2006 Annual Coalbed Methane Regional Ground-Water Monitoring Report: Northern Portion of the Powder River Basin

MBMG OPEN-FILE REPORT 556

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Supported by:
U.S. Bureau of Land Management
U.S. Department of Agriculture Forest Service
Montana Department of Natural Resources and Conservation
Big Horn Conservation District

2007

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Addendum

It was discovered in early 2007, while this publication was in its final editing stages, that the Moorhead spring is actually a flowing well. This will be updated in GWIC and corrected in the 2007 report planned for publication in early 2008.

Abstract

This report presents ground-water data collected from within the northern portion of the Powder River Basin during 2006, and brief discussions of those data. This is the fourth year in which the Montana coalbed-methane (CBM) regional ground-water 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 ground-water impacts and recovery, to help replace rumors with factual data, and to provide data and interpretations to aid environmental analyses and permitting decisions. Detailed discussions of the regional ground-water systems were presented in the first annual report (Wheaton and Donato, 2004). The current 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. Methane (natural gas) production from coalbeds is a potentially important industry in Montana. The CX field near Decker, Montana, operated by Fidelity Exploration and Production Company, began producing methane in April, 1999 (plate 1). The CX field now includes 728 wells, which produced methane, water, or both during 2006. A total of 10.7 million mcf (1 mcf = 1000 standard cubic feet) of CBM was produced in Montana during 2006, nearly all of which came from the CX field. Minor amounts of CBM production were also reported in the Dietz and Coal Creek fields and in wildcat wells in both Big Horn and Powder River counties (plate 1).

Coalbed methane is held in coal seams by adsorption on the coal due to weak bonding and water pressure. Reducing water pressure by pumping ground water from coal aquifers allows methane to desorb. Ground water is typically pumped at a rate and scale that reduces water pressure (head) to a few ft 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 ground-water drawdown, and impacts to surface-water quality and soils from water management practices.

Methane-prospective coalbeds in the Powder River Basin of Montana contain water that is dominated by ions of sodium and bicarbonate. Sodium adsorption ratios (SAR) will likely be between 34 and 57, and total dissolved solids concentrations between 875 and 1,525 mg/L. Sulfate concentrations in production water will be 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 2006 the MBMG regularly measured water levels in a network of monitoring wells covering much of the Powder River Basin in Montana with a focus on areas felt to have high CBM potential. The Dietz coalbed is used in discussions in this report because of the greater density and coverage of monitoring wells completed in this bed. Hydrostatic heads in the Dietz coal have been lowered as much as 150 ft or more within areas of production. Access to wells with greater drawdown is not possible due to the safety hazard presented by venting gas. The first reported water or gas production in Montana occurred during April, 1999 in the CX field. After nearly 8 years of CBM production, the 20-ft drawdown contour for the Dietz coal extends about 1.0 to 1.5 miles beyond the edges of the CX field, which is somewhat less than originally predicted (U.S. Bureau of Land Management, BLM/MT/PL-03/005, 2003). The radius of the 20-ft drawdown contour is expected to increase as the duration of production increases; however, little change in this radius during the past year can be discerned from 2006 monitoring data. Based on computer modeling and reviews of current data from mines and other CBM production fields, drawdown of 20 ft is expected to eventually reach as far as 4 miles beyond the edges of large production fields. Less drawdown will occur at greater distances, and drawdown of 10 ft was predicted to reach as far as 5 to 10 miles beyond production fields after 20 years (Wheaton and Metesh, Montana Bureau of Mines and Geology Open-File Report 458, 2002). Faults tend to act as barriers to ground-water flow and drawdown does not migrate across fault planes where measured in monitoring wells. Vertical migration of drawdown tends to be limited by shale layers.

Aquifers will recover after production ceases, but it may take decades for them 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 and the site-specific aquifer characteristics, including the extent of faults in the Fort Union Formation and proximity to recharge areas. Since 2004, recovery 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 79 to 234 ft. After 2 years, recovery in these four wells has now reached 63 to 78% of baseline levels.

Models and predictions are important for evaluating potential hydrogeologic impacts. However, inventories of existing resources and long-term monitoring of aquifer responses are necessary to determine the actual magnitude and duration of impacts. After 93 months of CBM production it continues to be apparent that these monitoring data and interpretations are key for making informed development decisions and for determining the true causes of observed changes in ground-water availability.

Introduction

This report presents ground-water data and interpretations from within the northern portion of the Powder River Basin (PRB) collected during 2006. This is the fourth year in which the Montana regional coalbed-methane (CBM) ground-water 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 ground-water impacts and lack of impacts, ground-water recovery, and to provide data and interpretations for use in environmental and permitting decisions. Additional background is presented in Wheaton and Donato (2004). Future reports are anticipated to be released early each spring.

This report includes: (1) a description of ground-water conditions outside of CBM production areas, which provides an overview of normal variations, helps improve our understanding of the ground-water regime in southeastern Montana, and provides water quality information for planning CBM projects; and (2) a description of ground-water conditions within and near CBM fields, which shows actual impacts from CBM production. The area covered by the CBM regional ground-water 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 Ground-Water Information Center (GWIC). 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. 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) web page (http://www.bogc.dnrc.state.mt.us/), and the Wyoming Oil and Gas Conservation Commission (WOGCC) web page (http://wogcc.state.wy.us/).

A total of 825 CBM wells produced water, gas, or both in Montana during 2006. 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 728 wells listed as producing gas or water during 2006. During 2006 Fidelity expanded the area of development within the CX field to the east, bringing new areas into production. Pinnacle Gas Resources, Inc. (Pinnacle) began production in the Coal Creek field during April 2005 and in the Dietz field during January 2006. During 2006, 42 wells are listed as producing water, CBM, or both in the Coal Creek field and 55 wells are listed as producing in the Dietz field.

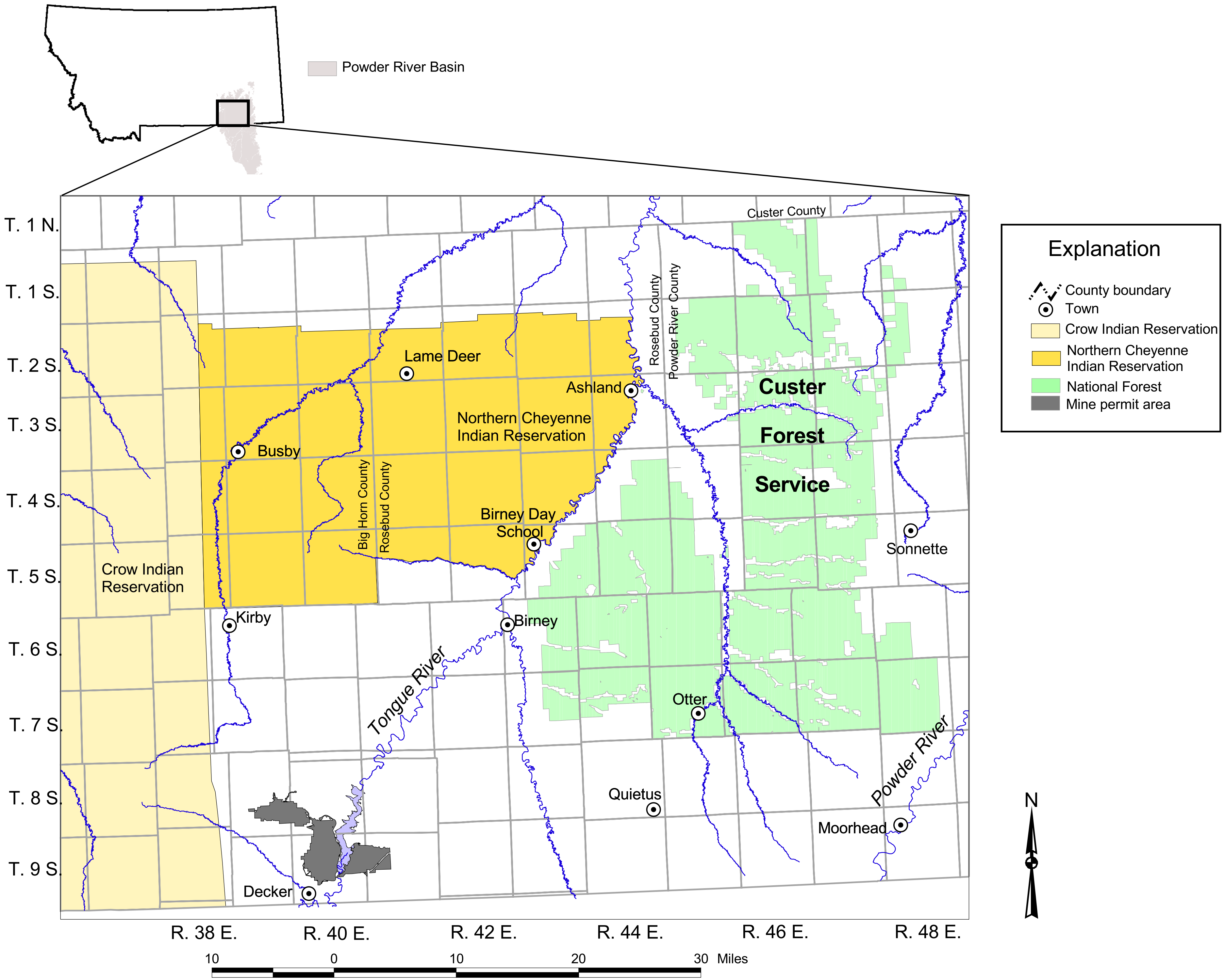


Figure 1. Location of study area.

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 (1,483 active wells during 2006) in Wyoming is adjacent to the CX field in Montana. The Hanging Woman Creek field (189 active wells during 2006) is near the center of the PRB along the state line. On the eastern edge of the PRB in Wyoming (the Powder River area in plate 1) 409 wells are listed as being active during 2006.

Hydrogeologic data were collected at 200 wells, 26 springs, and 3 streams during 2006. Of those monitored sites, 21 wells, 24 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 data are being stored in GWIC. Data has not been received for 2006. No new monitor wells were installed in 2006. 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 2006 are listed in appendix C. All data were entered in and 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. Bureau of Land Management, U.S. Department of Energy, and the Montana Department of Natural Resources and Conservation. The USDA Forest Service is providing funding in support of monitoring on the Custer Ranger District. The Rosebud, Big Horn, and Powder River Conservation Districts have been long-term supporters of coal hydrologeology work. The statewide Ground-Water Assessment Program, operated by the Montana Bureau of Mines and Geology, monitors several wells and springs in the Powder River Basin, and those data are incorporated in this work. Clay Schwartz monitors these wells and provides additional assistance to the Regional Program. Data are also collected by the Northern Cheyenne Indian Tribe with assistance from the United States Geological Survey. Technical discussions and reviews by Andy Bobst (U.S. BLM) continues 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 about Ashland (fig. 1 and plate 1). This is the Montana portion of the PRB believed to have the highest potential for CBM development (VanVoast 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 a geologic structure in southeast Montana and northeast Wyoming. Exposed formations include the Tertiary Fort Union Formation and the 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 in plate 1. The cross section is based on Montana Bureau of Mines and Geology (MBMG) monitoring wells and on published well logs and correlations (Lopez, 2006; McLellan and others, 1990; McLellan, 1991; Culbertson, 1987; Culbertson and Klett, 1979a,b). Generally, the coal 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).

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 Anderson and Dietz coal seams are mined near Decker. Ground-water monitoring wells are completed in numerous coalbeds and overburden and underburden sandstone units. The monitored intervals are indicated in figure 2, as are intervals that are the source units for monitored springs. Several sets of nomenclature are used for coalbeds in the Decker, Montana area. Table 1 shows the correlations between several different naming conventions.

Three distinct ground-water flow systems are present in the Powder River Basin: (1) local, (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 ground-water 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 flow toward and then follow the northward trend of the basin axis. Water quality also distinguishes the flow systems, with local ground-water quality typically dominated by Ca^{2+}, Mg^{2+} and $SO2_4^{2-}$ and regional systems dominated by Na^+ and HCO_3^-.

In regional bedrock aquifers, ground water flows from Wyoming northward towards the Yellowstone River. The coal-bearing Tongue River Member is bounded on the bottom by the Lebo Shale aquitard. Limited vertical flow through the Lebo Shale forces most ground water in the Tongue River Member to discharge to springs and streams along the contact between the units south of the Yellowstone River, adding baseflow to streams and supporting springs. 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 those units lying stratigraphically above this aquitard.

Locally, recharge along high, clinker-capped ridges and local outcrops produces shallow bedrock flow systems that follow topography. These local flow systems either discharge to alluvial aquifers, form springs at bedrock outcrops or seep vertically into the deeper bedrock aquifers. Some seepage between aquifers occurs; however, it is probably very limited due to the low permeability of the numerous shale layers. Regional flow systems are recharged near the perimeter of the PRB in areas where aquifers crop out. Regional ground-water flow is generally to the north and discharge

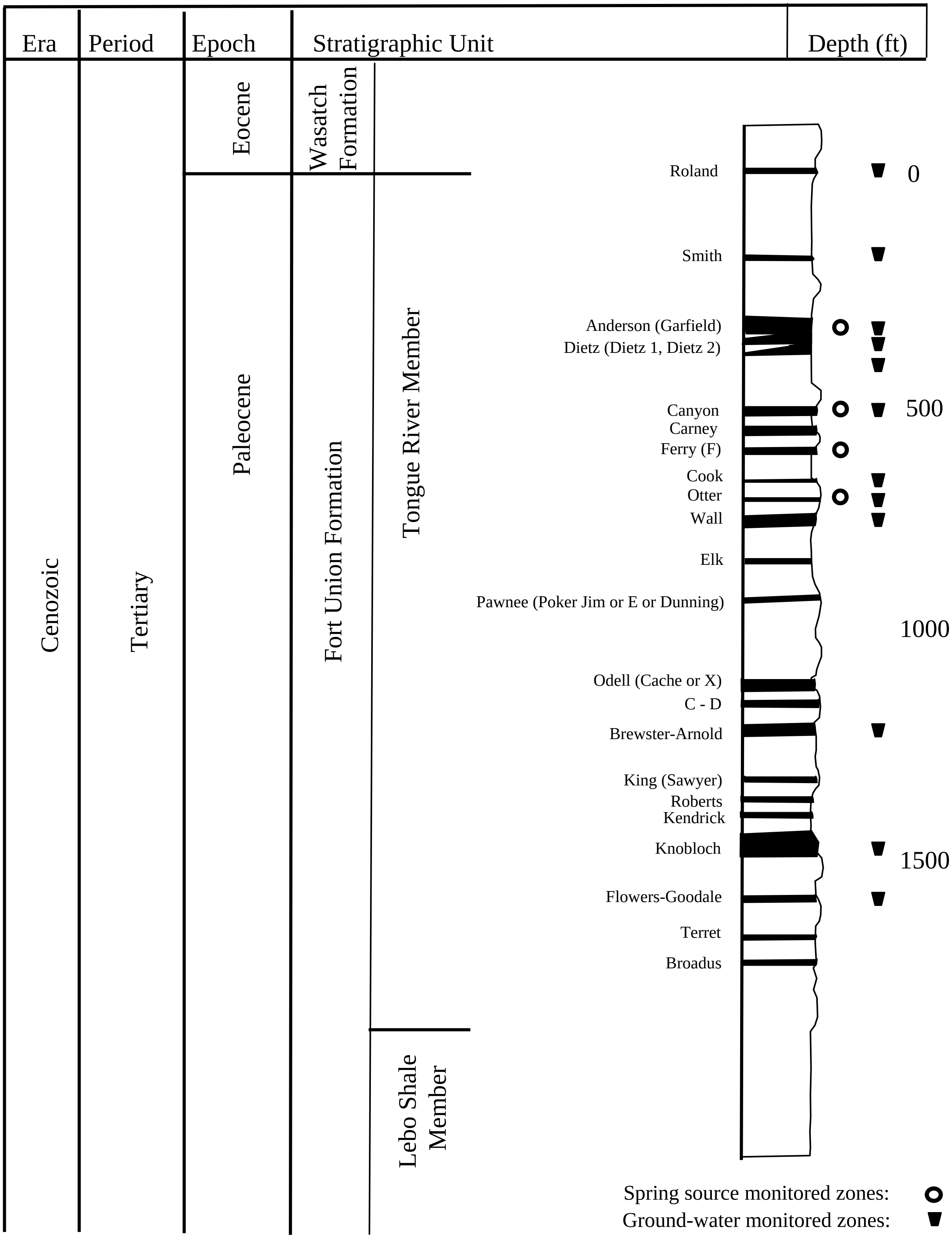


Figure 2. In the Ashland Ranger District, many coal beds have been mapped within the Tongue River Member of the Fort Union Formation. The general relative positions are shown here, with the right edge of the column indicating generally sandy interburden to the right and shale by the line curving to the left. Most coals do not exist across the entire District and the interburden thickness varies considerably. The indicated depths are only approximations. Sources: CSM maps; Matson and Blumer, 1973; McLellan and others, 1990; McLellan and others, 1991; Law and others, 1979; Fort Union Coal Assessment Team, 1999.

Table 1. Correlation of nomenclature used by the MBMG, USGS, coal mine companies, and CBM companies in the Decker, Montana area.

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 AND 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	COOK/CARNEY	D4	D4	CARNEY	COOK
WALL	WALL	D6	D6	WALL	WALL
					BREWSTER-ARNOLD
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 I-1959-A		

occurs as springs, in subcrop areas to alluvium, to streams, or leaves the PRB as deep ground-water flow. Alluvial aquifers occur adjacent to major streams and rivers.

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 PRB 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 nearer the basin axis (Lopez, 2006). East of the axis ground-water recharge to the Dietz coal occurs along outcrop areas and flow is generally toward the west and north, eventually discharging along outcrop areas. West of the basin axis recharge occurs in the topographically high areas in Wyoming and on the Crow Indian Reservation. Ground water flows to the east, toward the Tongue River. Near the Tongue River Reservoir it is interrupted by coal mines and coalbed-methane production. The effects of CBM production on the potentiometric surface of the Dietz coal is discussed later in this report.

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 suggest downward gradients (water-level altitude in wells is lower in deep aquifers than in shallow aquifers) or upward gradients (water-level altitude in wells is higher in deep aquifers than in shallow aquifers). Downward gradients are typical in the PRB. Areas of recharge have strong downward gradients, and upward gradients indicate proximity to discharge areas.

Ground-water quality in the Powder River Basin has been well-documented. The general chemical characteristics of ground water 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 chemically reduced zones where the water quality is dominated by ions of Na^{+} and HCO_3^{-} and low concentrations of Ca^{2+}, Mg^{2+} and SO_4^{2-} (Van Voast, 2003).

Hydrostatic pressure in coal aquifers is lowered during coalbed-methane production. This may affect water levels in wells and discharge rates of springs, which obtain their water from the developed coal seams. The magnitude, geographic extent, and duration of this drawdown are primary focuses of the regional monitoring program.

The ability of an aquifer to store and release water is determined by its storativity (S). Storativity is a combination of two distinct components: specific yield (S_y) and specific storage (S_s). Specific yield is a measure of the volume of water that can be drained from the pore spaces in a unit volume of material. 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. Specific storage is the volume of water released from a unit volume of aquifer per unit change in pressure head. Specific yield is several orders of magnitude greater than specific storage for a given aquifer (Fetter, 1994). Within unconfined or water table 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) specific storage is the primary means of water release as pores are not typically drained and water is not released due to specific yield.

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 (ft^3) of water would be released by completely draining 1 ft^3 of a coalbed aquifer. Typical values for specific storage for a confined coalbed aquifer are much less, on the order of 0.00006 ft^3 (Wheaton and Metesh, 2002). In this case, reducing the hydrostatic pressure of a confined coalbed by 1 foot would release 0.00006 ft^3 of water from a unit volume of material. The two examples of water released are basically comparable, as each represents a 1-ft change in water level. The difference in the quantities of water released is a function of how the water is released. When the water level in an unconfined aquifer is lowered, the pore spaces are drained. When the water level in a confined aquifer is lowered, the confining pressure is reduced, which releases water in response to the expansion of the aquifer's matrix and the water. Removal of water during CBM production typically reduces the hydrostatic pressure rather than draining the pores.

Coalbeds in the PRB are generally separated from other aquifers by shale units. Due to these confining shale units, in most areas water-level drawdown in response to CBM production 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 was 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.

Water-quality samples are collected from monitoring wells as part of the regional ground-water monitoring program and have been collected during previous projects in southeastern Montana. Water-quality data are available in GWIC for 100 samples from coalbed monitoring wells located in the area where CBM development is probable in southeastern Montana. Summary statistics for these data are presented in table 2. Based on these data, CBM production water in Montana can generally be expected to have TDS concentrations between about 875 and 1,525 mg/L and sodium adsorption ratios (SAR) values between 34 and 57. Low sulfate concentrations in coalbed water indicate reducing conditions and can be an important tool for CBM exploration (Van Voast, 2003). The median sulfate value for the samples included in this summary is 4.5 mg/L, though samples with concentrations as high as 471 mg/L were included in the selected data set.

Ground-water quality in coal seams is not expected to change in response to CBM production. Infiltration of produced water may, however, cause changes in shallow ground-water quality. To document possible changes, water-quality data are collected in shallow aquifers.

Table 2. Water-quality summary for coalbed aquifers in the portion of the Powder River Basin with coalbed methane potential in Montana.

	Specific Conductance (umhos/cm^2)	pH	Total Dissolved Solids (mg/L)	Sodium Adsorption Ratio	Sulfate (mg/L)
Median	1821	8.14	1201.0	45.8	4.5
Standard Deviation	494	0.40	322.8	11.4	64.4
Minimum	1055	7.45	568.2	11.3	0.0
Maximum	3061	9.36	2028.6	82.4	471.0
Count	100	100	100	100	100

Data source: MBMG file data (Montana Ground-Water Information Center)

The PRB area is semi-arid, receiving on average less than 15 in of precipitation per year, based on data from Fort Howes, Badger Peak, Bradshaw Creek, and Moorhead stations (plate 1). Typically in the PRB, May and June are the wettest months and November through March the driest. The annual average high temperature is in the low 60ºF range with July and August being the warmest. Annual average low temperature is about 30ºF; December and January are the coolest months.

Aquifers are recharged by precipitation and shallow ground-water 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 12.43 in, based on records from 1958 through 2006 (http://www.wrcc.dri.edu/summary/climsmmt.html). During 2006, Moorhead received 9.97 in of precipitation, which is 19% below normal (fig. 3). Long-term precipitation trends that may affect ground-water levels become more evident when the departure-from-average precipitation for each year is combined to show the cumulative departure (line graph in fig. 3). Cumulative departure from annual-average precipitation does not provide a quantitative measure of potential recharge, but rather an indication of periods of decreasing and increasing moisture in possible recharge areas.

Modern streams in the Montana PRB have formed valleys that cut through the entire coal-bearing Tongue River Member. Coal seams are exposed along valley walls, allowing ground-water seepage to form springs and allowing methane to naturally leak to the atmosphere. Ground-water 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 free methane is either held in a structural or sedimentary trap or is migrating.

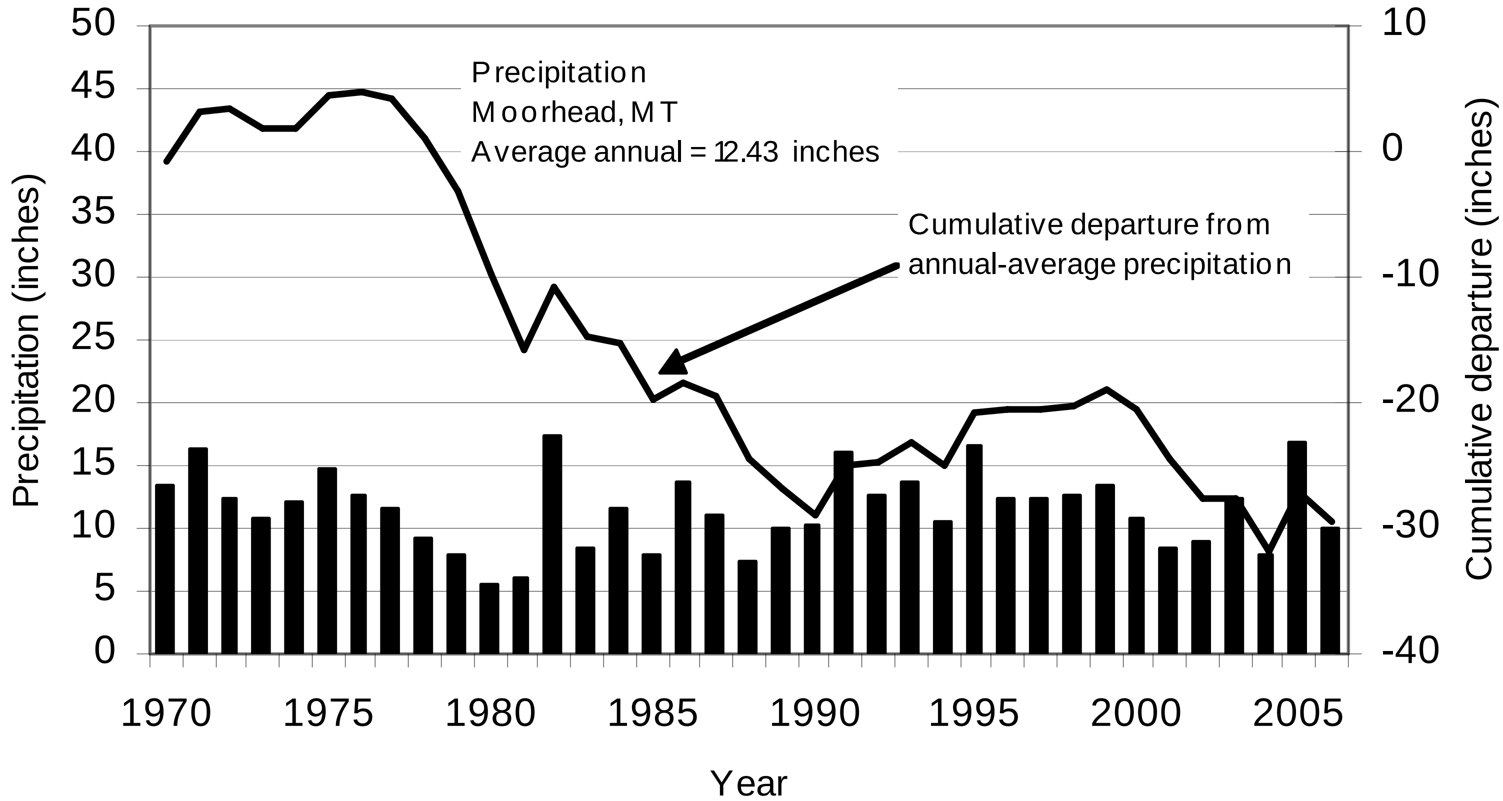


Figure 3. Annual precipitation (bar graph) at Moorhead MT. Cumulative departure from average precipitation provides a perspective on the long-term moisture trends that may effect ground-water recharge.

Ground-water conditions outside of potential coalbed-methane influence

Bedrock aquifer water levels

Ground-water levels and inferred flow directions in the Dietz coal seam are shown in plate 2. This plate shows the potentiometric surface and flow lines of the Dietz coal seam. There is little topographic control of flow patterns away from outcrop; however, near the outcrop areas, topography exerts a strong control on flow patterns. Ground water flows generally from south to north. However, recharge occurs 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.

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 CBM03-12, data from 1974 through 2006 from an overburden sandstone and the Canyon coal indicate a downward gradient (fig. 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 trend (fig. 3).

At site CBM03-11, the Anderson, Dietz, and Canyon coals also show a downward gradient, indicating a recharge zone (fig. 5). This site is in the south-central portion of the monitoring area, near the Anderson coal outcrop, and reflects background conditions.

Monitoring site CBM02-8 is just 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 discharge to nearby outcrops in Coal Creek and along the Tongue River (fig. 6). Water levels in wells completed in the deeper Flowers-Goodale overburden and Flowers-Goodale coal are higher than those measured in the Knobloch overburden and coal. The upward gradient suggests that this is a discharge area for the Flowers-Goodale units. Flowing wells near Birney, including the town water supply well, also reflect this upward gradient. These deeper wells flow at ground surface due to the high hydrostatic pressure at depth and the relatively low land surface near the Tongue River. Well CBM02-8DS is completed in channel sandstone overlying the Flowers-Goodale, also known as the “D” sandstone that has been identified as a possible injection bed (Lopez, 2007). Yield from this well was measured during drilling at approximately 35 gpm.

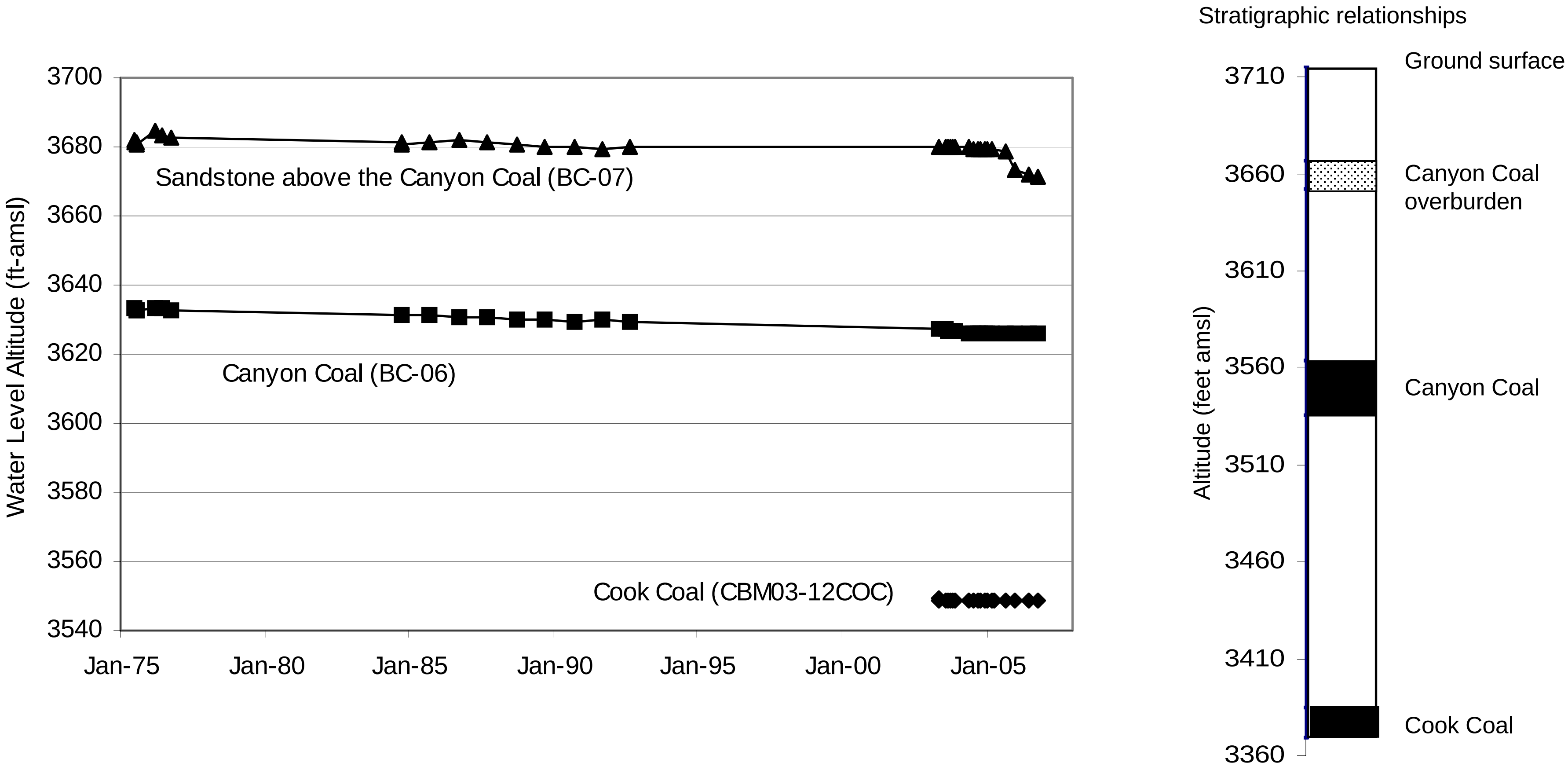


Figure 4. The long-term decrease in water levels in the Canyon overburden sandstone (BC-07), and Canyon coal (BC-06), likely relates to precipitation patterns shown on Figure 2. The short period of record for the Cook coal (CBM03-12COC) at this site does not show meteorological influence.

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

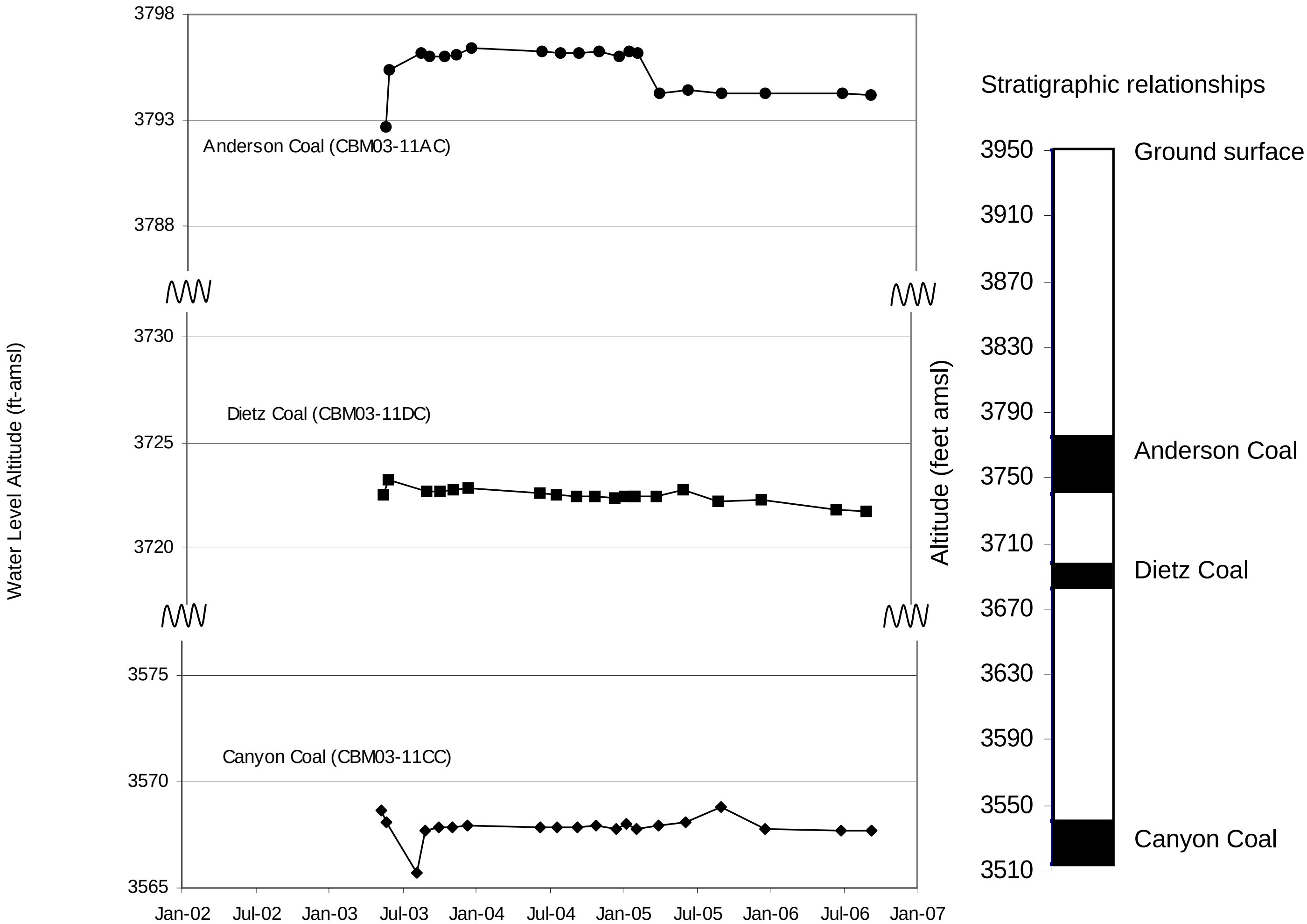


Figure 5 . A downward hydraulic gradient is evident between the Anderson, Dietz, and Canyon coalbeds at the CBM03-11 site.

