}, 1977. This is the earliest set of data for most of the MBMG monitoring wells in the area. An observation-well coverage was created in GMS for calibrating to the monitoring well static water levels (Figure 58). The calibration targets in GMS show the model-computed value relative to the observed value, +/- the assigned calibration interval. For this model, the calibration interval was set to be +/- 5.0 feet. Thus the calibration target is colored green if the computed head value is within +/- 5 feet of the observed value. The target will appear yellow if the computed value is within +/- 10 feet of the observed value. The red colored calibration targets show computed values in excess of +/-10 feet of observed values. An observation coverage was also created for flows on the Tongue River, but stream discharge data were insufficient for use in calibration of the model. Of the flow available for the Tongue River, the historical data did not include measurements at the times and locations needed for model calibration (Tongue River Surface-Water-Quality Monitoring Network, USGS [Online]).

Initial calibration resulted in dry cells in the recharge areas and elevated water levels near the center of the model. Parameter estimation (PEST) simulations were used to estimate the horizontal hydraulic conductivity (K_h) of the coal bed aquifer. PEST simulations using pilot points and polygons resulted in K_h values ranging from 0.1 to 10 ft/day. These values were consistent with values reported in the literature, 0.1 – 3.6 ft/day (Davis, 1984; Hedges, et al., 1980; Van Voast and Hedges, 1975). Ultimately, the K_h values were adjusted from the PEST results during calibration. The polygons were used to vary the K_h values for the coal bed aquifer modeled as layer 2 (figure 59). The K_h values for layer 1 were also assigned using polygons with rates of 100 ft/day for clinker areas and 0.1 ft/day for the shale and siltstone overburden.

The model was quite sensitive to changes in the recharge rates applied to areas identified as having significant clinker outcrops. Initial recharge rates were set to be 5.0% of the average annual precipitation of 15.3 in for the Youngs Creek-Squirrel Creek area (Hedges et al., 1980). This rate was only applied in the clinker recharge areas of the model. PEST was used to refine recharge rates assigned to the model area recharge polygons. The resultant recharge values from PEST simulations put too much water in the model and were adjusted to the values in Table 6. Recharge was applied to the model by specifying the recharge rates for given polygons in layer 1 (Figure 60). The amount of recharge to the coal bed aquifers from streams was not known.

Table 6: MODFLOW Model Settings

Model Settings	Maximum	Minimum	Comments
HK Layer 1 (ft/day) overburden	100	0.1	100 (clinker-gravel), 0.1 (shale,siltstone, andstone)
HK Layer 2 (ft/day) coal	10	0.6	Lower values where coal bed splits
Recharge (ft/day, in/yr)	.00113, 4.94	0, 0	Higher values in clinker recharge areas
Barrier Conductances	10	0.00001	Values related to fault offset and head differences.

Model Results

The steady state model was calibrated with the stresses of the dewatering pumping at Ash Creek mine and at the Decker mine. Pumping rates of 140 gpm (27,000 ft^3/day) were used for Ash Creek mine and 450 gpm (86,000 ft^3/day) for Decker mine dewatering (Hedges, et al., 1980; Western Water Consultants, 1983). Model simulations to represent the hydrology prior to dewatering (modeled without dewatering from Ash Creek and Decker mines) and during mine dewatering prior to CBM production (1977) were run and the difference in the heads computed (Figure 59). The drawdown contours show the compartmental nature of the aquifer as the result of the northeast trending faults. The drawdown in the steady state model is greater than that reported by Van Voast and Reiten (1988) for the Ash Creek mine and is less than their values for the Decker mine. The drawdown at Decker would better be simulated using a model with additional layers and under transient conditions.

Discussion

The primary objective of the modeling effort was to examine the limitations of the available data for the Ash Creek – West Decker mine areas. Aquifer parameters, based on previous investigations were used to constrain the model that incorporated ground water levels, stream discharge, and recharge. Each of these were varied within the model and evaluated for its importance to calibration.

Groundwater levels recorded August 2nd, 1977 were chosen for head calibration targets because they were the earliest set of data for most of the model area monitoring wells. As noted, however, the water levels were already in decline due to dewatering. The steady-state model solution assumes equilibrium has been reached in response to the pumping stresses and aquifer properties applied. A better solution may be achieved with transient simulations calibrated to the changing water levels.

Surface water flow measurements were not available for critical areas of the model. The model identified several reaches where field data for groundwater – surface water interaction are critical to model calibration.

The recharge area for the model was assumed to be the higher elevations where coal outcrops burned forming large clinker beds based on previous work by Van Voast and Reiten (1988), but the connections between the clinker and the coal bed aquifers are not well defined. A portion of the recharge in clinker areas most likely discharges to the shallow alluvium of the model area streams and the remainder recharges the coal bed aquifer. Recharge rates applied to the model were varied in the calibration process to achieve the observed heads, but better estimates of recharge rates could be produced if surface water flows were included in the calibration process.

The northeast-trending faults pay a major role in defining the model area flow system. Cross sections were constructed using borehole data across the faults to detect fault offset. The information gained from the cross sections was helpful in setting the barrier conductance factor in the barrier package. This factor was found to be a very sensitive parameter and small changes in this factor made major changes in the model head distribution and in the model stability. The values where selected by trial and error in the calibration process. The head differences across the faults were know in some locations and conductance values were selected to model this difference.

The model presented here was intended to serve as a pilot for more comprehensive modeling that would evaluate water-level drawdown and stream depletion from coal strip mining and CBM development. The next stage in comprehensive modeling will require the following:

- Synoptic stream flow measurements on the Tongue River with regard to stream losses and gains.
- Continue to improve the accuracy of aquifer parameters.
- More data from the Wyoming section of the model for better control of the stratigraphy and water levels.

Once the steady-state model has been transformed into a comprehensive model and calibrated to drawdown from both coal mines and CBM development, it will form the basis for future modeling efforts. The modeling techniques developed for this model will be transferable to future CBM fields for accurate water-level drawdown predictions.

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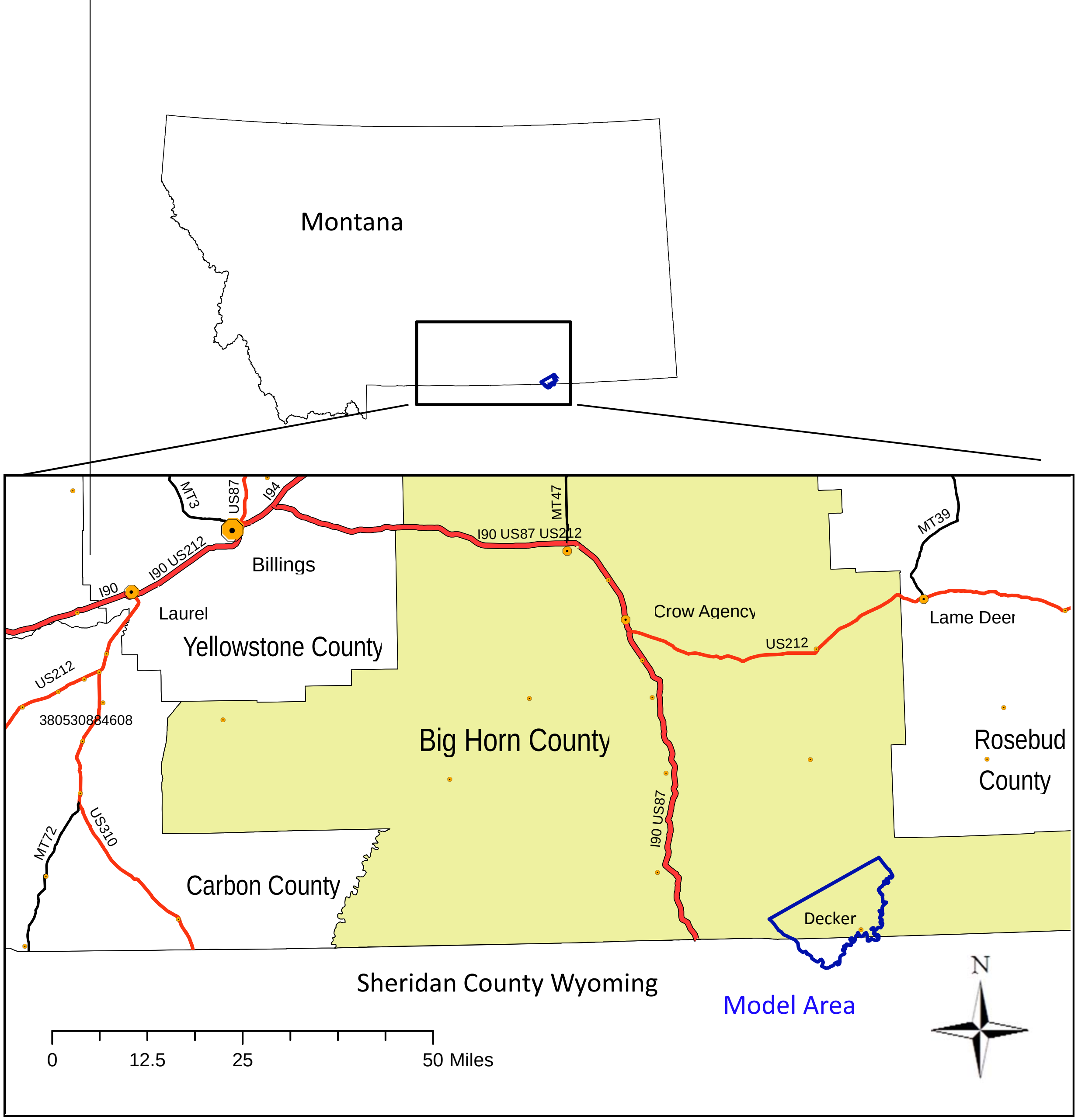

Figure 53: Location of the Ash Creek-Decker groundwater flow model showing the model boundary.

