1993–2006 coalbed natural gas regional groundwater monitoring report:

Powder River Basin, Wyoming

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Palo monitoring well, northern Campbell County, Powder River Basin, Wyoming. *Photo by David Croft, U.S. Bureau of Land Management, Buffalo Field Office (2009).*

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Cover: Streeter monitoring well, southeastern Johnson County, Powder River Basin, Wyoming. *Photo by David Croft, U.S. Bureau of Land Management, Buffalo Field Office (2010).*

1993–2006 coalbed natural gas regional groundwater monitoring report:

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Abstract

Coalbed natural gas (CBNG) is an important resource in northeastern Wyoming's Powder River Basin (PRB). This report presents and interprets well data collected from the Bureau of Land Management's (BLM) PRB deep monitoring well network. These data were collected from 111 monitoring wells from 1993 through 2006. The BLM deep monitoring well network was designed and constructed to evaluate potential leakage between the CBNG water-producing coal deposits and adjacent sandstone beds and to measure the effects of CBNG production on groundwater. Between 1987 and 2006, CBNG production in the Wyoming PRB produced 534,000 acre feet of groundwater.

Groundwater models and drawdown predictions have been used to forecast the potential hydrogeologic impacts of CBNG production in Wyoming. The BLM deep monitoring well data was used to evaluate impact analysis models (Applied Hydrology Associates Inc. [AHA] and Greystone Environmental Consultants Inc. [GEC] 2002). CBNG impacts to groundwater levels in all of the Fort Union Formation coal wells are less than drawdowns predicted by the 2002 groundwater model (AHA and GEC, 2002), which also predicted a higher rate of CBNG development in the PRB. Aquifer drawdown has been recorded in some of the overlying sandstone beds of the Wasatch Formation.

CHAPTER 1

Introduction

Since the late 1990s, Wyoming's PRB has been the center of extensive CBNG development, the production of which requires the extraction of groundwater. To help assess the impact on regional groundwater resources, the BLM entered into a cooperative agreement with the Wyoming State Geological Survey (WSGS) to compile and evaluate data collected by the BLM groundwater monitoring well network. BLM monitoring well data were collected and analyzed through the years 1993 to 2006, including information on well construction and completion, water levels, and wellhead gas pressure. This report discusses the affect on groundwater from the drawdown of CBNG production and compares the true data to the modeled (predicted) data.

Beginning in 1993 with eight wells in two locations, water-level and wellhead gas pressure data were collected by the BLM. The monitoring well network expanded to 111 wells at 48 locations in the PRB of northeastern Wyoming by 2006 (**Figure 1**). These monitoring data are available on the Wyoming Energy Resource Information Clearinghouse Web site at wygl.wygisc.org/wygeolib. Additional monitoring wells are located in the adjacent area of the northern PRB in southeastern Montana. This report summarizes the Wyoming portion of the monitoring well database (**Figure 1**). An evaluation of the collected data and the hydrographs and wellhead gas pressure charts for each well or well set site are discussed in the Appendix.

This report is part of an ongoing, cooperative project between agencies in Montana and Wyoming to conduct CBNG-related groundwater monitoring in the PRB. The adjacent BLM monitoring well network in the Montana portion of the PRB is managed by the Montana Bureau of Mines and Geology (MBMG).

The Montana monitoring well network reports include Wheaton and Donato (2004) for the year 2003, Wheaton et al. (2005) for the year 2004, Wheaton et al. (2006) for the year 2005, Wheaton et al. (2007) for the year 2006, and Wheaton et al. (2008) for the year 2007. Montana PRB monitoring reports are online at www.blm.gov/mt/st/en/fo/miles_city_field_office/cbng/monitoring.html. The data used in the Montana reports are available at mbmggwic.mtech.edu.

Since 1997, hydrologic impacts in the Wyoming PRB from CBNG development have been regionally confined to coal beds of the Tongue River Member in the Fort Union Formation and some of the lower sandstone beds in the overlying Wasatch Formation. By December 31, 2006, there were approximately 24,000 CBNG wells drilled and completed in the Wyoming PRB (Wyoming Oil and Gas Conservation Commission, 2008). This total includes both producing (72 percent) and shut-in (28 percent) wells. During 2006, CBNG operations in the Wyoming PRB produced 377 billion cubic feet (Bcf) of natural gas. The cumulative total groundwater production for the CBNG development in the Wyoming PRB was approximately 172 billion gallons at the end of December 2006 (Wyoming Oil and Gas Conservation Commission, 2008).

Drawdown maps were prepared for coal deposits in the Fort Union Formation (see **Figures 5–8**, **pages ?-?**). The 2006 drawdown maps were prepared for four combined coal zones based on their stratigraphic positions within the basin. These maps were compared to the predicted drawdowns and used to analyze groundwater impacts of CBNG production.

PURPOSE AND SCOPE

The purpose of this report is to compile, interpret, and evaluate data collected by the BLM deep monitoring well network in the Wyoming portion of the PRB through the end of 2006. This is an initial report and subsequent work will expand upon the first analysis.

BLM deep monitoring wells are installed for the purpose of monitoring impacts associated with the change of water levels in coal deposits during CBNG activities. The BLM began collection of monitoring

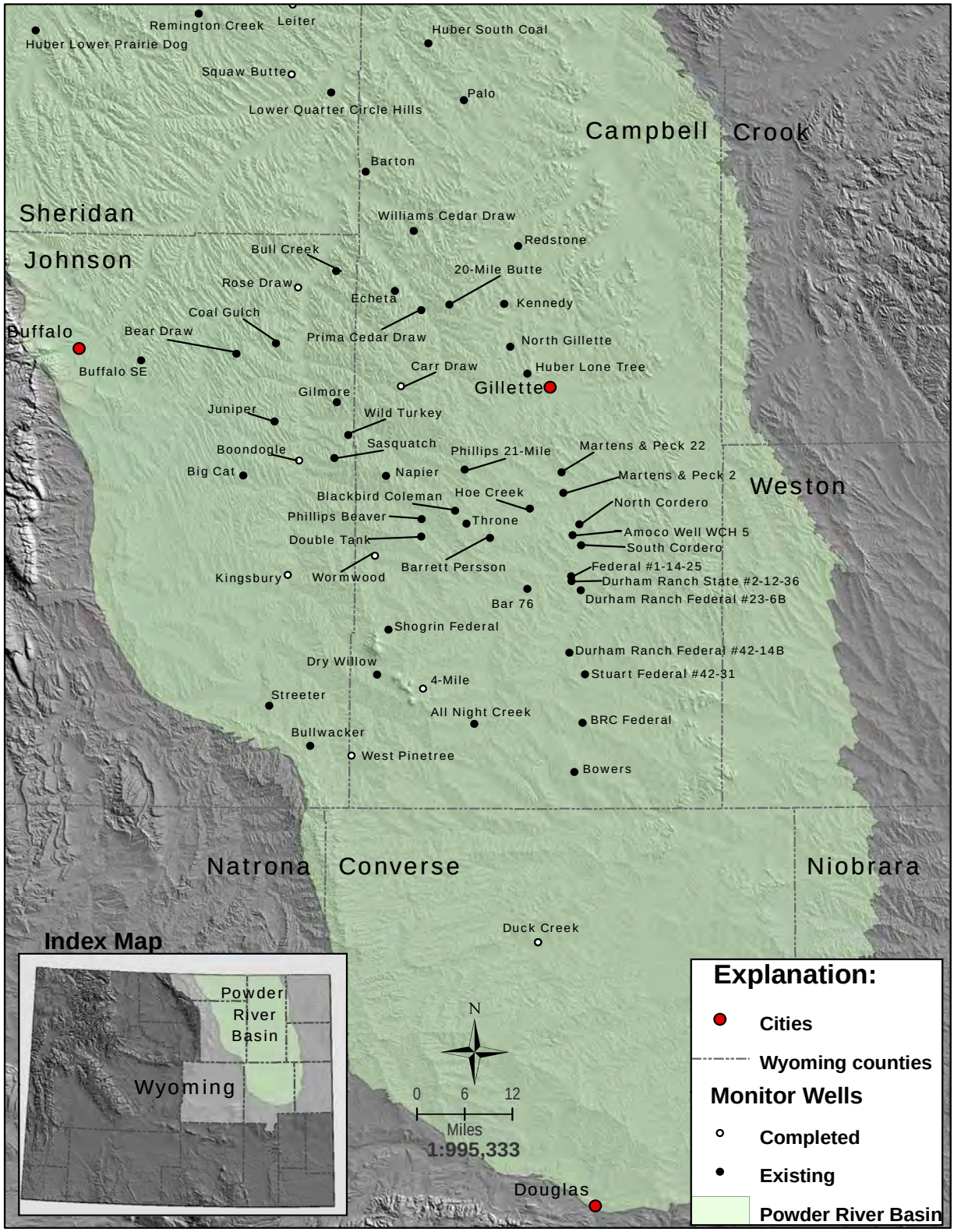

Figure 1. Locations within the Powder River Basin of deep monitoring well network wells as of 2006. Existing well locations denote wells that have been drilled but have no data. Completed wells are those associated with data and used as part of the report. *Illustration by Richard J. Hays, WSGS (2010).*

well data in 1993. Additional wells have been added annually to the network. Other BLM wells monitor shallow groundwater resources that may be potentially impacted by CBNG surface water discharges. Specifically, the purposes of the deep groundwater monitoring program are to:

1. Analyze and interpret data collected from the BLM deep monitoring well network and produce a report of the findings. The groundwater monitoring program was established under the Wyodak Coal Bed Methane Final Environmental Impact Statement (FEIS), 1999, and was in direct response to issues raised as a result of CBNG development in the PRB.

2. Monitor and measure leakage between the producing coal zones and adjacent (overlying and underlying) sandstone units and measure the overall extent of drawdown of water levels in the coal producing zones.

3. Compare the measured versus predicted impacts from the PRB FEIS and Wyodak EIS associated with water pumpage from the coal zones. This comparison will be further evaluated by the BLM and other federal and state agencies that are cooperative members of the Montana-Wyoming Inter-Agency Task Group. The predicted groundwater impact information is detailed in a 2002 groundwater modeling technical report (AHA and GEC, 2002).

BLM deep monitoring well data collected since 1993 were analyzed to assess the degree to which the BLM's original project objectives have been met. Some specific objectives initially developed for the groundwater monitoring program were to:

1. Establish baseline conditions for the potentiometric surface using the groundwater-level data collected by the BLM in the Wyoming PRB. These data are needed for the future calibration of groundwater modeling efforts.

2. Quantify drawdown in the coal bed production zone and leakage between the coal bed production zone and overlying/underlying strata. These data are critical to conduct an impact analysis of groundwater resources for areas within the PRB.

3. Measure wellhead total natural gas pressure build-up in production zone monitoring wells. Continuous monitoring data on total wellhead gas pressure for wells completed into production coal bed zones were and are used to estimate in-situ desorption pressure of total natural gas.

4. Measure potential changes in the percentage of methane in monitoring wells completed into production coal bed zones and overlying/underlying strata to detect possible gas migration from coal bed production zones to adjacent formations.

5. Quantify groundwater-level recovery and aquifer recharge rates within the monitoring wells. This would follow future cessation of CBNG production in the PRB. Little is known about groundwater recharge rates and mechanisms in the Wyoming PRB. The rates of water-level recovery following cessation of CBNG production may be used to estimate recharge rates and the duration of CBNG impacts. The rate of recovery will be analyzed when water-level recharge data become available after CBNG production is complete.

Monitoring of the Wyoming PRB may be separated into two time intervals (1993–2001 and 2002–2006) relative to the two BLM EISs (U.S. Bureau of Land Management, 1999, and U.S. Bureau of Land Management, 2003).

CBNG activity in the PRB for the period 1993–2002 follows:

- As of the end of 2002, there were 14,220 CBNG wells permitted in the Wyoming PRB. Of these, 10,732 wells were in production, and 3,488 were shut-in (Wyoming Oil and Gas Conservation Commission, 2008).

- There was a cumulative total of 532 Bcf of natural gas production by CBNG through 2001 (Wyoming Oil and Gas Conservation Commission, 2008).

- There was a cumulative total of 114,000 acre feet of CBNG water production in the Wyoming PRB through 2001 (Wyoming Oil and Gas Conservation Commission, April 1, 2008).

CBNG activity in the PRB for the period 2002–2006 follows:

- As of the end of 2006, there were 24,002 CBNG wells permitted in the Wyoming PRB. Of these, 17,202 were in production, and 6,800 wells were shut-in (Wyoming Oil and Gas Conservation Commission, 2008). These data show that approximately 10,000 additional CBNG wells were permitted for construction in the Wyoming PRB from January 2003 through December 2006.

- There was a cumulative total of 2,250 Bcf of natural gas production by CBNG activities in the Wyoming PRB through 2006 (Wyoming Oil and Gas Conservation Commission, 2008).

- There was a cumulative total of 390,000 acre feet of CBNG water production in the Wyoming PRB through 2006 (Wyoming Oil and Gas Conservation Commission, 2008).

STUDY AREA

The BLM deep well monitoring program is concentrated in Campbell, Johnson, and Sheridan counties in the northern portion of the PRB in northeastern Wyoming. As shown on **Figure 1**, the study area covers approximately 12,500 square miles (approximately 347 townships) extending from T. 32 N. to T. 58 N. and from R. 66 W. to R. 86 W. The PRB occupies the western part of the Northern Great Plains physiographic province. This project report concerns only the Wyoming portion of the PRB.

Geography

The Powder River structural basin is a 24,000-square-mile basin approximately 120 miles wide and 200 miles long (**Figure 2**). It is bound on the west by the Bighorn Mountains and on the east by the Black Hills. The south end is bound by a combination of the relatively low-lying Casper Arch, the Laramie Mountains, and the Hartville Uplift. The north end is partially closed by the Miles City Arch.

The majority of the PRB is sparsely populated. The largest communities are Buffalo, Gillette, Moorcroft, Newcastle, Sheridan, and Wright. Two rail lines transport large quantities of coal out-of-state. Interstate 90 (I-90) crosses the basin from east to west, and Interstate 25 (I-25) crosses the western PRB from the south, intersecting with I-90 near Buffalo. Relatively few federal, state, and county roadways connect the cities, towns, and smaller communities. The major industries in the basin include conventional oil and gas, CBNG, surface coal mining, agriculture (ranching and farming), and recreation/tourism.

The basin is drained almost primarily by the Powder River. Other drainages include the Belle Fourche, Cheyenne, Little Missouri, and Tongue rivers and their tributaries (**Figure 3**). The major drainages are composed of the Upper and Middle Powder River, Clear Creek, Crazy Woman Creek, Salt Creek, Upper Belle Fourche, Little Pawder River, Antelope Creek, and Cheyenne River sub-basins. PRB surface waters flow northward and eastward into the Missouri River system.

The grasslands of the basin consist of gently rolling plains with a few mesas and buttes. The annual average precipitation ranges between 10 and 15 inches, the humidity is low, the summers are generally warm (70° to 90°F), and the winters are generally cold (20° to -40°F) (Martner, 1986; Ostresh et al., 1990).

Structural Geology

The Powder River structural basin is a deep, north-plunging, asymmetric syncline. The structural axis of the basin in Wyoming trends north-northwest to south-southeast. The axis is parallel to and located several miles to the east of the western margin of the basin, which parallels the steeply-dipping, faulted

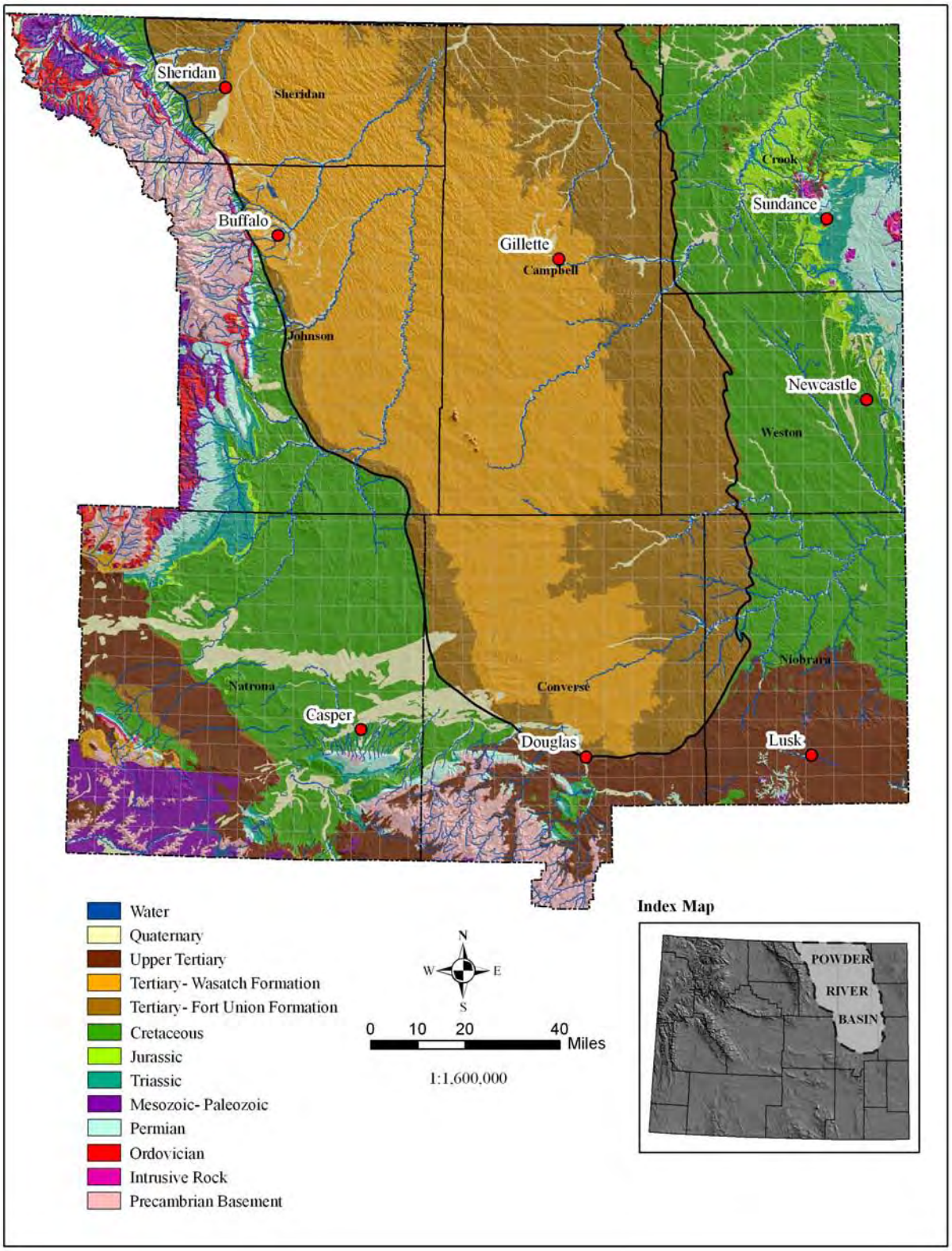

Figure 2. Generalized geologic map, Powder River Basin, Wyoming. *Illustration by Nikolaus W. Gribb, WSGS (2010).*

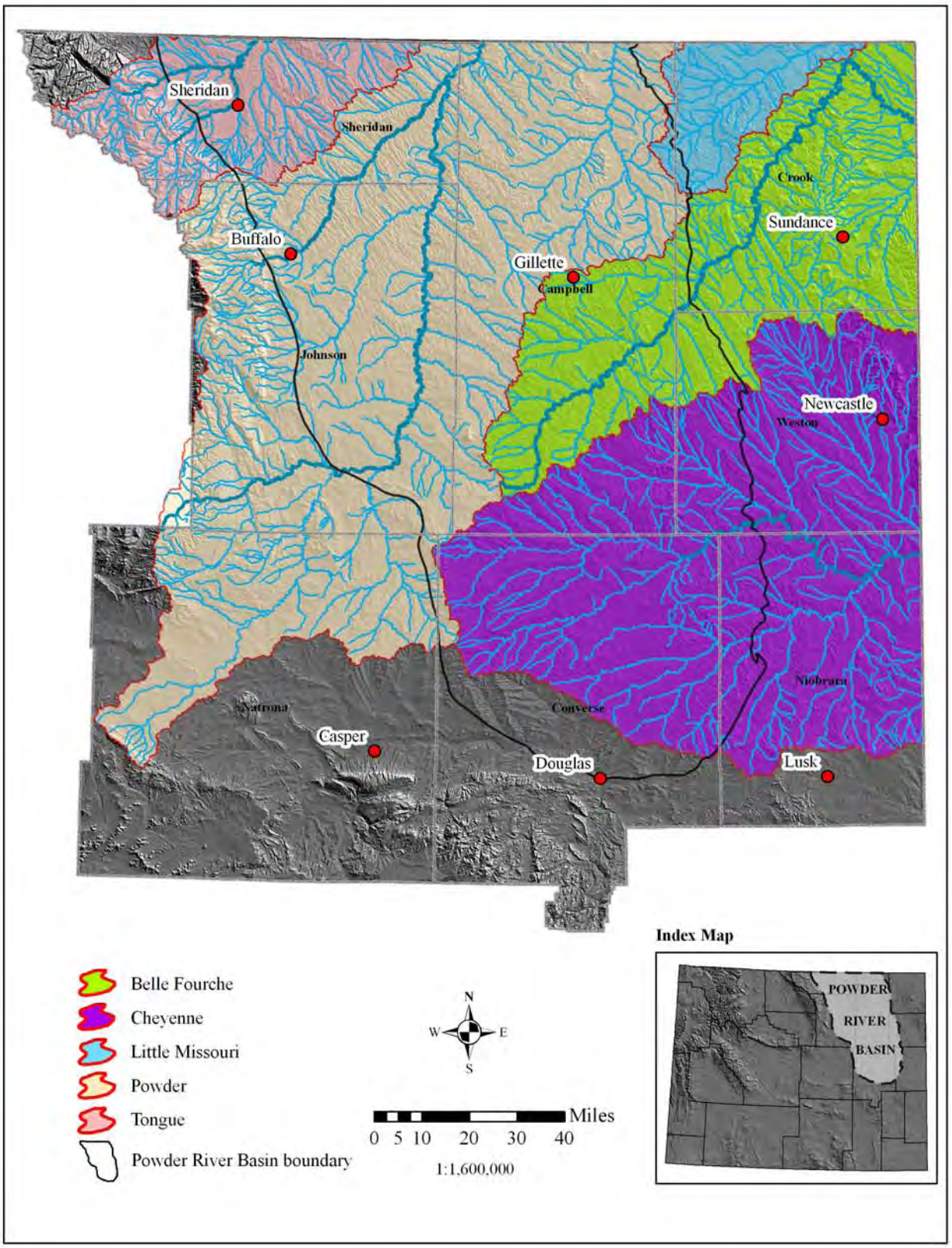

Figure 3. Major drainages, Powder River Basin, Wyoming. *Illustration by Gribb, (2010).*

eastern flank of the Bighorn Mountains (Feathers et al., 1981). The deepest part is along the basin axis, east of the Bighorn Mountains. The basin is filled with more than 18,000 feet of Paleozoic-, Mesozoic-, and Cenozoic-age sedimentary formations (Feathers et al., 1981). Geologic cross sections through the northern and central structural basin are presented in McLellan et al. (1990), and PRB coal cross sections are shown in Jones (2008).

On the eastern side of the basin, the formations dip gently from one to three degrees westward; therefore, most of the coal deposits mined in the Wyoming PRB are along the eastern basin margin (Jones, 2008). PRB coal deposits vary in size but can be more than 100 feet thick (Jones, 2008). Along the western basin margin and east of the Bighorn Mountains, the formations commonly have steep eastward dips from 20 to 25 degrees with locally overturned bedding (e.g., Ver Ploeg et al., 2008)

Structurally, the PRB is mildly deformed. Major reverse and thrust faults are present along the flanks of the surrounding uplifts, some of which have strike-slip components (Brown, W.G., 1993). Within the basin, there are normal faults with small displacements (typically less than 150 feet of vertical movement), regional lineaments associated with Precambrian basement motions, and gentle anticlinal and synclinal folds (Clarey and Stafford, 2008; Jones, 2008; Surdam et al., 2008; Ver Ploeg et al., 2008).

Geologic History

The geologic history of the coal-bearing formations in the PRB begins during the Late Cretaceous, when compressional plate tectonics of the Laramide Orogeny slowly elevated the land, draining away an existing sea and creating the uplifts and structural arches that now outline the PRB. This mountain-building period continued from the Late Cretaceous to the mid-Eocene (Snoke, 1993).

The interior of this newly formed Laramide intermontane basin was low, flat, and swampy. During the Paleocene and Eocene Epochs, these extensive swamps accumulated peat deposits that would later form thick coal deposits (e.g., Jones, 2008). The PRB was then slowly filled with continental sedimentary and volcaniclastic deposits almost to the mountain peaks, and it remained relatively full until the late Miocene Epoch, when regional erosion began lowering the ground surface down to its present level (Mears, 1993).

Stratigraphy

A generalized geologic map of the Wyoming PRB and surrounding areas is shown in **Figure 2**. **Figure 4** shows a generalized stratigraphic column for the Wyoming PRB.

Fort Union Formation

The Paleocene Fort Union Formation consists of a thick non-marine sequence of fine- to medium-grained lenticular sandstone interbedded with siltstone, shale, and coal. The Fort Union has three members – the Tongue River, Lebo Shale, and Tullock, in descending order. In most of the Wyoming PRB, the Fort Union is unconformably overlain by the Eocene Wasatch Formation (Feathers et al., 1981; Ver Ploeg et al., 2008).

The Fort Union Formation ranges in thickness from 1,100 to more than 2,500 feet (Feathers et al., 1981). The depositional environments include fluvial, floodplain, and wetlands. The wetlands were primarily large tree-filled swamps, at times covering most of the basin. These swamps accumulated thick, organic-rich peat deposits, which, after burial and thermal alteration, became the substantial coal deposits of economic importance today. These coal deposits also serve as the primary natural gas reservoirs for recent CBNG activity (Jones, 2008; Surdam et al., 2008).

- The Tullock Member is the oldest Tertiary unit in the Wyoming PRB. The Tullock Member is composed of brown sandstone interbedded with shale, siltstone, and thin coal beds deposited in a fluvial/floodplain/wetland environment (Zelt et al., 1999). The Tullock ranges in thickness from 500 feet in the northeastern PRB to 1,440 feet in southeastern basin (Brown, J.L., 1993).

- The Lebo Shale Member (middle member) consists of gray shale interbedded with gray siltstone, claystone, and sandstone deposited in a lacustrine environment. Fluvial, floodplain and wetland depositional envi-

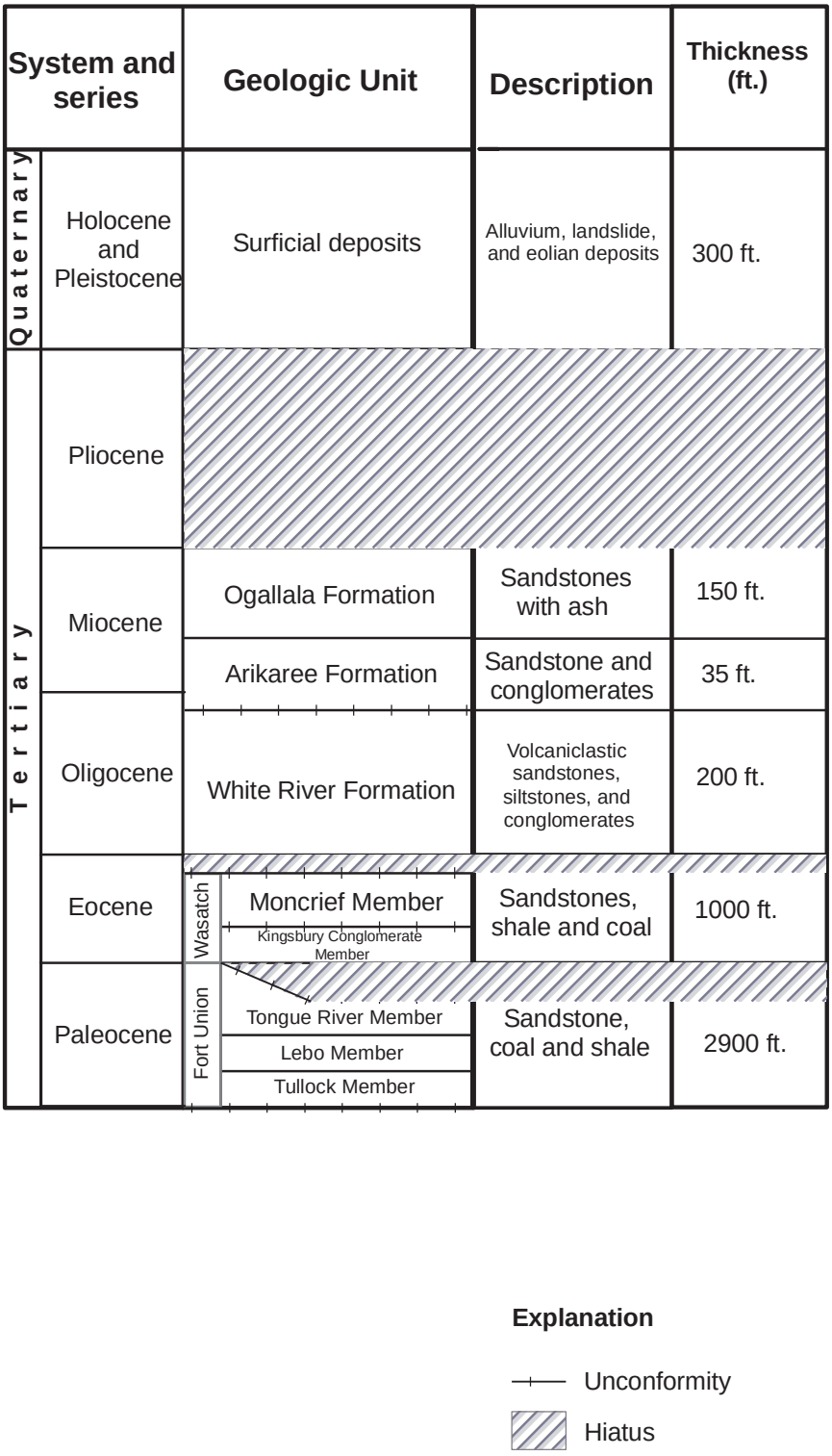

Figure 4. Generalized stratigraphic column from the lower Tertiary through the Quaternary, Powder River Basin, Wyoming. *Illustration by Gribb (2010).*

ronments also contributed sediment (Zelt et al., 1999). The Lebo Shale ranges from 500 feet thick in the northwestern PRB to 1,700 feet in the southwestern basin (Law, 1976).

- The Tongue River Member is the youngest Fort Union member. It consists of yellow fine- to medium-grained, massive, and cross-bedded lenticular sandstone, gray to brown mudstone, carbonaceous shale, and coal deposited in fluvial/flood plain/swamp environments (Zelt et al., 1999). Some coal deposits in the Tongue River Member exceed 200 feet in thickness (Glass and Lyman, 1998; Jones, 2008). Most of the Tongue River coal is subbituminous C in rank. Some lower rank lignite beds are present around the margins of the PRB (Glass and Lyman, 1998).

- The Tongue River coal deposits are thick, variable, and laterally extensive in the Wyoming PRB. The coal deposits vary unpredictably spatially in thickness as they thicken, thin, merge, split, abruptly terminate, or transitionally pinch out laterally. Coal deposits are divided into a hierarchy of stratigraphic names.

Over the past century, the nomenclature of the PRB coal deposits has evolved from work by local residents, geologists, federal agencies, Wyoming agencies, Montana agencies, coal mine operators, CBNG operators, and conventional oil and gas operators (Jones, 2008). Note that the interpretation of the named coal monitoring zones in the BLM deep monitoring wells and other wells within the Wyoming PRB may not match the coal nomenclature system listed in **Table 1** and modified from Jones (2008). The stratigraphic column and nomenclature table (**Table 1**) were developed in an attempt to standardize the nomenclature. The coal deposits of the Tongue River Member host the majority of the total recoverable CBNG resources in the Wyoming PRB, which is estimated at 25.2 trillion cubic feet of natural gas (De Bruin et al., 2004). This is enough to meet the energy needs of approximately 12 million homes for 25 years.

As of 2009, there were 13 large surface coal mines along the eastern PRB (there was also one pending mine). The main coal deposit being mined in the eastern PRB is the 50- to 100-foot-thick Upper and Lower Wyodak coal zones from the upper portion of the Tongue River Member (Jones, 2008).

In 2008, the WSGS defined seven major coal zones in the Tongue River Member of the Fort Union Formation (**Table 1**) (Jones, 2008). These coal zone definitions are based on basin-wide geophysical log correlations from 4,185 wells (Jones, 2008). These seven major coal zones in the Tongue River Member, in order from the uppermost stratigraphic position (youngest) to lowermost position (oldest), are listed in **Table 1**.

Wasatch Formation

The Eocene Wasatch Formation was deposited in nearly identical fluvial-floodplain-wetland environments as the underlying Paleocene Fort Union Formation. The contact between the Fort Union and Wasatch Formations is gradational in most of Wyoming's PRB and has proven to be very difficult to distinguish either in the field or on geophysical well logs. The Wasatch Formation consists of drab, fine- to coarse-grained, lenticular sandstone interbedded with variegated claystone and shale, with numerous coal deposits. The Wasatch has a total thickness of more than 2,000 feet in the central PRB and 1,500 feet in the northern part. As shown on **Figure 4**, the Wasatch has the greatest areal exposure at the ground surface of any geologic formation in the Wyoming PRB.

Groundwater Resources

Groundwater flow within the bedrock aquifers of the PRB is commonly both structurally and stratigraphically controlled, particularly adjacent to the Laramide mountain uplifts. Aquifers are predominantly within interstratified sequences of high- and low-permeability sedimentary beds. Groundwater flow occurs where there is permeability and sufficient head pressure. The PRB aquifers are commonly heterogeneous and anisotropic in character on both local and regional scales. Many of the Tertiary sandstone aquifers of the Fort Union and Wasatch are lenticular in nature and were deposited as sandy stream channels. (Clarey and Stafford, 2008)

Table 1. Stratigraphic column and coal nomenclature table for the Powder River Basin, Wyoming. *Table modified from Jones, 2008.*

Geologic unit	Member	Coal zone	Order	Coal deposit name
Eocene Wasatch Formation				
		Upper Wasatch	1	***Ulm***
			2	***Buffalo Cameron (Lake De Smet)***
			3	***Murray (Lake De Smet)***
			4	***Ucross (Lake De Smet)***
		Felix	5	***Felix Rider***
			6	***Upper Felix***
			7	***Felix***
		Lower Wasatch	8	***Arvada***
			9	(unnamed coal)
Paleocene Fort Union Formation				
	Tongue River			
	1	**Roland**	10	***Upper Roland***
			11	***Roland of Baker***
			12	***Roland of Taff***
	2	**Wyodak Rider**	13	***Smith Rider***
			14	***Smith/Big George***
			15	***Lower Smith***
	3	**Upper Wyodak**	16	***Anderson Rider***
			17	***Anderson***
			18	***Lower Anderson***
	4	**Lower Wyodak**	19	***Canyon Rider***
			20	***Canyon***
	5	**Cook**	21	***Cook***
			22	***Lower Cook***
	6	**Wall**	23	***Wall***
			24	***Lower Wall***
			25	***Pawnee***
	7	**Basal Tongue River**	26	***Moyer***

Locally, groundwater is unconfined (water-table conditions) in shallow outcrop areas of the Wasatch Formation in the central basin and in the shallow outcrop areas of the older (pre-Wasatch) formations along the margins of the basin (Feathers et al., 1981). Groundwater in the unconsolidated Quaternary deposits (e.g., alluvium) is also unconfined. Shallow groundwater flow (less than about 300 to 500 feet below ground surface) is primarily controlled by topography and stream drainage patterns and is discharged to the streams and rivers. The river drainages affecting the Wyoming PRB are the Little Bighorn, Tongue, Powder, Little Powder, Little Missouri, Belle Fourche, Cheyenne, Niobrara, and North Platte rivers.

Deep regional groundwater in the PRB bedrock aquifers flows from recharge areas or outcrops along the basin margins down-gradient towards the structural axis of the basin and north towards the Montana PRB (Davis, 1976). This overall trend may be substantially altered on the local scale by features such as faults, which can function as flow boundaries or conduits for flow, by the heterogeneous character of geologic formations (lenticular aquifers/confining units [aquitards]), and anthropogenic factors. Eventual discharge occurs along stream drainages as springs or as subcrop flow into overlying geologic units (Feathers et al., 1981). Subcrop flow from the deep regional bedrock flow discharges into alluvium along some stream valleys and helps maintain base flow where the streams are gaining (Davis, 1976). Based on local hydrogeologic data in the Wyoming PRB, Davis and Rechard (1977) and Brown (1980) estimated the average infiltration of water recharge into the Wasatch/Fort Union aquifers of the PRB from precipitation to be approximately 0.15 inch per year.

Fort Union Formation

Aquifers in the Fort Union Formation occur in the multiple stacked beds of sandstone and coal. The Fort Union sandstone beds are lenticular and discontinuous. The major coal deposits act as regionally extensive aquifers. Where the Tongue River outcrops along the basin's eastern margins, extensive clinker beds are present. Clinker beds are shales and sandstones that have baked and fused by burnt-out coal deposits, which often results in increase in groundwater permeability (Feathers et al., 1981). Low-permeability confining beds are interbedded with the coal and sandstone and consist of claystone, mudstone, and shale. As a result of these interbedded and stacked lithologies, the Fort Union exhibits heterogeneous stratification, anisotropic groundwater flow, and leaky, low-permeability confining strata interbedded between the permeable sandstone and coal deposits (Feathers et al., 1981; Hinaman, 2005). The Tongue River Member of the Fort Union is considered to be a confined to semi-confined aquifer across most of the PRB.

Locally, Fort Union coal deposits, which directly overlie or underlie adjacent sandstone beds, allow some degree of groundwater communication. The estimated porosity of the three members of the Fort Union is 30 percent for sand beds and 35 percent for non-sand beds (Hinaman 2005). The hydraulic conductivity of the Tongue River Member coal deposits, as determined by multi-well pumping tests, range from 4.6×10^{-7} to 8.6×10^{-4} feet per second (fps), with a median value of 2.3×10^{-5} fps (AHA and GEC, 2002). These reported conductivity values in fps may be converted to feet per day (fpd) with a range from 0.00066 to 1.2 fpd and a median value of 0.033 fpd. The *Wyoming Framework Water Plan* classifies the Fort Union Formation as a major aquifer in the PRB (WWC Engineering, 2007). Coal deposits and clinker typically exhibit better porosity and permeability than the sandstone beds of the Fort Union Formation. Typical aquifer properties of the clinker areas and associated coal deposits include transmissivity of up to 3 million gallons per day per foot of drawdown and well-specific capacity of greater than 2,000 gallons per minute per foot of drawdown (Feathers et al., 1981).

The CBNG development in the Tongue River Member from 1997 through 2006 and the associated pumping and extraction of more than 172 billion gallons of groundwater through 2006 has caused water-level drawdown in some of these coal deposits. Maximum drawdown from initial groundwater levels measured in BLM deep monitoring wells for the Tongue River coal deposits is up to 625 feet. The drawdown in these Tongue River Member coal deposits is the combined result of CBNG development, surface coal mine dewatering from 1980

through 2006, pumping of public water-supply wells, pumping of industrial/miscellaneous wells, pumping of other domestic/irrigation/stock water wells, and possible regional water-level decline from a decade-long drought. While the drawdown of the groundwater levels is not solely due to CBNG development, it is the major source for the drawdown in coal deposits of the Tongue River Member in the Wyoming PRB.

Wasatch Formation

The main water-bearing aquifers in the Wasatch Formation are the coal and sandstone beds. The rest of the formation consists of low-permeability interbedded shales, mudstones, siltstones, and claystones. Some Wasatch wells locally flow water at the ground surface under confined (artesian) pressure. Groundwater from the Wasatch Formation in its outcrop area (**Figure 4**) is extensively used for domestic consumption and livestock watering.

The hydraulic conductivity of the sandstone beds of the Wasatch Formation range from 2.3×10^{-7} to 2.3×10^{-4} fps, with a median value of 6.2×10^{-5} fps (AHA and GEC, 2002). These reported conductivity values in fps may be converted to fpd with a range from 3.3×10^{-4} to 0.33 fpd and a median value of 0.089 fpd. The Wyoming Framework Water Plan (WWC Engineering, 2007) classifies the Wasatch Formation as a major sandstone aquifer within the PRB.

POWDER RIVER BASIN GROUNDWATER MONITORING PROGRAM

Originally, groundwater monitoring in the PRB began as a result of environmental analyses associated with early CBNG projects, including the Marquiss, Lighthouse, Gillette North, and Gillette South projects. Thirty-six groundwater monitoring sites were required by the BLM as part of the approval of these projects between 1993 and 1999 (information provided by the BLM Buffalo Field Office, 2009).

In October 1999, a regional groundwater monitoring program was established under the Wyodak FEIS (U.S. Bureau of Land Management, 1999). The purpose of the program was to evaluate hydrologic communication between producing coals and overlying and underlying sandstone units, and to measure the areal extent of drawdown in the producing zone. These data would be used to verify impact analysis, provide "real time" impact quantification, and provide baseline data for calibration of subsequent CBM modeling efforts.

The Wyodak record of decision stipulated that 140 sets of two or more monitor wells would be drilled over a 10-year period, equaling about two sets per township throughout the projected PRB development area. These well sets were planned to be completed as CBNG development progressed across the basin, and the wells would be stipulated as part of the approval of projects proposed by the various operators.

Additional issues related to CBNG development were later identified during the completion of the Powder River Basin Oil and Gas Project FEIS in 2003, and a new groundwater monitoring approach modified the earlier 1999 Wyodak FEIS program. To address water quality issues and infiltration/recharge interactions of produced water on groundwater systems, modifications to the monitoring requirements and approach specified in the 1999 Wyodak FEIS were made. The BLM decided that by increasing the installation complexity of each monitoring site and selecting monitoring locations representative of major geologic conditions, fewer total well sites would be required. A key to reducing the required number of locations was to complete the wells as far ahead of development as possible.

The BLM developed a reduction from the original 140 proposed well sets of the Wyodak record of decision to between 35 and 40 sets of monitoring wells, equaling approximately four townships per well, for CBNG activity in the Wyoming PRB. These 35 to 40 well sets were planned to include additional monitoring zones including underlying sandstone, multiple coal deposits, and interlying or overlying sandstones and were to be completed within two years. This would allow for improved baseline data collection and provide a better understanding of the CBNG impacts as well as the dynamics of the groundwater system.

From 2002 to 2003, major CBNG operators met with the BLM and the Petroleum Association of

Wyoming (PAW) and agreed who would be responsible for most of the wells (34 of the proposed 47 sites). It was projected that the remaining 13 monitoring locations would be stipulated as part of the approval of other projects as opportunity and need arose. A cooperative agreement between the BLM and PAW, which represented Devon Energy, Marathon Oil Corporation, Williams Production, and Yates Petroleum Corporation, was signed May 30, 2003. Williams obligations were later divided after 2003 between Williams Production and Western/Lance.

BLM DEEP MONITORING WELL NETWORK DATA COLLECTION

Installation of monitoring equipment in the BLM deep monitoring well network has been conducted by BLM personnel from the Casper Field Office and the Buffalo Field Office. Preliminary locations for the proposed monitoring wells were identified soon after the approval of the 2003 PRB Oil and Gas Project FEIS. Final monitoring well locations were selected as CBNG development progressed into an area or when a preliminary location fell within a proposed federal plan of development. Monitoring wells are located on federally owned land where possible. A summary of BLM deep monitoring well data is included in the Appendix. Locations of these wells are illustrated on **Figure 1** and detailed in **Table 2**, and the well site names/acronyms are listed in **Table A-1** in the Appendix. Permit numbers for the BLM wells in the databases of the WOGCC and the WSEO were identified by the WSGS to the extent practicable and added to the summary table (**Table A-1** in the Appendix).

On federal holdings, monitoring wells and equipment were installed prior to the commencement of most CBNG production to determine baseline water levels. Some CBNG wells were installed on private lands prior to the completion of monitoring wells. Therefore, the decline of groundwater levels in some areas may have begun before baseline water levels were established. As a consequence of this staggered timing, some of the BLM deep monitoring wells do not have an accurate baseline groundwater level established.

