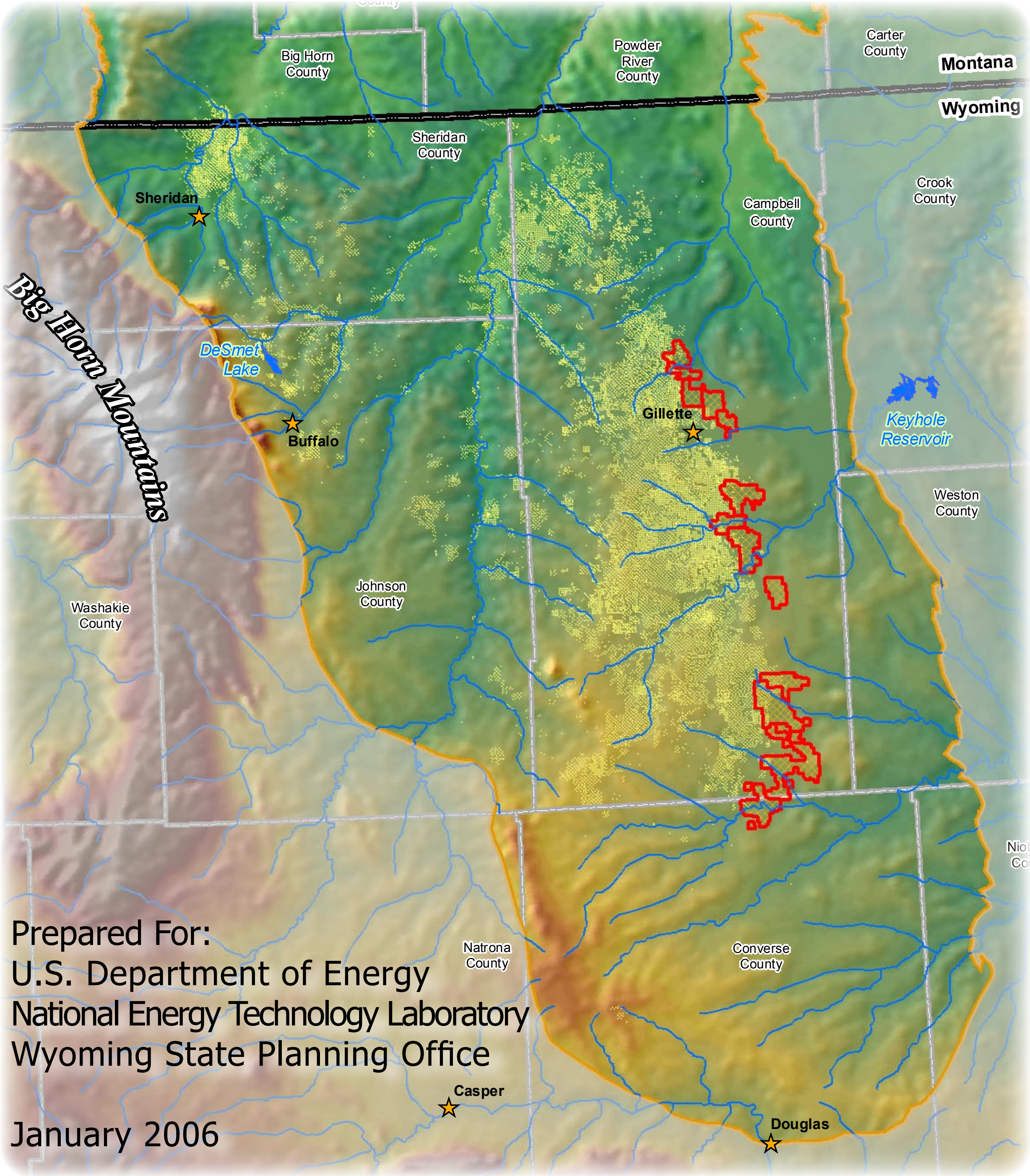
Feasibility Study of Expanded Coal Bed Natural Gas Produced Water Management Alternatives in the Wyoming Portion of the Powder River Basin
Phase One



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ACRONYMS AND ABBREVIATIONS

ASR	Aquifer Storage/Recovery
bls	Below Land Surface
bbl	Barrels
BCF	Billion Cubic Feet
bpd	Barrels per Day
bwpd	Barrels of Water Per Day
BER	Montana Board of Environmental Review
BLM	Bureau of Land Management
CBNG	Coal Bed Natural Gas
DOE	United States Department of Energy
EC	Electrical Conductivity
MBOGC	Montana Board of Oil & Gas Conservation
MDEQ	Montana Department of Environmental Quality
NPDES	National Pollution Discharge Elimination System
OTA	Office of Technology Assessment
ppm	Parts per Million
PRB	Powder River Basin
RMP	Resource Management Plan
SAR	Sodium Absorption Ratio
SDI	Subsurface Drip Irrigation
TCF	Trillion Cubic Feet
TDS	Total Dissolved Solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USGS	United States Geological Survey
µg/m3	Micrograms per cubic meter
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WSEO	Wyoming State Engineer’s Office
WWDC	Wyoming Water Development Commission

DISCLAIMER

This information is distributed solely for the purpose of technical peer review under applicable information quality guidelines. It has not been formally disseminated by the Department of Energy and should not be construed to represent any Agency determination or policy. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Department of Energy.