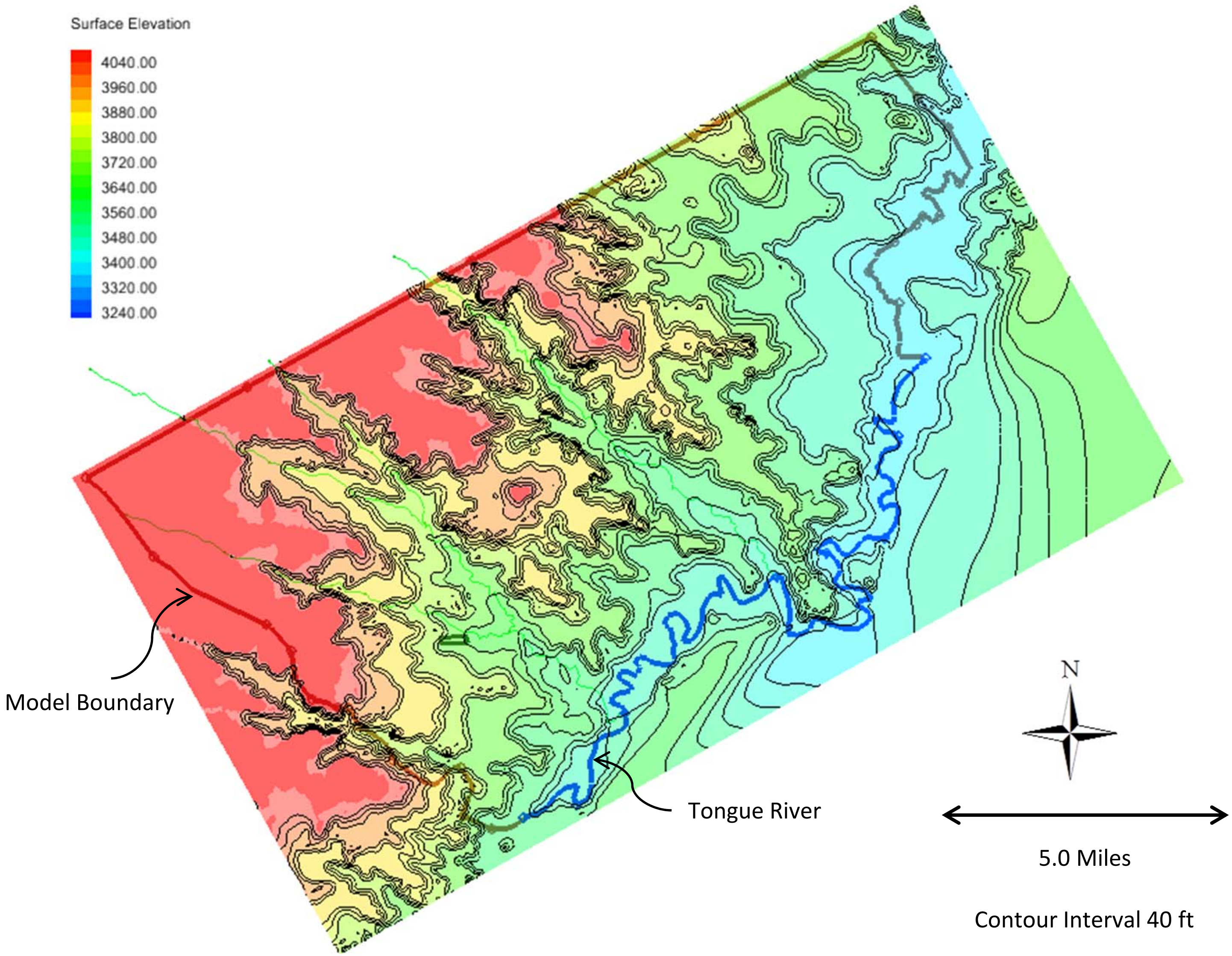

Figure 54: Model area land surface interpolation and model boundary

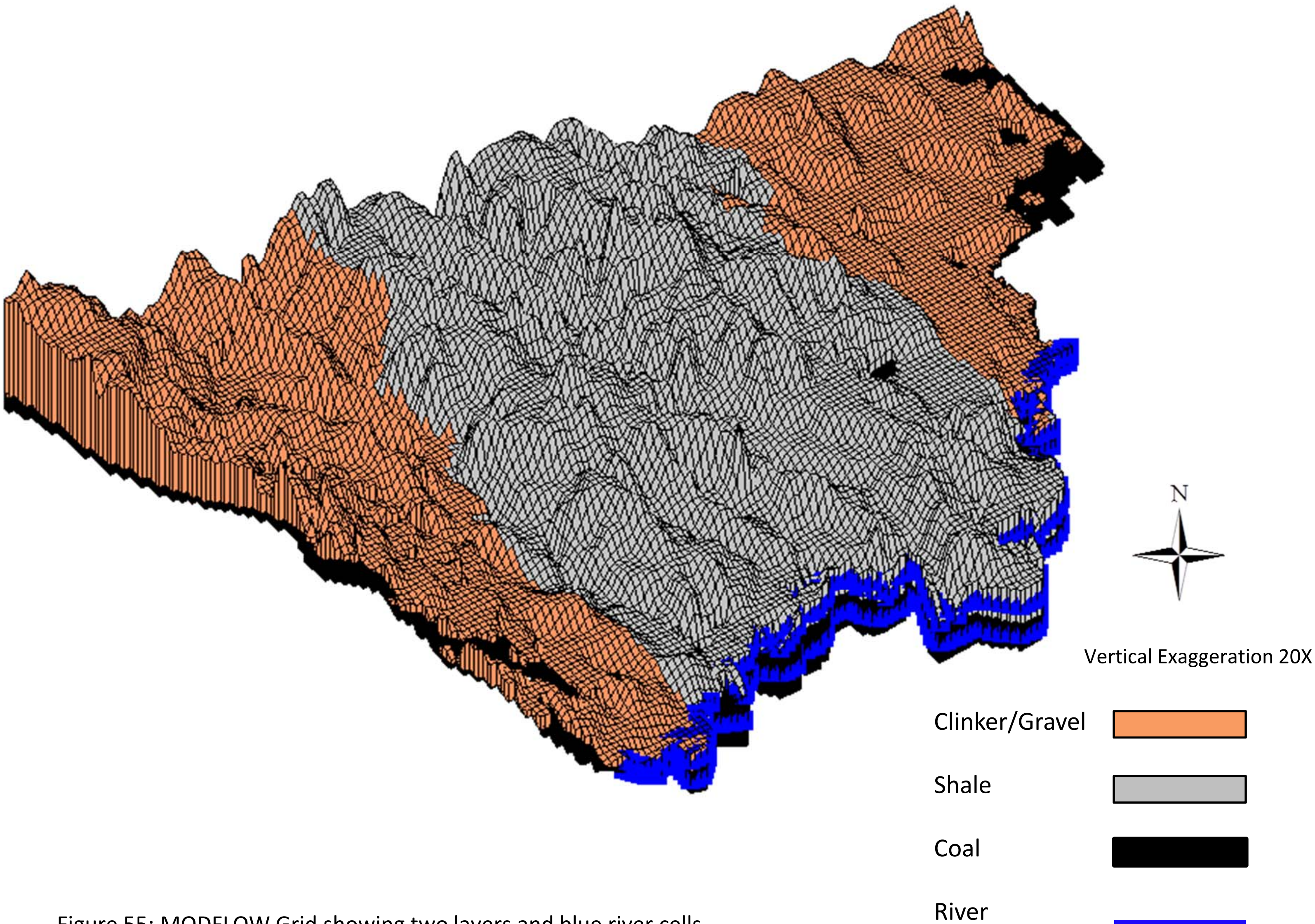

Figure 55: MODFLOW Grid showing two layers and blue river cells

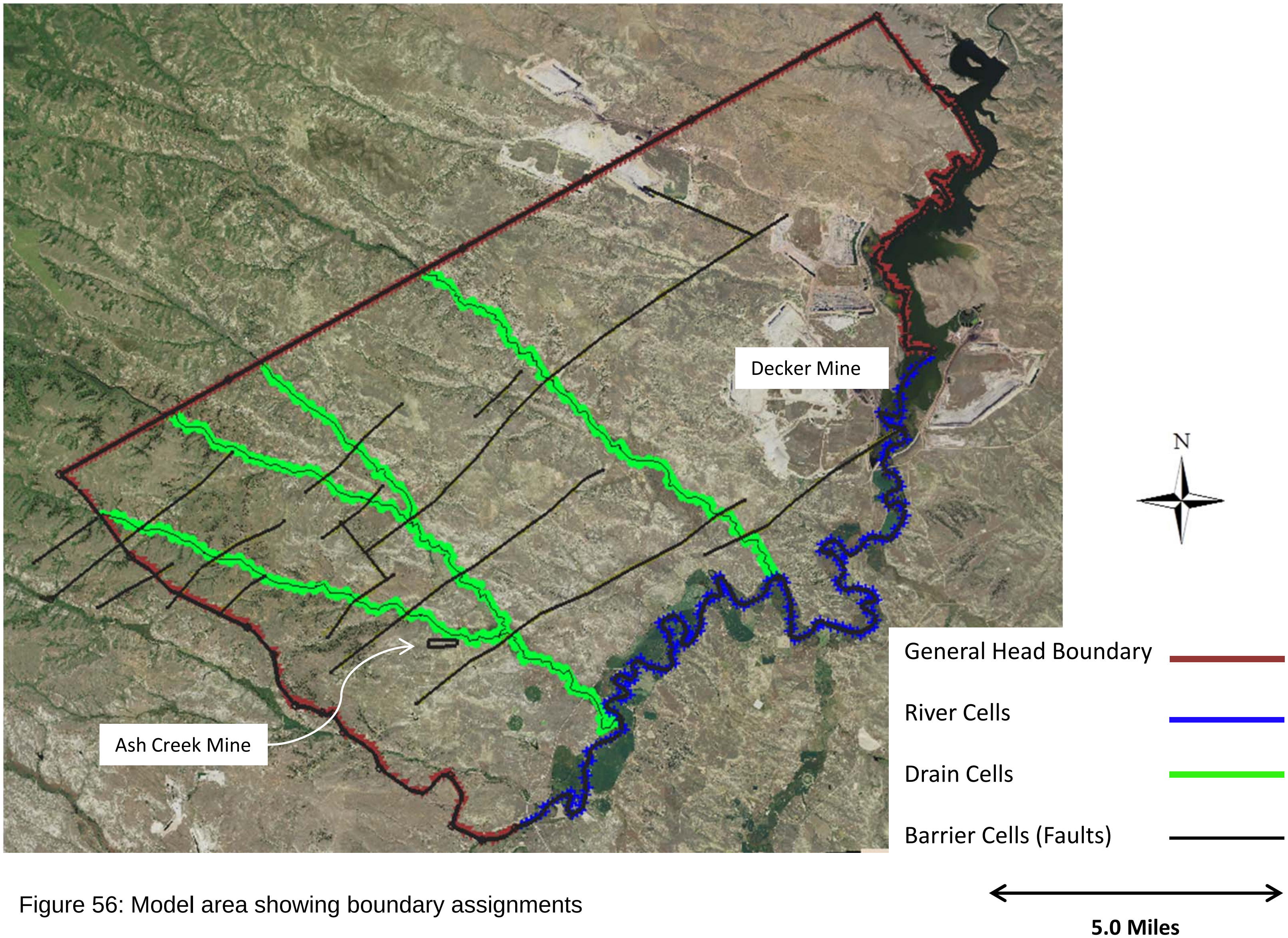

Figure 56: Model area showing boundary assignments

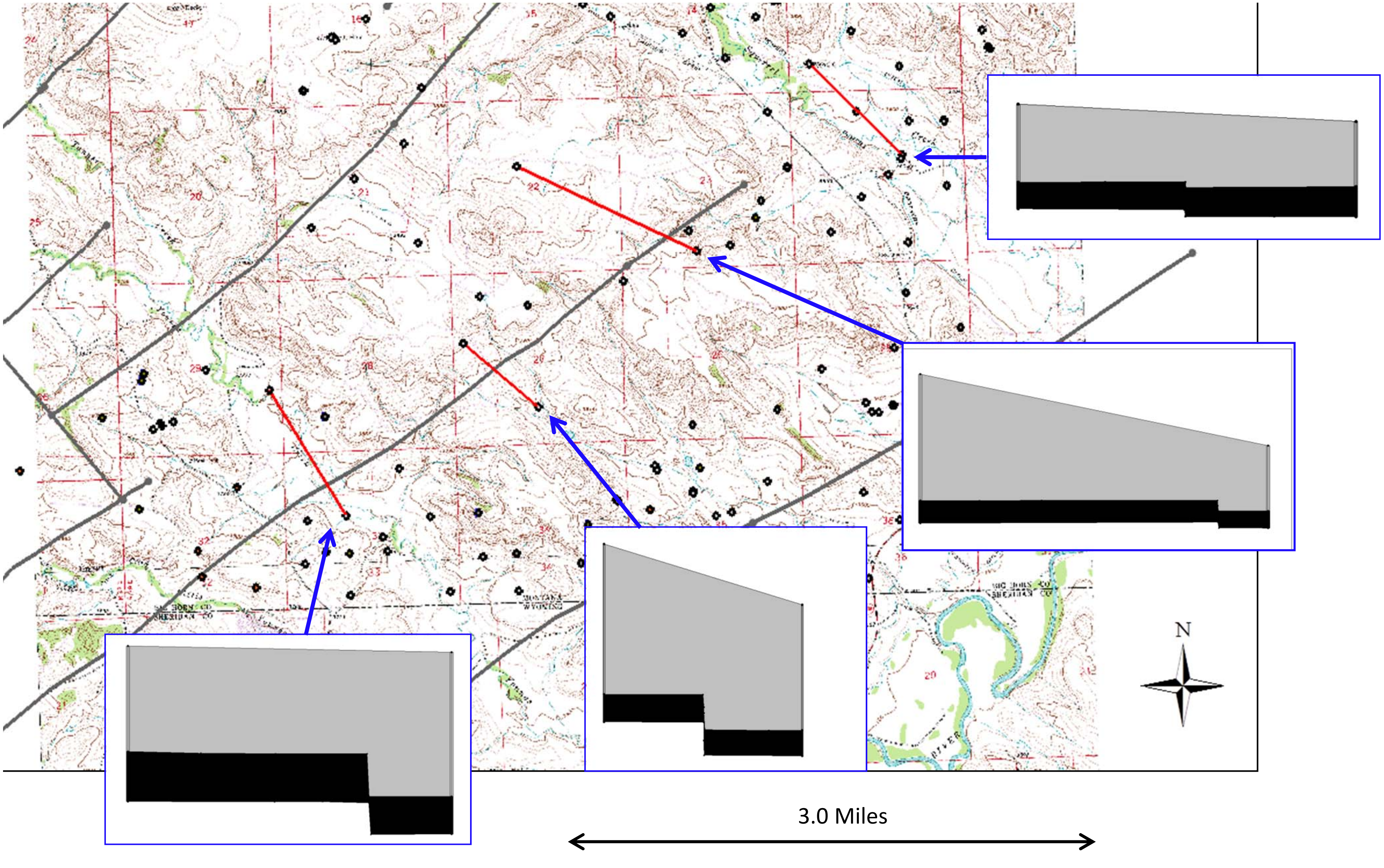

Figure 57: Borehole cross-sections (red) across a fault (grey) showing coal-bed aquifer offset at the indicated locations.

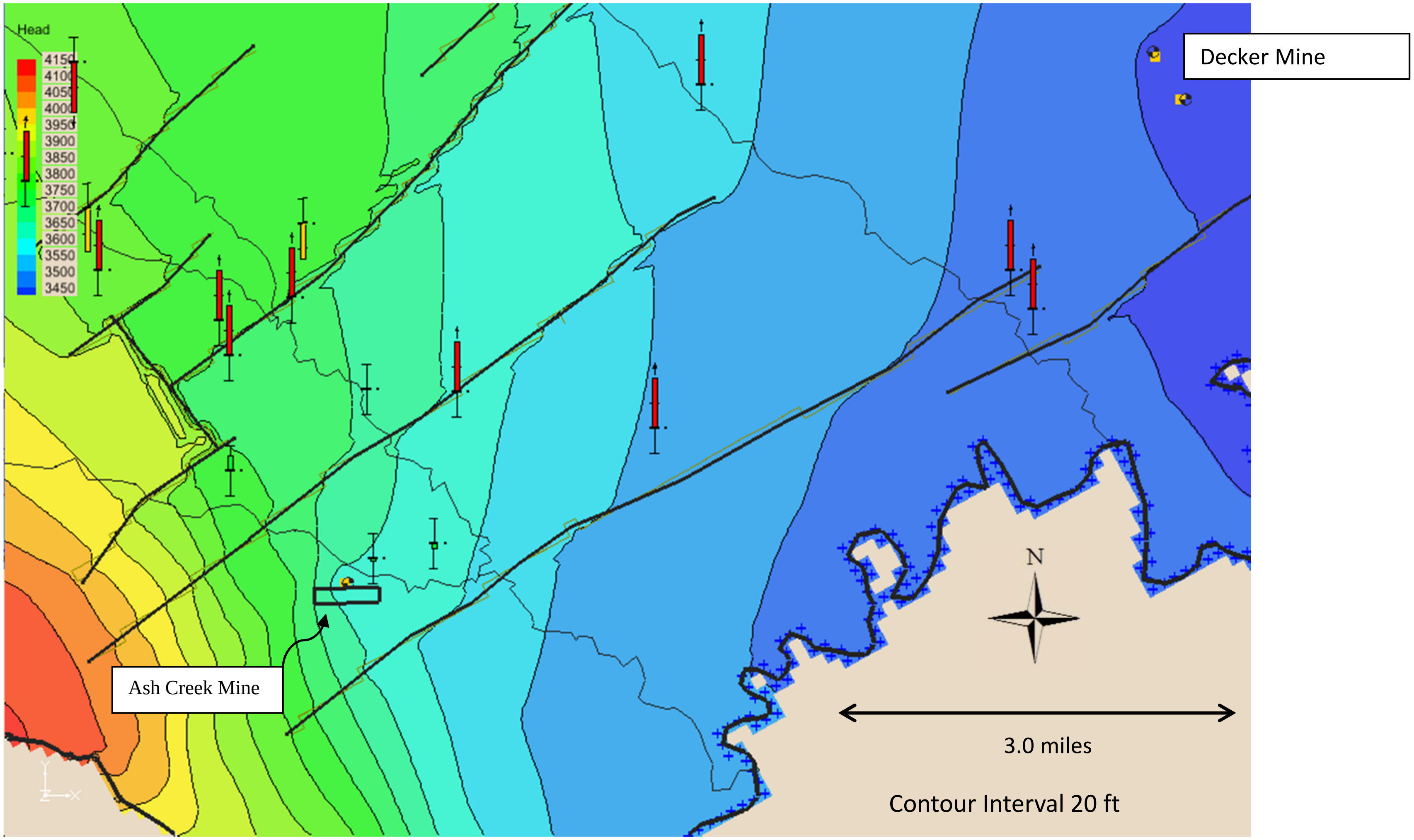

Figure 58: Steady state model run showing calibration markers. Green markers indicate agreement with the observed heads within +/- 5.0 feet.

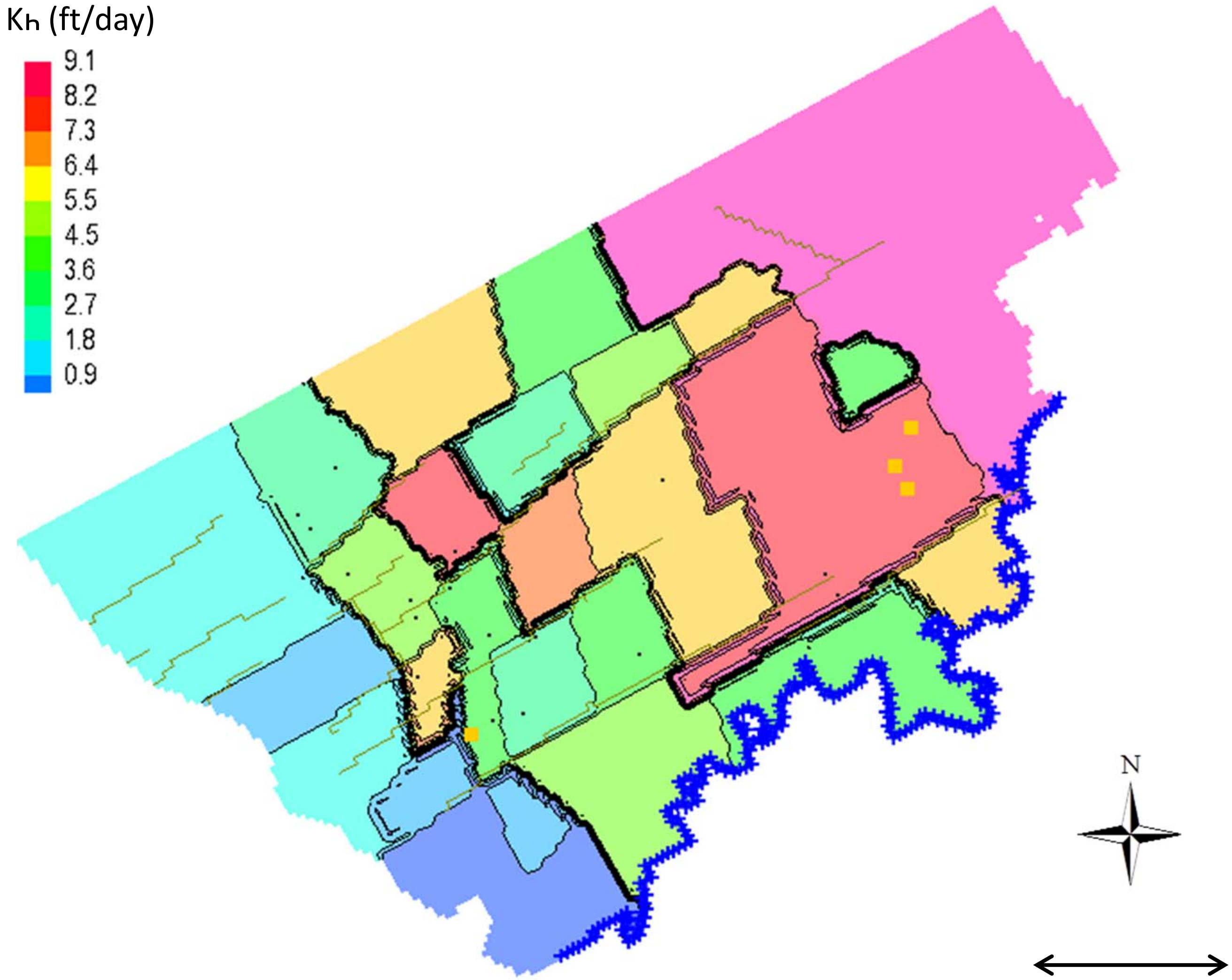

Figure 59: Horizontal hydraulic conductivities for layer 2 the coal bed aquifer were assigned using polygons.

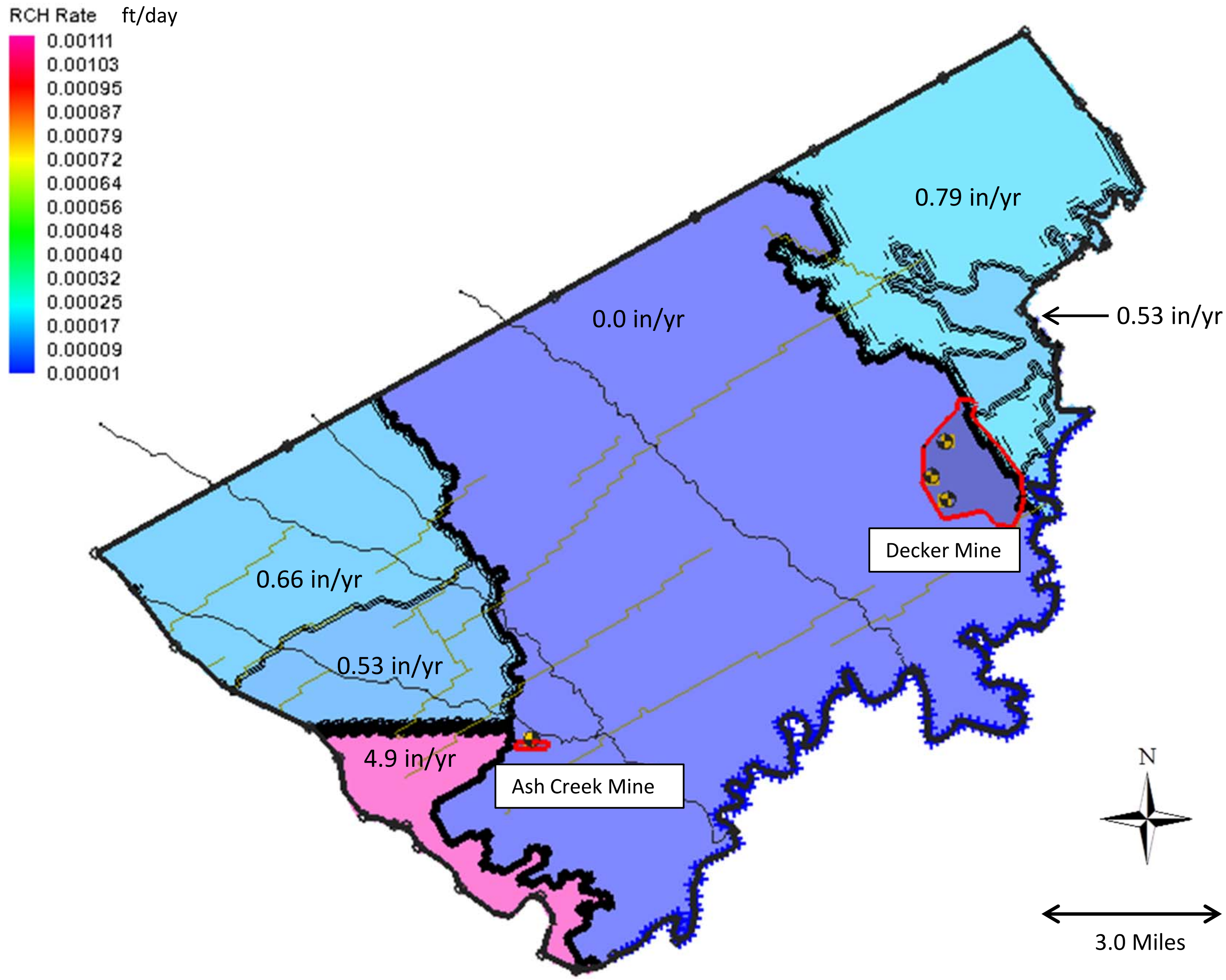

Figure 60: Polygons were used to apply recharge to the model at the given rates shown in the legend at ft/d