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

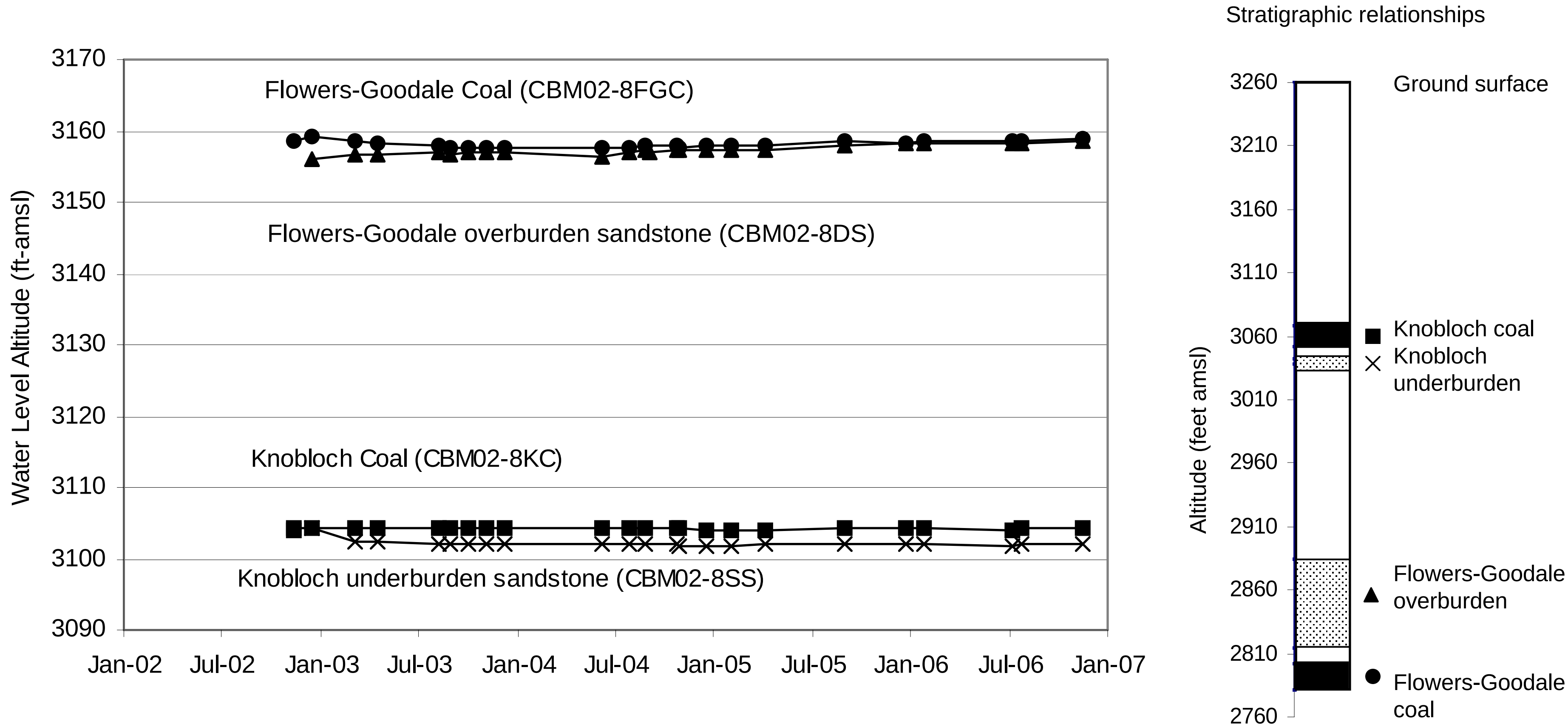


Figure 6. Water levels in wells completed in the stratigraphically deeper Flowers-Goodale units are higher than those in the shallower Knobloch coal units at the CBM02-08 site.

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

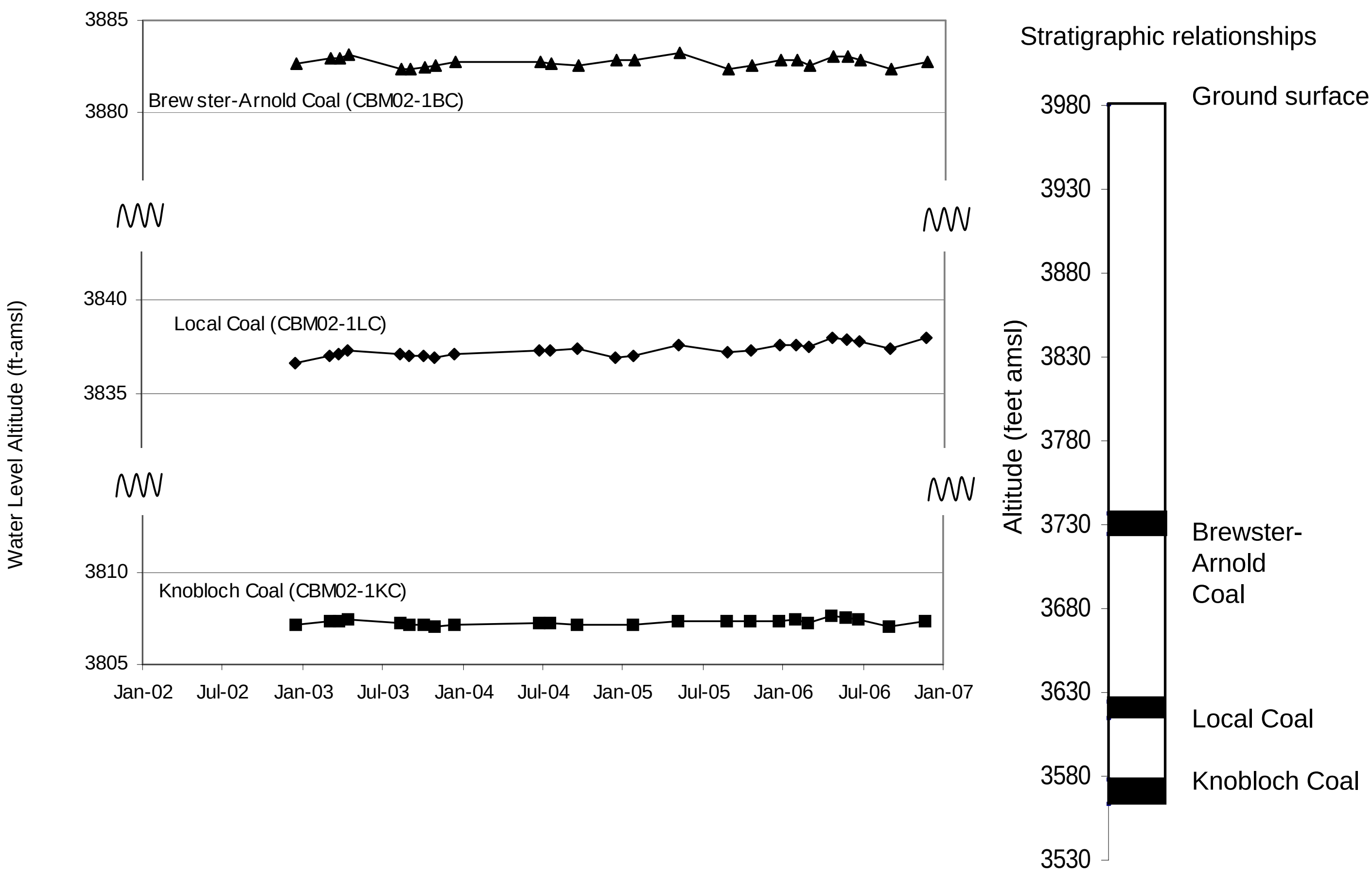


Figure 7. A downward hydrostatic gradient is evident between the Brewster-Arnold coal, local coal, and Knobloch coal at the CBM02-1 site.

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

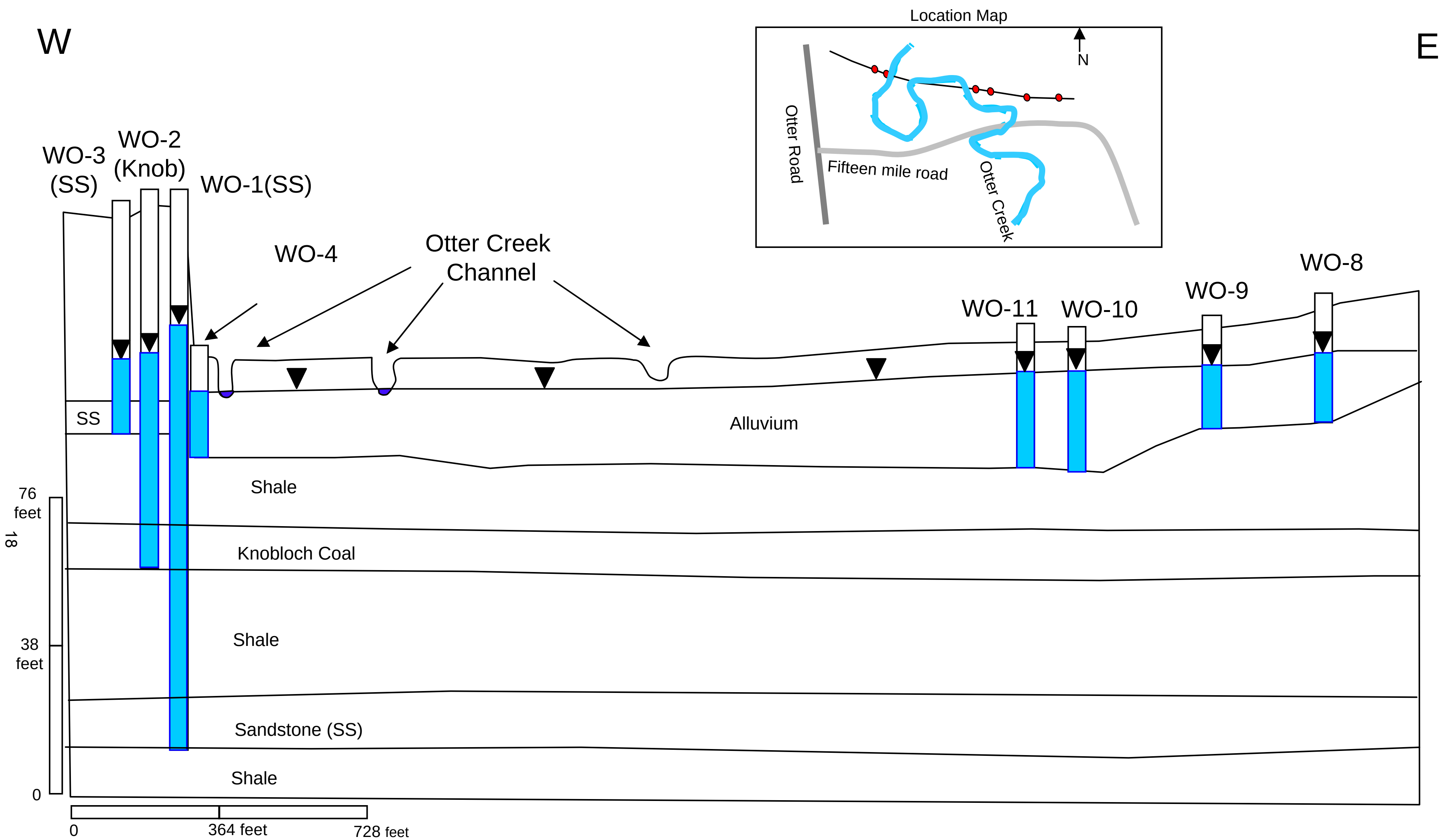


Figure 8. Geologic cross section for the Otter Creek alluvium and bedrock wells located in T05S R45E sec 23. Water levels in the alluvium are lower than the underlying bedrock aquifers. The water levels in the bedrock wells completed in stratigraphically deeper units are higher than those in shallower units. The water levels for this cross section were taken in December, 2006. Vertical exaggeration is 9.6:1.

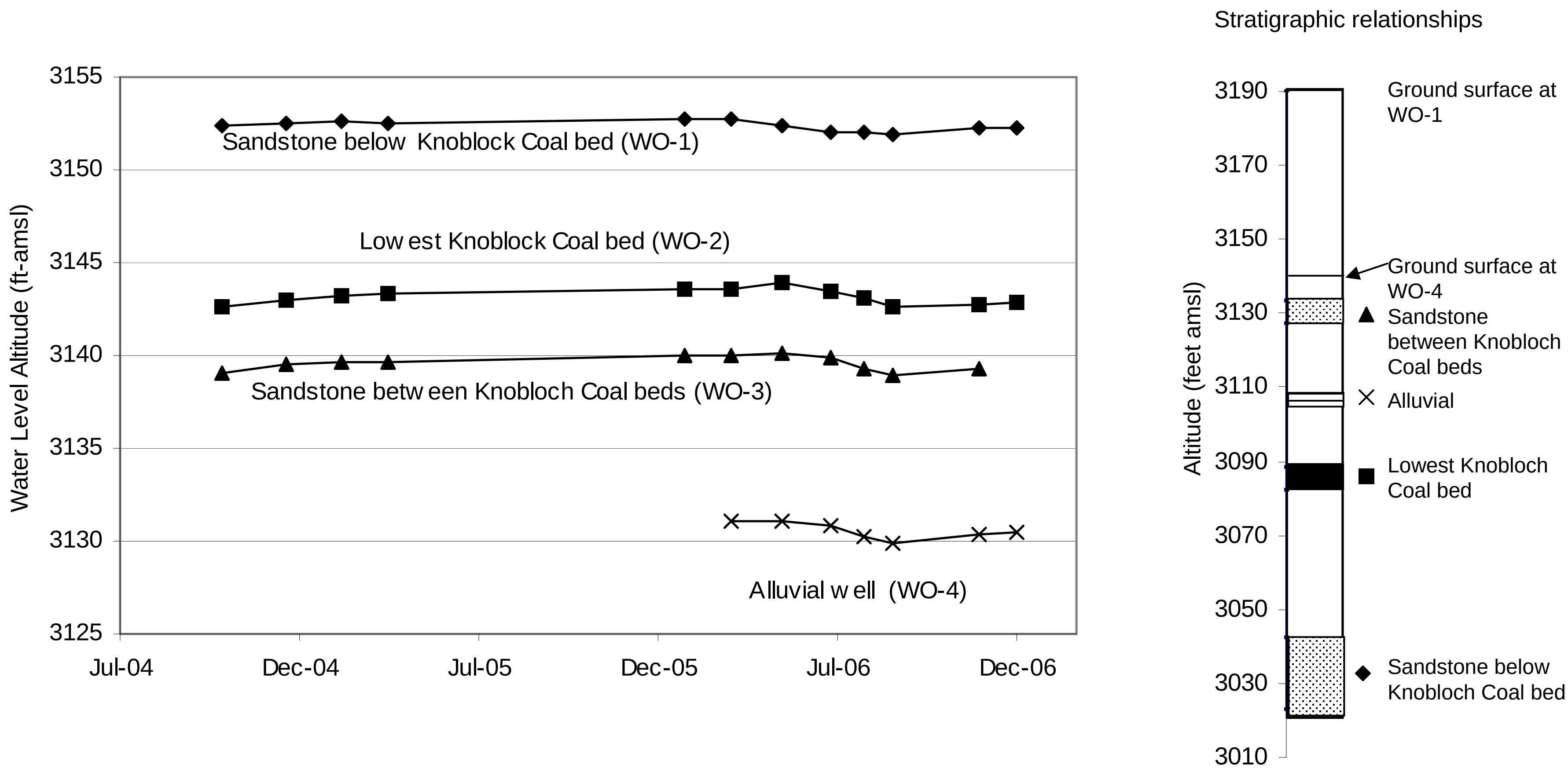


Figure 9. Bedrock aquifers at the Otter creek area have an upward vertical gradient, flowing wells are common in the area. The alluvial well appears to show the general seasonal water year cycle.

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

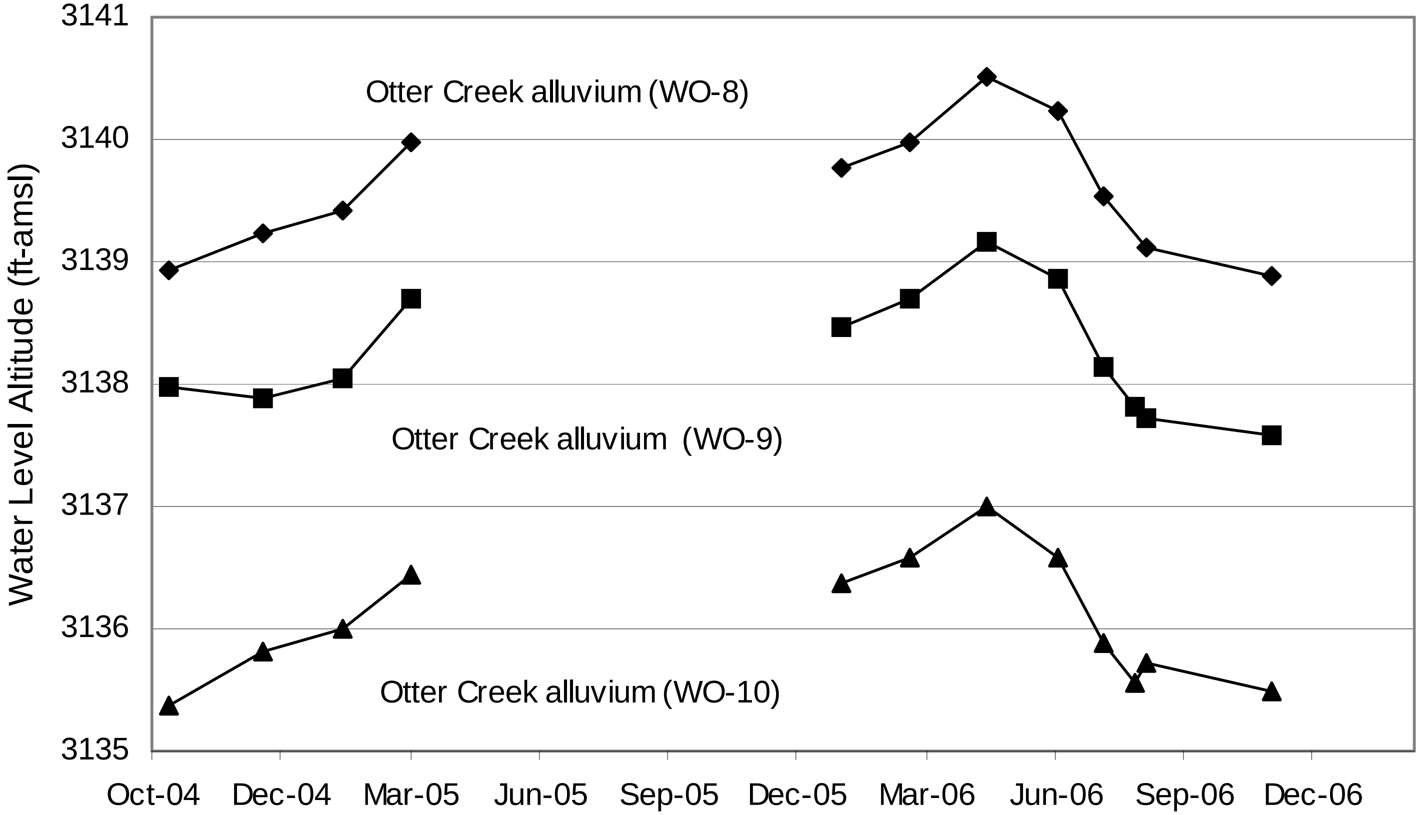


Figure 10. Water-level trends in the alluvium at the Otter Creek site probably relate to weather patterns. The alluvial aquifer appears to receive recharge from the bedrock aquifers in the area, based on the upward vertical gradient.

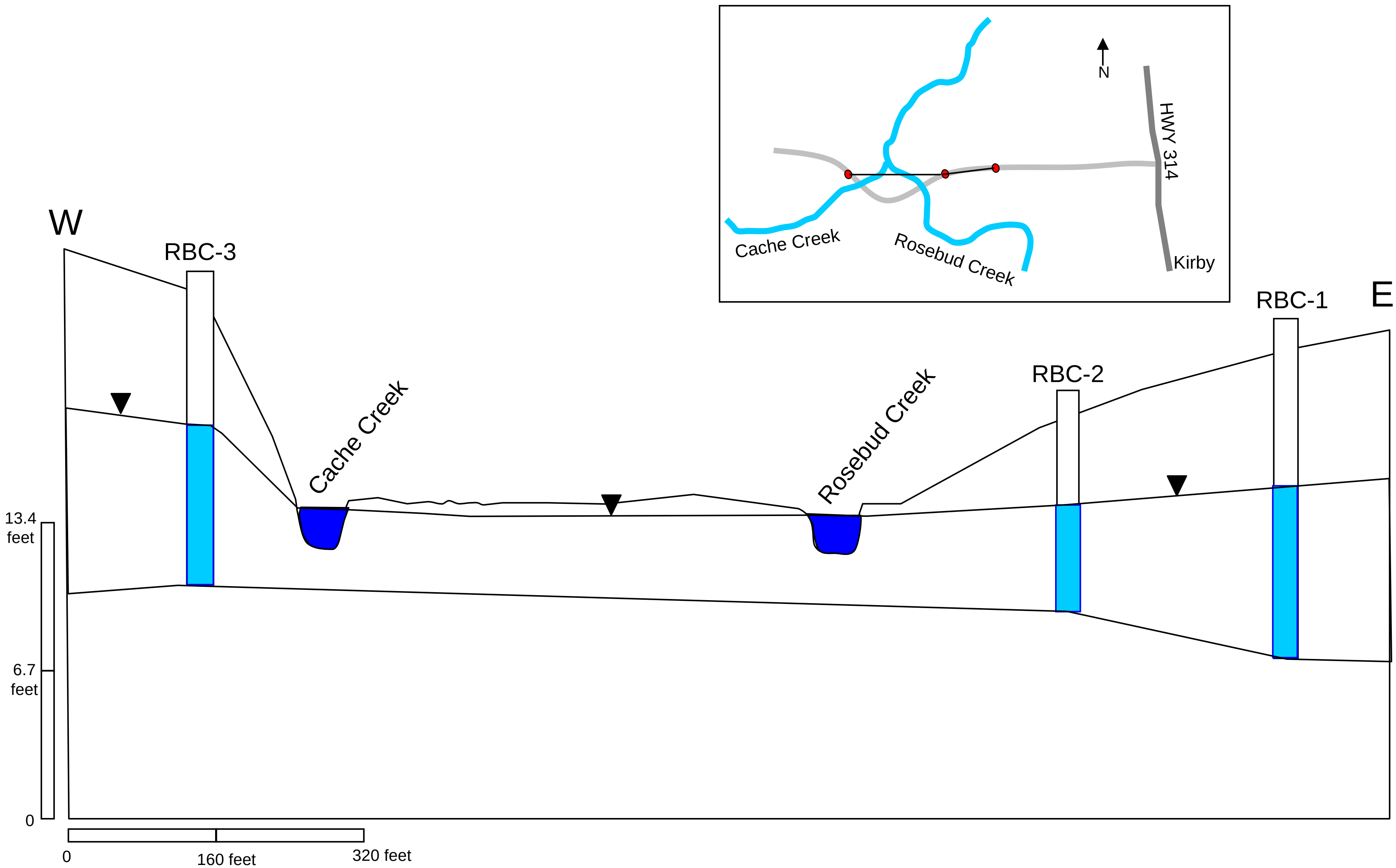


Figure 11. Cross section of the Rosebud creek site located in T06S R39E section 8. Water levels in this alluvial aquifer and surface water levels in Rosebud Creek are closely related. Well water levels are lowest in late summer and highest in early spring. The water levels at RBC-2 shows a correlation with the diurnal effect from the surrounding alfalfa plants. Water levels for this cross section were taken in January 2006.

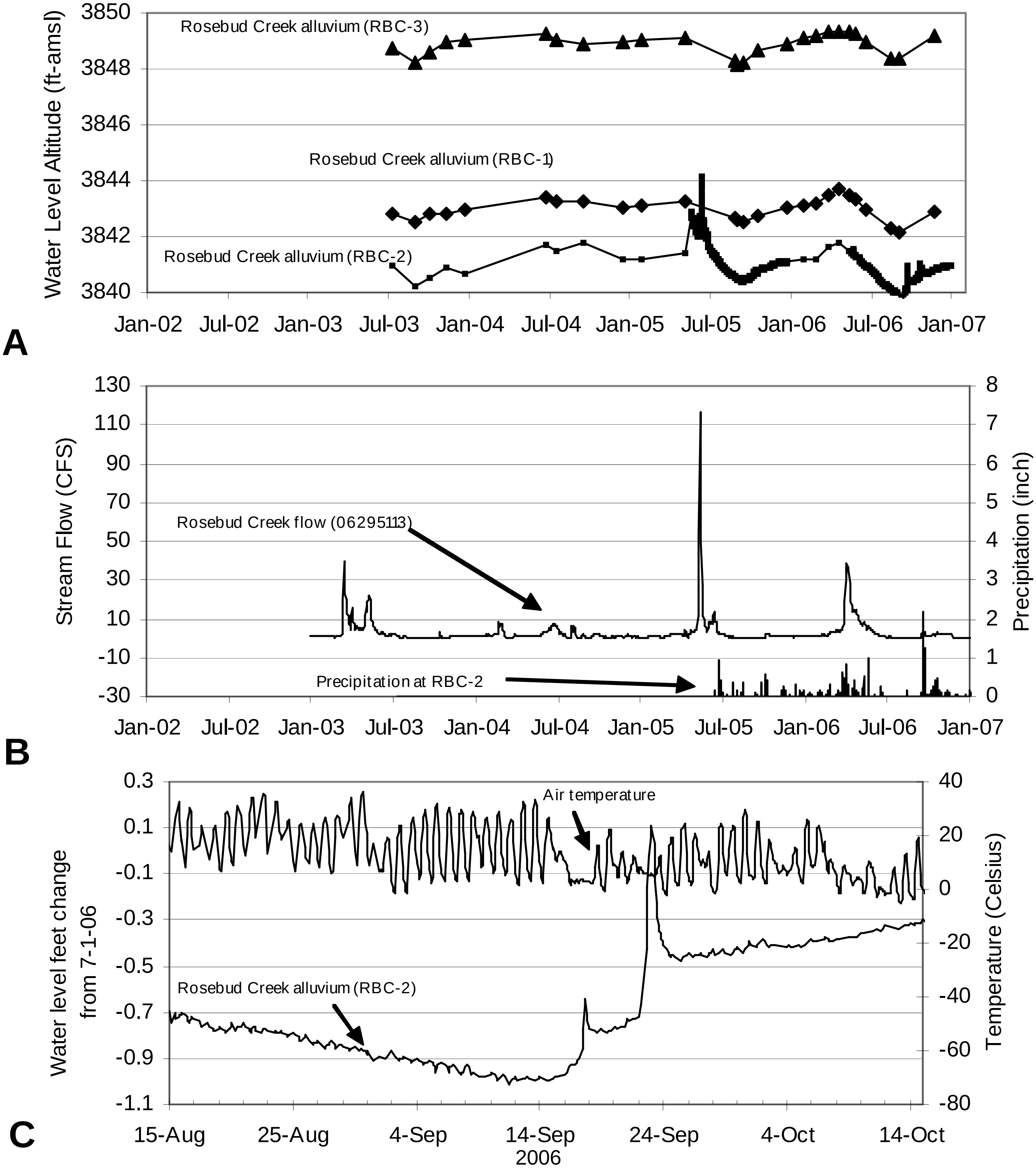


Figure 12. A) Ground-water levels are typically higher during wetter times of the year at the Rosebud Creek alluvium site. B) Rosebud Creek stream flow follows precipitation trends. C) Diurnal drawdown occurs in the aquifer due to the surrounding alfalfa fields as shown by the correlation between water levels and air temperature.

At monitoring site CBM02-1, 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, indicating a recharge zone (fig. 7). Water-level data from the Brewster-Arnold coal and the local coal demonstrate a slight annual trend, 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 ground-water zone (figs. 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, which in turn is providing baseflow for the creek. The deeper units (WO-1 and WO-2) are likely confined, and therefore are flowing towards their outcrop/subcrop areas.

Alluvial aquifer water levels and 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 a bedrock aquifer discharge zone (figs. 8, 9, and 10). Based on the upward hydrologic gradient at this site, the Otter Creek alluvium receives discharge from bedrock aquifers in this area. Alluvial water levels at this site vary with the seasonal trend. Otter Creek appears to be transitional between a gaining or 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 vary with precipitation trends. The geologic cross section shown in figure 11 crosses Rosebud Creek and a tributary. As shown in figure 11, ground water flows toward, and provides baseflow to, Rosebud Creek (i.e., it is a gaining stream). Data, particularly those from the continuous recorders at the site, show the relationships between meteorological conditions, ground-water levels, and surface-water flow (fig. 12). Ground-water levels show typical annual responses with highest levels during the late winter and early spring and lowest levels during late summer and fall (fig. 12a). Flow data in figure 12b for Rosebud Creek are from the U.S. Geological Survey gaging station near Kirby (station number 06295113) and are available from the website at http://waterdata.usgs.gov/mt/nwis/uv?06295113. Stream flows correlate well with precipitation events.

A comparison of the water-level and air temperature data at the RBC-2 site demonstrate part of the effect of transpiration on water table aquifers (fig. 12c). Diurnal fluctuations in the water table are the result of transpiration from the surrounding alfalfa crop. As air temperatures increase in the morning, plant growth increases and water consumption increases, lowering the water table. In the evening, as the air temperature decreases, plant stress on the water table decreases and the ground-water level recovers. The rate of withdrawal is greater than the rate of recovery, so over the period of the growing season, the water table is lowered. During September the air temperature dropped during a storm event. The transpiration demand decreased and precipitation reaching the water table caused a significant rise in the ground-water level. This event marked the beginning of the fall recharge period. Detailed precipitation data from this site for three fall precipitation events during September and October 2006 (MBMG file data), when compared to continuously recorded water levels, indicate a 6- to 18-hour lag period between the onset of rainfall and a rise in ground-water levels.

Water-quality samples were collected from four alluvial wells outside areas of coalbed-methane production in 2006 (appendix C). These samples were collected along Otter Creek, Rosebud Creek, and near site SL-5 near the state line. Concentrations of TDS ranged from 595 to 4,877 mg/L and SAR values between 0.9 and 9.6. Total dissolved solids concentrations were greatest at SL-5ALQ and least in the Rosebud Creek alluvium. The Rosebud Creek alluvium water quality is dominated by calcium, magnesium, and bicarbonate. All other water quality in the alluvium is dominated by sodium and sulfate. The data are available on GWIC and are represented by stiff diagrams showing relative major ion concentrations on plate 3.

Spring flow and water quality

Flow rates and specific conductivity data were collected at 26 springs within the project area during 2006. All of these springs are located outside the current area of potential CBM impacts. The locations of monitored springs are shown in plate 1, site data are in appendix B, and data collected during 2006 are available in the GWIC database. Springs are discharge points for ground-water flow systems. Local recharge occurs on ridge tops adjacent to springs or along the hillside between the spring and the top of the adjacent ridge. 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, it is assumed to be local in origin. Springs located at higher elevations, such as at the base of clinker zones on ridges, are recharged by local ground-water recharge. 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 Donato, 2004). 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 (RD), along Otter Creek, Alkali Spring discharges at rates of between 0.5 and 1.2 gpm. The discharge rate at this spring shows some seasonal influence (fig. 13). This spring represents either local flow or a mixture of regional and local flow systems. It appears that the Otter coal supplies some of the water to this spring.

The North Fork Spring is in the southeastern portion of the Ashland RD. This spring is located in a topographically high area and shows moderate seasonal influence in discharge rates which are less than 1 gpm (fig. 14). This spring is associated with an isolated portion of the Canyon coal and likely represents local ground-water recharge.

