

Prepared in cooperation with the Bureau of Land Management

## **Hydrologic and Geochemical Data Collected Near Skewed Reservoir, an Impoundment for Coal-Bed Natural Gas Produced Water, Powder River Basin, Wyoming**



Data Series 715

**Cover.** Skewed Reservoir (photograph by Jon Mason, U.S. Geological Survey, 2004).

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**U.S. Department of the Interior  
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## Conversion Factors

SI to Inch/Pound

<b>Multiply</b>	<b>By</b>	<b>To obtain</b>
<b>Length</b>		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
<b>Area</b>		
square meter (m <sup>2</sup> )	0.0002471	acre
hectare (ha)	2.471	acre
Square centimeter (cm <sup>2</sup> )	0.1550	square inch (in <sup>2</sup> )
<b>Volume</b>		
liter (L)	33.82	ounce, fluid (fl. oz)
cubic meter (m <sup>3</sup> )	264.2	gallon (gal)
<b>Mass</b>		
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32.$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ( $\mu\text{S}/\text{cm}$  at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter ( $\mu\text{g}/\text{L}$ ).

# Hydrologic and Geochemical Data Collected Near Skewed Reservoir, an Impoundment for Coal-Bed Natural Gas Produced Water, Powder River Basin, Wyoming

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## Abstract

The Powder River Structural Basin is one of the largest producers of coal-bed natural gas (CBNG) in the United States. An important environmental concern in the Basin is the fate of groundwater that is extracted during CBNG production. Most of this produced water is disposed of in unlined surface impoundments. A 6-year study of groundwater flow and subsurface water and soil chemistry was conducted at one such impoundment, Skewed Reservoir. Hydrologic and geochemical data collected as part of that study are contained herein. Data include chemistry of groundwater obtained from a network of 21 monitoring wells and three suction lysimeters and chemical and physical properties of soil cores including chemistry of water/soil extracts, particle-size analyses, mineralogy, cation-exchange capacity, soil-water content, and total carbon and nitrogen content of soils.

## Introduction

The Powder River Structural Basin (defined herein as the “Basin”) covers an area of more than 61,000 square kilometers (km<sup>2</sup>) in northern Wyoming and southern Montana (fig. 1). The Basin is an important source of energy resources, containing the largest coal resources of any coal field in the contiguous United States (Glass, 1997) and substantial oil and natural-gas resources. Recent technological advances have enabled the economical development of natural gas stored in coal beds. Development of coal-bed natural gas (CBNG) has increased rapidly in the Basin since the late 1990s. Between 2000 and 2010, more than 59,000 permits for CBNG wells were approved in the Wyoming part of the Basin (Wyoming Oil and Gas Conservation Commission, 2011).

Coal beds in the Fort Union Formation at depths of 100 to 1,000 meters (m) are the target of most CBNG development in the Powder River Structural Basin. Overlying the Fort Union Formation in much of the Basin are shales, siltstones, and sandstones of the Wasatch Formation. Quaternary-age unconsolidated soils overlie the Tertiary-age Wasatch and

Fort Union Formations in some areas. CBNG is captured by withdrawing water from the coal beds, which lowers the water pressure and releases the gas. Details on CBNG generation, reserves, and development within the Basin can be found in De Bruin and others (2000), Bartos and Ogle (2002), and Rice and others (2002).

Disposal of water extracted with CBNG development (referred to as produced water) is an important concern in the Powder River Structural Basin because of the quantities and quality of water produced. New wells in the Basin produce about 47 cubic meters (m<sup>3</sup>) of water per day (Wheaton and Brown, 2005), and water production declines gradually over the 7- to 10-year life of a well. Approximately 678 million barrels (108,000,000 m<sup>3</sup>) of water were produced in the Basin in 2008 (Wyoming Oil and Gas Conservation Commission, 2011). Produced water is generally a sodium-bicarbonate type with total dissolved solids in the range of 200 to 4,000 milligrams/liter (mg/L) and sodium-adsorption ratios of 5.6 to 69, (Rice and others, 2002; Bartos and Ogle, 2002; Jackson and Reddy, 2007). Sodium-adsorption ratio (SAR) is a measure of the concentration of sodium in water relative to the concentrations of calcium and magnesium. Water with an SAR greater than 13 is undesirable for irrigation because soil structure can deteriorate as sodium replaces calcium and magnesium on clay particles (Soil Survey Laboratory, 1995; Mace and Amrhein, 2001).