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I. INTRODUCTION AND BACKGROUND

The production of Coal Bed Natural Gas (CBNG) in the Powder River Basin (PRB) was initiated in the 1980s. Since its inception, the Wyoming Oil & Gas Conservation Commission (WOGCC) has issued more than 48,000 CBNG well permits; almost 24,000 CBNG wells have been drilled. Development in the State of Montana has been dramatically less due in large part to litigation from non-governmental organizations (NGOs) that have impeded development activities.

One of the primary issues involved in maintaining existing CBNG production operations as well as planning future production operations is water management. Unlike the majority of conventional natural gas wells, the highest level of water production for CBNG wells occurs as production is initiated. Initial production rates common to CBNG wells in the Wyoming portion of the PRB can range from 500 to 700 barrels of water per day (bwpd). Over time, water production rates decline and averages over the life of a well may be in the range of 2 to 5 gallons per minute (gpm), which is equivalent to approximately 34 to 85 bwpd, respectively. The combination of large numbers of wells and high initial water production rates has resulted in total annual water production rates of approximately 550 million barrels of produced water per year in Wyoming.

In addition to challenges associated with the overall volume of water produced, CBNG produced water has water quality characteristics that make managing the water challenging and complex. Although the quality of CBNG produced water is quite high, which further complicates the management of this resource, it may have a Sodium Adsorption Ratio (SAR) that could range from 5 to 60 and total dissolved solids (TDS) ranging from 500 to 3,500 mg/L depending on the area of the basin where the water is produced. The fact that the overall quality of the water is very high, typically meeting the majority of primary and secondary drinking water standards, has created a desire to beneficially use the water opposed to simply disposing of it as a waste. However, the specific characteristics common to CBNG produced water, such as SAR and TDS, have complicated management options and caused concerns by many area residents.

Since the inception of CBNG development in the PRB, water management strategies have evolved considerably. Today, CBNG projects commonly employ an array of water management strategies. These may include practices such as managed irrigation, aquifer storage/recovery, surface discharge, stock and wildlife watering, infiltration and storage impoundments, water treatment, and others (ALL, July 2003). The availability of what industry commonly refers to as a "tool box" of alternatives has been critical to the success of CBNG development to-date due to highly variable site-specific conditions and landowner requirements.

Further complicating the management of CBNG produced water in the PRB is the fact that many of the significant watersheds in the basin flow in a northerly direction and from Wyoming and into Montana. This is the case with some of the major watersheds where CBNG development is occurring, including the Tongue and Powder Rivers. In fact, much of the production from one of the most significant coal seams in the Wyoming portion of the basin, the Big George Coal, falls mainly within the Powder River Watershed.

In an effort to limit impacts to watersheds flowing into Montana, the States of Montana and Wyoming have taken considerable effort to work together and have generally agreed to manage CBNG produced water in such a fashion to avoid any significant changes in quality and quantity of the various applicable watersheds. More recently, the State of Montana has proposed new rules presently being considered by the Montana Department of Environmental Quality's (MDEQ's) Board of Environmental Review (BER) to further restrict discharges of CBNG produced water. These proposed rules would change the way CBNG produced water would be managed throughout the entire PRB. Two of the more significant proposed amendments include proposed rules II and VIII.

Proposed Rule II is a "zero discharge" requirement applicable to the Montana Pollutant Elimination Discharge System (MPDES) program. This proposed new rule requires that "*(1) except as provided in [New Rules III through IX], point-sources of methane wastewater shall achieve zero discharge of pollutants, which represents the minimum technology-based requirement. Zero discharge shall be accomplished by reinjection [sic] of methane wastewater into suitable geologic formations in the project area in compliance with all other applicable federal and state laws and regulations*." The rule does provide a means to obtain an exemption from the injection requirement, but timeframes to obtain an exemption may be greater than 12 months as the rule is currently proposed.

Proposed Rule VIII establishes "*treatment-based effluent limitations*" for CBNG produced water. The proposed rule requires that "*(1) If the department grants a waiver from the zero discharge requirement for all or a portion of the wastewater pursuant to [New Rules II and III], the amount of wastewater that obtains the waiver shall achieve the following minimum technology-based effluent limitations at the end of the pipe prior to discharge*:

(a) calcium average concentration between 0.1 mg/L and 0.2 mg/L;
(b) magnesium average concentration between 0.1 mg/L and 0.6 mg/L;
(c) sodium average concentration of 10 mg/L;
(d) bicarbonate average concentration of 30 mg/L and instantaneous maximum concentration of 115 mg/L;
(e) sodium adsorption ratio instantaneous maximum of 0.5;
(f) electrical conductivity average concentration of 233 µmhos/cm;
(g) total dissolved solids average concentration of 170 mg/L;
(h) ammonia average concentration of 0.1 mg/L and instantaneous maximum concentration of 0.3 mg/L; and
(i) arsenic concentration of <0.0001 mg/L."

