

GROUNDWATER MONITORING AT COAL BED NATURAL GAS PRODUCED WATER IMPOUNDMENTS: THE WYOMING DEQ DATABASE¹

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Abstract: Unlined impoundments are widely used for storage of water produced from coal bed natural gas (CBNG) operations in the Powder River Basin, but little published information exists regarding their potential effects on shallow groundwater resources. The Wyoming Department of Environmental Quality (DEQ) requires that CBNG operators characterize shallow groundwater at each CBNG impoundment site. If groundwater is found within the upper 150 to 200-feet of the surface, a well must be completed, a static water level measured and background water quality analyzed. At sites with Class III (Livestock) groundwater the DEQ requires operators to implement a “Compliance Groundwater Monitoring Plan” which typically entails installation of several wells and quarterly sampling of water quality.

The DEQ has maintained a database of groundwater monitoring results from CBNG impoundments since 2004. This is the first published summary of these data. As of December 2006, the database contained a total of 1106 impoundments. Groundwater was not encountered in about 45% of the 1,250 wells and boreholes. The database contains a total of 874 monitoring wells. The permitting status indicates that 75% of impoundments have been exempt from further groundwater monitoring (where no groundwater was encountered or it was Class IV), 15% have on-going monitoring requirements, 7% were not issued a permit, and 3% have their permit status pending. A total of 454 background water samples were analyzed for total dissolved solids (TDS) and other constituents. Approximately 80% of the background TDS concentrations were less than 5,000 mg/L, the class of use limit for class III groundwater. Although there are data gaps, particularly in the early data, this database will evolve and provide a valuable basis for assessing the effects of CBNG impoundments on shallow groundwater.

Additional Key Words: Shallow groundwater quality, water quality database, impoundments

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Introduction

Coal bed natural gas (CBNG) is an increasingly important energy source in North America. Increased demand for natural gas and commensurate higher prices has boosted the exploration and production of CBNG resources nationwide. The in-place coal bed methane resources of the United States are estimated to be more than 700 trillion cubic feet (Tcf), of which an estimated 100 Tcf may be economically recoverable (USGS, 2007). This is equivalent to a 5 year U.S. supply at present consumption rates. Along with CBNG gas production is a significant volume of produced water. Over 14 billion barrels (Bbbls) per year of produced water was generated in the U.S. in 2002, according to a recent Argonne National Laboratory study (DOE, 2004).

The Powder River Basin (PRB) of Wyoming and Montana contains an abundance of CBNG due to the thickness and number of coal beds in the Tertiary Fort Union Formation. However, it also results in some of the highest water/gas production ratios of any fields currently produced. Cumulative CBNG gas production in Wyoming through November 2006 has been 2,190 million MCF (MMCF) with cumulative water production of 4.13 billion barrels (Bbbls). At the end of 2006, there were about 17,000 active CBNG wells and 6,000 shut-in wells in the Wyoming PRB. Over the past 10 years, water production rates in the PRB have averaged 1.9 bbls water per MCF of gas, whereas the average in the San Juan Basin is about 0.031 bbls water per MCF (DOE, 2004). Average daily water production per well was 238 bbls over the past 10 years, falling from about 400 bbls in 1997 to about 130 bbls in 2006 (WOGCC, 2007).

The quality of CBNG produced water varies greatly between basins, which leads to very different water management practices and regulatory issues. CBNG produced water in the PRB is mildly saline and is generally acceptable for livestock. With careful soil and water management, it has also been successfully used for crop production through sprinkler systems in a “managed irrigation” approach (Harvey et al., 2005), and in sub-surface drip irrigation systems (BeneTerra, 2007). About 2 percent of all CBNG produced water in the Wyoming portion of the PRB is injected (HydroSolutions, 2005). A significant portion of produced water is directly discharged to surface drainages in the eastern portion of the PRB, where produced-water salinity and sodium content is generally less than or equivalent to that of the ambient surface waters. However, in the northern and western portions of the PRB, the salinity and sodium content of CBNG water is, in varying degrees, greater than that of the two principal streams, the Tongue River and Powder River. Direct discharges of untreated water have not generally been permitted by the Wyoming Department of Environmental Quality (DEQ) where meeting applicable water quality standards or protection of irrigated agriculture could be questionable. Consequently, gas producers increasingly turned to construction of earthen impoundments to manage produced waters. In Wyoming, such produced water impoundments are considered waters of the state and have their own set of water quality standards and requirements. Water balances of PRB impoundments typically indicate that less than 10% of water is lost to evaporation, while 90% or more infiltrates. DEQ may require monitoring of shallow groundwater in the immediate vicinity of the impoundment, to confirm that seepage does not degrade groundwater below standards for the class of use. The DEQ has maintained a database of groundwater monitoring results at these impoundments since 2004. This paper presents a summary of the initial groundwater information available from the database, and illustrates some of the baseline conditions and findings of compliance monitoring at CBNG impoundments in the Powder River Basin.