As of 2011, unlined impoundments were the most popular option for disposal of CBNG produced water. The State of Wyoming has issued more than 4,000 permits for impoundments in the Powder River Structural Basin (Wyoming State Engineer’s Office, written commun., 2007). The U.S. Geological Survey (USGS) and the Bureau of Land Management (BLM) conducted a study of groundwater flow and solute transport in the vicinity of Skewed Reservoir, a produced water impoundment in Johnson County, Wyoming, from 2003 to 2009. Findings of that study are documented in Healy and others (2008, 2011). This report provides data collected during the study. Data include major and trace element chemistry of impoundment water and groundwater from 21 observation wells and three suction lysimeters for samples obtained from August 2003 through November 2005. Also included are

## 2 Hydrologic and Geochemical Data Collected Near Skewed Reservoir, Powder River Basin, Wyoming

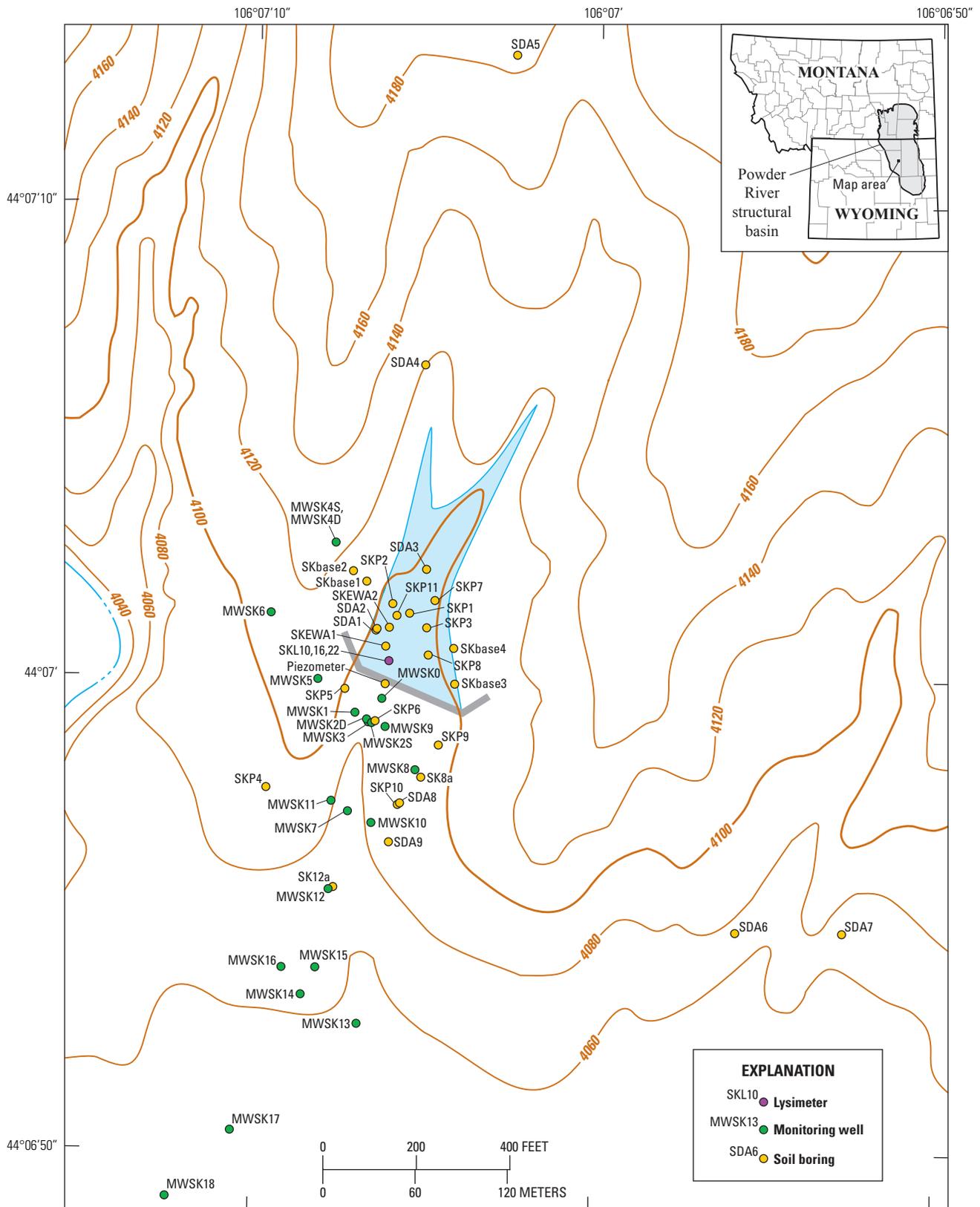


Figure 1. Location map for Skewed Reservoir study and monitoring network.

physical (soil-water content and particle size) and chemical (water/soil extract chemistry, mineralogy, cation-exchange capacity, and total carbon and nitrogen content) properties of soils. Data are provided in electronic spreadsheets as appendices.