Anticipated Impacts to CBNG Production: Based on ALL Consulting's experience with CBNG development in the PRB and input from the many contributors of this study, evaluation of the proposed amendments suggests that implementation of the new rules would significantly impede and/or likely cause the cessation of current and future CBNG development in the Wyoming portion of the PRB. The proposed rules would essentially preclude or severely limit any form of discharge into surface waters in Montana as well as waterways that flow into Montana from Wyoming. Because the discharge of CBNG produced water to surface streams and adjoining tributaries is a primary water management technique for CBNG production operations in the basin, the proposed rule would have a direct and significant impact to current and future development in Wyoming.

CBNG production projects require that water can be produced to the surface on an uninterrupted basis. To insure this possibility, CBNG developers typically employ a flexible plan that includes both primary and secondary water management alternatives. Many projects that do not exercise surface discharge as a primary management technique often rely on surface discharge as a critical backup to other water management practices such as managed irrigation, evaporation, industrial and municipal uses, and injection/re-injection. The availability of alternative (back-up) water management options is critical to the feasibility of other management techniques because without backups such as surface discharge, the CBNG project cannot sustain uninterrupted water production.

The proposed standards would also impact non-point source discharges from impoundments. A significant reduction or elimination of storage and infiltration impoundments would further reduce the options that CBNG developers have available for managing even the highest quality produced water from the basin. Typically, baring a few exceptional instances, alternatives other than surface discharge do not merit enough reliability or capacity to move forward with a large projects without having surface discharge as a backup. Indeed, eliminating impoundments would severely limit and possibly eliminate the feasibility of CBNG production throughout the majority of the basin.

Additionally, the proposed amendments would have a significant economic impact on the industry. Confining operators to a limited set of water management options would largely eliminate the possibility of production in areas that, for a variety of reasons, are incapable of irrigation, injection, or other use alternatives, therefore, reducing the amount of acreage available to operators for production. A decrease in available acreage would subsequently lead to a decrease in wells and overall resource production. Interest for development of infrastructure in the area could decline if there is not opportunity for significant production. This combination of events would likely either substantially reduce or result in the cessation of ongoing and future CBNG development in the Powder River Basin.

Economic impacts of any new regulations can be wide-ranging and profound. The Department of Energy has recently produced an economic analysis of the pending new standards (DOE, 2006). This analysis documents the impact of surface water standards of 1000 mg/L and 500 mg/L for TDS or discharges. Even these analyzed standards are not sufficiently restrictive to mirror the proposed MDEQ standards of 170 mg/L. The prospective standards used in the DOE analysis suggest that a valuable portion of the CBNG resource will be left in the ground of the Powder River Basin because of low profit margins caused by higher water management costs.

According to the United States Geological Survey (USGS), the PRB alone contains 16.5 trillion cubic feet (TCF) of untapped natural gas resources (USGS, 2002). Other estimates have supported even higher recoverable reserves, potentially of the magnitude of 25 to 30 TCF. To-date, less than 3 TCF of natural gas has been produced from the PRB based on production data maintained by the WOGCC and the Montana Board of Oil & Gas Conservation (MBOGC). Therefore, the new rules proposed by the State of Montana have the potential to impede approximately 13.5 to 27 TCF of natural gas from being produced from this region. Assuming a sales price of $10 per MCF, this would amount to approximately $135 billion to $270 billion being removed from the economies of Wyoming and Montana.

Implementing a zero discharge requirement would likely reduce production by 25 percent immediately upon enforcement of the rule. Within one year of implementation, production rates are expected to decrease by as much as 50 percent. Within five years production would likely decline by 90 percent, producing only 10 percent of what the region is capable and eliminating much (if not all) of the potential production in the region.

Purpose and Scope of Feasibility Study: Recognizing the significance of the proposed rule, the Governor of Wyoming and several state governmental agencies in Wyoming requested that the United States Department of Energy (DOE) fund and organize a multi-phased feasibility study to examine the technical and economic feasibility of a number of possible additional alternatives for handling Wyoming's CBNG produced water in the PRB. Given that the Montana rules may be passed early in 2006, the first phase of the feasibility study focuses on an array of short-term and long-term options. While it may happen that the proposed Montana standards are implemented early in 2006, both short-term and long-term options are needed to address existing and future production. At the same time, the feasibility report describes options that are able to manage large and small volumes of water because both are needed by the CBNG industry. Further, the study maintains a focus on alternatives that may have the greatest potential to support management of produced water from the Big George Coals, which produce some of the largest volumes of water in the basin. The second phase of the study will be developed once the first phase is completed.