Most of the BLM deep monitoring wells were installed by CBNG operators during the development of a project area. Monitoring well boreholes were drilled to a depth of 100 feet below the lowest gas production zone. Accompanying wire-line gamma-ray log and other geophysical data were analyzed by BLM personnel to select potential underburden and overburden sandstone zones for monitoring and to design coal zone completions.

All deep monitoring wells were constructed similar to CBNG wells so that the wellhead assembly would withstand high gas pressures. Shallow sandstone wells were constructed for low pressures, as hydraulic communication with underlying coal zones is considered unlikely. Most of the BLM wells have a single steel casing installed to the selected monitoring zone. Some wells are dual completions, where a packer was installed to isolate two different monitoring zones within a single well. The tubing diameter allows for passage of a water-level probe for manual water-level measurements. Some tubes have caused monitoring issues due to constricted annular space.

With the exception of some older wells installed as part of CBNG-exploration activities, most BLM monitoring wells are equipped with continuous-recording equipment. Pressure transducer sensors (installed probes) for recording water level and wellhead gas pressure measurements for each monitoring zone are connected to electronic data-logger equipment that is powered by solar panels connected to 12-volt batteries.

Monitoring of the wells is conducted by the BLM Buffalo Field Office, and most wells are visited on a monthly to quarterly basis. Manual measurements for water level and wellhead gas pressure are conducted to verify the continuous-recording electronic data.

Due to the nature of electronic pressure transducers, the recorded data may drift positively or negatively from the accurate measurement of a parameter. Manual measurements allow for the correction of the electronic data drift between each well station visit so that data integrity is maintained. Flexible, small-diameter airlines are also installed in most wells for independent measurement of water levels. These airline measurements allow for corrections to be made to the electronic water-level measurements, which can be affected by positive borehole gas pressure.

Table 2. Existing wells and potential new wells of the BLM deep monitoring well network by county, Powder River Basin, Wyoming (2006).

County	Well Site Name	Acronym	Latitude	Longitude	Elevation	Start Date
Campbell County	*4-Mile (new)*	*4MILE (new)*				
	20-Mile Butte	20MILE	44 26 12.67472	105 46 35.26046	4560	28-Jan-04
	Phillips 21-Mile	21MILE	44 07 40.56240	105 43 56.38083	5036	19-Mar-04
	All Night Creek	ANC	43 39 13.45846	105 42 09.60749	5220	6-Mar-02
	Amoco Section 36	467236B1	44 00 31.31313	105 27 32.25894	4684	4-Apr-02
	Bar 76	457301A	43 54 20.57655	105 34 15.34457	4768	19-Mar-02
	Barrett Persson	PERSSON	44 00 01.74529	105 39 59.89544	4945	19-Mar-02
	Barton	BARTON	44 40 51.42512	105 59 33.43770	-----	20-Mar-02
	Blackbird Coleman	BBIRD	44 04 25.86397	105 46 56.49654	4778	21-Mar-02
	Bowers	BOWERS	43 33 54.67096	105 27 00.06921	5017	25-Apr-02
	Carr Draw (new)	*CDU (new)*				
	Dilts	DILTS	43 39 23.75172	105 25 47.74415	4925	22-Mar-02
	Double Tank	DTANK	44 00 14.59994	105 50 30.03984	4818	26-Dec-02
	Dry Willow	DRYWILLS	43 44 28.07674	105 57 02.05271	----	15-Aug-99
	Echeta	ECHETA	44 27 39.79642	105 54 54.72446	4265	20-Mar-02
	Hoe Creek	HOE	44 03 26.74899	105 34 03.24337	4733	19-Mar-02
	Kennedy	KENNEDY	44 26 14.11879	105 38 09.72042	4490	21-Mar-02
	Huber Lone Tree	HUBERLT	44 18 25.45252	105 34 32.05859	3715	5-Apr-02
	MP2	MP2	44 05 05.65800	105 28 55.42529	4554	22-Mar-02
	MP22	MP22	44 07 24.16400	105 29 10.61407	4574	22-Mar-02
	Napier	NAPIER	44 06 52.35304	105 55 53.56260	4803	21-Mar-02
	North Cordero	477119C1	44 01 44.30912	105 26 29.77640	4650	4-Apr-02
	North Gillette	NGILL	44 21 12.62089	105 37 23.33962	4479	20-Nov-02
	Palo	PALO	44 48 58.41420	105 44 33.75824	4141	20-Mar-02
	Phillips Beaver Federal	BEAVFED	44 02 10.99162	105 50 29.62074	4783	6-Feb-03
	Pistol Point	PISTOL	43 49 40.44015	105 55 16.26912	5106	4-Apr-02
	Prima Cedar Draw	CEDAR	44 25 25.54376	105 50 47.44666	4279	21-Apr-04
	Redstone	REDSTN	44 32 41.36960	105 36 05.41405	4044	20-Mar-02
	South Cordero	467106C1	43 59 24.77936	105 26 13.87413	4640	4-Apr-02
	Sec. 6 Durham Ranch	457106C	43 54 13.79	105 26 11.50770	4695	22-Mar-02
	Sec. 14 Durham Ranch	447214A	43 47 14.02767	105 27 52.85053	4861	22-Mar-02
	Section 25	467225C	43 55 46.78789	105 27 39.18283	4658	22-Mar-02
	South Coal	SCOAL	44 55 25.25472	105 50 11.89985	----	20-Mar-02
	Stuart Section 31	447131A	43 44 49.35018	105 25 28.42410	4933	3-Apr-03
	Barrett Throne	THRONE	44 01 36.36020	105 43 36.19662	5028	19-Mar-02
	West Pinetree (new)	*WPT (new)*				
	Williams Cedar Draw	WCDU	44 39 04.25601	106 05 22.99279	4120	28-Mar-06
	Wormwood (new)	*WW (new)*				
Converse County	*Duck Creek (new)*	*DUCK (New)*				
Johnson County	Bear Draw Unit	BDU	44 20 16.26371	106 18 55.99678	4624	7-Mar-06
	Big Cat	BIGCAT	44 06 41.78353	106 17 38.76898	4480	10-Jul-03
	Boondogle (new)	*BOONDOGLE (new)*				
	Huber Buffalo SE	BUFFSE	44 19 23.15206	106 33 28.34214	4542	07-Feb-02
	Bull Creek	BULLCRK	44 29 40.98307	106 03 52.56737	3909	22-Nov-05
	Bullwacker	BULLWACK	43 36 34.10396	106 06 53.10396	5050	18-Nov-02
	Coal Gulch Unit	CGU	44 21 32.27853	106 12 57.52599	4500	4-Sep-05
	Gilmore	GILMORE	44 15 02.07217	106 03 31.96638	4536	4-Apr-02
	Juniper	JUNIPER	44 12 47.61391	106 13 00.97144	4400	14-Feb-02
	Kingsbury Unit (new)	*KDU (new)*				
	Sasquatch	SASQUAT	44 51 45.92025	106 11 11.15956	4745	17-Oct-01
	Streeter	STREETER	43 40 57.52531	106 13 09.21529	4745	4-Aug-04
	Prima Wild Turkey	WILDTUR	44 11 21.33853	106 01 42.45475	4344	16-Nov-04
Sheridan County	Lower Quarter Circle Hills	LQC	44 49 39.80989	106 05 01.84174	3618	5-Apr-05
	Leiter (test well)	LEITER	44 59 24.57215	106 11 08.68336	----	17-Oct-01
	Huber Lower Prairie Dog	HUBERPD	44 18 25.45252	105 34 32.05859	3715	20-Mar-00
	Remington Creek	REMCRK	----	----	----	----
	Squaw Butte (test well) (new)	*SQUAWB (new)*				

CHAPTER 2

GROUNDWATER MONITORING RESULTS, 1993–2006

The Tongue River Member coal deposits of the Fort Union Formation are the primary target for CBNG development. In the deeper portions of the PRB, groundwater in Tongue River coal deposits is under confining pressure. Tongue River coal aquifers exhibit water-level drawdowns due to the pumping of groundwater from CBNG production wells.

BLM deep monitoring wells constructed into Tongue River coal deposits are monitored for water level in the well and the total gas pressure at the wellhead. Water-level monitoring includes both manual and electronic methods. The water-level data and wellhead gas pressure charts of the BLM deep monitoring well data are included in the Appendix. The coal monitor wells are designed to record total pressure in the closed wellbore and wellhead pressure. The water level can be determined by subtracting the wellhead pressure from the total pressure and converting the remaining pressure into water level below land surface.

The actual drawdowns measured in the Fort Union coal monitoring wells were compared with the predicted 2006 drawdowns contained in the groundwater technical report (AHA and GEC, 2002). The 2002 groundwater model predicted groundwater drawdowns from the model would range from 500 to greater than 750 feet by the year 2006 (AHA and GEC, 2002); however, the greater predicted drawdowns in the AHA and GEC (2002) model were based on a greater degree of CBNG development in the PRB. Measured water-level drawdowns in the BLM coal monitoring wells did not exceed 500 feet except in four wells: HOEC (Wyodak coal), BULLWACKC (Big George coal), JUNIPERC (Big George coal), and 457301A1 (Wyodak coal).

CBNG FIELDS AND MONITORING WELLS

As of the end of 2006, the BLM deep monitoring well network in the Wyoming PRB includes 48 monitoring well sites, either as single wells or well sets (**Figure 1**). Well sets define wells that are constructed in different stratigraphic intervals, which include Fort Union (Tongue River Member) coal deposits, Fort Union sandstone beds, and Wasatch sandstone beds. Monitoring wells were constructed during different years and at various spatial locations proximal to the CBNG wells.

Locally, a monitoring well in the immediate vicinity of a pumping CBNG-production well may be within the zone of influence (cone of depression) of a pumping well. As a result, a greater drawdown in the monitoring well may be measured than would likely be measured in a monitoring well at a greater distance from CBNG-pumping wells.

Groundwater levels in some areas had likely been affected by CBNG development prior to the completion of BLM monitoring wells. Therefore, pre-existing drawdowns make it difficult to ascertain the original static water level (baseline level) for monitoring wells and to determine an accurate drawdown value. An evaluation of the collected data for each well is discussed in the Appendix.

Through 2006, the existing BLM deep monitoring well network consisted of 111 wells at 48 sites (**Table A-1** in the Appendix and **Figure 1**). The network is composed of 58 Fort Union coal wells, two Fort Union underlying sandstone wells, 52 Wasatch sandstone wells, and one Quaternary alluvial sand bed well. The 58 Fort Union coal wells are grouped by coal deposit(s) and summarized below:

6	Anderson coal wells
1	Wyodak/Anderson coal well
16	Big George coal wells
1	Big George/Lower Smith coal well
2	Smith coal wells
19	Wyodak coal wells
4	Canyon coal wells
3	Cook coal wells
1	Cook/Lower Wall/Pawnee coal well
3	Wall coal wells
1	Wall/Pawnee coal well
1	Pawnee coal well

The 58 BLM coal monitoring wells are listed in **Table 3** by well acronym, coal deposit(s), county, and year the well was first monitored. These wells are grouped by coal deposits, and the well locations are shown on **Figure 1**.

The 54 BLM sandstone and alluvial monitoring wells are listed in **Table 4** by well acronym, lithology, county, and year the well was first monitored. These wells are grouped by well sets, and the locations are shown on **Figure 1**.

SUMMARY OF WATER-LEVEL DRAWDOWN AND RISE IN MONITORING WELLS

Following is a summary of water-level drawdowns and rises in the Fort Union coal and Wasatch sandstone monitoring wells.

Fort Union Coal Monitoring Wells

Water-level drawdowns measured in the Fort Union coal monitoring wells are largely a function of the length of the monitoring period and the distance from CBNG production wells. The baseline water level has not been determined for all of the BLM deep monitoring wells. Some of the initial water levels in the databases and summary tables should be considered as initial water-level measurements and not as baseline water levels. It is more accurate to consider the first water-level measurements as initial readings that may or may not include some unknown amount of pre-existing drawdown. The greatest CBNG development impacts measured in the Fort Union coal wells from greatest to least water-level drawdown are shown in **Table 5**.

One Wyodak coal well (467236B1) was not equipped with monitoring equipment, but some manual measurements are available. As shown in **Table 5**, some coal wells are reported to be completed into two or more coals (e.g., HUBERLTC, Wyodak). The above-listed maximum drawdowns in **Table 5** may also be regrouped by coal deposit (**Table 5**). Multiple-listed coal wells (e.g., HUBERLTC, Wyodak-Anderson) are shown under each coal deposit and are listed two or more times.

As shown in **Table 5**, monitoring wells in the Big George, Wyodak, and Anderson coals recorded the largest water-level drawdowns. Two of the 58 Fort Union coal wells (Big George PISTOL and Wall LQCW) in the BLM deep monitoring well network showed a rise in water level from the initial water level. These two coal monitoring wells may be experiencing early aquifer recovery (or local recharge) as the magnitude of CBNG well pumping has declined in the vicinity. Recovery of water levels may occur as groundwater is redistributed in the coal zone from areas of higher head pressure into the lower pressure zone of influence in the CBNG-production area.

Wasatch Sandstone Monitoring Wells

The Twenty-one Wasatch sandstone wells and one Fort Union sandstone well showed the largest measured drawdown (feet). These are listed in **Table 6**.

The BLM Wasatch sandstone monitoring wells that showed the largest rise in water level (feet) are shown in **Table 7**.

The 12 Wasatch sandstone wells in **Table 7** may be recharged by surface discharge of CBNG-production water via ponds, reservoirs, and/or surface drainages. Discharged water may be infiltrating Wasatch aquifers, causing some shallow unconfined or confined groundwater levels to rise. Further evaluation of water-level rise in Wasatch sandstone wells will be conducted in future monitoring reports.

SUMMARY OF WELLHEAD GAS PRESSURES IN FORT UNION COAL WELLS

Wellhead gas pressures in BLM deep monitoring wells were recorded. In a typical CBNG well, the monitored wellhead gas pressures rise as natural gases desorb, while water-levels and formation head pressures (confined pressures) decrease. Over time, wellhead gas pressures decline with progressive CBNG-production (Appendix). The data are collected electronically at the monitoring wellhead. The graphs of the wellhead gas pressures are shown on the hydrographs for the coal monitoring wells in the Appendix. Sandstone monitoring wells were not monitored for wellhead gas pressure. **Table 8** shows

Table 3. Coal monitoring wells for BLM deep monitoring well network, Powder River Basin, Wyoming (1993–2006).

Well acronym	Coal deposit(s)	County	First Monitored	TD (ft)	Completion Interval (ft)
20MILEA	Anderson	Campbell	2004	933	896/933
BULLCRKC	Anderson	Johnson	2005		1338/1430
HUBERPDC	Anderson	Sheridan	2000	653	638/653
KENNEDYC	Anderson	Campbell	2000	743	706/738
NGILLAND	Anderson	Campbell	2001	575	534/582
REMCRKANDC	Anderson	Sheridan	2005	639	625/639
HUBERLTC	Wyodak/Anderson	Campbell	2000		
21MILEBGC	Big George	Campbell	2001	1325	1278/1325
ANCC	Big George	Campbell	2001	1051	984/1051
BBIRDBG	Big George	Campbell	2000	1156	
BDUC	Big George	Johnson	2006		2204/2314
BEAVFEDBG	Big George	Campbell	2003	1256	1186/1256
BIGCATBG	Big George	Johnson	2003	1967	1970/2047
BULLWACKC	Big George	Johnson	2002	1447	1342/1440
DTANKBG	Big George	Campbell	2002	1515	1152/1230
ECHETA	Big George or "Echeta"	Campbell	1999	880	861/867
GILMORE	Big George	Johnson	1998	1375	1320/1375
JUNIPERC	Big George	Johnson	2001	1614	1548/1614
NAPIERC	Big George	Campbell	2001	1705	1585/1674
PISTOL	Big George	Campbell	1997	1559	1459/1559
SASQUATC	Big George	Johnson	1998	1640	1435/1640
STREETERC	Big George coal #3	Johnson	2004	1400	1351/1378
WILDTURC	Big George	Johnson	2004	1332	1196/1288
CGUBG	Big George/Lower Smith	Johnson	2005		1796/1854
BUFFSEC	Smith	Johnson	2001	1610	1588/1596
CGUS	Smith	Johnson	2005		1481/1498
21MILEWC	Wyodak	Campbell	2001	1560	1508/1522
447131A2	Wyodak	Campbell	1998	780	664/780
447214A1	Wyodak	Campbell	1998	816	716/816
457106C1	Wyodak	Campbell	1997	363	328/363
457301A1	Wyodak	Campbell	1997	777	726/777
467106C1	Wyodak	Campbell	1995	363	310358
467225C1	Wyodak	Campbell	1996	525	420/525
467236B1	Wyodak	Campbell	1995	547	459/547
477119C1	Wyodak	Campbell	1995	392	334/392
477236B1	Wyodak	Campbell	1995	547	
BBIRDC	Wyodak	Campbell	2000	0	1426/1500
BOWERSC	Wyodak	Campbell	2002	752	
DILTSC	Wyodak	Campbell	1999	658	580/658
DTANKWY	Wyodak	Campbell	2002	1512	1452/1500
HOEC	Wyodak	Campbell	1998	910	830/910
MP2C	Wyodak	Campbell	1993	410	336/410
MP22C	Wyodak	Campbell	1993	515	438/515
PERSSONC	Wyodak	Campbell	2001	1334	1266/1334
THRONEC	Wyodak	Campbell	2001	1511	
NGILLCAN	Canyon	Campbell	2001	620	588/620
PALOC	Canyon	Campbell	2001	471	426/464
REDSTNC	Canyon	Campbell	1988	310	241/310
REMCRKCANC	Canyon	Sheridan	2005		625/639
BARTONC	Cook	Campbell	2002	1055	1024/1055
LQCC	Cook	Sheridan	2005	711	686/711
REMCRKCOOKC	Cook	Sheridan	2005	802	787/802
SCOALC	Cook/Lower Wall/Pawnee	Campbell	2001	818	782/818
20MILEW	Wall	Campbell	2004	1520	1496/1518
BARTONW	Wall	Campbell	2002	1245	1200/1245
CEDARC	Wall	Campbell	2004	1679	1577/1674
LQCW	Wall/Pawnee	Sheridan	2005	954	
20MILEP	Pawnee	Campbell	2004	1850	1692/1850

Table 4. Sandstone and alluvial monitoring wells for BLM deep monitoring well network, Powder River Basin, Wyoming (1993–2006).

Well acronym	Lithology	County	First Monitored	TD (ft)	Completion Interval (ft)
20MILES	Wasatch sandstone	Campbell	2004	550	1692/1850
21MILES	Wasatch sandstone	Campbell	2001	899	950/1030
447131A1	Wasatch sandstone	Campbell	1998	580	555/575
447131A3	Fort Union underlying sandstone	Campbell	1998	830	794/830
447214A2	Wasatch sandstone	Campbell	1998	690	666/690
457106C2	Wasatch sandstone	Campbell	1997	285	255/285
457301A2	Wasatch sandstone	Campbell	1997	679	659/679
467225C2	Wasatch sandstone	Campbell	1996	170	134/170
ANCS	Wasatch sandstone	Campbell	2001	1050	840/860
ANCSS	Wasatch sandstone	Campbell	2002	643	580/640
ANCVSS	Wasatch sandstone	Campbell	2002	420	350/420
ANCVVSS	Wasatch sandstone	Campbell	2002	240	200/240
BBIRDS	Wasatch sandstone	Campbell	2000		670/690
BDUS	Wasatch sandstone	Johnson	2006		
BIGCATS	Wasatch sandstone	Johnson	2003	2065	862/888
BEAVFEDS	Wasatch sandstone	Campbell	2003		552/625
BOWERSS	Wasatch sandstone	Campbell	2002	600	520/595
BOWERSSS	Wasatch sandstone	Campbell	2002	445	385/440
BOWERSVSS	Wasatch sandstone	Campbell	2002	355	265/350
BOWERSVVSS	Wasatch sandstone	Campbell	2002	83	65/80
BUFFSES	Wasatch sandstone	Johnson	2001		1482/1498
BUFFSESS	Wasatch sandstone	Johnson	2002		520/595
BUFFSEVSS	Wasatch sandstone	Johnson	2002		155/230
BUFFSEVVSS	Wasatch sandstone	Johnson	2002		55/130
BULLCRKS	Wasatch sandstone	Johnson	2005	978	1338/1430
BULLCRKSS	Wasatch sandstone	Johnson	2005	1652	
BULLWACKS	Wasatch sandstone	Johnson	2002	1300	
CEDARS	Wasatch sandstone	Campbell	2004		1390/1470
DILTSS	Wasatch sandstone	Campbell	1999		260/300
DRYWILLS	Wasatch sandstone	Campbell	1999	1734	148/202
HOES	Wasatch sandstone	Campbell	1998		150/210
HUBERLTS	Wasatch sandstone	Campbell	2000		490/530
HUBERPDS	Wasatch sandstone	Sheridan	2000		352/400
HUBERPDSS	Wasatch sandstone	Sheridan	2002	280	235/270
JUNIPERS	Wasatch sandstone	Johnson	2001	1150	1086/1130
JUNIPERSS	Wasatch sandstone	Johnson	2002		550/640
KENNEDYS	Wasatch sandstone	Campbell	2000		520/578
LQCS	Wasatch sandstone	Sheridan	2005	650	
MP2S	Wasatch sandstone	Campbell	1993		260/310
MP22S	Wasatch sandstone	Campbell	1993		340/400
MP22SS	Wasatch sandstone	Campbell	1998		107/185
MP22VSS	Wasatch sandstone	Campbell	1998		50/80
NAPIERS	Wasatch sandstone	Campbell	2001		1462/1522
NGILLS	Wasatch sandstone	Campbell	2001	736	215/320
PALOS	Wasatch sandstone	Campbell	2001		290/380
PERSSONS	Wasatch sandstone	Campbell	2001		1180/1230
REDSTNS	Wasatch sandstone	Campbell	1988		160/185
REMCRKS	Quaternary alluvial sand bed	Sheridan	2005	30.5	20/26
SCOALS	Wasatch sandstone	Campbell	2001		524/575
THRONES	Wasatch sandstone	Campbell	2001		1400/1450
SASQUATS	Wasatch sandstone	Johnson	2001		1296/1360
STREETERS	Wasatch sandstone	Johnson	2004		522/730
WILDTURS	Wasatch sandstone	Johnson	2004		998/1018

Table 5. Maximum water-level drawdowns and rises grouped by coal deposit for the Fort Union Formation coal monitoring wells, Powder River Basin, Wyoming (1993–2006).

Well acronym	Drawdown/rise (ft)	Coal Deposit(s)	TD (ft)	Initial Water Level (ft)	Measured Depth (ft)
Anderson wells (7)					
HUBERPDC	-456.2	Anderson	653	168	653
NGILLAND	-348.6	Anderson	575	500	582
KENNEDYC	-231.1	Anderson	743	428	738
HUBERLTC	-205.7	Wyodak/Anderson	N/A	453	723
REMCRKANDC	-107	Anderson	639	160	336
20MILEA	-98	Anderson	933	560	933
BULLCRKC	-17.1	Anderson	N/A	214	1430
Big George wells (17)					
BULLWACKC	-592	Big George	1447	93	1440
JUNIPERC	-583.1	Big George	1614	168	1614
BIGCATBG	-486.7	Big George	1967	200	2047
ANCC	-476.2	Big George	1051	439	1051
DTANKBG	-420.4	Big George	1515	295	1230
SASQUATC	-275.4	Big George	1640	230	1640
WILDTURC	-259.5	Big George	1332	268	1288
BEAVFEDBG	-241.3	Big George	1256	330	1256
21MILEBG	-195.7	Big George	933	626	1325
NAPIERC	-121.5	Big George	1705	432	1674
ECHETA	-78.9	Big George or "Echeta"	880	246	867
BBIRDBG	-38.3	Big George	N/A	N/A	N/A
GILMORE	-36.6	Big George	1375	369	1375
CGUBG	-27.8	Big George/Lower Smith	1854	469	1854
STREETERC	-20.6	Big George coal #3	1400	259	1378
BDUC	-10.3	Big George	N/A	494	2314
PISTOL	1.7	Big George	1559	457	1559
Smith coal wells (2)					
BUFFSEC	-28.8	Smith	1610	277	1596
CGUBG	-27.8	Big George/Lower Smith	1854	469	1854
Wyodak coal wells (19)					
HOEC	-625.9	Wyodak	910	231	910
457301A1	-557.6	Wyodak	777	162	777
467225C1	-402.8	Wyodak	525	48	525
21MILEWC	-395.5	Wyodak	1560	629	1522
447131A2	-320.8	Wyodak	780	332	780
447214A1	-311.9	Wyodak	816	268	816
THRONEC	-310.8	Wyodak	1511	815	N/A
DILTSC	-261.4	Wyodak	658	341	658
MP22C	-257.2	Wyodak	515	174	515
477236B1	-253.5	Wyodak	480	244	547
DTANKWY	-240.7	Wyodak	1512	149	1500
BOWERSC	-234	Wyodak	752	420	N/A
HUBERLTC	-205.7	Wyodak/Anderson	723	453	723
MP2C	-203.8	Wyodak	410	163	410
467106C1	-198.9	Wyodak	363	158	358
457106C1	-173.2	Wyodak	363	118	363
PERSSONC	-153.8	Wyodak	1334	826	1334
477119C1	-104.8	Wyodak	392	245	392
BBIRDC	-69.6	Wyodak	1500	371	1500
Canyon wells (4)					
REDSTNC	-220.7	Canyon	310	33	310
PALOC	-139.6	Canyon	471	299	464
NGILLCAN	-84.5	Canyon	620	447	620
REMCRKCANC	-57.8	Canyon	N/A	378	639
Cook wells (3)					
BARTONC	-154.7	Cook	1055	365	1055
REMCRKCOOKC	-98.1	Cook	802	378	802
LQCC	-9.2	Cook	711	23	711
Cook-Lower Wall-Pawnee well (1)					
SCOALC	-28.3	Cook/Lower Wall/Pawnee	N/A	561	818
Wall wells (4)					
CEDARC	-196.6	Wall	1679	231	1674
20MILEW	-130.1	Wall	1520	521	1518
BARTONW	-12.6	Wall	1245	200	1245
LQCW	0.9	Wall/Pawnee	954	15	N/A
Pawnee wells (1)					
20MILEP	-76.3	Pawnee	N/A	552	1850

the BLM coal monitoring wells that recorded the presence or absence of methane.

As shown in **Table 8**, monitoring wells in the Big George, Wyodak, and Anderson recorded the largest wellhead gas pressures. Sensors are designed to withstand 4x over-pressures without damage; however, sensors may fail to read pressures greater than design pressure. The pressure transducer probes monitoring two Big George coal wells (BULLWACKC and JUNIPERC) were damaged by excessive gas pressures, both wells recording more than 300 psi.

Some of the monitored coal deposits showed little to no build-up of wellhead gas pressures. Coal monitoring wells with the lowest wellhead gas pressure are shown in Table 9. These monitoring wells show no evidence of natural gas pressure. Wellhead gas pressure data are plotted over time on the well graphs in the Appendix.

A summary discussion of the wellhead gas pressures by coal deposit follows:

- Anderson wellhead gas pressure – The maximum wellhead gas pressures in four of the seven Anderson coal wells peaked in the second quarter of 2002 for HUBERLTC; in the first quarter of 2004 for 20MILEA; in the first quarter of 2004 for HUBERPDC; and in the third quarter of 2005 for REMCRKANDC (Appendix). The wellhead gas pressure curve for HUBERLTC or LTREEC well is an excellent example of a typical CBNG-production decline of gas pressure over time (Appendix). Wellhead pressures were very low for the remaining three Anderson coal wells (BULLCRKC, KENNEDYC, and NGILLAND) (Appendix).

- Big George wellhead gas pressure – The maximum wellhead gas pressures in four of the 17 Big George coal wells peaked in the fourth quarter of 2003 for BULLWACKC; in the fourth quarter of 2003 for ANCC; in the fourth quarter of 2004 for JUNIPERC; and in the third quarter of 2006 for WILDTURC (Appendix). The Big George coal wellhead gas pressure curves exhibit a typical CBNG-production decline of gas pressure over time. The recorded pressures are

Table 6. Maximum water-level drawdowns measured in the sandstone wells of the Wasatch Formation and Fort Union Formation monitoring wells, Powder River Basin, Wyoming (1993–2006). Note: Well 447131A3 is a Fort Union Formation underlying sandstone well; the rest are Wasatch.

Sandstone well acronym	Footage separation from coal zone (feet)	2006 Water level change (feet)
THRONES	56	-268.8
PERSSONS	36	-252.6
447131A3	-14 (below coal)	-248.7
457301A2	47	-218
BULLWACKS	(unknown)	-139.6
CEDARS	107	-105.4
SASQUATS	75	-100.3
447131A1	89	-58.9
457106C2	43	-57.3
MP2S	26	-52.9
MP22S	38	-42.5
447214A2	26	-21.2
NAPIERS	63	-20.5
KENNEDYS	128	-15.6
JUNIPERS	418	-11.9
STREETERS	621	-9.1
BULLCRKS	100	-8.4
20MILES	357	-7.1
WILDTURS	187	-7
HUBERLTS	117	-6
NGILLS	214	-5.7
HUBERPDS	238	-5.5

Table 7. Maximum water-level rises measured in the Wasatch Formation sandstone monitoring wells, Powder River Basin, Wyoming (1993–2006).

Well acronym	Footage separation from coal zone (feet)	Water-level rise (feet)
ANCS	124	26.1
BUFFSESS	993	11.3
BUFFSES	90	9.8
BUFFSEVVSS	1458	3.2
REDSTNS	56	2.6
BOWERSVVSS	632	1.1
ANCVVSS	744	0.6
BOWERSS	117	0.5
ANCVSS	564	0.3
21MILES	197	0.2
BOWERSVSS	362	0.2
BUFFSEVSS	1,358	0

Table 8. Highest recorded wellhead gas pressures by well and coal deposit, Powder River Basin, Wyoming (1993–2006).

Well acronym	Wellhead gas pressure (psi)	Coal deposit(s)
BULLWACKC	311.1	Big George
JUNIPERC	221.3	Big George
DILTSC	92.6	Wyodak
457106C1	83.7	Wyodak
WILDTURC	80.9	Big George
HUBERLTC	66.7	Wyodak/Anderson
467225C1	63.8	Wyodak
MP22C	61.2	Wyodak
457301A1	61	Wyodak
REMCRKANDC	60.4	Anderson
HOEC	60.4	Wyodak
REDSTNC	58.4	Canyon
PALOC	55.9	Canyon
467106C1	55.3	Wyodak
ANCC	48.5	Big George
HUBERPDC	45.1	Anderson
447131A2	37.9	Wyodak
477236B1	34.1	Wyodak
477119C1	33.8	Wyodak
21MILEWC	28.6	Wall
447214A1	28.1	Wyodak
MP2C	26.8	Wyodak
CGUS	21.9	Smith
20MILEA	19.4	Anderson
21MILEBG	15.3	Big George
ECHETA	14	Big George or “Echeta”
SCOALC	12.7	Cook/Lower Wall/Pawnee

Table 9. Lowest recorded wellhead gas pressures by well and coal deposit, Powder River Basin, Wyoming (1993–2006).

Well acronym	Wellhead gas pressure (psi)	Coal deposit
STREETERC	0.1	Big George #3
REMCRKCOOKC	0.1	Cook
NAPIERC	0.2	Big George
CEDARC	0.2	Wall
BDUC	0.2	Big George
BARTONC	0.2	Cook
REMCRKCANC	0.3	Canyon
GILMORE	0.3	Big George

very low for the remaining 13 Big George coal wells (21MILEBGC, BBIRDBG, BDUC, BEAVFEDBG, BIGCATBG, CGUBG, DTANKBG, ECHETA, GILMORE, NAPIERC, PISTOL, SASQUATC, and STREETERC) (Appendix).

- Canyon wellhead gas pressure – The maximum wellhead gas pressures in two of the four Canyon coal wells peaked in the second quarter of 2000 for REDSTNC; in the first quarter of 2001 for PALOC; and in the third quarter of 2005 for REMCRKCANC (Appendix). The recorded pressures are very low for the remaining two Canyon coal wells (NGILLC and REMCRKCANC) (Appendix).

- Cook wellhead gas pressure – The maximum wellhead gas pressures in two of the four Cook coal wells peaked in the fourth quarters of both 2004 and 2005 for SCOALC; and in early 2006 for LQCC (Appendix). The recorded pressures are very low for the remaining two Cook coal wells (BARTONC and REMCRKCOOKC) (Appendix).

- Pawnee wellhead gas pressure – The maximum wellhead gas pressures in the two Pawnee coal wells peaked in the third quarter 2006 for 20MILEP; and peaked in the fourth quarters of both 2004 and 2005 for SCOALC (Appendix).

- Wall wellhead gas pressure – The maximum wellhead gas pressures in two of the five Wall coal wells peaked in the fourth quarters of both 2004 and 2005 for SCOALC; and in the third quarter of 2005 for LQCW (Appendix). The recorded pressures are very low for the remaining three Wall coal wells (20MILEW, BARTONW, and CEDARC) (Appendix).

- Wyodak wellhead gas pressure – As shown in the Appendix, the maximum wellhead gas pressures in 10 of the 18 Wyodak coal wells peaked in the third quarter of 1995 for MP22C; in the second quarter of 1996 for 477119C1; in the fourth quarter of 1996 for MP2C; in the third quarter of 1997 for 477236B1; in the second quarter of 1999 for 467106C1; in the first quarter of 2000 for DILTSC; in the first quarter of 2001 for 467225C1; in the third quarter of 2001 for 447131A2; in the second quarter of 2003 for 457301A1; and in the second quarter of 2004 for 21MILEWC. The Wyodak coal wellhead gas pressure curves show a typical CBNG-production decline of gas pressure over time. The recorded pressures are very low for the remaining eight Wyodak coal wells (447214A1, 457106C1, BBIRDC, BOWERSC, DTANKWY, HOEC, PERSSONC, and THRONEC) (Appendix).

The Appendix includes further detailed discussions of the monitored wellhead gas pressures at individual BLM monitoring wells and well sets.

The two wells with the highest maximum wellhead gas pressures during monitoring (BULLWACKC [311.1 psi] and JUNIPERC [221.3 psi]) were not pumped as CBNG-production wells, though monitoring well data indicated these Big George coal wells were affected by local CBNG production. Water-level drawdowns measured in these wells were the second and third greatest measured drawdowns of 592.0 feet (BULLWACKC) and 583.1 feet (JUNIPERC), respectively.

The greatest drawdown measured in the BLM coal wells are:

#1	HOEC	-625.9 feet	(Wyodak)
#2	BULLWACKC	-592.0 feet	(Big George)
#3	JUNIPERC	-583.1 feet	(Big George)

A maximum drawdown of 139.6 feet was measured in the Wasatch sandstone monitoring well BULLWACKS. This shallower sandstone well is constructed above the BULLWACKC coal well and is affected by local CBNG activities.

CHAPTER 3

Comparison of observed to predicted impacts

The effects of CBNG production on groundwater resources are modeled in AHA and GEC (2002). The report developed a groundwater model and predicted potential water-level drawdown related to CBNG development in the upper Fort Union coal deposits and Wasatch sandstone beds from 2003 to 2030, and it predicted post-production water-level recoveries from 2030 to 2060. The observed drawdowns in the BLM deep monitoring wells were compared with predictions of AHA and GEC (2002) to evaluate how well the model predicted CBNG impacts.

COMPARISON OF PREDICTED VERSUS MEASURED DRAWDOWNS IN FORT UNION COAL WELLS

Four maps in the groundwater modeling technical report (Figure 6-2A on page 6-13; Figure 6-2B on page 6-15; Figure 6-2C on page 6-17; and Figure 6-2D on page 6-19 in AHA and GEC, 2002; see listing below) show modeled water levels for Fort Union coal deposits for 2006.

Four upper Fort Union Formation coal zones (Layers 8, 10, 12, and 14) were defined for the groundwater model of AHA and GEC (2002). AHA and GEC (2002) predicted that the maximum drawdowns in 2006 for the central portion of the Wyoming PRB would range from 500 feet to greater than 700 feet, as shown on the following listed figures from the AHA and GEC (2002) report:

- Figure 6-2A Modeled Drawdown Upper Fort Union Coals "Layer 8 Year 2006" predicted maximum drawdown of more than 700 feet;
- Figure 6-2B Modeled Drawdown Upper Fort Union Coals "Layer 10 Year 2006" predicted maximum drawdown of more than 700 feet;
- Figure 6-2C Modeled Drawdown Upper Fort Union Coals "Layer 12 Year 2006" predicted maximum drawdown of more than 700 feet; and
- Figure 6-2D Modeled Drawdown Upper Fort Union Coals "Layer 14 Year 2006" predicted maximum drawdown of more than 500 feet.

AHA and GEC (2002) did not specify which Fort Union coal deposits are contained within each defined layer of the groundwater model. Therefore, the WSGS interpreted which units correlate with each of the model coal layers. An approximate correlation for the complex coal nomenclature in the Wyoming PRB for the AHA and GEC (2002) groundwater model layers is believed by the WSGS to include (in descending order from the upper to lower layers):

- Layer 8 (Coal Unit 1) is equivalent to the Roland and Wyodak Rider coal zones in the Fort Union containing the Wyodak Rider, Smith Rider, Smith, Big George, and Lower Smith coal deposits.
- Layer 10 (Coal Unit 2) is equivalent to Upper Wyodak coal zone containing the Anderson Rider, Anderson, and Lower Anderson coal deposits.
- Layer 12 (Coal Unit 3) is equivalent to the Lower Wyodak and Cook coal zones containing the Canyon Rider, Canyon, Cook, and Lower Cook coal deposits.
- Layer 14 (Coal Unit 4) is equivalent to the Wall and Basal Tongue River coal zones containing the Wall, Lower Wall, Pawnee, and Moyer coal deposits.

Intervening layers (Layers 9, 11, and 13) and overlying/underlying layers (Layers 7 and 15) represent low-permeability confining zones between

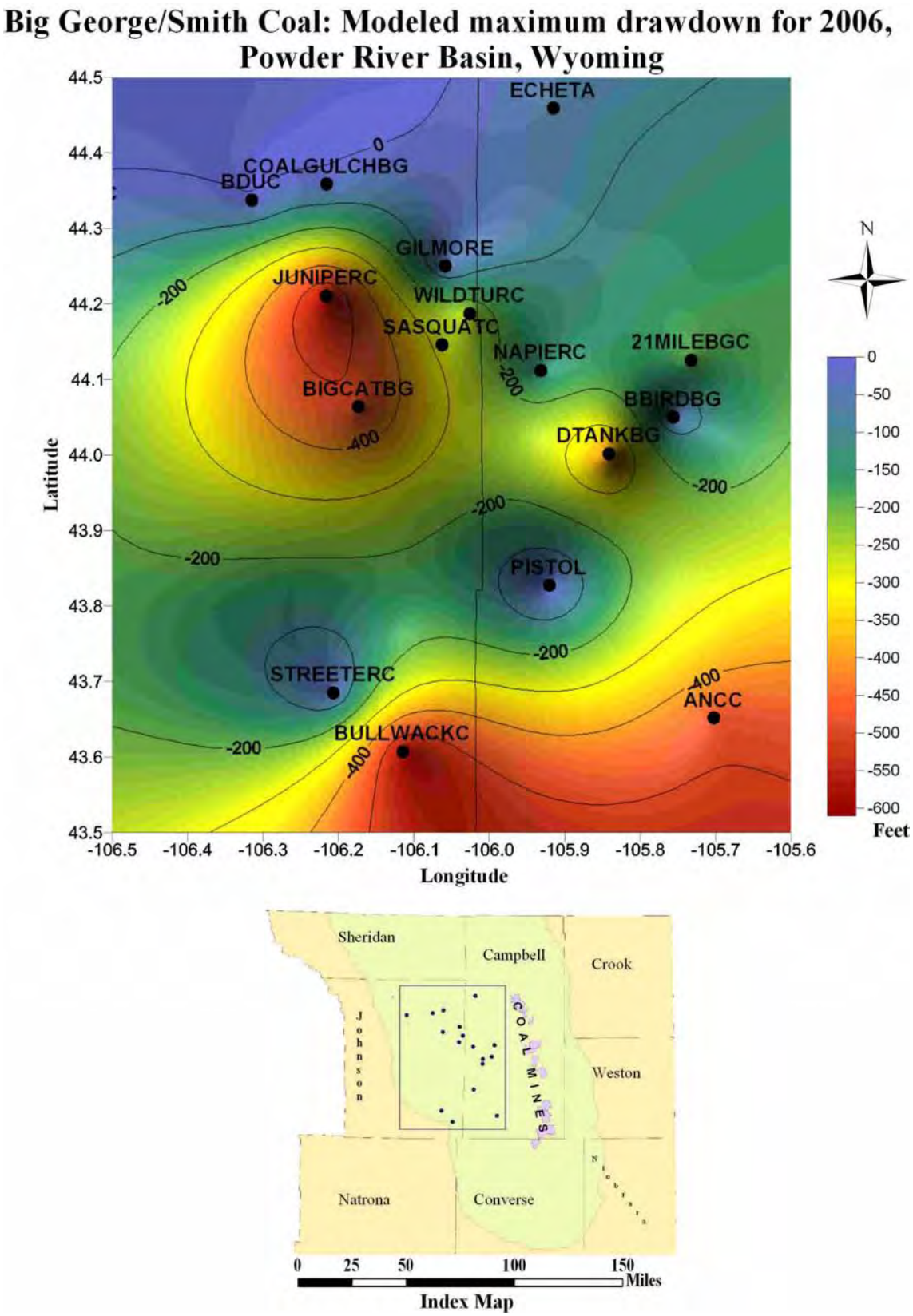

Figure 5. Big George/Smith coal: Maximum drawdown for 2006, Powder River Basin, Wyoming. *Illustration by Gribb (2007).*

coal zones (AHA and GEC, 2002). Recent hydrologic studies indicate that these low-permeability zones may not be hydrologically confined across the entire basin, and that they could include local areas of unconfined flow (Onsager and Cox, 2000; Cox and Onsager, 2002; Mavor et al., 2003; Clarey and Stafford, 2008).

Applying the coal zone correlations, as listed above, to the BLM deep monitoring well data, the WSGS developed the following preliminary correlations:

- Layer 8 – As shown in **Figure 5**, the Big George coal showed an actual maximum drawdown of 600 feet by 2006, which is approximately 100 feet less than the predicted drawdown of 700 feet by 2006 in AHA and GEC (2002). The Smith coal wells CGUS and BUFFSEC have each shown about 29 feet of drawdown, which is probably a function of their proximity to actively producing CBNG wells.