Cow Creek Spring, in the south-central part of the Ashland RD, is the water supply for the Fort Howes Work Center. A portion of the spring discharge is diverted and flows several miles through a gravity pipeline to Fort Howes. The discharge rate at the Cow Creek Spring ranges from about 7 gpm to 10 gpm and shows a strong seasonal trend (fig. 15). This spring flows from

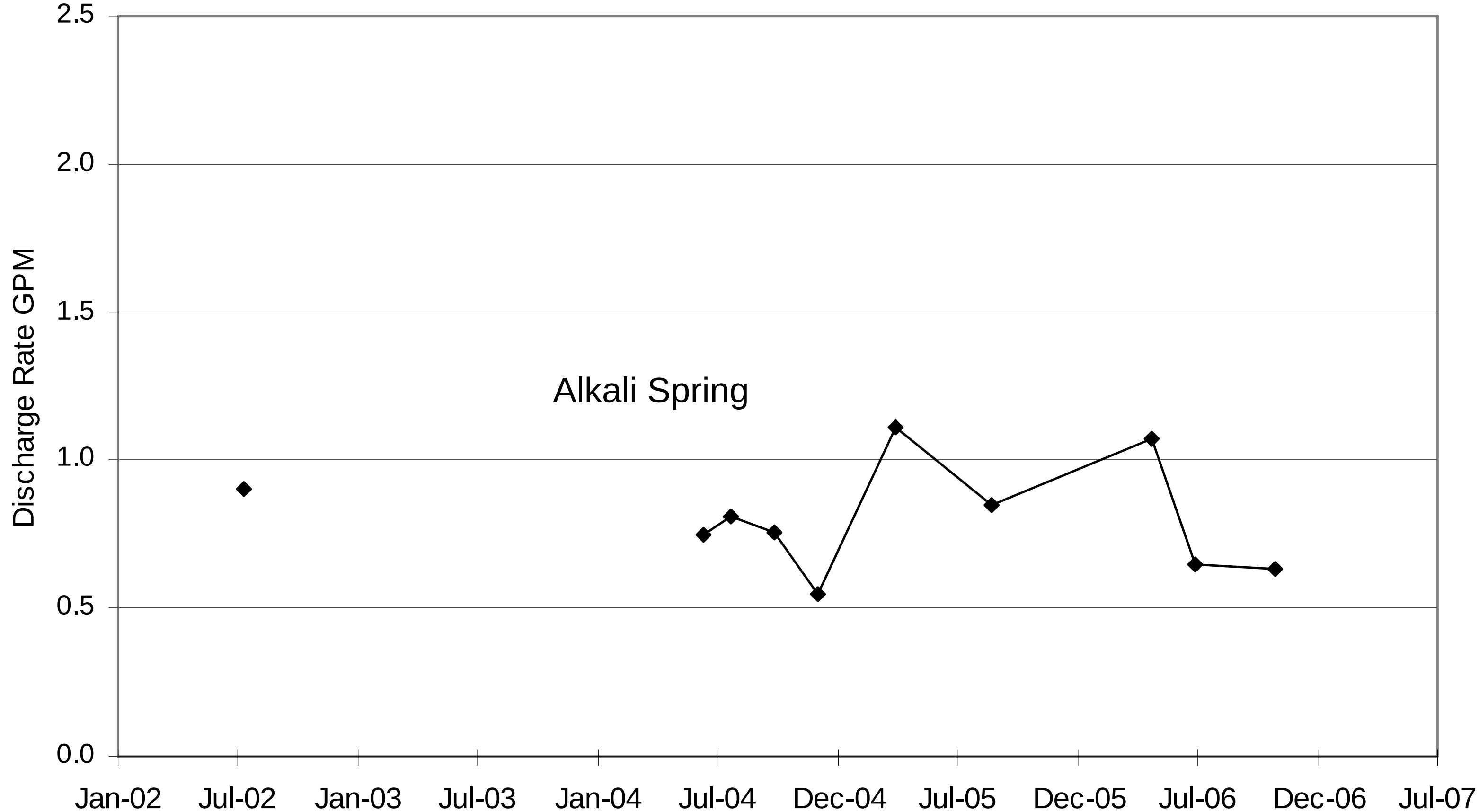


Figure 13. The Alkali Spring (GWIC M:197452) appears to be a combination of local and regional recharge associated with the Cook Coal aquifer. The spring discharges at about 0.8 gpm.

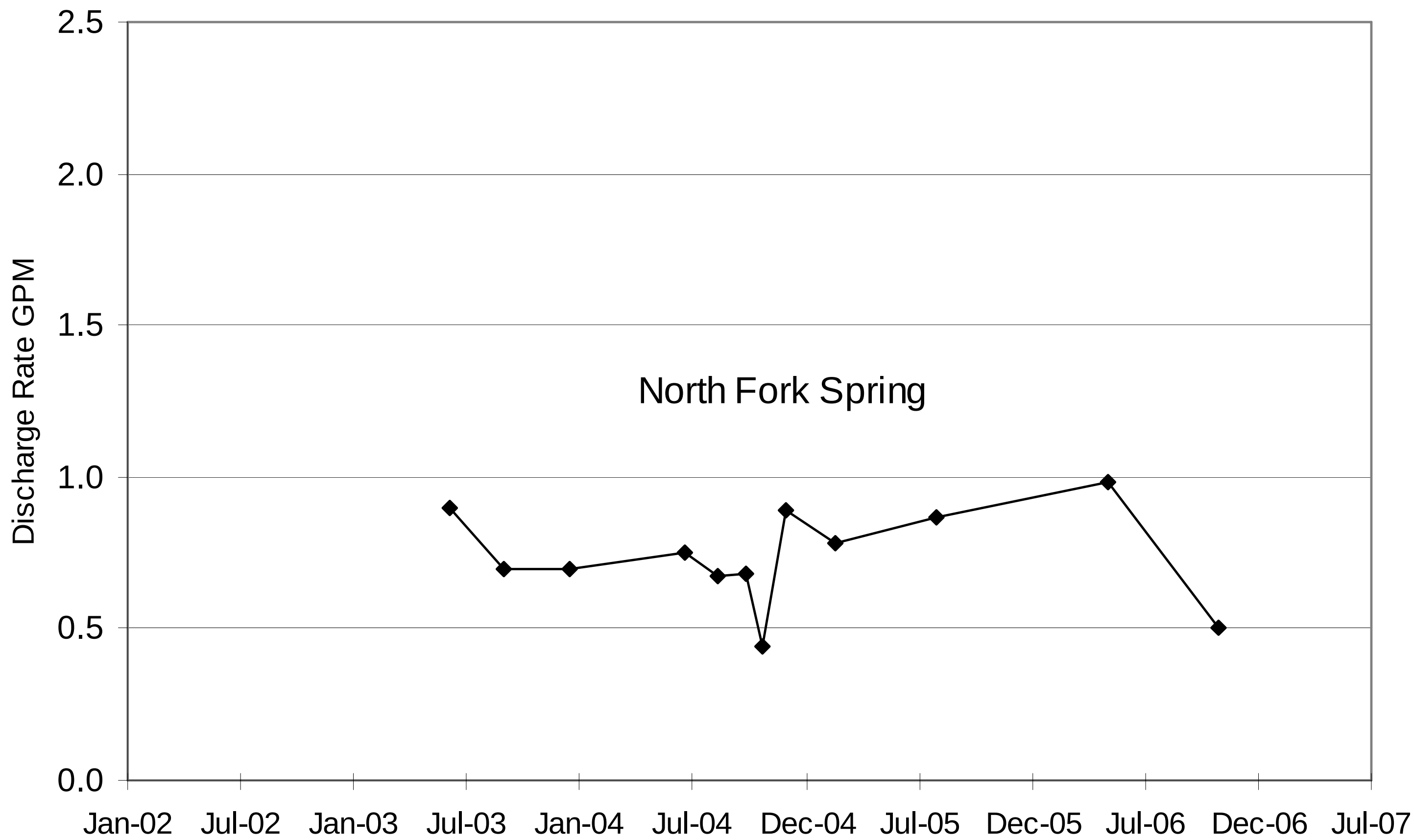


Figure 14. The North Fork spring (GWIC M: 205010) appears to be locally recharged by the Canyon Coal aquifer. The spring discharges less than 1 gpm.

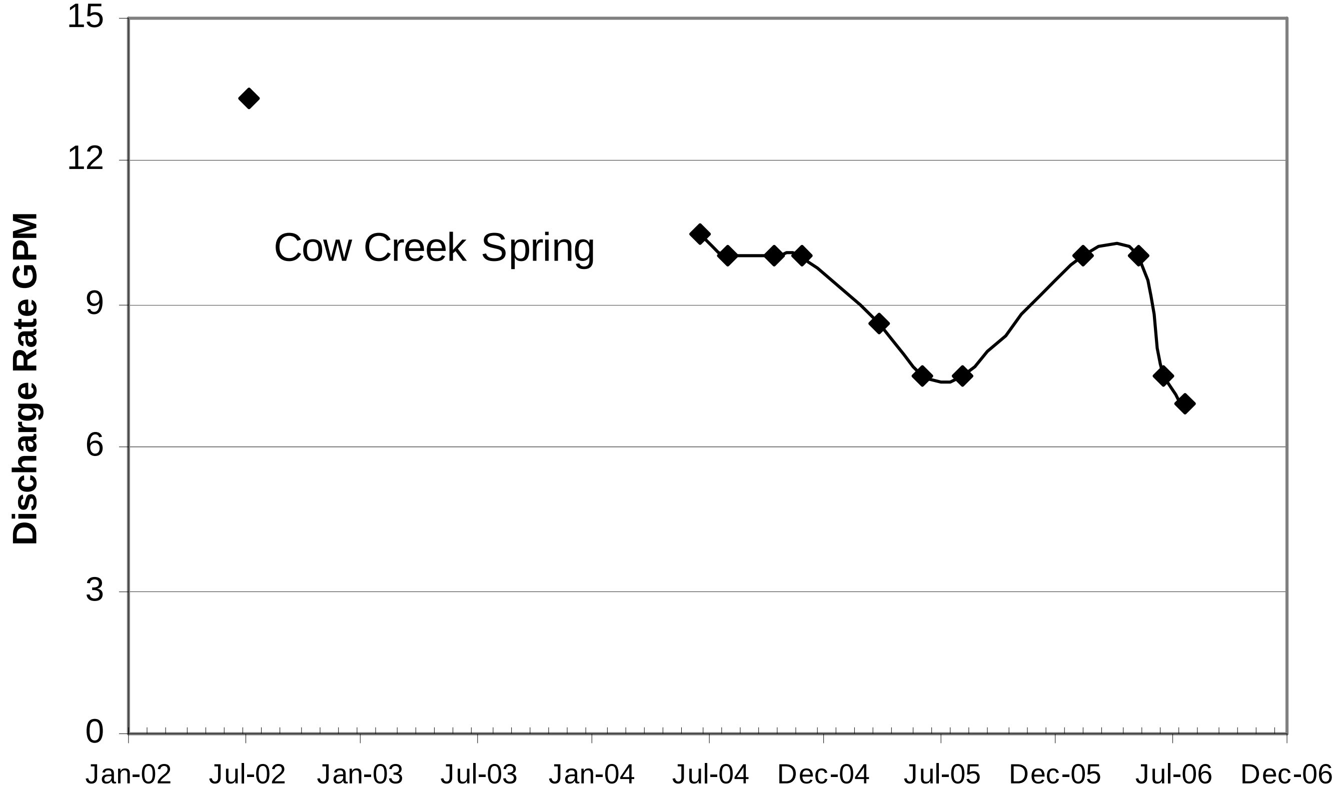


Figure 15. Cow Creek spring (GWIC M:7909) appears to be locally recharged by the clinker ridge above the spring. The spring discharges about 9 gpm. MBMG no longer monitors this site.

clinker of the Anderson coal which is recharged locally on the ridge above the spring. Monitoring at this spring was discontinued during summer 2006.

In the lower reaches of the Cow Creek watershed, spring 197395 discharges from a sandstone below the Otter coalbed. Discharge from this spring has been measured as high as 7.5 gpm, and has an average flow of 4 gpm (fig. 16). The sandstone that supports this spring is locally recharged. Discharge from this spring and subcropping aquifers nearby support a short reach of flowing water in Cow Creek.

Lemonade Spring is located east of the town of Ashland along U.S. Highway 212. This spring is associated with the Ferry coalbed, and probably receives local recharge. Discharge at this spring is between 1 and 1.5 gpm, showing moderate seasonal variations (fig. 17).

In the northern part of the Ashland RD, Bidwell Spring discharges from a local ground-water flow system, below the Ferry coalbed. Typical discharge rate for this spring is about 0.5 gpm (fig. 18).

Water-quality samples were collected from five springs and one creek outside areas of coalbed-methane production in 2006 (appendix C). Concentrations of TDS ranged from 321 to 1,860 mg/L with SAR values between 0.8 and 29.9. Three of the springs and the creek are within the Custer National Forest, Ashland RD. The other springs are located on Post Creek near the Tongue River and Moorhead Campground near the Powder River. Water quality at the Moorhead campground spring is dominated by sodium bicarbonate. Water-quality data from the other springs sampled during 2006 are not dominated by specific cations or anions. The data are available in GWIC and are represented by stiff diagrams showing relative major ion concentrations on plate 3.

Ground-water conditions within areas of coalbed-methane production and influence

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. Bureau of Land Management, 2003, p. 4–61) 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 that estimated water-production rate is shown in figure 19. In Montana, the first reported CBM production water was in April 1999 (Montana Board of Oil and Gas Conservation web page, http://www.bogc.dnrc.state.mt.us/). This trend is re-evaluated here based on 92 months (7 years and 8 months) of available production reports. The monthly average water-production rates for all CBM wells in Montana are plotted against normalized months in figure 19. The early production data (normalized months 1 through 4) appear to indicate the affects of infrastructure construction and well development. To establish an estimation of pumping rates, a best fit line was constructed using normalized months 1 through 90. Month five data cannot be considered to be hydrologically equivalent to month zero since

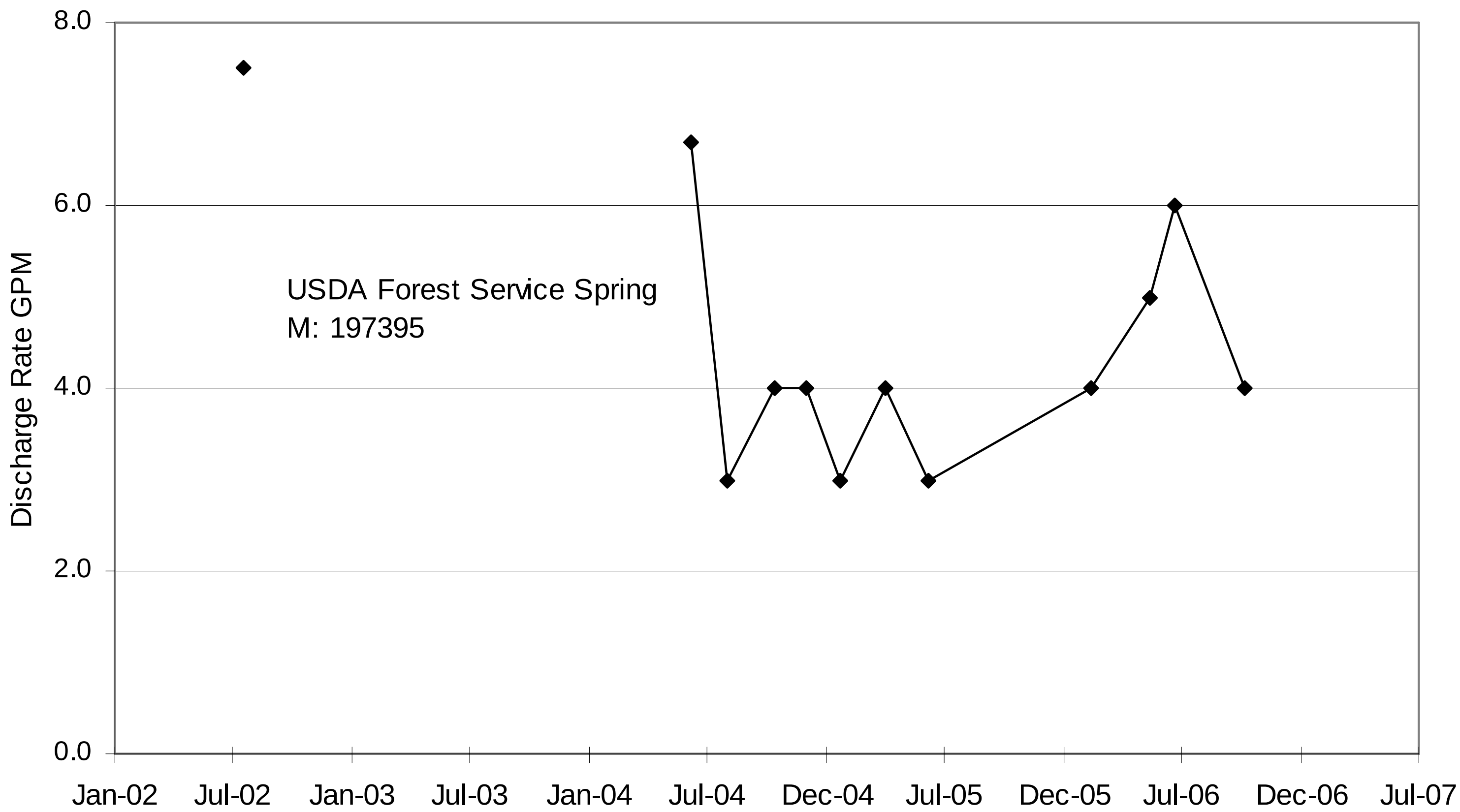


Figure 16. The USDA Forest Service Spring (GWIC M:197395) is locally recharged by the sandstone above the Cook Coal bed. The current discharge rate is around 4 gpm.

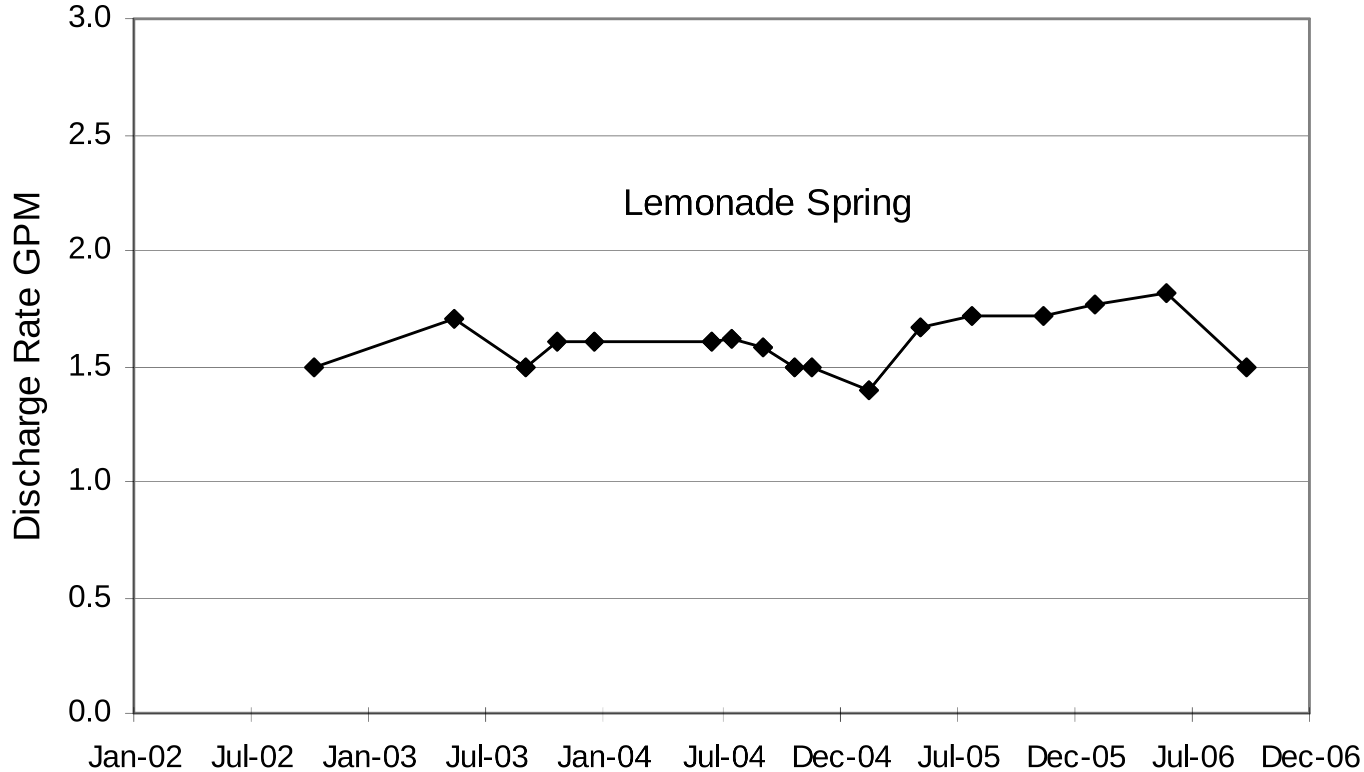


Figure 17. Lemonade Spring (GWIC M:198766) appears to be locally recharged by the Canyon and Ferry coal beds. The spring has a discharge between 1 and 1.5 gpm.

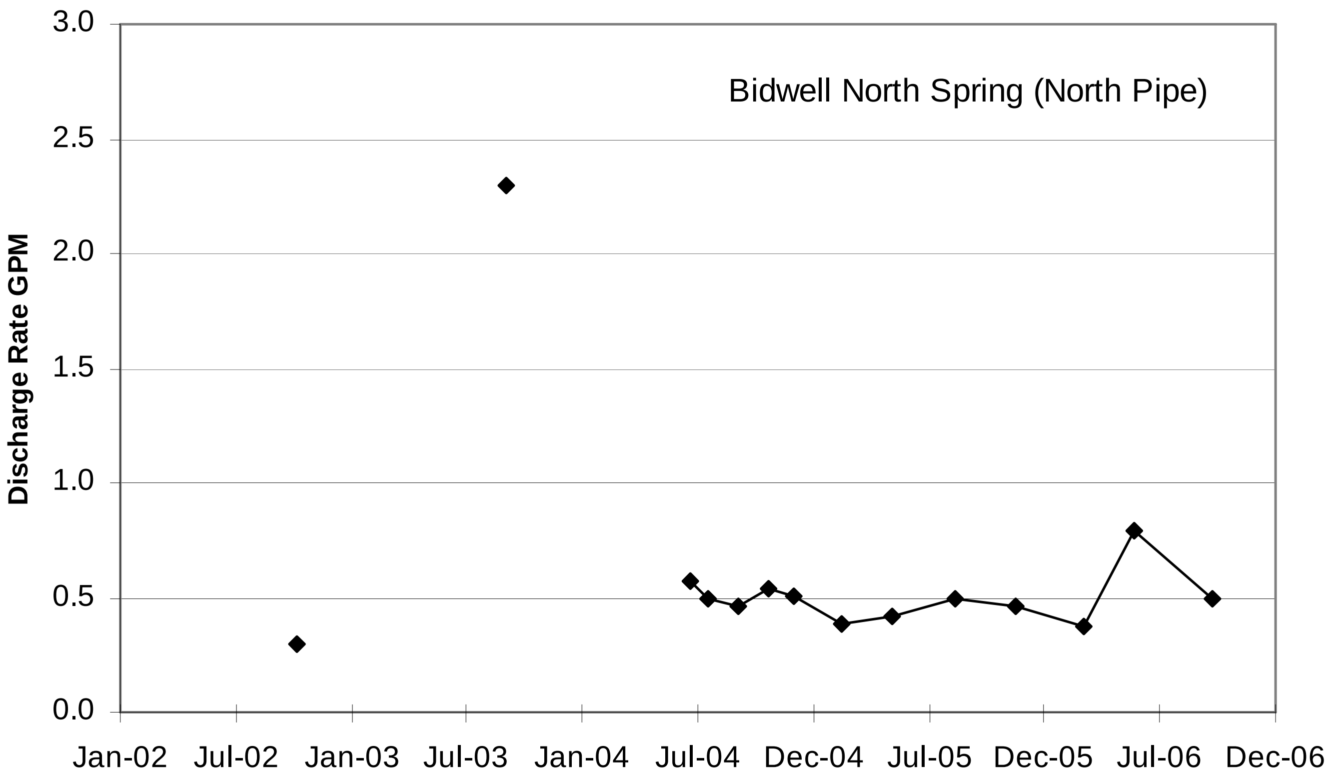


Figure 18. The Bidwell Spring (GWIC as M:198819) appears to be locally recharged by a flow system below the Canyon and Ferry coal beds. The spring discharge rate is about 0.5 gpm. The isolated high discharge in 2003 may represent a precipitation event.

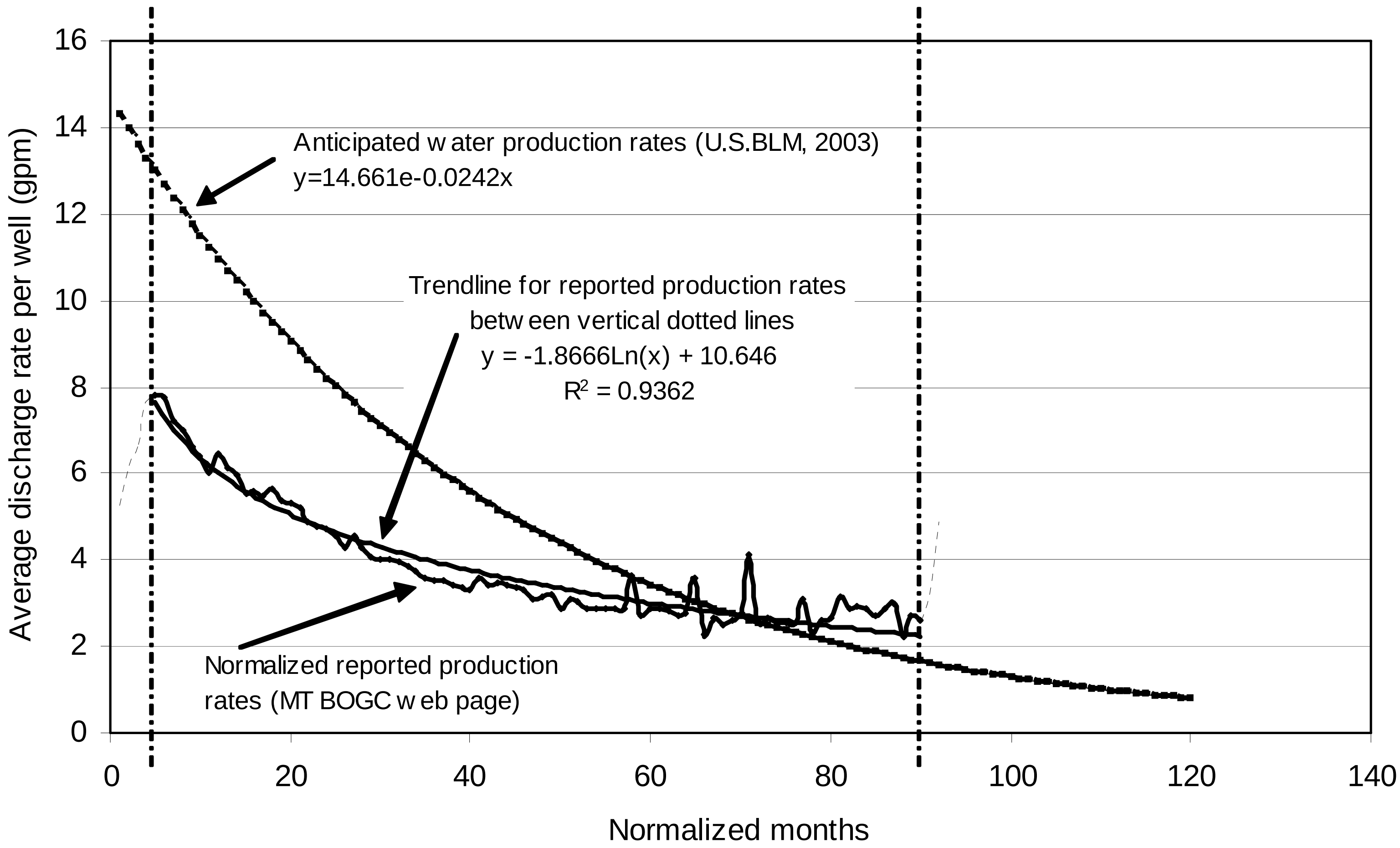


Figure 19. The monthly averages of actual reported water production from CBM wells in Montana have so far been lower than originally anticipated. Over time, the anticipated and observed trends intersect. Data points on the reported production curve that fall outside the vertical, dotted lines are not included in the trend analysis as they do not represent hydrogeologic response to stress.

some pumping had occurred. The average values for normalized months 91 and 92 of the dataset are questionable because the trend does not follow hydrogeologic concepts. A trendline based on normalized months 1 through 90 shows that the amount of water initially produced from each CBM well is less than was expected (fig. 19). The predicted and observed rates become comparable over time. The area between the two trendlines in figure 19 represents the difference in the amount of water that has been produced and the amount that was expected to be produced. This reduced 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. How well this trend will transfer to other areas of the PRB in Montana is not yet known.

Produced-water data for 2006 were retrieved for Montana (MBOGC) and Wyoming (WOGCC) and are summarized in table 3. A total of 828 wells were producing methane and/or water in Montana during 2006. These wells produced a total of 28 million barrels (bbls) of water. The average annual water discharge rates for individual wells in Montana ranged from 2.9 to 21.9 gpm. The overall water-discharge rates for wells in Montana averaged 4.2 gpm. In Wyoming in 2006, 90 million bbls of water were produced from the 2,081 wells in the two townships nearest Montana (57N and 58N). The average annual water discharge rate for individual wells ranged from 2.6 to 7.9 gpm and the overall average discharge rate in Wyoming was 5.9 gpm.

Table 3. Annual summary statistics for all wells in Montana and Wyoming reporting either gas or water production during 2006.

Field	Well count	Annual Total Water Production		Average Annual Water Discharge Rate	
		(bbls)	(acre-feet)	Per well (gpm)	Field total (gpm)
Montana CBM fields					
CX	728	2.5E+07	3165	3.9	1962
Dietz	55	5.5E+05	71	2.9	44
Coal Ck	42	2.9E+06	371	15.4	230
Wildcats	3	3.0E+05	39	21.9	24
Statewide	828	2.8E+07	3646	4.2	2260
Source: MBOGC web page (http://bogc.dnrc.mt.gov/default.asp)					
Wyoming CBM fields in townships 57N and 58N					
Prairie Dog Creek	1483	5.0E+07	6576	2.5	4076
Hanging Woman Creek	189	1.0E+07	1798	7.4	1115
Near Powder River	409	3.0E+07	3736	7.9	2316
Combined	2081	9.0E+07	12110	5.9	7507
Source: WOGCC web page (http://wogcc.state.wy.us/)					

Montana CBM Fields

CX gas field

Methane-water production. Data from CBM production wells in the CX field (plate 1) were retrieved from the Montana Board of Oil and Gas Conservation web page (http://www.bogc.dnrc.state.mt.us/). Wells classified as producing on the MBOGC web page cover an area of approximately 50 square miles. Roughly one-half of the area is west of the Tongue River and one-half is east of the river. During 2006, a total of 728 CBM wells produced either water, gas, or both in the CX field. Production is from the Anderson, Dietz, Canyon, Carney, Wall, King, and Flowers-Goodale coalbeds (fig. 2). The average water production rate for all wells over the entire year was 3.9 gpm. The highest water production rate for a single well over a 1-month reporting period was 41.2 gpm. Total monthly water production rates were least in February at 1,682 gpm, and highest in November at 2,523 gpm. The total water production for the year was 2.59×10^7 bbls or 1.48×10^8 ft^3. Along the western edge of the Fidelity project area near the Montana–Wyoming state line some wells are no longer being pumped and others are being pumped at a reduced rate as the methane-production rates in this area have declined.

Bedrock aquifer water levels and quality. Water-level trends in aquifers that are susceptible to CBM impacts in and adjacent to the CX field are presented in figures 20 through 27. Ground-water levels in this area respond to a combination of precipitation patterns, coal mining, and CBM production. Both coal mining and CBM production have created large areas of lowered ground-water levels in the coal seams.

The potentiometric surface for the Dietz coal is shown in plate 2. Drawdown within the Dietz coal that is interpreted to be specific to CBM production is shown in plate 4 and generally reflects the responses that are occurring in other coalbeds. Producing CBM wells located in the eastern part of the CX field are generally not near MBMG monitoring wells completed in the Dietz coal, and drawdown in that area is not measured as part of this study. 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 ft 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. Within the regional monitoring program area, more monitoring wells are completed in the Dietz than in other coal seams. Therefore, the best dataset to develop a drawdown map is from the Dietz coal. Drawdown was expected to reach 20 ft 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. Bureau of Land Management, 2003, p. 4–62). Current measured drawdown is similar to, but somewhat less than, expected. These monitoring data support the conclusions reached in the evaluations of impacts in the statewide CBM EIS (U.S. Bureau of Land Management, 2003).

Hydrostatic pressure in the combined Anderson and Dietz coal in well WR-34 near the Ash Creek mine declined about 21 ft between 1977 and 1979 due to mine dewatering. 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 baseline conditions in

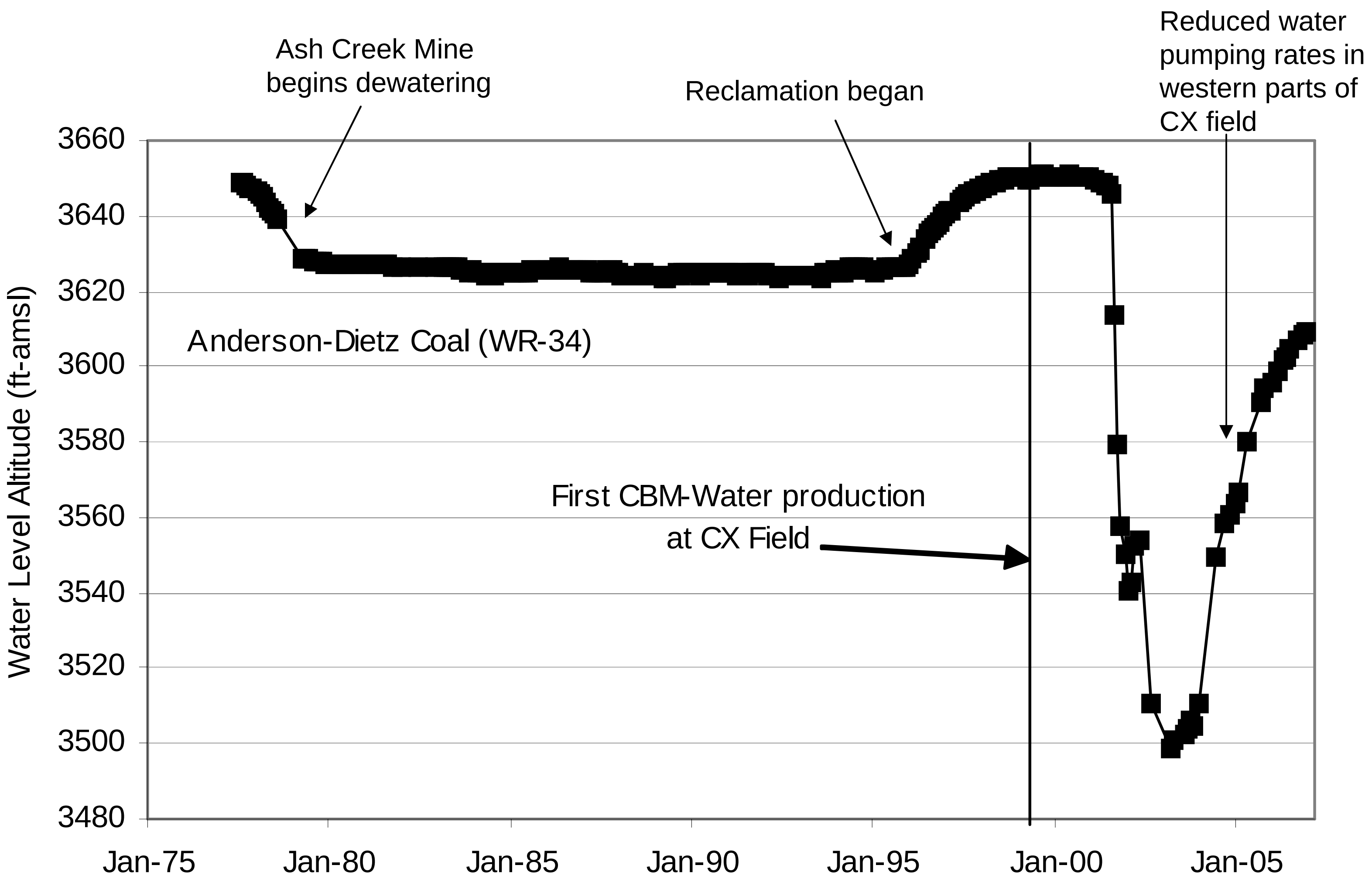


Figure 20. Water levels in the combined Anderson and Dietz coal (WR-34) in the Squirrel Creek area respond to both coal mining and coalbed methane production. The water level recovered starting in 2004 in response to water production decreases in this portion of the CX field.