As noted above, a primary focus of the study involves analysis of water management alternatives for the Big George coals. At the present stage of the development, many new wells from the Big George coal seam produce large volumes of lesser quality water. It is the Big George wells that would be impacted the most if new water regulations were issued by Montana. Following is the average daily water production data for Big George production by watershed:

Table 1: Big George Average 2005 Water Production by Watershed

Watershed	Total Water Produced (Bbls/Day)	Production Trend
Upper Tongue	0	
Middle Powder	130	
Little Powder	0	
Clear Creek	0	
Upper Powder	351,000	Still increasing
Crazy Woman	2,190	Peaked Oct 2004
Upper Belle Fourche	77,700	Peaked Dec 2002
Upper Cheyenne	200	
Antelope Creek	37,300	Peaked Dec 2004
Basin Total	**468,520**	

Water production from the Big George appears to be at a higher daily rate and its decline appears to be less than for other coals (Likwartz, 2005). The USGS has accumulated a set of over 50 samples of Big George water. While the range of EC values range from less than 1,000 to more than 4,000 µmhos/cm, the average is 2,759 µmhos/cm. SAR ranges from 7 to 45 with an overall average of 20.3 (Rice, 2005). In regards to volume, Big George production currently accounts for approximately 32 percent of the water produced every day by CBNG wells in the PRB. Considering the significance of the Big George coals relative to Wyoming's CBNG production in the PRB, the State of Wyoming requested that Big George production be prioritized in the first phase of the feasibility study. Therefore, considerable attention was paid to water management from these coals.

While the emphasis is on Big George coal reservoirs, other coal seams in the basin will also be affected by the proposed new regulations. For instance the Wall coal produces large volumes of water in the process of de-pressurization and because of that, operators are reluctant to begin producing the Wall (Searle, 2005). Locally, other coal seams may be particularly vulnerable to new, more restrictive surface water standards. These local coals, the Wall, and the Big George are all coals whose development could be drastically curtained or stopped by the adoption of the proposed Montana surface water standards.

II. FEASIBILITY ANALYSIS

Analyzing the feasibility of alternatives for managing produced water has been an ongoing activity of every CBNG developer in the PRB. Alternatives to managing water produced from CBNG development in the PRB was first documented as part of a DOE research project conducted by the Montana Board of Oil & Gas Conservation and ALL Consulting (ALL, 2002). In 2003, ALL Consulting completed a feasibility study of beneficial use alternatives for CBNG development in the western United States (ALL, July 2003). These studies documented how produced water is managed from CBNG activities in the PRB.

This feasibility study addresses a select set of potential water management alternatives, but does not necessarily address all of the existing techniques currently used. Rather, the study is focused on new or modified alternatives and alternatives specific to the Wyoming portion of the PRB. Alternatives analyzed in the study are listed below:

- Class V Injection into Shallow Sands
- High-Pressure Class V Injection
- Class V Re-Injection into Coal Seams
- Class IID Injection into Deep non-Underground Sources of Drinking Water Reservoirs
- Class IIR Injection into Secondary Recovery Projects
- Treatment and Discharge
- Dust Control and Other Process Water at Coal Mines
- Cooling Tower Water at Power Plants
- Subsurface Drip Irrigation
- Cattle Feedlots
- Public Water Supply
- Discharge to Public Reservoirs
- Coal Slurry Pipeline

In addition to the above alternatives, many of the contributors noted that large-scale pipelines would be needed for many of the alternatives considered. The concept of constructing large-scale pipelines to transport water from producing areas to water demand areas (e.g., coal mines, reservoirs, power plants, etc.) was not considered as a separate alternative, but specific consideration of large-scale pipelines may be further assessed in the second phase of the study.

The format of the feasibility analysis has been structured to address specific issues requested by the project Oversight Committee and the Department of Energy. Each of the alternative discussions includes the following general topics:

- General information specific to that alternative;
- A description of the alternative;
- Potential benefits of the alternative;
- Non-technical barriers to implementation (e.g., political/public perception);
- Technical and Economic feasibility;
- Environmental concerns;
- Potential volume capability; and
- Timing issues.

Methods used to complete this study were straightforward. The DOE established an Oversight Committee comprised of stakeholders throughout the state of Wyoming, with representation from the Wyoming Governor's Office, multiple state agencies, local governmental representatives, industry, and the DOE. The Oversight Committee provided input and direction to ALL Consulting for purposes of completing the study. A combination of Oversight Committee members and many other contributors provided input, data, historic information, and recent information pertaining to each of the alternatives evaluated. Industry contributors provided direct information on alternatives that had been attempted and/or considered. Other contributors, such as mining companies, were interviewed to further gage the feasibility of particular options. However, no bench scale or other physical testing was conducted as part of this feasibility study.