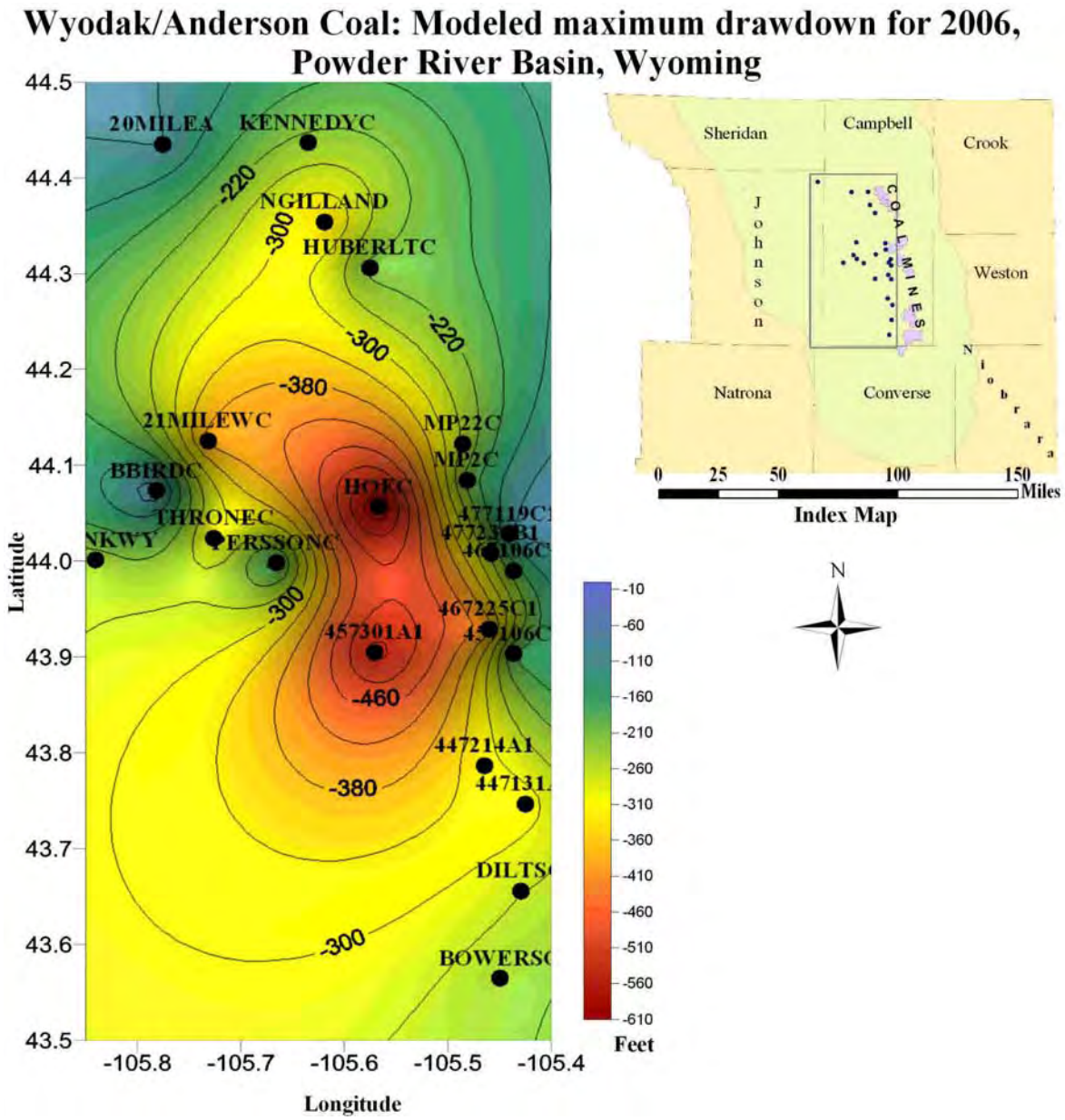

Figure 6. Wyodak/Anderson coal: Maximum drawdown for 2006, Powder River Basin, Wyoming. *Illustration by Gribb (2007).*

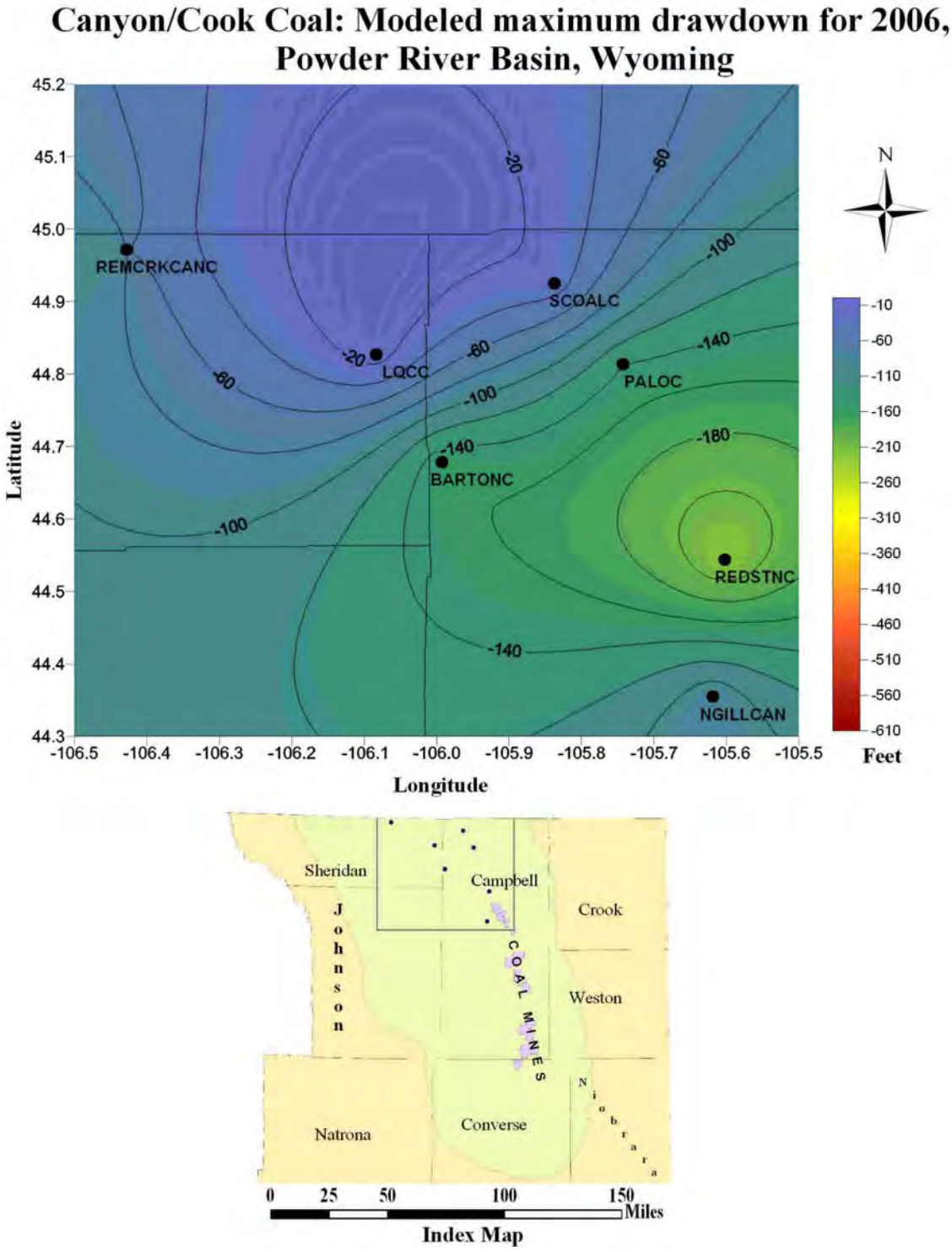

Figure 7. Canyon/Cook coal: Maximum drawdown for 2006, Powder River Basin, Wyoming. *Illustration by Gribb (2007).*

- Layer 10 – As shown in **Figure 6**, the Wyodak/Anderson coal showed an actual maximum drawdown of 450 feet by 2006, which is approximately 250 feet less than the predicted drawdown of 700 feet by 2006 in AHA and GEC (2002). The Wyodak coal showed an actual maximum drawdown of 625 feet by 2006, which is approximately 75 feet less than

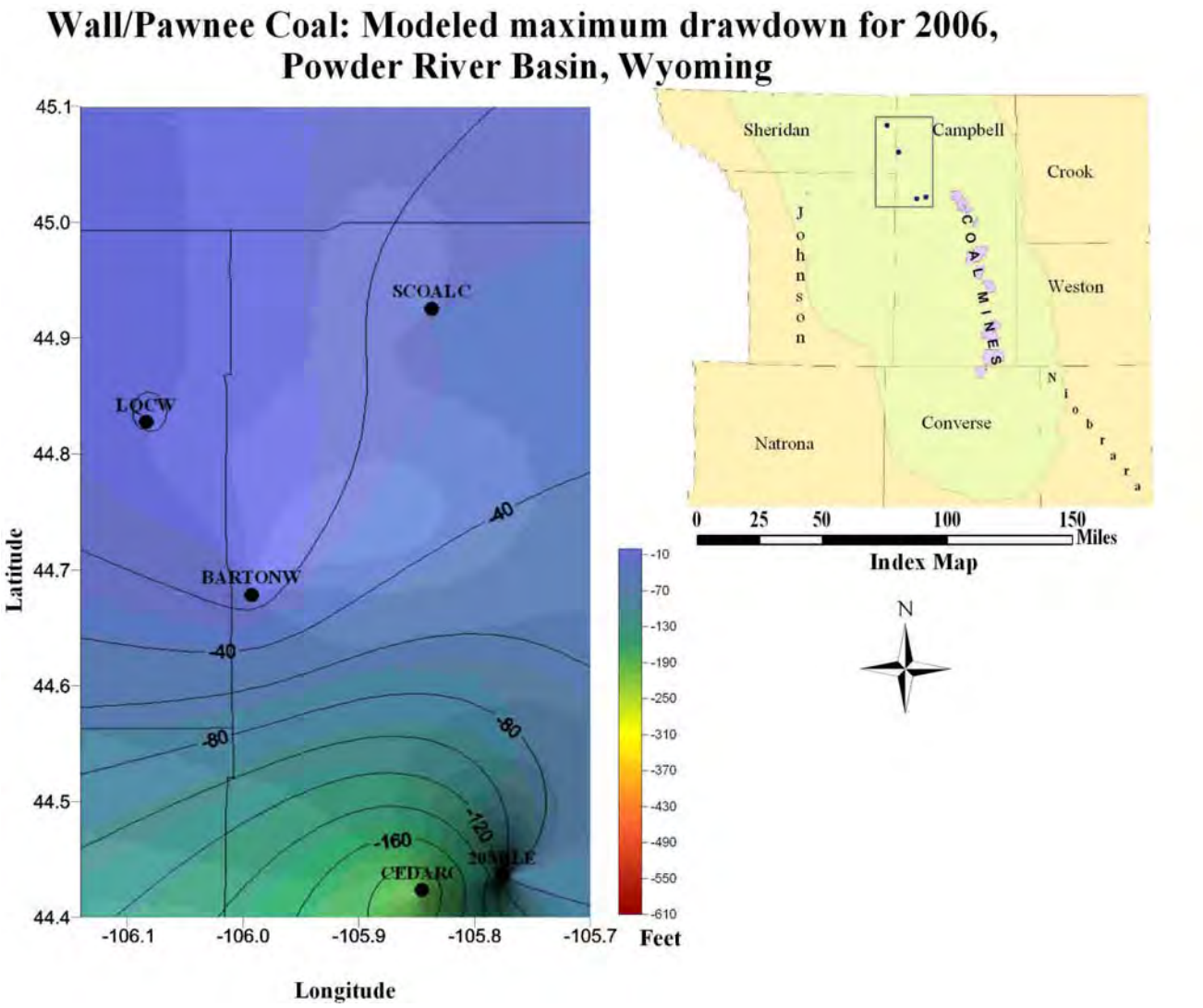

Figure 8. Wall/Pawnee coal: Maximum drawdown for 2006, Powder River Basin, Wyoming. *Illustration by Gribb (2007).*

the predicted drawdown of more than 700 feet by 2006 in AHA and GEC (2002).

- Layer 12 – As shown in **Figure 7**, the Canyon coal showed an actual maximum drawdown of 220 feet by 2006, which is approximately 480 feet less than the predicted drawdown of 700 feet by 2006 in AHA and GEC (2002). The Cook coal showed an actual maximum drawdown of 150 feet by 2006, which is approximately 550 feet less than the predicted drawdown of more than 700 feet in AHA and GEC (2002).

- Layer 14 – As shown in **Figure 8**, the Wall coal showed an actual maximum drawdown of 200 feet by 2006, which is approximately 300 feet less than the predicted drawdown of more than 500 feet by 2006 in AHA and GEC (2002). When the Cook/Lower Wall/Pawnee coal well SCOALC became dry in 2006, it only showed an actual drawdown of 8.5 feet.

To summarize the comparison between predicted versus actual measured drawdowns from initial levels in the coal wells, all of the Fort Union coal deposits are showing less drawdown than was predicted by

Table 10. Summary of sandstone monitoring wells through 2006; footage separation from coal zone, water level, total well depth, and initial water level in the well, Powder River Basin, Wyoming (1993–2006). Well 447131A3 is a Fort Union Formation underlying sandstone well, REMCRKS is an alluvial well, and the remainder are Wasatch Formation sandstone wells.

Sandstone well acronym	Footage separation from coal zone (feet)	Water level change (feet)	TD (ft)	Initial Water Level (ft)
21MILES	197	0.2	550	363
447131A1	89	-58.9	580	254
447131A3	-14 (below coal)	-248.7	830	334
447214A2	26	-21.2	690	25
457106C2	43	-57.3	285	96
457301A2	47	-218	679	176
467225C2	250	-1.6	170	90
ANCS	124	26.1	1050	321
ANCSS	344	-2.7	420	201
ANCVSS	564	0.3	420	200
ANCVVSS	744	0.6	240	95
BBIRDS	736	-0.4	690	251
BEAVFEDS	561	-4.6	625	242
BIGCATS	1,082	-0.7	2065	340
BOWERSS	117	0.5	600	332
BOWERSSS	272	-0.4	445	301
BOWERSVSS	362	0.2	355	256
BOWERSVVSS	632	1.1	83	60
BUFFSES	90	9.8	1498	338
BUFFSESS	993	11.3	595	144
BUFFSEVSS	1,358	0	230	144
BUFFSEVVSS	1,458	3.2	130	48
BULLCRKS	100	-8.4	1430	215
BULLWACKS	100	-139.6	1300	25
CEDARS	107	-105.4	975	228
DILTSS	280	-3.2	300	120
HOES	620	-0.5	210	101
HUBERLTS	117	-6	530	287
HUBERPDS	238	-5.5	280	197
HUBERPDSS	368	-0.7	280	193
JUNIPERS	418	-11.9	1150	168
JUNIPERSS	908	-0.7	428	640
KENNEDYS	128	-15.6	271	595
MP2S	26	-52.9	52	310
MP22S	38	-42.5	84	400
MP22SS	253	-1	38	185
MP22VSS	358	-2.6	20	80
NAPIERS	63	-20.5	403	1700
NGILLS	214	-5.7	122	736
PALOS	46	-1.4	245	385
PERSSONS	36	-252.6	508	1260
REDSTNS	56	2.6	25	185
REMCRKS	288	-0.2	5.3	30.5
SASQUATS	75	-100.3	224	2750
SCOALS	207	-0.4	465	582
STREETERS	621	-9.1	209	800
THRONES	56	-268.8	601	1511
WILDTURS	187	-7	128	1144

the AHA and GEC (2002) groundwater model. The maximum drawdown observed in the Wyodak coal of more than 625 feet is the closest to the predicted 2006 drawdown in the four coal layers defined by AHA and GEC (2002). All of the measured coal drawdowns are less than the predicted drawdowns; however, the AHA and GEC (2002) groundwater model was developed assuming a greater rate of CBNG development in the PRB than has actually occurred.

An additional consideration is that some of the BLM deep monitoring wells did not have a well established baseline (static water level) for the initial water-level measurement in the coal well. Therefore, the actual drawdown from a true static water-level condition for a well may be greater than reported for some of the BLM coal and sandstone wells.

COMPARISON OF PREDICTED VERSUS MEASURED DRAWDOWNS IN WASATCH SANDSTONE WELLS

Observed drawdowns in Wasatch sandstone wells were also compared with the predicted drawdowns in the 2002 model (AHA and GEC, 2002). Changes in water levels for sandstone monitoring wells are detailed in **Table 10**. AHA and GEC (2002) defined the Wasatch sandstone zones as Layers 2, 4, and 6, representing shallow, intermediate depth, and deep zones, respectively. Intervening layers (Layers 3 and 5) and underlying Layer 7 represent low-permeability confining zones interbedded between discontinuous sandstone zones of higher permeability (AHA and GEC, 2002). AHA and GEC (2002) did not show drawdown prediction maps of Wasatch water levels except for a few limited areas in the Wyoming PRB.

AHA and GEC (2002) show that, by the year 2006, as much as 50 feet or more of water-level drawdown may occur in deep Wasatch sandstone wells in the Caballo Creek sub-area. The Caballo Creek area is near well MP22S, MP2S, and 457106C2. The 50.0 feet or more of predicted drawdown by 2006 is comparable to the actual 42.5 feet of measured drawdown at MP22S. MP2S and 457106C2 wells showed 52.9 and 57.3 feet of drawdown, respectively, which are within the range of predictions. Similarity in Wasatch drawdown between the predicted and the actual measured drawdown may only be a coincidence not a validation of the AHA and GEC (2002) prediction since it is only three data points.

4-Mile monitoring well, southern Campbell County, Powder River Basin, Wyoming. *Photo by David Croft, U.S. Bureau of Land Management, Buffalo Field Office (2009).*

CHAPTER 4

SUMMARY AND FUTURE MONITORING PLAN

This report provides organization and compilation of data collected from the BLM deep monitoring well network in the Wyoming PRB from 1993 through 2006. Future tasks will build on this analysis.

Ten years (1997–2006) of CBNG development in the Wyoming PRB caused water-level drawdown in Fort Union coal deposits and associated sandstone beds. Other sources of drawdown could include surface coal mine dewatering, pumping of public water-supply wells, pumping of industrial/miscellaneous wells, pumping of other domestic/irrigation/stock water wells completed into the Tongue River Member and an extended drought. Groundwater resources are used for various purposes in the PRB, the production of CBNG is likely the major source for the drawdown in the Fort Union coal deposits and associated sandstone beds.

Data collected from the BLM deep monitoring well network record groundwater impacts related to CBNG development within the Wyoming PRB. The measured impacts by 2006 include a maximum groundwater-level drawdown of up to 625 feet and high wellhead gas pressures (greater than 300 psi) in some Fort Union coal monitoring wells. Impacts also include maximum groundwater-level drawdowns of more than 250 feet or more in three Wasatch sandstone monitoring wells.

All of the monitored Fort Union coal wells show less drawdown than was predicted by the 2002 groundwater model. The maximum drawdown observed in one of the Wyodak coal wells (more than 625 feet) is the closest to the predicted 2006 drawdown defined by the model (AHA and GEC, 2002). Because of the timing of CBNG development, some of the Fort Union coal wells did not have an established baseline (static water level) for the initial water-level measurement. Therefore, the actual drawdown from a static water-level condition for a coal well may be greater than measured. The AHA and GEC (2002) groundwater model predicted a greater groundwater drawdown in 2006 based on an increased rate of CBNG development in the PRB than what actually occurred. Therefore, it is not unexpected that the amount of measured drawdown in the BLM wells is less than was predicted by the 2002 groundwater model.

Two of the 58 Fort Union coal monitoring wells showed an increase in water level from initial water level and may indicate early aquifer recovery (or local recharge) as the magnitude of CBNG well pumping declined in the vicinity of these two wells.

Twenty-two Wasatch sandstone monitoring wells also showed drawdown. Eighteen Wasatch sandstone monitoring wells showed change , and 12 wells showed water level-rises. The one Fort Union underlying sandstone well showed a large drawdown and is presumed to be hydrologically connected to the overlying coal deposit. The Quaternary alluvial well was unaffected.

Twelve Wasatch sandstone monitoring wells showed water-level rises, and these wells may be impacted by surface discharge of CBNG-production water via ponds, reservoirs, and/or surface drainages. Discharged water may be infiltrating Wasatch aquifers, causing some shallow unconfined or confined groundwater levels to rise. Further evaluation of water-level rise in Wasatch sandstone wells will be conducted in future monitoring reports.

FUTURE MONITORING PLAN

- To further assess these groundwater concerns, additional analyses of the well data will be conducted. These analyses include:

- Incorporating initial data from 10 additional BLM deep monitoring well sets completed in 2007 and 2008 (4-Mile, Carr Draw, West Pinetree, Wormwood, Boondogle, Kingsbury Unit, Rose Draw, Leiter, Duck Creek, and Squaw Butte).

- Examining CBNG water production data in the vicinity of each of the monitoring wells to relate observed drawdown rates and patterns

to water production rates at various distances from the wells.

- Further examining relationships between drawdown in coal monitoring wells and drawdown in associated sandstone wells.

- Conducting additional work toward correcting database errors/discrepancies and also finding and resolving database anomalies.

EXISTING WELLS OF BLM DEEP MONITORING WELL NETWORK

At the end of 2006, there were 111 wells comprising the BLM deep monitoring well network in the Wyoming PRB. At that time the network consisted of 58 Fort Union coal wells, one Fort Union underlying sandstone well, 52 Wasatch sandstone wells, and one Quaternary alluvial well. The wells were drilled and completed into 10 coal deposits with some wells completed in more than one coal deposit. The BLM plans to add additional monitoring wells to the network as CBNG development continues in the PRB.

POTENTIAL FUTURE WELLS FOR BLM DEEP MONITORING WELL NETWORK

The BLM is working with the operators to install the additional wells as per an agreement between the BLM and the Petrolium Association of Wyoming. Future reports will include data collected from these proposed new wells and other wells as these data become available. Groundwater data collected from various resources will also be analyzed in an effort to meet the original objectives of this project. A listing

Table 11. Potential future wells for inclusion into the BLM deep monitoring well network, Powder River Basin, Wyoming (1993–2006).

County	Well name	Status	Township	Range	Section
Campbell County	Olmstead	Proposed	57	72	2
	South Prong	Complete	49	76	23
	Weston Hills	Proposed	54	71	22
	White Rock	Proposed	56	72	22
Converse County	Antelope Creek	Proposed	40	75	23
	Blizzard Hills	Proposed	37	73	4
Johnson County	Crazy Woman	Proposed	49	80	2
	East Yeagan	Proposed	46	78	11
	North Buffalo	Proposed	51	82	30
	Oops Well	Partially complete	49	77	16
	Piney Creek	Proposed	53	82	33
	Powder River	Proposed	44	78	3
	Reno Road	Proposed	45	80	7
	Rose Draw	Partially complete	52	77	19
	Trabing Road	Proposed	48	81	25
Sheridan County	Badger Creek	Proposed	57	81	29
	Big Corral Draw	Proposed	55	78	31
	Buffalo Creek	Proposed	56	80	31
	Cabin Creek	Proposed	57	77	27
	Fence Creek	Proposed	58	77	25
	South Cottonwood	Proposed			
	Ulm	Proposed	55	82	30
	Wyarno	Proposed	56	82	28

of potential future wells for inclusion into the BLM deep monitoring well network in the Wyoming PRB is presented in **Table 11**, and most of these well locations are shown on **Figure 1**.

Acknowledgments

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APPENDIX

Evaluation of the monitoring wells and well sets of the BLM deep monitoring well network, Powder River Basin, Wyoming (1993–2006)

The Appendix gives a description of each well set in the BLM deep monitoring well network and a summary of the data that have been collected at each site through 2006. All water levels reported here are depths in feet below the top of the wellhead. The conversion factor used is 1 psi of water pressure equals 2.31 feet high for a freshwater column.

As of the end of December 2006, the existing BLM deep monitoring well network consisted of 111 wells, at 48 locations, and it is composed of 58 Fort Union coal wells, one Fort Union underlying sandstone well, 51 Wasatch sandstone wells, and one Quaternary alluvial well. The 58 Fort Union coal wells are grouped by coal deposit(s) and summarized below:

6	Anderson coal wells
1	Wyodak/Anderson coal well
16	Big George coal wells
1	Big George-Lower Smith coal well
2	Smith coal wells
19	Wyodak coal wells
4	Canyon coal wells
3	Cook coal wells
1	Cook/Lower Wall/Pawnee coal well
3	Wall coal wells
1	Wall/Pawnee well
1	Pawnee coal well

The locations of the existing deep monitoring sites are shown on a location map (**Figure 1**) for the Buffalo Field Office – BLM deep monitoring well network. The well names, site names, acronyms, and number of wells in each well set for the BLM monitoring wells are listed in **Table A-1**.

EXISTING BLM DEEP MONITORING WELL NETWORK (1993–2006)

The following well descriptions include a number of graphs that have several abbreviated terms, which follow:

- **MR** – Manual Recording
- **TR** – Transducer Recording
- **GP** – Gas Pressure, this is the gas pressure as recorded by a pressure transducer
- **S** – Sand, pertaining to the Wasatch formation
- **SS** – Shallow Sand, pertaining to the Wasatch formation
- **VSS** – Very Shallow Sand, pertaining to the Wasatch formation
- **VVSS** – Very Very Shallow Sand, pertaining to the Wasatch formation

Table A-1. BLM deep monitoring well network well names, site names, and acronyms, Powder River Basin, Wyoming (1993–2006).

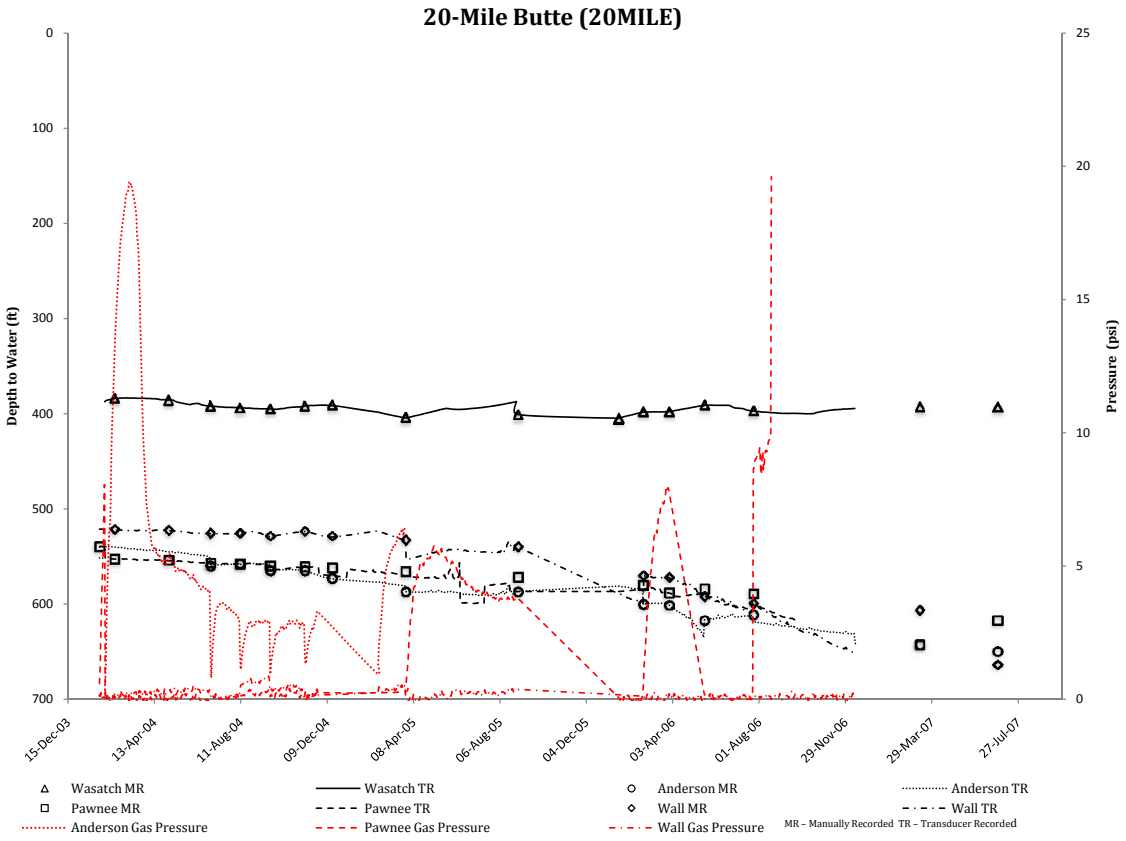
Well name(s)	Site name	Acronym(s)	Page
20-Mile Butte	20-Mile Butte	20MILE	38
Phillips 21-Mile Butte	Phillips 21-Mile Butte	21MILE	40
Stuart Federal #42-31B	Stuart Section 31	447131A	42
Durham Ranch Federal #42-14B	Durham Ranch Section 14	447214A1	44
Durham Ranch Federal #23-6B	Durham Ranch Section 6	457106C1	45
Bar 76 LL Federal #1-42-1	Bar 76	457301A1	46
South Cordero	South Cordero	467106C1	47
Federal #1-14-25	Section 25	467225C1	48
Durham Ranch State #2-12-36	Amoco Section 36	467236B1	50
North Cordero	North Cordero	477119C1	50
Amoco WCH 5	477236B1	477236B1	51
All Night Creek	All Night Creek	ANC	52
Barton	Barton	BARTON	54
Blackbird Coleman	Blackbird Coleman	BBIRD	55
Bear Draw Unit	Bear Draw	BDU	57
Phillips Beaver Federal	Beaver Federal	BEAVFED	58
Big Cat	Big Cat	BIGCAT	59
Bowers Oil/Gas Inc. State #4-36	Bowers	BOWERS	60
Buffalo Southeast	Buffalo Southeast	BUFFSE	62
Bull Creek	Bull Creek	BULLCRK	64
Bullwacker	Bullwacker	BULLWACK	65
Cedar Draw	Cedar Draw	CEDAR	66
Coal Gulch Unit	Coal Gulch	CGU	67
BRC Federal #33-1	Dilts	DILTS	68
Double Tank	Double Tank	DTANK	69
Dry Willow	Dry Willow	DRYWILL**S**	70
Echeta Coal Test	Echeta	ECHETA	71
Gilmore Oil & Gas Artesian Unit #1	Gilmore	GILMORE	72
Hoe Creek	Hoe Creek	HOE	73
Huber Lone Tree	Lone Tree	HUBERLT	74
Huber Lower Prairie Dog Creek	Lower Prairie Dog Creek	HUBERPD	75
Juniper Draw	Juniper	JUNIPER	77
Kennedy Wells	Kennedy	KENNEDY	79
Lower Quarter Circle Hills	Lower Quarter Circle Hills	LQC	80
Martens & Peck Section 2	MP2	MP2	82
Martens & Peck Section 22	MP22	MP22	83
Barrett Napier	Napier	NAPIER	85
North Gillette	North Gillette	NGILL	86
Palo Petroleum Recluse Field	Palo	PALO	87
Barrett Persson	Persson	PERSSON	88
Shogrin Federal #2	Pistol Point	PISTOL	89
Redstone	Redstone	REDSTN	90
Nance Petroleum Remington Creek	Remington Creek	REMCRK	91
Sasquatch Federal #12-2	Sasquatch	SASQUAT	93
Huber South Coal	South Coal	SCOAL	94
Streeter Road	Streeter	STREETER	95
Barrett Throne	Throne	THRONE	96
Williams Cedar Draw		WCDU	97
Prima Wild Turkey	Wild Turkey	WILDTUR	97

20-Mile Butte (20MILE)

Location: S32 T52N R74W
Date first monitored: January 28, 2004

The 20-Mile Butte (20MILE) monitoring well set consists of four wells. One well is constructed into each of the Anderson, Pawnee, and Wall coal beds, and one is constructed into an overlying Wasatch sandstone bed. Of the three Fort Union coal beds in this set, the Anderson is the shallowest coal, the Wall is intermediate in depth between the other two coals, and the Pawnee is the deepest. Initial water levels in all three coal zones were similar, even though 600 feet separates the top of the Anderson coal and the bottom of the Pawnee coal bed.

- The Anderson coal well (20MILEA) showed 98.0 feet of drawdown from the initial 2004 water level to 2006. The wellhead gas pressure reached a maximum of 19.4 psi.
- The Pawnee coal well (20MILEP) showed 76.3 feet of drawdown from 2004 to 2006. The rate of decline increased in 2006, and future examination of production data may indicate water production proximal to this well. The wellhead gas pressure was a maximum of 19.6 psi.
- The Wall coal well (20MILEW or 20MILEWC) showed 130.1 feet of drawdown from 2004 to 2006. Wellhead gas pressure did not rise significantly from 2004 to 2006 and showed a maximum reading of 0.9 psi.
- The overlying Wasatch sandstone well (20MILES), which is constructed into a sandstone bed 357 feet stratigraphically above the Anderson coal, showed 10.7 feet of drawdown from 2004 to 2006. This well showed little affect from CBNG-related drawdown in the underlying Anderson, Pawnee, and Wall coal beds at the 20-Mile Butte well set. The amount of drawdown measured in this sandstone well may be due to a short (two-year) monitoring period.



The Anderson, Pawnee, and Wall coal wells at 20-Mile Butte showed relatively constant rates of water-level decline from 2004 to 2006. The largest water-level decline was observed in the Wall coal, the second largest in the Anderson coal, and the smallest in the Pawnee coal. The water levels in these three coals were similar at approximately 500 to 650 feet deep, but the levels varied enough (a maximum of about 50 to 80 feet difference) to indicate the coals are under relatively confined hydrologic conditions and are hydraulically separated. The Wasatch well showed very little water-level decline and does not appear to be hydraulically connected with the underlying coals.

Wellhead gas pressures peaked in the Anderson well at 19.4 psi during the first quarter of 2004 and in the Pawnee coal well at 19.6 psi in the third quarter of 2006. Gas pressure dips in 2004 for the Anderson coal are the result of field visit venting events. The well is vented to facilitate manual measurements with pressure recovery following. The Wall well remained relatively stable at nearly zero pressure. The difference in the timing and levels of gas pressures between the coals are additional evidence of hydraulic separation of the coal beds in the 20-Mile well set.

Phillips 21-Mile Butte (21MILE)

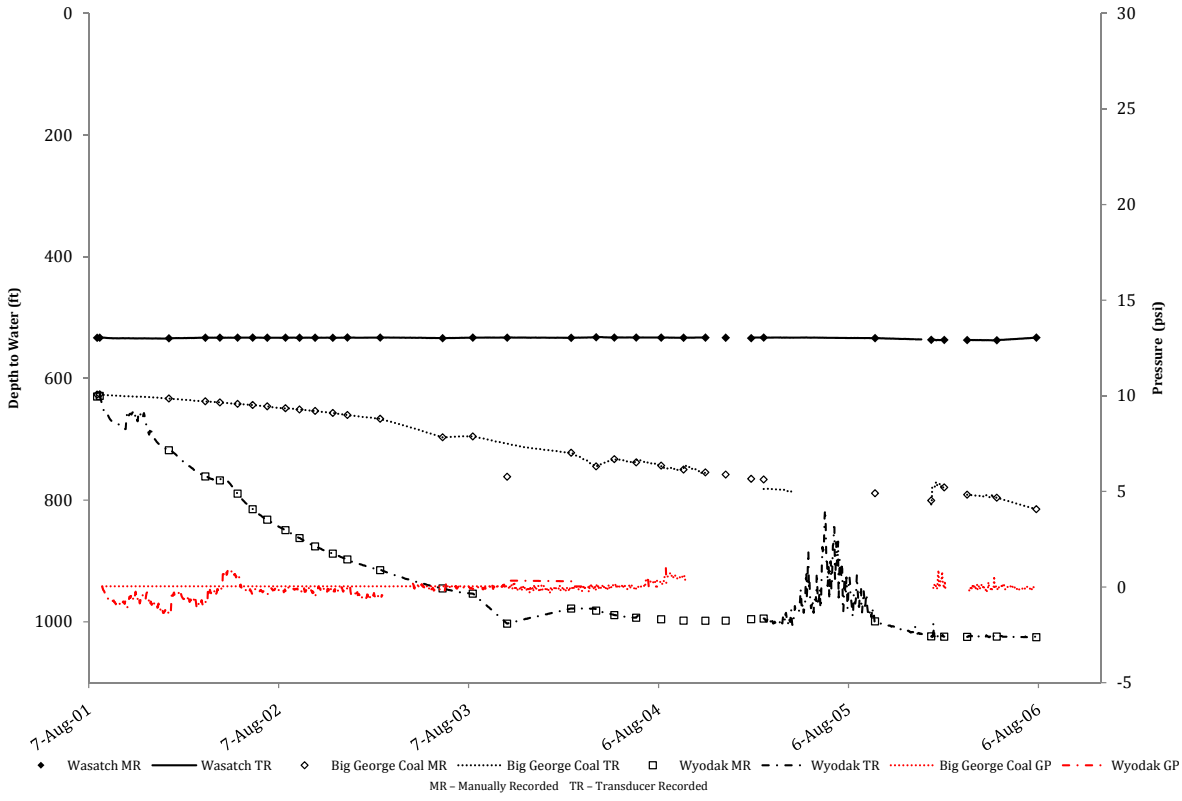
Location: S22 T48N R74W
Date first monitored: August 19, 2001

The Phillips 21-Mile Butte monitoring well set includes three wells. Two are constructed into the Big George and Wyodak coals in the Fort Union coal beds, and one is constructed into an overlying Wasatch sandstone bed. The Big George coal, at about 1,280 feet in depth, is shallower than the Wyodak coal at this location. The Wyodak is at about 1,500 feet in depth. The initial water levels in these two coal zones were similar.

- Big George coal well (21MILEBGC) showed 195.7 feet of drawdown from the initial water level in 2001 to 2006. The wellhead gas pressure recorded a maximum of 0.9 psi. The transducer at this well malfunctioned from February 2005 through September 2005 during which erroneous pressure readings were recorded.
- The Wyodak coal well (21MILEWC) showed 394.1 feet of drawdown from 2001 to 2006. The wellhead gas pressure was a maximum of 0.9 psi. The transducer at this site malfunctioned between February 2005 and December 2005 during which erroneous pressure readings were recorded.
- The overlying Wasatch sandstone well (21MILES), which is constructed into a sandstone bed 197 feet stratigraphically above the top of the Big George coal, showed an increase in water level of 0.2 feet from 2001 to 2006. The water level in this well is relatively stable and is apparently unaffected by drawdown in the underlying Big George and Wyodak coal beds.

The 21-Mile Big George well showed a relatively constant rate of water-level decline from 2001 to 2006. The Wyodak coal showed a rapid water-level decline from 2001 to 2003 and a slower decline from 2003 to 2006. The greatest water-level decline was

Phillips 21-Mile Butte (21MILE)



in the Wyodak well, which had nearly twice the drawdown of the Big George. Water levels for both coals were initially at 600 feet in depth in 2001, but the Wyodak well water level had declined to more than 1,000 feet in depth, and the Big George water level had dropped to 800 feet deep. The difference in water-level depths between the coals and the rapid decline rate in the Wyodak well are evidence that these coals are mostly confined and hydraulically separated. The Wasatch sandstone well is also hydraulically separated from the underlying coals.

The graph showing gas pressure (GP) for the Big George and Wyodak coals has been corrected for transducer errors experienced during 2004–2006. Transducer error displayed extreme negative readings for the Big George and Wyodak coals and high positive gas pressures in the Wyodak that were not confirmed with manual measurements.

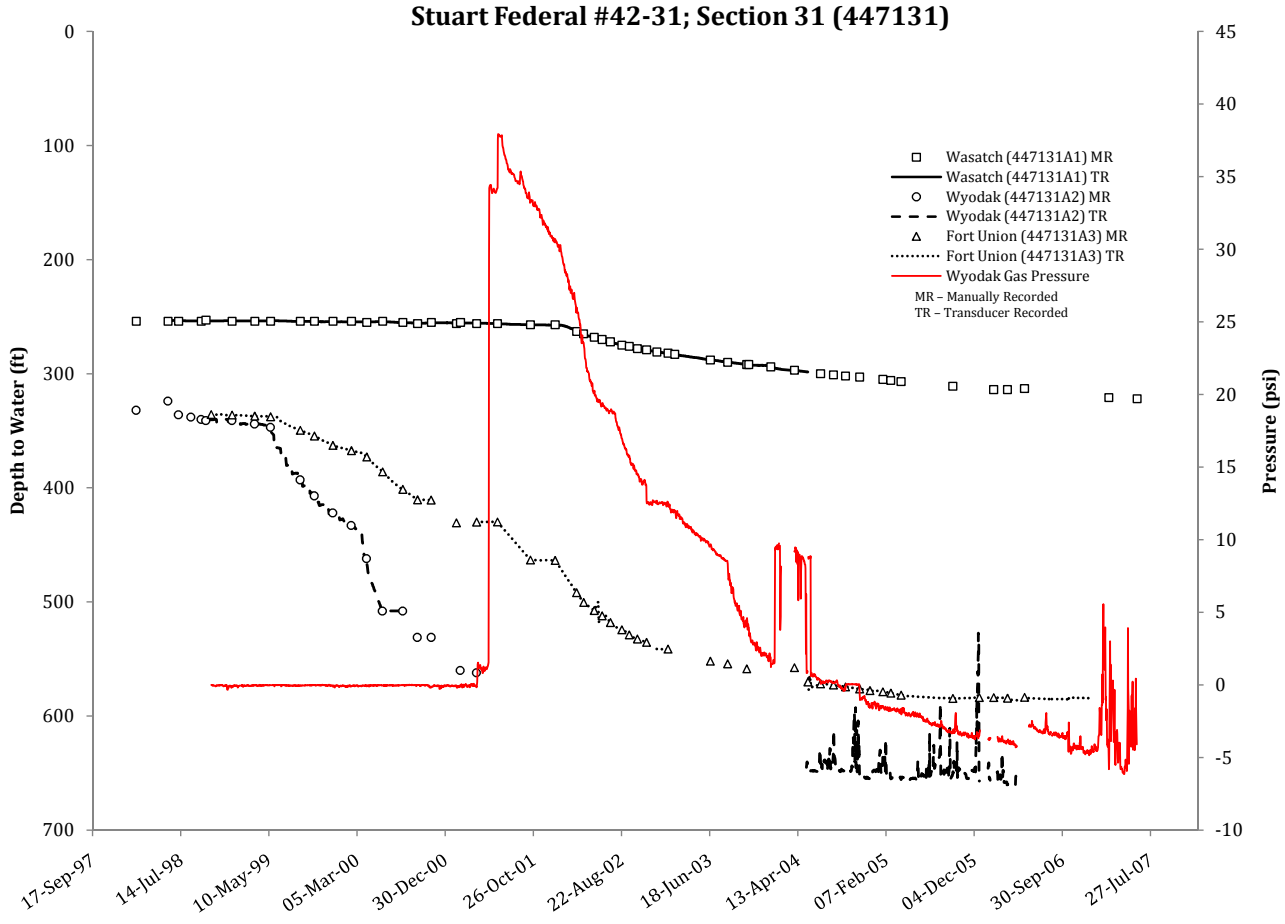
Stuart Federal #42-31 Wells; Section 31 Wells (447131)

Location: S31 T44N R71W

Date first monitored: August 18, 1997

The Stuart Section 31 (447131) monitoring well set includes three wells. One is constructed into the Wyodak coal, one into the Fort Union underburden sandstone beneath the Wyodak coal, and one into an overlying Wasatch sandstone bed.

- The Wyodak coal well (447131A2) showed an initial water level of 331.7 feet in 1998 and decreased to 561.9 feet by 2001. High wellhead gas pressure prevented manual measurements for the remainder of the monitoring period, but transducer data showed water levels as low as 650 feet in the 780-foot-deep well. The wellhead gas pressure peaked at 37.9 psi.
- The underlying Fort Union sandstone well (447131A3), which is constructed into a sandstone bed 14 feet stratigraphically beneath the base of the Wyodak coal, recorded 248.7 feet of drawdown from 1998 to 2006. This well is impacted by CBNG-related drawdown in the overlying Wyodak coal bed.
- The overlying Wasatch sandstone well (447131A1), which is constructed into a sandstone bed 89 feet stratigraphically above the top of the Wyodak coal, showed 58.9 feet of drawdown from 1998 to 2006. This well may be affected by the CBNG-related drawdown in the underlying coal beds.



The Wyodak wellhead gas pressure peaked at 38.0 psi in late June 2001. The water-level in the Wyodak coal well had declined to below about 650 feet deep at the same time, equaling about 320.8 feet of drawdown, or about 139 psi of water pressure reduction in the coal bed.

The Fort Union underlying sandstone well recorded a relatively steady rate of water-level decline from 336.0 to 580.0 feet from 1998 to 2004, and drawdown remained relatively stable (about 580 feet) since then. The water levels in the Wyodak coal and underlying sandstone well set were within 75 feet of each other and the drawdown curves showed a similar trend, which may indicate a hydraulic connection.

The Wasatch sandstone well showed a slow rate of water-level decline from 1997 to January 2002, after which decline rates increased from 2002 to 2006. Since drawdown in the coal well began mid-1997, and the drawdown rates in the Wasatch sandstone well did not sharply rise until 2002, it is unclear as to which water production is affecting this sandstone aquifer. The Wasatch well may be hydraulically connected to the Wyodak coal, but further analysis of water production records of nearby CBNG wells will be necessary before drawing conclusions. A CBNG well was installed in the same quarter-quarter by Lance Oil and Gas Company in 2002 (Stuart Federal #42-31-4471). Rapid drawdown in the Wasatch sandstone corresponded closely with the onset of water production in this nearby CBNG well.