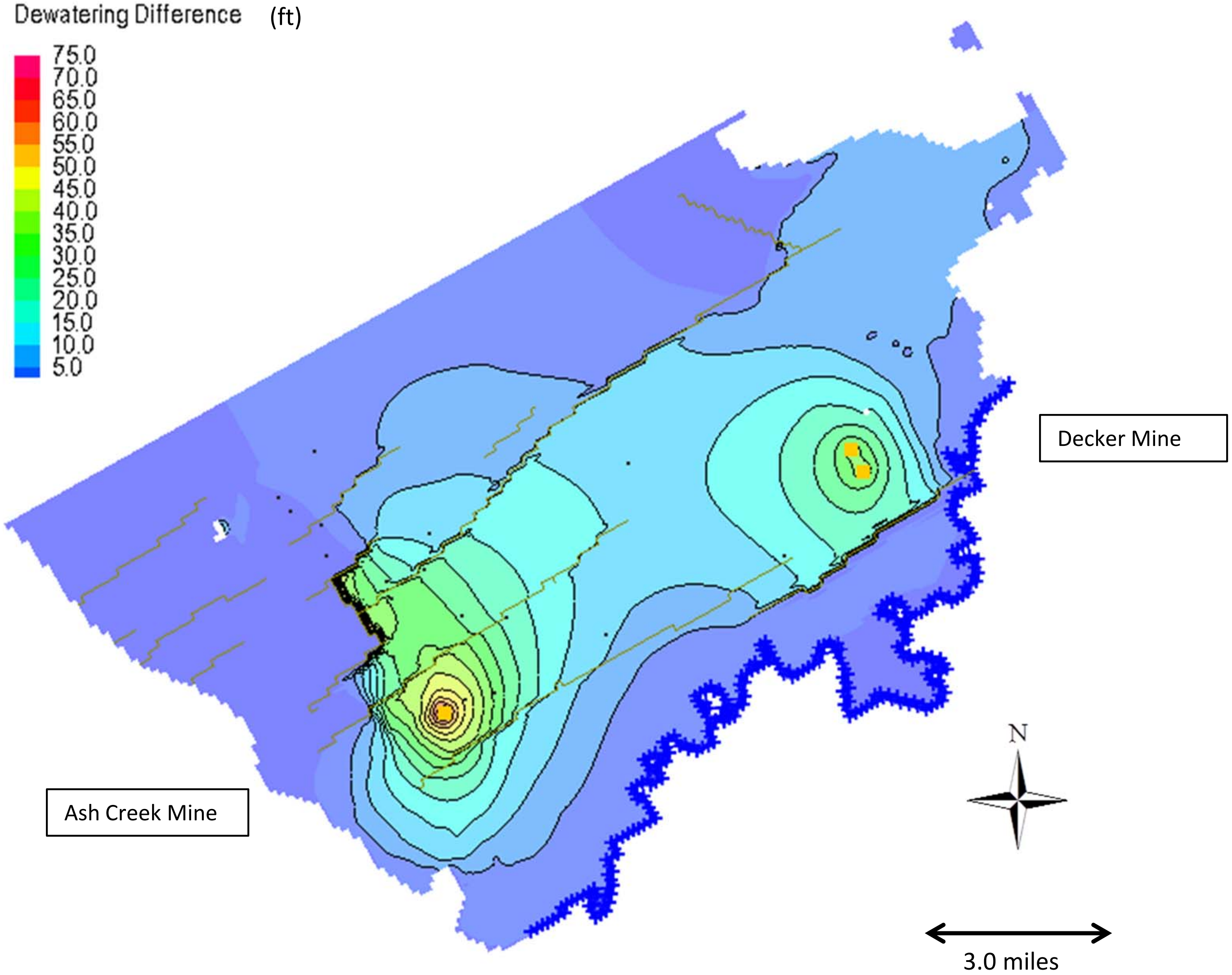

Figure 61: Modeled dewatering drawdown (feet) at Ash Creek and Decker mines.

Summary and 2011 Monitoring Plan

Coalbed-methane production continues in the CX, Coal Creek and Dietz areas in Montana, and near the state line in Wyoming. CBM development has been proposed in several additional areas (Plate 1). Depending upon a number of factors, including economic forces and industry priorities, CBM development may expand into those areas in the next several years. The regional groundwater monitoring network documents baseline conditions outside production areas, changes to the groundwater systems within the area of influence, and the extent of drawdown within the monitored aquifers. Outside the area of influence of CBM production, groundwater conditions reflect normal response to precipitation and the long-term response to coal mining.

Within the CX field, groundwater levels have been drawn down by over 200 feet in the producing coalbeds. The actual amount of drawdown in some wells cannot be measured due to safety concerns as a result of methane release from monitoring wells. After over 11 years of CBM production, drawdown of up to 20 feet has been measured in the coal seams at a distance of roughly 1 to 1.5 miles outside the production areas. These values have not changed substantially since 2004 (Wheaton and others, 2005). These distances are less than those predicted in the Montana CBM environmental impact statement. The Environmental Impact Statement predicted 20 feet of drawdown would reach 2 miles after 10 years of CBM production. Major faults generally act as barriers to groundwater flow and drawdown rarely migrates across fault planes where measured in monitoring wells. However, in cases where faults are not offset at least 10 feet more than the thickness of the coal, or where they scissor around a fulcrum, they are less likely to act as a barrier. Vertical migration of drawdown tends to be limited by shale layers; however in some cases minor changes in overburden head have been observed.

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

Water from production wells is expected to have TDS concentrations generally between 1,000 mg/L and 2,000 mg/L (Table 2). Sodium adsorption ratios in methane-bearing coal seams are high, generally between 30 and 40, but have reached near 80 in some samples.

Monitoring plans for 2011 are included in appendices A and B and shown on Plate 6. During the water year 2010-2011, monitoring sites located within approximately 6 miles of existing or proposed development will be monitored monthly. Outside of this area monitoring will occur quarterly or semi-annually depending on distance to production and amount of background data collected to date. Meteorological stations that are currently deployed at SL-3, RBC-2, and near Poker Jim Butte will continue to be maintained. Water-quality samples will be collected semi-annually from selected alluvial sites and annually from selected deep wells. In an effort to ensure all springs have been sampled at least once, this year’s spring sampling will include the springs Hagen 2 and Joe Anderson on the Ashland Ranger district. This year’s coal aquifer water quality sampling will include the three newly installed wells at SL-9. Monitoring priorities will be adjusted as new areas of production are proposed or developed. It is anticipated that CBM operators will continue to collect water-level data, and any data provided to MBMG will be incorporated into the future regional monitoring reports.

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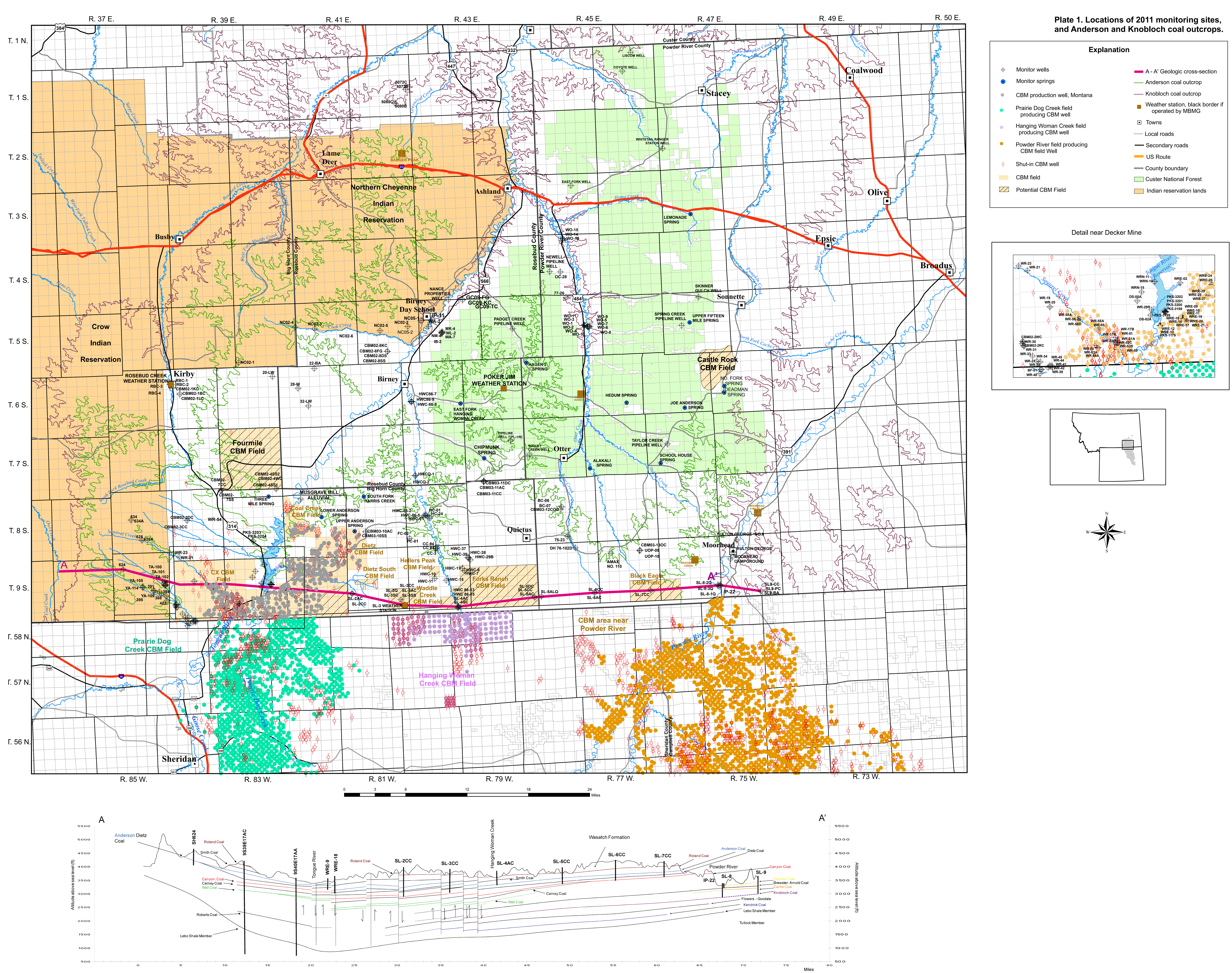
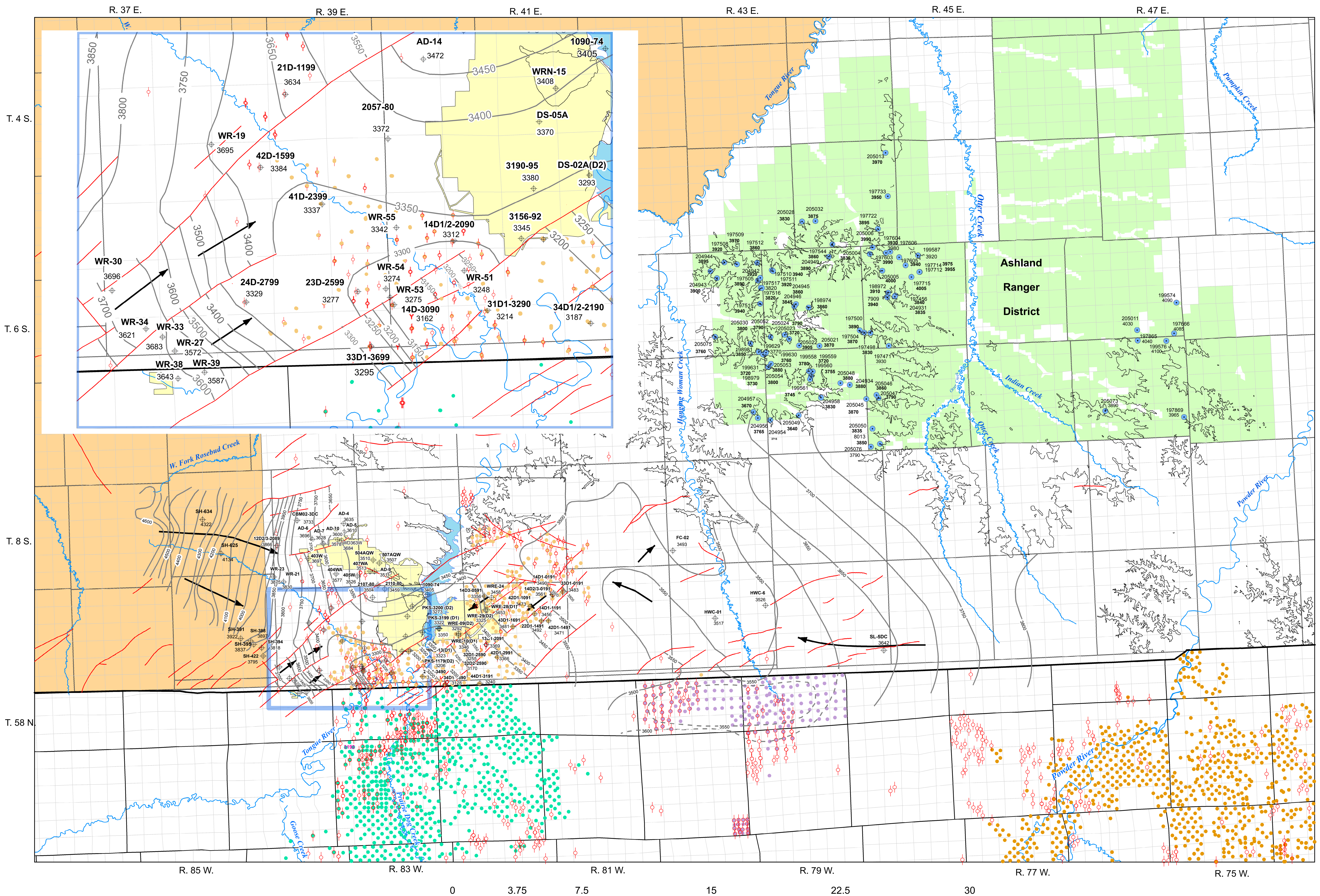


Plate 1. Locations of 2011 monitoring sites, and Anderson and Knobloch coal outcrops.

Plate 2. Potentiometric surface of the Dietz coal in the southern portion of the Powder River Basin, Montana, 2010.



Explanation

Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, 2009. Squirrel Creek area modified from Hedges and others, 1998), 50-ft contour intervals

Approximate direction of ground-water flow

HWC-6 3526 — MBMG Monitor well name, water-level altitude (ft) for water year 2010. (D1-Dietz 1, D2-Dietz 2)

199587 3920 — Spring with Dietz coal (GWIC identifier number)

Dietz coal outcrop

Fault, MBMG geological data, CX coal field area modified using Fidelity Company data

Mine area, includes active, permitted and reclaimed

CBM production well in the Dietz coal bed with production records during water year 2010.

CBM production well was listed as shut-in at the end of water year 2010.

Prairie Dog Creek field CBM well

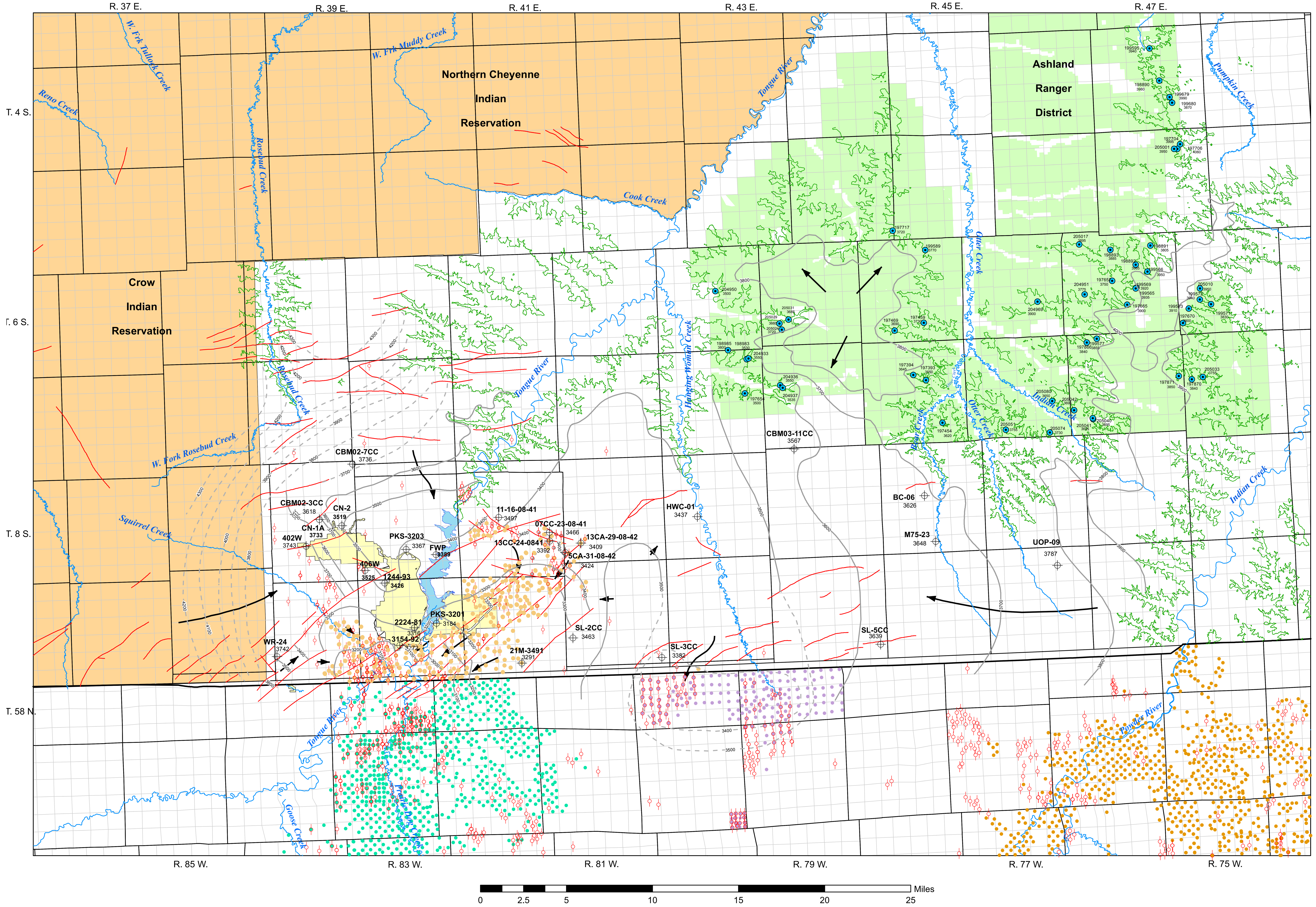
Hanging Woman Creek field CBM well

Powder River field CBM well

Indian Reservation land

National Forest area, Ashland Ranger District

Plate 3. Potentiometric surface of the Canyon coal in the southern portion of the Powder River Basin, Montana, 2010.