1. Class V Injection into Shallow Sands

Underground injection into shallow sand aquifer offers a potential means for managing some quantity of water produced from CBNG wells. This type of injection uses bore-holes drilled into shallow sands classified as Underground Sources of Drinking Water (USDWs) and then involves the pumping of the produced water into those aquifers. This particular option involves injection authorized by a Wyoming Department of Environmental Quality (WDEQ) Class V General CBNG Permit. Injection would be limited to permeable sands either between or below producing Fort Union coals. This would include Fort Union sands as well as Cretaceous sands below the Fort Union such as Fox Hills, Lance, etc. In the Powder River Basin, these Class V wells would be expected to extend from 500 feet to as much as 5,000 feet bls. Figure 1 is a map showing the location of existing Class V injection wells.

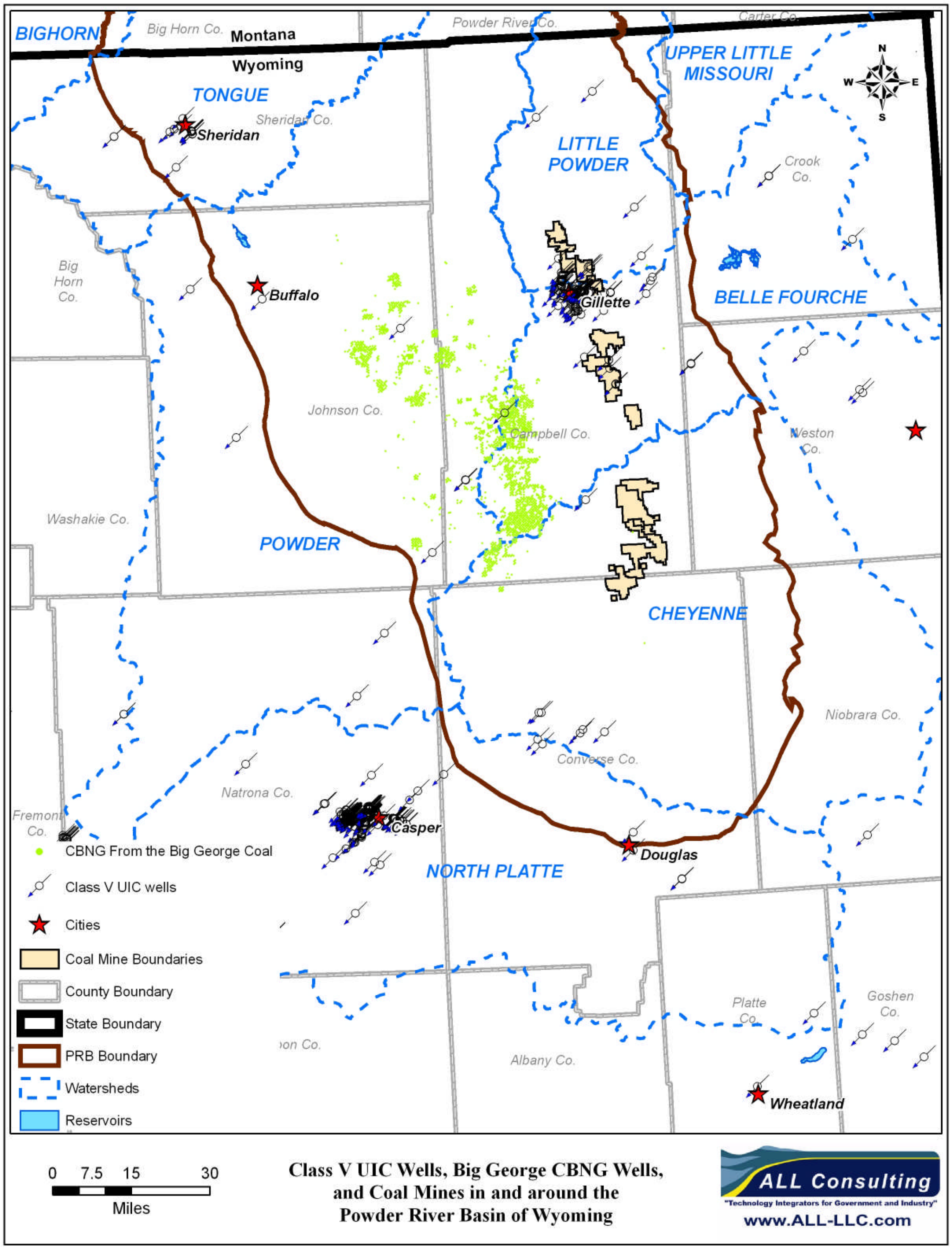
Description: Class V injection of CBNG produced water into a non-coal seam aquifer is a proven technology in the PRB, although its widespread use has not been demonstrated. The minimum requirements for a Class V injection well have been set by Volume 40 of the Code of Federal Regulations (40 CFR) Sections 144-147 and in Chapter 16 of the WDEQ Water Quality Division Rules and Regulations as promulgated within Wyoming Statute 35-11-101 through 1413. The Class V wells used to manage CBNG produced water are categorized as aquifer recharge wells and aquifer storage and recovery wells.