Durham Ranch Federal #42-14B Well; Section 14 Well (447214)

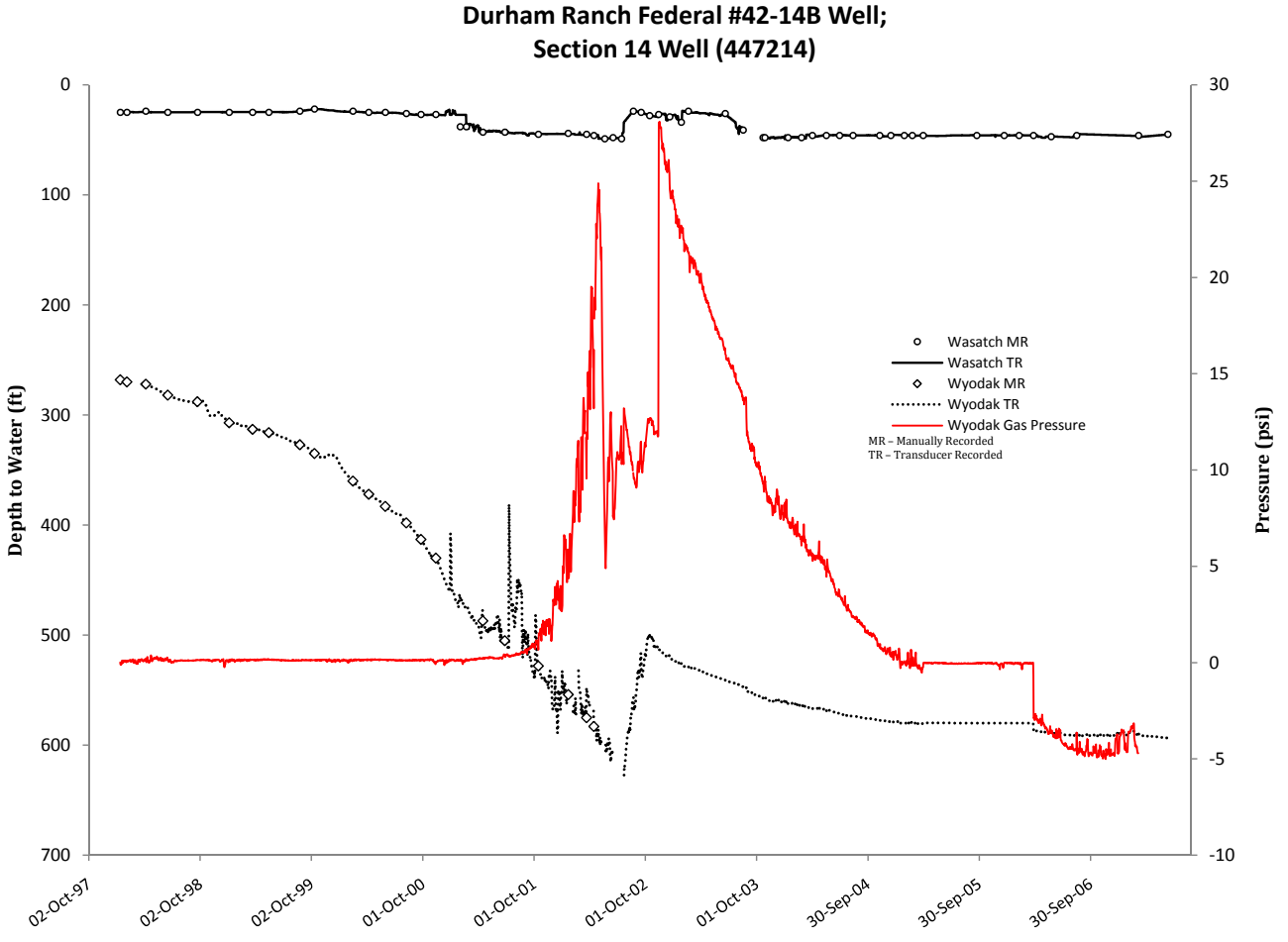
Location: S14 T44N R72W

Date first monitored: January 13, 1998

The Durham Ranch Federal #42-14B Well; Section 14 Well (447214) monitoring well set includes two wells. One is constructed into the Wyodak coal and one into an overlying Wasatch sandstone bed.

- The Wyodak coal well (447214A1), which had an initial water level measurement of 268.0 feet deep, became dry after 548 feet of drawdown. The last manual reading of 642.1 feet deep was recorded in 2002 before high wellhead gas pressures prevented further water-level readings. The well was found to be dry in 2002, indicating the water level was below the total well depth of 816 feet. The maximum wellhead gas pressure peaked at 28.1 psi. Erratic water levels recorded by the transducer generally coincided with the development of high pressure in the coal monitoring zone.
- The overlying Wasatch sandstone well (447214A2), which is constructed into a sandstone bed 26 feet stratigraphically above the top of the Wyodak coal, showed 21.8 feet of drawdown from the initial water level of 24.6 feet.

The difference in initial water levels between the Wyodak coal and Wasatch sandstone wells in 1998 was about 245 feet. Water levels in the coal well dropped dramatically and steadily whereas the sandstone water level dropped only about 25 feet. These conditions indicate little or no hydraulic communication between the sandstone well and the Wyodak coal well.



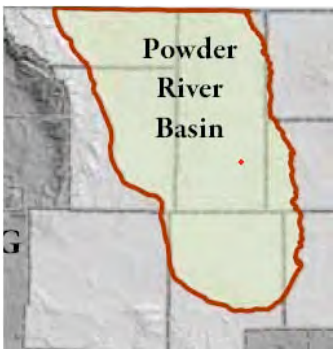
Durham Ranch Federal #23-6B Well; Section 6 Well (457106)

Location: S6 T45N R71W

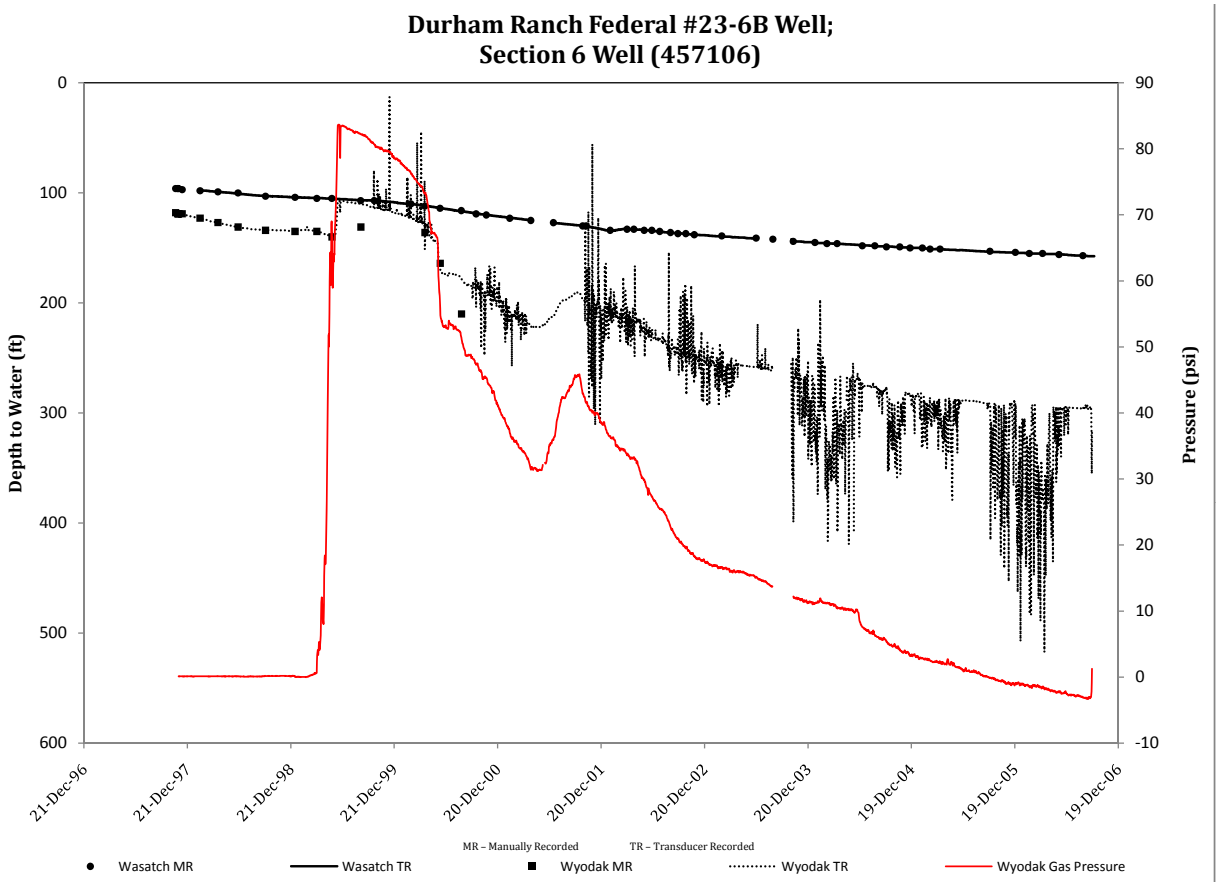
Date first monitored: November 10, 1997

The Durham Ranch Federal #23-6B Well; Section 6 Well (457106) monitoring well set includes two wells. One is constructed into the Wyodak coal and one into an overlying Wasatch sandstone bed.

- The Wyodak coal well (457106C1) became dry with more than 199 feet of drawdown from an initial water level in 1997 of 118.2 feet. The wellhead gas pressure peaked at 83.7 psi. Erratic water-level readings recorded by the transducer generally coincided with the development of high pressure in the coal monitoring zone; however, water level-trends were still discernable but lacking in accuracy.
- The overlying Wasatch sandstone well (457106C2), which is constructed into a sandstone bed 43 feet stratigraphically above the top of the Wyodak coal, showed 57.3 feet of drawdown from the initial water level to 2006. This well was affected by CBNG-related drawdown in the underlying Wyodak coal bed.



Wellhead gas pressure peaked in the Wyodak well at 83.7 psi during June 1999, and the coal water level declined to approximately 131 to 139 feet at about the same time. Both the coal and sandstone wells experienced drawdown from 1997 to 2006. The similarity of the two initial water level depths in 1997 (96.0 feet for the sandstone versus 119.0 feet for the coal) and the similar geometry of the drawdown curves for the two wells suggest hydraulic communication between the two monitoring zones.



Bar 76 LL Federal #1-42-1 Well (457301)

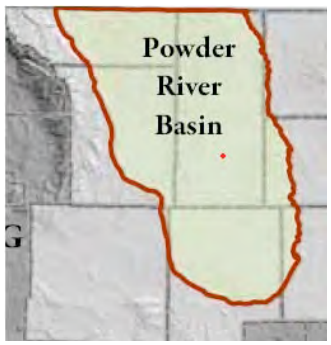
Location: S1 T45N R73W

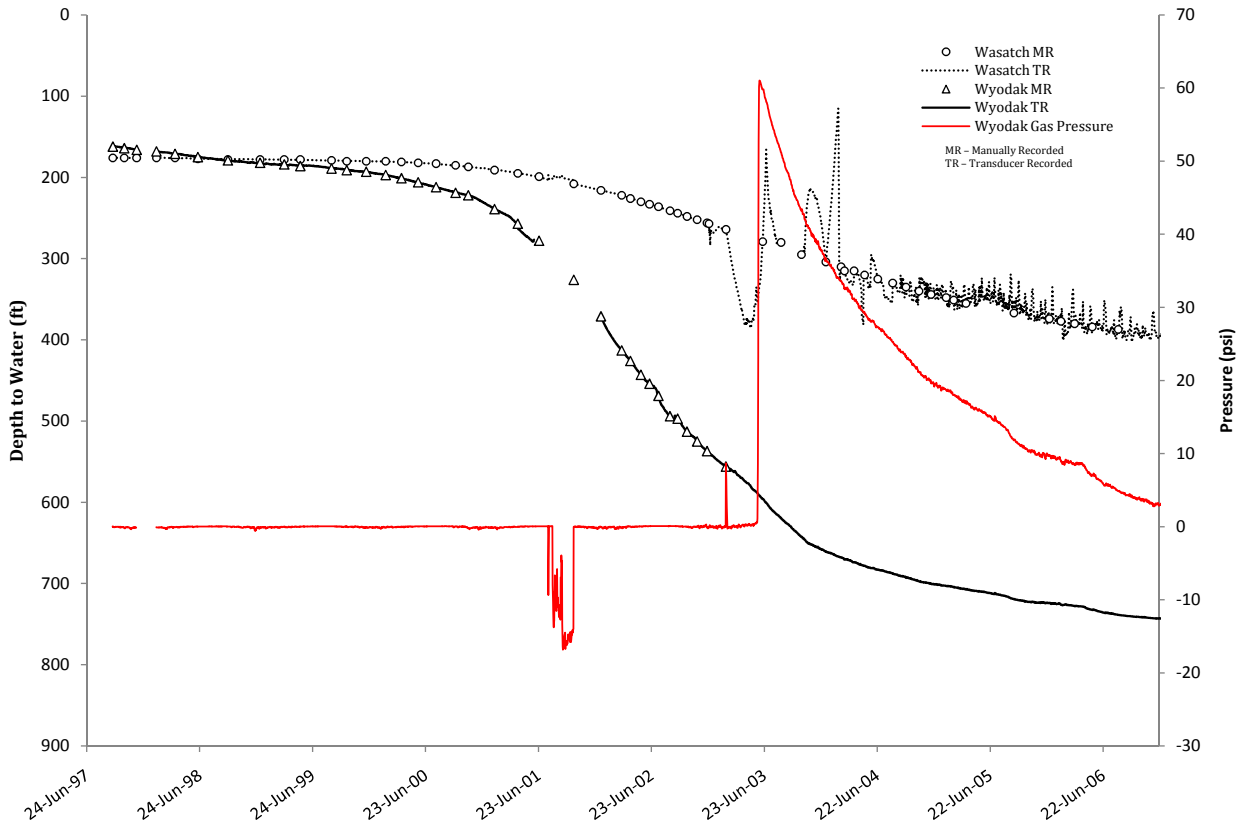
Date first monitored: September 16, 1997

The Bar 76 (457301) monitoring well set includes two wells. One is constructed into the Wyodak coal and the other into an overlying Wasatch sandstone bed as a dual completion.

- The Wyodak coal well (457301A1) recorded 581.2 feet of drawdown between 1998 and 2006 from an initial water level of 161.8 feet. The wellhead gas pressure peaked at 61.0 psi during this period.
- The overlying Wasatch sandstone well (457301A2), which is constructed into a sandstone bed 47 feet stratigraphically above the top of the Wyodak coal, recorded 218.4 feet of drawdown by 2006 from an initial water level of 176.0 feet deep in 1997. Water-level readings with the pressure transducer were erratic in 2003, but manual measurements have recorded a smooth water-level drawdown curve.

During June 2003, when the wellhead gas pressure peaked in the Wyodak well at 61.0 psi, the Wyodak water level declined from approximately 162 feet to 585 feet deep. Both of the wells showed drawdown occurring between 1997 and 2006. The closeness of the two initial water level depths in September 1997 (176.0 feet for the sandstone and 161.8 feet for the coal) and the similar geometry of the drawdown curves for the two wells indicate a possible hydraulic connection between the units. Both wells showed an increased rate of drawdown starting in 2001. The initial water levels in 1997 were 14 feet higher in the Wyodak well than in the Wasatch well. This is interesting as most of the other monitoring well sets showed Wasatch water levels as higher than the coal water levels. At this well set, the initial confining pressure in the Wyodak coal was higher than the initial confining pressure in the overlying Wasatch sandstone well.





South Cordero Well (467106C1)

Location: S6 T46N R71W

Date first monitored: May 21, 1995

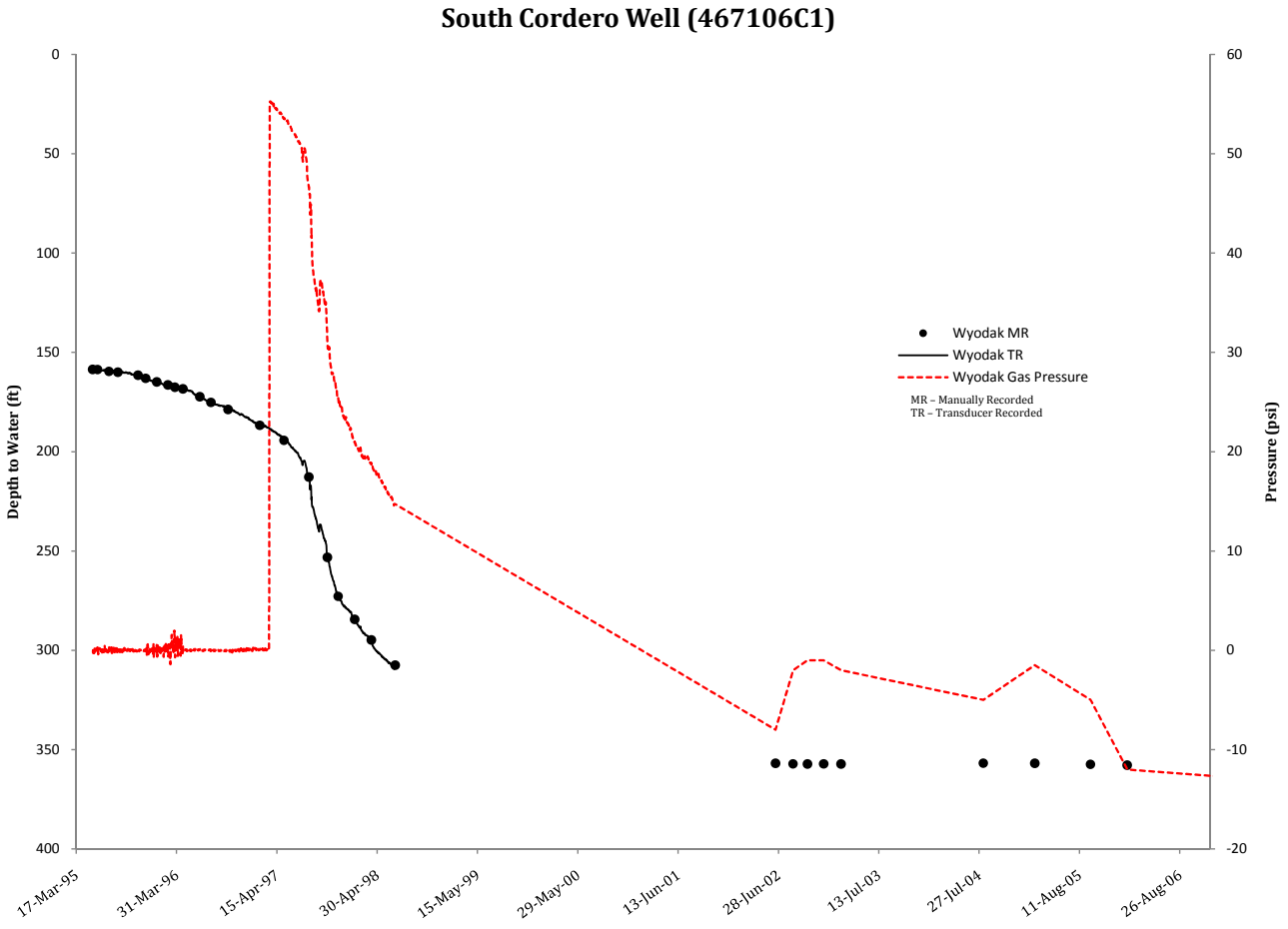
The South Cordero (467106C1) monitoring well is the only well at this location and is constructed into the Wyodak coal. There is no Wasatch sandstone monitoring well at this site.

- The Wyodak coal well (467106C1) showed 199.3 feet of drawdown from 1995 to 2006. The wellhead gas pressure peaked at 55.3 psi.

This well is located on the eastern portion of the basin (**Figure 1**) and was one of the earlier wells added to the BLM deep monitoring well network.

This well had an initial water level of 159.0 feet deep in June 1995. In March 1997, when the wellhead gas pressure peaked at 55.3 psi, the Wyodak water level

had declined by only 29 feet to 188.0 feet deep. Since March 1997, both the water level and gas pressure in this well continued to decline. Wellhead gas pressure readings were trending negative (vacuum condition) at the end of 2006 as a result of blowers being installed on the CBNG production wells in the nearby area, which are used to enhance gas recovery. This condition is common to wells on the eastern margin of the basin in Campbell County.



Federal #1-14-25 Well; Section 25 Wells (467225)

Location: S25 T46N R72W

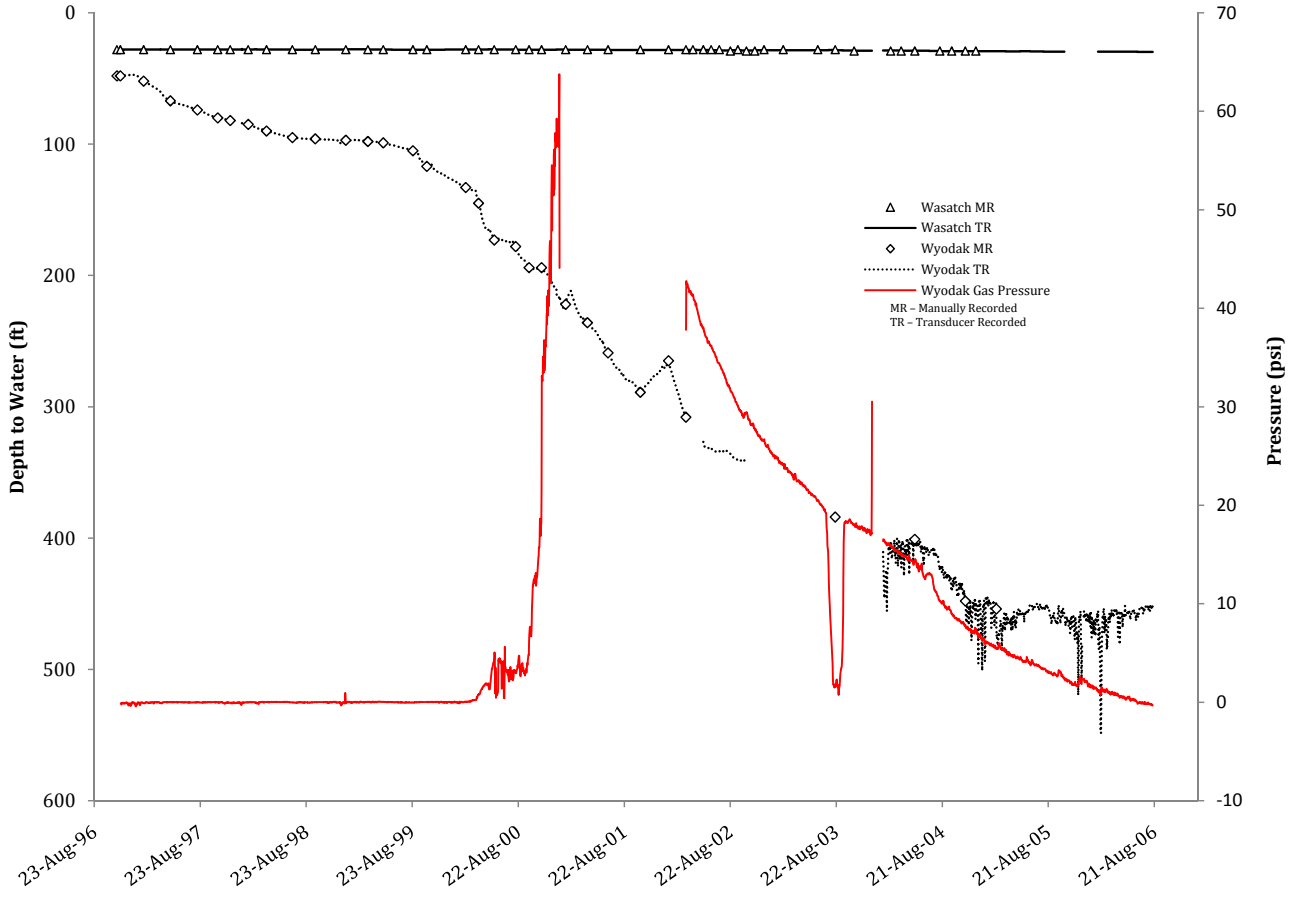
Date first monitored: November 9, 1996

The Section 25 (467225) monitoring well set includes two wells: one well is constructed into the Wyodak coal and one well into an overlying Wasatch sandstone bed.

- The Wyodak coal well (467225C1) became dry with more than 414 feet of drawdown from an initial water level of 48.3 feet deep. The wellhead gas pressure peaked at 63.8 psi. The transducer readings have been periodically erratic since 2003.
- The overlying Wasatch sandstone well (467225C2), which is constructed into a sandstone bed 250 feet stratigraphically above the top of the Wyodak coal, showed 1.6 feet of drawdown from 1996 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.

When the wellhead gas pressure peaked in the Wyodak well at 63.8 psi in January 2001, the Wyodak water level had declined from approximately 48 feet to 200 feet deep. The Wyodak well showed steady drawdown from 1996 to 2006. The two initial water-level depths in November 1996 (28.1 feet for the sandstone versus 48.3 feet for the coal) and the water-level curves for the two wells show no evidence of hydraulic connection. It is interesting to note that in 1996, the initial water levels in the two wells were only 20 feet apart. Wellhead gas pressure readings in the coal well were trending

Federal #1-14-25; Section 25 (467225)



negative (vacuum condition) at the end of 2006 as a result of blowers being installed on nearby CBNG production wells to enhance gas production in the area. The gas pressure dip in 2003 for the Wyodak coal is the result of field visit venting events. The well is vented to facilitate manual measurements with pressure recovery following.

Durham Ranch State #2-12-36 Well; Amoco Section 36 Well (467236B1)

Location: S36 T72N R47W

Date first monitored: No data available

Monitored water-level and wellhead gas pressure data were not available for this monitoring well.

North Cordero Well (477119C1)

Location: S19 T47N R71W

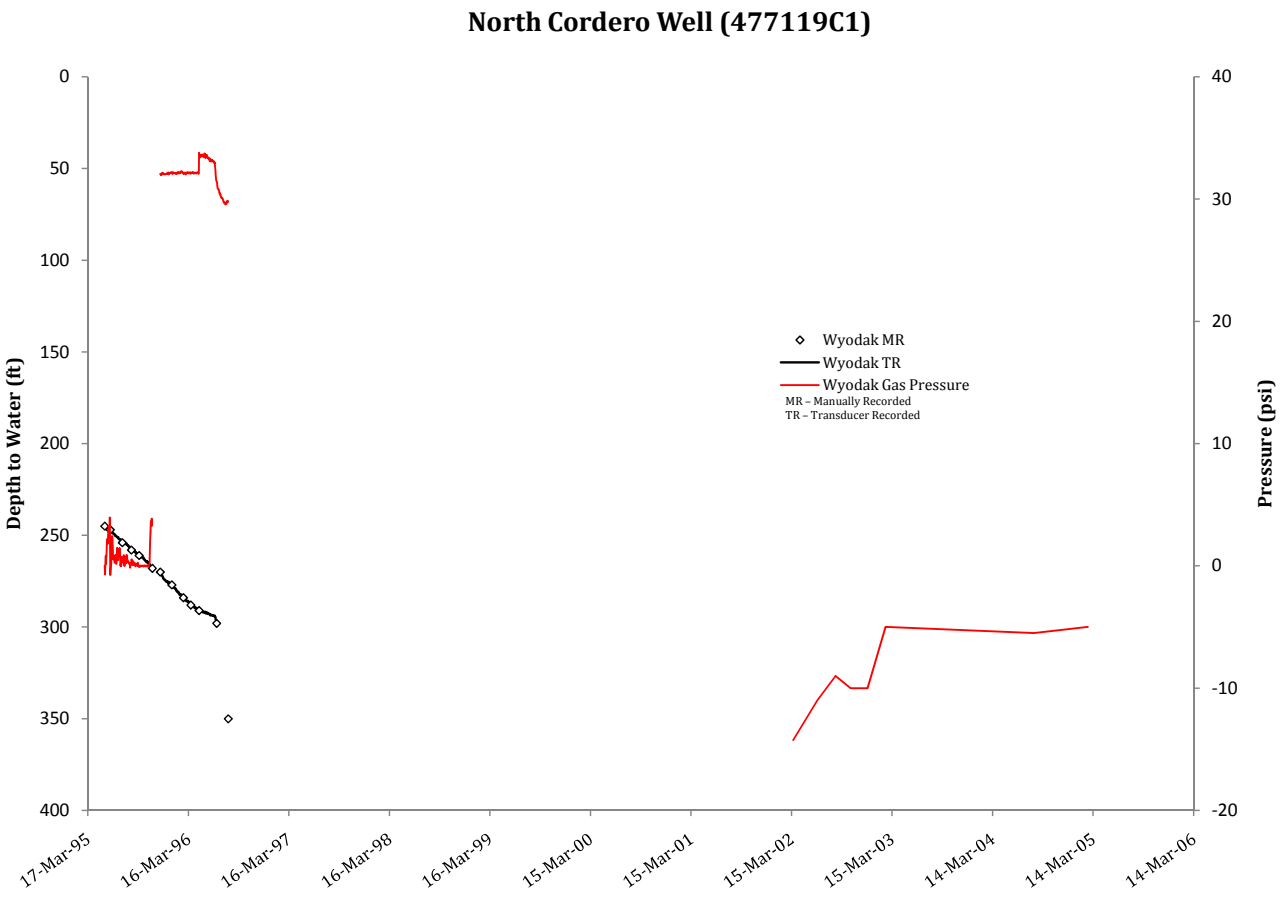
Date first monitored: May 17, 1995

The North Cordero (477119C1) monitoring well is the only well at this location and is constructed into the Wyodak coal. There is no Wasatch sandstone monitoring well at this coal well location.

- This Wyodak coal well (477119C1) became dry by 2000 with 53 feet of drawdown from an initial water level of 245 feet deep. The wellhead gas pressure peaked at 33.8 psi.

In April 1996, when the wellhead gas pressure peaked in the Wyodak well at 34 psi, the Wyodak water level

had declined from approximately 245 feet to 291 feet deep (46 feet of drawdown). Since that time, the gas pressure declined. Wellhead gas pressure readings have been negative (vacuum condition) since late 2001 as a result of blowers being installed on nearby CBNG production wells to enhance gas production in this area.



Amoco Well WCH 5 West Campbell Hydrological Well (477236B1)

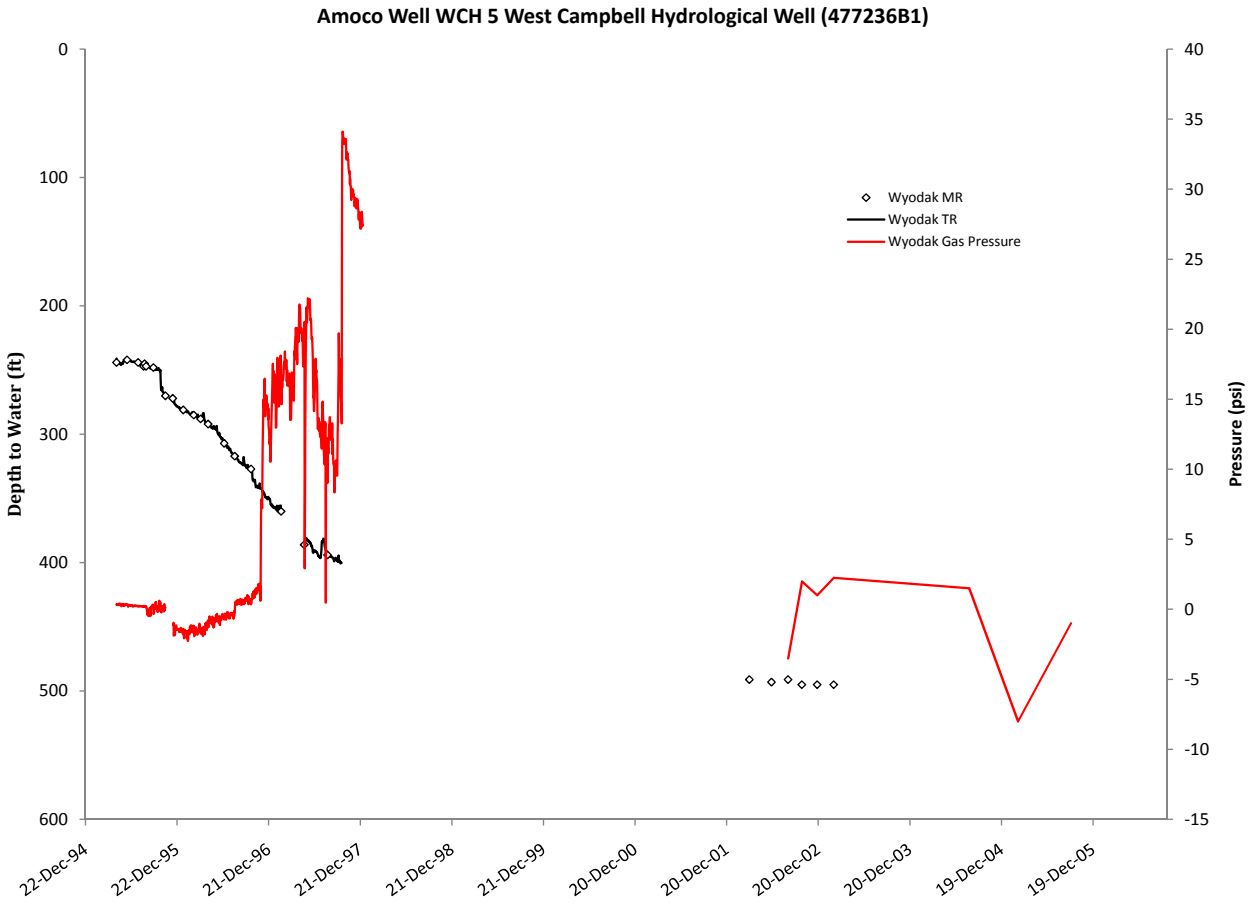
Location: S36 T47N R72W

Date first monitored: April 25, 1995

The Amoco Well WCH 5 West Campbell Hydrological Well (477236B1) monitoring well is the only well at this location and is constructed into the Wyodak coal bed. There is no Wasatch sandstone monitoring well at this coal well location.

- This Wyodak coal well became dry by 2003 with more than 253 feet of drawdown from an initial water level of 241.0 feet deep. The wellhead gas pressure peaked at 34.1 psi.

When the wellhead gas pressure peaked in October 1997 at slightly more than 34 psi, the water level in the well had declined from about 242 to 295 feet deep (53 feet of drawdown). The decline in the formation water head pressure would have been about 23 psi.



All Night Creek (ANC)

Location: S36 T43N R74W

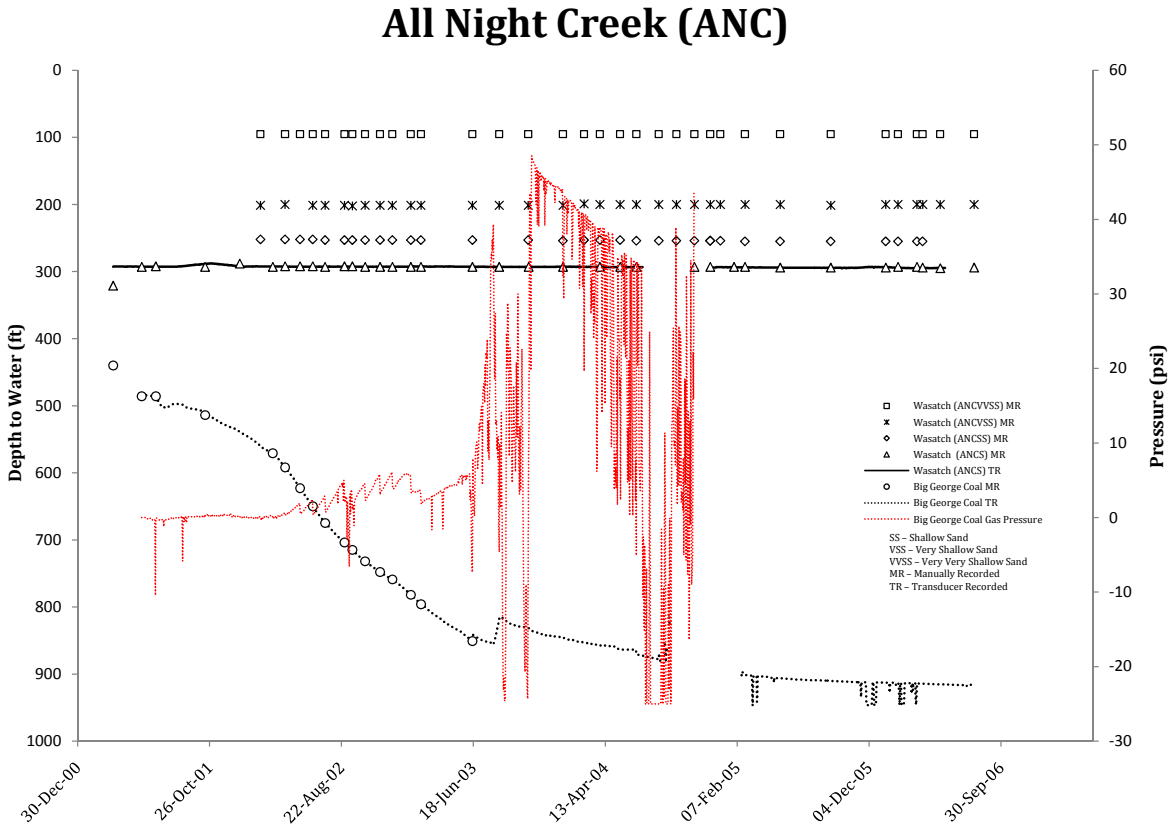
Date first monitored: March 21, 2001

The All Night Creek (ANC) monitoring well set includes five wells. One is constructed into the Big George coal, and the other four are constructed into a series of overlying Wasatch sandstone beds.

- The Big George coal well (ANCC) showed 476.2 feet of drawdown from the initial water level in 2001. The wellhead gas pressure peaked at 48.5 psi. This well had one of the largest recorded water-level drawdowns.
- The closest overlying Wasatch sandstone well (ANCS), which is constructed into a sandstone bed 124 feet stratigraphically above the top of the Big George coal, recorded a water-level rise of 26.1 feet. This well was not affected by CBNG-related drawdown.
- Another shallow overlying Wasatch sandstone well (ANCSS), which is constructed into a sandstone bed 344 feet stratigraphically above the top of the Big George coal, recorded 2.7 feet of drawdown from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Big George coal bed.

- A very shallow overlying Wasatch sandstone well (ANCVSS), which is constructed into a sandstone bed 564 feet stratigraphically above the top of the Big George coal, showed a water-level rise of 0.3 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown.
- A very very shallow Wasatch sandstone well (ANCVVSS), which is constructed into a sandstone bed 744 feet stratigraphically above the top of the Big George coal, showed a water-level rise of 0.6 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown.

During October 2003, when the wellhead gas pressure peaked in the Big George well at more than 48 psi, the Big George water level had declined from approximately 440 feet to 846 feet deep. The water-level curves for the four Wasatch sandstone wells showed three wells with water-level rises and one with less than 3 feet of decline. These data show no evidence of hydraulic connection.



Barton Monitoring Wells (BARTON)

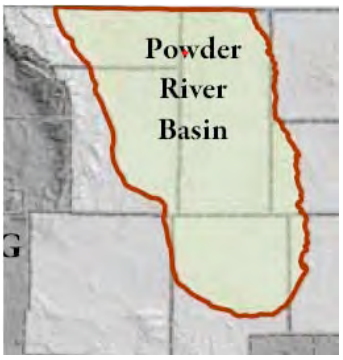
Location: S7 T45N R71W

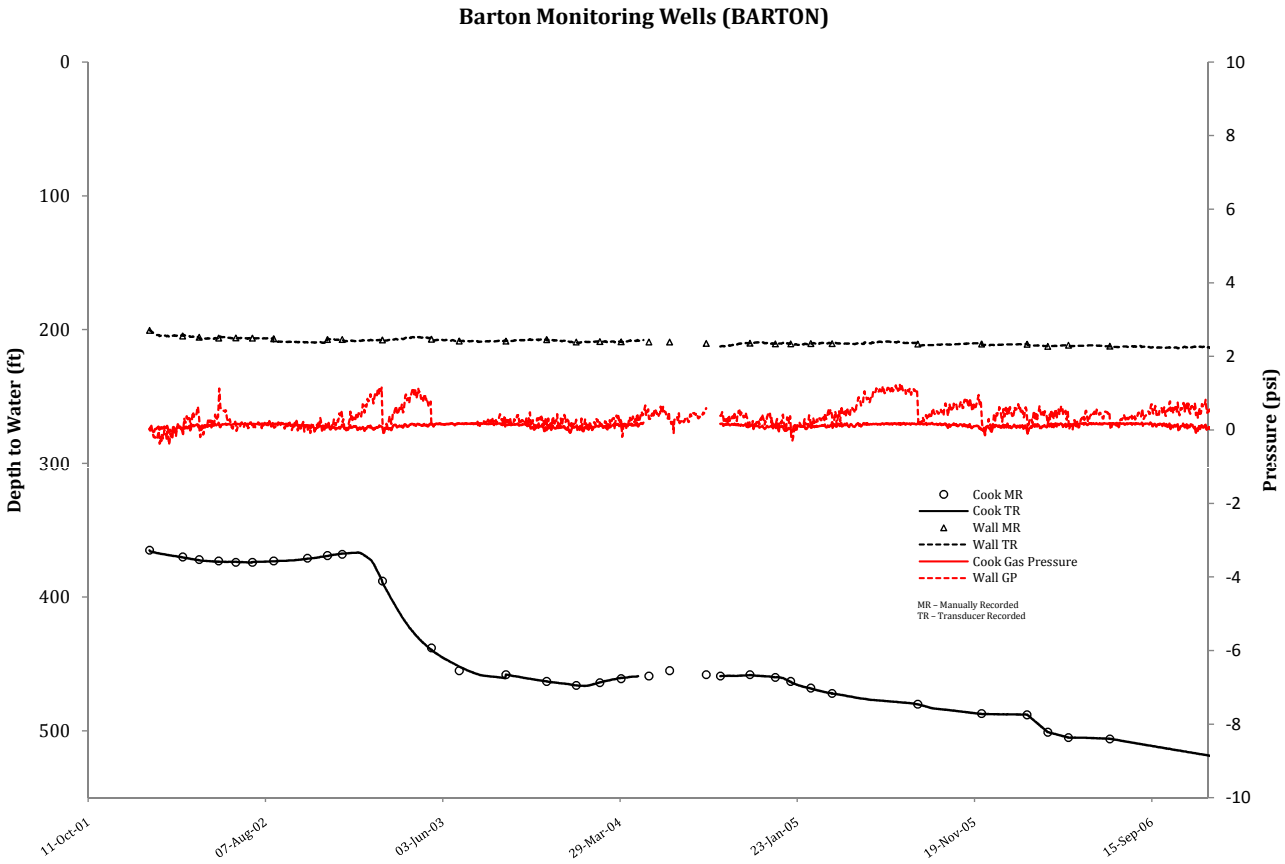
Date first monitored: January 23, 2002

The Barton (BARTON) monitoring well set includes two coal wells. One is constructed into the shallower Cook coal and the other into the deeper Wall coal. There is no Wasatch sandstone monitoring well associated with these two wells.

- The Cook coal well (BARTONC) showed 154.7 feet of drawdown from 2002 to 2006. The wellhead gas pressure peaked at 0.2 psi.
- The Wall coal well (BARTONW) showed 12.6 feet of drawdown from 2002 to 2006. The wellhead gas pressure peaked at 1.2 psi.

The wellhead gas pressures in both the Cook and Wall wells remained nearly zero during this period. The cyclical elevations in gas pressure could be the result of temperature effects on the sensors. The Cook water level declined from approximately 201 feet to 213 feet deep. During the same period, the Wall water level showed a larger decline from approximately 366 feet to 506 feet deep (about 140 feet of drawdown). The water-level curves for the two wells show no evidence of hydraulic connection.