Explanation

- Potentiometric surface: dashed where inferred (Ashland Ranger District area from Wheaton and others, water year 2010), 100-ft contour intervals
- Approximate direction of ground-water flow
- WR-24 / 3742 — Monitor well name, water-level altitude (ft) for last data in water year 2010.
- 199595 / 3940 — Spring with Canyon coal (GWIC identifier number)
- Canyon coal outcrop
- Fault, MBMG geological data, CX coal field area modified using Fidelity Company data
- Mine area, includes active, permitted and reclaimed
- CBM production well in Montana with production records during water year 2010.
- CBM production well was listed as shut-in at the end at the end of water year 2010
- Prairie Dog Creek field CBM well
- Hanging Woman Creek CBM field well
- Powder River field CBM well
- Indian Reservation land
- National Forest area, Ashland Ranger District

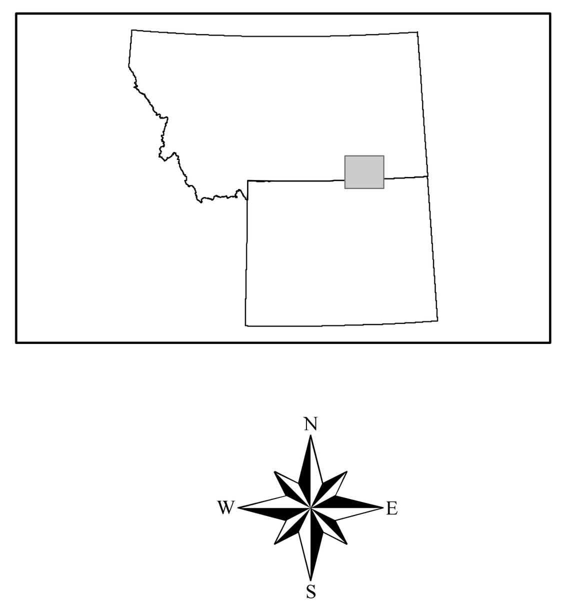
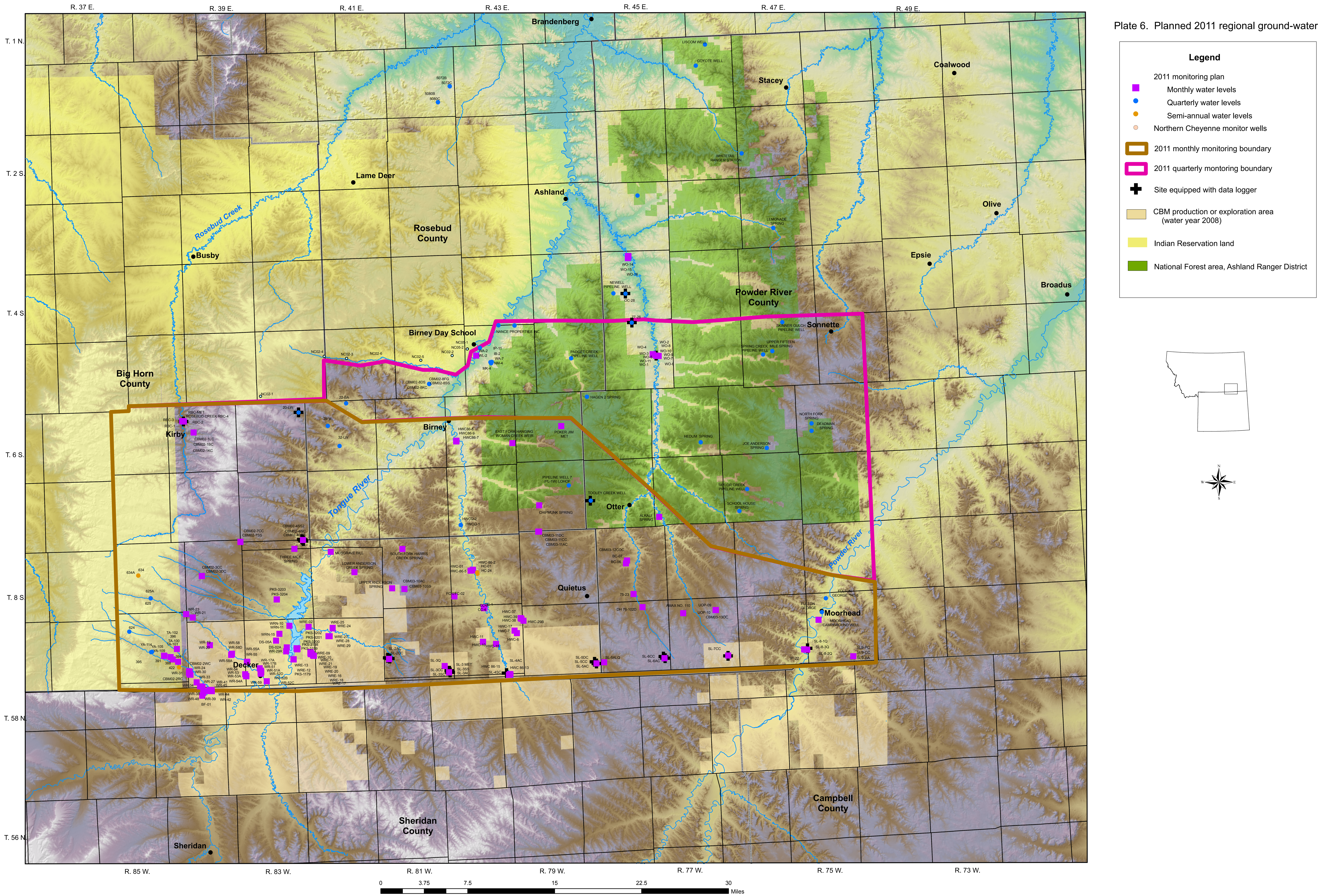


Plate 4. Area of CBM-related potentiometric decline for the Dietz coal in the southern portion of the Powder River Basin, Montana

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

Plate 6. Planned 2011 regional ground-water plan.



GWIC ID	Site Name	Longitude	Latitude	Township	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2011 SWL monitoring	2011 QW sample collection
7573	WO-15	-106.1855	45.5186	04S	45E	4	BDDB	Powder River	3022	Alluvium	63	12.0	10/13/2010	10.34	3011.7	Monthly	
7574	WO-16	-106.1861	45.5158	04S	45E	4	CAAC	Powder River	3040	Alluvium	61	3.7	10/13/2010	24.67	3015.3	Monthly	
7589	Newell Pipeline Well	-106.2143	45.4727	04S	45E	19	DADD	Powder River	3290	Tongue River Formation	325	5.0	10/13/2010	282.08	3007.9	Quarterly	
7755	77-26	-106.1839	45.4352	05S	45E	4	ABCC	Powder River	3284	Knobloch Coal	217	3.6	10/13/2010	147.91	3136.1	Quarterly	
7770	WO-8	-106.1411	45.3922	05S	45E	23	ABCA	Powder River	3155	Alluvium	33	12.0	10/13/2010	15.70	3139.3	Monthly	
7772	WO-9	-106.1419	45.3925	05S	45E	23	ABCA	Powder River	3150	Alluvium	45	21.8	10/13/2010	12.10	3137.9	Monthly	
7775	WO-10	-106.1430	45.3925	05S	45E	23	ABCB	Powder River	3145	Alluvium	41		10/13/2010	9.40	3135.6	Monthly	
7776	WO-5	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Knobloch Underburden	192	20.4	10/13/2010	18.26	3141.7	Monthly	
7777	WO-6	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Lower Knobloch Coal	82	7.0	10/13/2010	25.11	3134.9	Monthly	
7778	WO-7	-106.1386	45.3922	05S	45E	23	ABDA	Powder River	3160	Alluvium	40	29.0	10/13/2010	27.25	3132.8	Monthly	
7780	WO-1	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3190	Knobloch Underburden	172	8.0	10/13/2010	38.44	3151.6	Monthly	
7781	WO-2	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3188	Lower Knobloch Coal	112	19.0	10/13/2010	45.78	3142.2	Monthly	
7782	WO-3	-106.1494	45.3947	05S	45E	23	BBAA	Powder River	3186	Knobloch Overburden	66	17.8	10/13/2010	47.22	3138.8	Monthly	
7783	WO-4	-106.1486	45.3941	05S	45E	23	BBAA	Powder River	3140	Alluvium	32		10/13/2010	9.69	3130.3	Monthly	
7903	HWC86-9	-106.5027	45.2966	06S	43E	19	DACD	Rosebud	3170	Alluvium	44		10/14/2010	11.50	3158.5	Monthly	
7905	HWC86-7	-106.5033	45.2958	06S	43E	19	DDBA	Rosebud	3170	Alluvium	71		10/14/2010	9.99	3160.0	Monthly	Semi-Annual
7906	HWC86-8	-106.5030	45.2961	06S	43E	19	DDBA	Rosebud	3170	Alluvium	67		10/14/2010	9.26	3160.7	Monthly	
8074	WR-21	-106.9791	45.0877	08S	39E	32	DBBC	Big Horn	3890	Dietz 1 and Dietz Coals Combined	206	4.0	10/13/2010	58.22	3831.8	Monthly	
8101	HWC-86-2	-106.4827	45.1350	08S	43E	17	DDCA	Big Horn	3460	Alluvium	50		10/14/2010	20.38	3439.6	Monthly	
8103	HWC-86-5	-106.4822	45.1341	08S	43E	17	DDDC	Big Horn	3455	Alluvium	33		10/14/2010	15.79	3439.2	Monthly	
8107	HWC-01	-106.4866	45.1338	08S	43E	20	DDDD	Big Horn	3530	Canyon Coal	232	7.5	10/14/2010	90.97	3439.0	Monthly	
8110	Near Mouth of Horse Creek * HC-01 O-4	-106.4750	45.1313	08S	43E	21		Big Horn	3455	Alluvium	20	16.5	10/14/2010	11.11	3443.9		
8118	HC-24	-106.4747	45.1297	08S	43E	21	BDBB	Big Horn	3500	Canyon Overburden	150	7.1	10/14/2010	53.36	3446.6	Semi-Annual	
8140	FC-01	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Anderson Coal	133	0.0	10/14/2010	129.05	3606.0	Monthly	
8141	FC-02	-106.5166	45.1025	08S	43E	31	BBDA	Big Horn	3735	Dietz Coal	260		10/14/2010	243.41	3491.6	Monthly	
8191	BC-06	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Coal	188	4.6	10/14/2010	89.74	3625.3	Monthly	
8192	BC-07	-106.2100	45.1387	08S	45E	16	DBCB	Powder River	3715	Canyon Overburden	66	0.8	10/14/2010	36.27	3678.7	Monthly	
8347	WR-23	-106.9905	45.0922	09S	38E	1	AADC	Big Horn	3960	Dietz 1 and Dietz Coals Combined	322	6.0	10/13/2010	84.27	3875.7	Monthly	
8368	SH-391	-107.0320	45.0413	09S	38E	22	DADC	Big Horn	3987	Dietz 1 and Dietz Coals Combined	175		10/13/2010	61.65	3925.4	Monthly	
8371	SH-388	-107.0205	45.0391	09S	38E	23	CDAD	Big Horn	3975	Dietz Coal	190		10/13/2010	79.46	3895.5	Monthly	
8372	SH-396	-107.0088	45.0491	09S	38E	24	BBBC	Big Horn	3939	Anderson-Dietz 1 and 2 Coals	280	25.0	10/13/2010	56.83	3882.2	Monthly	
8377	SH-394	-107.0075	45.0330	09S	38E	25	BCBA	Big Horn	3909	Dietz Coal	242	5.0	10/13/2010	92.79	3816.2	Monthly	
8379	SH-422	-107.0061	45.0261	09S	38E	25	CBDC	Big Horn	3917	Dietz Coal	187		10/13/2010	123.25	3793.8	Semi-Annual	
8387	SH-395	-107.0618	45.0361	09S	38E	26	ABAB	Big Horn	3900	Dietz Coal	299	15.0	10/13/2010	64.60	3835.4	Monthly	
8412	WR-58	-106.9122	45.0408	09S	39E	14	DDBD	Big Horn	3631	Alluvium	55	21.0	10/13/2010	14.38	3616.9	Monthly	
8413	WR-58D	-106.9138	45.0394	09S	39E	14	DDCC	Big Horn	3627	Alluvium	27	15.0	10/13/2010	13.45	3614.0	Monthly	
8417	WR-19	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Dietz 1 and Dietz Coals Combined	305	20.0	10/13/2010	136.05	3699.4	Monthly	
8419	WR-20	-106.9505	45.0525	09S	39E	16	AABA	Big Horn	3835	Anderson Coal	166	15.0	10/13/2010	108.37	3726.9	Monthly	
8428	WR-54A	-106.8902	45.0147	09S	39E	25	DADB	Big Horn	3631	Anderson-Dietz 1 and 2 Overburden	211	1.0	10/13/2010	127.73	3503.5	Monthly	
8430	WR-53A	-106.8888	45.0122	09S	39E	25	DDAA	Big Horn	3608	Anderson-Dietz 1 and 2 Overburden	187		10/13/2010	109.78	3498.1	Monthly	
8436	WR-24	-106.9877	45.0202	09S	39E	29	BBDD	Big Horn	3777	Canyon Coal	146		10/13/2010	32.64	3744.6	Monthly	
8441	WR-33	-106.9758	45.0066	09S	39E	32	ACAA	Big Horn	3732	Anderson-Dietz 1 Clinker and Coal	165		10/13/2010	51.48	3680.8	Monthly	
8444	WR-27	-106.9658	45.0008	09S	39E	33	DBBD	Big Horn	3672	Anderson-Dietz 1 and 2 Coals	363	25.0	10/13/2010	76.83	3595.2	Monthly	
8446	WR-45	-106.9538	44.9966	09S	39E	33	DDCC	Big Horn	3638	Alluvium	64	30.0	10/13/2010	9.76	3628.4	Monthly	
8447	WR-44	-106.9522	44.9966	09S	39E	33	DDCD	Big Horn	3637	Alluvium	64	30.0	10/13/2010	9.27	3627.6	Monthly	
8451	WR-42	-106.9502	44.9966	09S	39E	33	DDDD	Big Horn	3637	Alluvium	66	30.0	10/13/2010	10.06	3626.6	Monthly	
8456	WRN-10	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3433	Dietz 2 Coal	79	3.4	10/13/2010	24.52	3408.8	Monthly	
8461	WRN-15	-106.8275	45.0638	09S	40E	9	AADD	Big Horn	3500	Dietz 2 Coal	140		9/29/2010	91.55	3408.3	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2011 SWL monitoring	2011 QW sample collection
8471	DS-05A	-106.8338	45.0555	09S	40E	9	DCAB	Big Horn	3506	Dietz 2 Coal	166	5.0	9/29/2010	106.11	3399.4	Monthly	
8500	WRE-09	-106.7741	45.0397	09S	40E	13	DCBC	Big Horn	3511	Dietz 2 Coal	232		9/29/2010	166.32	3344.4	Monthly	
8501	WRE-10	-106.7741	45.0383	09S	40E	13	DCCB	Big Horn	3519	Dietz Coal	183		9/29/2010	148.88	3369.6	Monthly	
8504	WRE-11	-106.7736	45.0383	09S	40E	13	DCCD	Big Horn	3509	Anderson Coal	127		9/29/2010	83.91	3425.0	Monthly	
8574	DS-02A	-106.8166	45.0416	09S	40E	15	DBCC	Big Horn	3430	Dietz 2 Coal	150		9/29/2010	56.36	3373.6	Monthly	
8650	WR-55	-106.8858	45.0300	09S	40E	19		Big Horn	3591	Tongue River Formation	288	15.0	10/13/2010	161.82	3429.4	Monthly	
8651	WR-55A	-106.8863	45.0302	09S	40E	19	CBBD	Big Horn	3591	Anderson-Dietz 1 and 2 Overburden	72		10/13/2010	46.30	3544.8	Monthly	
8687	WRE-12	-106.8038	45.0311	09S	40E	23	BCCD	Big Horn	3463	Anderson Coal	172		9/14/2010	85.87	3377.3	Monthly	
8692	WRE-13	-106.8044	45.0311	09S	40E	23	BCCD	Big Horn	3463	Dietz Coal	206		9/14/2010	91.40	3371.2	Monthly	
8698	WRE-16	-106.7697	45.0352	09S	40E	24	AACB	Big Horn	3551	Anderson Coal	458		10/14/2010	62.83	3487.7	Monthly	
8706	WR-17B	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3575	Anderson-Dietz 1 and 2 Overburden	160		10/13/2010	74.77	3499.9	Monthly	
8708	WR-51	-106.8620	45.0186	09S	40E	29		Big Horn	3541	Tongue River Formation	344	4.4	10/13/2010	131.15	3409.9	Monthly	
8709	WR-51A	-106.8622	45.0186	09S	40E	29	BDCB	Big Horn	3541	Anderson-Dietz 1 and 2 Overburden	187		10/13/2010	42.06	3499.2	Monthly	
8710	WR-52B	-106.8627	45.0147	09S	40E	29	CACB	Big Horn	3519	Alluvium	55	59.7	10/13/2010	12.79	3506.0	Monthly	
8721	WRE-27	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3524	Anderson Coal	77	0.5	9/29/2010	47.37	3476.4	Monthly	
8723	WRE-28	-106.7391	45.0586	09S	41E	8	CABC	Big Horn	3525	Dietz Coal	153		9/29/2010	61.88	3463.3	Monthly	
8726	WRE-29	-106.7411	45.0586	09S	41E	8	CBAD	Big Horn	3523	Dietz 2 Coal	217		9/29/2010	110.46	3412.8	Monthly	
8754	CC-1	-106.4646	45.0875	09S	43E	4	ABDD	Big Horn	3520	Alluvium	28	4.2	10/14/2010	14.06	3505.9	Monthly	
8757	CC-4	-106.4659	45.0874	09S	43E	4	ABDD	Big Horn	3511	Alluvium	25	4.8	10/14/2010	6.93	3504.1	Monthly	
8758	CC-3	-106.4654	45.0864	09S	43E	4	ACAA	Big Horn	3521	Alluvium	35	4.6	10/14/2010	14.20	3506.8	Monthly	
8777	HWC-38	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3586	Alluvium	41		10/14/2010	18.74	3567.3	Monthly	
8778	HWC-17	-106.4133	45.0570	09S	43E	13	BCAA	Big Horn	3610	Anderson Coal	82	6.9	10/14/2010	51.79	3558.2	Monthly	
8779	HWC-07	-106.4094	45.0536	09S	43E	13	CAAA	Big Horn	3595	Anderson Coal	66		10/14/2010	29.81	3565.2	Monthly	
8782	HWC-15	-106.4468	45.0412	09S	43E	22	ACCA	Big Horn	3600	Anderson Coal	129	10.0	10/14/2010	34.24	3565.8	Monthly	
8796	HWC-29B	-106.3969	45.0688	09S	44E	7	BBCC	Big Horn	3620	Anderson Coal	92		10/14/2010	45.32	3574.7	Monthly	
8835	AMAX NO. 110	-106.1153	45.0699	09S	46E	8	BACC	Powder River	3965	Dietz Coal	240	1.4	10/14/2010	169.70	3795.3	Monthly	
8846	UOP-09	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3929	Canyon Coal	262	0.8	10/21/2010	157.70	3771.3	Monthly	
8847	UOP-10	-106.0578	45.0720	09S	46E	11	BBBA	Powder River	3930	Canyon Overburden	207	4.4	10/21/2010	143.78	3786.2	Monthly	
8863	Fulton George *NO.6	-105.8628	45.0807	09S	48E	5	ACDD	Powder River	3380	Tongue River Formation	410	4.0	10/25/2010	17.01	3363.0	Quarterly	
8888	HWC 86-13	-106.4262	45.0020	10S	43E	2	ABCA	Big Horn	3640	Alluvium	53	3.9	10/14/2010	11.49	3628.5	Monthly	Semi-Annual
94661	Liscom Well	-106.0323	45.7782	01S	46E	3	DBAA	Powder River	3275	Fort Union Formation	135	10.0	10/6/2010	97.51	3177.5	Quarterly	
94666	Coyote Well	-106.0505	45.7524	01S	46E	16	AACC	Powder River	3294	Fort Union Formation	190	5.0	10/6/2010	136.74	3157.3	Quarterly	
100472	East Fork Well	-106.1642	45.5935	03S	45E	10	B	Powder River	3210		193	5.0	10/6/2010	139.06	3070.9	Quarterly	
103155	Padget Creek Pipeline Well	-106.2940	45.3939	05S	44E	22	BBBD	Rosebud	3385	Tongue River Formation	135	10.0	10/21/2010	65.36	3319.6	Quarterly	
105007	Tooley Creek Well	-106.2697	45.2153	07S	45E	19	CAAA	Powder River	3755	Fort Union Formation	110	12.0	10/13/2010	35.95	3719.1	Quarterly	
121669	WRE-18	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3573	Anderson Coal	445		10/14/2010	97.38	3475.7	Monthly	
122766	WR-59	-106.8526	45.0050	09S	40E	32	ACAD	Big Horn	3470	Alluvium	34	10.0	10/13/2010	9.11	3461.0	Monthly	Semi-Annual
122767	WRE-20	-106.7716	45.0369	09S	40E	24	ABAB	Big Horn	3519	Anderson Coal	120		9/29/2010	95.15	3424.3	Monthly	
122769	WR-38	-106.9650	44.9938	37N	63E	23	BBCB	Sheridan	3693	Dietz 1 and Dietz Coals Combined	286	3.8	10/13/2010	76.35	3616.6	Monthly	
122770	WR-39	-106.9555	44.9952	37N	63E	23	ABBC	Sheridan	3666	Anderson-Dietz 1 and 2 Coals	312		10/13/2010	66.34	3599.7	Monthly	
123795	WRE-25	-106.7333	45.0683	09S	41E	5	DCCA	Big Horn	3549	Anderson Coal	115		9/29/2010	62.91	3486.5	Monthly	
123796	WR-17A	-106.8641	45.0216	09S	40E	29	BBAC	Big Horn	3574	Anderson-Dietz 1 and 2 Overburden	88		10/13/2010	45.33	3528.6	Monthly	