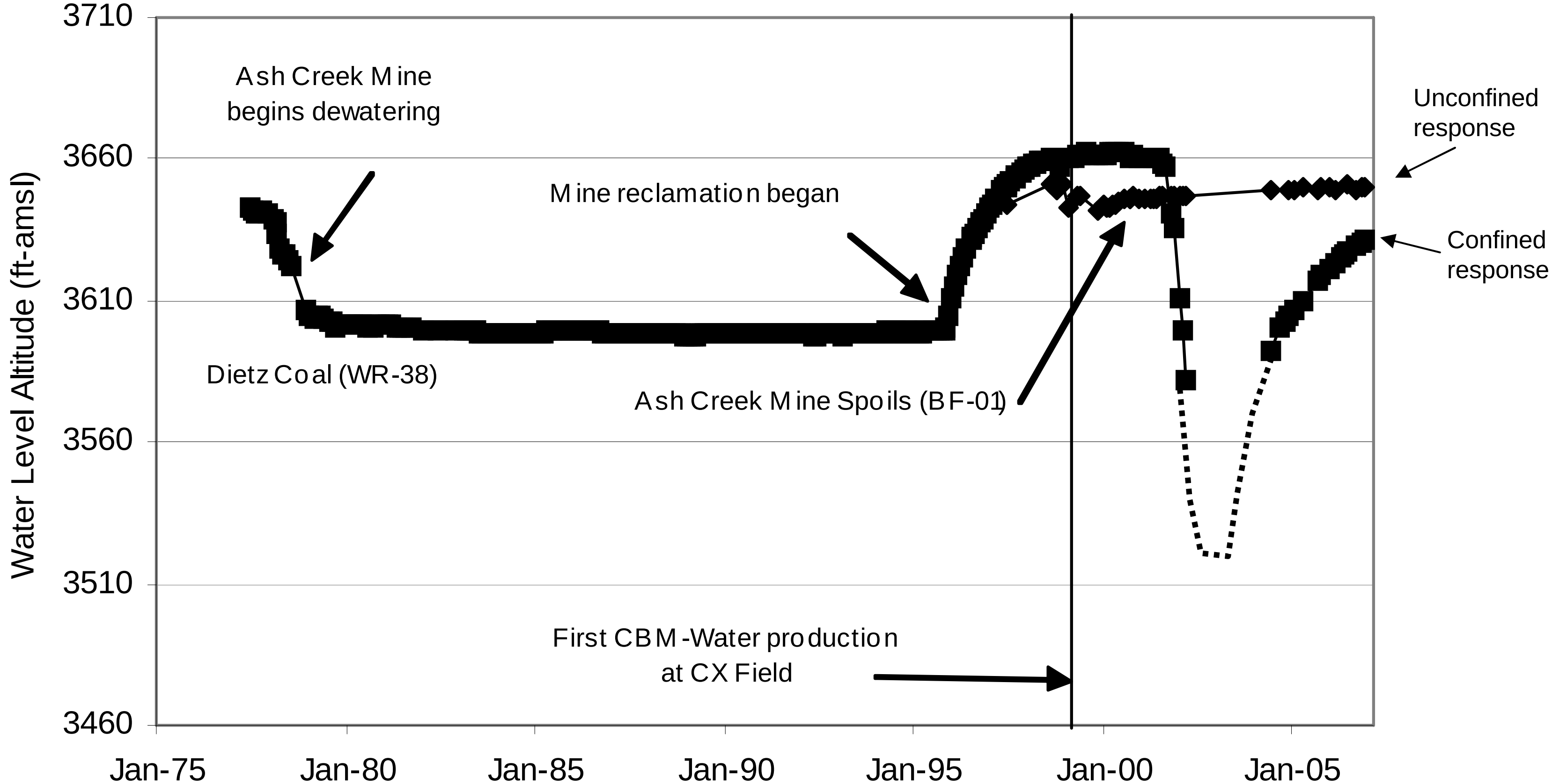


Figure 21. The mine spoils well is being dewatered for CBM production but the water levels show no response to the lowered water levels. However, water levels have decreased by 80 feet in the Dietz Coal in response to the CBM production.

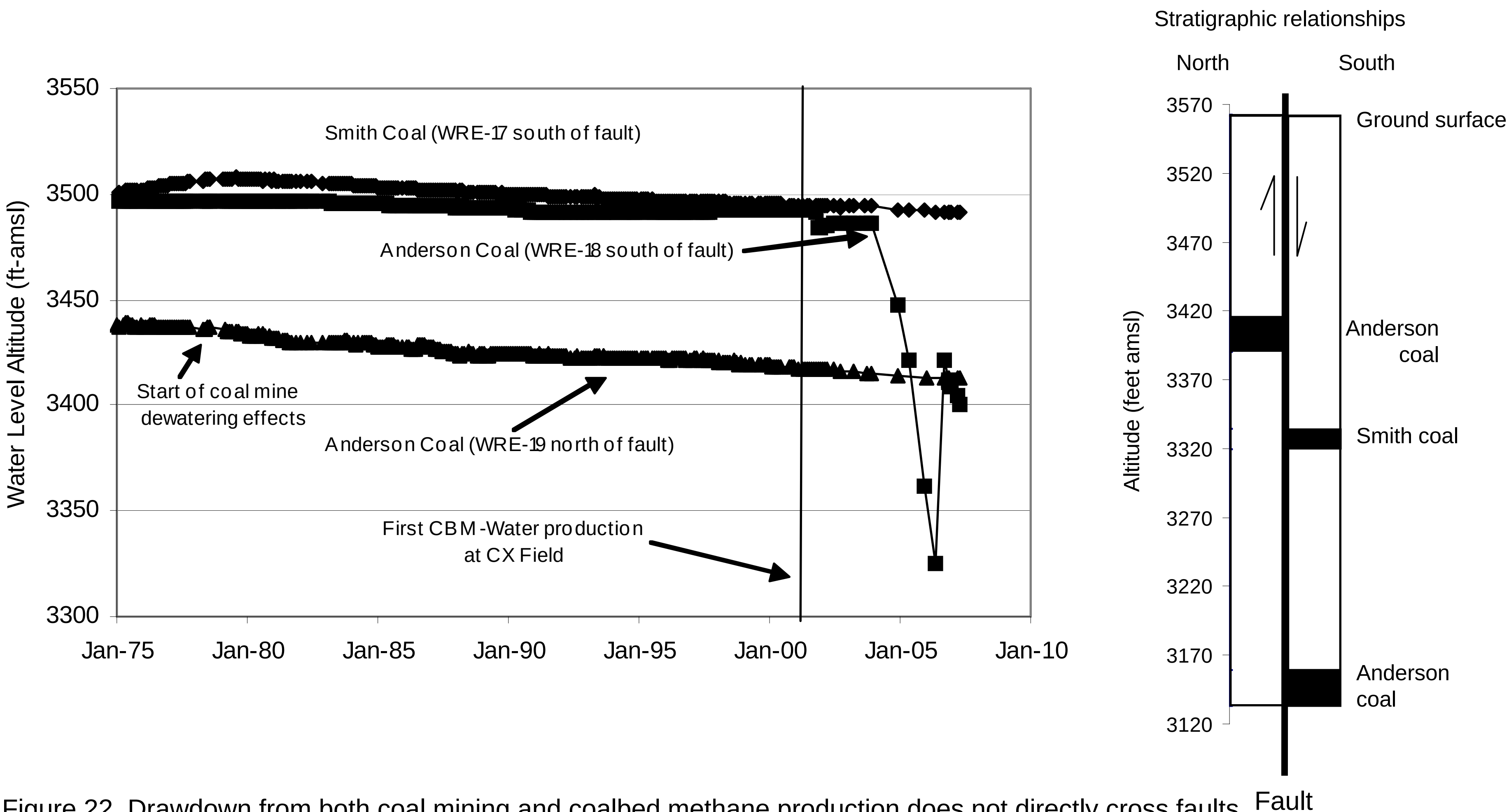


Figure 22. Drawdown from both coal mining and coalbed methane production does not directly cross faults in the project area. Mining has occurred north of this fault since the early 1970's and only minor drawdown has been measured at WRE-18 since the mid-1980's. The pressure reduction has probably migrated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

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

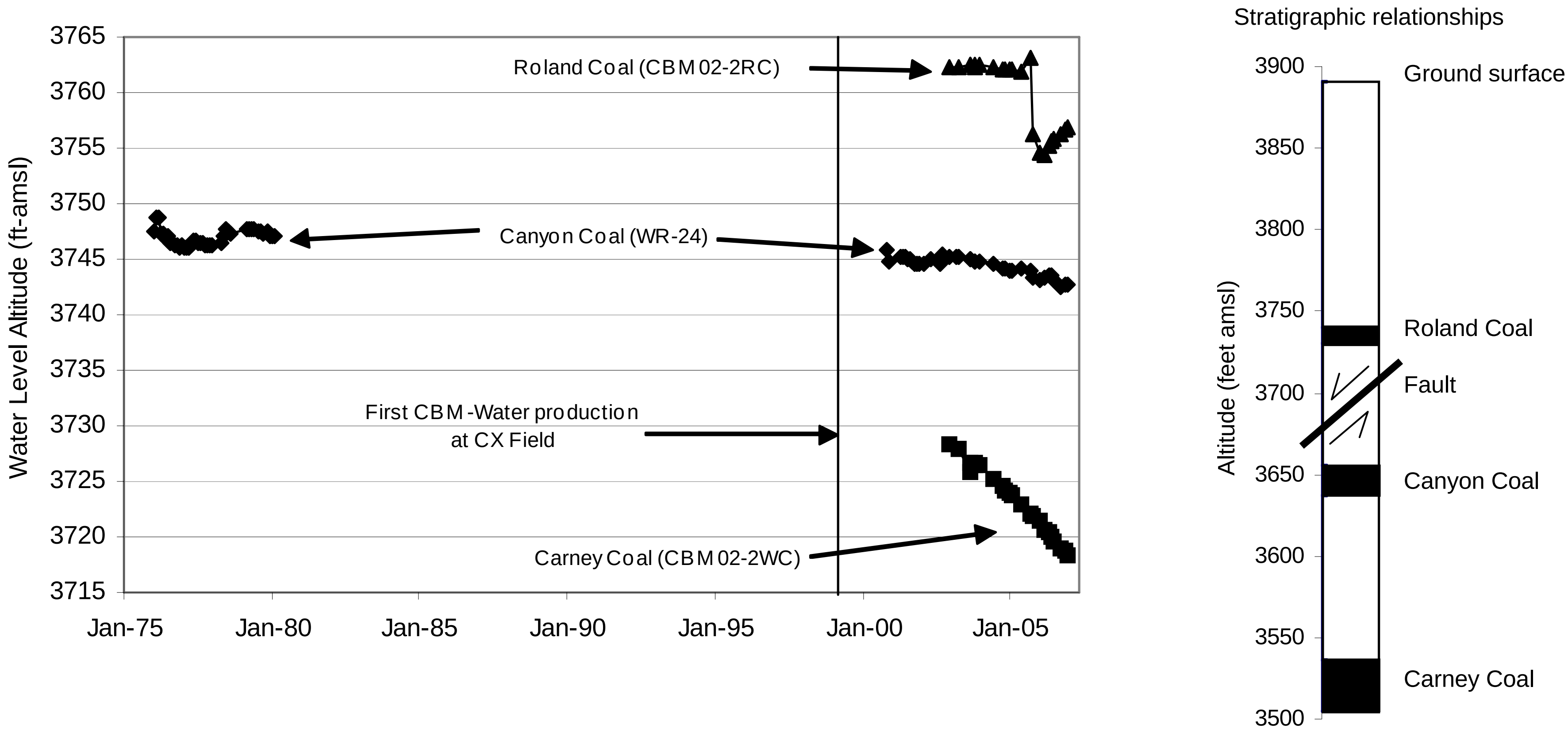


Figure 23. The long-term decrease in water levels in the Canyon Coal is probably related to precipitation patterns. The short period of record for the Carney coal at the CBM02-02 site does not indicate meteorological influence but has responded to CBM related drawdown since its installation. The Roland Coal has not been developed for CBM production and the water-level decline is not likely a response to CBM activities.

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

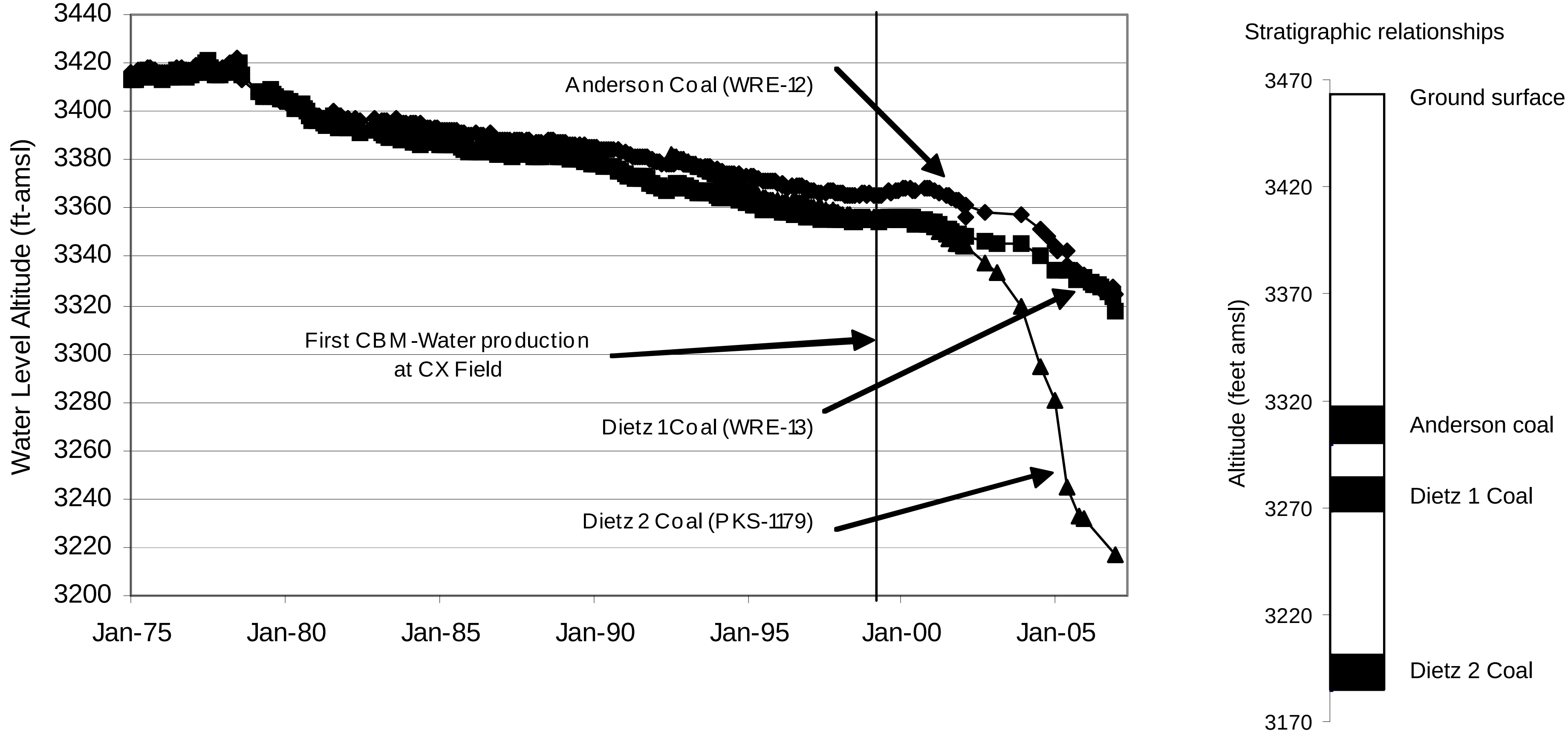


Figure 24. In some locations, the water level response to CBM production in deeper coal seams (PKS-1179) is far greater than in shallower coal seams (WRE-12 and WRE-13). This trend has been noted in coal mining areas also.

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

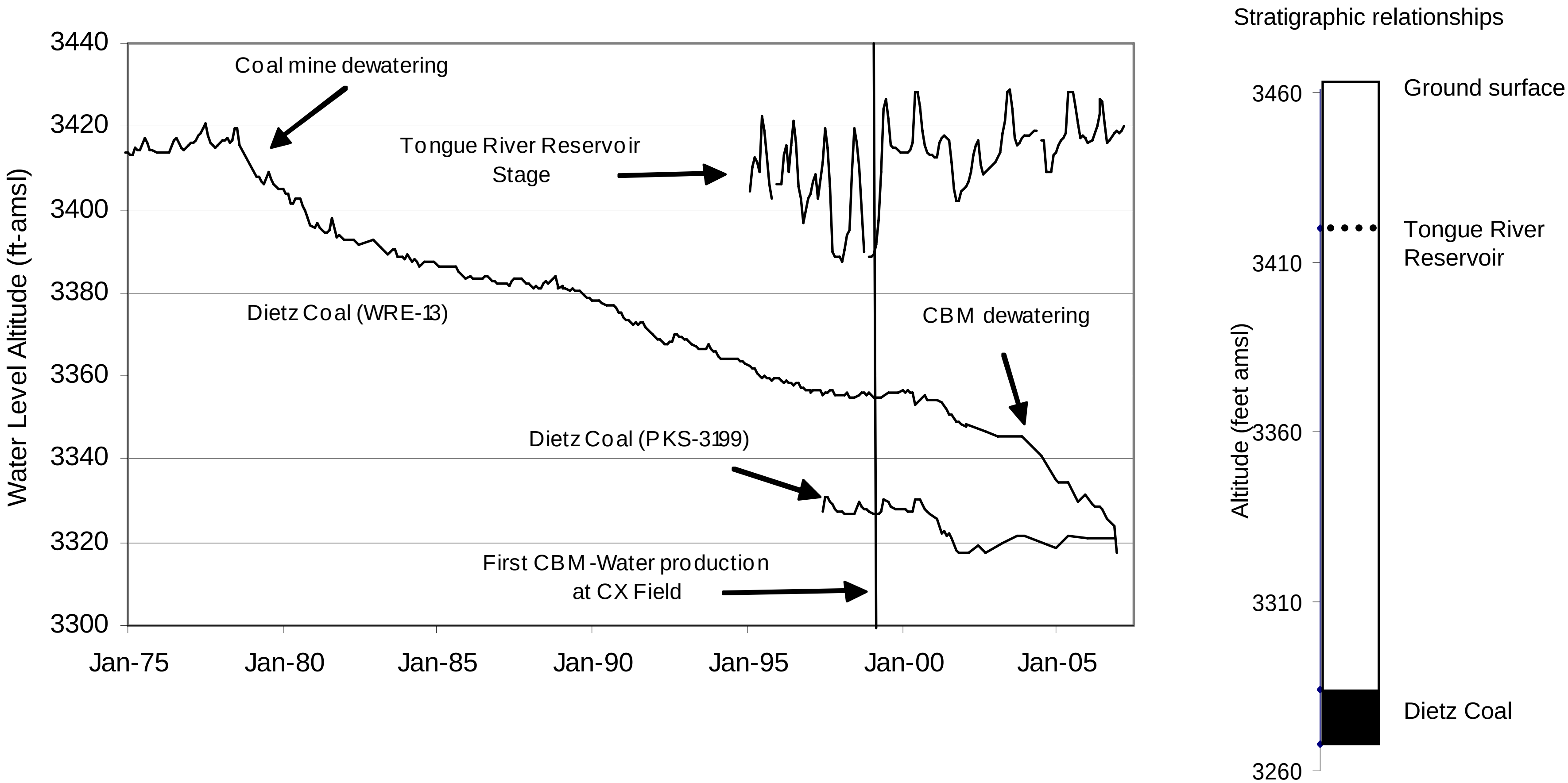


Figure 25. Annual fluctuations of stage level in the Tongue River Reservoir are reflected in water levels in the Dietz coal (WRE-13 and PKS-3199); however, coal mine and CBM influences dominate when present.

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

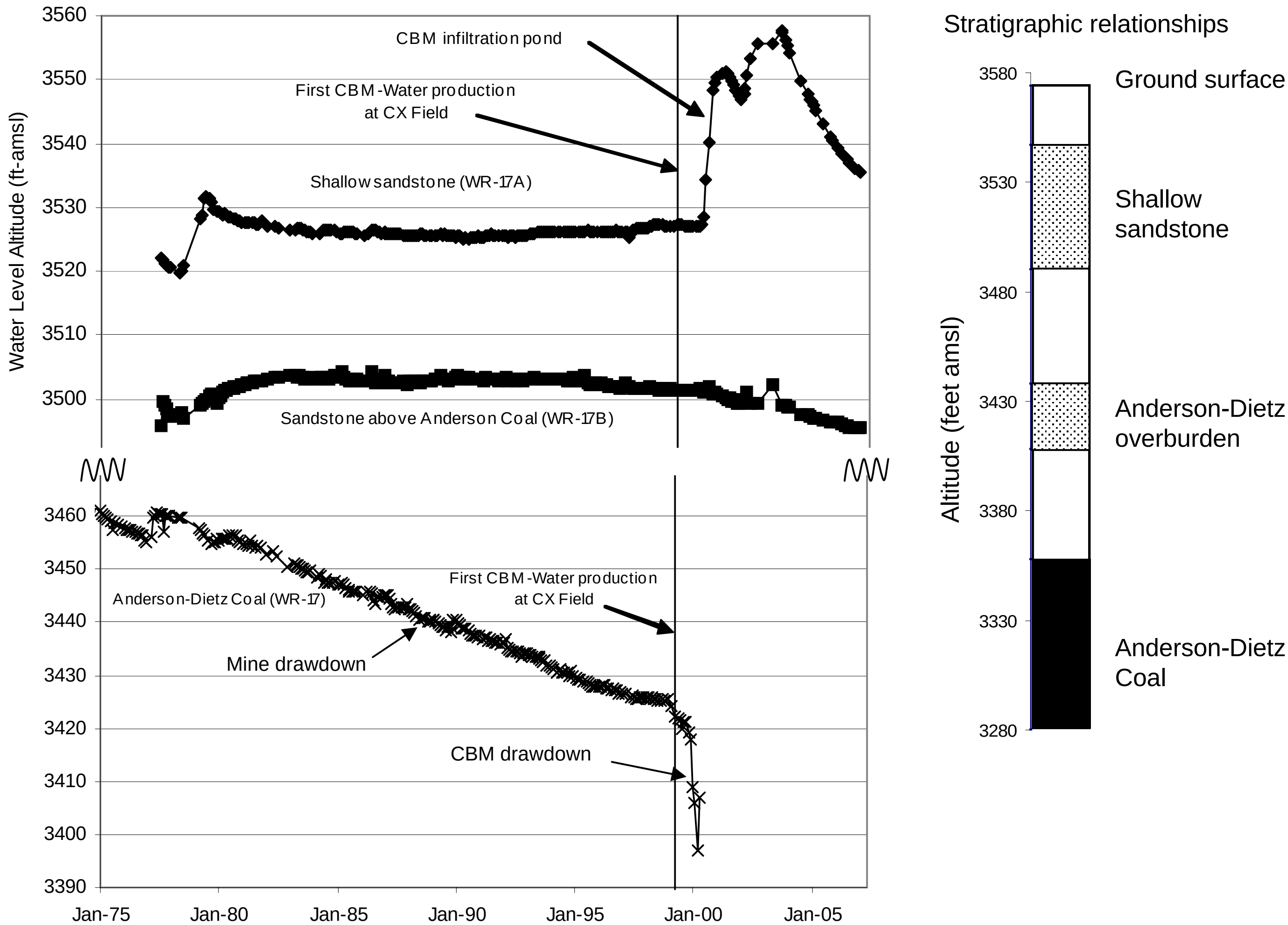


Figure 26. Long-term water-level trends in the Anderson overburden(WR-17A and WR-17B) in the Squirrel Creek area, may relate to precipitation patterns. These wells demonstrate the rise in water table in 1999 at WR-17A is believed to be in response to infiltration of water from a CBM holding pond. The water level in this aquifer is now dropping as the pond no longer receives water.

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

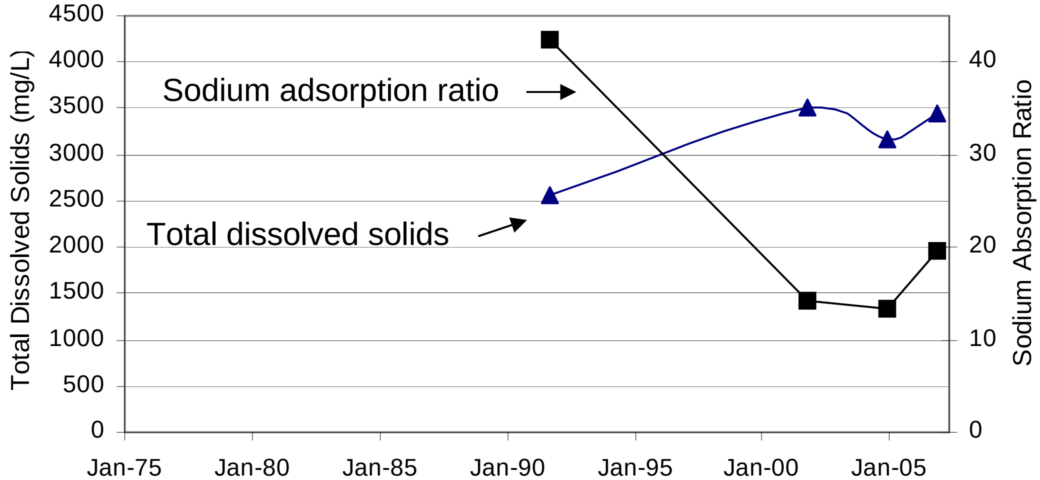


Figure 27. Water quality samples have been collected periodically from WR-17A. As the water level increased (see figure 26) the TDS also increased. At the same time the SAR is decreased due to the dissolution of calcium and magnesium salts.

1998 (fig. 20). Between 2001 and 2003 ground-water levels at this site were lowered to about 150 ft 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 2003, the water levels have recovered to within 41 ft of baseline conditions. This represents 73% recovery during a 4-year period. This recovery appears to be due to a reduction in the pumping rates and number of producing CBM wells in this area.

Ground-water level responses due to the Ash Creek mine pit dewatering are also evident at well WR-38 (fig. 21). The water level in this well dropped about 80 ft 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 29 ft of baseline conditions, or a water-level recovery of about 63%. 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 has not responded to lowered water levels in the coal due to CBM production. The spoils aquifer is probably unconfined and the lack of a measurable response is not surprising.

Monitoring wells installed to evaluate the concept that faults in the Fort Union Formation are typically no-flow boundaries (Van Voast and Hedges, 1975; Van Voast and Reiten, 1988) show that dewatering of the mine pit, which is less than 1 mile from the fault, has lowered water levels in the Anderson coal and overburden aquifers for over 25 years on the north side of the fault. Monitoring data (fig. 22) indicate mine-pit-related drawdown in the Anderson coal (WRE-19) north of the fault but not in the Smith (WRE-17) and Anderson (WRE-18) coal seams south of the fault. Methane production south of the fault shows the inverse response as water levels in the Anderson coal (WRE-18) south of the fault have been lowered about 159 ft since 2001, then for a 4-month period in 2006 the water level began to rise then began to lower again. The water levels at WRE-19 north of the fault have not responded to CBM production, indicating that the fault acts as a barrier to flow within the Anderson coalbed.

Near the western edge of the CX field, but across a fault from active CBM wells, water levels in the Carney coal (CBM02-2WC) have been responding to CBM-related drawdown since the well was installed in 2003. Water levels in this well are now 58 ft lower than the first measurement (fig. 23). It appears that the drawdown observed at this site results from migration of drawdown around the edges of a scissor fault. 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 Roland coal (CBM02-2RC) is stratigraphically higher than the CBM production zones, and during 2005 the water level at this well dropped about 8 ft, but during 2006 the water level has been rising. The cause of the water-level changes in the Roland coal is not apparent. CBM production is unlikely to have had any effect on this unit, and the type of response is much different than that measured in the other coal aquifers at this site.

Near the East Decker mine, water levels have responded to coal mining in the Anderson, Dietz, and Dietz 2 coals (fig. 24). Drawdown has increased, particularly in the Dietz 2 coal, in response to CBM production in the area. This site provides an example of the increased drawdown in deeper coal aquifers that has been noted in coal mine research (Van Voast and Reiten, 1988). Note the far greater magnitude of drawdown in the Dietz 2 coal than in the other coal seams at this site.

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 are more strongly influenced by mining and CBM production (fig. 25). Average reservoir stage is about 3,420 ft, which indicates, when compared to the Dietz potentiometric surface, that some water has always seeped from the Tongue River Reservoir to the coal seam. The rate of seepage is likely increasing due to the increasing gradient between the reservoir and the Dietz potentiometric surface. However, the amount of the increased seepage related to CBM production is limited by faulting (plate 2).

Water levels in Anderson overburden in the Squirrel Creek watershed (fig. 26) show possible correlation with precipitation patterns and no drawdown due to either coal mining or CBM production. The water level in the Anderson coal at this site (WR-17) was lowered 37 ft by coal mine dewatering and about 30 ft by CBM production. Water levels are no longer collected from this Anderson coal well because of the volume of methane that is released when the well is opened. The deeper overburden aquifer (WR-17B) is separated from the Anderson coal by over 50 ft of shale, siltstone, and coal. Water levels at this well show no vertical movement of water or water pressure in response to mine dewatering (which began in 1972) and CBM water production (which began in 1999). The water-level trend of this deeper sandstone aquifer appears to relate to the local drought conditions. The shallow, water-table aquifer (WR-17A) shows a rapid rise following the start of CBM production. This rise, totaling about 30 ft, is interpreted to be a response to infiltration of CBM production water from an adjacent holding pond. This pond is no longer used to hold CBM production water, and the shallow water table has returned to within 8.5 ft above baseline. The deeper overburden aquifer (WR-17B) at this site shows no response to the holding pond.

Water-quality samples have been collected periodically from WR-17A (fig. 27). The TDS concentration has increased from 2,567 mg/L to 3,441 mg/L and the SAR has decreased from 42.5 to 19.6. The TDS increase and SAR decrease is interpreted to be in response to water infiltrating from the CBM pond, through the underlying material and entering the aquifer. The introduction of these salts did not change the class of use for this aquifer (Class III). In 2006 the TDS concentration was 3,434 mg/L with a SAR value of 19.6. Water quality under this pond is expected to return to baseline values as available salts are flushed from the flow path (Wheaton and others, in press). The length of time needed for flushing to be completed is not yet known.

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 (fig. 28). Since 1999 the overall trend for alluvial water levels at WR-58 has been to decline slightly in response to drought conditions. Farther downstream, in the CBM production area (WR-52D), the overall water level trend in the alluvium was stable until 2000 when it increased. The water-level trend at WR-52D now appears to be decreasing to approximate baseline 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.

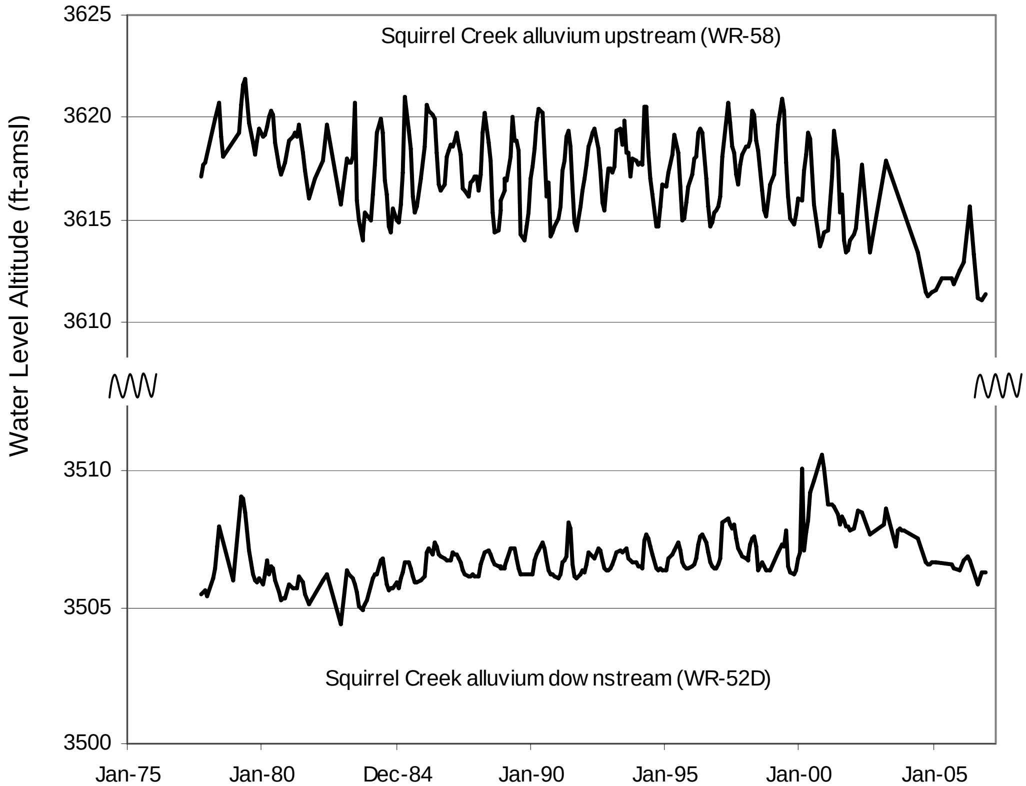


Figure 28. In addition to normal annual cycles, long-term precipitation trends affect water-table levels in the Squirrel Creek alluvium. Upstream of CBM production Squirrel Creek alluvium is not influenced by CBM production (WR-58), but adjacent to CBM production the water level rise since 1999 and fall during 2004 likely relates to infiltration ponds located in between these sites (WR-52D).

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

A water-quality sample was collected from the Squirrel Creek alluvium (WR-59) in August 2006 (appendix C). The TDS concentration was 5,618 mg/L and the SAR value was 5.6. There is little difference between these data and data from a previous sample collected in 1993 (GWIC). The water quality reflects Squirrel Creek alluvium, which is dominated by sodium, magnesium, and sulfate.

Coal Creek and Dietz gas fields

Methane water production. 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 (http://www.bogc.dnrc.state.mt.us/). 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 2006, a total of 42 CBM wells produced water in the Coal Creek field. Production was from the Wall and Flowers-Goodale coalbeds (fig. 2). The average water production rate for all wells over the 12-month production period was 15.4 gpm (table 3). The highest water production rate for a single well over a 1-month reporting period was 42.7 gpm. Average total field production rates were least in April at 165 gpm and highest in November at 352 gpm. Total monthly water production was least in April at 7.1×10^6 gallons and reached the maximum in November at 1.5×10^7 gallons. The total water production for the 12-month period was 1.2×10^8 gallons, or 368 acre ft.