Blackbird Coleman (BBIRD)

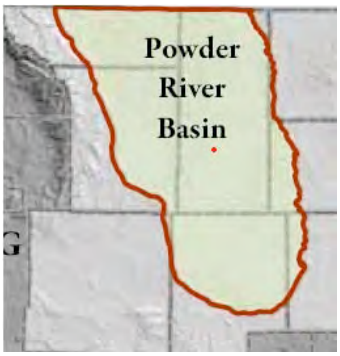
Location: S16 T47N R74W

Date first monitored: July 17, 2002

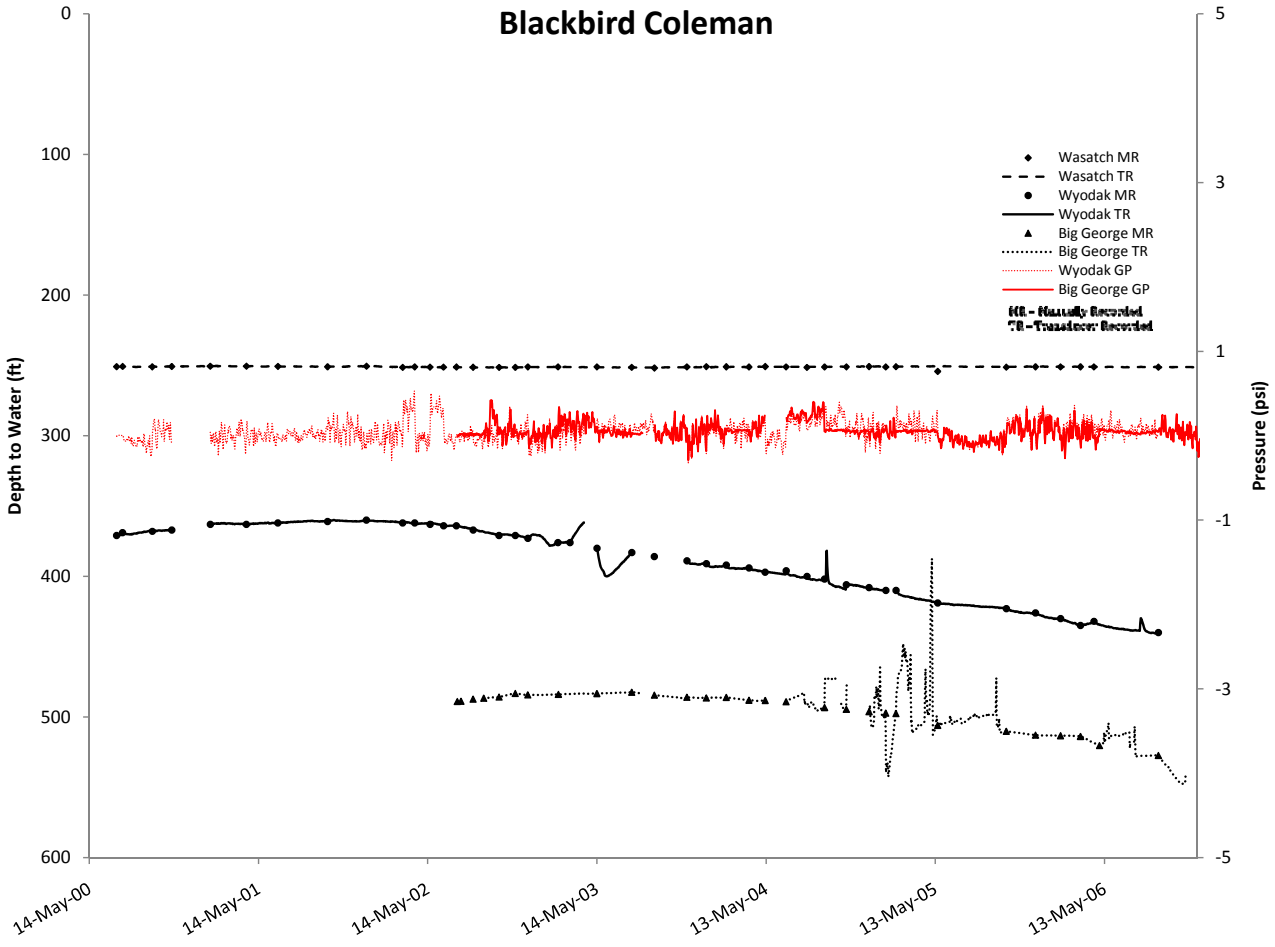
The Blackbird Coleman (BBIRD) monitoring well set includes three wells. One is constructed into the shallower Big George coal, another into the deeper Wyodak coal, and the third into an overlying Wasatch sandstone bed.

- The Big George coal well (BBIRDBG) showed 38.3 feet of drawdown from the initial water level in 2002 to 2004. The wellhead gas pressure peaked at 0.4 psi.
- The Wyodak coal well (BBIRDC) showed 69.6 feet of drawdown from 2000 to 2006. The wellhead gas pressure peaked at 0.5 psi.
- The overlying Wasatch sandstone well (BBIRDS), which is constructed into a sandstone bed 736 feet stratigraphically above the top of the Wyodak coal and 448 feet above the top of the Big George coal, showed 0.39 feet of drawdown from 2000 to 2006. BBIRDS was not affected by CBNG-related drawdown.

For the monitoring period from 2000 to 2006, the wellhead gas pressures in both the Big George and Wyodak wells remained nearly zero. The Big George water level rose from 489 to 483 feet deep from July 2000 to August 2001, and then the level declined from approximately 483 feet to 527 feet deep from August 2001 to September 2004 (end of data available). During the same period, the Wyodak water level rose from 371 to 361 feet deep from July 2000 to August 2001, and then it declined from approximately 361 feet to 441 feet deep (about 140 feet of drawdown) from August 2001 to 2006.



The plotted Big George and Wyodak water-level curves mirror each other in shape; however, the two levels indicate hydraulic separation as the Big George water level is more than 100 feet deeper than the Wyodak level. The water-level curves for the two coal wells show no evidence of hydraulic connection.



Bear Draw Unit (BDU)

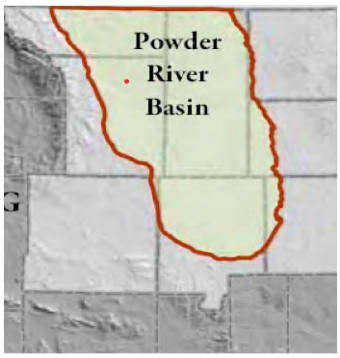
Location: S1 T50N R79W

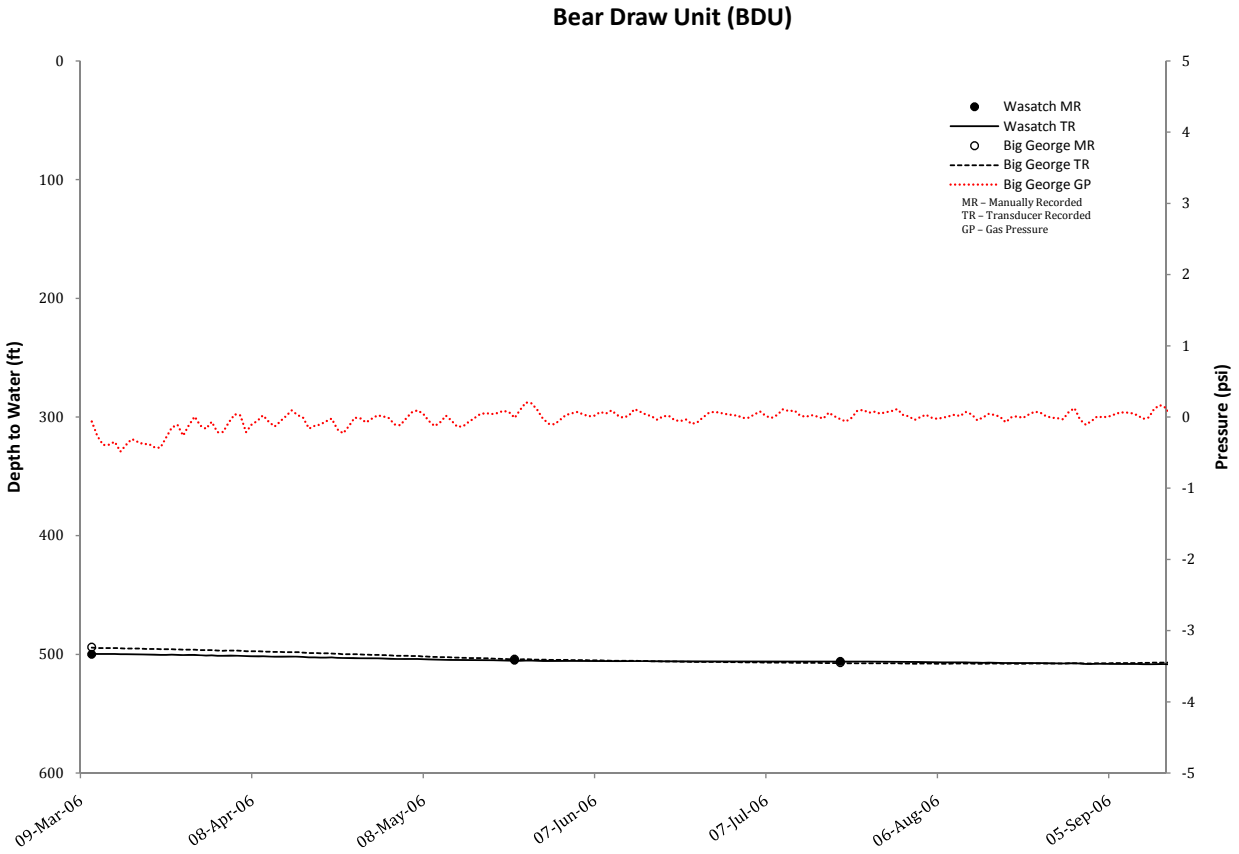
Date first monitored: March 11, 2006

The Bear Draw Unit (BDU) monitoring well set includes two wells. One is constructed into the Big George coal and the other into an overlying Wasatch sandstone bed.

- The Big George coal well (BDUC) showed 10.3 feet of drawdown from the initial water level in March 2006. The wellhead gas pressure peaked at 0.2 psi in 2006.
- The overlying Wasatch sandstone well (BDUS), which is constructed into a sandstone bed 153 feet stratigraphically above the top of the Big George coal, showed 14.1 feet of drawdown from March 2006 to December 2006.

During this period, the wellhead gas pressures in the Big George well remained nearly zero. The Big George water level declined from approximately 495 to 505 feet. The Wasatch level declined from approximately 500 to 514 feet deep. The water levels measured in both wells were at nearly identical depths. The water-level curves for the two wells showed no large drawdowns over the 10-month monitoring period.





Phillips Beaver Federal (BEAVFED)

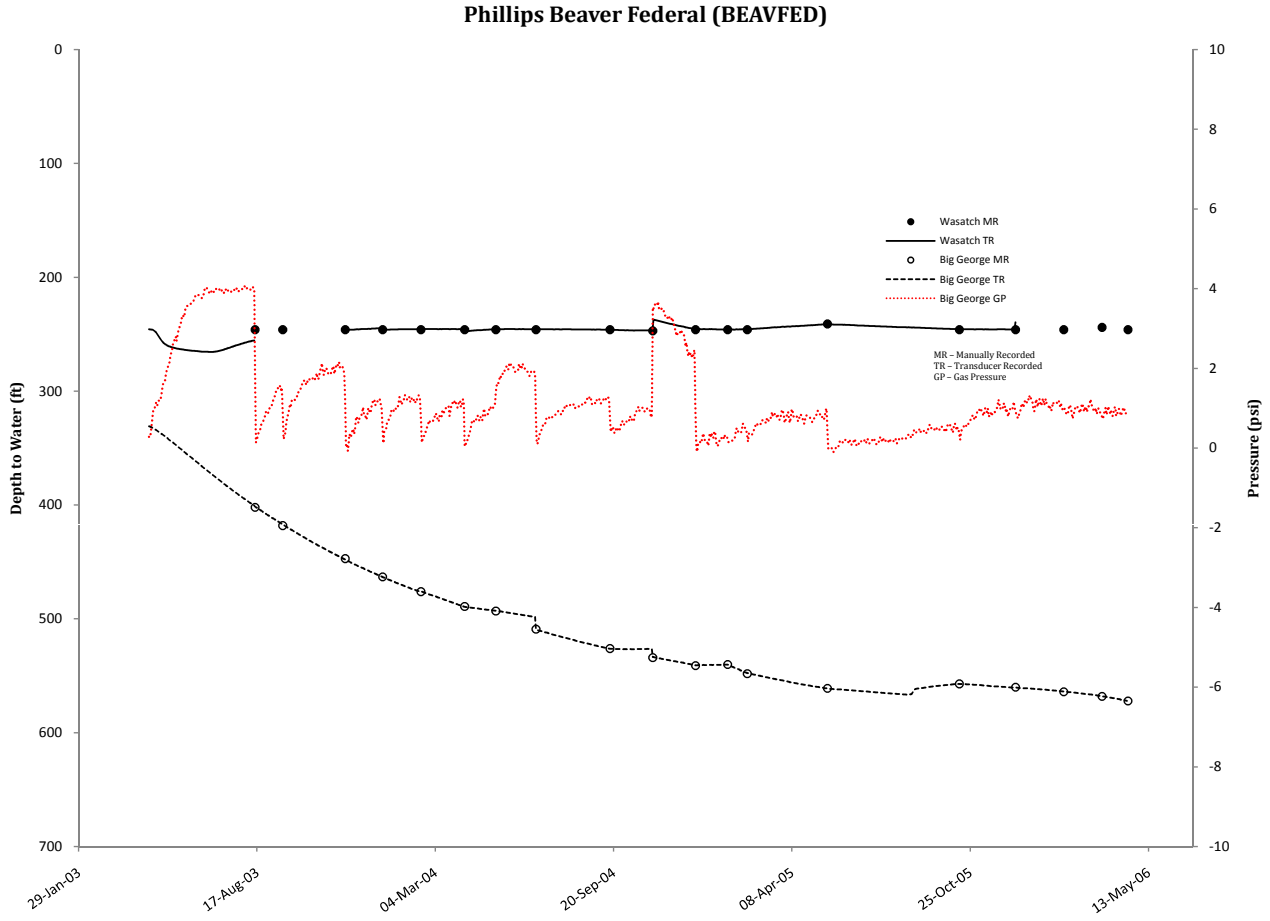
Location: S23 T47N R75W

Date first monitored: April 18, 2003

The Phillips Beaver Federal (BEAVFED) monitoring well set includes two wells. One is constructed into the Big George coal and the other into an overlying Wasatch sandstone bed.

- The Big George coal well (BEAVFEDBG or BEAVFEDC) showed 241.3 feet of drawdown from the initial water level in 2003. The wellhead gas pressure peaked at 4.1 psi.
- The overlying Wasatch sandstone well (BEAVFEDS), which is constructed into a sandstone bed 561 feet stratigraphically above the top of the Big George coal, showed 4.6 feet of drawdown. This well is not likely affected by CBNG-related drawdown in the underlying Big George coal bed.

The wellhead gas pressures were very low in the Big George well from 2003 to 2006, exceeding 4 psi in August 2003. By 2006, the gas pressure declined to 1 psi. The cyclical elevations in gas pressure could be the result of temperature effects on the sensors. The Big George water level steadily declined from 331 to 572 feet deep (241 feet of drawdown) from 2003 to 2006. The water level in the Wasatch well remained relatively stable at about 245 feet deep. The Wasatch well showed no evidence of hydraulic connection with the underlying Big George coal.



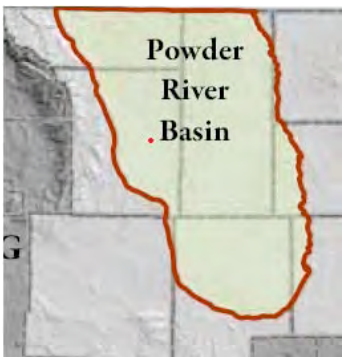
Big Cat (BIGCAT)

Location: S24 T48N R79W

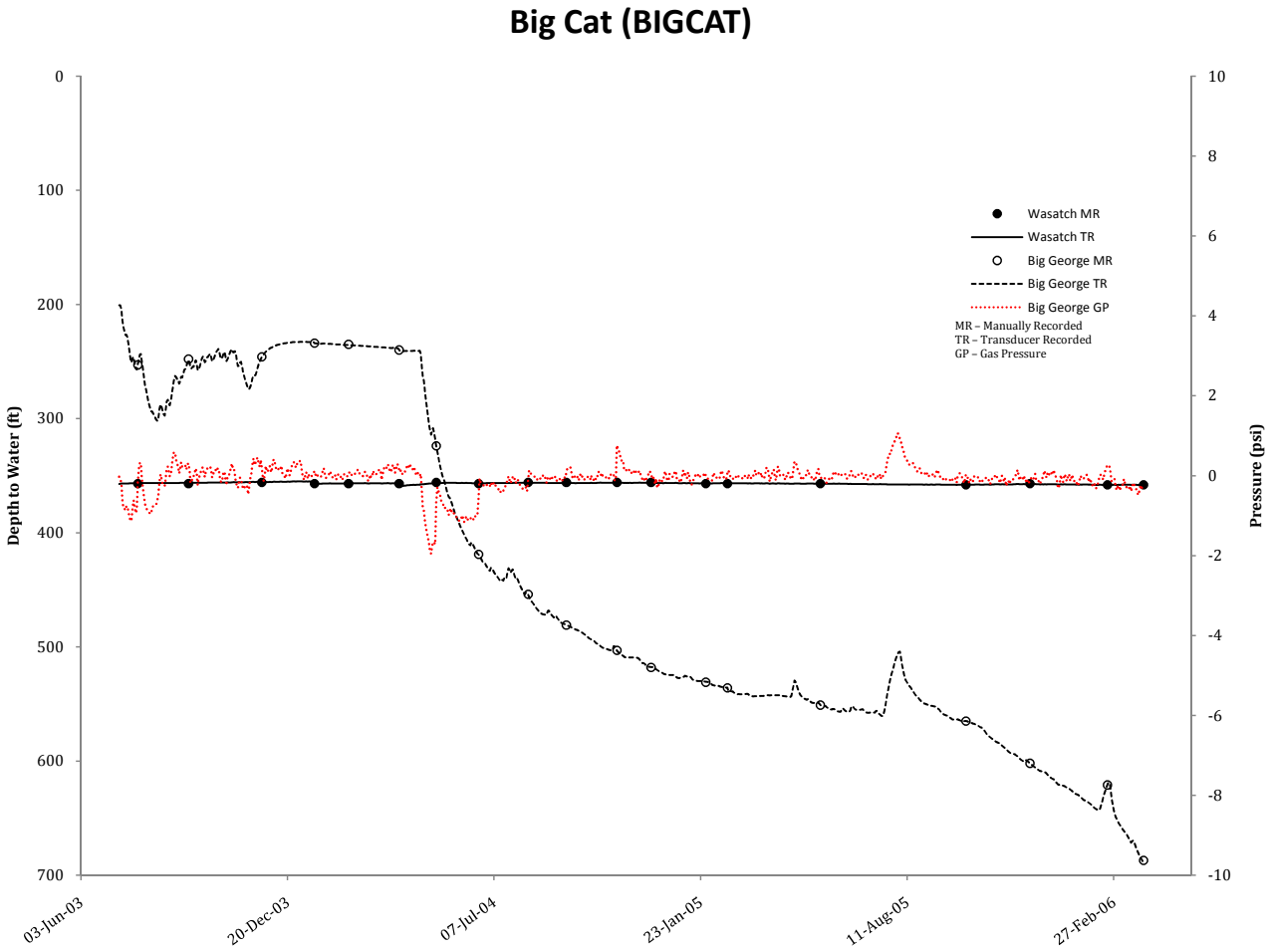
Date first monitored: July 10, 2003

The Big Cat (BIGCAT) monitoring well set includes two wells. One is constructed into the Big George coal and one into a Wasatch sandstone bed.

- The Big George coal well (BIGCATBG or BIGCATC) showed 486.7 feet of drawdown from the initial water level in 2003. The wellhead gas pressure peaked at 1.0 psi.
- The overlying Wasatch sandstone well (BIGCATS), which is constructed into a sandstone bed 1,082 feet stratigraphically above the top of the Big George coal bed, showed 0.7 feet of drawdown from 2003 to 2006. BIGCATS was not affected by CBNG-related drawdown in the underlying Big George coal bed.



Wellhead gas pressure peaked at 1 psi in the coal well during August 2005. The Big George water level remained relatively stable from July 2003 to April 2004. From April 2004 to 2006, the Big George water level recorded a rapid drawdown from 243 to 686 feet deep (443 feet of drawdown). The water level in the Wasatch sandstone well remained relatively stable at about 356 feet deep. The Wasatch sandstone well is not hydraulically connected to the underlying Big George coal.



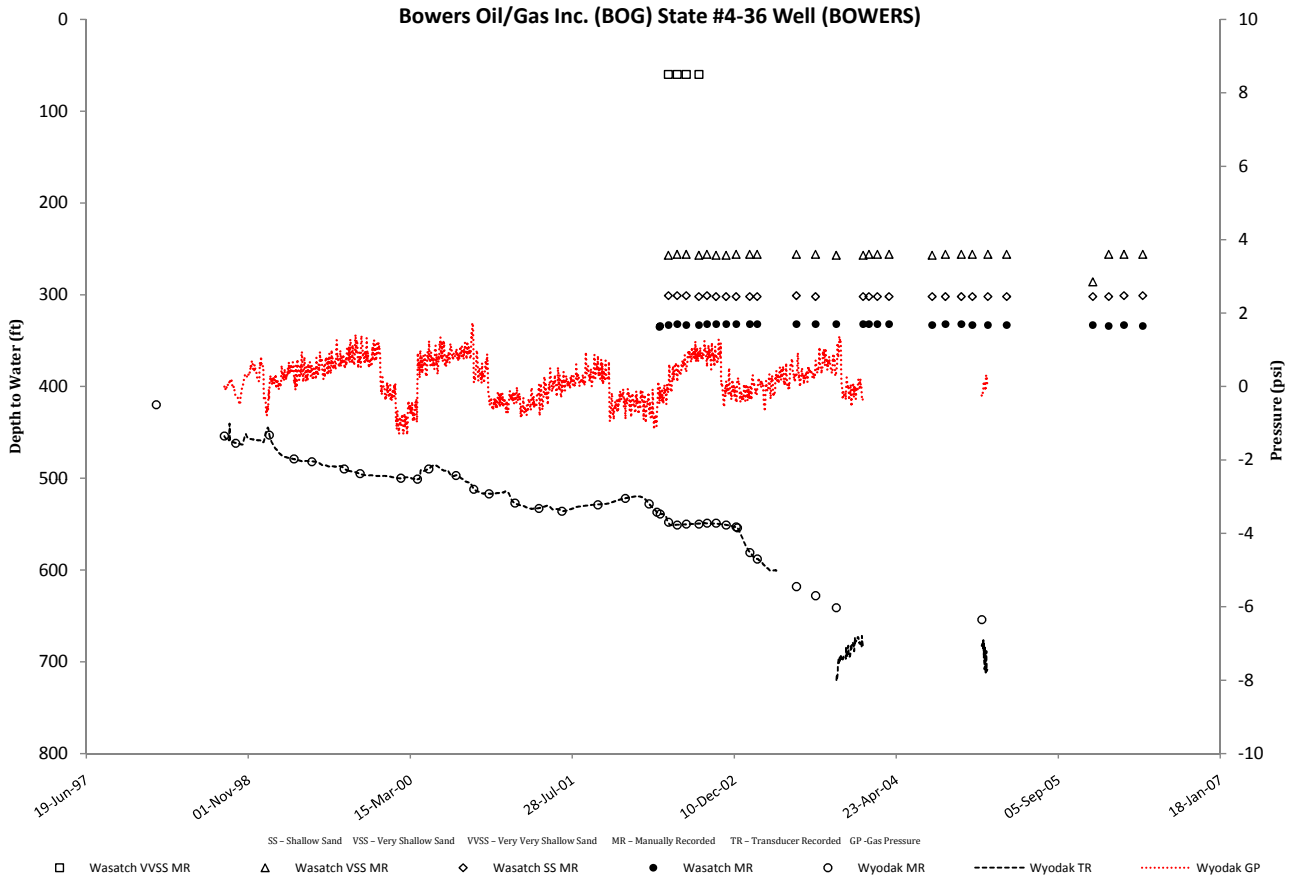
Bowers Oil/Gas Inc. (BOG) State #4-36 Well (BOWERS)

Location: S36 T42N R72W

Date first monitored: January 21, 1998

The Bowers Oil & Gas Inc. (BOG) State #4-36 (BOWERS) monitoring well set includes five wells. One is constructed into the Wyodak coal, and the other four are constructed into a series of overlying Wasatch sandstone beds.

- The Wyodak coal well (BOWERSC) showed 234.1 feet of drawdown from the initial water level in 1998. The wellhead gas pressure peaked at 1.7 psi.
- The overlying Wasatch sandstone well (BOWERSS), which is constructed into a sandstone bed 117 feet stratigraphically above the top of the Wyodak coal, showed a water-level rise of 0.5 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal.
- The shallow Wasatch sandstone well (BOWERSSS), which is constructed into a sandstone bed 272 feet stratigraphically above the top of the Wyodak coal, showed 0.4 feet of drawdown from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal.
- The very shallow Wasatch sandstone well (BOWERSVSS), which is constructed into a sandstone bed 362 feet stratigraphically above the top of the Wyodak coal, showed a water-level rise of 0.2 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.



- The very shallow Wasatch sandstone well (BOWERSVVSS), which is constructed into a sandstone bed 632 feet stratigraphically above the top of the Wyodak coal, showed a water-level rise of 1.1 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.

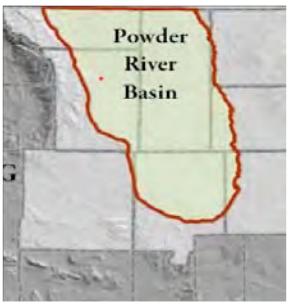
In September 2000, the wellhead gas pressure peaked at 1.7 psi when the water level in the Wyodak well was about 500 feet deep. Cyclical oscillations could be the result of temperature as they showed a seasonal variation. The Wyodak water level showed steady drawdown from about 420 to 653 feet deep (233 feet of drawdown) from 1998 to 2005. The water levels in the four overlying Wasatch sandstone wells remained relatively stable at about 58 feet (VVSS), 256 feet (VSS), 302 feet (SS), and 332 feet (S) deep. The four Wasatch sandstone wells are not hydraulically connected to the underlying Wyodak coal and have different water levels, which indicate the sandstone beds are not hydraulically connected to each other.

Buffalo Southeast (BUFFSE)

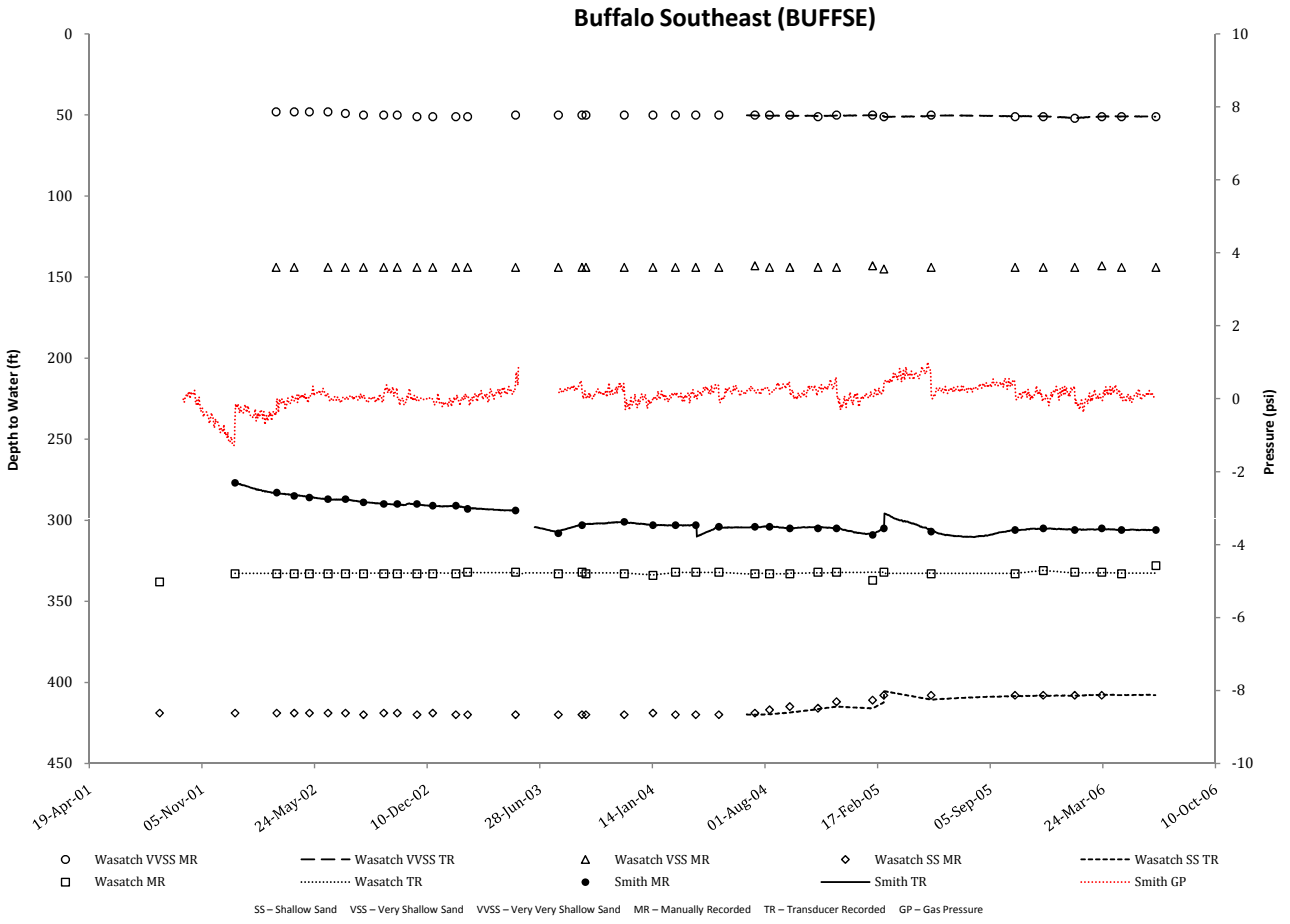
Location: S12 T50N R81W

Date first monitored: August 22, 2001

The Buffalo Southeast (BUFFSE) monitoring well set includes five wells. One is constructed into the Smith coal, and the other four are constructed into a series of overlying Wasatch sandstone beds.



- The Smith coal well (BUFFSEC) showed 28.8 feet of drawdown from the initial water level in 2002. The wellhead gas pressure peaked at 1.0 psi.
- The overlying Wasatch sandstone well (BUFFSES), which is constructed into a sandstone bed 90 feet stratigraphically above the top of the Smith coal, showed a water-level rise of 9.8 feet from 2001 to 2006. This well was not affected by CBNG-related drawdown in the underlying Smith coal bed.
- The shallow Wasatch sandstone well (BUFFSESS), which is constructed into a sandstone bed 993 feet stratigraphically above the top of the Smith coal, showed a water-level rise of 11.3 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Smith coal bed.
- The very shallow Wasatch sandstone well (BUFFSEVSS), which is constructed into a sandstone bed 1,358 feet stratigraphically above the top of the Smith coal, showed a water-level rise of 0.03 feet from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Smith coal bed.
- The very very shallow Wasatch sandstone well (BUFFSEVVSS), which is constructed into a sandstone bed 1,458 feet stratigraphically above the top of the Smith



coal, showed 3.2 feet of drawdown from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Smith coal bed.

In May 2005, the wellhead gas pressure peaked at 1 psi when the water level in the Smith well was about 305 feet deep. The water level in the Smith coal well showed steady drawdown from about 277 to 306 feet deep (29 feet of drawdown) from 2001 to 2006. The water levels in the four overlying Wasatch wells remained relatively stable at about 50 feet (VVSS), 144 feet (VSS), 332 feet (S), and 420 feet (SS). It is interesting to note that the water level (420 feet deep) in the Wasatch shallow sandstone well (BUFFSESS) is generally deeper than the Wasatch sandstone well (BUFFSES) at 332 feet. The overlying four Wasatch sandstone wells are not hydraulically connected to the underlying Wyodak coal and have four different water levels. This indicates the sandstone beds are not hydraulically connected to each other.

Bull Creek (BULLCRK)

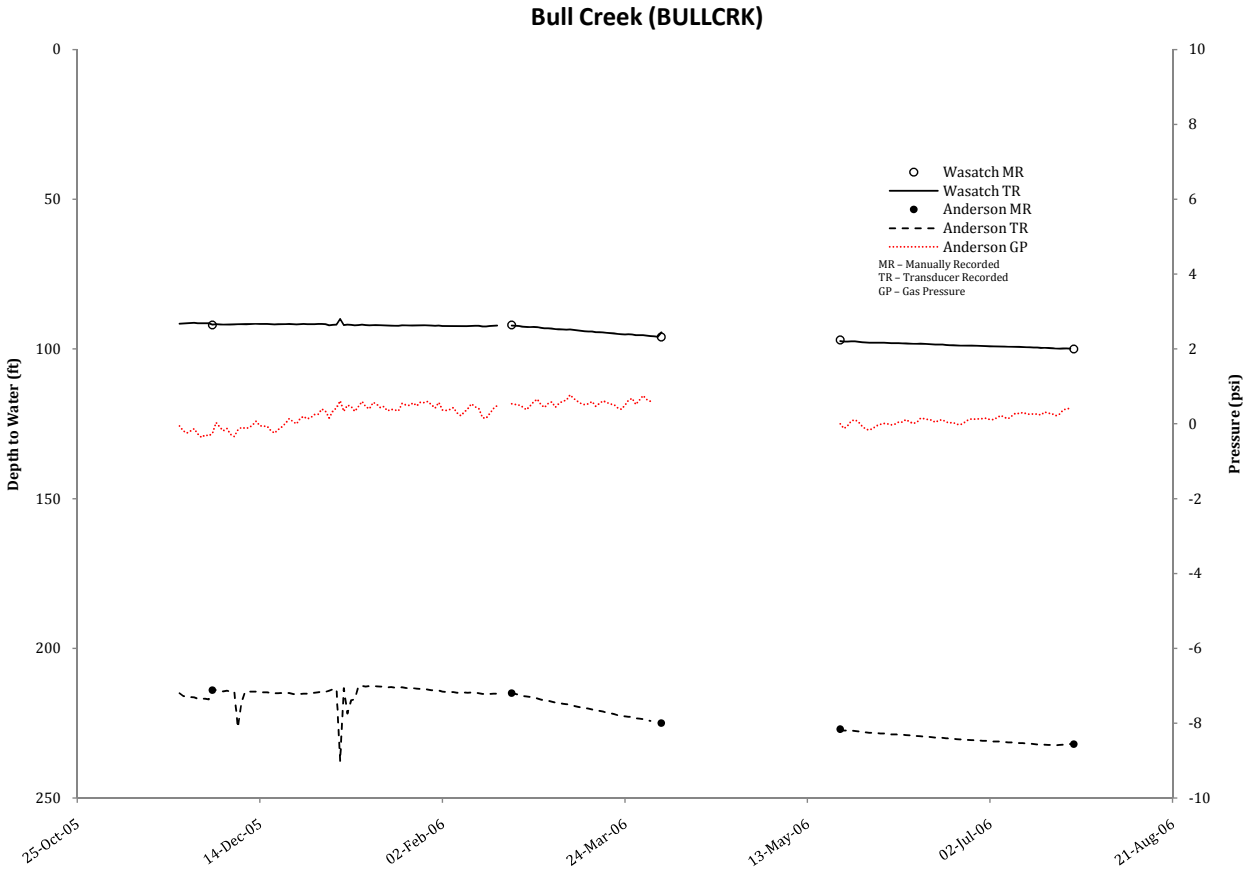
Location: S12 T52N R77W

Date first monitored: November 22, 2005

The Bull Creek (BULLCRK) monitoring well set includes two wells. One is constructed into the Anderson coal and the other into an overlying Wasatch sandstone bed.

- The Anderson coal well (BULLCRKC) showed 17.1 feet of drawdown from the initial water level in 2005. The wellhead gas pressure peaked at 0.8 psi.
- The overlying Wasatch sandstone well (BULLCRKS), which is constructed into a sandstone bed 100 feet stratigraphically above the top of the Anderson coal, showed 8.4 feet of drawdown from 2005 to 2006. This well may have been affected by CBNG-related drawdown in the underlying Anderson coal bed.
- The Wasatch shallow sand well (BULLCRKSS) does not as of yet have more than one reading for both transducer and manually recorded water levels. The initial reading for the manually recorded water depth was 5 feet, and the transducer recorded water depth was 4.51 feet.

Wellhead gas pressure peaked at 0.8 psi in March 2006. The Anderson water level remained stable at about 215.0 feet from November 2005 to February 2006, but the rate of drawdown increased slightly in February 2006. The Wasatch water level declined from 92 to 100 feet from 2005 to 2006. The rate of drawdown increased slightly in the Wasatch well since March 2006. The slightly steeper decline rate of the water level in the Anderson well in February 2006 was followed one month later by a slightly increased rate of drawdown in the Wasatch well.



Bullwacker (BULLWACK)

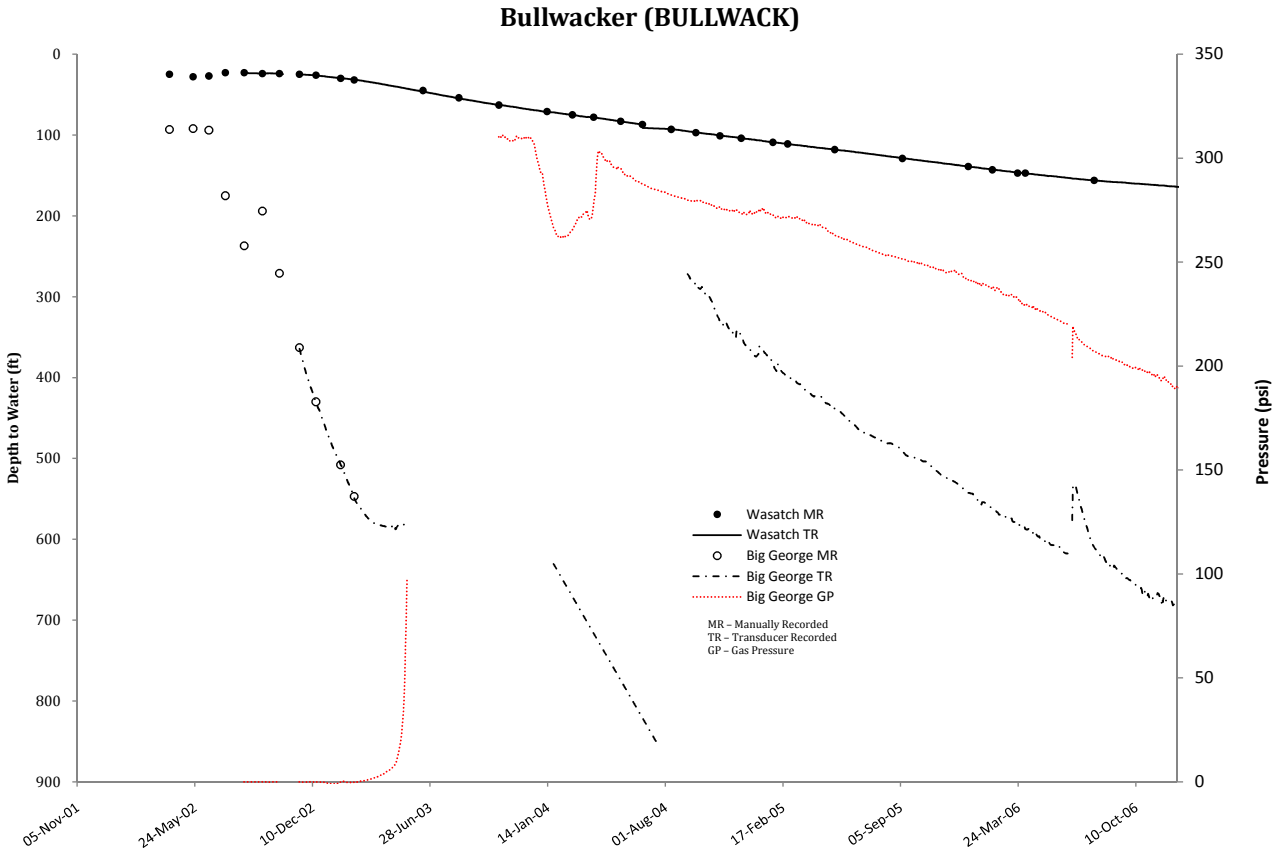
Location: S12 T52N R77W

Date first monitored: April 11, 2002

The Bullwacker (BULLWACK) monitoring well set includes two wells. One is constructed into the Big George coal and the other into an overlying Wasatch sandstone bed.

- The Big George coal well (BULLWACKC) showed 592.0 feet of drawdown from the initial water level in 2002. The wellhead gas pressure peaked at 311.1 psi.
- The overlying Wasatch sandstone well (BULLWACKS), which is constructed into a sandstone bed 100 feet stratigraphically above the top of the Big George coal, showed 139.6 feet of drawdown from 2002 to 2006. This well is possibly affected by CBNG-related drawdown in the underlying Big George coal bed.

The high wellhead gas pressure (more than 300 psi) in this well affected the monitoring of both gas pressure and water levels. Data collection was fragmented by high-pressure (over-range) damage to the sensors and safety-limited physical access. The Big George wellhead gas pressure peaked at 311.1 psi in the fourth quarter of 2003. The Wasatch water level showed relatively steady decline from 25 to 165 feet deep from 2002 to 2006. The Big George water level showed relatively rapid drawdown from about 93 to 685 feet deep during the same period. The drawdown experienced by the Wasatch sandstone is possibly related to CBNG development in the underlying Big George coal bed below it.



Prima Cedar Draw (CEDAR)

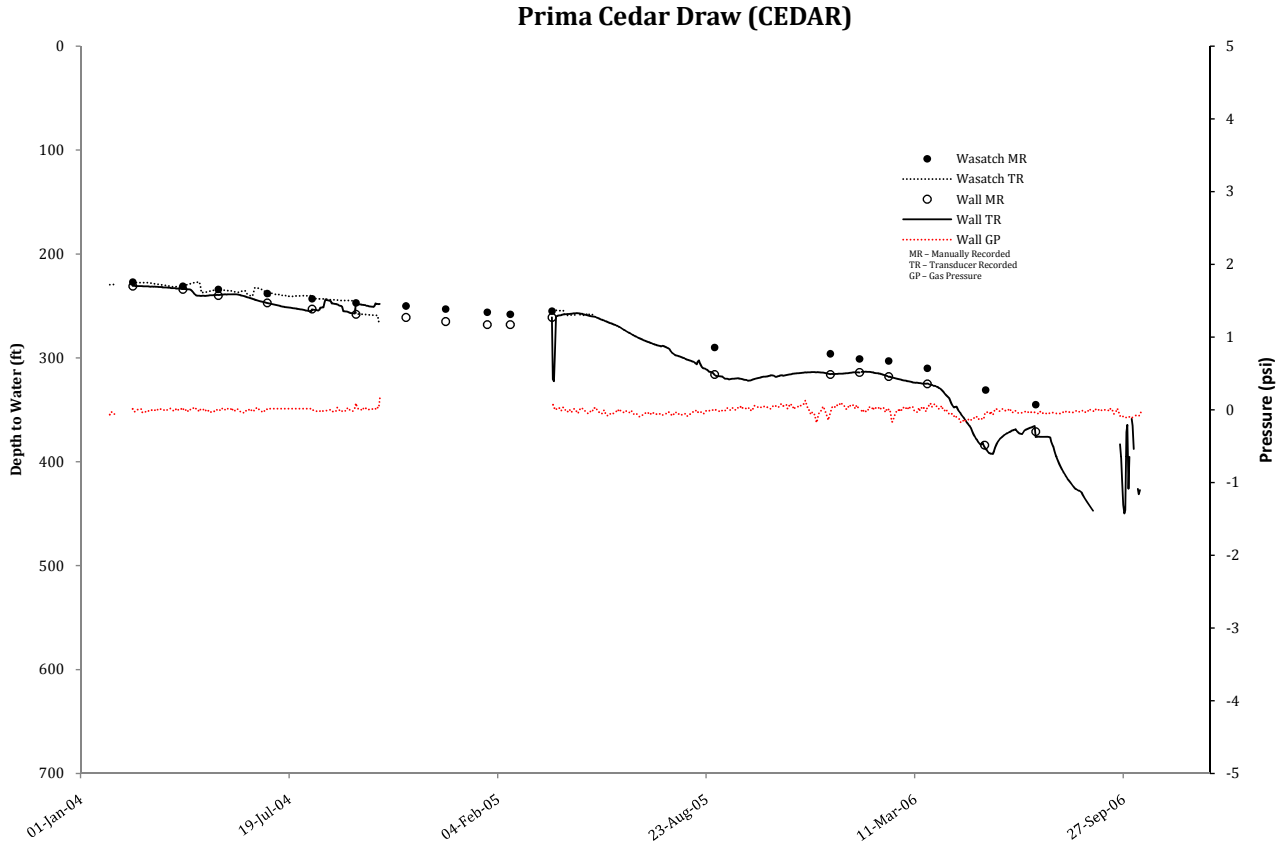
Location: S2 T51N R75W

Date first monitored: January 29, 2004

The Prima Cedar Draw (CEDAR) monitoring well set includes two wells. One is constructed into the Wall coal and the other into an overlying Wasatch sandstone bed.