Appendix A. Site details, water-level data, and 2011 monitoring schedule for groundwater monitoring wells

GWIC ID	Site Name	Longitude	Latitude	Township	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2011 SWL monitoring	2011 QW sample collection
123797	WRE-19	-106.7736	45.0369	09S	40E	24	ABBA	Big Horn	3520	Anderson Coal	140		9/29/2010	96.66	3423.6	Monthly	
123798	WRN-11	-106.8094	45.0733	09S	40E	3	DABA	Big Horn	3437	Anderson-Dietz 1 Clinker and Coal	50		10/13/2010	23.35	3413.5	Monthly	
127605	WR-54	-106.8902	45.1470	09S	39E	25		Big Horn	3630	Anderson and Dietz Coal	384	20	10/13/2010	207.69	3422.2	Monthly	
130475	WRE-24	-106.7333	45.0688	09S	41E	5	DCCA	Big Horn	3552	Dietz Coal	154	20.0	9/29/2010	67.98	3484.1	Monthly	
130476	WR-31	-106.9863	45.0163	09S	39E	29	CBAA	Big Horn	3895	Anderson Coal	316	2.0	10/13/2010	184.07	3711.1	Monthly	
132716	WR-48	-106.9650	44.9933	37N	63E	23	BBCB	Sheridan	3694	Anderson Coal	167		10/13/2010	40.05	3653.8	Monthly	
132903	WR-58A	-106.9123	45.0403	09S	39E	14	DDBD	Big Horn	3631	Alluvium	24	8.0	10/13/2010	14.15	3617.2	Monthly	
132907	WR-53	-106.8880	45.0125	09S	39E	25		Big Horn	3607	Anderson and Dietz Coal	384	20.0	10/13/2010	185.96	3421.1	Monthly	
132908	WR-30	-106.9874	45.0165	09S	39E	29	CBAB	Big Horn	3895	Dietz 1 and Dietz Coals Combined	428	5.0	10/31/2010	202.37	3692.2	Monthly	
132909	WR-34	-106.9702	45.0015	09S	39E	33	CBBB	Big Horn	3772	Anderson-Dietz 1 and 2 Coals	522		10/13/2010	152.10	3620.0	Monthly	
132910	WRE-02	-106.7756	45.0712	09S	40E	1	DBCC	Big Horn	3457	Alluvium	79		9/29/2010	40.11	3416.7	Monthly	
132958	WRE-21	-106.7730	45.0386	09S	40E	24	ABAB	Big Horn	3529	Anderson Coal	130		9/29/2010	85.59	3443.8	Monthly	
132959	WRE-17	-106.7683	45.0347	09S	40E	24	AACD	Big Horn	3562	Anderson-Dietz 1 and 2 Overburden	250		10/14/2010	65.17	3496.7	Monthly	
132960	WR-52C	-106.8629	45.0164	09S	40E	29	CABC	Big Horn	3530	Alluvium	62	20.0	10/13/2010	18.59	3511.4	Monthly	
132961	WR-52D	-106.8616	45.0164	09S	40E	29	CABD	Big Horn	3529	Alluvium	40	1.0	10/13/2010	23.39	3505.9	Monthly	
132973	PKS-1179	-106.8040	45.0314	09S	40E	23	CBBB	Big Horn	3458	Dietz 2 Coal	282	5.0	9/13/2010	139.09	3318.9	Monthly	
144969	Pipeline Well 7(PL-1W) LOHOF	-106.3074	45.2354	07S	44E	14	ABD	Rosebud	3850	Tongue River Formation	225	15.0	10/13/2010	143.02	3707.0	Quarterly	
157879	5072B	-106.4904	45.7393	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal	109	2.0	9/8/2010	34.59	3125.4	Quarterly	
157882	5072C	-106.4905	45.7394	01S	42E	24	ACBB	Rosebud	3160	Rosebud Coal Overburden	106	0.3	9/8/2010	29.34	3130.7	Quarterly	
157883	5080B	-106.5126	45.7199	01S	42E	26	DCBA	Rosebud	3260	Knobloch Coal	89	1.3	9/8/2010	42.88	3217.1	Quarterly	
157884	5080C	-106.5126	45.7200	01S	42E	26	DCBA	Rosebud	3260	Knobloch Overburden	110	0.3	9/8/2010	36.32	3223.7	Quarterly	
161749	BF-01	-106.9667	44.9897	58N	84W	22	ACCC	Sheridan	3680	Coal Mine Spoils Bank	125		4/27/2010	31.84	3648.2	Monthly	
166351	PKS-3204	-106.8299	45.1067	08S	40E	28	ADA	Big Horn	3500	Anderson-Dietz1 Coalbed	82		10/13/2010	74.68	3425.3	Monthly	
166358	PKS-3203	-106.8302	45.1068	08S	40E	28	ADA	Big Horn	3500	Canyon Coal	201		10/13/2010	115.72	3384.3	Monthly	
166359	PKS-3202	-106.7981	45.0451	09S	40E	14	CAA	Big Horn	3438	Alluvium	60	5.0	9/29/2010	40.74	3397.3	Monthly	
166362	PKS-3201	-106.7971	45.0437	09S	40E	14	CAA	Big Horn	3438	Canyon Coal	390	50.0	9/29/2010	98.16	3339.8	Monthly	
166370	PKS-3200	-106.7969	45.0440	09S	40E	14	CAA	Big Horn	3438	Dietz 2 Coal	242	20.0	9/29/2010	174.26	3263.7	Monthly	
166388	PKS-3199	-106.7966	45.0443	09S	40E	14	CAA	Big Horn	3439	Dietz Coal	165	20.0	9/29/2010	115.66	3323.3	Monthly	
166389	PKS-3198	-106.7964	45.0446	09S	40E	14	CAA	Big Horn	3440	Anderson Coal	112		9/29/2010	87.66	3352.3	Monthly	
166761	WR-29R	-106.8153	45.0465	09S	40E	15	ACCD	Big Horn	3461	Anderson-Dietz 1 Clinker and Coal	72		10/13/2010	45.70	3415.3	Monthly	
183559	Nance IP-11 Bridge	-106.4549	45.4114	05S	43E	8	BCDC	Rosebud	3085	Tongue River Formation	540		10/14/2010	-11.75	3096.8	Quarterly	
183560	Nance Properties INC	-106.4205	45.4387	05S	43E	4	AAAB	Rosebud	3035	Alluvium	20		10/14/2010	12.30	3022.7	Quarterly	
183563	Fulton George	-105.8709	45.0637	09S	48E	8	CABC	Powder River	3360	Alluvium	30	1.0	10/25/2010	17.29	3342.7	Quarterly	
183564	Whitetail Ranger Station	-105.9758	45.6404	02S	47E	19	CDCA	Powder River	4045	Fort Union Formation	60		10/6/2010	42.47	4002.5	Quarterly	
183565	Skinner Gulch Pipeline Well	-105.9171	45.4275	05S	47E	3	BCCD	Powder River	3730	Tongue River Formation	167		10/13/2010	51.49	3678.5	Quarterly	
184222	SH-624	-107.0917	45.0725	09S	38E	7	DADB	Big Horn	4645	Anderson-Dietz1 Coalbed	435		10/13/2010	349.78	4294.9	Quarterly	
184223	SH-625	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Dietz Coal	186		10/13/2010	46.69	4139.9	Quarterly	
184224	SH-625A	-107.0522	45.1133	08S	38E	28	DADB	Big Horn	4187	Anderson Coal	91		10/13/2010	54.12	4132.6	Quarterly	
184225	SH-634	-107.0728	45.1422	08S	38E	17	DADD	Big Horn	4481	Dietz Coal	348	12.0	10/13/2010	151.21	4329.3	Semi-Annual	
184226	SH-634A	-107.0883	45.1422	08S	38E	17	DADD	Big Horn	4481	Anderson Coal	159		10/13/2010	115.51	4365.7	Semi-Annual	
186195	WR-41	-106.9498	44.9950	09S	39E	34	CCCC	Big Horn	3643	Alluvium	40	1.0	10/13/2010	17.54	3625.1	Monthly	
189743	MBMG MONITORING WELL HWC-29A	-106.3974	45.0697	09S	44W	7	BBCC	Big Horn	3619		98		10/14/2010	43.85	3575.2	Monthly	
189802	HWC-37	-106.4017	45.0723	09S	43E	12	ADBB	Big Horn	3578	Alluvium	32		10/14/2010	10.55	3567.5	Monthly	

GWIC ID	Site Name	Longitude	Latitude	Township	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2011 SWL monitoring	2011 QW sample collection
189838	HWC-39	-106.4004	45.0713	09S	43E	12	ADBD	Big Horn	3591	Alluvium	39		10/14/2010	25.55	3565.5	Monthly	
190902	HWC-10	-106.4695	45.0444	09S	43E	21	BADA	Big Horn	3610	Dietz Coal	229		10/14/2010	98.78	3511.2	Monthly	
190904	HWC-11 TR-77	-106.4696	45.0444	09S	43E	21	BADA	Big Horn	3615	Anderson Coal	135	8.0	10/14/2010	52.51	3562.5	Monthly	
191139	20-LW	-106.7801	45.3391	06S	40E	1	CDDC	Big Horn	3940	Wall Coal	253	0.2	10/14/2010	84.82	3855.2	Quarterly	
191155	22-BA	-106.6954	45.3484	06S	41E	3	BADD	Rosebud	3530	Brewster-Arnold Coal	262	0.4	10/14/2010	107.06	3422.9	Quarterly	
191163	28-W	-106.7292	45.3211	06S	41E	16	BBCC	Rosebud	3715	Wall Coal	144	1.3	10/14/2010	108.21	3606.8	Quarterly	
191169	32-LW	-106.7098	45.2955	06S	41E	21	DDDC	Rosebud	3530	Wall Coal	51	0.2	10/14/2010	37.05	3493.0	Quarterly	
191634	75-23	-106.2011	45.0966	08S	45E	34	BDBC	Powder River	3780	Canyon Coal	247		10/14/2010	134.01	3646.0	Monthly	
192874	YA-109	-107.0312	45.0407	09S	38E	22	DADC	Big Horn	3830	Alluvium	44		10/13/2010	33.93	3796.1	Monthly	
198465	HWC-6	-106.4093	45.0536	09S	43E	13	CAAA	Big Horn	3595	Dietz Coal	152		10/14/2010	70.43	3524.6	Monthly	
198489	HWC 86-15	-106.4235	45.0025	10S	43E	2	AABC	Big Horn	3630	Alluvium	63	30.0	10/14/2010	15.20	3614.8	Monthly	Semi-Annual
203646	CBM02-1KC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3980	Knobloch Coal	417	0.5	10/13/2010	173.95	3806.4	Monthly	
203655	CBM02-1BC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3984	Brewster-Arnold Coal	256	5.0	10/13/2010	101.94	3881.9	Monthly	
203658	CBM02-1LC	-106.9671	45.3186	06S	39E	16	DBCA	Big Horn	3982	Local Coals	366	2.0	10/13/2010	144.73	3837.0	Monthly	
203669	CBM02-2WC	-106.9884	45.0207	09S	39E	29	BBDC	Big Horn	3792	Carney Coal	290	10.0	10/13/2010	76.14	3715.9	Monthly	
203670	CBM02-2RC	-106.9889	45.0185	09S	39E	29	BCBD	Big Horn	3890	Roland Coal	159	1.0	10/13/2010	132.55	3757.5	Monthly	
203676	CBM02-3CC	-106.9608	45.1392	08S	39E	16	BAAA	Big Horn	3920	Canyon Coal	376	0.3	10/13/2010	303.16	3616.8	Monthly	
203678	CBM02-3DC	-106.9607	45.1391	08S	39E	16	BAAA	Big Horn	3920	Dietz Coal	235	0.1	10/13/2010	187.15	3732.9	Monthly	
203680	CBM02-4WC	-106.7802	45.1798	07S	40E	36	CDDC	Big Horn	3500	Wall Coal	291	0.2	10/14/2010	181.88	3318.1	Monthly	
203681	CBM02-4SS1	-106.7803	45.1798	07S	40E	36	CDDC	Rosebud	3500	Wall Coal Overburden	221	5.0	10/14/2010	77.64	3422.4	Monthly	
203690	CBM02-4SS2	-106.7803	45.1798	07S	40E	36	CDDC	Big Horn	3500	Canyon Underburden	97	30.0	10/14/2010	36.80	3463.2	Monthly	
203693	CBM02-7CC	-106.8906	45.1801	08S	39E	1	AAAA	Big Horn	3900	Canyon Coal	263	1.5	10/13/2010	165.35	3734.7	Monthly	
203695	CBM02-7SS	-106.8906	45.1799	08S	39E	1	AAAA	Big Horn	3900	Canyon Overburden	190	5.0	10/13/2010	90.66	3809.3	Monthly	
203697	CBM02-8KC	-106.5473	45.3689	05S	42E	28	DDAC	Rosebud	3262	Knobloch Coal	208	1.0	10/14/2010	159.69	3102.6	Quarterly	
203699	CBM02-8SS	-106.5472	45.3688	05S	42E	28	DDAC	Rosebud	3262	Knobloch Underburden	224	10.0	10/14/2010	160.51	3101.7	Quarterly	
203700	CBM02-8DS	-106.5470	45.3687	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Overburden	446	0.3	10/14/2010	103.63	3156.9	Quarterly	
203701	CBM02-8FG	-106.5471	45.3688	05S	42E	28	DDAC	Rosebud	3261	Flowers-Goodale Coal	480	0.5	10/14/2010	103.09	3157.5	Quarterly	
203703	CBM03-10AC	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson Coal	560	0.3	10/14/2010	531.51	3598.5	Monthly	
203704	CBM03-10SS	-106.6045	45.1141	08S	42E	29	ADAD	Big Horn	4130	Anderson-Dietz 1 and 2 Overburden	462	1.0	10/14/2010	372.53	3757.5	Monthly	
203705	CBM03-11AC	-106.3632	45.1793	08S	44E	5	BBBB	Big Horn	3950	Anderson Coal	211	1.0	10/13/2010	155.80	3794.2	Monthly	
203707	CBM03-11DC	-106.3641	45.1793	08S	44E	5	BBBB	Big Horn	3950	Dietz Coal	271	0.2	10/13/2010	229.45	3720.6	Monthly	
203708	CBM03-11CC	-106.3647	45.1793	08S	44E	5	BBBB	Big Horn	3950	Canyon Coal	438	1.5	10/13/2010	383.41	3566.6	Monthly	
203709	CBM03-12COC	-106.2121	45.1352	08S	45E	16	DBCB	Powder River	3715	Cook Coal	351	3.0	10/14/2010	167.74	3547.3	Monthly	
203710	CBM03-13OC	-106.0572	45.0722	09S	46E	11	BBBA	Powder River	3931	Otter Coal	500	1.5	10/21/2010	338.54	3592.5	Monthly	
205082	Spring Creek Pipeline Well	-105.9538	45.3883	05S	47E	20	ACAC	Powder River	3630	Tongue River Formation	50		10/13/2010	16.55	3613.5	Quarterly	
207064	RBC-1	-106.9836	45.3327	06S	39E	8	CAAA	Big Horn	3855	Alluvium	27		10/13/2010	13.86	3840.8	Monthly	
207066	RBC-2	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849	Alluvium	17		10/13/2010	10.68	3838.7	Monthly	Semi-Annual
207068	RBC-3	-106.9868	45.3331	06S	39E	8	BDCD	Big Horn	3860	Alluvium	25		10/13/2010	12.30	3847.6	Monthly	
207075	YA-114	-107.0543	45.0461	09S	38E	21	ADBD	Big Horn	4000	Alluvium			10/13/2010	13.71	3986.3	Quarterly	
207076	YA-105	-107.0527	45.0465	09S	38E	21	ACAC	Big Horn	4015	Alluvium			10/13/2010	12.26	4002.7	Quarterly	
207080	TA-100	-107.0090	45.0479	09S	38E	23	BBCC	Big Horn	3900	Alluvium			10/13/2010	14.93	3885.1	Quarterly	
207081	TA-101	-107.0090	45.0482	09S	38E	24	BBCC	Big Horn	3910	Alluvium			10/13/2010	16.82	3893.2	Quarterly	
207083	TA-102	-107.0076	45.0486	09S	38E	24	BBCB	Big Horn	3910	Alluvium			10/13/2010	22.01	3888.0	Quarterly	
207096	IB-2	-106.4372	45.3930	05S	43E	21	BBDB	Rosebud	3192	Knobloch Underburdern	245		10/14/2010	123.21	3068.4	Quarterly	
207097	MK-4	-106.4363	45.3919	05S	43E	21	BBDC	Rosebud	3195	Knobloch Coal	188		10/14/2010	123.11	3072.2	Quarterly	
207098	NM-4	-106.4361	45.3916	05S	43E	21	BCAB	Rosebud	3195	Nance Coal	294		10/14/2010	120.20	3075.1	Quarterly	
207099	WL-2	-106.4358	45.3919	05S	43E	21	BBDC	Rosebud	3188	Knobloch Coal	199		10/14/2010	120.93	3066.7	Quarterly	
207101	OC-28	-106.1928	45.4717	04S	45E	21	CCBD	Powder River	3171	Knobloch Coal			10/14/2010	62.22	3108.8	Quarterly	
207143	HC-01	-106.4750	45.1314	08S	43E	21	BBDA	Big Horn	3457	Alluvium	20	17.0	10/14/2010	13.78	3443.2	Semi-Annual	
210094	WO-14	-106.1849	45.5183	04S	45E	4	BDDB	Powder River	3010		66		10/13/2010	8.44	3001.6	Monthly	
214096	HWCQ-2	-106.5009	45.1913	07S	43E	32	AAAA	Rosebud	3340	Alluvium	19		10/14/2010	12.51	3327.5	Monthly	
214097	HWCQ-1	-106.5005	45.1912	07S	43E	32	AAAA	Rosebud	3340	Alluvium	20		10/14/2010	12.59	3327.4	Monthly	
214354	WA-7	-106.4347	45.3933	05S	43E	21	BABC	Rosebud	3179	Alluvium			10/14/2010	53.78	3125.2	Quarterly	