A total of 55 CBM wells produced water in the Dietz field during 2006. Production is from the Dietz, Canyon, Cook, and Wall coalbeds (fig. 2). The average water production rate for all wells over the 12-month production was 2.9 gpm. The highest water production rate for a single well over 1-month reporting period was 23 gpm. Average total field production rates were least in May at 2.8 gpm and highest in November at 156 gpm. Total monthly water production was least in May at 8.5×10^4 gallons and reached the maximum in November at 6.7×10^6 gallons. The total water production for the 12-month period was 2.3×10^7gallons, or 71 acre ft.

Bedrock aquifer water levels. Two miles west of the Tongue River and about 4 miles north of the Tongue River Dam, at site CBM02-4 (plate 1), the water level in the Wall coal has been lowered about 11 ft since April 2005 in response to water production in the Coal Creek and Dietz (fig. 29). The nearest CBM well is about 2.5 miles from site CBM02-4. Water levels in the sandstone overburden wells show no response at this site (fig. 29).

Monitoring well site CBM02-7 is located about 6 miles northwest of the Coal Creek field (plate 1). No response has been measured in either the overburden sandstone or Canyon coal at this site (fig. 30).

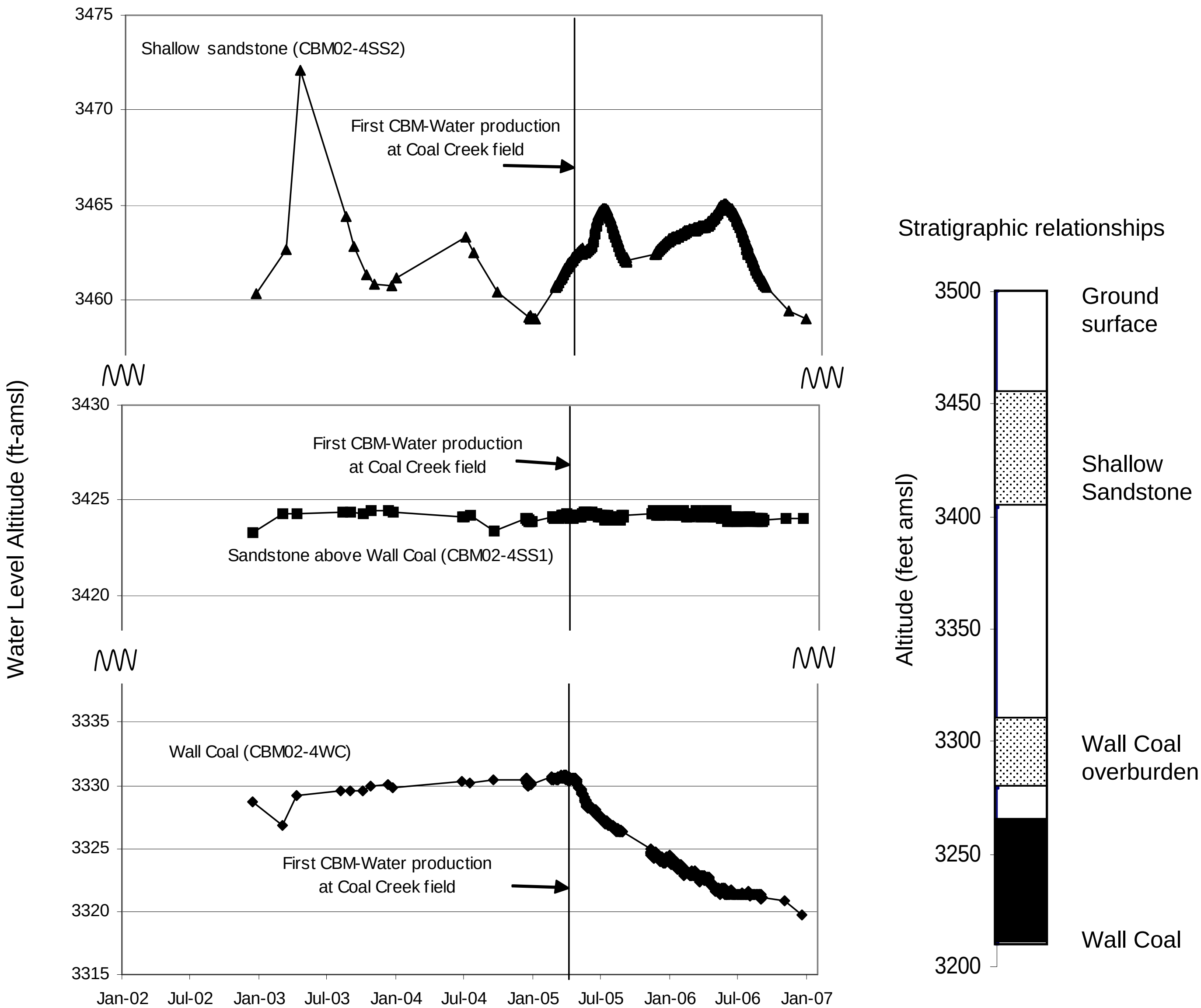


Figure 29. A downward hydraulic gradient is evident between the shallow sandstone, Wall overburden sandstone, and Wall coal at the CBM02-4 site. Water-level trends in the Wall coal and overburden are probably not related to meteorological patterns while those in the shallower sandstone may be. The water level in the Wall Coal aquifer has decreased 11ft in response to CBM development.

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

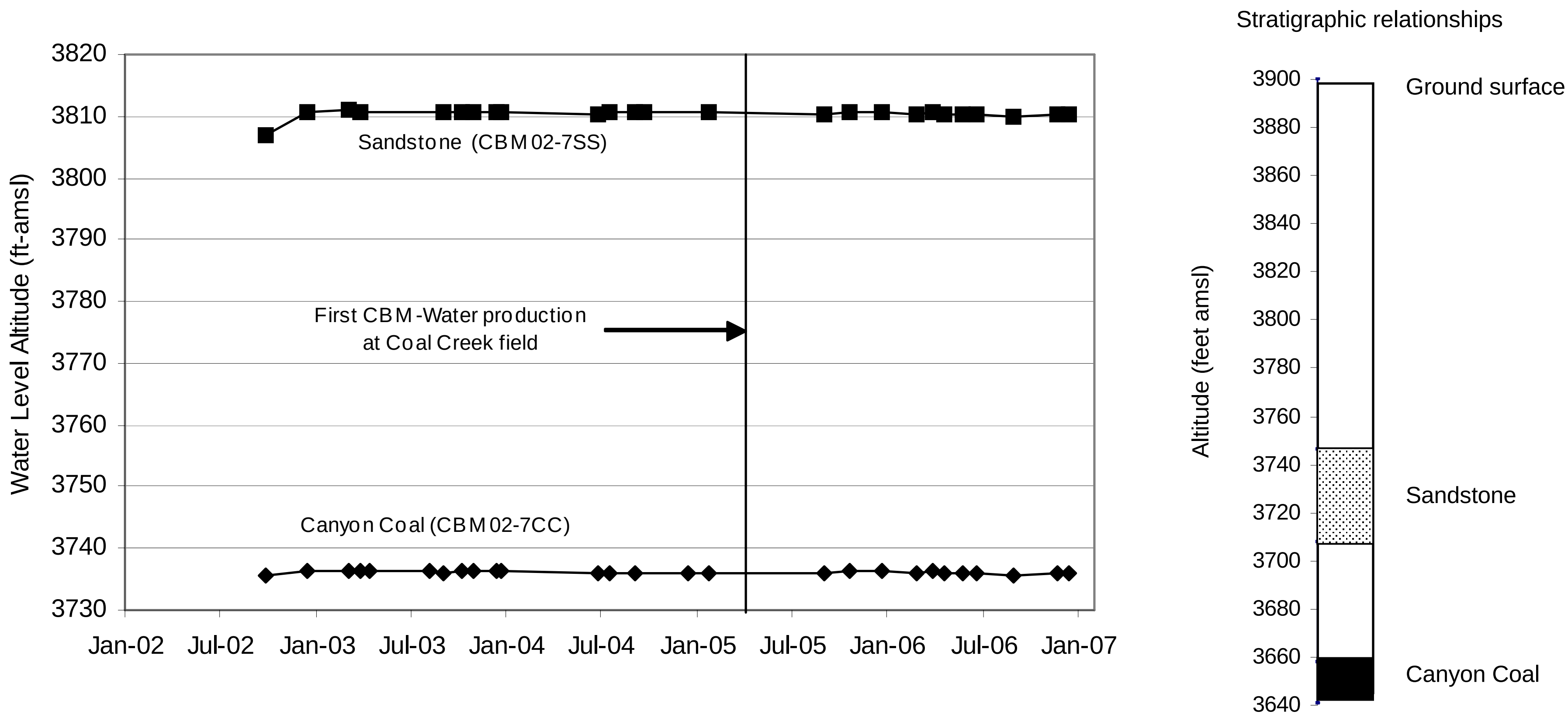


Figure 30. The CBM02-7 site is located about 6 miles west of the Coal Creek CBM field. The water levels for the overburden sandstone and Canyon Coal show no response to CBM pumping in the Coal Creek field.

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

Alluvial aquifer water quality. A domestic well was sampled north of the Tongue River reservoir (M:228592; Musgrave Bill) in August 2006 (appendix C). The TDS concentration was 747 mg/L and the SAR value was 1.3. The water quality is dominated by calcium and bicarbonate. The dominant ions in the water-quality samples do not indicate an influence from CBM production. The data are available on GWIC and are represented by stiff diagrams showing relative major ion concentrations in plate 3.

Wyoming CBM fields near the Montana border

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

Prairie Dog Creek gas field

Methane 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 Roberts coalbeds (fig. 2). During 2006, a total of 1,483 CBM wells produced water. The average water production per well for the 12-month period was 2.5 gpm, and the average producing rate for the field was 4,076 gpm. Cumulative production for the year was 6,576 acre ft.

Aquifer water levels. Water-level drawdown in Montana that results from 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 in this report.

Hanging Woman Creek gas field

Methane water production. During November 2004, Nance Petroleum began pumping water from CBM wells in the Hanging Woman Creek watershed, directly south of the Montana–Wyoming state line (plate 1). Nance is producing CBM from the Roland, Anderson, Dietz, Canyon, Cook, Brewster-Arnold, Knobloch, Roberts, and Kendrick coalbeds (fig. 2). During 2006, a total of 189 CBM wells produced water. The average water production rate per well over the 12-month period was 7.4 gpm. The total water production for the 12-month period was 6.0×10^8 gallons, or 1,798 acre ft at an average cumulative field-discharge rate of 1,115 gpm.

Bedrock aquifer water levels. 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, Smith, and Anderson coalbeds (fig. 31). The water level in the Anderson coal has been lowered about 36 ft at this site in response to CBM production (fig. 32). The water level in the Smith coal has also dropped; however, the cause of this drop is unclear. Vertical migration of changes in hydrostatic pressure does not seem likely given the short time, and additional monitoring may help explain the changes in the Smith coal.

Site SL-3 is located 6 miles west of site SL-4 and about 1 mile north of the nearest Wyoming CBM well. Monitoring wells at SL-3 include the alluvium of North Fork Waddle Creek, an overburden sandstone, and the Smith, Anderson, and Canyon coals (fig. 33). Water levels in the overburden and Smith are not responding to CBM production. The water level in the Anderson coal has dropped about 6 ft, and water level in the Canyon coal has dropped about 87 ft (fig. 34).

Alluvial aquifer water levels and quality. Based on water-level trends and lithology, the Hanging Woman Creek alluvium near the state line appears to be hydrologically isolated from the Anderson and Smith coalbeds (figs. 31 and 35). Changes in water levels in the alluvium reflect water table response to seasonal weather patterns (fig. 35). Alluvial water-level changes at SL-3Q (fig. 36) appear to be in response to seasonal weather patterns and not to CBM production, as no change in overburden water levels has been detected. However, the differences in water-level trends between SL-3Q and HWC86-13 and HWC86-15 have not yet been explained (figs. 35 and 36).

Water-quality samples were collected at HWC86-13 and HWC86-15 during August 2006 (appendix C). The TDS concentrations in the alluvial water range between 6,030 mg/L and 7,731 mg/L and SAR values are 10.0 and 9.7, respectively. The water quality in the alluvium is dominated by sodium and sulfate. There is very little difference between these data and data from samples collected at these wells in 1987 (GWIC). A water-quality sample was also collected on North Fork Waddle Creek at SL-3Q during August 2006 (appendix C). The TDS concentration is 3,152 mg/L with a SAR value of 5.2. The water quality is dominated by sodium sulfate. There appears to be no effect from CBM development in the alluvial aquifer at this site. The data are available on GWIC and are represented by stiff diagrams showing relative major ion concentrations in plate 3.

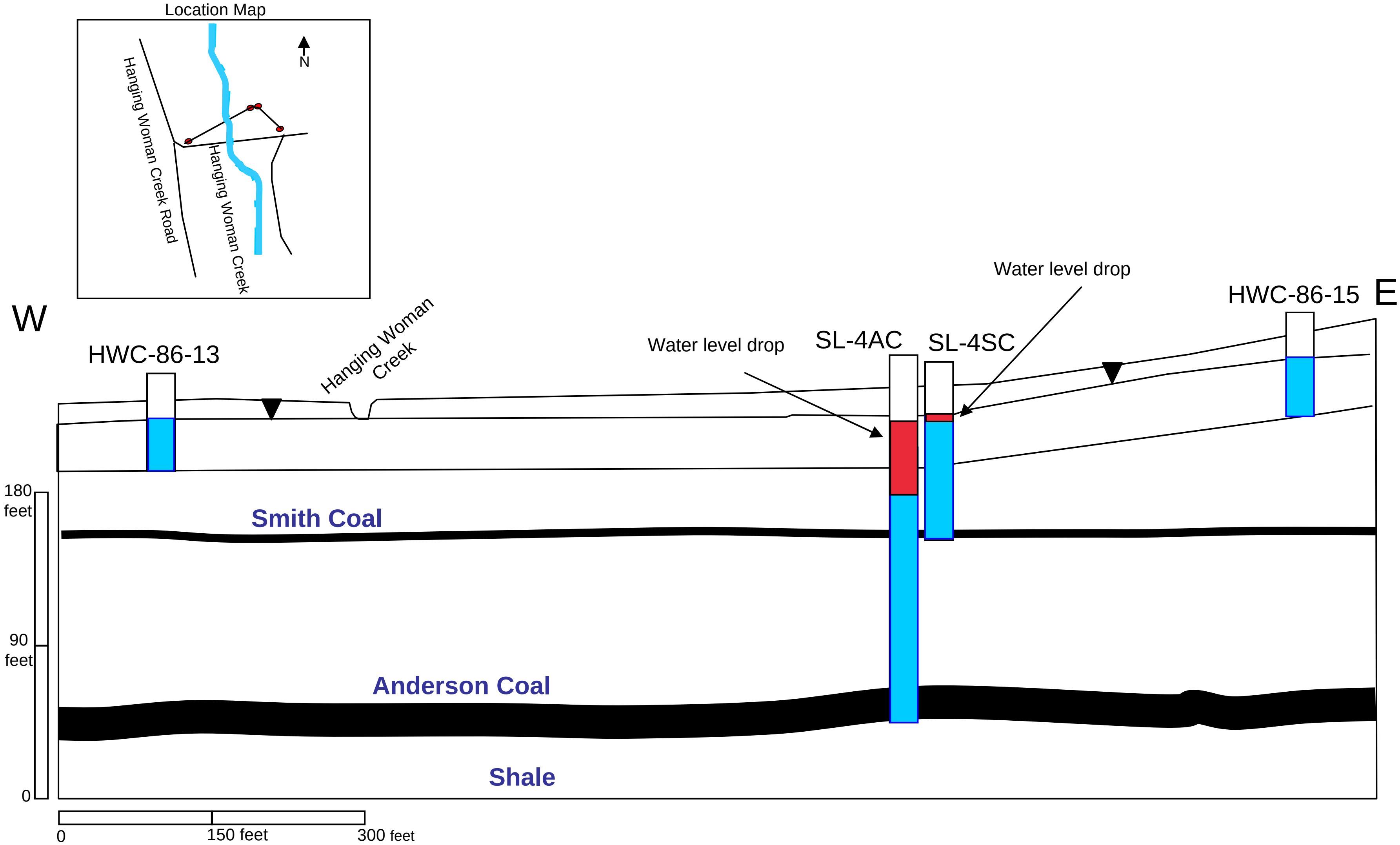
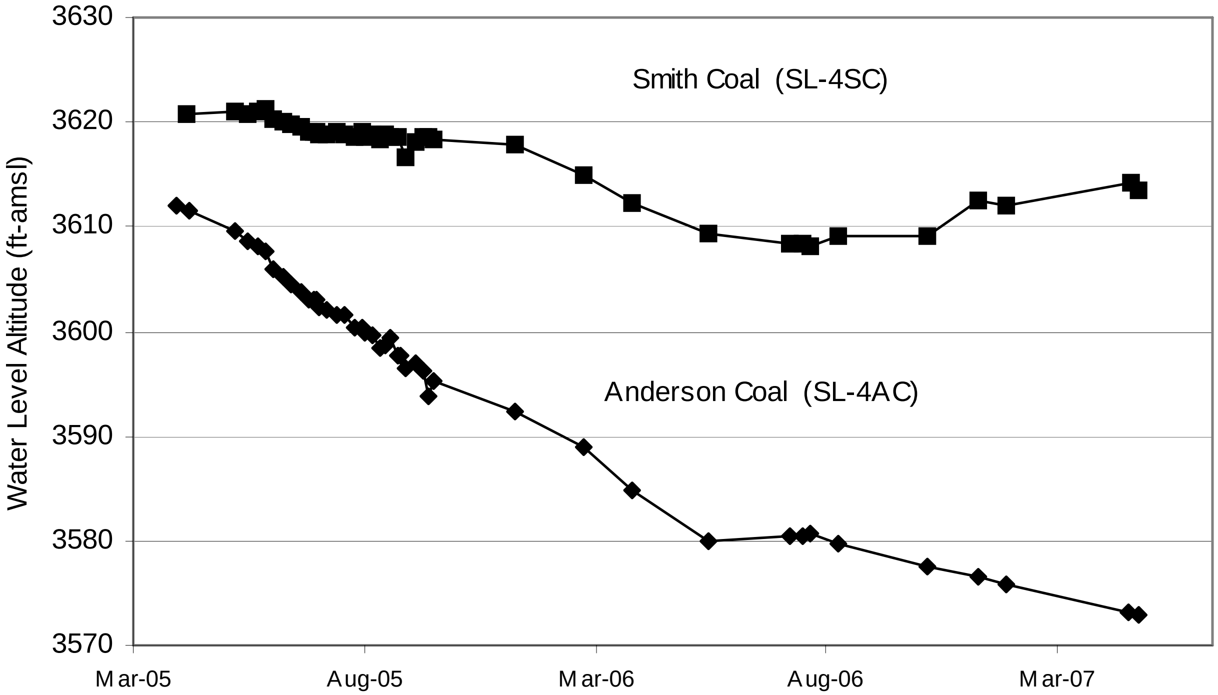


Figure 31. Geological cross section for the alluvium and bedrock wells near the Montana / Wyoming state line on Hanging Women Creek located in T10S R43E section 2. Water levels in the alluvium fluctuate with meteorological changes. Water levels in the Anderson Coal and Smith Coal have lowered in response to CBM production. The Anderson has lowered by about 36ft and the Smith has lowered about 8ft 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 December 2006. Vertical exaggeration is 1.7:1.



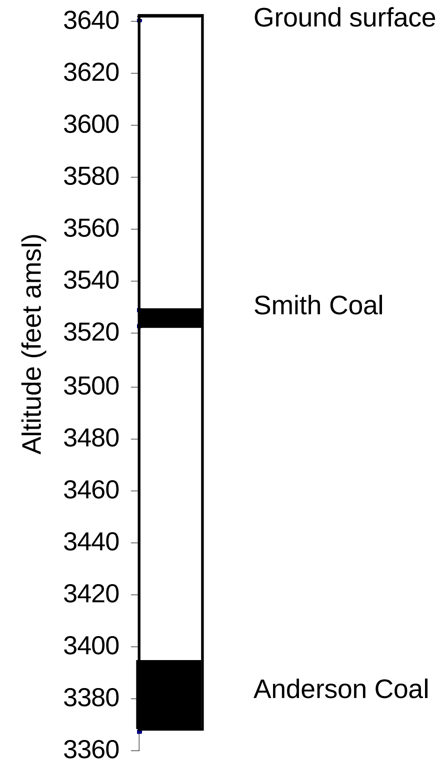


Figure 32. The SL-4 site is located about 1 mile north of the nearest CBM field. Water levels in the Anderson Coal have lowered about 37 feet since April 2005 in response to CBM development. Water levels in the Smith Coal have decreased, to a lesser degree, but a relationship to CBM has not been established. Water production from CBM wells in this field began during November, 2004.

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

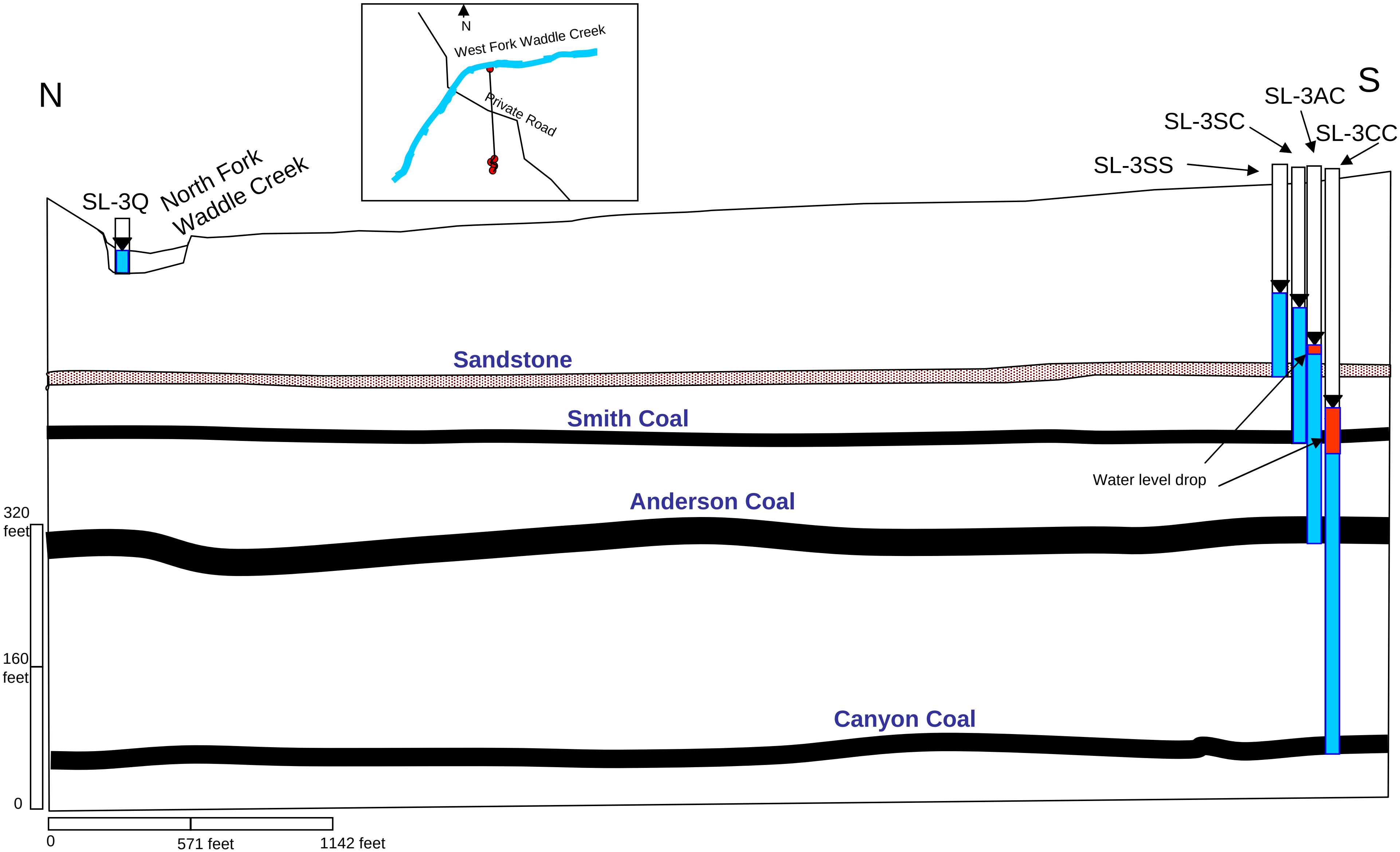


Figure 33. Geologic cross section for alluvium, an overburden sandstone, Smith, Anderson, and Canyon coal beds located at T9S R42E section 36. A downward hydraulic gradient is evident between each of the aquifer zones. The water levels for the cross section were taken in December 2006. The water level in the Anderson Coal has lowered about 6 feet and the Canyon coal has lowered about 87 feet since well installation. The wells are located roughly 1 mile north from nearest CMB field. Vertical exaggeration is 3.6:1.

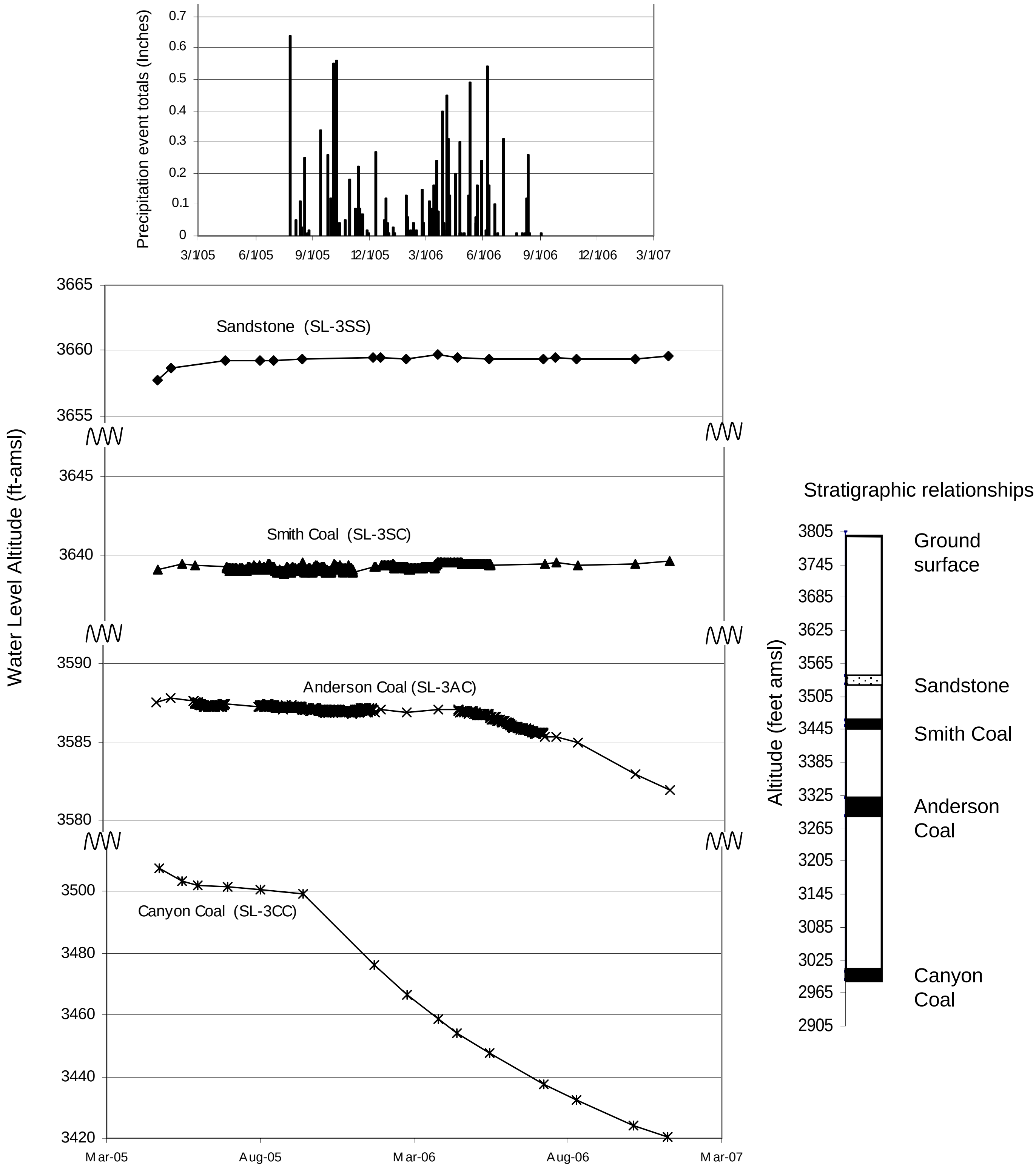


Figure 34. Water levels in the overburden sandstone, Smith, and Anderson coals are not responding to CBM development. However the water level in the Canyon Coal has dropped about 87 feet in response to CBM production.

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

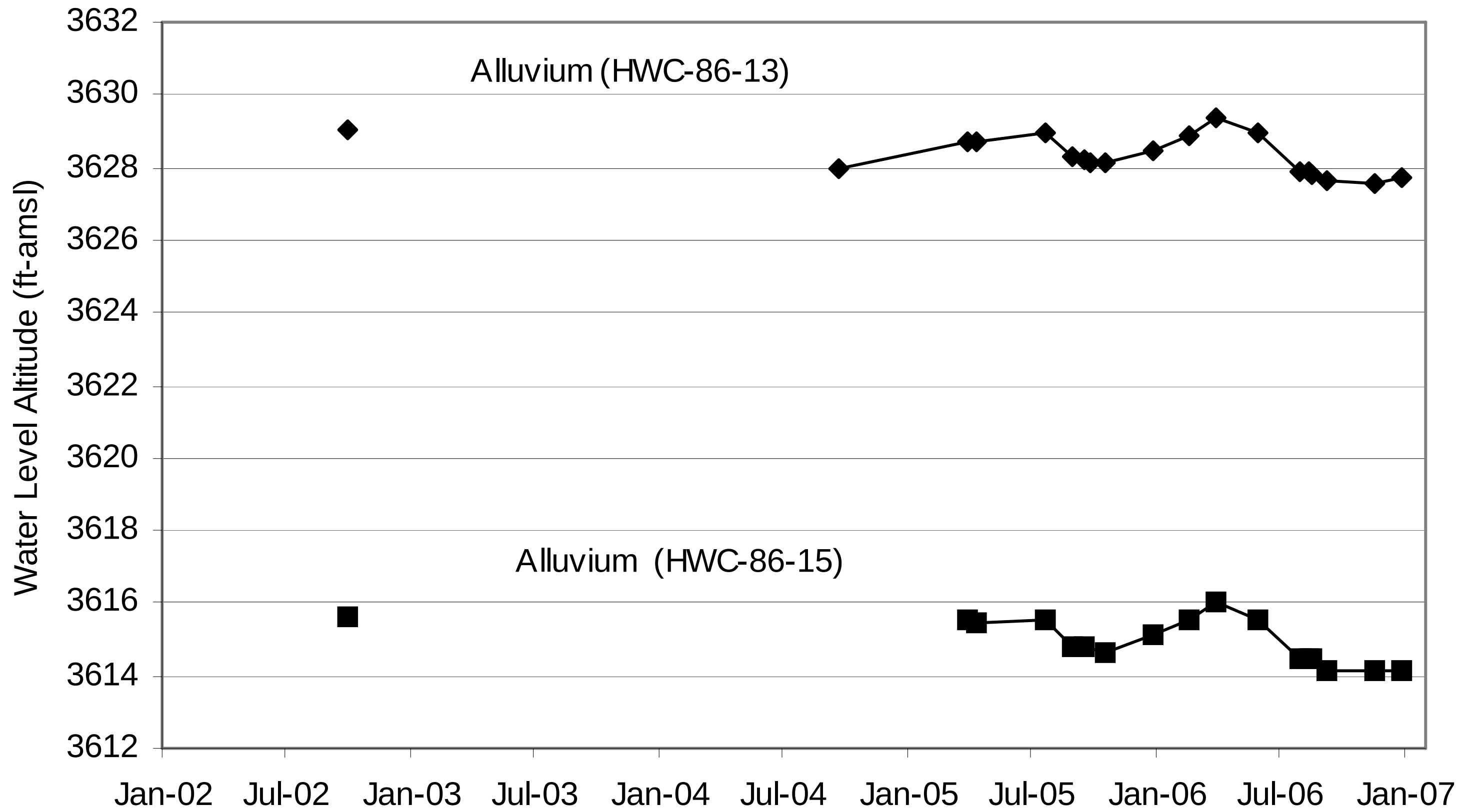


Figure 35. The water level in the alluvial aquifer reflects water table response to meteorological pattern.

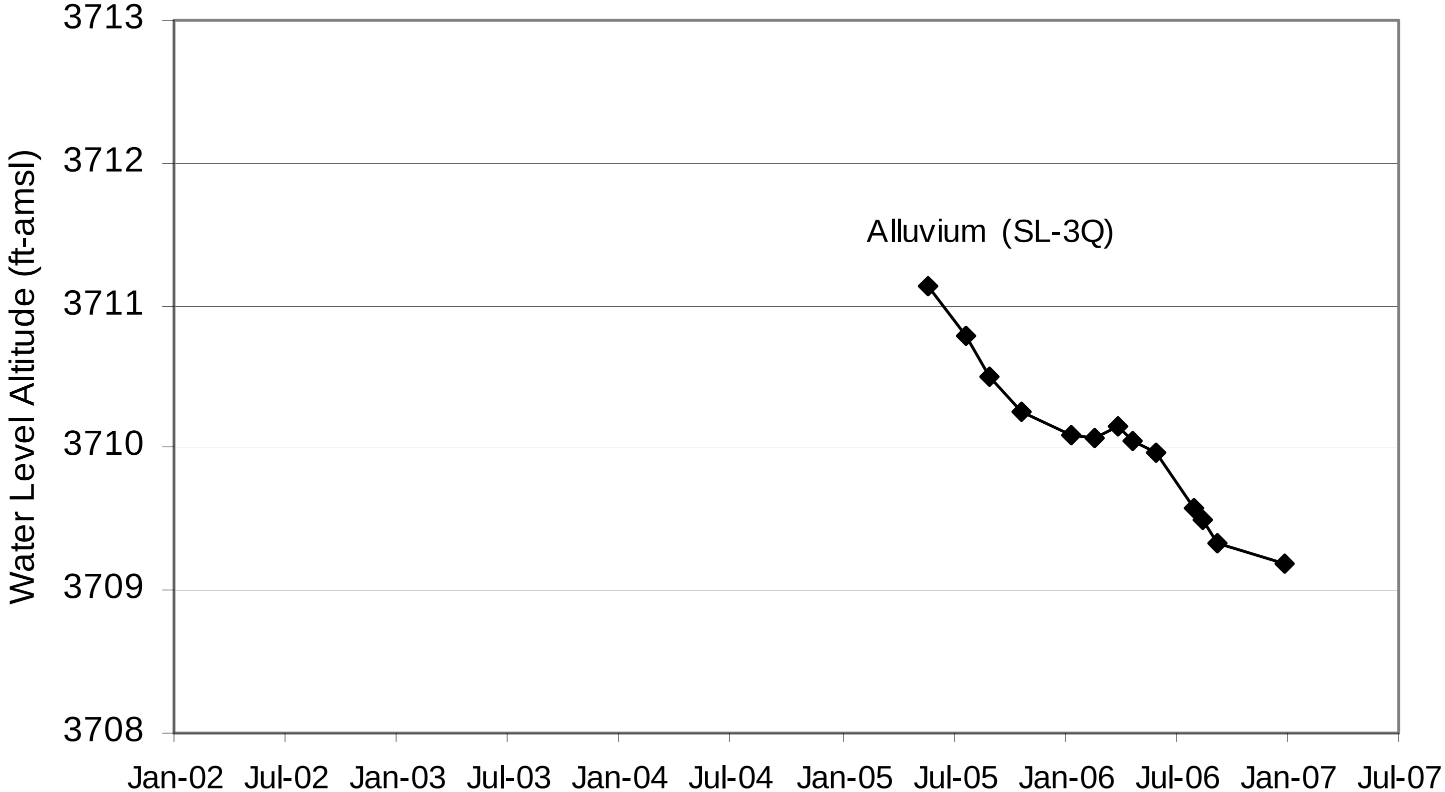


Figure 36. Water levels in the alluvium at site SL-3 appear to be in response to seasonal weather patterns and not to CBM production.