Class V shallow injection wells may be designed to place water into permeable aquifers that exist between coal seams or below them, as described below:

- **Coal Sequence Injection**: Many coal-bearing formations, like the Fort Union Formation in the PRB of Wyoming, contain multiple permeable sands that are hydrologically separated from adjacent zones by aquitards (De Lapp, 2005). In many areas, the CBNG-producing coal seams are interbedded with sand beds forming a series of discontinuous lenses of coal and sand within the predominantly claystone sequence. Despite the discontinuity of the coals and sands, sets of interbedded layers can be hydrologically separated by either clay/shale zones or other aquitards. Throughout the life of the producing field, the hydrologic separation must be continuous enough to prevent lateral recharge of the interbedded coal seams and stop injection from penetrating the confining formation. The sequence of interbedded formations provides an opportunity for various types of injection, potentially including disposal, aquifer storage/recovery, and possibly aquifer recharge.

Figure 1: Class V Injection Wells in the Powder River Basin

This map presets the location of Class V injection wells located within the boundaries of the Powder River Basin with respect to the location of Big George CBNG production.



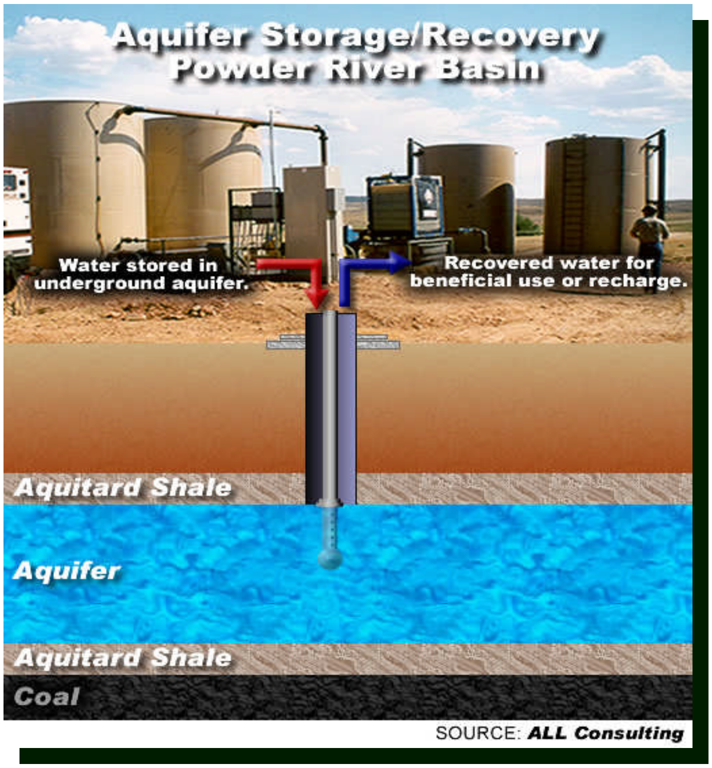
Sources: Wyoming Department of Environmental Quality, Wyoming Oil & Gas Conservation Commission, ALL Consulting (2005)

- **Non-Coal Sequence Injection**: The most commonly used injection alternative relative to CBNG production operations is disposal into formations that are well below coal deposits (Olson, 2005). The use of this type of injection technology is most common in areas where CBNG produced water is of poor quality and has little or no beneficial use. In these situations, injection into what are often deep underground aquifers may be the sole option for managing produced water. The actual type of injection alternative chosen will be dependant upon quality of the produced water and groundwater as well as any beneficial use.

If the desire is to beneficially use the injected water, options such as aquifer recharge or aquifer storage/recovery should be considered. Aquifer recharge could be considered to replenish depleted aquifers that may have experienced several years of pumping such as an aquifer used for domestic or municipal supply. Aquifer Storage/Recovery (ASR) wells as shown diagrammatically in Figure 2 below can be used to manage CBNG produced water. ASR is the process of injecting water into an aquifer for storage and subsequent recovery for beneficial use, using the same well. Beneficial uses include, but are not limited to, public drinking water, agricultural uses, future recharge, and industrial uses. The storage aquifers may be the primary drinking water source for a region, a secondary drinking water source, or may be used for agricultural or industrial purposes. ASR is regularly used in areas with no drinking water source, areas undergoing seasonal depletions, and in areas where salt water is intruding into the fresh water aquifer (EPA, 1999). When injection is considered using Class V type wells for beneficial uses, pre-treatment of the produced water may be required before it is injected into an aquifer for either recharge or ASR. For example, treatment of water may be required to prevent the injection of bacteria contaminated water when the water has been temporarily stored in an impoundment. Water may also need to be treated before injection to insure that it meets water quality constraints that may be part of a WDEQ permit or otherwise required by a water user. Treatment of the water is dependant upon the quality of the water, the proposed use of the water, and the storage history of the water, if any.

Figure 2: Typical ASR Well

This figure shows a typical well configuration of a Class V ASR well in the Powder River Basin of Wyoming.