GWIC ID	Site Name	Longitude	Latitude	Township	Range	Sect	Tract	County	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Most recent static water level date	Average Static water level (feet)	Ave. static water level altitude (feet)	2011 SWL monitoring	2011 QW sample collection
215085	WO-11	-106.1433	45.3927	05S	45E	23	ABCC	Powder River	3145	Alluvium	39		10/13/2010	9.50	3135.5	Monthly	
219125	SL-2AC	-106.6358	45.0276	09S	42E	30	BDAC	Big Horn	3925	Anderson Coal	671		10/14/2010	343.07	3581.9	Monthly	
219136	SL-3Q	-106.5386	45.0161	09S	42E	36	BBAD	Big Horn	3725	Alluvium	40	2.0	10/14/2010	15.71	3709.3	Monthly	Semi-Annual
219138	SL-3SC	-106.5313	45.0080	09S	42E	36	DBCB	Big Horn	3805	Smith Coal	358	2.0	10/14/2010	167.30	3637.7	Monthly	
219139	SL-3AC	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Anderson Coal	523	2.0	10/14/2010	221.49	3583.5	Monthly	
219140	SL-3CC	-106.5313	45.0082	09S	42E	36	DBCB	Big Horn	3805	Canyon Coal	817	0.1	10/14/2010	392.67	3412.3	Monthly	
219141	SL-4SC	-106.4243	45.0031	10S	43E	2	ABAA	Big Horn	3640	Smith Coal	120	2.0	10/14/2010	31.11	3608.9	Monthly	
219169	SL-4AC	-106.4244	45.0031	10S	43E	2	ABAA	Big Horn	3640	Anderson Coal	279	2.0	10/14/2010	65.17	3574.8	Monthly	
219617	SL-3SS	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3805	Smith Coal Overburden	278	5.0	10/14/2010	147.10	3657.9	Monthly	
219927	SL-5AC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Anderson Coal	223	1.0	10/14/2010	134.09	3675.9	Monthly	
219929	SL-5DC	-106.2714	45.0119	09S	44E	36	ABBD	Big Horn	3810	Dietz Coal	322	0.7	10/14/2010	169.89	3640.1	Monthly	
220062	SL-6AC	-106.1514	45.0148	09S	45E	36	ABBB	Big Horn	4220	Anderson Coal	492	0.1	10/14/2010	379.19	3840.8	Monthly	
220064	SL-6CC	-106.1513	45.0148	09S	45E	36	ABBB	Big Horn	4220	Canyon Coal	685	0.5	7/1/2010	523.15	3696.9	Monthly	
220069	SL-7CC	-106.0392	45.0147	09S	46E	36	BBBB	Big Horn	4173	Canyon Coal	515	1.0	4/20/2010	457.32	3715.7	Monthly	
220076	SL-5CC	-106.2715	45.0119	09S	44E	36	ABBD	Big Horn	3810	Canyon Coal	431	6.0	10/14/2010	179.12	3630.9	Monthly	
220385	SL-2CC	-106.6360	45.0273	09S	42E	30	BCBC	Big Horn	3920	Canyon Coal	1301		10/14/2010	450.76	3469.2	Monthly	
220851	SL-8-1Q	-105.8998	45.0176	09S	47E	25	DDDB	Powder River	3397	Alluvium	19	1.0	10/21/2010	12.96	3383.7	Monthly	
220857	SL-8-2Q	-105.9052	45.0182	09S	47E	25	DCDB	Powder River	3394	Alluvium	14	0.3	10/21/2010	11.79	3382.3	Monthly	Semi-Annual
220859	SL-8-3Q	-105.9028	45.0177	09S	47E	25	DDCB	Powder River	3398	Alluvium	19	1.0	10/21/2010	15.46	3383.0	Monthly	
221592	IP-22 MONTANA STATE LAND FLOWING WELL	-105.9003	45.0177	09S	47E	25	DDBD	3395				10/21/2010	10/21/2010	-17.86		Monthly	
223236	USGS 452355106333701	-106.5603	45.3986	05S	42E	16	CCAB	Rosebud	3400		376		11/3/2009	262.63	3137.4		
223237	USGS 452408106382201	-106.6397	45.4022	05S	41E	14	BDCD	Rosebud	3510		360		11/3/2009	238.60	3271.4		
223238	USGS 452139106504701	-106.8464	45.3608	05S	40E	31	BDCC	Big Horn	4440		681		6/6/2005	619.15	3820.9		
223240	USGS 452411106301601	-106.5044	45.4030	05S	42E	14	ADDC	Rosebud	3220		420		11/3/2010	107.32	3112.7		
223242	USGS 452416106413001	-106.6917	45.4044	05S	41E	17	ADBD	Rosebud	3740		353		11/3/2009	182.02	3558.0		
223243	USGS 452429106435201	-106.7311	45.4080	05S	40E	13	ADAB	Big Horn	3940		380		11/3/2009	200.23	3739.8		
223687	MBMG MONITORING SITE RBC-4	-106.9863	45.3332	06S	39E	8		3840.95		5.05		10/13/2010	10/13/2010	4.63			
223695	Moorhead Campground Well	-105.8773	45.0542	09S	48E	17	BCBB	Powder River	3400	Pawnee			10/21/2010	1.77	3398.2	Monthly	
223801	SL-5ALQ	-106.2579	45.0129	09S	45E	31	BBA	Powder River	3810	Alluvium	35		10/14/2010	9.37	3800.6	Monthly	
223869	Poker Jim MET	-106.3164	45.3098	06S	44E	23	BBAA	Rosebud	4115							Monthly	
223890	Taylor Creek Pipeline Well	-105.9928	45.2213	07S	47E	21	BBCC	Powder River	3910	Tongue River Formation	150		10/25/2010	109.36	3800.6	Quarterly	
223952	WA-2	-106.4621	45.4020	05S	43E	17	BCDD	Rosebud	3069	Alluvium			10/14/2010	11.32	3057.2	Monthly	Semi-Annual
226919	NC05-1 Near Birney Village	-106.4769	45.4106	05S	43E	7	C	Rosebud	3170		780						
227246	DH 76-102D	-106.1862	45.0798	09S	45E	3	ADCC	Rosebud	3811	Dietz Coal	144		10/14/2010	20.36	3790.6	Monthly	
228592	Musgrave Bill	-106.7319	45.1639	08S	41E	5	ACDB	Big Horn	3335	Alluvium	22		10/14/2010	11.99	3323.0	Monthly	Semi-Annual
231583	RBC-MET	-106.9844	45.3327	06S	39E	8	CAAA	Big Horn	3849							Monthly	
231591	SL-3 MET	-106.5313	45.0079	09S	42E	36	DBCB	Big Horn	3725							Monthly	
251797	MBMG MONITORING WELL GC09-KC	-106.391897	45.437635	05S	43E	2	BAB			125KNCB			3/25/2010	99.83		Quarterly	
251798	MBMG MONITORING WELL GC09-FG	-106.391897	45.437635	05S	43E	2	BAB			125FGCB			3/25/2010	122.79		Quarterly	
251799	MBMG MONITORING WELL GC09-TC	-106.391897	45.437635	05S	43E	2	BAB			125TTCB			3/25/2010	72.60		Quarterly	

Appendix B. Site details, discharge data, and 2011 monitoring schedule for monitored springs and streams.

GWIC ID	Site name	Longitude	Latitude	Township	Range	Section	Tract	County
197247	South Fork Harris Creek Spring	-106.60530	45.16420	08S	42E	5	DDDB	Big Horn
197452	Alkali Spring	-106.15010	45.19140	07S	46E	31	BACD	Powder River
197607	Upper Fifteen Mile Spring	-105.93720	45.39200	05S	47E	16	DCDC	Powder River
198766	Lemonade Spring	-105.92550	45.54550	03S	47E	28	ACAA	Powder River
199568	Hedum Spring	-106.07100	45.28230	06S	46E	26	CDBA	Powder River
199572	Deadman Spring	-105.87430	45.29030	06S	48E	29	BABB	Powder River
205004	Hagen 2 Spring	-106.26880	45.34500	06S	45E	6	ACDC	Powder River
205010	North Fork Spring	-105.87360	45.29960	06S	48E	20	BDCA	Powder River
205011	Joe Anderson Spring	-105.95470	45.27150	06S	47E	34	CABA	Powder River
205041	School House Spring	-106.00810	45.19440	07S	47E	32	BABA	Powder River
205049	Chipmunk Spring	-106.36110	45.21200	07S	44E	21	CCBB	Rosebud
223687	Rosebud Creek RBC-4	-106.98630	45.33320	06S	39E	8	C	Big Horn
223877	East Fork Hanging Woman Creek Weir	-106.40410	45.29090	06S	43E	25	ABDD	Rosebud
228591	Three Mile Spring	-106.79584	45.16904	07S	40E	35	BDAC	Big Horn
228776	Upper Anderson Spring	-106.62610	45.11550	08S	42E	30	ADAA	Big Horn
240578	Lower Anderson Spring	-106.69128	45.13732	08S	41E	15	ABBB	Big Horn

GWIC ID	Spring source lithology	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Average spring yield (gpm)	Most recent yield date	2011 planned flow monitoring	2011 planned QW sample collection
197247		Anderson	Regional	3690	1.67	9/26/2008	Monthly	
197452	Coal	Otter	Local	3470	0.82	9/25/2008	Monthly	
197607	Colluvium	Cook	Local	3805	0.72	9/26/2008	Quarterly	
198766		Ferry	Local	3660	1.70	10/1/2008	Quarterly	
199568	Sandstone	Cook	Local	3680	0.78	9/26/2008	Quarterly	
199572	Sandstone	Canyon	Local	3940	1.05	9/26/2008	Quarterly	
205004	Clinker	Anderson/Dietz	Local	3890	0.79	9/26/2008	Quarterly	One time
205010		Canyon	Local	3960	0.77	9/26/2008	Quarterly	
205011		Anderson	Local	4050	5.67	9/26/2008	Quarterly	One time
205041	Sandstone	Canyon	Local	3735	1.27	9/26/2008	Quarterly	
205049	Sandstone	Dietz	Local	3670	0.80	9/25/2008	Monthly	
223687				3841			Monthly	
223877		Otter	Regional & Local	3475	0.14	9/26/2008	Monthly	
228591		Dietz	Local	3620	3.68	9/25/2008	Monthly	
228776				3920	0.33	9/26/2008	Monthly	
240578		Anderson	Regional & Local	3665	0.43	9/26/2008	Monthly	

	Gwic Id	Site Name	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC
Sites currently outside areas of potential CBM influence	223877	East Fork Hanging Woman Creek Weir	10/13/2009 14:07	1028.52	2.32	8.7	MBMG	8.09
			5/26/2010 16:25	804.14	2.24	18.2	MBMG	8.25
	228591	Three Mile Spring	10/14/2009 12:19	306.01	0.82	9.2	MBMG	8.02
			5/19/2010 15:20	271.62	0.80		MBMG	8.11
	207066	Well RBC-2	5/25/2010 11:13	556.00	0.80	7.7	MBMG	7.9
	223687	RBC-4	3/10/2010 15:00	472.16	0.48	1.2	MBMG	8.22
	205049	Chipmunk Spring	10/13/2009 14:14	2932.85	9.40	7.6	MBMG	7.86
			5/19/2010 11:30	2855.95	9.17		MBMG	7.94
	8103	HWC-86-5	5/26/2010 10:25	2830.40	7.21	10	MBMG	8.22
	157879	5072B	6/14/2010 15:00	2811.24	3.44	11.6	MBMG	8.2
	157882	5072C	6/14/2010 15:17	3049.82	3.63	12.4	MBMG	7.67
	203697	CBM02-8KC	11/4/2009 13:00	1127.75	32.48		MBMG	8.37
	207099	WL-2	11/3/2009	1515.84	73.32		MBMG	8.19
	203693	CBM02-7CC	7/15/2010 16:10	944.12	25.90	17.1	MBMG	8.2
	251797	GC09-KC	11/3/2009 13:14	3683.35	8.46	12	MBMG	7.9
	8107	HWC-01-O-2 TR-26	7/13/2010 15:12	1504.77	42.56	14	MBMG	8.15
Sites within current areas of potential CBM influence	228592	Musgrave Bill Alluvial	10/14/2009 11:16	908.82	1.51	12.1	MBMG	7.63
			6/30/2010 19:03	1126.64	1.69	11.9	MBMG	8.09
	223952	WA-2	10/13/2009 11:53	1851.09	22.47	10.2	MBMG	7.81
			5/19/2010 12:45	1737.09	21.62	10.1	MBMG	8.03
	7905	Well HWC-86-7	10/13/2009 14:42	3673.24	8.27	9.1	MBMG	7.57
			5/25/2010 14:55	3339.87	7.90	9.2	MBMG	8.13
	8888	Well HWC-86-13	10/13/2009 18:45	6646.31	10.82	9.6	MBMG	7.94
			5/26/2010 13:59	5928.92	10.59	10.3	MBMG	7.58
	198489	Well HWC-86-15	10/13/2009 17:59	8046.81	10.89	98	MBMG	7.41
			5/26/2010 12:59	7658.98	10.55	10.7	MBMG	7.82
	219136	Well SL-3Q	10/22/2009 10:46	3411.31	5.26	8.7	MBMG	7.56
			6/30/2010 12:00	3426.96	5.05	9.6	MBMG	7.61
	220851	Well SL-8-1Q	5/18/2010 20:34	3372.88	5.17		MBMG	8.08
	220857	Well SL-8-2Q	10/21/2009 17:09	2606.01	4.70	10.7	MBMG	7.51
			5/18/2010 19:20	1962.61	3.79	8.5	MBMG	8.19
	220859	Well SL-8-3Q	10/21/2009 16:08	2003.64	3.50	12.1	MBMG	7.6
	122766	Well WR-59	10/14/2009 9:42	6492.86	6.19	12.4	MBMG	7.52
			5/27/2010 15:52	5701.44	6.15	8.9	MBMG	8.17
	228776	Upper Anderson Creek Spring	10/22/2009 9:15	3781.91	9.50	7.8	MBMG	7.83
			5/19/2010 9:15	3755.45	8.79		MBMG	8.12
	240578	Lower Anderson Creek Spring	10/22/2009 10:00	1525.68	3.10	11.2	MBMG	7.44
			5/19/2010 9:50	1382.88	2.96		MBMG	7.87
	8436	WR-24	7/14/2010 12:29	2166.24	21.84	9.7	MBMG	8.09
	8444	WR-27	7/14/2010 14:36	1233.34	38.05	15.6	MBMG	8.08
	122769	WR-38	7/14/2010 18:30	1502.93	40.01	14.4	MBMG	8.4
	8692	WRE-13	7/15/2010 9:35	1797.61	38.90	15	MBMG	8.6
	223801	SL-5ALQ	5/18/2010 15:00	4117.43	9.42	9.5	MBMG	8.23