Gas field near Powder River

Methane water production. Near the Powder River, CBM is being produced from the Wyodak (Anderson), Canyon, Wall, Cook, Pawnee, and Cache coalbeds (fig. 2). During 2006, a total of 409 wells produced water in this area. The cumulative production for the 12-month period was 1.0×10^9 gallons, or 3,069 acre ft. Average water-production rate per well was 7.9 gpm and the average total production rate for the area was 2,316 gpm.

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, and so at least some portion of it is natural.

Two monitoring wells 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. Water levels are not currently measured at this well either. Well SL-6AC is completed in the Anderson coal and no CBM-related change in water levels have been noted in this well (GWIC data).

Alluvial aquifer water levels and quality. South of Moorhead, ground-water flow through the Powder River alluvium is roughly parallel to the river flow (figs. 37 and 38). This site is located on a large meander of the river, and the river likely loses flow to the alluvium on the upgradient end of the meander and gains at the lower end. A stock well (GWIC M:221592) 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 ft 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 two wells at SL-8 in August 2006 (appendix C). Wells SL-8-2Q (M:220857) and SL-8-3Q (M:220859) have concentrations of TDS of 2,827 and 2,096 mg/L and SAR values of 4.7 and 3.5, respectively. The water quality is dominated by calcium, sodium, and sulfate. The TDS and SAR values are higher in the well closest to the Powder River (fig. 36) but no CBM impacts are apparent. There are also insufficient data to identify seasonality trends. The data are available on GWIC and are represented by stiff diagrams showing relative major ion concentrations in plate 3.

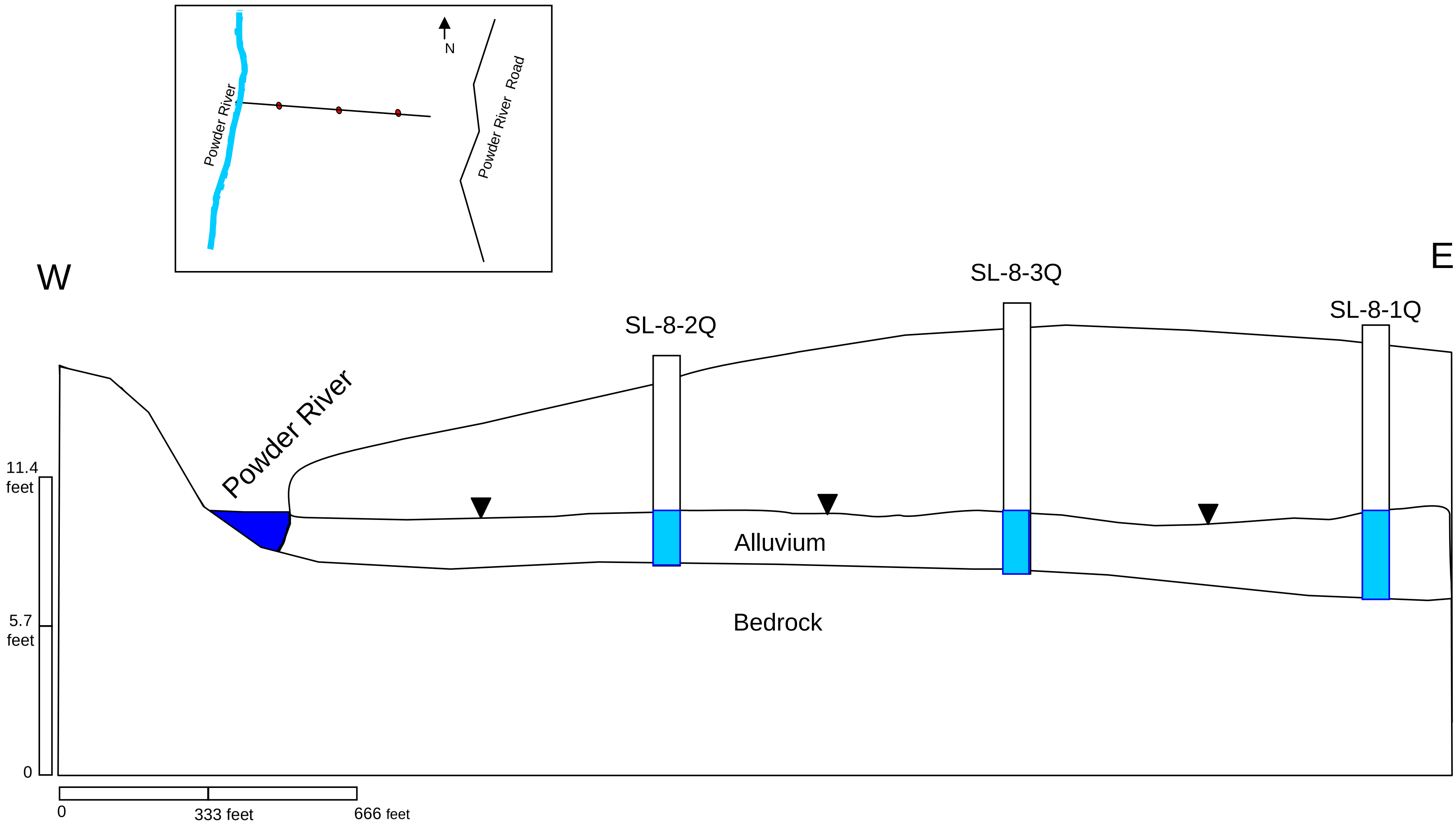


Figure 37. Cross section of alluvial wells south of Moorhead near the Powder River located in T09S R47E section 25. Ground water in the alluvium appear to flow parallel to the river. Water levels for this cross section were taken in January 2006. Vertical exaggeration is 58:1.

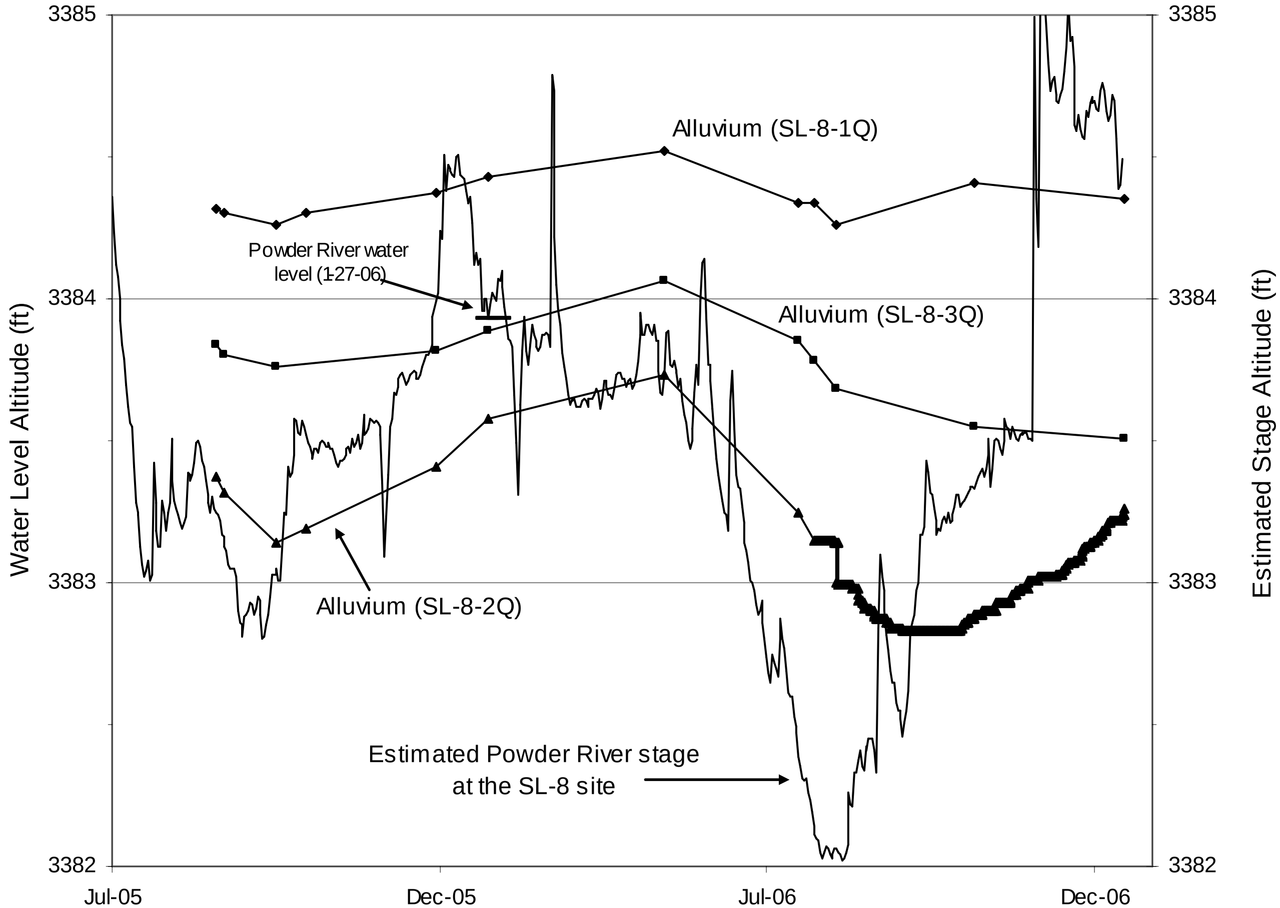


Figure 38. Ground-water flow in the alluvial aquifer at SL-8 is roughly parallel to the Powder River. The ground water-level trends follow river stage trends. The river alternates between gaining (summer) and loosing (winter). Estimated Powder River stage at SL-8 is based on stage at Moorhead gaging station (USGS data) and the surveyed river water-level altitude at SL-8 on 1/27/06.

Summary and 2007 monitoring plan

Coalbed-methane production continues in the CX field in Montana, and in Wyoming near the state line. Water production has begun in the Coal Creek and Dietz fields in Montana. The regional ground-water monitoring network documents baseline conditions outside production areas, changes to the ground-water systems within the area of influence, and the aerial limits of drawdown within the monitored aquifers. Outside the area of influence of CBM production, ground-water conditions reflect normal response to precipitation and the long-term response to coal mining.

Water discharge rates from individual CBM wells in the CX field have been lower than predicted, averaging 4.2 gpm during 2006 from 828 wells. The highest water production rate, averaged over a 1-month period, was 42.7 gpm from one well, and some wells are producing methane without pumping water.

Within the CX field, ground-water levels have been drawndown by over 150 ft 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 7 years of CBM production, drawdown of up to 20 ft has been measured in the coal seams at a distance of roughly 1 mile and a maximum distance of 1.5 miles outside the production areas. These distances are similar to but somewhat less than predicted in the Montana CBM environmental impact statement. The EIS predicted 20 ft of drawdown would reach 2 miles after 10 years of CBM production. At the Coal Creek field, 11 ft of drawdown during a period of 21 months has been measured at a distance of 2.5 miles from the nearest producing well. Faults tend to act as barriers to ground-water flow and drawdown does not migrate across fault planes where measured in monitoring wells. Vertical migration of drawdown tends to be limited by shale layers.

Water levels will recover after production ceases, but it may take decades for them 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, and the site-specific aquifer characteristics, including the extent of faults in the Fort Union Formation and proximity to recharge areas. Since 2004, recovery 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 79 to 234 ft. After 2 years, recovery in these four wells is 63 to 78% of baseline levels.

Water from production wells is expected to have TDS concentrations generally between 875 mg/L and 1,525 mg/L (Class II or Class III waters). Data collected during 2006 from coal seams where SO_4 concentrations were low support those values, with the lowest measured TDS being 1,075 mg/L and the highest measured TDS being 2,029 mg/L. Sodium adsorption ratios in methane-bearing coal seams are high, and data collected during 2006 indicate values between 36.8 and 66.3.

Monitoring plans for 2007 are included in appendices A and B. During 2007, monitoring sites located within approximately 6 miles of existing or proposed development (except for the Castle Rock area, which has no pipeline) will be monitored monthly. Outside of this area monitoring will occur semi-annually or quarterly depending on distance to production and amount of background data collected to date. Meteorological stations currently deployed at SL-3, RBC-2, and near Poker Jim Butte will be maintained. A data logger will be installed at the SL-4 Smith Coal site to determine cause of drawdown. Data loggers will be installed at the gassy SL-6 and SL-7 sites. Data loggers and Specific Conductance meters will also be installed at the SL-8 site on the Powder River. Water-quality samples will be collected semi-annually from selected alluvial sites. Monitoring priorities will be adjusted as new areas of production are proposed or developed.

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Appendix A

Site details, water-level data and 2007 monitoring plan
for ground-water monitoring wells

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County
5072B	157879	-106.49040	45.73930	01S	42E	24	ACBB	ROSEBUD
5072C	157882	-106.49050	45.73940	01S	42E	24	ACBB	ROSEBUD
5080B	157883	-106.51260	45.71990	01S	42E	26	DCBA	ROSEBUD
5080C	157884	-106.51260	45.72000	01S	42E	26	DCBA	ROSEBUD
LISCOM WELL	94661	-106.03230	45.77820	01S	46E	3	DBAA	POWDER RIVER
COYOTE WELL	94666	-106.05050	45.75240	01S	46E	16	AACC	POWDER RIVER
WHITETAIL RANGER STATION	183564	-105.97580	45.64040	02S	47E	19	CDCA	POWDER RIVER
EAST FORK WELL	100472	-106.16420	45.59350	03S	45E	10	B	POWDER RIVER
WO-15	7573	-106.18550	45.51860	04S	45E	4	BDDB	POWDER RIVER
WO-16	7574	-106.18610	45.51580	04S	45E	4	CAAC	POWDER RIVER
WO-14	210094	-106.18490	45.51830	04S	45E	4	BDDB	POWDER RIVER
NEWELL PIPELINE WELL	7589	-106.21430	45.47270	04S	45E	19	DADD	POWDER RIVER
OC-28	207101	-106.19280	45.47170	04S	45E	21	CCBD	POWDER RIVER
USGS 452429106435201	223243	-106.73110	45.40800	05S	40E	13	ADAB	BIG HORN
USGS 452139106504701	223238	-106.84640	45.36080	05S	40E	31	BDCC	BIG HORN
USGS 452408106382201	223237	-106.84640	45.36080	05S	41E	14	BDCD	ROSEBUD
USGS 452416106413001	223242	-106.69170	45.40440	05S	41E	17	ADBD	ROSEBUD
USGS 452411106301601	223240	-106.50440	45.40300	05S	42E	14	ADDC	ROSEBUD
USGS 452355106333701	223236	-106.56030	45.39860	05S	42E	16	CCAB	ROSEBUD
CBM02-8KC	203697	-106.54730	45.36890	05S	42E	28	DDAC	ROSEBUD
CBM02-8SS	203699	-106.54720	45.36880	05S	42E	28	DDAC	ROSEBUD
CBM02-8DS	203700	-106.54700	45.36870	05S	42E	28	DDAC	ROSEBUD
CBM02-8FG	203701	-106.54710	45.36880	05S	42E	28	DDAC	ROSEBUD
NANCE PROPERTIES INC	183560	-106.42050	45.43870	05S	43E	4	AAAB	ROSEBUD
NC05-1 NEAR BIRNEY VILLAGE	226919	-106.47690	45.41060	05S	43E	7	C	ROSEBUD
NC05-2	228124	-106.47720	45.41050	05S	43E	7	CCDC	ROSEBUD
WA-2	223952	-106.46210	45.40200	05S	43E	17	BCDD	ROSEBUD
IB-2	207096	-106.43720	45.39300	05S	43E	21	BBDB	ROSEBUD
MK-4	207097	-106.43630	45.39190	05S	43E	21	BBDC	ROSEBUD
NM-4	207098	-106.43610	45.39160	05S	43E	21	BCAB	ROSEBUD
WL-2	207099	-106.43580	45.39190	05S	43E	21	BBDC	ROSEBUD
WA-7	214354	-106.43470	45.39330	05S	43E	21	BABC	ROSEBUD
PADGET CREEK PIPELINE WELL	103155	-106.29400	45.39390	05S	44E	22	BBBD	ROSEBUD
77-26	7755	-106.18390	45.43520	05S	45E	4	ABCC	POWDER RIVER
WO-8	7770	-106.14110	45.39220	05S	45E	23	ABCA	POWDER RIVER
WO-9	7772	-106.14190	45.39250	05S	45E	23	ABCA	POWDER RIVER
WO-10	7775	-106.14300	45.39250	05S	45E	23	ABCB	POWDER RIVER
WO-5	7776	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER
WO-6	7777	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER
WO-7	7778	-106.13860	45.39220	05S	45E	23	ABDA	POWDER RIVER
WO-1	7780	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER
WO-2	7781	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER
WO-3	7782	-106.14940	45.39470	05S	45E	23	BBAA	POWDER RIVER
WO-11	215085	-106.14330	45.39270	05S	45E	23	ABCC	POWDER RIVER
WO-4	7783	-106.14860	45.39410	05S	45E	23	BBAA	POWDER RIVER
SKINNER GULCH PIPELINE WELL	183565	-105.91710	45.42750	05S	47E	3	BCCD	POWDER RIVER
SPRING CREEK PIPELINE WELL	205082	-105.95380	45.38830	05S	47E	20	ACAC	POWDER RIVER

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Rang e	Secti on	Tract	County
RBC-1	207064	-106.98360	45.33270	06S	39E	8	CAAA	BIG HORN
RBC-2	207066	-106.98440	45.33270	06S	39E	8	CAAA	BIG HORN
RBC-3	207068	-106.98680	45.33310	06S	39E	8	BDCD	BIG HORN
RBC-MET	231583	-106.98440	45.33270	06S	39E	8	CAAA	BIG HORN
CBM02-1KC	203646	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN
CBM02-1BC	203655	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN
CBM02-1LC	203658	-106.96710	45.31860	06S	39E	16	DBCA	BIG HORN
20-LW	191139	-106.78010	45.33910	06S	40E	1	CDDC	BIG HORN
22-BA	191155	-106.69540	45.34840	06S	41E	3	BADD	ROSEBUD
28-W	191163	-106.72920	45.32110	06S	41E	16	BBCC	ROSEBUD
32-LW	191169	-106.70980	45.29550	06S	41E	21	DDDC	ROSEBUD
HWC86-9	7903	-106.50270	45.29660	06S	43E	19	DACD	ROSEBUD
HWC86-7	7905	-106.50330	45.29580	06S	43E	19	DDBA	ROSEBUD
HWC86-8	7906	-106.50300	45.29610	06S	43E	19	DDBA	ROSEBUD
POKER JIM MET	223869	-106.31640	45.30980	06S	44E	23	BBAA	ROSEBUD
CBM02-4WC	203680	-106.78020	45.17980	07S	40E	36	CDDC	BIG HORN
CBM02-4SS1	203681	-106.78030	45.17980	07S	40E	36	CDDC	ROSEBUD
CBM02-4SS2	203690	-106.78030	45.17980	07S	40E	36	CDDC	BIG HORN
HWCQ-2	214096	-106.50090	45.19130	07S	43E	32	AAAA	ROSEBUD
HWCQ-1	214097	-106.50050	45.19120	07S	43E	32	AAAA	ROSEBUD
PIPELINE WELL 7(PL-1W) LOHOF	144969	-106.30740	45.23540	07S	44E	14	ABD	ROSEBUD
TOOLEY CREEK WELL	105007	-106.26970	45.21530	07S	45E	19	CAAA	POWDER RIVER
TAYLOR CREEK PIPELINE WELL	223890	-105.99280	45.22130	07S	47E	21	BBCC	POWDER RIVER
634	184225	-107.07280	45.14220	08S	38E	17	DADD	BIG HORN
634A	184226	-107.08830	45.14220	08S	38E	17	DADD	BIG HORN
625	184223	-107.05220	45.11330	08S	38E	28	DADB	BIG HORN
625A	184224	-107.05220	45.11330	08S	38E	28	DADB	BIG HORN
CBM02-7CC	203693	-106.89060	45.18010	08S	39E	1	AAAA	BIG HORN
CBM02-7SS	203695	-106.89060	45.17990	08S	39E	1	AAAA	BIG HORN
CBM02-3CC	203676	-106.96080	45.13920	08S	39E	16	BAAA	BIG HORN
CBM02-3DC	203678	-106.96070	45.13910	08S	39E	16	BAAA	BIG HORN
WR-21	8074	-106.97910	45.08770	08S	39E	32	DBBC	BIG HORN
PKS-3203	166358	-106.83020	45.10680	08S	40E	28	ADA	BIG HORN
PKS-3204	166351	-106.82990	45.10670	08S	40E	28	ADA	BIG HORN
MUSGRAVE BILL	228592	-106.73194	45.16389	08S	41E	5	ACDB	BIG HORN
CBM03-10AC	203703	-106.60450	45.11410	08S	42E	29	ADAD	BIG HORN
CBM03-10SS	203704	-106.60450	45.11410	08S	42E	29	ADAD	BIG HORN
HWC-86-2	8101	-106.48270	45.13500	08S	43E	17	DDCA	BIG HORN
HWC-86-5	8103	-106.48220	45.13410	08S	43E	17	DDDC	BIG HORN
HWC-01	8107	-106.48660	45.13380	08S	43E	20	DDDD	BIG HORN
HC-24	8118	-106.47470	45.12970	08S	43E	21	BDBB	BIG HORN
HC-01	207143	-106.47500	45.13140	08S	43E	21	BBDA	BIG HORN
FC-01	8140	-106.51660	45.10250	08S	43E	31	BBDA	BIG HORN
FC-02	8141	-106.51660	45.10250	08S	43E	31	BBDA	BIG HORN
CBM03-11AC	203705	-106.36320	45.17930	08S	44E	5	BBBB	BIG HORN
CBM03-11DC	203707	-106.36410	45.17930	08S	44E	5	BBBB	BIG HORN
CBM03-11CC	203708	-106.36470	45.17930	08S	44E	5	BBBB	BIG HORN

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County
BC-06	8191	-106.21000	45.13870	08S	45E	16	DBCB	POWDER RIVER
BC-07	8192	-106.21000	45.13870	08S	45E	16	DBCB	POWDER RIVER
CBM03-12COC	203709	-106.21210	45.13520	08S	45E	16	DBCB	POWDER RIVER
75-23	191634	-106.20110	45.09660	08S	45E	34	BDBC	POWDER RIVER
WR-23	8347	-106.99050	45.09220	09S	38E	1	AADC	BIG HORN
SH-624	184222	-107.09170	45.07250	09S	38E	7	DADB	BIG HORN
YA-114	207075	-107.05430	45.04610	09S	38E	21	ADBD	BIG HORN
YA-105	207076	-107.05270	45.04650	09S	38E	21	ACAC	BIG HORN
391	8368	-107.03200	45.04130	09S	38E	22	DADC	BIG HORN
YA-109	192874	-107.03120	45.04070	09S	38E	22	DADC	BIG HORN
TA-100	207080	-107.00900	45.04790	09S	38E	23	BBCC	BIG HORN
388	8371	-107.02050	45.03910	09S	38E	23	CDAD	BIG HORN
396	8372	-107.00880	45.04910	09S	38E	24	BBBC	BIG HORN
TA-101	207081	-107.00900	45.04820	09S	38E	24	BBCC	BIG HORN
TA-102	207083	-107.00760	45.04860	09S	38E	24	BBCB	BIG HORN
394	8377	-107.00750	45.03300	09S	38E	25	BCBA	BIG HORN
422	8379	-107.00610	45.02610	09S	38E	25	CBDC	BIG HORN
395	8387	-107.06180	45.03610	09S	38E	26	ABAB	BIG HORN
WR-58	8412	-106.91220	45.04080	09S	39E	14	DDBD	BIG HORN
WR-58D	8413	-106.91380	45.03940	09S	39E	14	DDCC	BIG HORN
WR-58A	132903	-106.91230	45.04030	09S	39E	14	DDBD	BIG HORN
WR-19	8417	-106.95050	45.05250	09S	39E	16	AABA	BIG HORN
WR-20	8419	-106.95050	45.05250	09S	39E	16	AABA	BIG HORN
WR-54A	8428	-106.89020	45.01470	09S	39E	25	DADB	BIG HORN
WR-53A	8430	-106.88880	45.01220	09S	39E	25	DDAA	BIG HORN
WR-24	8436	-106.98770	45.02020	09S	39E	29	BBDD	BIG HORN
WR-31	130476	-106.98630	45.01630	09S	39E	29	CBAA	BIG HORN
WR-30	132908	-106.98740	45.01650	09S	39E	29	CBAB	BIG HORN
CBM02-2WC	203669	-106.98840	45.02070	09S	39E	29	BBDC	BIG HORN
CBM02-2RC	203670	-106.98890	45.01850	09S	39E	29	BCBD	BIG HORN
WR-33	8441	-106.97580	45.00660	09S	39E	32	ACAA	BIG HORN
WR-27	8444	-106.96580	45.00080	09S	39E	33	DBBD	BIG HORN
WR-45	8446	-106.95380	44.99660	09S	39E	33	DDCC	BIG HORN
WR-44	8447	-106.95220	44.99660	09S	39E	33	DDCD	BIG HORN
WR-42	8451	-106.95020	44.99660	09S	39E	33	DDDD	BIG HORN
WR-34	132909	-106.97020	45.00150	09S	39E	33	CBBB	BIG HORN
WR-41	186195	-106.94980	44.99500	09S	39E	34	CCCC	BIG HORN
WRE-02	132910	-106.77560	45.07120	09S	40E	1	DBCC	BIG HORN
WRN-10	8456	-106.80940	45.07330	09S	40E	3	DABA	BIG HORN
WRN-11	123798	-106.80940	45.07330	09S	40E	3	DABA	BIG HORN
WRN-15	8461	-106.82750	45.06380	09S	40E	9	AADD	BIG HORN
DS-05A	8471	-106.83380	45.05550	09S	40E	9	DCAB	BIG HORN
WRE-09	8500	-106.77410	45.03970	09S	40E	13	DCBC	BIG HORN
WRE-10	8501	-106.77410	45.03830	09S	40E	13	DCCB	BIG HORN
WRE-11	8504	-106.77360	45.03830	09S	40E	13	DCCD	BIG HORN
PKS-3202	166359	-106.79810	45.04510	09S	40E	14	CAA	BIG HORN
PKS-3201	166362	-106.79710	45.04370	09S	40E	14	CAA	BIG HORN

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Rang e	Secti on	Tract	County
PKS-3200	166370	-106.79690	45.04400	09S	40E	14	CAA	BIG HORN
PKS-3199	166388	-106.79660	45.04430	09S	40E	14	CAA	BIG HORN
PKS-3198	166389	-106.79640	45.04460	09S	40E	14	CAA	BIG HORN
WR-29R	166761	-106.81530	45.04650	09S	40E	15	ACCD	BIG HORN
DS-02A	8574	-106.81660	45.04160	09S	40E	15	DBCC	BIG HORN
WR-55A	8651	-106.88630	45.03020	09S	40E	19	CBBD	BIG HORN
WRE-12	8687	-106.80380	45.03110	09S	40E	23	BCCD	BIG HORN
WRE-13	8692	-106.80440	45.03110	09S	40E	23	BCCD	BIG HORN
PKS-1179	132973	-106.80400	45.03140	09S	40E	23	CBBB	BIG HORN
WRE-16	8698	-106.76970	45.03520	09S	40E	24	AACB	BIG HORN
WRE-18	121669	-106.76830	45.03470	09S	40E	24	AACD	BIG HORN
WRE-17	132959	-106.76830	45.03470	09S	40E	24	AACD	BIG HORN
WRE-20	122767	-106.77160	45.03690	09S	40E	24	ABAB	BIG HORN
WRE-19	123797	-106.77360	45.03690	09S	40E	24	ABBA	BIG HORN
WRE-21	132958	-106.77300	45.03860	09S	40E	24	ABAB	BIG HORN
WR-17B	8706	-106.86410	45.02160	09S	40E	29	BBAC	BIG HORN
WR-51A	8709	-106.86220	45.01860	09S	40E	29	BDCB	BIG HORN
WR-52B	8710	-106.86270	45.01470	09S	40E	29	CACB	BIG HORN
WR-17A	123796	-106.86410	45.02160	09S	40E	29	BBAC	BIG HORN
WR-52C	132960	-106.86290	45.01640	09S	40E	29	CABC	BIG HORN
WR-52D	132961	-106.86160	45.01640	09S	40E	29	CABD	BIG HORN
WR-59	122766	-106.85260	45.00500	09S	40E	32	ACAD	BIG HORN
WRE-25	123795	-106.73330	45.06830	09S	41E	5	DCCA	BIG HORN
WRE-24	130475	-106.73330	45.06880	09S	41E	5	DCCA	BIG HORN
WRE-27	8721	-106.73910	45.05860	09S	41E	8	CABC	BIG HORN
WRE-28	8723	-106.73910	45.05860	09S	41E	8	CABC	BIG HORN
WRE-29	8726	-106.74110	45.05860	09S	41E	8	CBAD	BIG HORN
SL-2AC	219125	-106.63580	45.02760	09S	42E	30	BDAC	BIG HORN
SL-2CC	220385	-106.63600	45.02730	09S	42E	30	BCBC	BIG HORN
SL-3Q	219136	-106.53860	45.01610	09S	42E	36	BBAD	BIG HORN
SL-3SC	219138	-106.53130	45.00800	09S	42E	36	DBCB	BIG HORN
SL-3AC	219139	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN
SL-3CC	219140	-106.53130	45.00820	09S	42E	36	DBCB	BIG HORN
SL-3SS	219617	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN
SL-3 MET	231591	-106.53130	45.00790	09S	42E	36	DBCB	BIG HORN
CC-1	8754	-106.46460	45.08750	09S	43E	4	ABDD	BIG HORN
CC-4	8757	-106.46590	45.08740	09S	43E	4	ABDD	BIG HORN
CC-3	8758	-106.46540	45.08640	09S	43E	4	ACAA	BIG HORN
HWC-38	8777	-106.40170	45.07230	09S	43E	12	ADBB	BIG HORN
HWC-37	189802	-106.40170	45.07230	09S	43E	12	ADBB	BIG HORN
HWC-39	189838	-106.40040	45.07130	09S	43E	12	ADBD	BIG HORN
HWC-17	8778	-106.41330	45.05700	09S	43E	13	BCAA	BIG HORN
HWC-6	198465	-106.40930	45.05360	09S	43E	13	CAAA	BIG HORN
HWC-7	198464	-106.40930	45.05370	09S	43E	13	DAAA	BIG HORN
HWC-10	190902	-106.46950	45.04440	09S	43E	21	BADA	BIG HORN
HWC-11 TR-77	190904	-106.46960	45.04440	09S	43E	21	BADA	BIG HORN
HWC-15	8782	-106.44680	45.04120	09S	43E	22	ACCA	BIG HORN

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	GWIC ID	Longitude	Latitude	Town-ship	Range	Section	Tract	County
HWC-29B	8796	-106.39690	45.06880	09S	44E	7	BBCC	BIG HORN
SL-5AC	219927	-106.27140	45.01190	09S	44E	36	ABBD	BIG HORN
SL-5DC	219929	-106.27140	45.01190	09S	44E	36	ABBD	BIG HORN
SL-5CC	220076	-106.27150	45.01190	09S	44E	36	ABBD	BIG HORN
DH 76-102D	227246	-106.18620	45.07980	09S	45E	3	ADCC	ROSEBUD
SL-5ALQ	223801	-106.25790	45.01290	09S	45E	31	BBA	POWDER RIVER
SL-6AC	220062	-106.15140	45.01480	09S	45E	36	ABBB	BIG HORN
SL-6CC	220064	-106.15130	45.01480	09S	45E	36	ABBB	BIG HORN
AMAX NO. 110	8835	-106.11530	45.06990	09S	46E	8	BACC	POWDER RIVER
UOP-09	8846	-106.05780	45.07200	09S	46E	11	BBBA	POWDER RIVER
UOP-10	8847	-106.05780	45.07200	09S	46E	11	BBBA	POWDER RIVER
CBM03-13OC	203710	-106.05720	45.07220	09S	46E	11	BBBA	POWDER RIVER
SL-7CC	220069	-106.03920	45.01470	09S	46E	36	BBBB	BIG HORN
SL-8-1Q	220851	-105.89980	45.01760	09S	47E	25	DDDB	POWDER RIVER
SL-8-2Q	220857	-105.90520	45.01820	09S	47E	25	DCDB	POWDER RIVER
SL-8-3Q	220859	-105.90280	45.01770	09S	47E	25	DDCB	POWDER RIVER
FULTON GEORGE *NO.6	8863	-105.86280	45.08070	09S	48E	5	ACDD	POWDER RIVER
FULTON GEORGE	183563	-105.87090	45.06370	09S	48E	8	CABC	POWDER RIVER
HWC 86-13	8888	-106.42620	45.00200	10S	43E	2	ABCA	BIG HORN