Additional data on groundwater quality in areas near CBNG produced water impoundments in the Powder River Structural Basin are available from other sources. Unpublished data can be obtained from the BLM (Kathy Brus, written commun., BLM, 2012) and the Wyoming Department of Environmental Quality (WDEQ) (Carrie Steinhorst, written commun., WDEQ, 2012). BLM collects water-quality samples from networks of monitoring wells and suction lysimeters in the vicinity of eight impoundments in the Basin. WDEQ maintains a database of groundwater-quality analyses for approximately 170 monitoring wells located near 146 impoundment in the Basin (Steinhorst and others, 2010). Wheaton and Brown (2005) present preliminary results of groundwater-quality monitoring at three impoundment sites.

## Study Site

This study was conducted at Skewed Reservoir (fig. 1), an impoundment constructed specifically for disposal of CBNG water, in Johnson County, Wyoming. The 1-hectare, unlined reservoir was constructed in a naturally occurring ephemeral drainage about 300 m distant from Beaver Creek (fig. 1) by erecting a 6-m high dam of compacted native surficial soils in July 2003. Produced water from six CBNG wells was pumped into the reservoir starting on August 16, 2003 and ending in early May 2004. In August 2005 the dam was removed and the area reclaimed. Capacity of the reservoir was about 12,000 m<sup>3</sup>. The impoundment was constructed in Quaternary-age unconsolidated deposits, approximately 8-m thick and overlying Tertiary-age bedrock. The study area is typical of the semiarid grasslands of the Powder River Structural Basin. Average temperature in Gillette, about 50 km to the northeast, is about 7 degrees Celsius (°C), and average annual precipitation is 398 millimeters (mm) (Western Regional Climate Center, 2010).

## Methods

Prior to the reservoir receiving water from CBNG operations, twenty-one 50-mm-diameter monitoring wells were installed (fig. 1). Wells MWSK 0 and 1 were installed with a solid-stem auger. Wells MWSK 3 and 9 through and including MWSK 18 were installed with a rotary drill rig. The remaining wells were installed with a hollow-stem auger; soil samples were collected through the hollow stem for lithologic descriptions and for particle-size, mineralogical, soil-water content, and water-soluble-ion analyses. Most wells were screened at the bottom of the unconsolidated deposits immediately overlying the bedrock. Descriptions of well construction, lithology,

and electrical conductivity and gamma borehole logs are contained in Smith and others (2011).

Suction-cup lysimeters (50-mm diameter) were installed into the soils beneath the base of the reservoir at approximate depths of 3 m (site name SKL10), 5 m (SKL16), and 7 m (SKL22). A hand auger was used to bore holes for the lysimeters. Suction lysimeters allow collection of water samples when the soils are less than fully saturated; however, a groundwater mound quickly formed beneath the reservoir, so lysimeters sampled groundwater throughout the study (Healy and others, 2011).

Initially, groundwater was not encountered above bedrock, except in the Beaver Creek alluvial aquifer, south of the reservoir location. Ten wells (MWSK 0, 1, 2s, 4s, 4d, 7, 8, 9, 10, and 11) were initially dry (fig. 1). Wells MWSK 13 to 17 were completed within the saturated zone of the Beaver Creek alluvial aquifer (fig. 1). Six other wells (MWSK 2d, 3, 5, 6, 12, and 18) were screened in bedrock and also initially encountered groundwater (fig. 1). A confined sandstone aquifer was encountered at depths of about 33 m in well MWSK 3 and 18 m in well MWSK 18.

Water samples were collected approximately monthly from August 2003 through July 2004 and quarterly thereafter. Water samples from wells generally were obtained after measuring groundwater levels and purging three casing volumes with either submersible pumps or bailers. Lysimeter water samples were obtained by applying suction to each lysimeter, waiting about 4 hours, and then applying positive air pressure to push the water sample out of the lysimeter through a sampling tube. The first sample was discarded, the process was repeated, and the second sample was saved for analysis. Grab samples were collected from the surface of the reservoir.