	Gwic Id	Site Name	Sample Date	TDS	SAR	Water Temp	Lab pH	Lab SC
Sites currently outside areas of potential CBM influence	223877	East Fork Hanging Woman Creek Weir	10/13/2009 14:07	1028.52	2.32	8.7	MBMG	8.09
			5/26/2010 16:25	804.14	2.24	18.2	MBMG	8.25
	228591	Three Mile Spring	10/14/2009 12:19	306.01	0.82	9.2	MBMG	8.02
			5/19/2010 15:20	271.62	0.80		MBMG	8.11
	207066	Well RBC-2	5/25/2010 11:13	556.00	0.80	7.7	MBMG	7.9
	223687	RBC-4	3/10/2010 15:00	472.16	0.48	1.2	MBMG	8.22
	205049	Chipmunk Spring	10/13/2009 14:14	2932.85	9.40	7.6	MBMG	7.86
			5/19/2010 11:30	2855.95	9.17		MBMG	7.94
	8103	HWC-86-5	5/26/2010 10:25	2830.40	7.21	10	MBMG	8.22
	157879	5072B	6/14/2010 15:00	2811.24	3.44	11.6	MBMG	8.2
	157882	5072C	6/14/2010 15:17	3049.82	3.63	12.4	MBMG	7.67
	203697	CBM02-8KC	11/4/2009 13:00	1127.75	32.48		MBMG	8.37
	207099	WL-2	11/3/2009	1515.84	73.32		MBMG	8.19
	203693	CBM02-7CC	7/15/2010 16:10	944.12	25.90	17.1	MBMG	8.2
	251797	GC09-KC	11/3/2009 13:14	3683.35	8.46	12	MBMG	7.9
	8107	HWC-01-O-2 TR-26	7/13/2010 15:12	1504.77	42.56	14	MBMG	8.15
Sites within current areas of potential CBM influence	228592	Musgrave Bill Alluvial	10/14/2009 11:16	908.82	1.51	12.1	MBMG	7.63
			6/30/2010 19:03	1126.64	1.69	11.9	MBMG	8.09
	223952	WA-2	10/13/2009 11:53	1851.09	22.47	10.2	MBMG	7.81
			5/19/2010 12:45	1737.09	21.62	10.1	MBMG	8.03
	7905	Well HWC-86-7	10/13/2009 14:42	3673.24	8.27	9.1	MBMG	7.57
			5/25/2010 14:55	3339.87	7.90	9.2	MBMG	8.13
	8888	Well HWC-86-13	10/13/2009 18:45	6646.31	10.82	9.6	MBMG	7.94
			5/26/2010 13:59	5928.92	10.59	10.3	MBMG	7.58
	198489	Well HWC-86-15	10/13/2009 17:59	8046.81	10.89	98	MBMG	7.41
			5/26/2010 12:59	7658.98	10.55	10.7	MBMG	7.82
	219136	Well SL-3Q	10/22/2009 10:46	3411.31	5.26	8.7	MBMG	7.56
			6/30/2010 12:00	3426.96	5.05	9.6	MBMG	7.61
	220851	Well SL-8-1Q	5/18/2010 20:34	3372.88	5.17		MBMG	8.08
	220857	Well SL-8-2Q	10/21/2009 17:09	2606.01	4.70	10.7	MBMG	7.51
			5/18/2010 19:20	1962.61	3.79	8.5	MBMG	8.19
	220859	Well SL-8-3Q	10/21/2009 16:08	2003.64	3.50	12.1	MBMG	7.6
	122766	Well WR-59	10/14/2009 9:42	6492.86	6.19	12.4	MBMG	7.52
			5/27/2010 15:52	5701.44	6.15	8.9	MBMG	8.17
	228776	Upper Anderson Creek Spring	10/22/2009 9:15	3781.91	9.50	7.8	MBMG	7.83
			5/19/2010 9:15	3755.45	8.79		MBMG	8.12
	240578	Lower Anderson Creek Spring	10/22/2009 10:00	1525.68	3.10	11.2	MBMG	7.44
			5/19/2010 9:50	1382.88	2.96		MBMG	7.87
	8436	WR-24	7/14/2010 12:29	2166.24	21.84	9.7	MBMG	8.09
	8444	WR-27	7/14/2010 14:36	1233.34	38.05	15.6	MBMG	8.08
	122769	WR-38	7/14/2010 18:30	1502.93	40.01	14.4	MBMG	8.4
	8692	WRE-13	7/15/2010 9:35	1797.61	38.90	15	MBMG	8.6
	223801	SL-5ALQ	5/18/2010 15:00	4117.43	9.42	9.5	MBMG	8.23

	Gwic Id	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Fe (mg/l)	Mn (mg/l)	SiO2 (mg/l)	HCO3 (mg/l)	CO3 (mg/l)	SO4 (mg/l)	Cl (mg/l)
Sites currently outside areas of potential CBM influence	223877	1470	100	79.1	128	10.5	0.014	0.004	22.7	542.5	0	410.8
		127	84.8	69.5	115	9.4	0.011	0.008	9.74	266.1	0	375.8
	228591	549	30.3	24.1	24.8	11.1	<0.002	0.001	22.3	168.4	0	100.5
		530	30.5	25.1	24.5	12.6	<0.007	<0.001	21	85.4	0	105.2
	207066	1110	62.7	62.6	38.7	8.93	1.56	0.247	27.1	556.7	0	76.23
	223687	822	59.8	55.2	21.4	8.14	0.053	0.043	11.2	372.1	0	128.5
	205049	3680	106	149	640	11.4	<0.010	<0.001	13.1	971.1	0	1504
		3700	103	156	632	11.6	<0.072	<0.003	10.7	871.1	0	1480
	8103	3570	126	172	530	13	0.065	0.131	15.5	843	0	1540
	157879	3170	270	202	307	13.9	1.04	0.296	11	746.6	0	1612
	157882	3420	256	286	356	16.5	2.29	0.086	11.8	681.9	0	1764
	203697	1720	6.95	4.97	459	3.55	8.9	0.28	42.5	1126.5	14.4	<25.0
	207099	2510	3.55	1.71	672	4.42	0.09	0.014	12.4	1527.4	0	<25.0
	203693	1538	8.25	2.6	333	4.81	0.046	<0.005	7.23	650	0	259.6
	251797	4460	194	197	700	15.1	<0.292	0.42	14.9	660.2	0	2229
	8107	2480	10.7	2.35	590	5.76	0.124	0.005	8.63	1749.5	0	<12.5
Sites within current areas of potential CBM influence	228592	1523	113	66.7	81.7	5.22	0.386	0.157	20.1	553.5	0	332.6
		1580	149	102	109	5.52	0.031	0.013	18.7	503.1	0	473.2
	223952	2890	24.9	25.9	671	6.62	0.123	0.012	9.74	1750.7	0	191
		2640	23.9	25.8	640	7.2	0.1	0.009	9.52	1579.5	0	194.7
	7905	4190	167	208	678	21.1	0.751	1.06	20.5	1007.7	0	2078
		4260	155	207	639	19.9	0.484	0.746	17.9	933.3	0	1814
	8888	6750	365	303	1155	12.2	6.9	2.18	12.2	755.2	0	4402
		6440	321	293	1091	10.8	6.73	1.83	12	840.6	0	3762
	198489	8100	484	445	1380	12.5	9.34	2.14	13.8	855.2	0	5272
		7990	462	448	1328	11.2	8.62	2.11	12.5	783.2	0	4977
	219136	3780	290	217	486	6.39	1.92	0.562	10.4	512.4	0	2142
		3480	302	232	480	6.61	1.97	0.572	9.49	477.3	0	2144
	220851	4020	322	174	463	11.1	0.399	1.09	13.7	652.7	0	1849
	220857	3200	318	94.9	372	10.9	0.62	1.07	19.5	603.9	0	1323
		2510	241	71.8	261	5.95	0.512	0.58	16.2	400.5	0	1028
	220859	2750	263	76.7	251	12.5	0.011	0.008	16.8	369.3	0	1065
	122766	6310	280	550	774	32.1	8.21	1.13	23.1	829.5	0	4410
		5980	254	549	761	29.8	6.44	0.914	19.1	686.9	0	3716
	228776	4400	136	208	755	10.6	1.85	0.101	9.4	935.7	0	2175
		4290	126	226	713	10.2	0.646	0.082	7.61	994.3	0	2157
	240578	2040	110	135	205	9.66	<0.146	<0.011	16.8	651.5	0	714.3
		2001	102	126	189	9.21	<0.036	<0.002	15.8	628.7	0	617.9
	8436	3130	30.8	21.7	647	10.3	0.174	0.015	8.58	780.8	0	1050
	8444	2040	7.7	1.82	452	7.32	0.067	<0.005	10.7	960.5	0	267.9
	122769	2350	10.3	2.13	540	5.78	0.027	<0.005	9.25	1268.8	58.6	236.6
	8692	2520	12.9	3.23	603	6.7	0.088	0.008	8.99	1781.8	272.1	<12.5
	223801	4830	207	214	809	6.79	<0.072	0.013	7.88	632	0	2547

	Gwic Id	NO3-N (mg/l)	F (mg/l)	OPO4-P (mg/l)	Ag (ug/l)	Al (ug/l)	As (ug/l)	B (ug/l)	Ba (ug/l)	Be (ug/l)	Br (ug/l)	Cd (ug/l)	Co (ug/l)
Sites currently outside areas of potential CBM influence	223877	7.45	<0.5 P	1.52	<0.5	<0.5	<37.8	0.573	214	69.2	<0.9	<500	<0.5
		6.32	0.362 P	1.15	<0.05	<0.10	<1.00	0.907	154	<0.10	<0.10	<50	<0.10
	228591	8.18	0.982 P	0.815	<0.05	<0.1	<7.6	6.17	127	62.8	<0.2	<50	<0.1
		8.55	0.963 P	0.99	<0.05	0.392	<2.3	6.18	118	59.1	<0.2	83	<0.1
	207066	3.14	0.300 P	0.634	<0.05	<0.10	<1.00	2.36	84.8	<0.10	<0.10	<50	<0.10
	223687	3.55	<0.2 P	0.435	<0.05	<0.10	2.56	0.742	53.1	67.6	<0.10	<50	<0.10
	205049	26.87	0.508 P	1.7	<1.0	<0.5	<37.8	0.348	290	15.7	<0.9	<1000	<0.5
		29.49	0.22 P	1.48	<0.25	<2.0	<23.2	<4.0	325	15.4	<2.0	261	<1.0
	8103	16.52	<0.5 P			<0.50	<5.00	<1.00	262	<0.50	<0.50	<250	<0.50
	157879	12.58	<0.25	0.484	<0.25	<1.0	<10.0	<0.92	282	6.13	<1.0	<250	<1.0
	157882	12.43	<0.25	0.452	<0.25	<1.0	10.3	<0.92	499	8.86	<1.0	<250	<1.0
	203697	10.4	<0.5 P	13.28	<0.5	<0.7	8432	1.74	387	316	<1.1	<500	<1.4
	207099	64.99	<0.5 P	4.56	<0.5	<0.7	<43.0	2.49	320	328	<1.1	<500	<1.4
	203693	4.79	0.061	3.4	0.064	<1.0	<10.0	<0.9	40.2	14.3	<1.0	<50	<1.0
	251797	<25.0	<0.5 P	<2.5	<2.5	<1.4	<435.0	<2.3	360	44.1	<2.1	<2500	<2.9
	8107	21.32	<0.25	4.19	<0.25	<1.0	<10.0	<0.9	83.7	402	<1.0	282	<1.0
Sites within current areas of potential CBM influence	228592	15.98	<0.5 P	<0.5	<0.5	<0.5	<37.8	0.413	96.2	52.7	<0.9	<500	<0.5
		18.76	1.68	0.398	<0.05	<1.0	<10.0	<0.9	81.7	55.7	<1.0	<50	<1.0
	223952	55.78	<0.5 P	3.14	<1.0	<0.5	<37.8	0.569	281	25.9	<0.9	<1000	<0.5
		54.72	0.600 P	2.64	<0.25	<1.0	<11.6	<2.0	266	23.9	<1.0	<250	<0.5
	7905	<25.0	<0.5 P	<2.5	<2.5	<1.0	<75.6	1.24	336	28.7	<1.8	<2500	<1.0
		22.7	<0.25 P	1.15	<0.25	<1.0	<10.0	<2.0	305	<1.0	<1.0	<250	<1.0
	8888	10.67	<0.5 P	<1.0	<1.0	<1.0	<75.6	2.41	234	8.43	<1.8	<1000	<1.0
		10.96	<0.5 P	0.619	<0.5	<1.00	<10.00	2.57	191	<1.00	<1.00	<500	<1.00
	198489	<50.0	0.549 P	<5.0	<5.0	<1.0	<75.6	3.45	214	7.11	<1.8	<5000	<1.0
		16.22	<0.5 P	0.557	<0.5	<1.00	<10.00	3.2	204	<1.00	<1.00	<500	<1.00
	219136	<10.0	<0.5 P	<1.0	<1.0	<1.4	<435.0	<2.3	103	7.7	<2.1	<2500	<2.9
		9.98	<0.25	0.352	<0.25	<2.0	<0.2	<1.8	106	7.46	<2.0	<250	<2.0
	220851	214.4	<0.5 P	0.388	<0.25	<2.0	<23.2	<4.0	130	23.6	<2.0	<250	<1.0
	220857	166.6	<0.5 P	<1.0	<1.0	<1.4	<217	<2.3	141	20.6	<2.1	<1000	<2.9
		138.2	9.84 P	0.369	<0.25	<1.0	11.6	<2.0	88.5	16.7	4	251	<0.5
	220859	135	2.93 P	<0.5	<0.5	<0.5	<37.8	1.06	99.2	21.3	<0.9	<500	<0.5
	122766	<50.0	<0.5 P	<5.0	<5.0	<1.0	<75.6	3.52	362	17	<1.8	<5000	<1.0
		20.71	<0.5	0.707	<0.5	<1.00	<10.00	2.61	220	<1.00	<1.00	<500	<1.00
	228776	21.06	<0.5 P	<0.05	<0.05	<0.1	<7.6	0.229	70.4	7.25	<0.2	<50	<0.1
		20.58	<0.25 P	0.496	<0.25	<2.0	<23.2	<4.0	100	6.16	<2.0	<250	<1.0
	240578	10.86	<0.5 P	0.714	<0.5	<0.7	<43.0	<1.1	249	18.9	<1.1	<500	<1.4
		10.24	3.12 P	0.749	<0.05	<1.0	<11.6	<2.0	190	15.4	<1.0	<50	<0.5
	8436	11.18	<0.25	1.32	<0.25	<1.0	<10.0	<0.9	60.1	10.4	<1.0	<250	<1.0
	8444	11.06	<0.05	1.92	0.063	<1.0	<10.0	<0.9	28.3	15.5	<1.0	102	<1.0
	122769	12.72	<0.25	3.07	<0.25	<1.0	<10.0	<0.9	45.9	21	<1.0	<250	<1.0
	8692	10.59	<0.25	2.35	<0.25	<1.0	<10.0	<0.9	60	596	<1.0	<250	<1.0
	223801	11.37	0.386 P	0.486	<0.25	<2.0	<23.2	<4.0	248	7.37	<2.0	<250	<1.0

	Gwic Id	Cr (ug/l)	Cu (ug/l)	Hg (ug/l)	Li (ug/l)	Mo (ug/l)	Ni (ug/l)	Pb (ug/l)	Sb (ug/l)	Se (ug/l)	Sn (ug/l)	Sr (ug/l)	Ti (ug/l)	Tl (ug/l)
Sites currently outside areas of potential CBM influence	223877	<0.3	<0.5	<2.0		71.1	4.25	<0.6	<2.0	<0.5	1.69	<0.5	1298	4.72
		0.23	<0.20	0.568		45.8	3.89	0.434	<0.10	<0.10	2.83	<0.10	1339	3.22
	228591	<0.1	2.47	0.394		58.4	6.68	<0.1	<0.4	0.129	3.05	<0.1	788	1.03
		0.157	1.93	1.06		50.5	5.13	<0.3	<0.5	<0.4	3.24	<0.1	815	0.919
	207066	0.26	<0.20	<0.40		28.5	2.71	0.34	<0.10	<0.10	<0.40	<0.10	1073	0.648
	223687	0.224	<0.10	0.924		28.2	2.06	0.787	<0.10	<0.20	0.277	<0.10	713	1.37
	205049	<0.3	<0.5	<2.0		161	1.35	<0.6	<2.0	<0.5	1.71	<0.5	2788	15.6
		<1.0	<3.0	<9.1		67.3	<3.0	<3.0	<5.1	<4.0	<3.0	<1.0	2657	17.1
	8103	<0.50	<1.00	<2.00		129	3.06	0.991	<0.50	<0.50	<2.00	<0.50	2241	18
	157879	<0.9	<1.0	<2.5		77.6	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	13423	16
	157882	<0.9	<1.0	<2.5		93.9	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	8294	17.5
	203697	2.63	14.9	<5.1		44.3	2	7.44	10.4	<0.8	<1.6	<0.6	249	32.9
	207099	<0.8	3.28	<5.1		60.3	1.48	<2.0	<1.3	<0.8	<1.6	<0.6	356	<1.4
	203693	<0.9	<1.0	<2.5		113	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	475	2.34
	251797	1.94	<1.1	<10.1		181	<1.4	<3.9	<2.6	<1.6	<3.2	<1.1	7631	29
	8107	<0.9	<1.0	<2.5		113	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	313	<1.0
Sites within current areas of potential CBM influence	228592	<0.3	<0.5	<2.0		22.2	0.878	<0.6	<2.0	<0.5	<0.5	<0.5	615	3.99
		<0.9	<1.0	14.6		17.1	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	757	4.94
	223952	<0.3	<0.5	<2.0		98.2	<0.5	<0.6	<2.0	<0.5	0.836	<0.5	1637	2.29
		<0.5	<1.5	<4.5		38.7	<1.5	<1.5	<2.5	<2.0	<1.5	<0.5	1526	<3.5
	7905	1.07	<1.0	<3.9		129	7.92	1.84	<4.0	<1.0	<1.0	<1.0	2787	23
		1.07	<2.0	<4.0		111	7.36	2.5	<1.0	<1.0	<4.0	<1.0	2609	23.7
	8888	2.9	<1.0	<3.9		189	1.17	2.18	<4.0	<1.0	<1.0	<1.0	5311	47.3
		2.61	<2.00	<4.00		153	1.27	4.07	<1.00	<1.00	<4.00	<1.00	5233	39.5
	198489	3	<1.0	<3.9		216	1.56	2.18	<4.0	<1.0	1.46	<1.0	6978	58.9
		2.91	<2.00	<4.00		191	1.59	5.03	<1.00	<1.00	<4.00	<1.00	7158	60.4
	219136	<1.7	<1.1	<10.1		135	<1.4	<3.9	<2.6	<1.6	<3.2	<1.1	4818	24.8
		<1.8	<2.0	<5.0		141	<2.0	<1.8	<2.0	<2.0	<1.8	<2.0	5015	13.8
	220851	2.27	<3.0	<9.1		<4.0	<3.0	<3.0	<5.1	<4.0	<3.0	<1.0	2670	19.7
	220857	<1.7	<1.1	<10.1		37.4	3.64	<3.9	<2.6	<1.6	<3.2	4.1	2215	14.2
		0.875	4.5	<4.5		<2.0	1.85	<1.5	<2.5	<2.0	<1.5	<0.5	1637	10.5
	220859	0.315	<0.5	<2.0		35.8	2.36	<0.5	<2.0	<0.5	11.1	<0.5	1820	12.1
	122766	0.995	<1.0	<3.9		270	4.4	1.2	<4.0	<1.0	<1.0	<1.0	5679	49.5
		<1.00	<2.00	<4.00		217	3.59	2.22	<1.00	<1.00	<4.00	<1.00	5469	38.8
	228776	0.3	<0.1	1.29		290	0.147	<0.1	<0.4	<0.1	0.628	<0.1	4406	19.2
		3.42	<3.0	<9.1		139	<3.0	<3.0	<5.1	<4.0	<3.0	<1.0	4656	22.4
	240578	<0.8	<0.5	<5.1		179	<0.7	<2.0	<1.3	<0.8	<1.6	<0.6	2538	8.44
		<0.5	<1.5	<4.5		98.1	<1.5	<1.5	<2.5	<2.0	<1.5	<0.5	2533	7.19
	8436	<0.9	<1.0	<2.5		180	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	967	9
	8444	<0.9	<1.0	<2.5		134	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	106	2.51
	122769	<0.9	<1.0	<2.5		110	<1.0	<0.9	<1.0	<1.0	<0.9	<1.0	198	2.17
	8692	<0.9	1.72	<2.5		145	1.77	2.81	<1.0	<1.0	<0.9	<1.0	491	<1.0
	223801	<1.0	<3.0	<9.8		45.3	<3.0	<3.0	<5.1	<4.0	<3.0	<1.0	2758	27.8