Regulatory Framework

The DEQ received data which indicated that water infiltrating from unlined produced water impoundments had the potential to pollute the state's groundwater resources. These data indicate that seepage water can act as a solvent or alter the oxidation state of the subsurface, leaching compounds (e.g., sulfate salts), and other constituents to groundwater. Groundwater contamination is primarily a function of the amount and type of leachable compounds in the unsaturated zone, but other contributing factors include, the depth to groundwater, size and operating head of the impoundment, chemistry of the produced water, and the chemistry and classification of the receiving groundwater (WDEQ, 2007).

DEQ has established the following regulatory definitions:

- (a) Impoundment: an impoundment is an unlined reservoir, pond, pit, or natural depression that receives produced water from coal bed methane operations;
- (b) On-Channel Impoundment: an impoundment that receives coal bed methane produced water will be considered "on-channel" when sited on or within a distance of 500 feet of a designated water feature as defined on a United States Geologic Survey (USGS) 1:24,000 scale topographic map, or within a distance of 500 feet of the floodplain or mapped alluvium (including alluvial mixtures) of a stream system as defined on a Wyoming State Geological Survey 1:100,000 scale surficial geology map, and;
- (c) Off-Channel Impoundment: an impoundment that receives coal bed methane produced water will be considered "off channel" when the impoundment does not meet the criteria established for an "on-channel" above.

Groundwater monitoring beneath an impoundment is usually required when the water-bearing zone is capable of producing and sustaining a yield of 0.5 gallons/minute or more of water over a 24 hour period. A discussion of techniques to determine this yield is contained in Attachment 2 of the DEQ's Compliance Monitoring Guidelines. If groundwater is encountered in a boring and a monitoring well is properly completed and developed, and if groundwater is present in sufficient quantity for sampling, then a sample must be submitted for analysis. In this situation, the DEQ assumes that the yield is of sufficient volume to be protected. Depending upon the resultant classification of the groundwater by the DEQ, additional monitoring may be required.

In accordance with Water Quality Rules and Regulations, (WQRR) Chapter VIII, groundwater is classified by the WDEQ in order to apply standards to protect water quality. Groundwater is classified by the WDEQ as Class I (domestic use), Class II (irrigation use), Class III (livestock use), Special A or Class IV (industrial use). Groundwater is classified by use, and by ambient water quality. If there is no existing (appropriated) use of the groundwater, the groundwater classification is based upon the parameters listed in WQRR, Chapter VIII, Table 1. An abbreviated version of this table, showing the minimum list of compliance groundwater monitoring parameters is provided in Table 1. A minimum list of analytes to be sampled is contained in Attachment 3 of the DEQ Compliance Monitoring Guidelines.

Table 1. Groundwater Classes of Parameters Required for Groundwater Compliance Monitoring At Impoundments.

Use Suitability Parameter	I	II	III	IV	
	Domestic Conc. (mg/L)	Agriculture Conc. (mg/L)	Livestock Conc. (mg/L)	Industry A Conc. (mg/L)	Industry B Conc. (mg/L)
Arsenic	0.05	0.10	0.20		
Selenium	0.05	0.02	0.05		
Sulfate	250.0	200.0	3000.0		
Total Dissolved Solids	500.0	2000.0	5000.0	<10000	>10000
pH	6.5 - 8.5 su	4.5 - 9.0 su	6.5 - 8.5 su		
SAR	---	8.00	---		

The WDEQ typically does not require a subsurface investigation beneath the following classes of impoundments:

- (i) Impoundments less than 2.0 acre feet in capacity.
- (ii) Impoundments that have a Wyoming Pollution Discharge Elimination System (WYPDES) permit issued prior to August 1, 2004.
- (iii) On-channel impoundments that are not required as part of a water management plan in a WYPDES permit.

DEQ requires a subsurface investigation for all unlined off-channel pits permitted by the Wyoming Oil and Gas Conservation Commission.