Samples were analyzed for major dissolved-ion chemistry and trace elements by using standard methods (Rice and others, 2002; Bartos and Ogle, 2002). Samples obtained prior to January 2006 were analyzed in USGS laboratories (U.S. Geological Survey, 2011); samples obtained later were analyzed by laboratories contracted with the BLM (Bureau of Land Management, 2011). Temperature, pH, specific conductance, and alkalinity were determined in the field (U.S. Geological Survey, variously dated). Dissolved organic carbon (DOC) was analyzed in groundwater samples obtained in May and October 2004. DOC concentrations were determined for filtered samples by using an OI Model 770 Total Organic Carbon analyzer at the USGS laboratory in Boulder, Colo.; samples were analyzed in duplicate, and an average of the duplicate analyses is reported.

Soil samples were collected at numerous locations throughout the study area (fig. 1). Samples were collected by hand with a bucket auger or by use of direct-push hydraulic drill rig. Soil samples were analyzed for water content and particle size according to methods described in Dane and Topp (2002). Soil samples were sieved in the laboratory; chemical analyses were performed on the fraction of particles that were less than 2 mm in diameter. Water/soil extracts (10:1 deionized water to dry soil by mass) were obtained by using the method

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of Healy and others (2008); extracts were analyzed for major ion chemistry by using standard methods described in Rice and others (2002).

Cation-exchange capacity on samples of bulk soil and soil was determined by utilizing a modification of the unbuffered salt-extraction method described by Sumner and Miller (1996); 0.1 molar (M)  $\text{SrCl}_2$  and 0.1M  $\text{CaCl}_2$  were used instead of 0.2M  $\text{NH}_4\text{Cl}$  and 0.2M  $\text{KNO}_3$  (Blair F. Jones, oral commun., U.S. Geological Survey, 2005).

Bulk soil and soil samples were prepared for x-ray diffraction (XRD) analysis by air-drying the sample and splitting by hand. The representative splits were then processed for either bulk XRD or clay mineral identification according to the respective methods for each. XRD identification of minerals in bulk soil and soil samples was accomplished according to methods described in Eberl (2003) by utilizing a micronized sample to which a known amount of zinc oxide was mixed as a reference intensity pattern. Identification of minerals was accomplished with the Jade 7 software (MDI, 2005), and XRD patterns of bulk samples were analyzed with the RockJock software (Eberl, 2003) to quantify the minerals. RockJock can generally quantify minerals to  $\pm 5$  percent of a particular phase if a good degree of fit (ideally  $<0.1$ ) can be obtained for the calculated pattern versus the measured pattern. Clay minerals were prepared and analyzed by methods described in Moore and Reynolds (1997) by using the glass-slide method and a four-step technique that notes changes in mineralogy following air-drying, ethylene glycol solvation, heating to  $400^\circ\text{C}$ , and heating to  $550^\circ\text{C}$ .

Total carbon and nitrogen were determined on soil samples obtained from boreholes MWSK8 and SDA8 by using the dry combustion technique (Nelson and Sommers, 1982; Bremner and Mulvaney, 1982). Samples were analyzed in duplicate, and the average of the duplicate analyses is reported.

Tritium concentration in soil water was determined for a select number of soil samples. The soil samples were heat sealed with vapor-locking plastic wrapping in the field immediately after they were obtained and were shipped to the USGS

isotope laboratory in Menlo Park, Calif., for analysis. Water was extracted from the soil samples by using the vacuum distillation method described by Revesz and Woods (1990). Tritium concentration in the extracted water was analyzed on a gas proportional counter (Ostlund and Dorsey, 1977). Concentrations and analytical standard deviations are reported in tritium units and are decay corrected to the date of sample collection.

## Hydrologic And Geochemical Data

Results are presented in appendixes in the form of spreadsheets. Appendix 1 contains information on sampling site locations. Appendix 2 contains major and minor water chemistry from groundwater samples obtained from wells and lysimeters in the groundwater monitoring network. Appendix 3 lists trace-element concentrations in groundwater samples. DOC concentrations in groundwater are presented in Appendix 4. Appendix 5 contains nutrient concentrations for selected groundwater samples. Appendix 6 lists results of particle-size analysis for selected soil samples. Major ion-chemistry of water/soil extracts are presented in Appendix 7. Appendix 8 contains results of cation exchange analysis, presented as milliequivalents per 100 grams of soil (meq/100 g). Appendix 9 lists mineralogy of selected soil samples. Appendix 10 contains results of total carbon and total nitrogen analyses on soils from two boreholes (MWSK8 and SDA8). Appendix 11 presents tritium concentrations in soil water for selected soil samples.

## Acknowledgments

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