	Gwic Id	U (ug/l)	V (ug/l)	Zn (ug/l)	Zr (ug/l)	Ce (ug/l)	Cs (ug/l)	Ga (ug/l)	La (ug/l)	Nb (ug/l)	Nd (ug/l)	Pd (ug/l)	Pr (ug/l)	Rb (ug/l)
Sites currently outside areas of potential CBM influence	223877	<0.5	7.38	1.95	<4.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.477	<0.5
		<0.10	6.46	1.79	<2.80	<0.10	<0.10	<0.10	<0.20	<0.10	<0.10	<0.10	0.559	<0.10
	228591	<0.1	3.15	41.1	1.36	<0.1	<0.1	0.204	<0.1	<0.1	<0.1	<0.1	0.266	<0.1
		<0.2	3.06	33	1.39	<0.1	<0.1	0.252	<0.1	<0.1	<0.2	<0.1	<0.9	<0.1
	207066	<0.10	0.811	0.326	<2.80	<0.10	<0.10	<0.10	<0.20	<0.10	<0.10	<0.10	0.46	<0.10
	223687	<0.10	3.04	0.84	<0.81	0.14	<0.10	<0.10	<0.10	<0.10	<0.20	<0.10	0.223	<0.10
	205049	<0.5	8.98	<0.4	<4.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.927	<0.5
		<2.0	8.88	<2.0	<11.1	3.66	<1.0	<1.0	<1.0	<1.0	<2.0	<1.0	<9.1	<1.0
	8103	<0.50	16.5	<0.50	<14.00	<0.50	<0.50	<0.50	<1.00	<0.50	<0.50	<0.50	1.05	<0.50
	157879	<1.0	<1.0	<1.0	<5.0	13.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	4.9	<1.0
	157882	<1.0	<1.0	<1.0	7.56	13.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	3.01	<1.0
	203697	<0.5	1.14	11.9	44.8	5.16	19.6	0.713	2.59	9.4	<1.3	8.14	<0.9	2.17
	207099	<0.5	<0.5	<0.4	<10.1	1.19	<0.7	<0.6	<0.7	<0.6	<1.3	<0.7	<0.9	<0.5
	203693	<1.0	<1.0	<1.0	12.5	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
	251797	<1.0	3.88	<0.9	33.2	<1.0	<1.4	<1.1	<1.5	<1.3	<2.7	<1.5	2.34	<1.0
	8107	<1.0	<1.0	<1.0	258	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
Sites within current areas of potential CBM influence	228592	<0.5	8.25	<0.4	18.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.3	<0.5
		<1.0	10.6	<1.0	9.47	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
	223952	<0.5	<0.5	<0.4	<4.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.622	<0.5
		<1.0	<0.5	<1.0	<5.6	<0.5	<0.5	<0.5	<0.5	<0.5	<1.0	<0.5	<4.5	<0.5
	7905	<1.0	14.4	<0.8	<9.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.935	<1.0
		<1.0	14.3	<1.0	<28.0	<1.0	<1.0	<1.0	<2.0	<1.0	<1.0	<1.0	1.14	<1.0
	8888	<1.0	19.7	<0.8	<0.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.07	<1.0
		<1.00	19.3	<1.00	<28.00	<1.00	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	2.57	<1.00
	198489	<1.0	37.7	<0.8	<9.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.82	<1.0
		<1.00	40.9	<1.00	<28.00	<1.00	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	3.75	<1.00
	219136	<1.0	3.08	<0.9	<20.2	<1.0	<1.4	<1.1	<1.5	<1.3	<2.7	<1.5	<1.8	<1.0
		<2.0	2.68	<2.0	<10.0	<1.8	<2.0	<5.0	<1.8	<2.0	<1.7	<2.0	<5.0	<2.0
	220851	<2.0	26.6	<2.0	<11.1	<1.0	<1.0	<1.0	<1.0	<1.0	<2.0	<1.0	<9.1	<1.0
	220857	<1.0	24.9	1.01	<20.2	<1.0	4.4	4.1	<1.5	<1.3	<2.7	4.5	<1.8	4
		<1.0	15.7	<1.0	27.4	<0.5	<0.5	<0.5	<0.5	<0.5	<1.0	<0.5	<4.5	<0.5
	220859	<0.5	23.4	1.37	<4.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.676	<0.5
	122766	<1.0	29.1	<0.8	<9.3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.13	<1.0
		<1.00	32	<1.00	<28.00	<1.00	<1.00	<1.00	<2.00	<1.00	<1.00	<1.00	2.44	<1.00
	228776	<0.1	1.16	0.079	6.31	<0.1	<0.1	0.191	<0.1	<0.1	<0.1	<0.1	1.72	<0.1
		<2.0	1.66	<2.0	<11.1	<1.0	<1.0	<1.0	<1.0	<1.0	<2.0	<1.0	<9.1	<1.0
	240578	<0.5	<0.5	1.13	<10.1	<0.5	<0.7	<0.6	<0.7	<0.6	<1.3	<0.7	<0.9	<0.5
		<1.0	<0.5	<1.0	<5.6	<0.5	<0.5	<0.5	<0.5	<0.5	<1.0	<0.5	<4.5	<0.5
	8436	<1.0	<1.0	<1.0	5.22	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
	8444	<1.0	<1.0	<1.0	111	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
	122769	<1.0	<1.0	<1.0	199	<0.9	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<1.0	<1.0
	8692	<1.0	<1.0	<1.0	224	0.997	<1.0	<2.5	<0.9	<1.0	<0.9	<1.0	<2.5	<1.0
	223801	<2.0	38.2	<2.0	15.1	<1.0	<1.0	<1.0	<1.0	<1.0	<2.0	<1.0	<9.1	<1.0

	Gwic Id	Th (ug/l)	W (ug/l)	NO2-N (mg/l)	NO3+NO2-N (mg/l)	Kjeldahl-N (mg/l)	Total N as N (mg/l)	Dissolved Organic Carbon (mg/l)
Sites currently outside areas of potential CBM influence	223877	8.79	<0.5	<0.5				
		7.73	<0.10	<0.10				
	228591	13.6	<0.1	0.436				
		10.4	<0.1	0.323				
	207066	12.6	<0.10	<0.10				
	223687	4.76	<0.10	<0.10				
	205049	9.14	<0.5	<0.5				
		7.44	<1.0	<2.0				
	8103	7.81	<0.50	<0.50				
	157879	14.4	<1.0	<1.0	<0.25	0.167		3.13
	157882	17.6	<1.0	<1.0	<0.25	0.315		4.19
	203697	9.61	5.27	<1.3				
	207099	4.86	<0.3	<1.3				
	203693	7.38	<1.0	<1.0	<0.05	<0.2		2.25
	251797	17.2	<0.6	<2.6				
	8107	5.06	<1.0	<1.0	<0.25	<0.2		3.22
Sites within current areas of potential CBM influence	228592	7.56	<0.5	<0.5				
		6.69	<1.0	<1.0	<0.05	1.62		2.42
	223952	7.4	<0.5	<0.5				
		5.63	<0.5	<1.0				
	7905	15.7	<1.0	<1.0				
		14.9	<1.0	<1.0				
	8888	6.71	<1.0	<1.0				
		6.13	<1.00	<1.00				
	198489	6.09	<1.0	<1.0				
		5.91	<1.00	<1.00				
	219136	<3.14	<0.6	<2.6				
		<5.0	<2.0	<2.0	<0.25	2.7		5.97
	220851	3.16	<1.0	<2.0				
	220857	3.51	<0.6	<2.6				
		1.42	<0.5	<1.0				
	220859	7.11	<0.5	<0.5				
	122766	35.5	<1.0	<1.0				
		28.8	<1.00	<1.00	<0.5	<0.2	<1.0	<1.0
	228776	9.06	<0.1	<0.1				
		6.68	4	<2.0				
	240578	6.87	<0.3	<1.3				
		5.09	<0.5	<1.0				
	8436	10.2	<1.0	<1.0	<0.25	3.52		8.39
	8444	5.79	<1.0	<1.0	<0.05	<0.2		3.42
	122769	5.94	<1.0	<1.0	<0.25	<0.2		2.75
	8692	8.69	<1.0	<1.0	<0.25	4.23		7.51
	223801	<1.0	<1.0	<2.0				

	Gwic Id	Dissolved Inorganic Carbon (mg/l)
Sites currently outside areas of potential CBM influence	223877	
	228591	
	207066	
	223687	<0.25
	205049	
	8103	
	157879	
	157882	
	203697	2.96
	207099	2.44
	203693	
	251797	5.54
	8107	
Sites within current areas of potential CBM influence	228592	
	223952	
	7905	
	8888	
	198489	
	219136	
	220851	
	220857	
	220859	
	122766	
	228776	
	240578	
	8436	
	8444	
	122769	
	8692	
	223801	

Appendix D. Well location and chemistry analysis for CBM produced water sampled at the well-head

GWIC ID	API #	Formation	Top	TD	Well Name	Latitude	Longitude	Completion Date	July 2010 producing months
241161	25-003-21948-00-00	Dietz 1 Coal	530	551	Visborg 2390 44D1	45.02417876	-106.7881254	7/28/2005	60
241182	25-003-21727-00-00	Dietz 1 Coal	458	478	Visborg 2790 44D1	45.0098934	-106.8096134	10/23/2003	81
241216	25-003-21791-00-00	Dietz 1 Coal	369	389	Visborg 3590 34D1	44.99657456	-106.7918459	12/3/2003	79
241221	25-003-21772-00-00	Dietz 1 Coal	507	524	Visborg State 3690 32D1	45.00382598	-106.7726076	12/12/2003	79
241302	25-003-22034-00-00	Dietz 1 Coal	413	438	Homes 2891 12D1	45.01844681	-106.7234332	9/21/2005	58
257510	25-003-21380-00-00	Dietz 1, 2, 3	267	346	Consol 2499 34D	45.02525873	-106.89581	8/19/1999	131
257511	25-003-21371-00-00	Dietz 1 Coal*	346	432	Consol 2599 42D	45.01815558	-106.8901134	8/27/1999	131
257512	25-003-21890-00-00	Dietz 1, 2, 3	375	457	Federal 2699 24D	45.01065876	-106.9224247	1/27/2005	66
257513	25-003-21897-00-00	Dietz 1, 2, 3	428	508	State 3699 22D	45.00425956	-106.9021627	7/29/2004	72
257514	25-003-21958-00-00	Dietz 1 Coal	526	552	Visborg Fed 2490 23D1	45.02852012	-106.7790382	2/23/2005	65
257516	25-003-21802-00-00	Dietz 1 Coal	519	546	Visborg Federal 2590 21D1	45.02275474	-106.7796508	12/9/2003	79
257517	25-003-21722-00-00	Dietz 1 Coal	426	452	Visborg 2690 14D1	45.01196405	-106.8014911	9/22/2003	82
257518	25-003-21402-00-00	Dietz 1 Coal*	320	382	Consol 3090 13D	45.01589247	-106.8861706	9/15/1999	130
257519	25-003-21268-00-00	Dietz 1 Coal	198	235	Consol 3190 32D1	45.00419911	-106.8763905	10/3/1999	129
257520	25-003-22278-00-00	Dietz 1 Coal	458	509	Porter 0191 14D1	45.06918577	-106.6610957	6/15/2006	49
257521	25-003-22447-00-00	Dietz 1 Coal	172	191	Rancholme 1191 14D1	45.05370971	-106.6833561	4/14/2006	47
257522	25-003-22300-00-00	Dietz 1 Coal	137	157	Rancholme 1491 22D1	45.04751964	-106.6754394	10/20/2005	57
257523	25-003-21994-00-00	Dietz 1 Coal	493	511	Holmes 1991 44D1	45.02509746	-106.7481127	8/19/2005	59
257524	25-003-22019-00-00	Dietz 1 Coal	442	465	Holmes 2091 22D1	45.03210811	-106.7385972	9/6/2005	58
257525	25-003-22029-00-00	Dietz 1 Coal	290	308	Holmes 2091 44D1	45.02571578	-106.7267644	9/23/2005	58

All wells operated by Fidelity Exploration & Production Co.

Dietz 1 Coal* indicates this well is listed as completed in the D1 in some locations on the MT BOGC website and in the D123 coal in other locations.

Appendix D. Well location and chemistry analysis for CBM produced water sampled at the well-head

GWIC ID	July 2010 water production (bbl)	July 2010 gas production (mcf)	Field Conductivity (uS/cm)	Field pH	Water Temp (C)	Colorimeter (ppm)			
						Fe	Mn	P	NH4
241161	1705	732	2156	7.26	18.4	0.136	0.228	0.076	nd
241182	315	76	2234	7.38	17.0	0.171	0.000	0.068	nd
241216	15	0	2064	7.23	16.6	0.082	0.000	0.050	nd
241221	3150	71	2212	7.39	18.5	0.111	0.202	0.096	nd
241302	1680	1582	2210	6.80	17.6	0.065	0.002	0.089	nd
257510	3027	0	1455	7.03	16.0	0.142	1.477	0.101	0.227
257511	6251	98	1966	6.87	16.3	0.133	1.446	0.500	0.087
257512	6651	0	1948	7.07	17.5	0.091	0.433	0.573	0.131
257513	14943	146	1525	7.33	18.1	0.105	4.141	0.137	0.022
257514	3502	511	2201	7.09	19.4	0.108	0.000	0.069	nd
257516	2310	928	2205	7.16	18.2	0.118	0.000	0.071	nd
257517	2647	300	2034	7.40	20.0	0.178	0.000	0.071	nd
257518	12871	122	2258	7.14	15.6	0.128	0.000	0.392	0.073
257519	2150	0	1209	6.90	13.0	0.055	0.130	0.689	0.167
257520	1855	82	2377	7.47	18.7	0.071	0.886	0.232	0.095
257521	5266	407	2439	6.50	14.2	0.097	1.663	0.193	0.090
257522	1037	2882	2475	7.09	13.5	0.086	0.806	0.173	nd
257523	403	570	2338	6.83	17.2	0.135	1.698	0.132	nd
257524	1007	152	2337	7.16	17.3	0.179	0.000	0.076	nd
257525	0	2243	2179	7.36	15.3	0.864	0.350	0.108	nd

Appendix D. Well location and chemistry analysis for CBM produced water sampled at the well-head

GWIC ID	MBMG Analytical Laboratory (ppm)					
	Fe	Mn	Phosphate	Nitrate	Total Kjeldahl Nitrogen	Total Nitrogen
241161	0.095	<.005	0.103	<.051	2.930	2.880
241182	0.091	<.005	0.097	<.015	3.090	3.080
241216	0.084	<.005	0.080	<.05	3.080	3.030
241221	0.069	<.005	0.123	0.137	3.280	3.420
241302	0.055	<.005	0.119	6.580	3.210	9.790
257510	0.124	<.005	0.074	<.2	2.020	2.120
257511	0.118	<.005	0.089	1.050	2.96	4.01
257512	0.098	0.008	0.110	2.990	2.320	5.310
257513	0.086	<.005	0.104	3.92	1.9	5.83
257514	0.069	<.005	0.098	<.037	3.390	3.350
257516	0.091	<.005	0.097	6.000	3.070	9.080
257517	0.166	<.005	0.086	<.057	2.620	2.560
257518	0.109	<.005	0.087	1.540	3.100	4.640
257519	0.032	<.005	0.118	<.2	1.54	1.58
257520	0.285	<.005	0.132	0.285	3.100	3.390
257521	0.095	0.006	0.160	<.063	3.650	3.590
257522	0.094	<.005	0.138	<.031	3.740	3.710
257523	0.123	<.005	0.104	<.018	3.430	3.410
257524	0.087	<.005	0.102	0.063	3.610	3.670
257525	0.279	0.015	0.107	8.350	3.920	12.300

Appendix D. Well location and chemistry analysis for CBM produced water sampled at the well-head

	Major cations and anions+										Alkalinity		
GWIC ID	Ca	Mg	Na	K	Sr	Fl	Cl	NO_3	Ortho P	SO_4	CO_3	HCO_3	Total
241161	4.6	1.9	590	6	0.43	1.8	16	<.05	<.1	<.5	13	1760	1470
241182													
241216													
241221	5.2	3.2	600	6.4	0.46	2	11	0.09	<.1	<.5	3	1800	1500
241302	4.8	2.7	620	8	0.34	2	16	<.05	<.1	<.5	13	1780	1480
257510	3.4	1.2	380	5	0.15	4	9.9	<.05	<.1	3	0	1120	920
257511	6.8	2.6	510	5.7	0.28	1.4	10	<.05	<.1	<.5	0	1500	1230
257512	7.9	3.4	520	6.3	0.23	0.2	17	<.05	<.1	<.5	0	1540	1260
257513	5.1	1.6	410	4.1	0.2	3.5	23	<.05	<.1	<.5	5	1170	1570
257514	4.1	2	610	6.4	0.45	1.9	16	0.08	<.1	<.5	13	1760	1460
257516	4.5	2.2	610	6	0.39	1.7	13	<.05	<.1	<.5	7	1800	3300
257517	19	9.6	2780	26	1.5	1.9	16	<.05	<.1	<.5	6	1600	1320
257518	9.3	3.8	600	6	0.35	1.4	18	<.05	<.1	3.4	0	1810	1490
257519	2.1	1	330	2.8	0.13	2.6	9.1	<.05	0.1	<.5	0	940	770
257520	6.2	3.2	650	7.2	0.36	2.4	36	<.05	<.1	<.5	24	1830	1540
257521	5.6	3.4	680	5.6	0.39	2	30	<.05	<.1	9.6	22	1930	1620
257522													
257523	5	3.2	640	6.9	0.46	1.7	14	<.05	<.1	<.5	20	1880	1580
257524	5	3	660	7.4	0.43	1.9	15	<.05	<.1	<.5	21	1900	1600
257525													

+Major cation and anion and alkalinity analysis performed by the Wyoming Geological Survey at the University of Wyoming.