SOURCE: ***ALL Consulting***

Potential Benefits: These shallow Class V wells often make use of non-productive CBNG wells and are, therefore, available to the operator at low cost or no cost. The wells can be located nearby the producing wells so that pipeline costs can be low. Produced water injected into these wells is preserved for future beneficial use. The water injected into a shallow aquifer may well be the same quality and will retain the same potential beneficial uses as when the water is produced. Depending on whether the disposal zone is in between coal seams or beneath the coals, the injected water will be able to be produced by wells of the same depths or somewhat deeper water wells as ranchers are used to drilling in the area. Injection zone depth will determine whether or not local agricultural users will be able to tap this water after it is injected. If the CBNG project produces water from coal seams between 500 to 2,000 feet below the surface, injection into sands between those coals will allow ranchers to access this water in a customary and economical manner. But if that water is injected into Cretaceous sands between 4,000 and 5,000 feet below the surface, local ranchers may not be able to install supply wells that are in any way economical.

Non-Technical Barriers to Implementation: Owners of local water wells and springs may protest permits. Nearby CBNG producers may oppose installation of injection wells in close proximity to producing coals. The WDEQ provides public notice for all Class V permit applications and places notice in newspapers of general circulation. Any citizen is free to protest an application. If a protest is submitted, a public hearing is then scheduled for all parties to present their technical merits (Passehl, 2005). The WDEQ will then decide what action to take relative to the permit based on the merits of the application. Opponents have the ability to delay applications by way of protests, appeals, and lawsuits. The resultant delays could even have the effect of killing a CBNG project (De Lapp, 2005). It might also be expected that public opinion would generally look favorably on Class V injection into shallow sands because the water resource is being preserved and the water is not threatening the surface environment (Williams, 2005).

Technical Feasibility: Technical feasibility of Class V injection into shallow sands will depend on the ability of the sands to accept water at a rate commensurate with the well's cost. Within the PRB, approximately 150 Class V injection permits have been issued for CBNG water injection (an unknown number of wells were actually drilled). Thirty three (33) wells were completed in shallow sands and used at least once while nine (9) wells were completed in shallow coals (the coal wells will be discussed under another option) (Likwartz, 2005). Of these wells, 16 were listed as successful by the operator and were used for up to three years. Of the 150 permits, 42 (approximately 25 percent) were completed, and 16 (approximately 10 percent) were considered successful.

Of the limited number of successful tests, perhaps the most prominent was the somewhat unusual situation of injecting produced water to recharge a depleted municipal water supply source. In this case, the City of Gillette, Wyoming's well field had been locally depleted. The well field was completed in Lower Fort Union sands at a depth of approximately 1,500 feet. These sands had been pumped for a number of years to supply water for the public use and consumption. Over time, water levels in the City's wells had decreased considerably. The City coordinated with a CBNG operator to install Class V aquifer recharge wells that were sufficient to manage all of the produced water from a small, CBNG producing project. In this example, the best injection well averaged over one million barrels per year for over three years (Olson, 2005). Although this example is unique, it does illustrate the potential capability of Class V shallow injection wells.

Feasibility of underground injection as a tool for managing produced water involves several technical considerations including geologic, economic, and engineering questions. These may vary significantly by operator and location. There are, however, a common set of questions that must be answered for any proposed injection well, including:

- **Formation Suitability**: Selection of a suitable injection zone may potentially include reservoir characteristics, depth, relative location to producing wells and locally important aquifers, significance of local fracturing and faulting, condition of active and abandoned wells within the area, as well as other artificial penetrations.

- **Isolation**: The receiving formation must be vertically and laterally separated or otherwise confined from other USDWs. The well must also be equipped to isolate the receiving zone from other porous zones in the well to avoid unauthorized fluid movement into zones that are not permitted for injection.

- **Porosity**: Porosity is the percentage of void spaces or openings in a consolidated or unconsolidated material (EPA, 1999). Reservoir rocks are typically high in porosity, while confining zone rocks range from high to very low porosity.

- **Permeability**: Permeability is defined as a measure of the relative ease with which a porous medium can transmit a liquid under a potential gradient (EPA, 1999). A reservoir rock will have sufficiently high permeability to allow fluid movement. Confining zone rocks will have very low permeability and will act as seals rather than zones of fluid movement. Often porosity and permeability are not correlative; highly porous sands can have very low permeability while low porosity sands can be highly permeable due to natural fractures.

- **Storage Capacity**: The storage capacity of a geologic unit can be estimated using a simplistic approach by estimating the pore volume of the entire injection zone.

- **Reservoir Pressure**: The reservoir pressure is the static pressure within the receiving formation expressed either as psi or fluid head. Reservoir pressure may limit the rate at which fluids can be injected and/or may limit the total volume of fluid that can be injected.

- **Water Quality**: The quality and chemistry of water of the injectate, and water within the receiving formation will determine the type of injection well to be used. The chemical compatibility of their fluids will also play a part in the feasibility assessment of the injection plan.