- The Wall coal well (CEDARC) showed 196.6 feet of drawdown from the initial water level in 2004. The wellhead gas pressure peaked at 0.2 psi.
- The overlying Wasatch sandstone well (CEDARS), which is constructed into a sandstone bed 107 feet stratigraphically above the top of the Wall coal, showed 105.4 feet of drawdown from 2004 to 2006. This well was affected by CBNG-related drawdown in the underlying Wall coal bed.

Wellhead gas pressure in the Wall well peaked at the very low level of 0.2 psi in October 2004 and then remained near zero from 2004 to 2006. The water levels in both the Wall and Wasatch wells declined from 2004 to 2006. During this period, the Wall water level declined from 228 to 447 feet deep, and the Wasatch level declined from 229 to 345 feet. The water levels in the two wells started at nearly the same level in 2004 and showed a nearly identical drawdown curve from 2004 to 2006. These water-level data indicate the Wall and Wasatch are hydraulically connected.



Coal Gulch Unit Wells (COALGULCH or CGU)

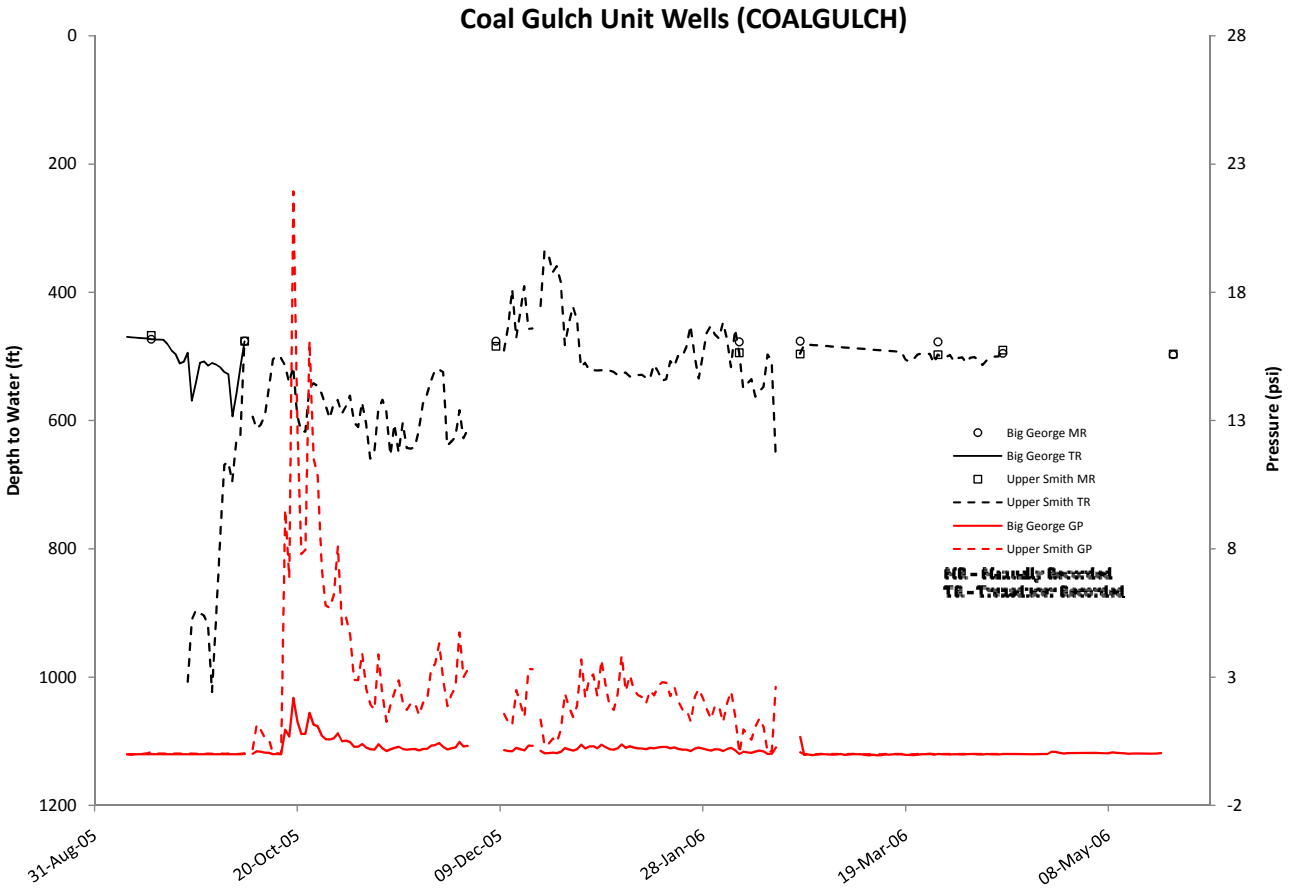
Location: S26 T51N R78W

Date first monitored: September 8, 2005

The Coal Gulch Unit Wells (COALGULCH) monitoring well set includes two coal wells. One is constructed into the combined Big George-Lower Smith coals and the other into the Smith coal. There is no Wasatch sandstone monitoring well at this location.

- The combined Big George-Lower Smith coal well (COALGULCHBG) is completed from 1,637 to 1,670 feet deep (Lower Smith) and from 1,796 to 1,854 feet (Big George) and showed 27.8 feet of drawdown from the initial water level in 2005. The wellhead gas pressure peaked at 2.2 psi.
- The Upper Smith coal well (COALGULCHS) is completed from 1,481 to 1,498 feet deep and showed 29.2 feet of drawdown from the initial water level in 2005 to 2006. The wellhead gas pressure peaked at 21.9 psi.

These two coal wells recorded drawdowns of less than 30 feet from 2005 to 2006. The water levels for both coals are similar, indicating that the two coal beds are hydraulically connected.



BRC Federal #33-1 Dilts (DILTS)

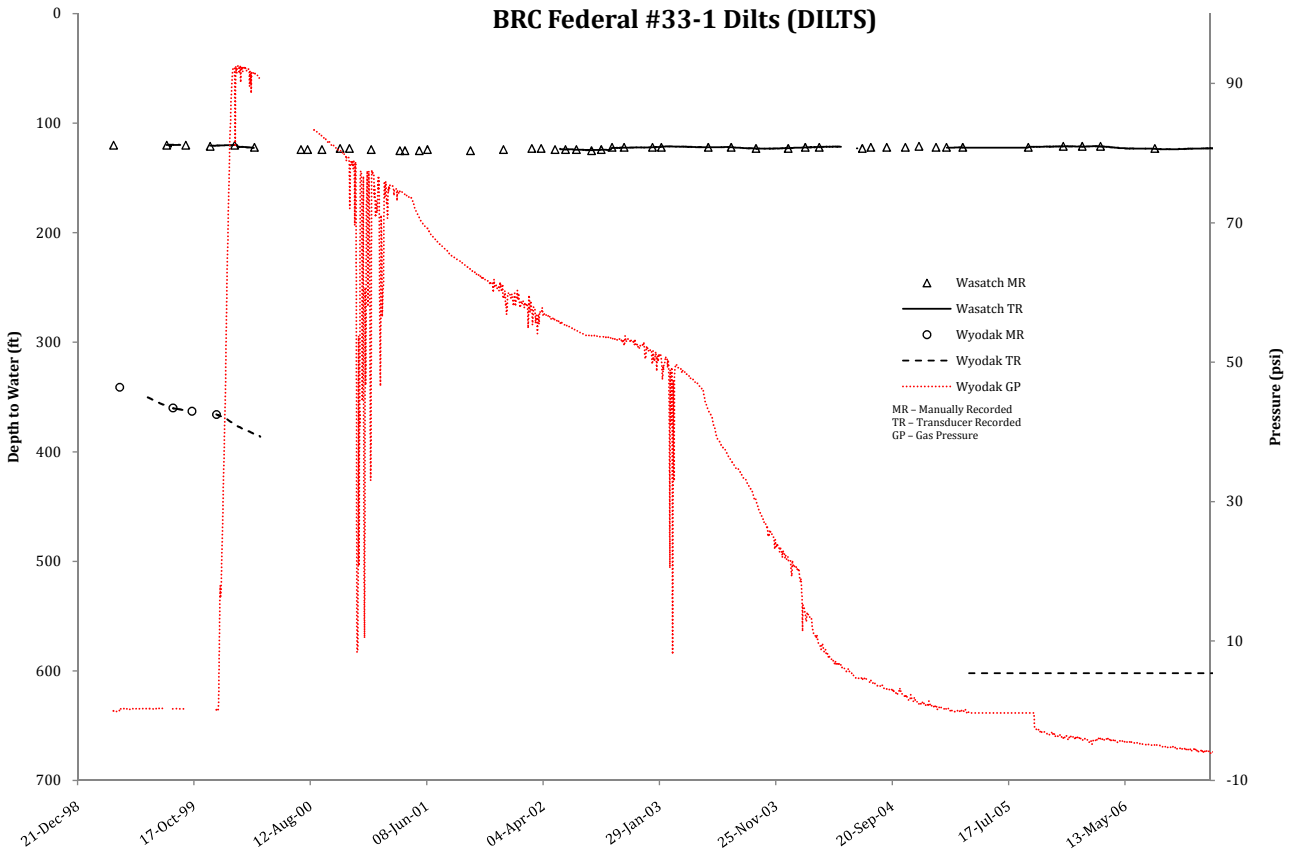
Location: S31 T43N R71W

Date first monitored: March 24, 1999

The BRC Federal #33-1 (DILTS) monitoring well set includes two wells. One is constructed into the Wyodak coal and one into an overlying Wasatch sandstone bed.

- When the Wyodak coal well (DILTSC) became dry in 2000, the drawdown was 45.5 feet from the initial water level of 340.6 feet deep in 1999. The wellhead gas pressure peaked at 92.6 psi.
- The overlying Wasatch sandstone well (DILTSS), which is constructed into a sandstone bed 280 feet stratigraphically above the top of the Wyodak coal, showed 3.2 feet of drawdown from the initial water level in 1999 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.

When the wellhead gas pressure peaked in February 2000, the water level in the Wyodak well was about 367 feet deep (36.0 feet of drawdown or 15.6 psi confining pressure decline). The Wyodak well declined 25 feet from April 1999 to December 1999 when the last manual measurement was taken. Transducer recordings continued until April 2000 at which point the water level had decreased to 386 feet. Measurements in the Wyodak coal bed were not recorded again until April 2005 with a reading of 602 feet and a total drawdown of 261 feet. The water level remained steady through December 2006 in the 658-foot-deep well. The water level in the Wasatch sandstone well remained relatively stable throughout the time period suggesting that there is no hydrologic connection with the underlying Wyodak coal bed.



Double Tank (DTANK)

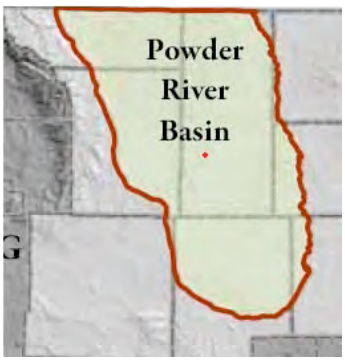
Location: S23 T44N R76W

Date first monitored: December 19, 2002

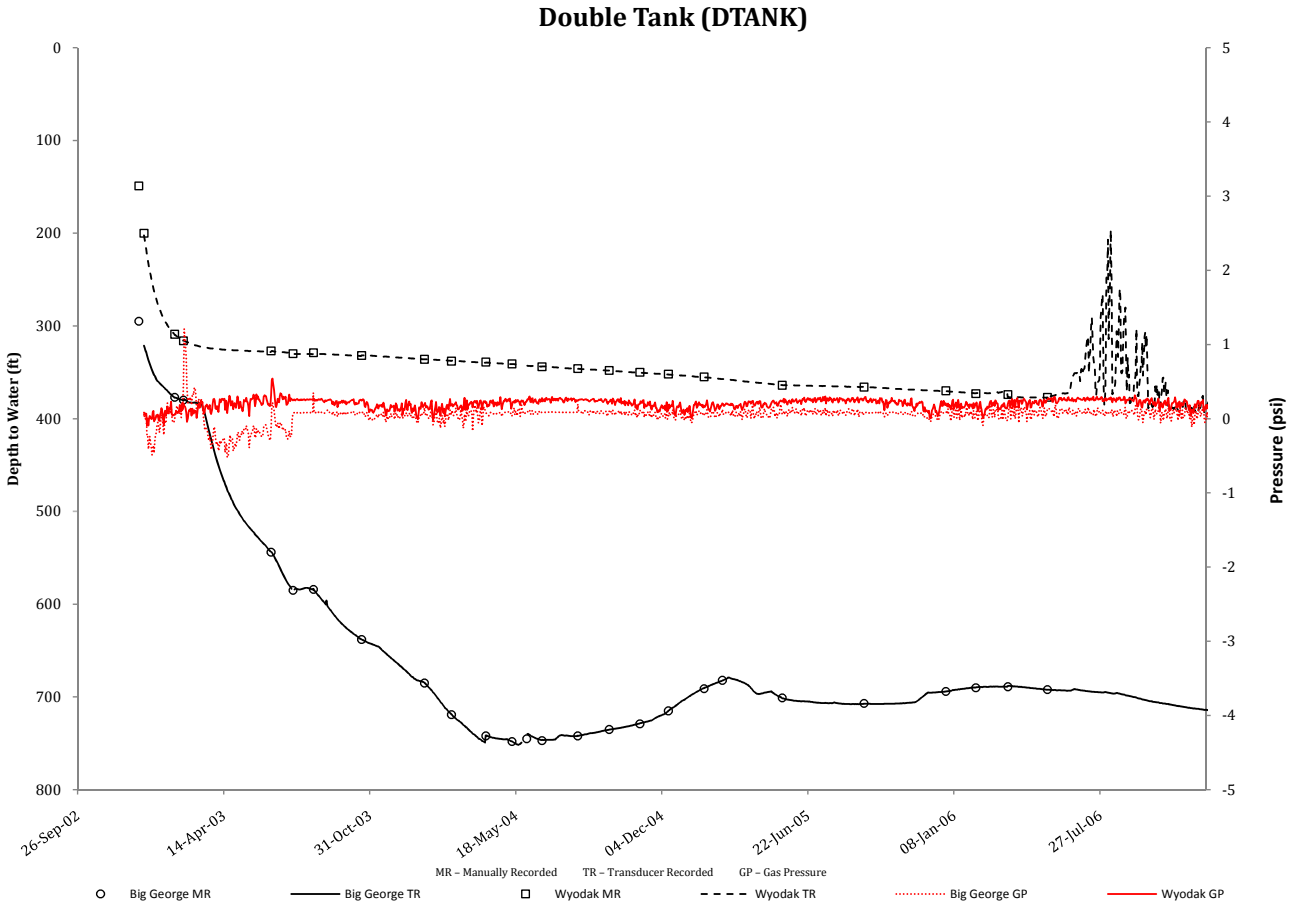
The Double Tank (DTANK) monitoring well set includes two coal wells. One is constructed into the Big George coal and the other into the Wyodak. There is no Wasatch sandstone monitoring well associated with these two wells at this location.

- The Big George coal well (DTANKBG) showed 420.4 feet of drawdown from the initial water level in 2002. The wellhead gas pressure peaked at 1.2 psi.
- The Wyodak coal well (DTANKWY) showed 240.7 feet of drawdown from the initial water level in 2002. The maximum wellhead gas pressure peaked at 0.5 psi.

Wellhead gas pressures were low (less than 1.5 psi) in the two coal wells. The Big George water level steadily declined from 295 to 751 feet deep (a drawdown of 456 feet) from 2002 to May 2004. The level then rose to 679 feet deep by March 2005 and declined again to 715 feet deep by the end of 2006. The water level in the Wyodak well declined rapidly from 149 feet deep in December 2002 to 320 feet deep by March 2003. The Wyodak level steadily declined from 320 feet in March 2003 to 389 feet deep by the end of 2006.



The initial December 2002 to March 2003 water level declines in the two coal wells closely match. These data suggest that there is a possible connection between the Wyodak and Big George coal beds.



Dry Willow Well (DRYWILLS)

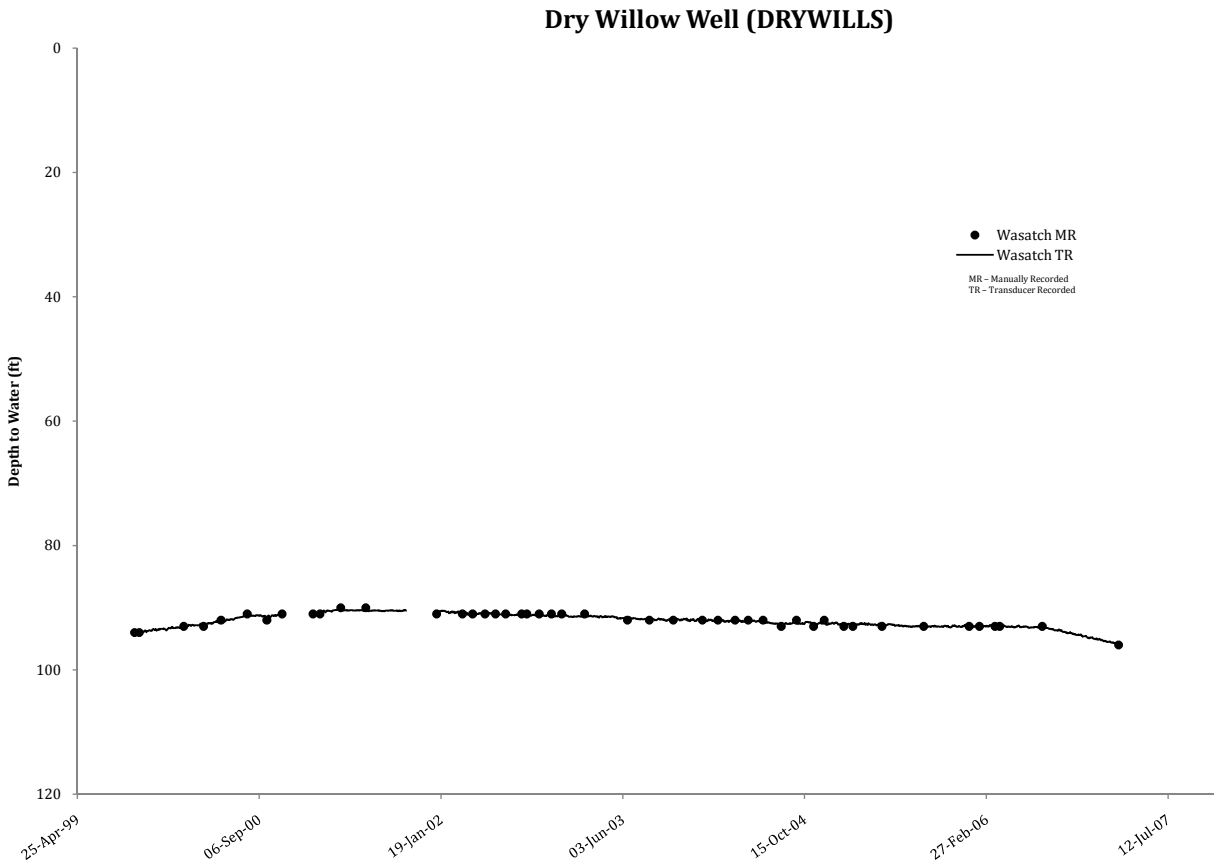
Location: S35 T44N R76W

Date first monitored: September 29, 1999

The Dry Willow Well (DRYWILLS) monitoring well is constructed into a Wasatch sandstone bed. There is no Fort Union coal bed associated with this well. The Dry Willow well was taken over from a uranium operation monitoring system.

- The DRYWILLS Wasatch sandstone well was completed with the main water-bearing zone from 148 to 202 feet deep. The well showed 1.4 feet of drawdown from the initial water level in 1999. This well was not affected by CBNG-related drawdown in the underlying and nearby coal beds.

The water level in this Wasatch sandstone well remained relatively stable.

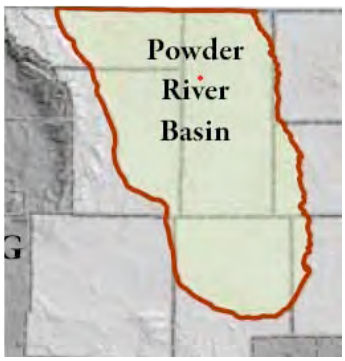


Echeta Coal Test Well (ECHETA)

Location: S30 T52N R75W

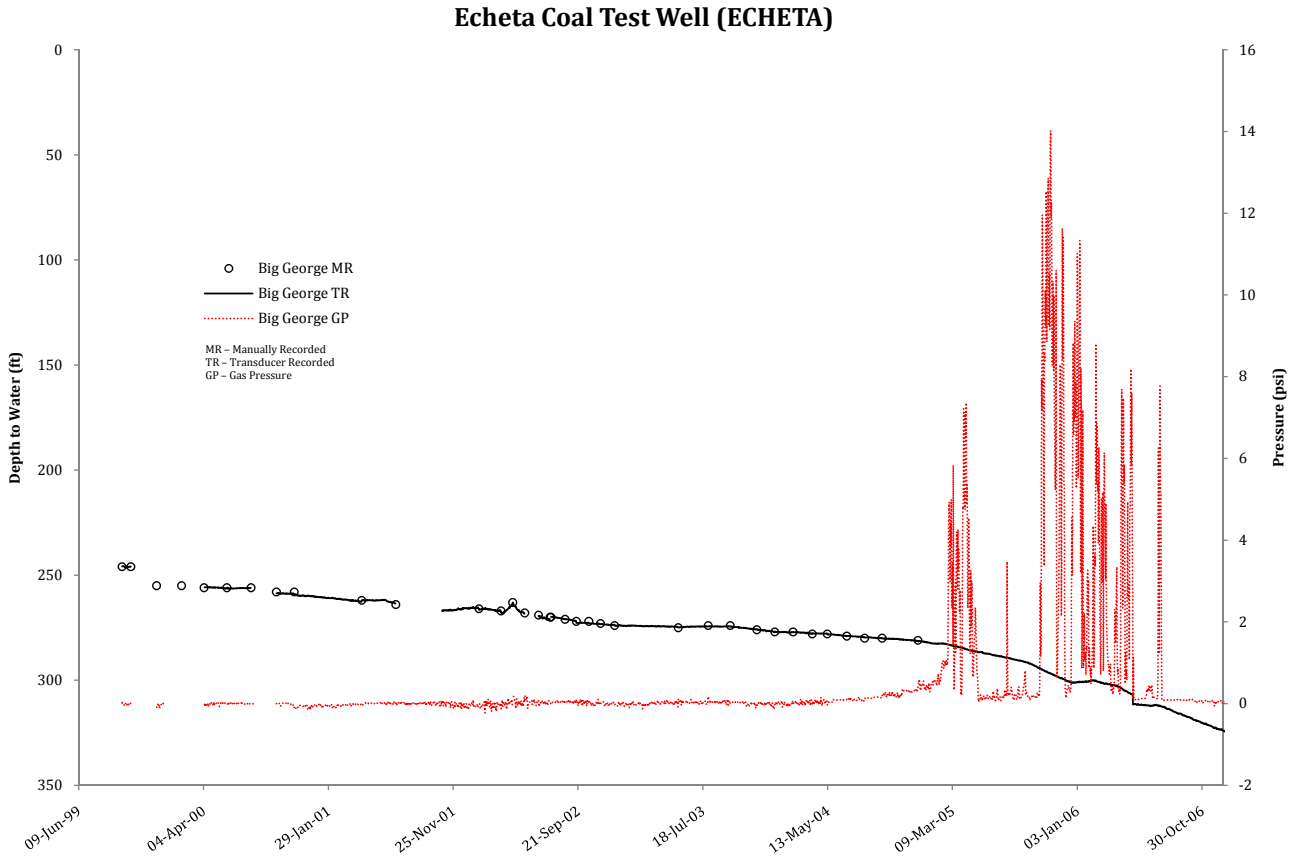
Date first monitored: September 21, 1999

The Echeta Coal Test Well (ECHETA) monitoring well is constructed into the Big George or "Echeta" coal. There is no Wasatch sandstone monitoring well associated directly with the Echeta well.



- The Big George or "Echeta" coal well (ECHETA) showed 78.9 feet of drawdown from the initial water level in 1999. During this period, the wellhead gas pressure peaked at 14.0 psi.

The water level steadily declined from 246 to 325 feet in depth. The maximum wellhead gas pressure (14.0 psi) occurred in October 2005 with the water level at 297 feet deep (51 feet of drawdown).

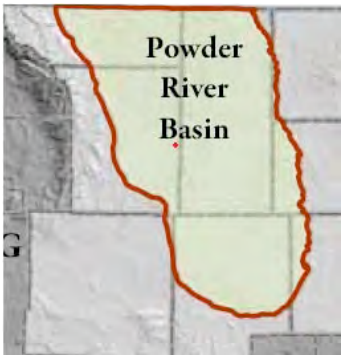


Gilmore Oil & Gas Artesian Unit #1 Well (GILMORE)

Location: S1 T49N R77W

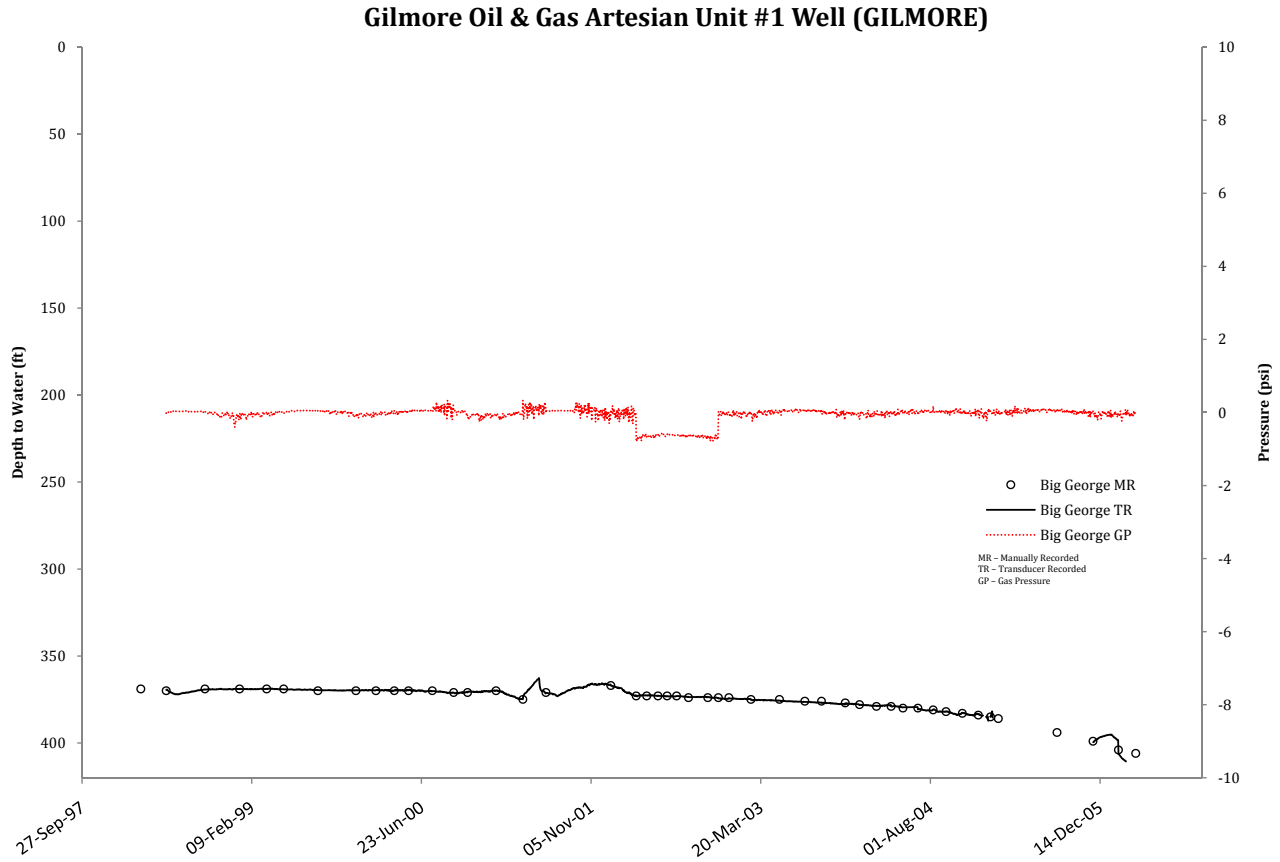
Date first monitored: March 19, 1998

The Gilmore Oil & Gas Artesian Unit #1 (GILMORE) monitoring well is constructed into the Big George coal. There is no Wasatch sandstone monitoring well associated with this well.



- The Big George coal well (GILMORE) showed 36.6 feet of drawdown from the initial water level in 1998. The wellhead gas pressure peaked at 0.3 psi.

The wellhead gas pressure remained at nearly zero from 1998 to 2006. The water level steadily declined from 369 to 410 feet.



Hoe Creek (HOE)

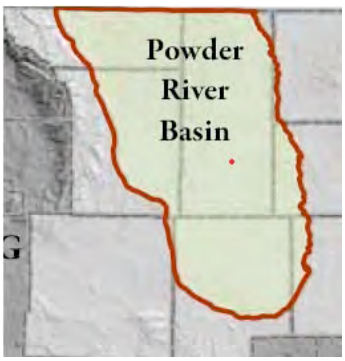
Location: S7 T47N R72W

Date first monitored: January 5, 1998

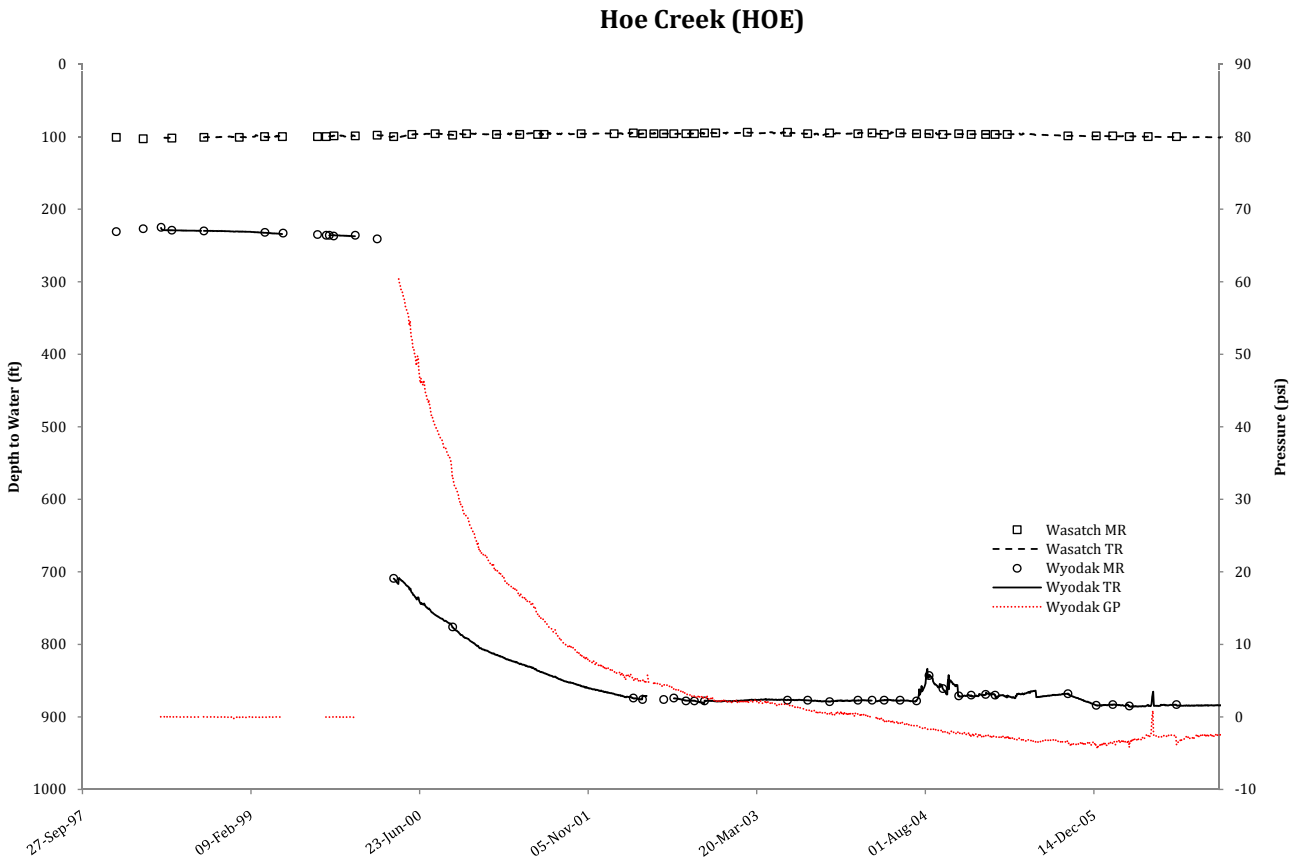
The Hoe Creek (HOE) monitoring well set includes two wells. One is constructed into the Wyodak coal and one into an overlying Wasatch sandstone bed.

- The Wyodak coal well (HOEC) showed more than 653 feet of drawdown from the initial water level of 231.25 feet in 1998. The wellhead gas pressure peaked at 60.4 psi.
- The overlying Wasatch sandstone well (HOES), which is constructed into a sandstone bed 620 feet stratigraphically above the top of the Wyodak coal, showed about 0.5 feet of drawdown from 1998 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.

The Wyodak wellhead gas pressure peaked in April 2000 and then steadily declined. Wellhead gas pressure readings were trending negative (vacuum condition) by the end of 2006 as a result of blowers being installed on the nearby CBNG production wells used to enhance gas recovery. This condition is common to wells along the eastern margin of the PRB in Campbell County.



The Wasatch water level remained relatively steady at about 100 feet deep from 1998 to 2006. The Wyodak water level declined steadily from 225 to 241 feet deep from January 1998 to February 2000. From February 2000 to August 2002, the water level showed a relatively rapid drawdown from 241 to 875 feet deep. The level then declined at a slower rate from 875 to 884 feet deep by the end of 2006. The Wasatch sandstone well is not hydraulically connected to the underlying Wyodak coal.



Huber Lone Tree Wells (HUBERLT)

Location: S13 T50N R73W

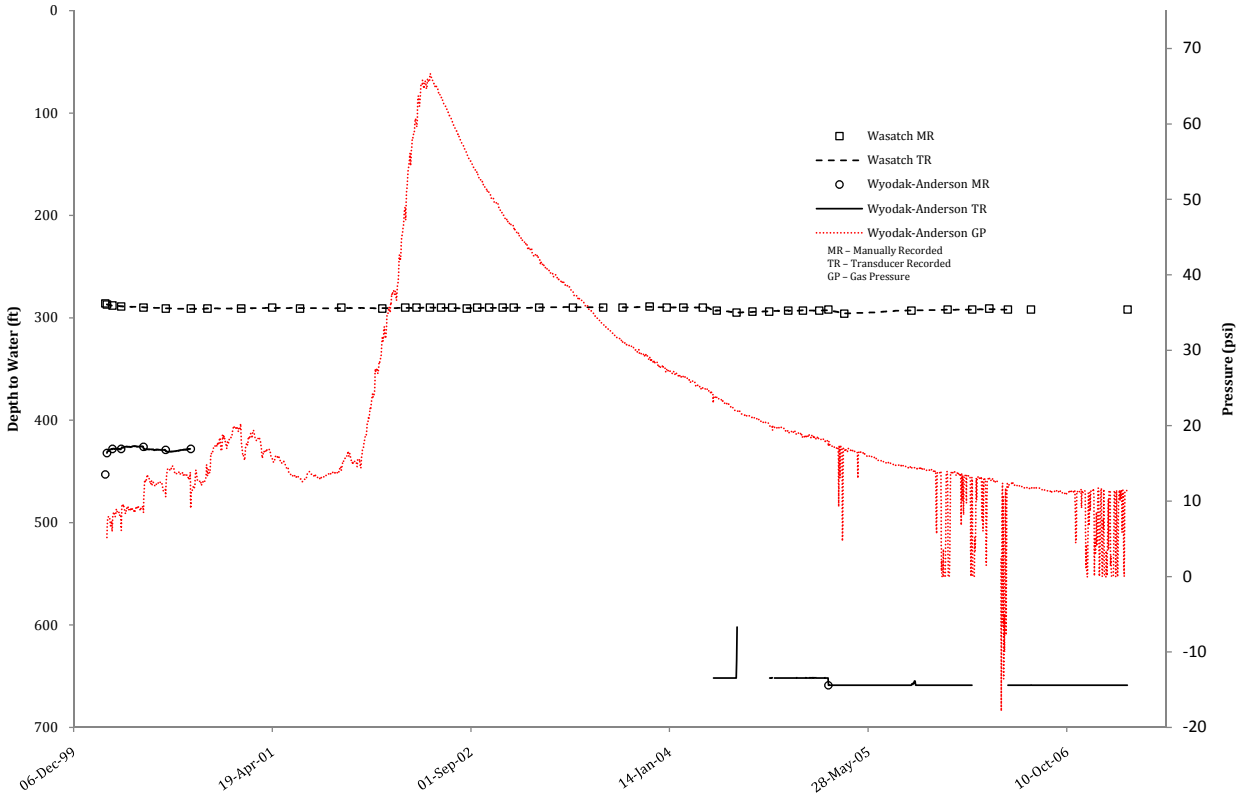
Date first monitored: February 24, 2000

The Huber Lone Tree (HUBERLT) monitoring well set includes two wells. One is constructed into the Wyodak-Anderson coal and one into an overlying Wasatch sandstone bed.

- The Wyodak-Anderson coal well (HUBERLTC) became dry by 2005, and the observed drawdown was greater than 198 feet from the initial water level of 453.1 feet in 2000. The wellhead gas pressure peaked at 66.7 psi.
- The overlying Wasatch sandstone well (HUBERLTS), which is constructed into a sandstone bed 117 feet stratigraphically above the top of the Wyodak-Anderson coal, showed 6.0 feet of drawdown from 2000 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak-Anderson coal bed.

The maximum wellhead gas pressure in the coal well peaked in May 2002 and steadily declined. The Wasatch water level remained relatively stable between 289 and 292 feet deep from 2000 to 2006. The Wyodak-Anderson water level declined from about 453 to 651 feet deep from 2002 to 2005. The Wasatch sandstone well is apparently not hydraulically connected to the underlying Wyodak-Anderson coal at this location.

Huber Lone Tree Wells (HUBERLT)

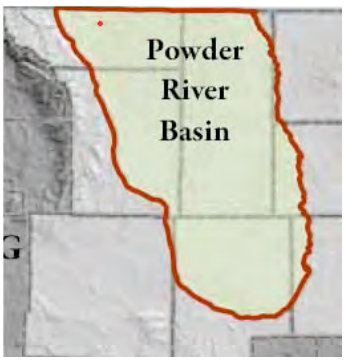


Huber Lower Prairie Dog Creek Wells (HUBERPD)

Location: S10 T57N R83W

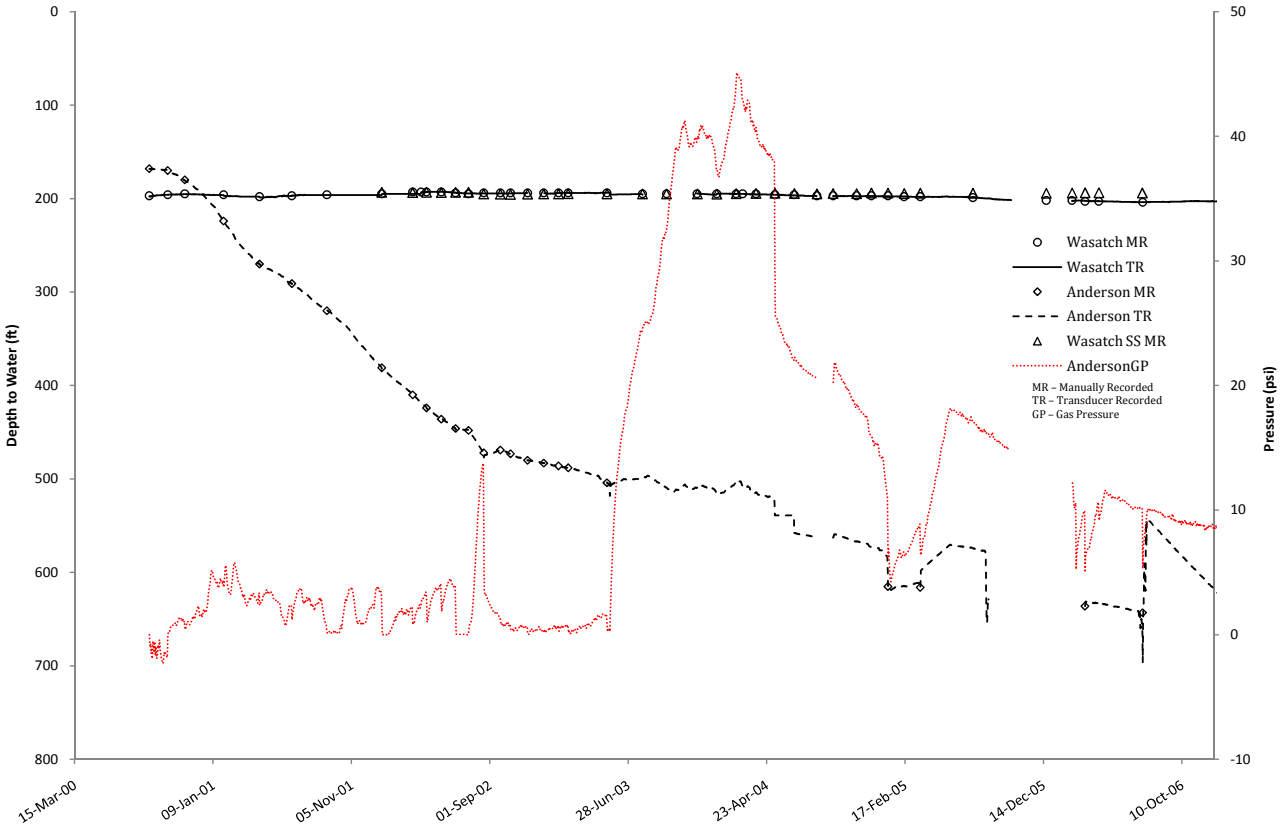
Date first monitored: August 24, 2000

The Huber Lower Prairie Dog Creek (HUBERPD) monitoring well set includes three wells. One is constructed into the Anderson coal, and the other two are constructed into overlying Wasatch sandstone beds.



- The Anderson coal well (HUBERPDC) showed 439.5 feet of drawdown from the initial water level of 168.4 feet deep in 2000 to 2006. The wellhead gas pressure peaked at 45.1 psi.
- The overlying Wasatch sandstone well (HUBERPDS), which is constructed into a sandstone bed 238 feet stratigraphically above the top of the Anderson coal bed, showed 5.5 feet of drawdown from 2000 to 2006. This well apparently was not affected by CBNG-related drawdown in the underlying Anderson coal bed.
- The shallow Wasatch sandstone well (HUBERPDSS), which is constructed into a sandstone bed 368 feet stratigraphically above the top of the Anderson coal bed, showed 0.71 feet of drawdown from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Anderson coal bed.

The Anderson wellhead gas pressure started to increase in late May 2003 when the water level in the coal well had declined to 504 feet deep (336



feet of drawdown). The water levels in the Wasatch sandstone well and the shallow Wasatch sandstone well remained steady at about 200 feet deep from 2000 to 2006. Both Wasatch wells have nearly identical water-level depths. The water level in the Anderson coal well steadily declined from 168 to 624 feet deep during this period.