Given the heterogeneity of the Fort Union and Wasatch formations, the initial boring must be located within approximately 50 feet of the bank of the proposed impoundment to the required depth of investigation to determine if groundwater exists beneath the impoundment. For impoundments less than 50 acre feet in capacity, at least one boring must be advanced to the first occurrence of groundwater in bedrock or to a depth of 150 feet below the elevation of the ground surface at the impoundment if no groundwater is encountered. For impoundments equal to or greater than 50 acre feet in capacity, a boring must be advanced to the first occurrence of groundwater in bedrock, or to a depth of 200 feet below the surface elevation of the impoundment if no groundwater is encountered. If groundwater is encountered in the boreholes within the required depths of investigation, a monitor well must be installed in order to obtain a representative groundwater sample. The monitor well must be constructed and developed in accordance with Water Quality Rules and Regulations, Chapter 11, Part G (Attachment 6).

After a monitoring well is installed, the operator has the option of determining the yield of the groundwater before submitting a sample for analysis. If the groundwater bearing zone does not yield 0.5 gallons/minute as per the provisions of Attachment 2, no additional monitoring of that groundwater interval shall be required. However, the operator must investigate if other groundwater-bearing zones exist within the required depth of investigation. If groundwater is encountered during the subsurface investigation in unconsolidated materials and/or the bedrock

formation and an impoundment will be utilized for storage of produced water, information on well construction and the impoundment must be submitted to the DEQ for determining whether a compliance monitoring plan is necessary. The baseline and compliance monitoring water quality data are provided by operators to DEQ and imported into DEQ's Compliance Monitoring Data Reporting spreadsheet (see: <http://deq.state.wy.us/wqd/groundwater/index.asp>). The data contained in the spreadsheet are added to an electronic groundwater database that is maintained by the DEQ and is available upon request. At this writing, DEQ is finalizing a web-based version of the database which will be available on-line by mid-2007.

Impoundment Database Analysis

The Wyoming DEQ Impoundment Monitoring database was analyzed to produce preliminary categorical findings of basic characteristics and background data, which are summarized in Table 2. This analysis is based on the database version current through December 22, 2006. Data for many of the sites investigated early in the process were not submitted digitally. DEQ staff attempted to fill in some basic skeletal data for these sites so that at least parts of the database are complete. In doing so, an emphasis was placed on unique identifiers for each impoundment and information necessary to track compliance issues (e.g. baseline and trigger values assigned in the permit). Much of the information not essential to compliance tracking (e.g. on-channel/off-channel and bedrock/alluvial well completions) is not complete in the database at this time. One result of operator's reluctance to submit digital data has been that the DEQ now requires the digital data prior to reviewing submittals.

The database contained a total of 1,625 records (rows), which reduced to a total of 1,106 non-duplicate impoundments. Approximately 56% of the impoundments were classified as "On-channel", 13% "Off-channel", and 31% had insufficient information to be categorized. Of the On-channel impoundments, 29% were listed as "Existing On-Channel", implying that they likely were existing stock ponds, with the others being "New On-channel". The large number of not yet categorized impoundments reflects data that has not been submitted to the DEQ.

The database contained a total of 874 non-duplicate monitoring wells associated with the impoundments. This is less than the total number of impoundments, because not all impoundments require monitoring wells; for example where borings did not encounter groundwater, or one of the other categorical exclusions (as described in, "Regulatory Framework" above). Conversely, impoundments sites with Class III or better groundwater typically require one or more monitoring wells. Most monitoring wells (at least 46%) are reported to be completed in bedrock, with 7% being completed in alluvium. For 47% of wells, operators did not specify which type of aquifer the well was completed in. Of a total of approximately 1,250 wells and/or boreholes reported, 45% did not encounter groundwater.

The database contained 445 background water quality samples for which a groundwater class of use was assigned. Of these, three were Class I, one was Class II, 267 were Class III, and 174 were Class IV. Background TDS concentrations ranged from 250 to 25,900 mg/L. Of the available data, 4% were less than or equal to 500 mg/L, 33% were greater than 500 and less than or equal to 2,000 mg/L, 42% were greater than or equal to 2,000 and less than 5,000 mg/L, and 21% were greater than 5,000 mg/L. Sulfate concentrations were often a high proportion of total anions, and based on the available data, 12% were less than or equal to 200 mg/L, 68% were greater than 200 mg/L and less than or equal to 3,000 mg/L, and 20% were greater than 3,000 mg/L. Sodium Adsorption Ratio (SAR), which is only a parameter for Class II (agricultural) uses, was equal to or less than 8.0 in 55% of the samples, while 45% exceeded 8.0.