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date
5072B	3160.0	ROSEBUD COAL	109.0	2.0	2/22/2006
5072C	3160.0	ROSEBUD COAL OVERBURDEN	106.0	0.3	2/22/2006
5080B	3260.0	KNOBLOCH COAL	88.5	1.3	2/22/2006
5080C	3260.0	KNOBLOCH OVERBURDEN	110.0	0.3	2/22/2006
LISCOM WELL	3275.0	FORT UNION FORMATION	135.0	10.0	9/27/2005
COYOTE WELL	3294.0	FORT UNION FORMATION	190.0	5.0	9/27/2005
WHITETAIL RANGER STATION	4045.0	FORT UNION FORMATION	60.0		1/11/2006
EAST FORK WELL	3210.0		193.0	5.0	4/1/1961
WO-15	3022.0	ALLUVIUM	63.0	12.0	1/26/2006
WO-16	3040.0	ALLUVIUM	61.0	3.7	1/26/2006
WO-14	3010.0		66.1		10/18/2004
NEWELL PIPELINE WELL	3290.0	TONGUE RIVER FORMATION	325.0	5.0	
OC-28	3171.0	KNOBLOCH COAL			1/29/2006
USGS 452429106435201	3940.0		380.0		8/24/2005
USGS 452139106504701	4440.0		680.5		6/6/2005
USGS 452408106382201	3510.0		360.0		8/25/2005
USGS 452416106413001	3740.0		353.0		8/24/2005
USGS 452411106301601	3220.0		420.0		6/16/2005
USGS 452355106333701	3400.0		376.0		8/25/2005
CBM02-8KC	3262.3	KNOBLOCH COAL	208.0	1.0	1/27/2006
CBM02-8SS	3262.2	KNOBLOCH UNDERBURDEN	224.0	10.0	1/27/2006
CBM02-8DS	3260.5	FLOWERS-GOODALE OVERBURDEN	446.0	0.3	1/27/2006
CBM02-8FG	3260.6	FLOWERS-GOODALE COAL	480.4	0.5	1/27/2006
NANCE PROPERTIES INC	3035.0	ALLUVIUM	20.0		1/11/2006
NC05-1 NEAR BIRNEY VILLAGE	3170.0		780.0		
NC05-2	3170.0		348.0		
WA-2	3068.5	ALLUVIUM			10/25/1980
IB-2	3191.6	KNOBLOCH UNDERBURDEN	245.0		12/22/2005
MK-4	3195.3	KNOBLOCH COAL	188.0		12/22/2005
NM-4	3195.3	NANCE COAL	294.0		12/22/2005
WL-2	3187.6	KNOBLOCH COAL	199.0		12/22/2005
WA-7	3179.0	ALLUVIUM			12/22/2005
PADGET CREEK PIPELINE WELL	3385.0	TONGUE RIVER FORMATION	135.0	10.0	2/3/2006
77-26	3284.0	KNOBLOCH COAL	216.8	3.6	1/26/2006
WO-8	3155.0	ALLUVIUM	33.0	12.0	1/26/2006
WO-9	3150.0	ALLUVIUM	45.0	21.8	1/26/2006
WO-10	3145.0	ALLUVIUM	41.4		1/26/2006
WO-5	3160.0	KNOBLOCH UNDERBURDEN	192.0	20.4	1/26/2006
WO-6	3160.0	LOWER KNOBLOCH COAL	82.0	7.0	1/26/2006
WO-7	3160.0	ALLUVIUM	40.0	29.0	1/26/2006
WO-1	3190.0	KNOBLOCH UNDERBURDEN	172.0	8.0	1/26/2006
WO-2	3188.0	LOWER KNOBLOCH COAL	112.0	19.0	1/26/2006
WO-3	3186.0	KNOBLOCH OVERBURDEN	66.0	17.8	1/26/2006
WO-11	3145.0	ALLUVIUM	38.5		1/26/2006
WO-4	3140.0	ALLUVIUM	31.5		12/31/2006
SKINNER GULCH PIPELINE WELL	3730.0	TONGUE RIVER FORMATION	167.0		1/26/2006
SPRING CREEK PIPELINE WELL	3630.0	TONGUE RIVER FORMATION	50.0		1/26/2006

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date
RBC-1	3854.7	ALLUVIUM	26.8		1/31/2006
RBC-2	3849.4	ALLUVIUM	16.9		1/31/2006
RBC-3	3859.9	ALLUVIUM	24.6		1/31/2006
RBC-MET	3849.4				
CBM02-1KC	3980.3	KNOBLOCH COAL	417.0	0.5	1/31/2006
CBM02-1BC	3983.9	BREWSTER-ARNOLD COAL	255.5	5.0	1/31/2006
CBM02-1LC	3981.8	LOCAL COALS	366.0	2.0	1/31/2006
20-LW	3940.0	WALL COAL	253.0	0.2	2/2/2006
22-BA	3530.0	BREWSTER-ARNOLD COAL	262.0	0.4	8/30/2005
28-W	3715.0	WALL COAL	144.0	1.3	2/2/2006
32-LW	3530.0	WALL COAL	51.0	0.2	2/2/2006
HWC86-9	3170.0	ALLUVIUM	44.0		2/2/2006
HWC86-7	3170.0	ALLUVIUM	71.0		2/2/2006
HWC86-8	3170.0	ALLUVIUM	67.0		2/2/2006
POKER JIM MET	4115.0				
CBM02-4WC	3500.0	WALL COAL	291.0	0.2	12/23/2005
CBM02-4SS1	3500.0	WALL COAL OVERBURDEN	221.0	5.0	12/23/2005
CBM02-4SS2	3500.0	CANYON UNDERBURDEN	96.6	30.0	12/23/2005
HWCQ-2	3340.0	ALLUVIUM	19.0		2/2/2006
HWCQ-1	3340.0	ALLUVIUM	19.5		2/2/2006
PIPELINE WELL 7(PL-1W) LOHOF	3850.0	TONGUE RIVER FORMATION	225.0	15.0	2/3/2006
TOOLEY CREEK WELL	3755.0	FORT UNION FORMATION	110.0	12.0	1/11/2006
TAYLOR CREEK PIPELINE WELL	3910.0	TONGUE RIVER FORMATION	150.0		1/26/2006
634	4480.5	DIETZ COAL	348.0	12.0	12/5/2001
634A	4481.2	ANDERSON COAL	159.1		12/5/2001
625	4186.6	DIETZ COAL	186.0		1/13/2006
625A	4186.7	ANDERSON COAL	90.6		1/13/2006
CBM02-7CC	3900.0	CANYON COAL	263.4	1.5	12/22/2005
CBM02-7SS	3900.0	CANYON OVERBURDEN	190.3	5.0	12/22/2005
CBM02-3CC	3920.0	CANYON COAL	376.4	0.3	12/22/2005
CBM02-3DC	3920.0	DIETZ COAL	235.0	0.1	12/22/2005
WR-21	3890.0	DIETZ 1 AND DIETZ COALS COMBINED	206.0	4.0	1/13/2006
PKS-3203	3500.0	CANYON COAL	201.0		12/10/2005
PKS-3204	3500.0	ANDERSON-DIETZ 1 COAL BED	82.0		12/10/2005
MUSGRAVE BILL	3335.0	ALLUVIUM	21.5		9/7/2006
CBM03-10AC	4130.0	ANDERSON COAL	560.0	0.3	12/22/2005
CBM03-10SS	4130.0	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	462.0	1.0	12/22/2005
HWC-86-2	3460.0	ALLUVIUM	50.0		12/22/2005
HWC-86-5	3455.0	ALLUVIUM	33.0		12/22/2005
HWC-01	3530.0	CANYON COAL	232.0	7.5	12/28/2005
HC-24	3500.0	CANYON OVERBURDEN	150.0	7.1	10/20/2005
HC-01	3457.0	ALLUVIUM	19.7	17.0	10/20/2005
FC-01	3735.0	ANDERSON COAL	133.0	0.0	8/31/2005
FC-02	3735.0	DIETZ COAL	260.0		8/31/2005
CBM03-11AC	3950.0	ANDERSON COAL	211.0	1.0	12/18/2005
CBM03-11DC	3950.0	DIETZ COAL	271.0	0.2	12/18/2005
CBM03-11CC	3950.0	CANYON COAL	438.0	1.5	12/18/2005

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date
BC-06	3715.0	CANYON COAL	188.0	4.6	12/18/2005
BC-07	3715.0	CANYON OVERBURDEN	66.0	0.8	12/18/2005
CBM03-12COC	3715.0	COOK COAL	351.0	3.0	12/18/2005
75-23	3780.0	CANYON COAL	247.0		12/18/2005
WR-23	3960.0	DIETZ 1 AND DIETZ COALS COMBINED	322.0	6.0	1/13/2006
SH-624	4644.7	ANDERSON-DIETZ 1 COAL BED	435.1		12/14/2003
YA-114	4000.0	ALLUVIUM			1/6/2006
YA-105	4015.0	ALLUVIUM			1/6/2006
391	3987.0	DIETZ 1 AND DIETZ COALS COMBINED	175.0		1/6/2006
YA-109	3830.0	ALLUVIUM	43.8		12/23/2005
TA-100	3900.0	ALLUVIUM			1/13/2006
388	3975.0	DIETZ COAL	190.0		1/6/2006
396	3939.0	ANDERSON-DIETZ 1 AND 2 COALS	280.0	25.0	1/13/2006
TA-101	3910.0	ALLUVIUM			1/13/2006
TA-102	3910.0	ALLUVIUM			1/13/2006
394	3909.0	DIETZ COAL	242.0	5.0	1/6/2006
422	3917.0	DIETZ COAL	187.0		1/6/2006
395	3900.0	DIETZ COAL	299.0	15.0	1/6/2006
WR-58	3631.3	ALLUVIUM	55.0	21.0	12/28/2005
WR-58D	3627.4	ALLUVIUM	27.0	15.0	12/28/2005
WR-58A	3631.4	ALLUVIUM	24.0	8.0	12/28/2005
WR-19	3835.4	DIETZ 1 AND DIETZ COALS COMBINED	305.0	20.0	12/28/2005
WR-20	3835.3	ANDERSON COAL	166.0	15.0	12/28/2005
WR-54A	3631.2	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	211.0	1.0	12/28/2005
WR-53A	3607.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	187.0		12/28/2005
WR-24	3777.2	CANYON COAL	146.0		12/23/2005
WR-31	3895.2	ANDERSON COAL	316.0	2.0	12/23/2005
WR-30	3894.6	DIETZ 1 AND DIETZ COALS COMBINED	428.0	5.0	12/23/2005
CBM02-2WC	3792.0	CARNEY COAL	290.0	10.0	12/23/2005
CBM02-2RC	3890.0	ROLAND COAL	159.0	1.0	12/23/2005
WR-33	3732.3	ANDERSON-DIETZ 1 CLINKER AND COAL	165.0		12/23/2005
WR-27	3672.0	ANDERSON-DIETZ 1 AND 2 COALS	363.0	25.0	12/23/2005
WR-45	3638.2	ALLUVIUM	64.0	30.0	10/19/2005
WR-44	3636.9	ALLUVIUM	64.0	30.0	10/19/2005
WR-42	3636.7	ALLUVIUM	66.0	30.0	10/19/2005
WR-34	3772.1	ANDERSON-DIETZ 1 AND 2 COALS	522.0		12/23/2005
WR-41	3642.7	ALLUVIUM	40.0	1.0	10/19/2005
WRE-02	3456.8	ALLUVIUM	79.0		1/6/2006
WRN-10	3433.3	DIETZ 2 COAL	79.0	3.4	12/10/2005
WRN-11	3436.8	ANDERSON-DIETZ 1 CLINKER AND COAL	50.0		12/10/2005
WRN-15	3499.8	DIETZ 2 COAL	140.0		1/5/2006
DS-05A	3505.5	DIETZ 2 COAL	166.0	5.0	1/5/2006
WRE-09	3510.7	DIETZ 2 COAL	232.0		1/6/2006
WRE-10	3518.5	DIETZ COAL	183.0		1/6/2006
WRE-11	3508.9	ANDERSON COAL	127.0		1/6/2006
PKS-3202	3438.0	ALLUVIUM	60.0	5.0	12/28/2005
PKS-3201	3438.0	CANYON COAL	390.0	50.0	12/28/2005

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date
PKS-3200	3438.0	DIETZ 2 COAL	242.0	20.0	12/28/2005
PKS-3199	3439.0	DIETZ COAL	165.0	20.0	12/28/2005
PKS-3198	3440.0	ANDERSON COAL	112.0		12/28/2005
WR-29R	3461.0	ANDERSON-DIETZ 1 CLINKER AND COAL	72.0		12/10/2005
DS-02A	3430.0	DIETZ 2 COAL	150.0		1/5/2006
WR-55A	3591.1	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	72.0		12/28/2005
WRE-12	3463.2	ANDERSON COAL	172.0		12/10/2005
WRE-13	3462.6	DIETZ COAL	206.0		12/10/2005
PKS-1179	3458.0	DIETZ 2 COAL	282.0	5.0	12/10/2005
WRE-16	3550.5	ANDERSON COAL	458.0		12/10/2005
WRE-18	3573.1	ANDERSON COAL	445.0		12/10/2005
WRE-17	3561.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	250.0		12/10/2005
WRE-20	3519.4	ANDERSON COAL	120.0		1/6/2006
WRE-19	3520.3	ANDERSON COAL	140.0		1/6/2006
WRE-21	3529.4	ANDERSON COAL	130.0		1/6/2006
WR-17B	3574.7	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	160.0		12/28/2005
WR-51A	3541.3	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	187.0		12/28/2005
WR-52B	3518.8	ALLUVIUM	55.0	59.7	12/28/2005
WR-17A	3573.9	ANDERSON-DIETZ 1 AND 2 OVERBURDEN	88.0		12/28/2005
WR-52C	3530.0	ALLUVIUM	62.0	20.0	12/28/2005
WR-52D	3529.3	ALLUVIUM	40.0	1.0	12/28/2005
WR-59	3470.1	ALLUVIUM	34.0	10.0	12/28/2005
WRE-25	3549.4	ANDERSON COAL	114.5		1/6/2006
WRE-24	3552.1	DIETZ COAL	154.0	20.0	1/6/2006
WRE-27	3523.8	ANDERSON COAL	77.0	0.5	1/6/2006
WRE-28	3525.2	DIETZ COAL	153.0		1/6/2006
WRE-29	3523.3	DIETZ 2 COAL	217.0		1/6/2006
SL-2AC	3925.0	ANDERSON COAL	671.0		1/6/2006
SL-2CC	3920.0	CANYON COAL	1301.0		1/6/2006
SL-3Q	3725.0	ALLUVIUM	40.0	2.0	1/12/2006
SL-3SC	3805.0	SMITH COAL	358.0	2.0	1/20/2006
SL-3AC	3805.0	ANDERSON COAL	523.0	2.0	1/20/2006
SL-3CC	3805.0	CANYON COAL	817.0	0.1	1/12/2006
SL-3SS	3805.0	SMITH COAL OVERBURDEN	278.0	5.0	1/20/2006
SL-3 MET	3725.0				
CC-1	3520.0	ALLUVIUM	28.0	4.2	12/28/2005
CC-4	3511.0	ALLUVIUM	25.0	4.8	12/28/2005
CC-3	3521.0	ALLUVIUM	34.5	4.6	12/28/2005
HWC-38	3586.0	ALLUVIUM	40.5		1/13/2006
HWC-37	3578.0	ALLUVIUM	32.0		1/13/2006
HWC-39	3591.0	ALLUVIUM	39.0		1/13/2006
HWC-17	3610.0	ANDERSON COAL	82.0	6.9	1/13/2006
HWC-6	3595.0	DIETZ COAL	151.6		1/13/2006
HWC-7	3624.0		67.0		12/28/2006
HWC-10	3610.0	DIETZ COAL	229.0		12/28/2005
HWC-11 TR-77	3615.0	ANDERSON COAL	135.0	8.0	12/28/2005
HWC-15	3600.0	ANDERSON COAL	129.0	10.0	1/13/2006

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Land-surface altitude (feet)	Aquifer	Well total depth (feet)	Well yield (gpm)	Static water level date
HWC-29B	3620.0	ANDERSON COAL	92.0		1/13/2006
SL-5AC	3810.0	ANDERSON COAL	223.0	1.0	1/13/2006
SL-5DC	3810.0	DIETZ COAL	322.0	0.7	1/13/2006
SL-5CC	3810.0	CANYON COAL	430.5	6.0	1/13/2006
DH 76-102D	3811.0	DIETZ COAL	144.0		10/19/2006
SL-5ALQ	3810.0	ALLUVIUM	35.0		9/16/2005
SL-6AC	4220.0	ANDERSON COAL	492.0	0.1	12/9/2005
SL-6CC	4220.0	CANYON COAL	685.0	0.5	11/17/2005
AMAX NO. 110	3965.0	DIETZ COAL	240.0	1.4	1/11/2005
UOP-09	3929.0	CANYON COAL	261.5	0.8	1/27/2006
UOP-10	3930.0	CANYON OVERBURDEN	207.3	4.4	1/27/2006
CBM03-13OC	3931.0	OTTER COAL	500.0	1.5	1/27/2006
SL-7CC	4173.0	CANYON COAL	515.0	1.0	10/20/2005
SL-8-1Q	3396.7	ALLUVIUM	19.0	1.0	1/27/2006
SL-8-2Q	3394.1	ALLUVIUM	13.8	0.3	1/27/2006
SL-8-3Q	3398.5	ALLUVIUM	19.0	1.0	1/27/2006
FULTON GEORGE *NO.6	3380.0	TONGUE RIVER FORMATION	410.0	4.0	1/11/2006
FULTON GEORGE	3360.0	ALLUVIUM	30.0	1.0	1/11/2006
HWC 86-13	3640.0	ALLUVIUM	53.0	3.9	12/28/2005

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Static water level (feet)	Static water level altitude (ft)	Comments	2007 planned SWL monitoring	2007 planned QW sample collection
5072B	35.61	3124.4		QUARTERLY	
5072C	29.25	3130.8		QUARTERLY	
5080B	46.70	3213.3		QUARTERLY	
5080C	35.66	3224.3		QUARTERLY	
LISCOM WELL	98.37	3176.6		QUARTERLY	
COYOTE WELL	134.86	3159.1		QUARTERLY	
WHITETAIL RANGER STATION	41.29	4003.7		QUARTERLY	
EAST FORK WELL	82.00	3017.0		QUARTERLY	
WO-15	8.53	3013.5		SEMI-ANNUAL	
WO-16	22.74	3017.3		SEMI-ANNUAL	
WO-14	9.93	3000.1		SEMI-ANNUAL	
NEWELL PIPELINE WELL				SEMI-ANNUAL	
OC-28	68.81	3102.2		SEMI-ANNUAL	
USGS 452429106435201	200.26	3739.7			
USGS 452139106504701	624.70	3815.3			
USGS 452408106382201	238.61	3271.4			
USGS 452416106413001	181.98	3558.0			
USGS 452411106301601	106.90	3113.1			
USGS 452355106333701	262.69	3137.3			
CBM02-8KC	157.98	3104.3		QUARTERLY	
CBM02-8SS	160.06	3102.1		QUARTERLY	
CBM02-8DS	102.24	3158.3		QUARTERLY	
CBM02-8FG	101.96	3158.7		QUARTERLY	
NANCE PROPERTIES INC	10.24	3024.8		QUARTERLY	
NC05-1 NEAR BIRNEY VILLAGE					
NC05-2					
WA-2	45.20	3145.0		MONTHLY	SEMI-ANNUAL
IB-2	119.53	3072.1		QUARTERLY	
MK-4	119.65	3075.7		QUARTERLY	
NM-4	120.14	3075.2		QUARTERLY	
WL-2	117.30	3070.3		QUARTERLY	
WA-7	55.15	3123.8		QUARTERLY	
PADGET CREEK PIPELINE WELL	74.68	3310.3		QUARTERLY	
77-26	145.32	3138.7		SEMI-ANNUAL	
WO-8	15.23	3139.8		QUARTERLY	
WO-9	11.53	3138.5		QUARTERLY	
WO-10	8.63	3136.4		QUARTERLY	
WO-5	16.97	3143.0		QUARTERLY	
WO-6	24.27	3135.7		QUARTERLY	
WO-7	26.58	3133.4		QUARTERLY	
WO-1	37.26	3152.7		QUARTERLY	
WO-2	44.46	3143.5		QUARTERLY	
WO-3	46.05	3140.0		QUARTERLY	
WO-11	8.81	3136.2		QUARTERLY	
WO-4	9.57	3130.4		QUARTERLY	
SKINNER GULCH PIPELINE WELL	49.50	3680.5		QUARTERLY	
SPRING CREEK PIPELINE WELL	16.27	3613.7		QUARTERLY	

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Static water level (feet)	Static water level altitude (ft)	Comments	2007 planned SWL monitoring	2007 planned QW sample collection
RBC-1	11.60	3843.1		MONTHLY	
RBC-2	8.21	3841.2		MONTHLY	SEMI-ANNUAL
RBC-3	10.77	3849.1		MONTHLY	
RBC-MET				MONTHLY	
CBM02-1KC	172.82	3807.5		MONTHLY	
CBM02-1BC	101.02	3882.8		MONTHLY	
CBM02-1LC	144.13	3837.6		MONTHLY	
20-LW	93.94	3846.1		MONTHLY	
22-BA	110.10	3419.9		QUARTERLY	
28-W	109.87	3605.1		MONTHLY	
32-LW	37.48	3492.5		MONTHLY	
HWC86-9	10.44	3159.6		MONTHLY	
HWC86-7	8.98	3161.0		MONTHLY	SEMI-ANNUAL
HWC86-8	9.47	3160.5		MONTHLY	
POKER JIM MET				MONTHLY	
CBM02-4WC	175.87	3324.1		MONTHLY	
CBM02-4SS1	75.73	3424.3		MONTHLY	
CBM02-4SS2	36.83	3463.2		MONTHLY	
HWCQ-2	11.83	3328.2		QUARTERLY	
HWCQ-1	11.87	3328.1		QUARTERLY	
PIPELINE WELL 7(PL-1W) LOHOF	133.53	3716.5		QUARTERLY	
TOOLEY CREEK WELL	37.11	3717.9		QUARTERLY	
TAYLOR CREEK PIPELINE WELL	122.84	3787.2		QUARTERLY	
634	156.11	4324.4		SEMI-ANNUAL	
634A	113.81	4367.4		SEMI-ANNUAL	
625	48.18	4138.4		QUARTERLY	
625A	54.76	4131.9		QUARTERLY	
CBM02-7CC	163.77	3736.2		MONTHLY	
CBM02-7SS	89.40	3810.6		MONTHLY	
CBM02-3CC	301.12	3618.9		MONTHLY	
CBM02-3DC	184.69	3735.3		MONTHLY	
WR-21	57.40	3832.6		MONTHLY	
PKS-3203	121.60	3378.4		MONTHLY	
PKS-3204	73.37	3426.6		MONTHLY	
MUSGRAVE BILL	5.54	3321.5		MONTHLY	SEMI-ANNUAL
CBM03-10AC	531.11	3598.9		MONTHLY	
CBM03-10SS	372.30	3757.7		MONTHLY	
HWC-86-2	19.62	3440.4		MONTHLY	
HWC-86-5	14.45	3440.6		MONTHLY	
HWC-01	87.89	3442.1		MONTHLY	
HC-24	52.72	3447.3		SEMI-ANNUAL	
HC-01	11.39	3445.6		SEMI-ANNUAL	
FC-01	129.04	3606.0		MONTHLY	
FC-02	240.63	3494.4		MONTHLY	
CBM03-11AC	155.71	3794.3		QUARTERLY	
CBM03-11DC	227.76	3722.2		QUARTERLY	
CBM03-11CC	382.22	3567.8		QUARTERLY	

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Static water level (feet)	Static water level altitude (ft)	Comments	2007 planned SWL monitoring	2007 planned QW sample collection
BC-06	89.05	3626.0		QUARTERLY	
BC-07	41.96	3673.0		QUARTERLY	
CBM03-12COC	166.43	3548.6		QUARTERLY	
75-23	130.20	3649.8		MONTHLY	
WR-23	84.04	3876.0		MONTHLY	
SH-624	348.02	4296.7		QUARTERLY	
YA-114	13.51	3986.5		QUARTERLY	
YA-105	11.14	4003.9		QUARTERLY	
391	61.10	3925.9		MONTHLY	
YA-109	37.72	3792.3		MONTHLY	
TA-100	13.94	3886.1		QUARTERLY	
388	81.01	3894.0		MONTHLY	
396	56.81	3882.2		MONTHLY	
TA-101	15.81	3894.2		QUARTERLY	
TA-102	21.09	3888.9		QUARTERLY	
394	90.22	3818.8		MONTHLY	
422	122.12	3794.9		SEMI-ANNUAL	
395	62.38	3837.6		MONTHLY	
WR-58	18.73	3612.6		MONTHLY	
WR-58D	18.87	3608.5		MONTHLY	
WR-58A	18.73	3612.6		MONTHLY	
WR-19	140.24	3695.2		MONTHLY	
WR-20	115.33	3720.0		MONTHLY	
WR-54A	127.92	3503.3		MONTHLY	
WR-53A	110.04	3497.9		MONTHLY	
WR-24	34.02	3743.2		MONTHLY	
WR-31	182.32	3712.9		MONTHLY	
WR-30	200.47	3694.1		MONTHLY	
CBM02-2WC	70.62	3721.4		MONTHLY	
CBM02-2RC	135.36	3754.6		MONTHLY	
WR-33	51.92	3680.4		MONTHLY	
WR-27	132.51	3539.5		MONTHLY	
WR-45	11.30	3626.9		MONTHLY	
WR-44	11.05	3625.9		MONTHLY	
WR-42	10.76	3625.9		MONTHLY	
WR-34	176.10	3596.0		MONTHLY	
WR-41	18.09	3624.6		MONTHLY	
WRE-02	35.45	3421.4		MONTHLY	
WRN-10	28.49	3404.8		MONTHLY	
WRN-11	33.94	3402.9		MONTHLY	
WRN-15	115.01	3384.8		MONTHLY	
DS-05A	136.83	3368.7		MONTHLY	
WRE-09	213.95	3296.8		MONTHLY	
WRE-10	173.17	3345.3		MONTHLY	
WRE-11	95.51	3413.4		MONTHLY	
PKS-3202	37.63	3400.4		MONTHLY	
PKS-3201	159.43	3278.6		MONTHLY	

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Static water level (feet)	Static water level altitude (ft)	Comments	2007 planned SWL monitoring	2007 planned QW sample collection
PKS-3200	157.27	3280.7		MONTHLY	
PKS-3199	117.89	3321.1		MONTHLY	
PKS-3198	82.32	3357.7		MONTHLY	
WR-29R	46.03	3415.0		MONTHLY	
DS-02A	44.37	3385.6		MONTHLY	
WR-55A	45.14	3546.0		MONTHLY	
WRE-12	130.92	3332.3		MONTHLY	
WRE-13	130.93	3331.7		MONTHLY	
PKS-1179	226.42	3231.6		MONTHLY	
WRE-16	69.69	3480.8		MONTHLY	
WRE-18	211.79	3361.3		MONTHLY	
WRE-17	69.92	3492.0		MONTHLY	
WRE-20	106.19	3413.2		MONTHLY	
WRE-19	107.29	3413.0		MONTHLY	
WRE-21	112.71	3416.7		MONTHLY	
WR-17B	78.37	3496.3		MONTHLY	
WR-51A	30.97	3510.3		MONTHLY	
WR-52B	5.69	3513.1		MONTHLY	
WR-17A	34.56	3539.3		MONTHLY	
WR-52C	19.21	3510.8		MONTHLY	
WR-52D	22.95	3506.4		MONTHLY	
WR-59	9.42	3460.7		MONTHLY	SEMI-ANNUAL
WRE-25	61.07	3488.3		MONTHLY	
WRE-24	68.45	3483.7		MONTHLY	
WRE-27	48.87	3474.9		MONTHLY	
WRE-28	66.10	3459.1		MONTHLY	
WRE-29	129.46	3393.8		MONTHLY	
SL-2AC	374.21	3550.8		MONTHLY	
SL-2CC	470.82	3449.2		MONTHLY	
SL-3Q	14.91	3710.1		MONTHLY	SEMI-ANNUAL
SL-3SC	165.71	3639.3		MONTHLY	
SL-3AC	219.10	3585.9		MONTHLY	
SL-3CC	329.44	3475.6		MONTHLY	
SL-3SS	145.54	3659.5		MONTHLY	
SL-3 MET				MONTHLY	
CC-1	14.44	3505.6		MONTHLY	
CC-4	-27.36	3538.4		MONTHLY	
CC-3	-14.79	3535.8		MONTHLY	
HWC-38	21.02	3565.0		MONTHLY	
HWC-37	11.51	3566.5		MONTHLY	
HWC-39	26.82	3564.2		MONTHLY	
HWC-17	20.89	3589.1		MONTHLY	
HWC-6	69.15	3525.9		MONTHLY	
HWC-7	30.42	3593.6		MONTHLY	
HWC-10	94.87	3515.1		MONTHLY	
HWC-11 TR-77	13.49	3601.5		MONTHLY	
HWC-15	12.32	3587.7		MONTHLY	

Appendix A. Site details, water-level data, and 2007 monitoring schedule for ground-water monitoring wells

Site Name	Static water level (feet)	Static water level altitude (ft)	Comments	2007 planned SWL monitoring	2007 planned QW sample collection
HWC-29B	45.96	3574.0		MONTHLY	
SL-5AC	132.11	3677.9		MONTHLY	
SL-5DC	167.98	3642.0		MONTHLY	
SL-5CC	180.43	3629.6		MONTHLY	
DH 76-102D	23.98	3787.0		MONTHLY	
SL-5ALQ	14.85	3795.2		MONTHLY	
SL-6AC	374.80	3845.2		MONTHLY	
SL-6CC	521.75	3698.3	59 PSI SHUT IN	MONTHLY	
AMAX NO. 110	166.66	3798.3		MONTHLY	
UOP-09	153.27	3775.7		MONTHLY	
UOP-10	141.47	3788.5		MONTHLY	
CBM03-13OC	383.64	3547.4		MONTHLY	
SL-7CC	456.92	3716.1	16 PSI SHUT IN	MONTHLY	
SL-8-1Q	12.27	3384.4		MONTHLY	
SL-8-2Q	10.54	3383.6		MONTHLY	
SL-8-3Q	14.57	3383.9		MONTHLY	SEMI-ANNUAL
FULTON GEORGE *NO.6	16.19	3363.8		QUARTERLY	
FULTON GEORGE	19.95	3340.1		QUARTERLY	
HWC 86-13	11.58	3628.4		MONTHLY	SEMI-ANNUAL

Appendix B

Site details, discharge data, and 2007 monitoring schedule for monitoring springs

Appendix B. Site details, discharge data, and 2007 monitoring schedule for monitored springs.

GWIC ID	Site name	Longitude	Latitude	Township	Range	Section	Tract	County	Spring source lithology
197247	SOUTH FORK HARRIS CREEK SPRING	-106.60530	45.16420	08S	42E	5	DDDB	BIG HORN	
197391	UPPER ANDERSON CREEK SPRING	-106.67810	45.13610	08S	41E	14	BBDD	BIG HORN	
197452	ALKALI SPRING	-106.15010	45.19140	07S	46E	31	BACD	POWDER RIVER	COAL
197607	UPPER FIFTEEN MILE SPRING	-105.93720	45.39200	05S	47E	16	DCDC	POWDER RIVER	COLLUVIUM
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	SANDSTONE
205004	HAGEN 2 SPRING	-106.26880	45.34500	06S	45E	6	ACDC	POWDER RIVER	CLINKER
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	SANDSTONE
205049	CHIPMUNK SPRING	-106.36110	45.21200	07S	44E	21	CCBB	ROSEBUD	SANDSTONE
228591	THREE MILE SPRING	-106.80030	45.18940	07S	40E	35	BDAC	BIG HORN	
223695	MOORHEAD CAMPGROUND SPRING	-105.87730	45.05420	09S	48E	17	BCBB	POWDER RIVER	SANDSTONE
223877	EAST FORK HANGING WOMAN CREEK WEIR	-106.40410	45.29090	06S	43E	25	ABDD	ROSEBUD	
199572	DEADMAN SPRING	-105.87430	45.29030	06S	48E	29	BABB	POWDER RIVER	SANDSTONE
223687	ROSEBUD CREEK RBC-4	-106.98630	45.33320	06S	39E	8	C	BIG HORN	
228776	UPPER ANDERSON SPRING	-106.62610	45.11550	08S	42E	30	ADAA	BIG HORN	

Appendix B. Site details, discharge data, and 2007 monitoring schedule for monitored springs.