These data show no evidence of hydraulic connection between the Anderson coal and the two Wasatch wells. The 5.5 feet of drawdown observed in the Wasatch sandstone well (HUBERPDS) may be attributed to natural causes and/or to relatively slow leakage through low-permeability confining units adjacent to this sandstone bed.

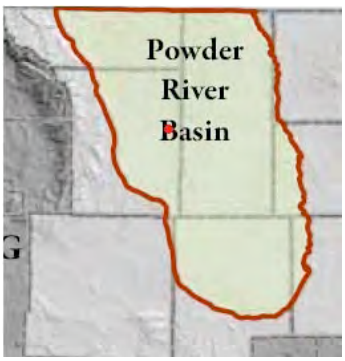
Juniper Draw Wells (JUNIPER)

Location: S15 T49N R78W

Date first monitored: March 21, 2001

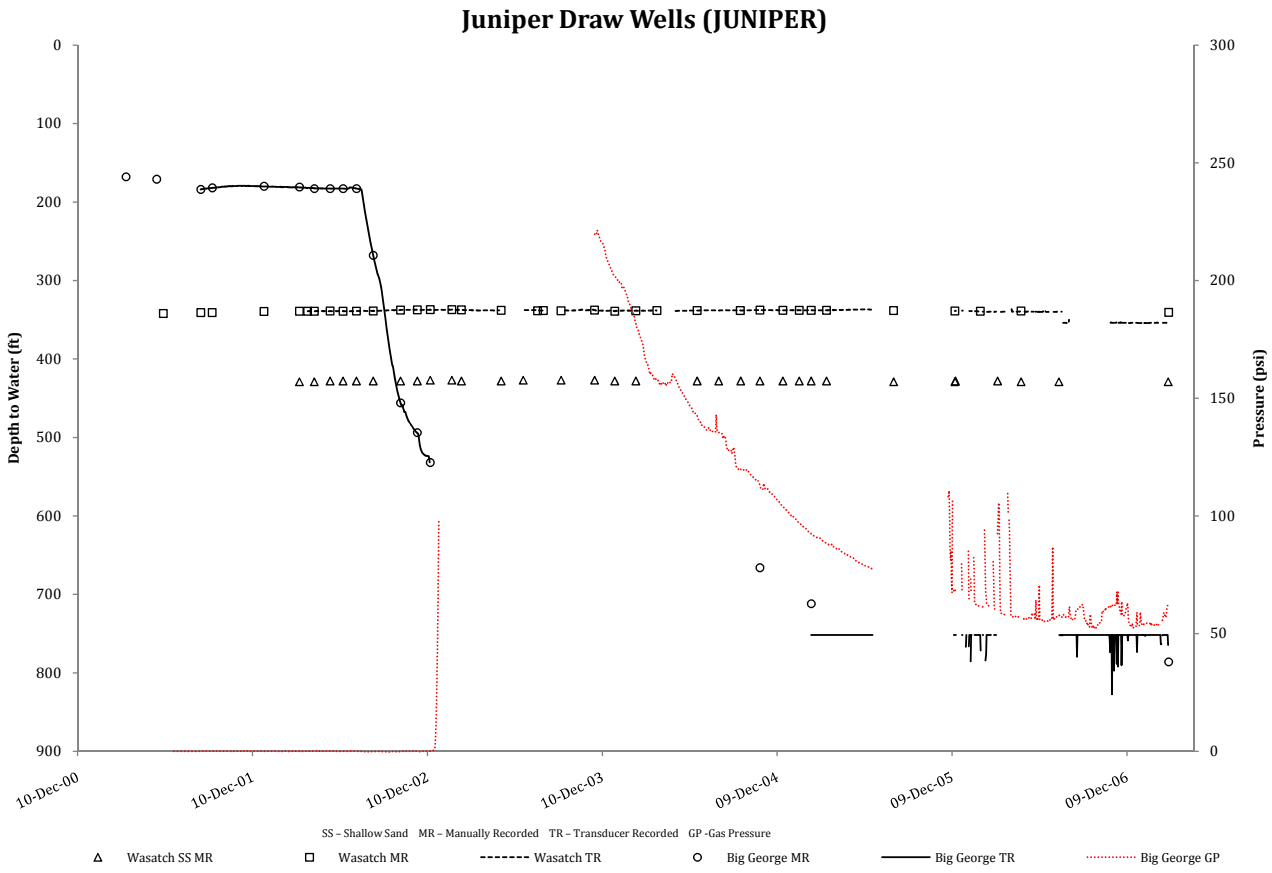
The Juniper Draw Wells (JUNIPER) monitoring well set includes three wells. One is constructed into the Big George coal, and the other two are constructed into overlying Wasatch sandstone beds.

- The Big George coal well (JUNIPERC) showed 583.1 feet of drawdown from the initial water level in 2001. The wellhead gas pressure peaked at 221.3 psi.
- The overlying Wasatch sandstone well (JUNIPERS), which is constructed into a sandstone bed 418 feet stratigraphically above the top of the Big George coal, showed 11.9 feet of drawdown from 2001 to 2006.
- The shallow Wasatch sandstone well (JUNIPERSS), which is constructed into a sandstone bed 908 feet stratigraphically above the top of the Big George coal, showed 0.7 feet of drawdown from 2002 to 2006. This well was not affected by CBNG-related drawdown in the underlying Big George coal bed.



The Big George coal well showed a relatively stable water level with slight decline (15 feet) from the first quarter of 2001 to the third quarter of 2002. A rapid rate of water-level decline level occurred from third quarter 2002 to the end of 2004 and totaled more than 530 feet. The water level in the well continued to decline but at a much slower rate since the beginning of 2005.

The water levels in the two Wasatch sandstone wells exhibited little decline in water levels from 2001/2002 to 2006. The two sandstone water levels remained about 90 feet apart. The JUNIPER Big



George water level was initially 168 to 183 feet deep and above both water levels in the Wasatch wells. Since the fourth quarter of 2002, the Big George water level drawdown dropped below the water levels of the two Wasatch wells.

The difference in water-level depths between the Big George coal and the two Wasatch wells and the rapid decline rate in the Big George coal without an apparent response in the Wasatch wells indicate that these coal and sandstone wells are not hydraulically connected.

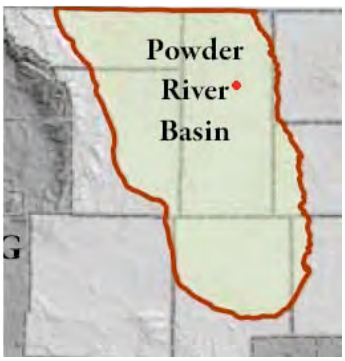
Kennedy Wells (KENNEDY)

Location: S33 T52N R73W

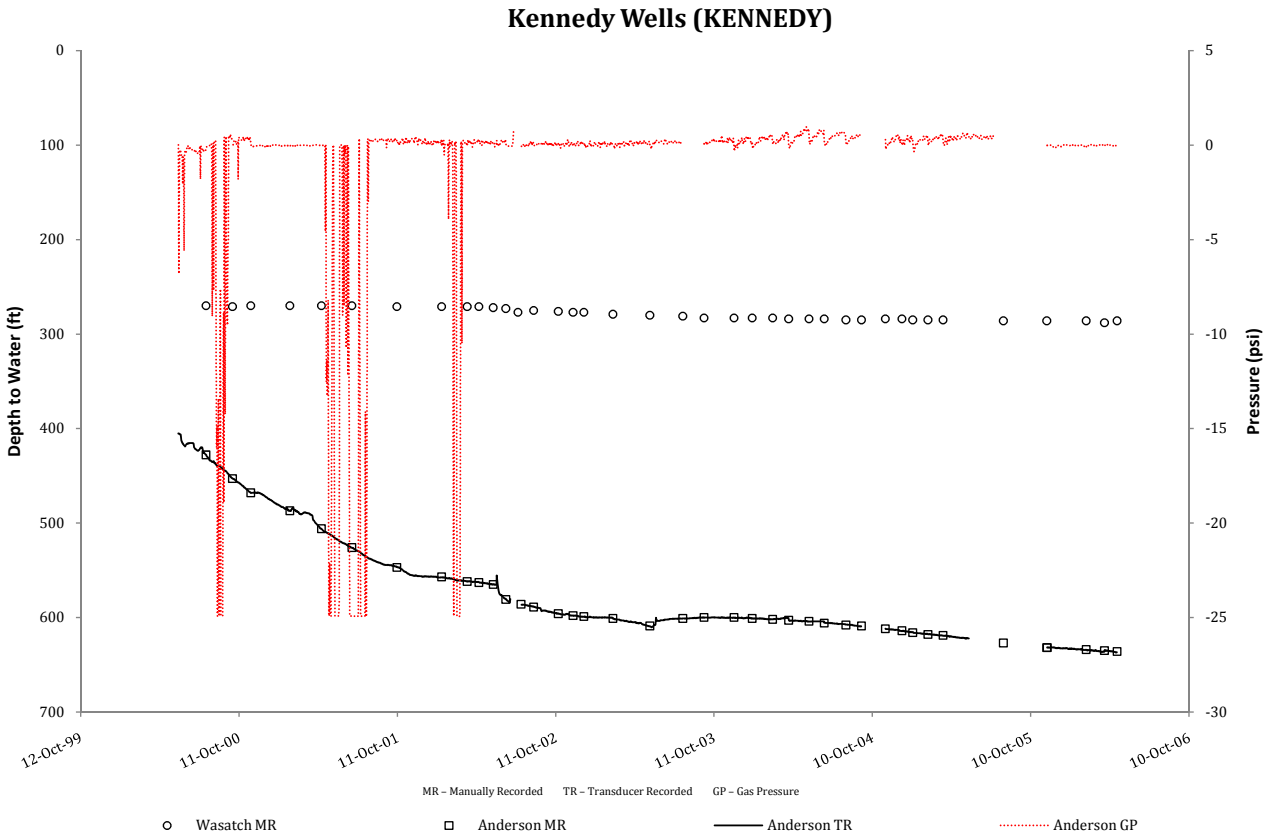
Date first monitored: May 24, 2000

The Kennedy (KENNEDY) monitoring well set includes two wells. One is constructed into the Anderson coal and the other into an overlying Wasatch sandstone bed.

- The Anderson coal well (KENNEDYC) showed 231.1 feet of drawdown from the initial water level in 2000. The wellhead gas pressure peaked at 1.0 psi.
- The overlying Wasatch sandstone well (KENNEDYS), which is constructed into a sandstone bed 128 feet stratigraphically above the top of the Anderson coal, showed 15.6 feet of drawdown from 2000 to 2006. This well was affected by CBNG-related drawdown in the underlying Anderson coal bed.



The Anderson wellhead gas pressure remained at nearly zero from 2000 to 2006. The water levels in the Wasatch well showed a slow rate of drawdown from 271 to 287 feet deep. The water level in the Anderson coal well recorded a more rapid decline rate from 406 to 598 feet deep from 2000 to November 2002 and a slower decline from 598 to 636 feet deep from November 2002 to 2006. These data show evidence of some degree of hydraulic connection between the Anderson and Wasatch wells.



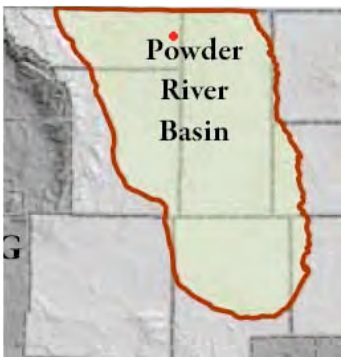
Lower Quarter Circle Hills Wells (LQC)

Location: S14 T56N R77W

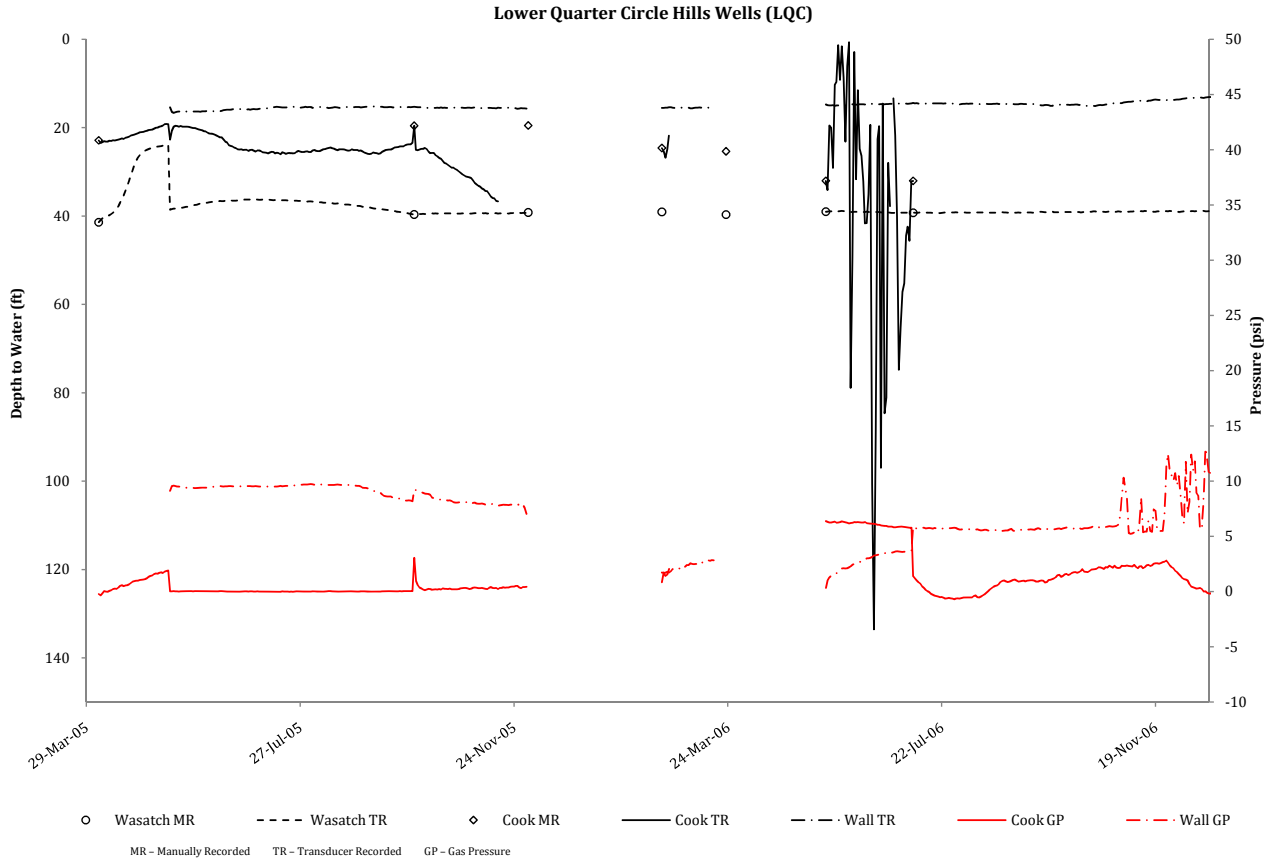
Date first monitored: April 5, 2005

The Lower Quarter Circle Hills (LQC) monitoring well set includes three wells. One is constructed into the shallower Cook coal, another into the deeper Wall coal, and the third into an overlying Wasatch sandstone bed.

- The Cook coal well (LQCC) showed 9.2 feet of drawdown from the initial water level in 2005 to 2006. The wellhead gas pressure peaked at 6.4 psi.
- The Wall coal well (LQCW) showed a water-level rise of 0.9 feet from 2005 to 2006. The wellhead gas pressure peaked at 9.7 psi.
- The overlying Wasatch sandstone well (LQCS), which is constructed into a sandstone bed 171 feet stratigraphically above the top of the upper coal bed (Cook), showed a water-level rise of 2.2 feet from 2005 to 2006. This well was not affected by CBNG-related drawdown in the underlying Cook or Wall coal beds.



The Cook wellhead gas pressure fluctuated from 2005 to 2006, reaching a maximum of 6.4 psi in May 2006. The Wall wellhead gas pressure showed a broad peak of about 9.7 psi from May to October 2005 and then declined. The water level in the Wasatch well rose from 41 feet deep in April 2005 to 23 feet in May 2005, which was followed by a rapid decline to 38 feet deep later that month. Since May 2005, the Wasatch level remained between 36 and 39 feet deep. The Cook water level showed fluctuations from 19 to 37 feet deep with highs and lows from 2005 to 2006. The Wall water level remained relatively stable between 14 and 16 feet from 2005 to 2006. These data do not show any clear evidence of a hydraulic connection between the Cook, Wall, and Wasatch wells.



The shallower Wasatch well had the deepest water level (between 36 and 39 feet deep) compared to the water levels in the Cook well (between 24 and 26 feet) and the Wall well (between 14 and 16 feet deep). The deeper Wall coal also had a water level 10 feet higher than the Cook coal. These data show that the confining pressures within the coal wells are greater than in the Wasatch well and that there is potential for an upward component of vertical groundwater flow at this site. The difference between these well water levels is relatively small (maximum head of about 25 feet or 11 psi of hydrologic pressure).

Martens & Peck Section 2 Wells (MP2)

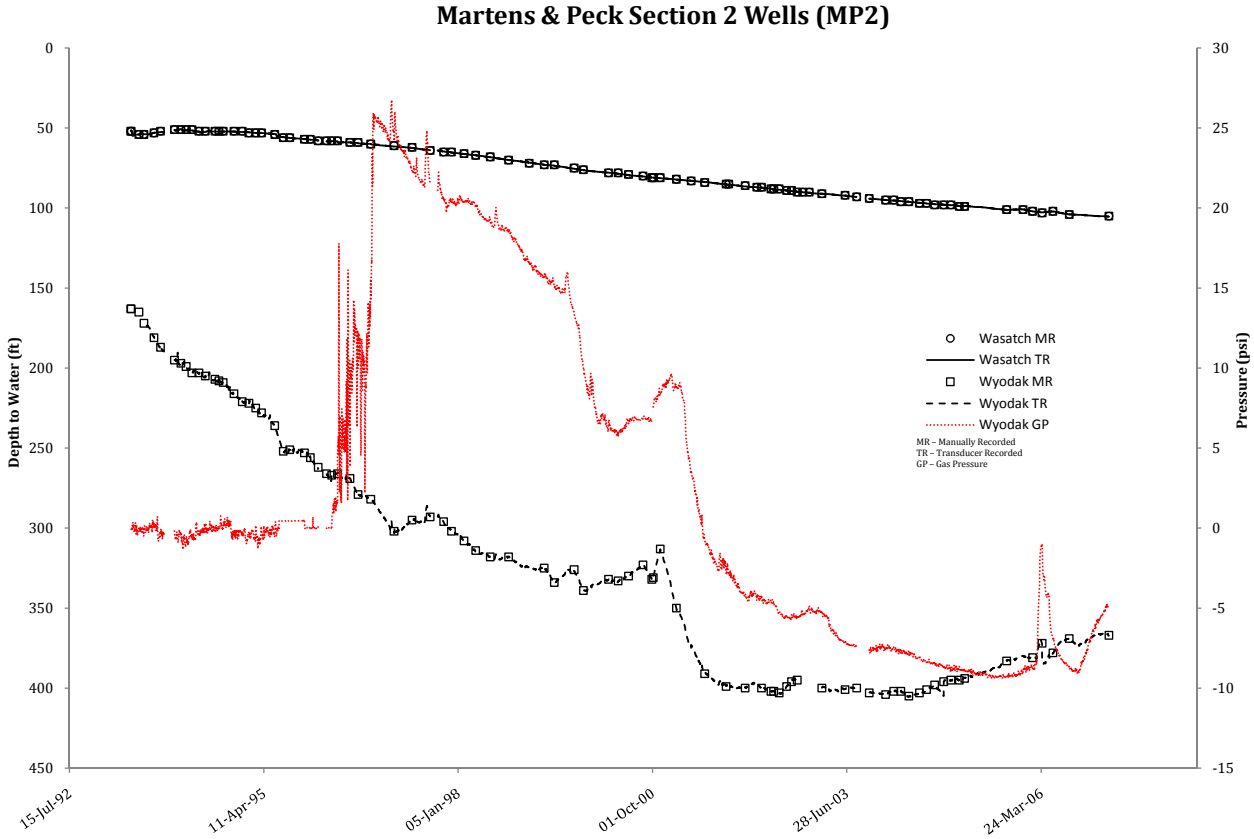
Location: S2 T47N R72W

Date first monitored: March 26, 1993

The Martens & Peck Section 2 (MP2) monitoring well set includes two wells. One is constructed into the Wyodak coal and one into an overlying Wasatch sandstone bed.

- The Wyodak coal well (MP2C) showed 203.8 feet of drawdown from the initial water level in 1993. The wellhead gas pressure peaked at 26.8 psi.
- The overlying Wasatch sandstone well (MP2S), which is constructed into a sandstone bed 26 feet stratigraphically above the top of the Wyodak coal, showed 52.9 feet of drawdown from 1993 to 2006. This well was affected by CBNG-related drawdown in the underlying Wyodak coal bed.

The Wyodak wellhead gas pressure peaked in January 1997 when the water level in the well had declined to about 275 feet deep (112 feet of drawdown or 48.5 psi confining pressure decline). The Wasatch water level generally declined at a steady rate from 52 to 105 feet deep from 1993 to 2006. The Wyodak water level declined from 163 feet deep in May 1993 to 405 feet deep in May 2004 and then rose from 405 feet to 368 feet deep by the end of 2006. These data indicate that a hydraulic connection exists between the Wyodak and Wasatch wells.



Martens & Peck Section 22 Wells (MP22)

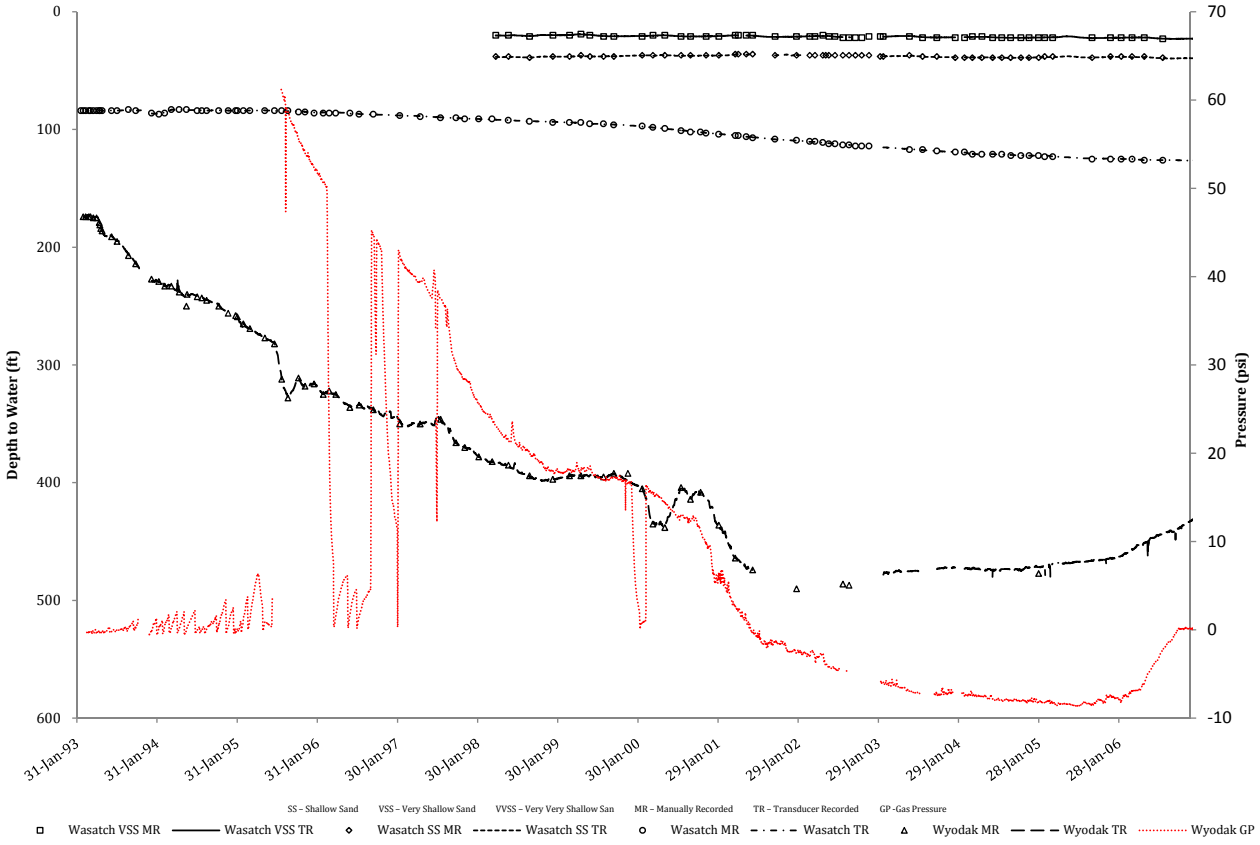
Location: S22 T48N R72W

Date first monitored: March 1, 1993

The Martens & Peck Section 22 (MP22) monitoring well set includes four wells. One is constructed into the Wyodak coal and the other three into a series of overlying Wasatch sandstone beds.

- When the Wyodak coal well (MP22C) became dry by 2000, the drawdown exceeded 246 feet from the initial water level of 173.8 feet in 1993. The wellhead gas pressure peaked at 61.2 psi.
- An overlying Wasatch sandstone well (MP22S), which is constructed into a sandstone bed 38 feet stratigraphically above the top of the Wyodak coal, showed 42.5 feet of drawdown from 1993 to 2006. This well was affected by CBNG-related drawdown in the underlying Wyodak coal bed.
- The shallow Wasatch sandstone well (MP22SS), which is constructed into a sandstone bed 253 feet stratigraphically above the top of the Wyodak coal, showed 1.0 feet of drawdown from 1998 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.
- The very shallow Wasatch sandstone well (MP22VSS), which is constructed into a sandstone bed 358 feet stratigraphically above the top of the Wyodak coal, showed 2.6 feet of drawdown from 1998 to 2006. This well was not affected by CBNG-related drawdown in the underlying Wyodak coal bed.

Martens & Peck Section 22 Wells (MP22)



From 1993 to January 2002, the MP22C Wyodak well showed a relatively constant rate of water-level decline from 174 to 490 feet in depth. From January 2002 through 2006, the Wyodak water level had been rising with about 90 feet of rise to 431 feet deep.

The water levels in the three Wasatch wells are shallow (20 feet deep in MP22VSS, 38 feet in MP22SS, and from 84 to 126 feet deep in MP22S) compared to the deeper water level of the Wyodak coal well (174 feet deep initially). These data indicate the Wyodak coal and sand wells at this well set location are under relatively confined hydrologic conditions and separated from each other by intervening low-permeability confining units. The water level in the MP22S well shows a relatively steady decline and is likely affected by regional CBNG development.

Barrett Napier Wells (NAPIER)

Location: S24 T48N R76W

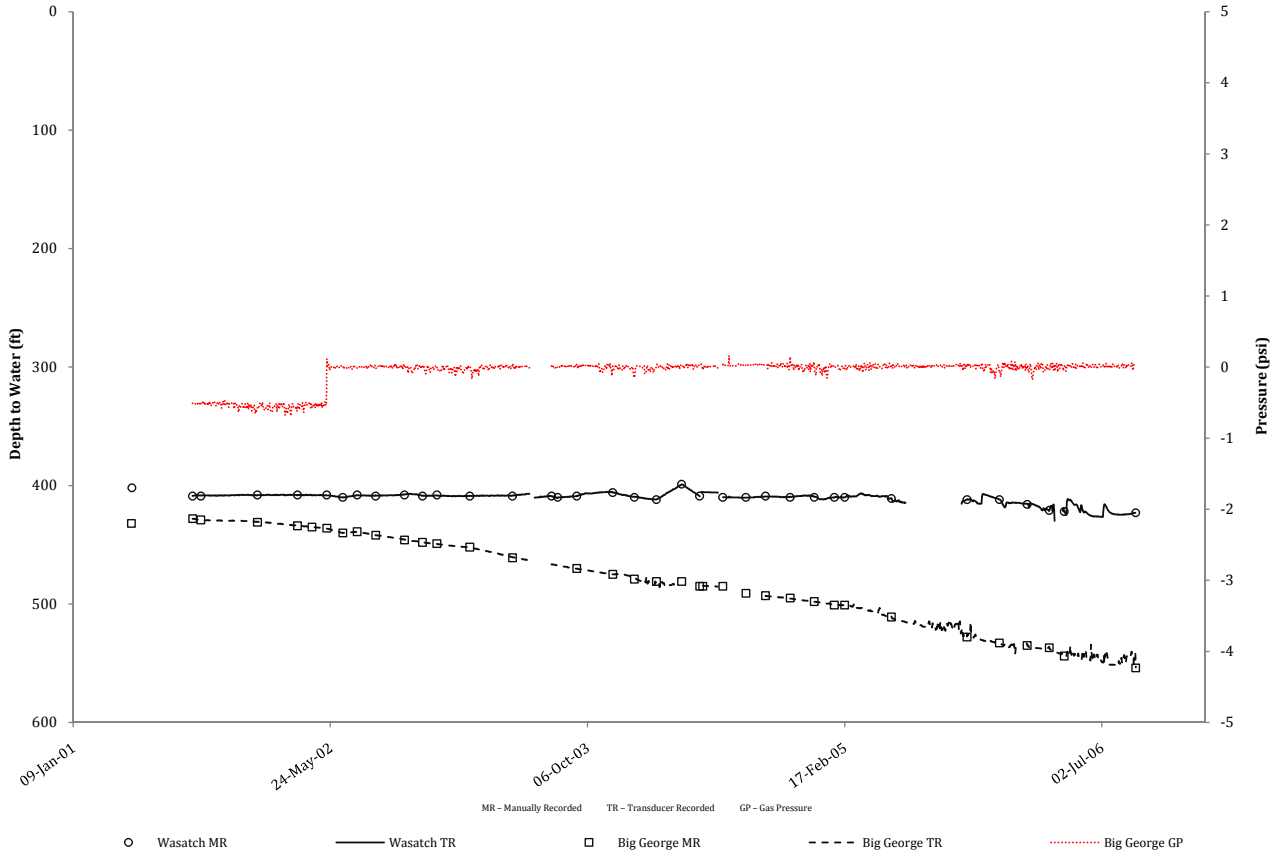
Date first monitored: March 2, 2001

The Barrett Napier (NAPIER) monitoring well set includes two wells. One is constructed into the Big George coal and the other into an overlying Wasatch sandstone bed.

- The Big George coal well (NAPIERC) showed 121.5 feet of drawdown from the initial water level in 2001 to 2006. The wellhead gas pressure peaked at 0.2 psi.
- The overlying Wasatch sandstone well (NAPIERS), which is constructed into a sandstone bed 63 feet stratigraphically above the top of the Big George coal, showed 20.5 feet of drawdown from 2001 to 2006. This well was affected by CBNG-related drawdown in the underlying Big George coal bed and/or CBNG development in the vicinity.

The Wasatch water level showed a relatively steady drawdown from 402 to 427 feet deep (25 feet of drawdown) from 2001 to 2006, and then the level rose a few feet during 2006. The Big George water level showed a steady decline from 428 feet to 551 feet deep during this period. These data indicate some degree of hydraulic connection between the Big George and Wasatch wells in this well set.

Barrett Napier Wells (NAPIER)



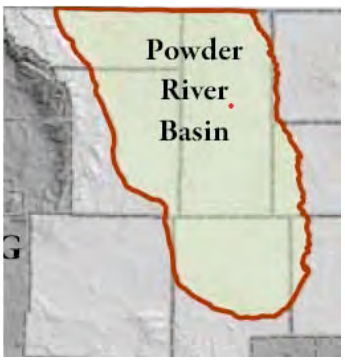
North Gillette Wells (NGILL)

Location: S34 T51N R73W

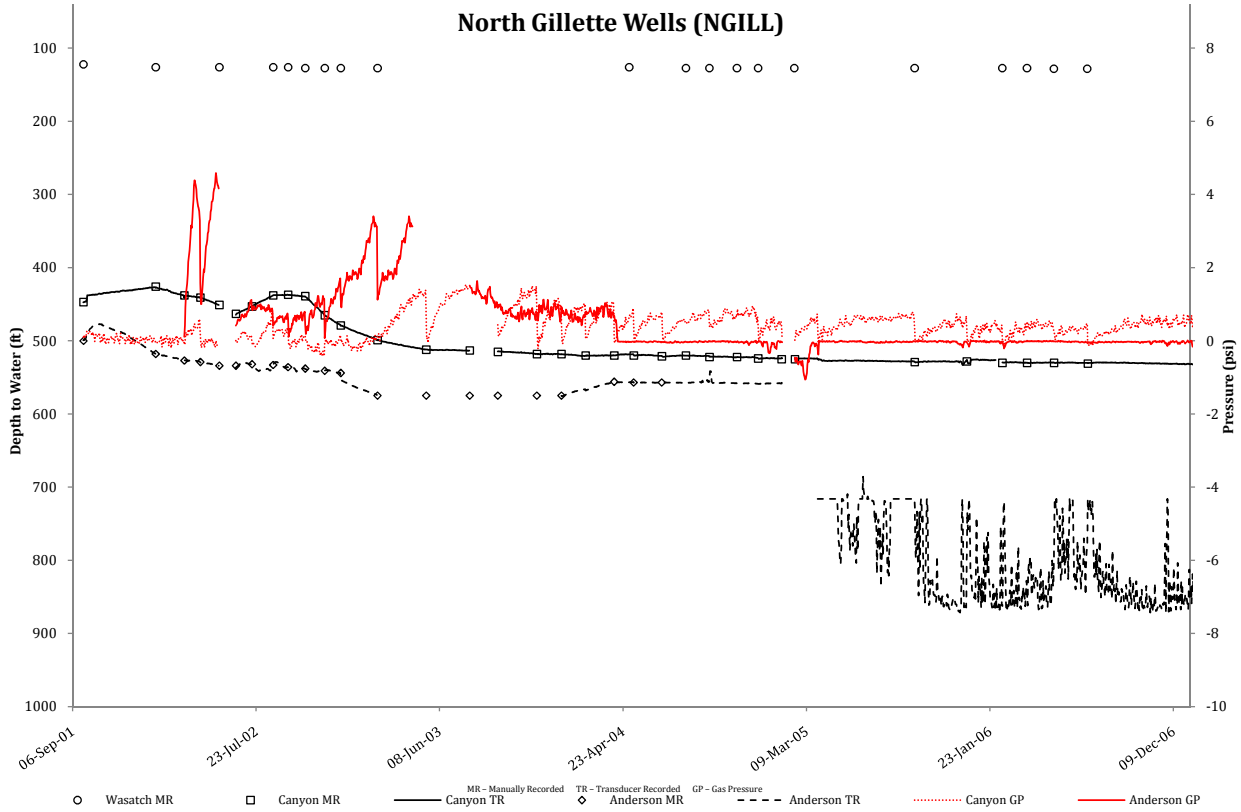
Date first monitored: September 25, 2001

The NGILL monitoring well set includes three wells. One is constructed into the shallower Anderson coal, another into the deeper Canyon coal, and the third into an overlying Wasatch sandstone bed.

- The Anderson coal well (NGILLAND) became dry by 2003, and the drawdown exceeded 57 feet from the initial water level of 500 feet in December 2001. The wellhead gas pressure peaked at 4.6 psi.
- The Canyon coal well (NGILLCAN) showed 84.5 feet of drawdown from 2001 to 2006. The wellhead gas pressure peaked at 1.5 psi.
- The overlying Wasatch sandstone well (NGILLS), which is constructed into a sandstone bed 214 feet stratigraphically above the top of the shallower Anderson coal, showed 5.7 feet of drawdown from 2001 to 2006. This well is little (if any) affected by CBNG-related drawdown in the underlying Anderson and Canyon coals.



The Wasatch water level generally declined from 122 feet to 128 feet deep over the period. The Anderson water level showed a maximum fluctuation between 477 and 575 feet deep but rose and declined over the monitoring period from the initial level of 486 to 558 feet deep. The Canyon water level also rose and declined with fluctuations between 429 and 532 feet deep. Canyon level declined from approximately 438 to 532 feet deep from 2001 to 2006. The water level declines measured in the Anderson and Canyon wells are relatively similar and indicate some degree of hydraulic connection between the two wells. There is little evidence of hydraulic connection with the overlying Wasatch sandstone well. Depressions in Canyon coal gas pressure could be the result of venting during manual measurement collection.



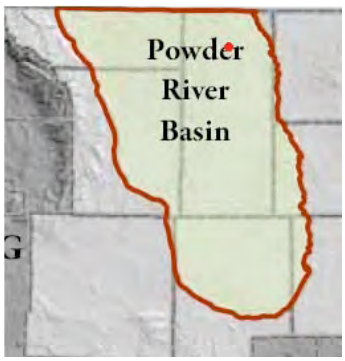
Palo Petroleum Recluse Field Wells (PALO)

Location: S22 T56N R74W

Date first monitored: February 7, 2001

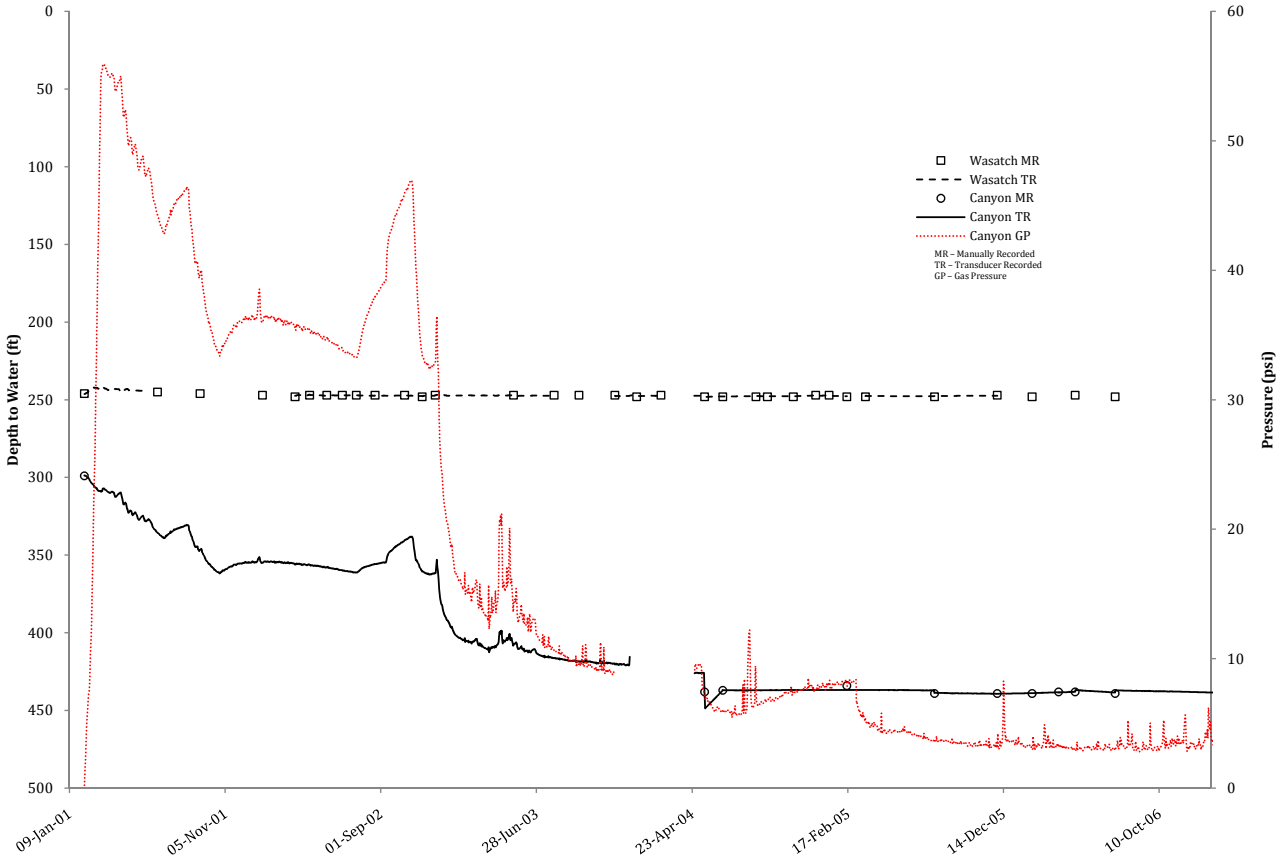
The Palo Petroleum Recluse Field (PALO) monitoring well set includes two wells. One is constructed into the Canyon coal and one into an overlying Wasatch sandstone bed.

- The Canyon coal well (PALOC) showed 139.6 feet of drawdown from the initial water level in 2001 to 2006. The wellhead gas pressure peaked at 55.9 psi.
- The overlying Wasatch sandstone well (PALOS), which is constructed into a sandstone bed 46 feet stratigraphically above the top of the Canyon coal, showed 1.35 feet of drawdown from 2001 to 2006. This well was not affected by CBNG-related drawdown in the underlying Canyon coal bed.



In March 2001, when the Canyon wellhead gas pressure peaked at nearly 56 psi, the water level in the well had declined from 299 to 307 feet deep. The Canyon water level showed a general decline from 299 to 438 feet deep from 2001 to 2006. The Wasatch water level remained relatively stable with very little decline from 246 to 248 feet deep. These data indicate there is no hydraulic connection between the Canyon coal and Wasatch sandstone wells.

Palo Petroleum Recluse Field Wells (PALO)



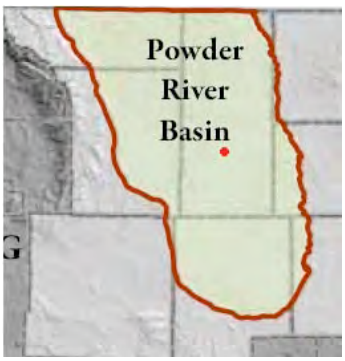
Barrett Persson Wells (PERSSON)

Location: S32 T47N R73W

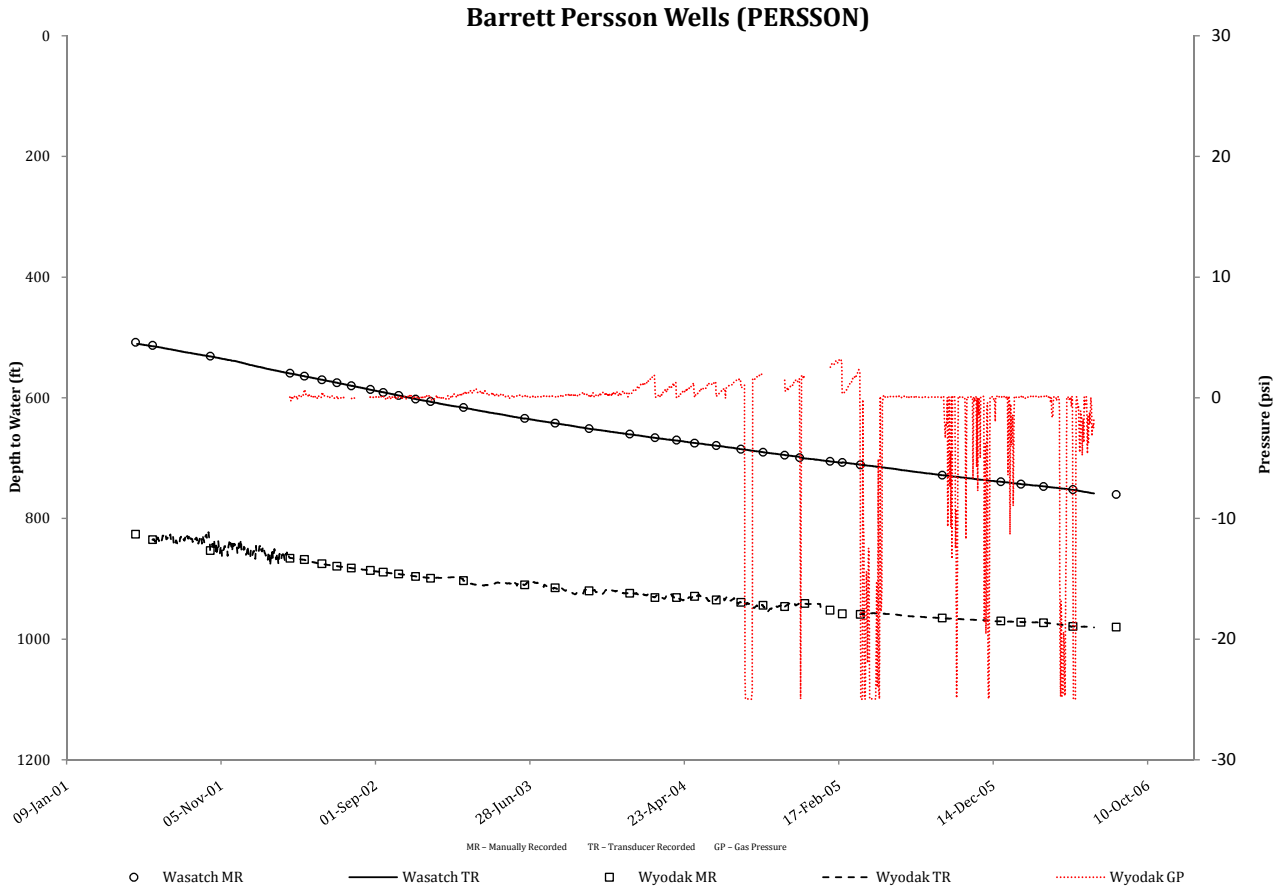
Date first monitored: December 6, 2000

The Barrett Persson (PERSSON) monitoring well set includes two wells. One is constructed into the Wyodak coal and the other into an overlying Wasatch sandstone bed.