Table 2. Summary of the Wyoming DEQ Impoundment Monitoring Database - Basic Numbers, Types and Background Characteristics.

	Numbers	Percents
Date Range of Water Sample Data	11/3/2003 - 12/22/06	
Total Database Records (Rows)	1625	
Total Number of Impoundments (duplicates removed)	1106	
Off-Channel Sites ¹	148	13%
On-Channel Sites ¹	621	56%
Impoundments With Insufficient Information to be Categorized	343	31%
Total Number of Wells and Boreholes	1250	
Wells/Boreholes With "No Groundwater Encountered"	556	45%
Total Number of Monitoring Wells (duplicates removed)	874	
Alluvial Wells	82	7%
Bedrock Wells	577	46%
Wells for which Aquifer is Uncategorized	586	47%
Background Samples With Assigned Class of Use	445	
Class I Background Samples	3	0.7%
Class II Background Samples	1	0.2%
Class III Background Samples	267	60%
Class IV Background Samples	174	39%
All Background Samples For TDS	454	
TDS Background Samples <= 500 mg/L	19	4%
TDS Background Samples > 500 and <= 2,000 mg/L	150	33%
TDS Background Samples >2,000 and <= 5,000 mg/L	192	42%
TDS Background Samples > 5,000 mg/L	93	21%
All Background Samples For Sulfate (SO ₄)	454	
SO ₄ Background Samples <= 200 mg/L	53	12%
SO ₄ Background Samples > 200 and <= 3,000 mg/L	309	68%
SO ₄ Background Samples > 3,000 mg/L	92	20%
All Background Samples For SAR	426	
SAR Background Samples <= 8.0	233	55%
SAR Background Samples > 8.0	193	45%

¹ As defined in DEQ rules referenced above.

The database also contains results of compliance groundwater monitoring at impoundment sites. Of the 1,106 impoundments contained in the database, Wyoming Water Quality Rules and Regulations Chapter 3 construction permits were issued for 162. Compliance monitoring data are available for 77 of these. Many of the remaining impoundments have never been built or, if built, had not received produced water. Compliance monitoring is not required until discharge

begins. A total of 395 quarterly and monthly compliance samples were reported. The bulk of the compliance samples, 361, are at impoundments with Class III groundwater. A preliminary summary of the Class III compliance monitoring data is provided in Table 3.

Table 3. Summary of the Wyoming DEQ Impoundment Monitoring Database for Compliance Monitoring at Impoundments above Class III Groundwater.

	Numbers	Percents
Impoundments with Compliance Monitoring Permits	162	
Impoundments Submitting Compliance Monitoring Data	77	48%
Total number of Compliance Samples	395	
Quarterly Compliance Samples	243	62%
Monthly Compliance Samples	152	38%
All Class III Compliance Samples	361	
TDS Compliance Samples > 5,000 mg/L	12	3.4%
TDS Compliance Samples <= 2,000 mg/L	143	40%
Sulfate Compliance Samples > 3,000 mg/L	5	1.4%
Sulfate Compliance Samples <= 200 mg/L	25	7%
Arsenic Compliance Samples > 0.2 mg/L	2	0.6%
Selenium Compliance Samples > 0.05 mg/L	10	2.8%

Note: The available number of compliance samples varies for each chemical constituent.

The limited compliance monitoring data available through 2006 do not allow for definitive conclusions regarding the effects of impoundment seepage on shallow groundwater quality. Less than 10 impoundment sites had one year or more of monitoring data reported through 2006. The available compliance data indicate that relatively few sites so far have exceeded compliance parameters for class of use limits. Only 12 TDS samples at three impoundments (about 3%) of the total submitted exceeded the class of use limit and this was the most frequently exceeded class of use limit. Compliance monitoring found TDS levels of less than 2,000 mg/L in about 40% of samples, similar to the proportion in the background samples. There were 5 samples from 1 impoundment that exceeded the class of use limit for sulfate, while 10 samples from 4 impoundments exceeded the class of use limit for selenium. Continued monitoring showed that parameters which had exceeded class of use limits came back into compliance. Groundwater at all six of the impoundments that exceeded class of use limits at some point in time had fallen back below class of use limits as of January 2007.

This database will evolve and provide a valuable means of assessing effects of CBNG impoundments on shallow groundwater, and will also provide background information on the shallow groundwater resources of the Powder River Basin.

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