GWIC ID	Nearest overlying coalbed association to spring	Spring recharge origin	Altitude	Spring yield (gpm)	Spring yield date	2007 planned flow monitoring	2007 planned QW sample collection		
197247	ANDERSON	REGIONAL	3690	0.6	6/19/2002	MONTHLY			
197391	ANDERSON	REGIONAL & LOCAL	3665	0.3	6/18/2002	MONTHLY			
197452	OTTER	LOCAL	3470	1.1	3/30/2005	MONTHLY	ONCE		
197607	COOK	LOCAL	3805	0.6	1/26/2006	QUARTERLY			
198766	FERRY	LOCAL	3660	1.8	2/3/2006	QUARTERLY			
199568	COOK	LOCAL	3680	0.6	7/30/2005	QUARTERLY			
205004	ANDERSON/DIETZ	LOCAL	3890	0.6	2/11/2006	QUARTERLY			
205010	CANYON	LOCAL	3960	0.9	7/30/2005	QUARTERLY			
205011	ANDERSON	LOCAL	4050	0.7	7/30/2005	QUARTERLY			
205041	CANYON	LOCAL	3735	0.9	8/21/2005	QUARTERLY			
205049	DIETZ	LOCAL	3670	0.6	10/20/2003	MONTHLY			
228591	DIETZ	LOCAL	3620	12.5	6/9/2003	MONTHLY			
223695	PAWNEE	REGIONAL	3400	1.6	1/27/2006	MONTHLY			
223877	OTTER	REGIONAL & LOCAL	3475	20	11/10/2005	MONTHLY	SEMI-ANNUAL		
199572	CANYON	LOCAL	3940	0.6	9/12/2002	QUARTERLY			
223687			3840.95			MONTHLY			
228776			3920.0	0.06	9/9/2006	MONTHLY			

Appendix C

Ground-water quality data collected during 2006

Gwic Id	Site Name	Aquifer	Sample	Latitude	Longitude	Location (TRS)	County	State
	Sites outside of areas of possible CBM influence							
7573	WO-15		2007Q0329	45.51860	-106.18550	04S 45E 4BDDB	POWDER RIVER	MT
7775	WO-10		2007Q0338	45.39250	-106.14300	05S 45E 23ABCB	POWDER RIVER	MT
197607	UPPER FIFTEEN MILE SPRING		2007Q0328	45.39200	-105.93720	05S 47E 16DCDC	POWDER RIVER	MT
207066	WELL RBC-2		2007Q0334	45.33270	-106.98440	06S 39E 8CAAA	BIG HORN	MT
223877	EAST FORK HANGING WOMAN CREEK WEIR		2007Q0336	45.29090	-106.40410	06S 43E 25ABDD	ROSEBUD	MT
199573	WILLOW SPRING		2007Q0694	45.28310	-105.88790	06S 48E 30DBBA	POWDER RIVER	MT
228591	THREE MILE SPRING		2007Q0365	45.16972	-106.79750	07S 40E 35CDDD		MT
204956	CLARK DRAW 1 SPRING		2007Q0693	45.21110	-106.40960	07S 43E 24CADA	ROSEBUD	MT
223801	SL-5ALQ ALLEN LOYD		2007Q0335	45.01290	-106.25790	09S 45E 31BBA	POWDER RIVER	MT
223695	MOORHEAD CAMPGROUND SPRING		2007Q0113	45.05420	-105.87730	09S 48E 17BCBB	POWDER RIVER	MT
8506	WELL DS-03		2007Q0822	45.04190	-106.82000	09S 40E 15CACD	BIG HORN	MT
	Sites within areas of possible CBM influence							
223952	WA-2		2007Q0331	45.40200	-106.46210	05S 43E 17BCDD	ROSEBUD	MT
228592	MUSGRAVE BILL ALLUVIAL		2007Q0364	45.16389	-106.73194	08S 41E 5ACDB	BIG HORN	MT
123796	WELL WR-17A		2007Q0821	45.02160	-106.86410	09S 40E 29BBAC	BIG HORN	MT
122766	WELL WR-59		2007Q0333	45.00500	-106.85260	09S 40E 32ACAD	BIG HORN	MT
219136	WELL SL-3Q		2007Q0339	45.01610	-106.53860	09S 42E 36BBAD	BIG HORN	MT
220857	WELL SL-8-2Q		2007Q0112	45.01820	-105.90520	09S 47E 25DCDB	POWDER RIVER	MT
220859	SL-8-3Q		2007Q0111	45.01770	-105.90280	09S 47E 25DDCB	POWDER RIVER	MT
7905	WELL HWC86-7		2007Q0332	45.29580	-106.50330	06S 43E 19DDBA	ROSEBUD	MT
198489	HWC 86-15		2007Q0330	45.00250	-106.42350	10S 43E 2AABC	BIG HORN	MT
8888	HWC 86-13		2007Q0337	45.00200	-106.42620	10S 43E 2ABCA	BIG HORN	MT

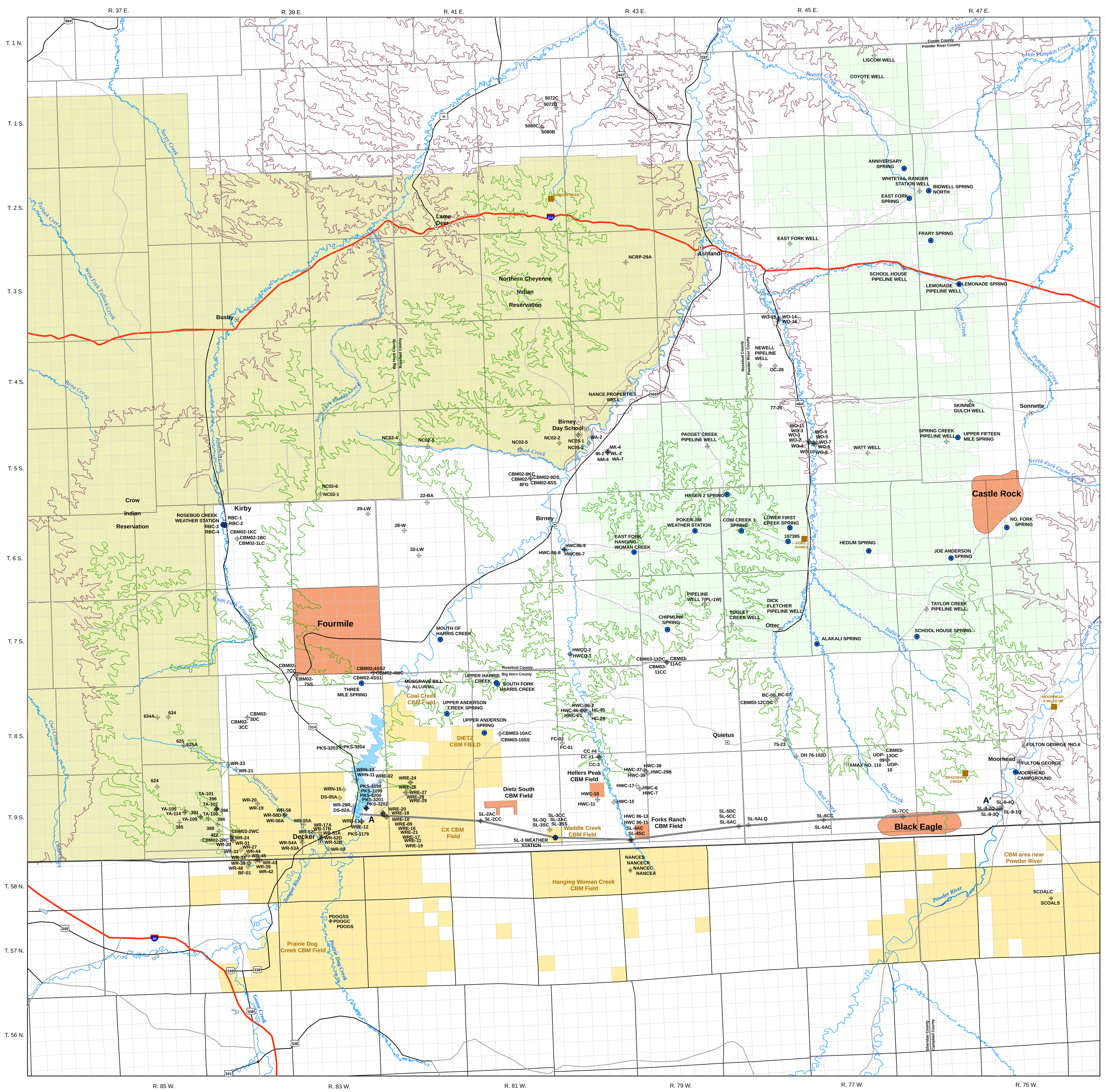
Gwic Id	Site Type	Depth (feet)	Agency	Sample Date	Water Temperature (c)	Field pH	Field specific conducta	Lab	Lab pH	Lab specific conduc	Procedure	Calcium (mg/l)	Magnesiu m (mg/l)
7573	WELL	63	MBMG	8/18/2006	10.9	7.49	3653	MBMG	7.48	3420	DISSOLVED	110.0	194.0
7775	WELL	41.4	MBMG	8/18/2006	10.6	7.52	4228	MBMG	7.71	4140	DISSOLVED	145.0	277.0
197607	SPRING		MBMG	8/18/2006	18.5	7.03	2360	MBMG	7.28	2310	DISSOLVED	106.0	113.0
207066	WELL	16.9	MBMG	8/15/2006	9.5	7.50	886	MBMG	7.6	1062	DISSOLVED	69.6	66.0
223877	STREAM		MBMG	8/18/2006	15	7.79	1270	MBMG	7.93	1430	DISSOLVED	81.8	69.6
199573	SPRING		MBMG	10/28/2006	9	6.99	2647	MBMG	6.92	2480	DISSOLVED	140.0	111.0
228591	SPRING		MBMG	9/7/2006	13	7.85	491	MBMG	7.38	499	DISSOLVED	32.7	26.2
204956	SPRING		MBMG	10/28/2006	9.8	6.90	1999	MBMG	6.92	1933	DISSOLVED	91.7	84.0
223801	WELL	35	MBMG	8/16/2006	10.7	7.03	5800	MBMG	7.98	5430	DISSOLVED	258.0	268.0
223695	SPRING		MBMG	7/27/2006	13.3	8.38	1118	MBMG	7.67	1147	DISSOLVED	3.4	1.2
8506	WELL	67	MBMG	11/21/2006	11.7	7.10	3320	MBMG	7.36	3320	DISSOLVED	126.0	81.8
223952	WELL	37.8	MBMG	8/17/2006	11.3	7.59	2753	MBMG	7.78	2820	DISSOLVED	25.5	27.0
228592	WELL	21.5	MBMG	9/7/2006	12.5	7.43	1059	MBMG	7.33	1036	DISSOLVED	103.0	54.8
123796	WELL	88	MBMG	11/22/2006	11.6	7.70	4644	MBMG	7.62	4590	DISSOLVED	45.2	116.0
122766	WELL	34	MBMG	8/17/2006	11.8	7.31	6100	MBMG	7.63	5840	DISSOLVED	266.0	532.0
219136	WELL	40	MBMG	8/15/2006	10.9	7.10	3726	MBMG	7.38	3680	DISSOLVED	259.0	195.0
220857	WELL	13.8	MBMG	7/27/2006	11.4	7.14	3468	MBMG	7.3	3420	DISSOLVED	364.0	112.0
220859	WELL	19	MBMG	7/27/2006	11	7.17	2655	MBMG	7.35	2610	DISSOLVED	291.0	85.5
7905	WELL	71	MBMG	8/17/2006				MBMG	7.66	3570	DISSOLVED	139.0	185.0
198489	WELL	62.52		8/16/2006	11.5	7.00	8260	MBMG	7.44	7710	DISSOLVED	450.0	429.0
8888	WELL	53	MBMG	8/16/2006	11.2	7.02	6720	MBMG	7.52	6400	DISSOLVED	373.0	313.0

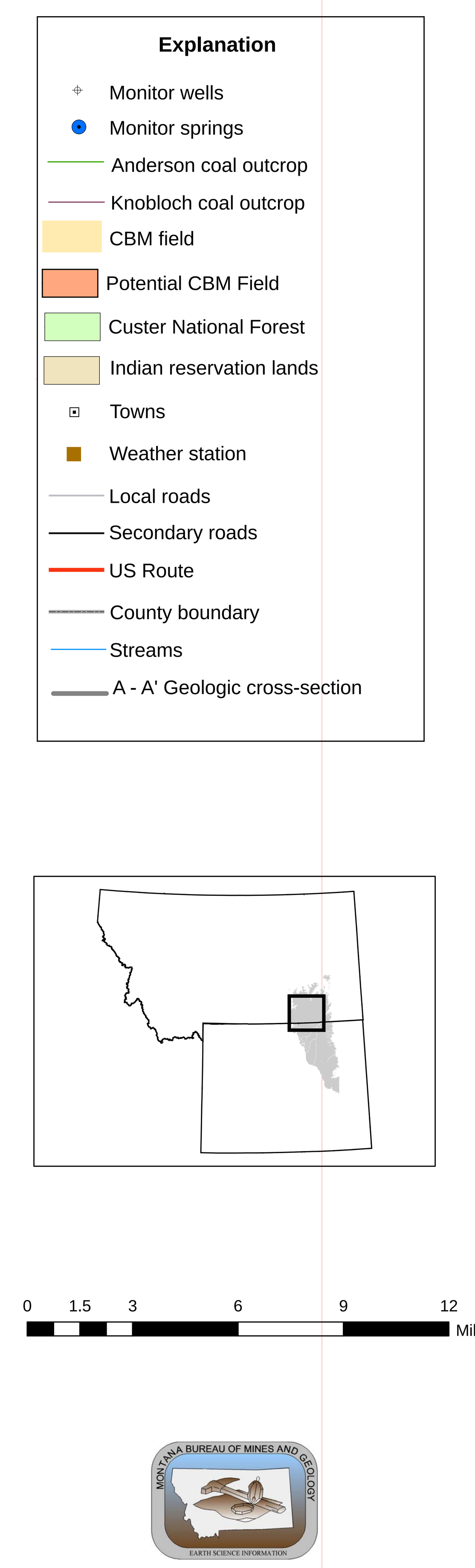
Gwic Id	Sodium (mg/l)	Sodium absorption ratio	Potassium (mg/l)	Iron (mg/l)	Manganese (mg/l)	Silica (mg/l)	Bicarbonate (mg/l)	Carbonate (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)	Flouride (mg/l)	Orthophosphate (mg/l)	Silver (ug/l)	Aluminum (ug/l)
7573	523.0	6.9	25.6	0.702	0.540	24.0	684.4	0	1620.0	<25.0	<2.5 P	<2.5	<2.5	<10	160.0
7775	547.0	6.1	23.4	5.670	0.948	27.7	885.7	0	1995.0	<25.0	<2.5 P	<2.5	<2.5	<10	<100
197607	299.0	4.8	10.5	0.009	0.008	13.5	1045.1	0	515.0	5.2	<0.5 P	0.782	<0.5	<5	<30
207066	41.4	0.9	9.3	2.820	0.217	29.3	582.8	0	84.6	3.9	<0.5 P	0.683	<0.05	<1	<10
223877	102.0	2.0	13.4	0.078	0.015	22.6	577.3	0	272.0	6.7	<0.5 P	1.190	<0.5	<1	<10
199573	332.0	5.1	8.7	0.201	0.139	11.5	766.2	0	879.0	<10.0	<1.0 P	<1.0	<1.0	<5	<50
228591	25.0	0.8	11.9	<0.005	<0.001	23.0	177.9	0	106.0	7.0	0.98 P	1.000	<0.05	<1	<30
204956	263.0	4.8	9.0	0.960	0.158	15.4	677.8	0	557.0	12.2	<0.5 P	1.160	<0.5	<5	<30
223801	922.0	9.6	7.8	<0.05	0.032	11.6	777.1	0	3026.0	<50.0	<5.0 P	<5.0	<5.0	<10	<100
223695	251.0	29.9	2.0	0.051	0.002	7.2	702.4	0	<2.5	23.3	<0.5 P	1.930	<0.05	<1	<10
8506	733.0	12.5	28.6	2.980	1.570	27.6	1361.2	0	1180.0	115.0	<0.50 P	1.220	<0.50	<5	<300
223952	620.0	20.4	6.9	0.113	0.018	12.1	1661.6	0	193.0	57.5	<0.5 P	2.760	<0.5	<5	<30
228592	66.5	1.3	5.0	0.504	0.304	20.4	428.6	0	274.0	10.9	<0.25 P	0.286	0.078	<1	<30
123796	1095.0	19.6	13.8	<0.05	0.081	8.4	993.4	0	1641.0	26.4	32.1 P	<1.00	<1.0	<10	<300
122766	684.0	5.6	30.0	8.530	1.050	24.1	721.0	0	3711.0	<50.0	<5.0 P	<5.0	<5.0	<10	<100
219136	453.0	5.2	6.7	1.910	0.522	10.5	473.4	0	1987.0	<25.0	<2.5 P	<2.5	<2.5	<5	<50
220857	398.0	4.7	8.6	0.033	0.998	20.0	501.4	0	1460.0	214.0	<2.5 P	<1.0	<1.0	<5	<50
220859	261.0	3.5	9.6	1.750	0.913	18.9	412.4	0	1094.0	128.0	<2.5 P	<1.0	<1.0	<1	<10
7905	540.0	7.1	19.7	0.366	0.840	21.8	843.0	0	1511.0	<25.0	<2.5 P	<2.5	<2.5	<5	<50
198489	1204.0	9.7	12.3	8.390	1.980	13.7	768.6	0	5226.0	<50.0	<5.0 P	<5.0	<5.0	<10	<100
8888	1086.0	10.0	13.1	6.360	2.050	14.0	807.6	0	3825.0	<50.0	<5.0 P	<5.0	<5.0	<10	<100

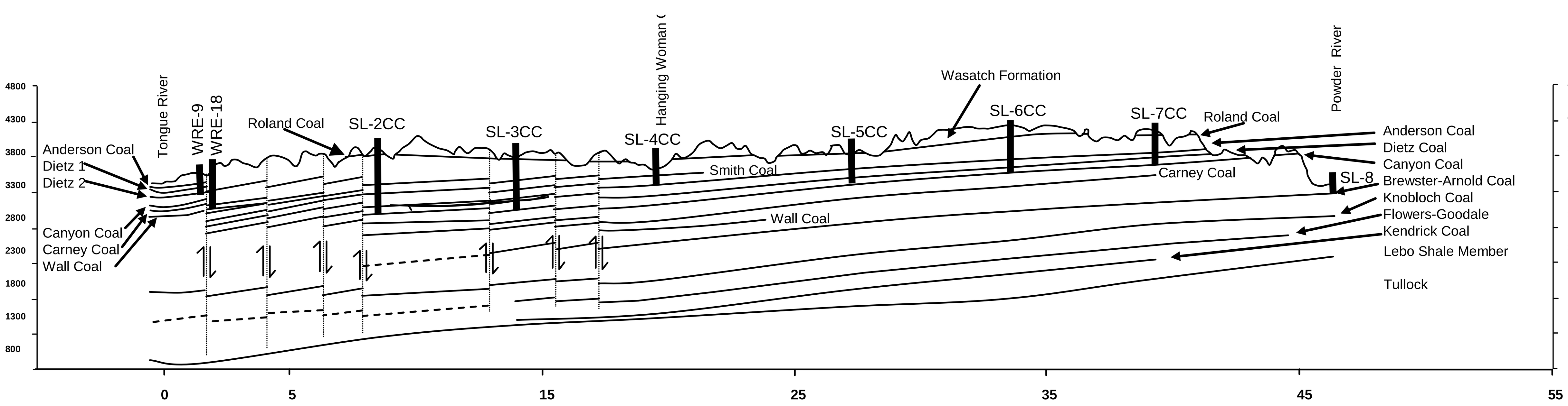
Gwic Id	Arsenic (ug/l)	Boron (ug/l)	Barium (ug/l)	Beryllium (ug/l)	Bromide (ug/l)	Cadmium (ug/l)	Cobalt (ug/l)	Chromium (ug/l)	Copper (ug/l)	Lithium (ug/l)	Molybdenum (ug/l)	Nickel (ug/l)	Lead (ug/l)	Antimony (ug/l)	Selenium (ug/l)	Strontium (ug/l)	Titanium (ug/l)
7573	<10	461.0	21.1	<10	<2500	<5	<10	<20	<20	145.0	<50	<10	<20	<20	<10	2808	<5
7775	<10	427.0	<20	<20	<2500	<10	<20	<20	<20	164.0	<100	<20	<20	<20	<10	3336	<10
197607	<5	547.0	16.5	<2	<500	<1	<2	<10	<5	195.0	<10	<2	<10	<10	<5	2136	<10
207066	2.6	116.0	70.4	<2	<50	<1	<2	<2	<2	53.5	<10	<2	<2	<2	<1	1209	<1
223877	1.2	210.0	72.5	<2	<500	<1	<2	<2	<2	79.8	<10	<2	<2	<2	<1	1309	<1
199573	<5	<150	15.0	<10	<1000	<5	<10	<10	<10	155.0	<50	<10	<10	<10	<5	3648	<5
228591	6.4	159.0	67.4	<2	100	<1	<2	2.250	<2	83.8	<10	<2	<2	<2	3.470	988	<1
204956	<5	521.0	20.7	<2	<500	<1	<2	<10	<5	129.0	<10	<2	<10	<10	<5	2078	1.49
223801	<10	<300	<20	<20	<5000	<10	<20	<20	<20	213.0	<100	<20	<20	<20	<10	3812	<10
223695	<1	106.0	166.0	<2	82	<1	<2	9.280	3.110	25.1	<10	<2	<2	<2	1.360	142	<1
8506	23.3	<150	32.8	<10	<500	<5	<10	<10	<10	170.0	<50	<10	<10	<10	<5	4548	<10
223952	<5	308.0	32.1	<2	<500	<1	<2	<10	<5	116.0	<10	<2	<10	<10	<5	1763	<1
228592	<1	87.8	63.3	<2	<50	<1	<2	<2	<2	22.1	<10	<2	<2	<2	<1	617	<1
123796	<10	<300	<20	<20	<1000	<10	<20	<20	<20	413.0	<100	<20	<20	<20	30.100	6193	<10
122766	<10	<300	<20	<20	<5000	<10	<20	<20	<20	322.0	<100	<20	<20	<20	<10	6367	<10
219136	<5	<300	<10	<10	<2500	<5	<10	<10	<10	166.0	<50	<20	<10	<10	<5	5305	<10
220857	<5	<150	23.5	<10	<1000	<5	<10	12.400	<10	53.3	<50	<10	<10	<10	<5	2953	<5
220859	3.2	84.5	30.6	<2	<1000	<1	<2	5.240	2.800	43.6	<10	<10	<2	<2	1.260	2429	<5
7905	<5	306.0	26.0	<10	<2500	<5	<10	<10	<10	141.0	<50	<10	<10	<10	<5	2540	<5
198489	<10	<300	<20	<20	<5000	<10	<20	<20	<20	245.0	<100	<20	<20	<20	<10	7524	<10
8888	<10	<300	<20	<20	<5000	<10	<20	<20	<20	236.0	<100	<20	<20	<20	<10	6309	<10

Gwic Id	Thallium (ug/l)	Uranium (ug/l)	Vanadium (ug/l)	Zinc (ug/l)	Zirconium (ug/l)	Total Dissolved Solids
7573	<50	29.5	<50	<10	<10	2836
7775	<50	11.6	<50	<20	<20	3458
197607	<25	5.73	<10	2.16	<2	1579
207066	<5	0.67	<5	<2	<2	595
223877	<5	5.43	<5	<2	<2	854
199573	<25	1.2	<25	<10	<10	1860
228591	<5	2.77	47	<2	<2	321
204956	<20	<3	<10	<2	<2	1368
223801	<50	50	<50	<20	<20	4877
223695	<5	<1	<5	<2	<2	635
8506	<25	4.69	<25	<10	<20	2969
223952	<25	<3	<10	<2	<2	1764
228592	<5	5.06	<5	8.21	<2	747
123796	<50	8.65	<50	<20	<20	3434
122766	<50	28	<50	<20	<20	5612
219136	<25	<3	<25	<10	<20	3148
220857	<25	25.9	<25	<10	<10	2825
220859	<5	20.8	<5	3.38	<2	2094
7905	<25	12.7	<25	<10	<10	2833
198489	<50	34.1	<50	24.8	<20	7724
8888	<50	17.4	<50	<20	<20	6030

Plate 1. Locations of 2006 monitoring sites, proposed 2007 monitoring site plan, and Anderson and Knobloch coal outcrops.







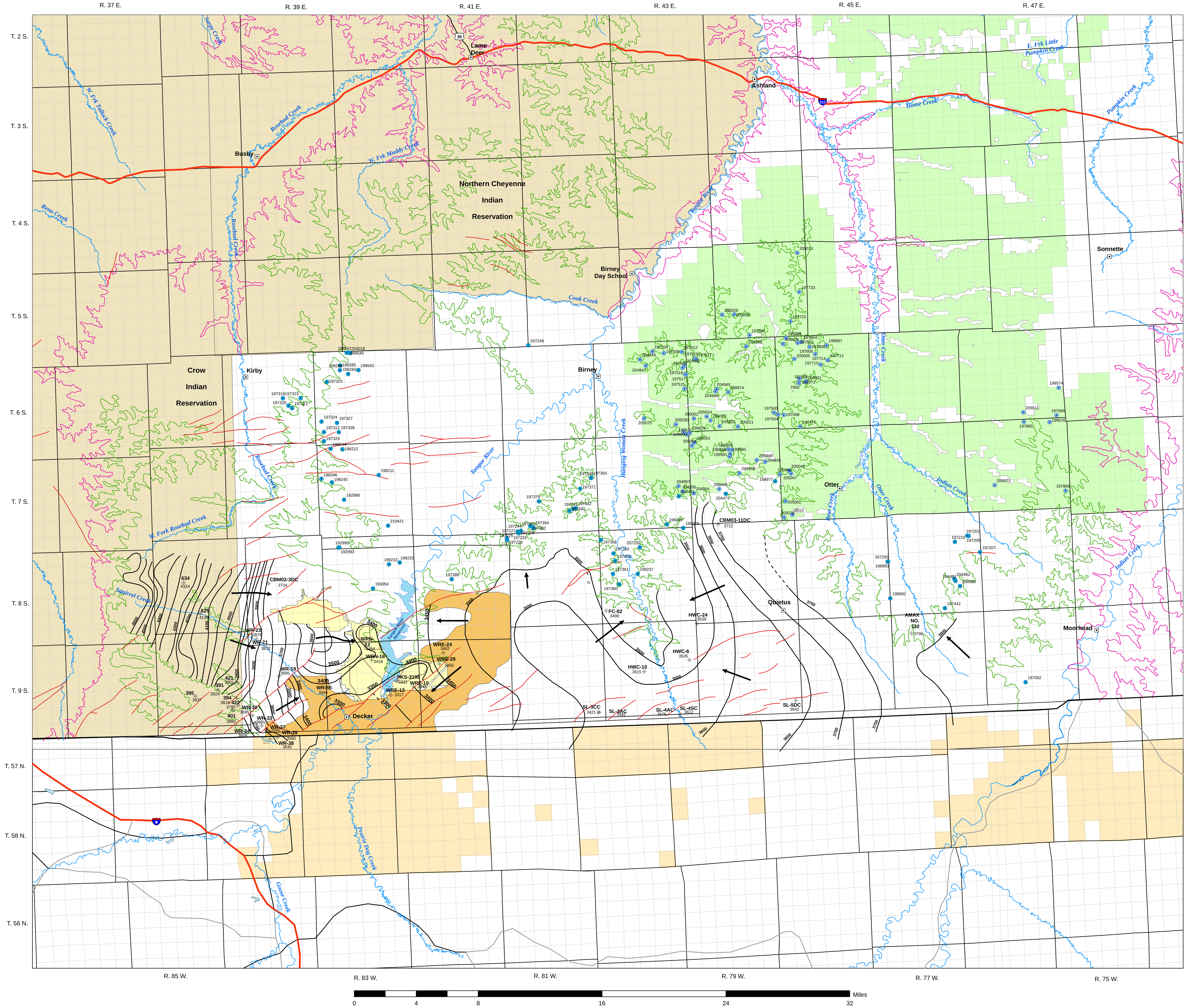
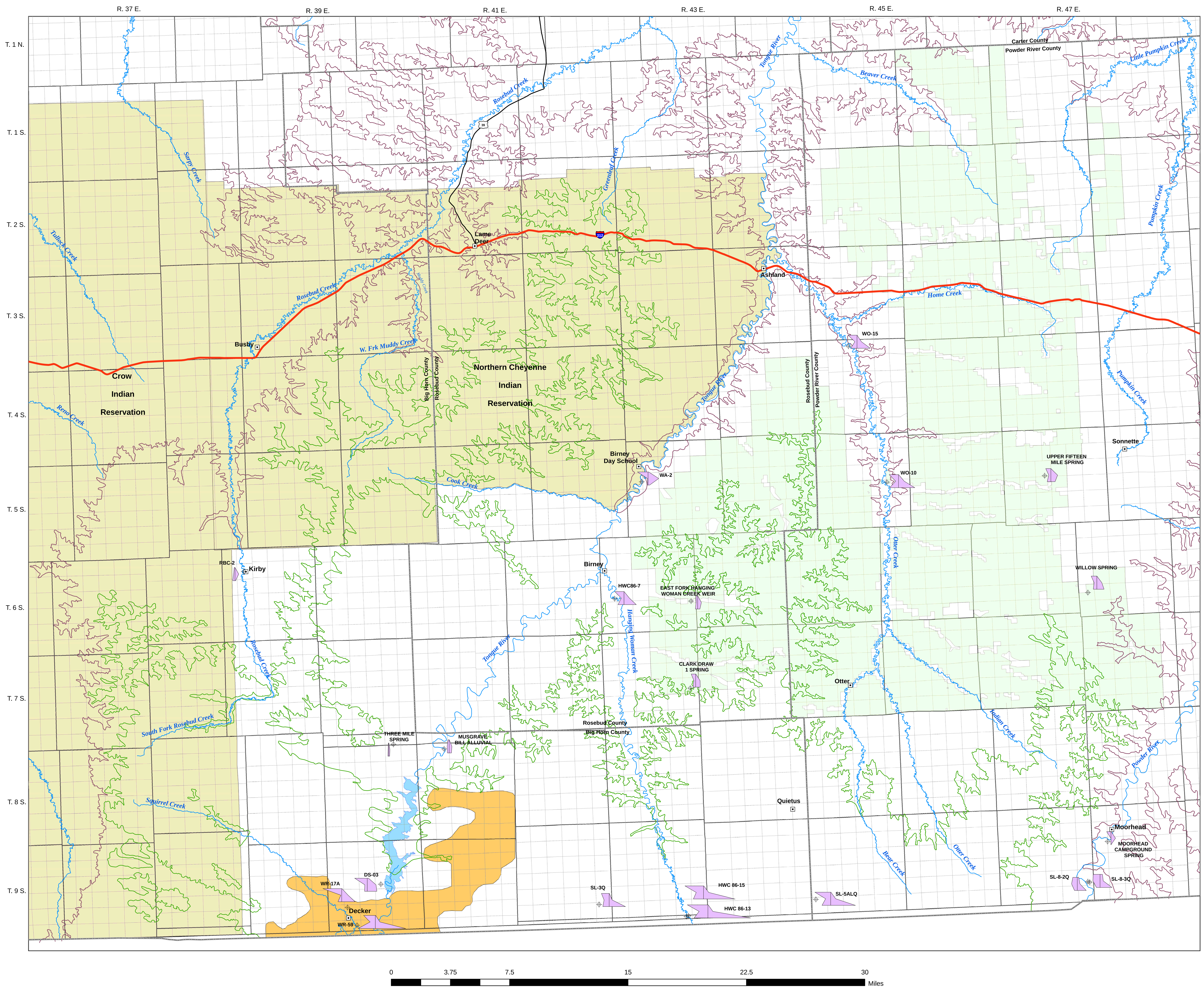


Plate 2. Potentiometric surface for the Dietz coal bed in the southern portion of the Powder River Basin, Montana.

Explanation

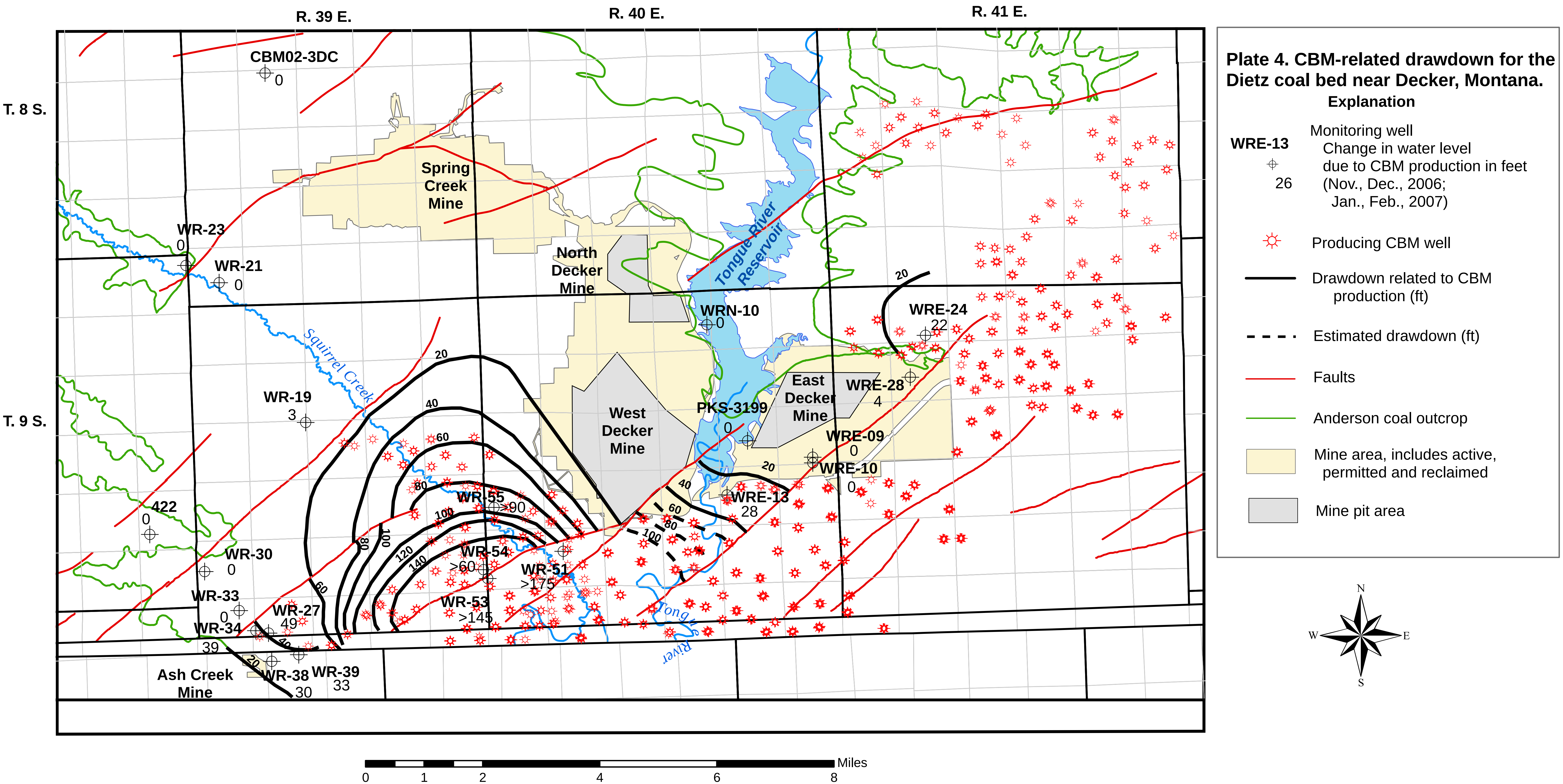
- Potentiometric surface, dashed where inferred (in ranges 37 and 38 east, modified from Hedges and others, 1998)
- Approximate direction of ground-water flow
- WR-39 3566 — Well name, water-level altitude (ft) (November, 2006, December, 2006)
- 197319 — Spring with Dietz coalbed association GWIC Identifier Number
- Anderson coal outcrop
- Knobloch coal outcrop
- Faults
- Mine area, includes active, permitted and reclaimed
- Mine pit boundary
- Area of active CBM production (12/31/2006)
- CBM production field
- Indian Reservation land
- Custer National Forest

Plate 3. Water quality samples collected during the 2006 field season.



Explanation

- Water quality sites 2006
- Stiff diagram showing concentrations of sodium, chloride, calcium, bicarbonate, magnesium, and sulfate.
- Anderson coal outcrop
- Knobloch coal outcrop
- Custer National Forest
- Area of active CBM production
- Indian Reservation land



R. 39 E.
R. 40 E.
R. 41 E.
T. 8 S.
T. 9 S.
CBM02-3DC
0
Spring
Creek
Mine
North
Decker
Mine
West
Decker
Mine
East
Decker
Mine
Ash Creek
Mine
Tongue River
Reservoir
Squirrel Creek
Tongue River
WR-23
0
WR-21
0
WR-19
3
422
0
WR-30
0
WR-33
0
WR-34
39
WR-27
49
WR-38
30
WR-39
33
WR-55
>90
WR-54
>60
WR-51
>175
WR-53
>145
WRN-10
0
PKS-3199
0
WRE-24
22
WRE-28
4
WRE-09
0
WRE-10
0
WRE-13
28
0 1 2 4 6 8 Miles
Plate 4. CBM-related drawdown for the Dietz coal bed near Decker, Montana.
Explanation
WRE-13
26
Monitoring well
Change in water level due to CBM production in feet (Nov., Dec., 2006; Jan., Feb., 2007)
Producing CBM well
Drawdown related to CBM production (ft)
Estimated drawdown (ft)
Faults
Anderson coal outcrop
Mine area, includes active, permitted and reclaimed
Mine pit area
N
S
E
W