- The Wyodak coal well (PERSSONC) showed 153.7 feet of drawdown from the initial water level in 2001 to 2006. Wellhead gas pressure peaked at 3.2 psi, but this is likely due to transducer error.
- The overlying Wasatch sandstone well (PERSSONS), which is constructed into a sandstone bed 36 feet stratigraphically above the top of the Wyodak coal, showed 252.6 feet of drawdown from 2001 to 2006. This well was affected by CBNG-related drawdown in the underlying Wyodak coal bed.



The Wasatch water level declined from 508 to 760 feet deep from 2001 to 2006. The Wyodak water level showed a steady rate of decline from 826 to 980 feet deep over this period. These data indicate a general hydraulic connection between the Wyodak coal and Wasatch sandstone wells. Depressions in Wyodak gas pressure could be the result of venting during manual measurement collection.

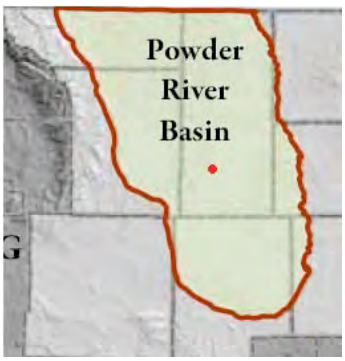


Shogrin Federal #2 Well (Pistol Point) (PISTOL)

Location: S31 T42N R75W

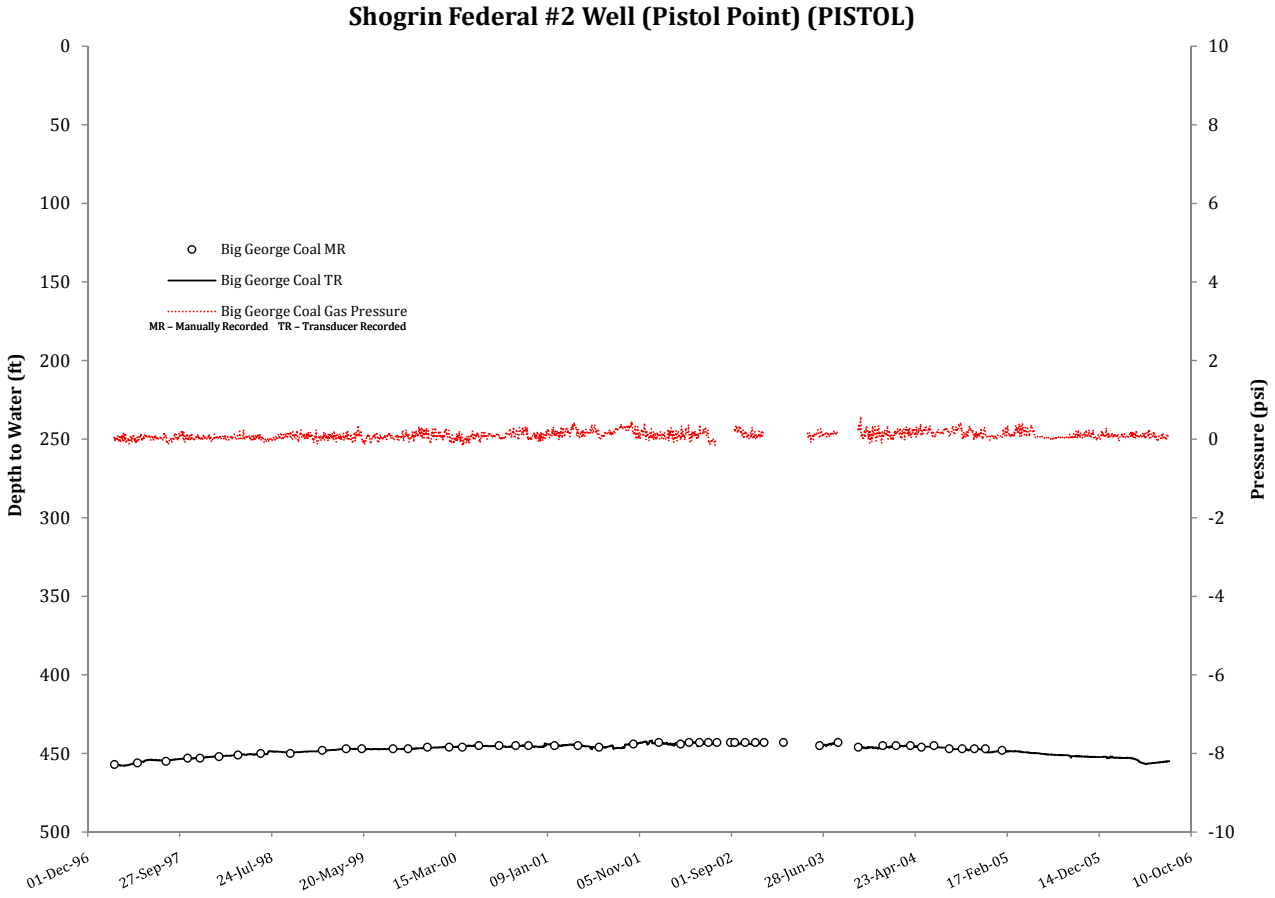
Date first monitored: February 26, 1997

The Shogrin Federal #2 Well (Pistol Point) (PISTOL) monitoring well is constructed into the Big George coal. There is no Wasatch sandstone monitoring well associated with this coal well.



- This Big George coal well showed a water-level rise of 1.6 feet from the initial water level in 1997. The wellhead gas pressure peaked at 0.6 psi.

The Big George wellhead gas pressure remained at nearly zero from 1997 to 2006. The water level showed very little variation. It slowly rose from 457 to 443 feet deep from February 1997 to January 2002 and then declined from 443 to 455 feet deep by 2006. Overall, the water level in this well rose.



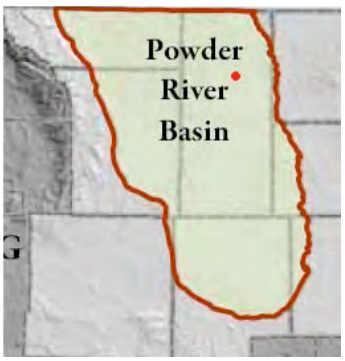
Redstone Wells (REDSTN)

Location: S26 T53N R73W

Date first monitored: October 9, 1998

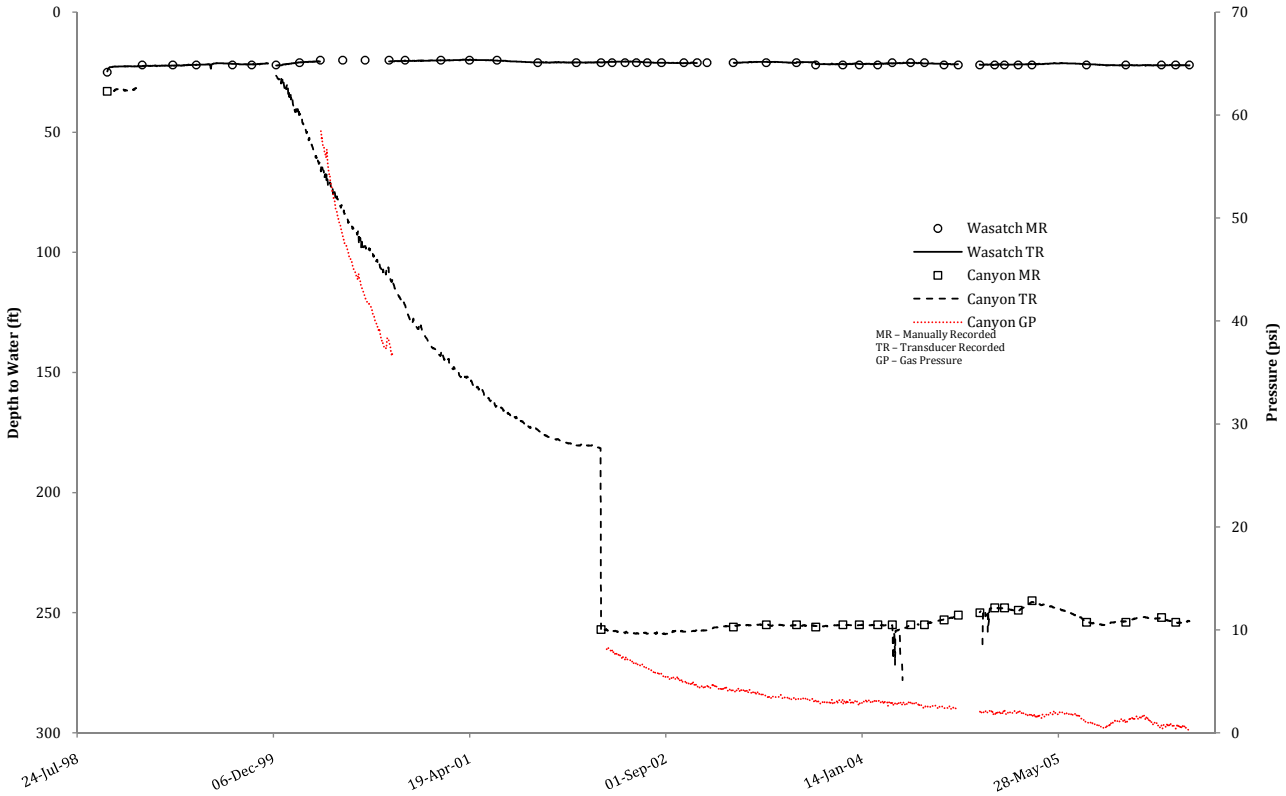
The Redstone (REDSTN) monitoring well set includes two wells. One is constructed into the Canyon coal and the other into an overlying Wasatch sandstone bed.

- The Canyon coal well (REDSTNC) showed 220.7 feet of drawdown from the initial water level in 1998. The wellhead gas pressure peaked at 58.4 psi.
- The overlying Wasatch sandstone well (REDSTNS), which is constructed into a sandstone bed 56 feet stratigraphically above the top of the Canyon coal bed, showed a water-level rise of 2.6 feet from 1998 to 2006. This well was not affected by CBNG-related drawdown in the underlying Canyon coal bed.



The data for the Canyon wellhead gas pressure are absent before April 2000, and the recorded gas pressure data are not complete. The Wasatch water level remained relatively stable with variation between 20 and 23 feet deep from 1998 to 2006. The Canyon coal water level declined from 33 to 254 feet deep over this period. These data indicate there is no hydraulic connection between the Canyon Coal and Wasatch wells.

Redstone Wells (REDSTN)

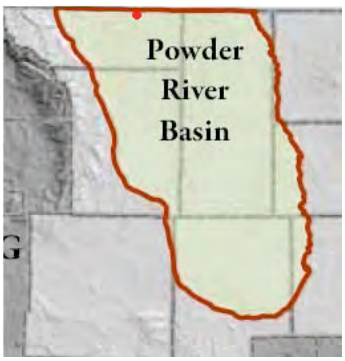


Nance Petroleum Remington Creek Wells (REMCRK)

Location: S30 T58N R79W

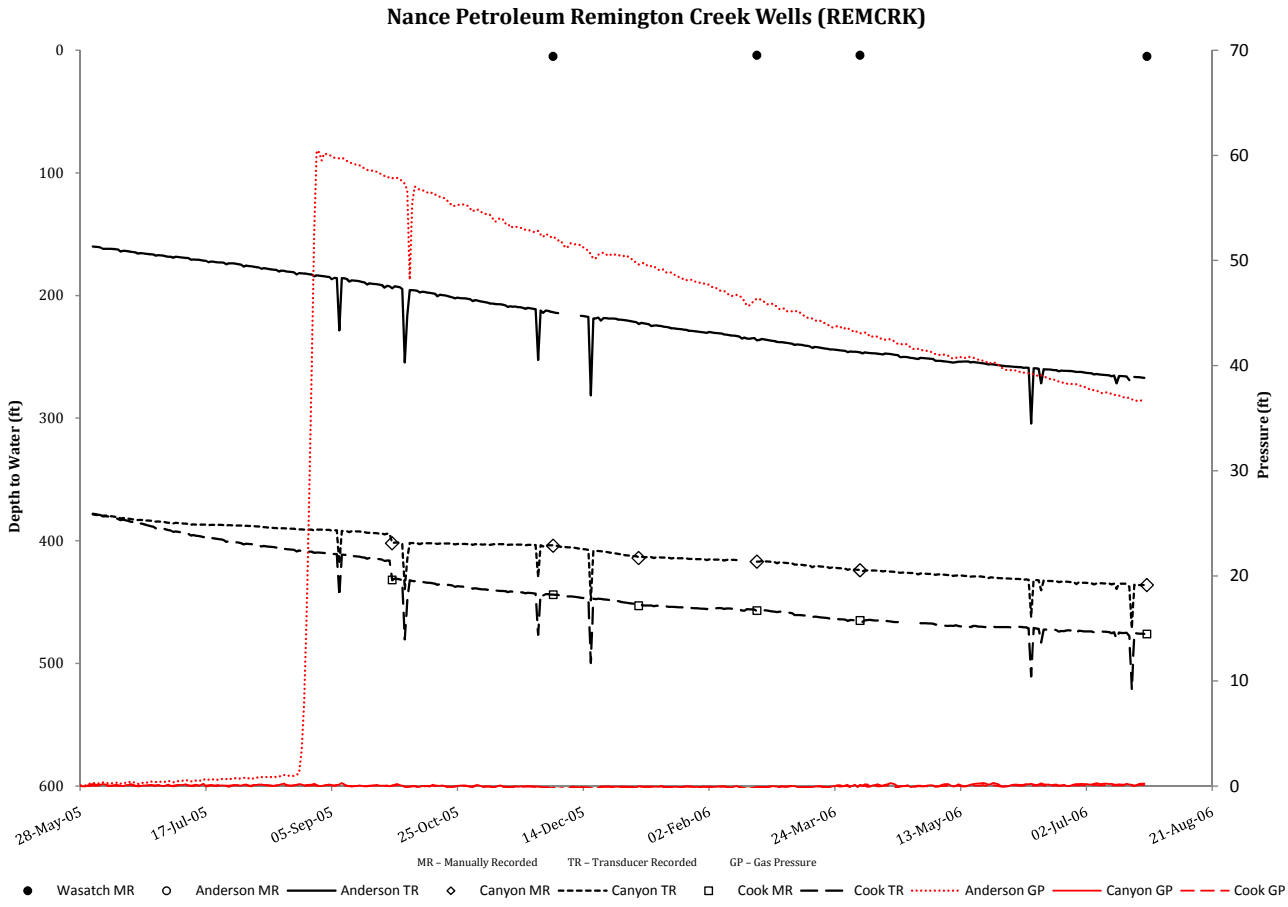
Date first monitored: May 23, 2005

The Nance Petroleum Remington Creek (REMCRK) monitoring well set includes four wells. One is constructed into the shallower Anderson coal, one into the intermediate Canyon coal, another into the deeper Cook coal, and one into a shallow Quaternary alluvial bed (unconsolidated deposit).



- The Anderson coal well (REMCRKANDC) showed 107.0 feet of drawdown from the initial water level in 2005. The wellhead gas pressure peaked at 60.4 psi.
- The Canyon coal well (REMCRKCANC) showed 57.8 feet of drawdown from 2005. The wellhead gas pressure peaked at 0.3 psi.
- The Cook coal well (REMCRKCOOKC) showed 98.1 feet of drawdown, and wellhead gas pressure peaked at 0.1 psi.
- The Quaternary alluvial well (REMCRKS), which is constructed into an alluvial sand bed 288 feet stratigraphically above the top of the shallow Anderson coal, showed 0.22 feet of drawdown. This shallow (30.5 feet total depth) alluvial well was not affected by CBNG-related drawdown in the underlying Anderson, Canyon, and Cook coal beds.

Anderson wellhead gas pressure peaked at 60.4 psi in August 2005 and then declined at a steady rate.



The water level in the Anderson well had declined to 183 feet deep (23 feet of drawdown) when the gas pressure peaked. The wellhead gas pressures in the other two coal wells remained at nearly zero during the entire monitoring period. Depressions in Canyon coal gas pressure could be the result of venting during manual measurement collection.

The Quaternary alluvial water level remained relatively stable at between 4 and 5 feet from 2005 to 2006. The Anderson water level declined at a steady rate from 160 to 267 feet (107 feet of drawdown) over this period. The water-level decline curves for the Canyon and Cook coals showed steady decline rates and divergence. The water levels in the Canyon and Cook coals started at about the same depth (378 feet) in June 2005. By 2006, the water levels declined to 436 feet deep (58 feet of drawdown) for the Canyon and 476 feet deep (98 feet of drawdown) in the Cook. The Cook water level declined 40 feet deeper than the Canyon level by 2006. The Cook water level declined at a slower rate than the Canyon and Anderson water levels.

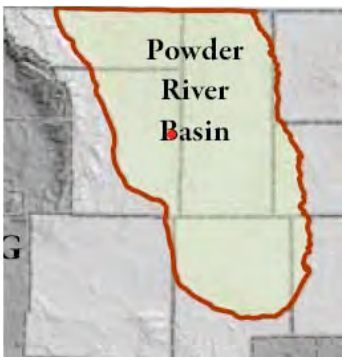
These data indicate there is no hydraulic connection between the Quaternary alluvial well with the three coal wells. The steady decline of water levels in all three coal wells indicates a general hydraulic connection between the three coal beds. The nearly identical water level in June 2005 for the Canyon and Cook coals indicates that they are hydraulically connected, but the 40 feet of divergence between these wells' decline curves indicate the hydraulic connection is limited.

Sasquatch Federal #12-2 Wells (SASQUAT)

Location: S12 T48N R77W

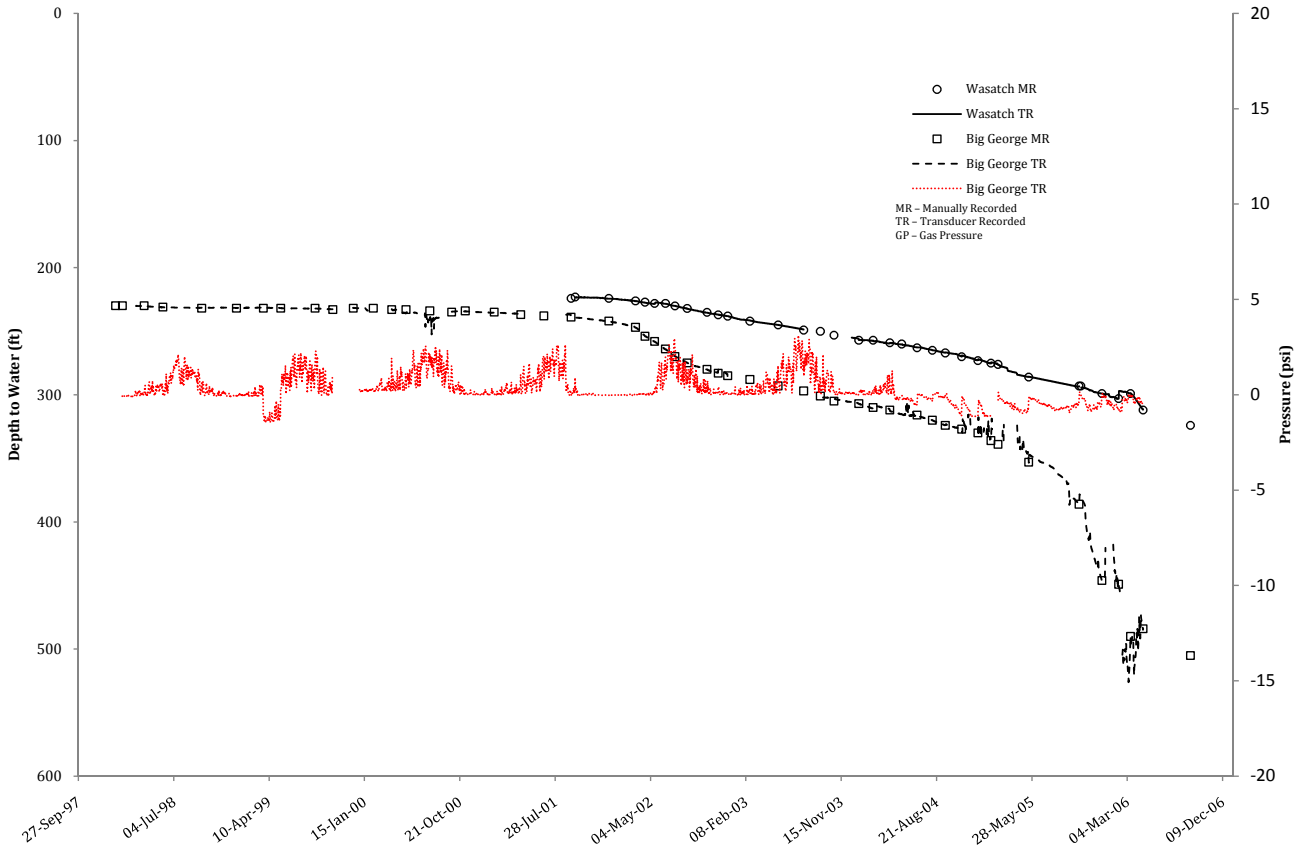
Date first monitored: January 14, 1998

The Sasquatch Federal #12-2 Wells (SASQUAT) monitoring well set includes two wells. One is constructed into the Big George coal and one into an overlying Wasatch sandstone bed.



- The Big George coal well (SASQUATC) showed 275.4 feet of drawdown from the initial water level in 1998. The wellhead gas pressure peaked at 3.1 psi, but all fluctuation in the gas pressure may be due to transducer error.
- The overlying Wasatch sandstone well (SASQUATS), which is constructed into a sandstone bed 75 feet stratigraphically above the top of the Big George coal, showed 100.3 feet of drawdown from 2001 to 2006. This well was affected by CBNG-related drawdown in the underlying Big George coal bed. The Big George wellhead gas pressure showed multiple cycles of highs and lows between about 0 and 3 psi and overall remained at a relatively low level. This gas pressure change could be the result of temperature effects on the sensor as the oscillations appear to be seasonal. The Wasatch water level declined from 224 to 324 feet deep. The water level showed an increasing decline rate from 230 to 524 feet deep followed by a slight rise from 524 to 476 feet deep during 2006. These data indicate a hydraulic connection between the Wasatch and Big George wells in this well set.

Sasquatch Federal #12-2 Wells (SASQUAT)



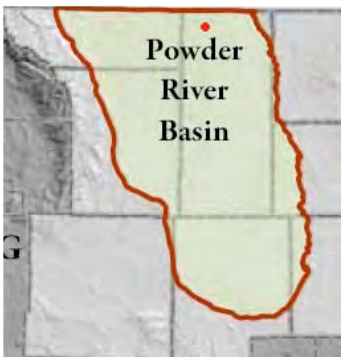
Huber South Coal Wells (SCOAL)

Location: S13 T57N R75W

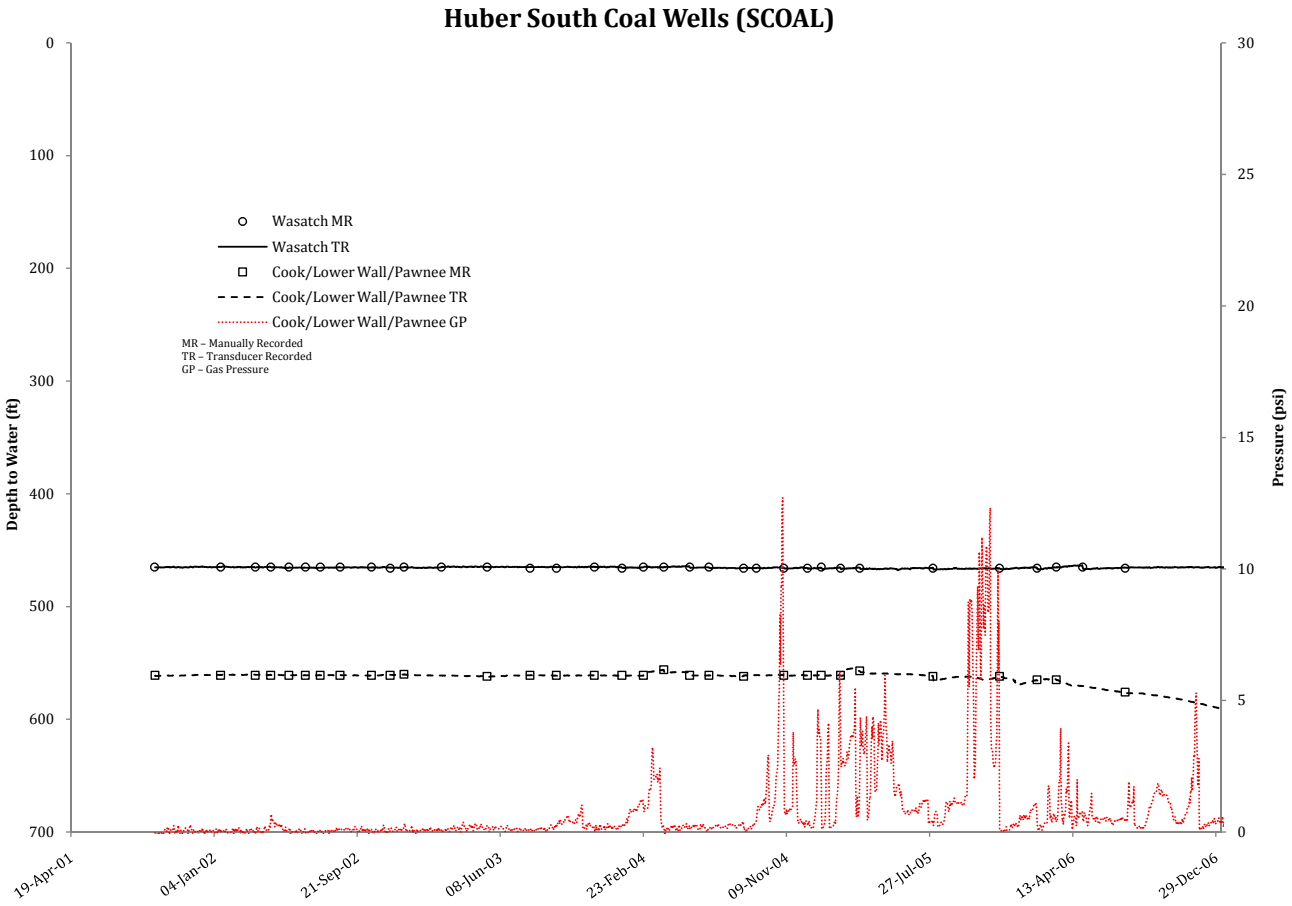
Date first monitored: September 18, 2001

The Huber South Coal (SCOAL) monitoring well set includes two wells. One is constructed into the combined Cook/Lower Wall/Pawnee coal beds and the other into an overlying Wasatch sandstone bed.

- The Cook/Lower Wall/Pawnee coal well (SCOALC) drawdown was more than 8.5 feet from the initial water level of 561.4 feet in 2001. The wellhead gas pressure data shows a peak of 12.7 psi, but this is likely due to transducer error.
- The overlying Wasatch sandstone well (SCOALS), which is constructed into a sandstone bed 207 feet stratigraphically above the top of the Cook coal, showed 0.4 feet of drawdown from 2001 to 2006. This well was not affected by CBNG-related drawdown in the underlying Cook/Lower Wall/Pawnee coal beds.



When the SCOALC wellhead gas pressure peaked at 12.7 psi in November 2004 and peaked again at 12.3 psi in November 2005, the water level in the coal well was at 561 feet deep (1 foot of rise) in November 2004 and at 565 feet deep (3 feet of drawdown) in November 2005. The Wasatch water level showed a relatively stable level at 465 and 466 feet deep from 2001 to 2006. The Cook/Lower Wall/Pawnee water level declined from 562 to 589 feet deep. These data indicate there is no hydraulic connection between the Wasatch sandstone and the Cook/Lower Wall/Pawnee coal wells.



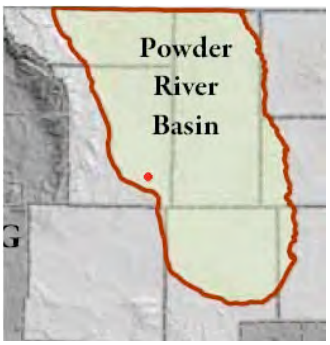
Streeter Road Wells (STREETER)

Location: S22 T43N R78W

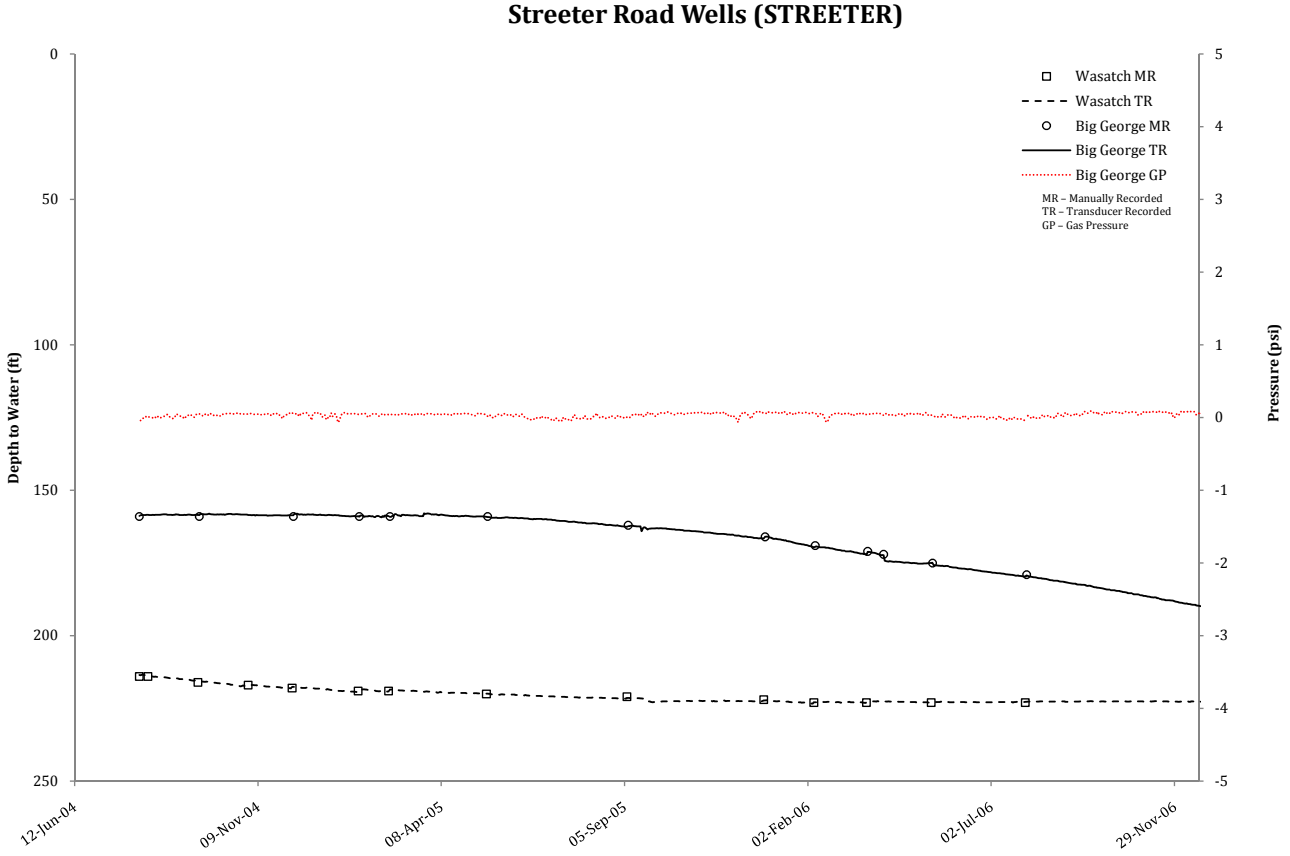
Date first monitored: August 4, 2004

The Streeter Road Wells (STREETER) monitoring set includes two wells. One is constructed into the Big George coal and the other into an overlying Wasatch sandstone bed.

- The Big George #3 coal well (STREETERC) showed 20.6 feet of drawdown from the initial water level in 2004. The wellhead gas pressure peaked at 0.1 psi.
- The overlying Wasatch sandstone well (STREETERS) showed 9.1 feet of drawdown from 2004 to 2006. This well is constructed into a sandstone bed 621 feet stratigraphically above the top of the Big George #3 coal bed. This well may be affected by CBNG-related drawdown in the underlying Big George #3 coal bed.



The Big George #3 wellhead gas pressure recorded nearly zero pressure over the monitoring period. The Wasatch water level recorded a slight decline from 214 to 223 feet deep. The Big George #3 coal water level declined from 159 to 180 feet deep. These data indicate a possible hydraulic connection between the Wasatch and Big George #3 wells.



Barrett Throne Wells (THRONE)

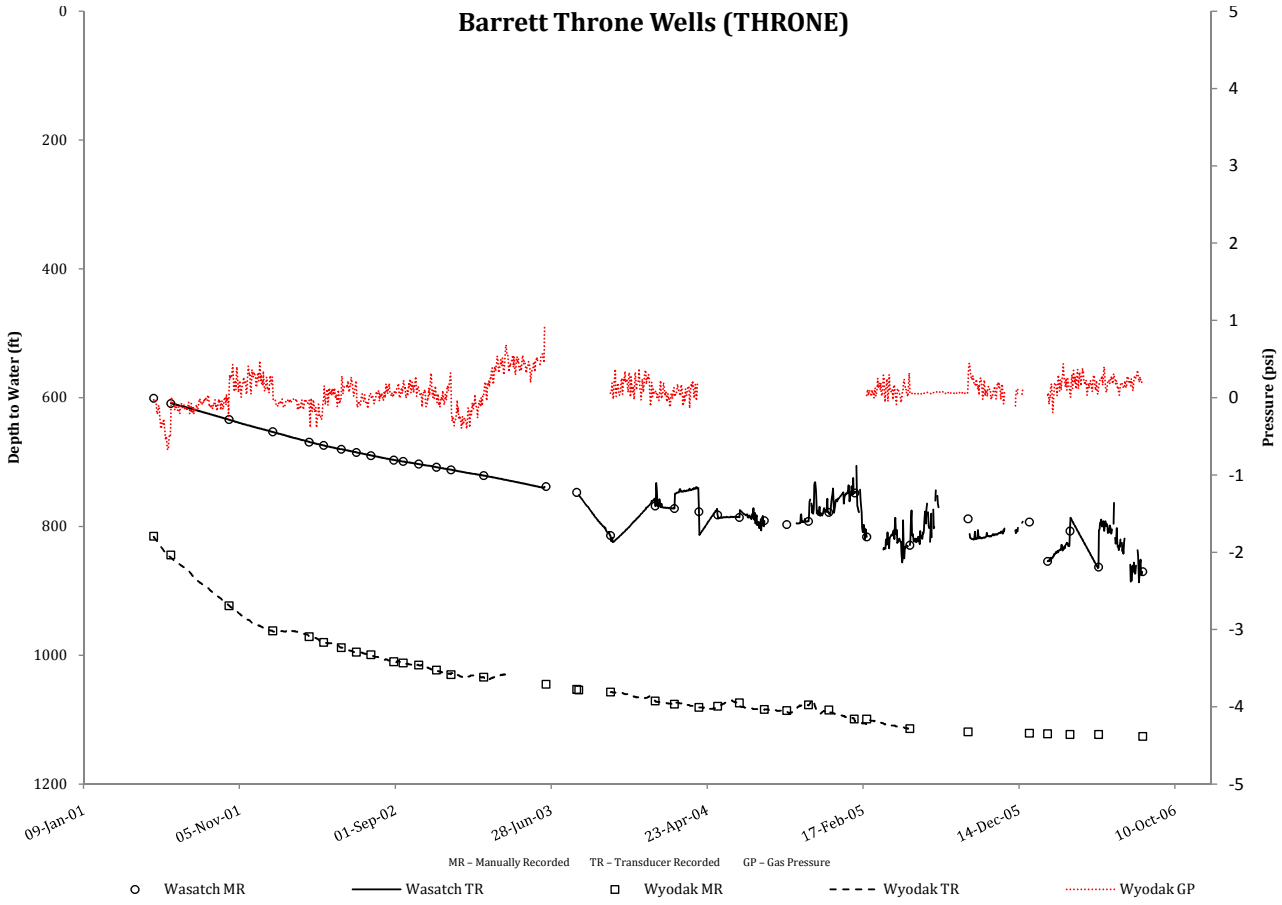
Location: S26 T47N R74W

Date first monitored: May 24, 2001

The Barrett Throne Wells (THRONE) monitoring set includes two wells. One is constructed into the Wyodak coal and the other into an overlying Wasatch sandstone bed.

- The Wyodak coal well (THRONEC) showed 310.8 feet of drawdown from the initial water level in 2001. The wellhead gas pressure peaked at 1.0 psi.
- The overlying Wasatch sandstone well (THRONES), which is completed into a sandstone bed 56 feet above the top of the Wyodak coal, showed 268.8 feet of drawdown from 2001 to 2006. This well was affected by CBNG-related drawdown in the underlying Wyodak coal bed.

The Wyodak wellhead gas pressure remained at nearly zero pressure from 2001 to 2006. The Wasatch water level showed a steady rate of decline from 601 to 870 feet deep. The Wyodak water level declined from 816 to 1,126 feet deep. The decline curves of the Wyodak and Wasatch water levels generally parallel each other. These data indicate a hydraulic connection between the Wasatch and Wyodak wells in this well set.



Williams Cedar Draw Well (WCDU)

Location: S15 T53N R75W

Date first monitored: No data available

Monitored water-level and wellhead gas pressure data were not available for this monitoring well.

Prima Wild Turkey Wells (WILDTUR)

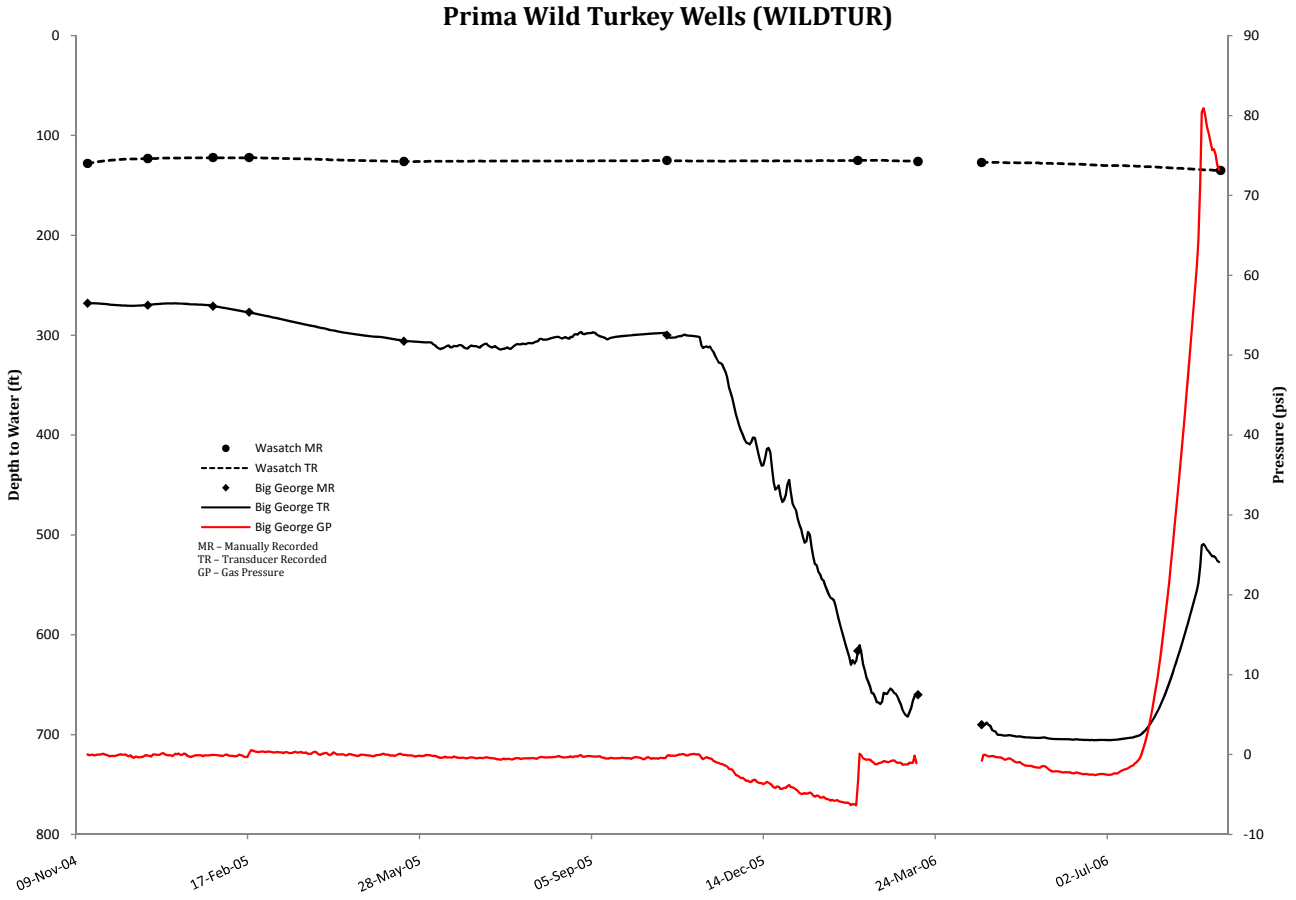
Location: S29 T49N R76W

Date first monitored: November 16, 2004

The Prima Wild Turkey (WILDTUR) monitoring set includes two wells. One is constructed into the Big George coal and one into an overlying Wasatch sandstone bed.

- The Big George coal well (WILDTURC) showed 259.3 feet of drawdown from the initial water level in 2004. The wellhead gas pressure peaked at 80.9 psi.
- The overlying Wasatch sandstone well (WILDTURS) showed 7 feet of drawdown from 2004 to 2006. This well is constructed into a sandstone bed 187 feet stratigraphically above the top of the Big George coal. This well was not affected by CBNG-related drawdown in the underlying Big George coal bed.

When the Big George wellhead gas pressure peaked in August 2006, the water level was at 515 feet deep (247 feet of drawdown), which had risen from a low of 705 feet deep (437 feet of drawdown) in July 2006.



After the August 2006 peak, the gas pressure in the coal well started to decline.

The Wasatch water level showed a relatively small decline from 128 to 135 feet deep from 2001 to 2006. The Big George water level declined from 268 to 705 feet deep during the same period. The water level decline in the coal well was slow for the first 34 feet of the decline from November 2004 to November 2005, very rapid for the next 388 feet of decline from November 2005 to April 2006, and slow for the next 15 feet of decline from April-July 2006. It then rose rapidly (194 feet) with an associated gas pressure peak from July-August 2006. Since August 2006, the coal water level declined slightly. These data indicate no hydraulic connection between the Wasatch and Big George wells.

WSGS

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Mission Statement

The Wyoming State Geological Survey's (WSGS) mission is to promote the beneficial and environmentally sound use of Wyoming's vast geologic, mineral, and energy resources while helping protect the public from geologic hazards. By providing accurate information and expanding knowledge through the application of geologic principles, the WSGS contributes to economic growth and improvement in the quality of life for Wyoming's residents.