The most common problem for Class V shallow injection wells appears to be the loss of permeability over time. Permeability losses could be caused by plugging of reservoir pores with fines suspended in the water or by clay swelling (Olson, 2005). These problems are common to all types of injection wells that require careful pre-injection tests to determine the vulnerability of the aquifer’s rock-frame to plugging by fines and to chemical effects. Injection testing may involve either full-hole or sidewall cores through the aquifer and lab tests of pore-throat sizes and water-rock compatibility analysis. Tests may be necessary on each injection well due to aquifer variations and other issues that have the potential to negatively impact placing water underground.

Wyoming Class V regulatory issues are straightforward. The general Class V Permits, currently in place in Wyoming, provide a mechanism for Class V injection activities as presented below:

- Class V shallow injection wells may inject all CBNG produced water, but not drilling fluids, spent oilfield chemicals, other industrial wastes, or hazardous wastes in any quantity;

- Class V shallow injection wells may inject any volume of water as long as the pressure of injection is controlled to prevent the receiving formation from fracturing. The volume of water injected and the maximum daily injection volume must be reported when applying for coverage under a permit;

- To obtain a permit, the operator must fully characterize the class of use of the receiving aquifer's water and the CBNG water to be injected. No CBNG produced water may be injected into an aquifer with a better classification than the produced water;

- Class V injection wells may be constructed to allow injection of CBNG produced water into an aquifer with Class I, II, III, IV(a), and IV(b) groundwater as long as the baseline class of use of the receiving aquifer will not be degraded by the injection; and

- The operator is required to maintain and operate the subject injection well(s) in a manner that is compliant with the standards for the permit. If for any reason, injection activities violate groundwater standards, injection is not allowed under individual permit, the general permit, or any form of rule authorization.

In addition to the General Permits, CBNG operators can make application for individual injection well permits.

Economic Feasibility: The economics of Class V shallow injection wells will depend on the amount of water that each well can manage in an environmentally conservative manner, the cost of drilling and completing the well, the costs of drilling non-successful injection wells, and the operating costs of the well. Historical PRB per barrel costs for Class V shallow injection wells are extremely variable from less than $0.10/bbl to over $5.00/bbl as reported by operators (Likwartz, 2005). Costs may include capital expenses of the well and surface equipment, which may exceed $100,000. In addition, costs for electricity or natural gas to pump the water, operating expenses, monitoring and reporting expenses, and permitting expenses must also be accounted for. In the Wyoming portion of the PRB, only 25 percent of the Class V shallow injection wells drilled were able to be used for injection. This meager success rate means that for each Class V shallow injection well, as many as four (4) bore-holes may need to be drilled and tested.

The relatively low success rate for Class V shallow injection wells combined with the relative minimal volume that an individual well commonly has the capacity to accept severely limits this alternative for use in managing CBNG produced water in the PRB. However, this alternative is still experimental in nature and future feasibility and use of this technology may improve.

Environmental Concerns: All injection wells share common concerns of pipeline integrity, surface equipment integrity, and mechanical integrity of the borehole. These mechanical faults could lead to surface releases as well as shallow releases into alluvial aquifers. The mechanical aspects of Class V shallow injection wells is generally inspected before the well can be used and the WDEQ permit requires periodic reporting and inspections after the beginning of injection.

The additional concern of subsurface migration of injectate out of the injection zone is also present. If the injection zone is between coal seams, nearby producing CBNG wells may serve as monitoring wells.

If the injection zone is beneath the Fort Union coals, subsurface migration is less of a concern since the sands are usually separated by thick impermeable shales.

Potential Volume Capability: Shallow Class V injection wells in the Wyoming portion of the PRB have a history of accepting between 500 and 4,000 bpd of produced water (Likwartz, 2005). For perspective, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George. Therefore, between 30 and 150 successful Class V shallow injection wells would be needed to meet the demands of the project. Considering the current success rate of 25 percent, the operator may need to drill 120 to 600 bore-holes in order to achieve the necessary number of successful Class V shallow injectors and have sufficient capacity to manage all the water produced from a single Big George CBNG project.

Timing Issues: Key issues that impact the timing of Class V shallow injection wells include completion of the permitting process, drilling, completing, and hook-up of wells for use. Permitting timeframes have been streamlined as a result of the WDEQ's decision to issue general permits for Class V injection wells. However, the current low success rate of wells poses a significant challenge to timing as well as the high variability in injection capacities of individual wells.

2. High-Pressure Class V Injection

Injection into shallow sands is frequently unsuccessful; historically only 25% of the wells are successful as injection wells. Injection success can be greatly enhanced by the use of high pressure injection (De Lapp, 2005). High pressure Class V injection wells will use pressures in excess of the pressures allowed under the WDEQ General Permit forms. High pressure Class V injection wells could employ continuous injection over the local fracture pressure; these wells would inject water into the pore space of shallow sands and into fractures created and maintained by the high pressures. The injection targets would be the same as those sands described for Class V shallow injection wells (above). The local fracture pressure will be tested as described above and injection maintained above the point of fracturing.

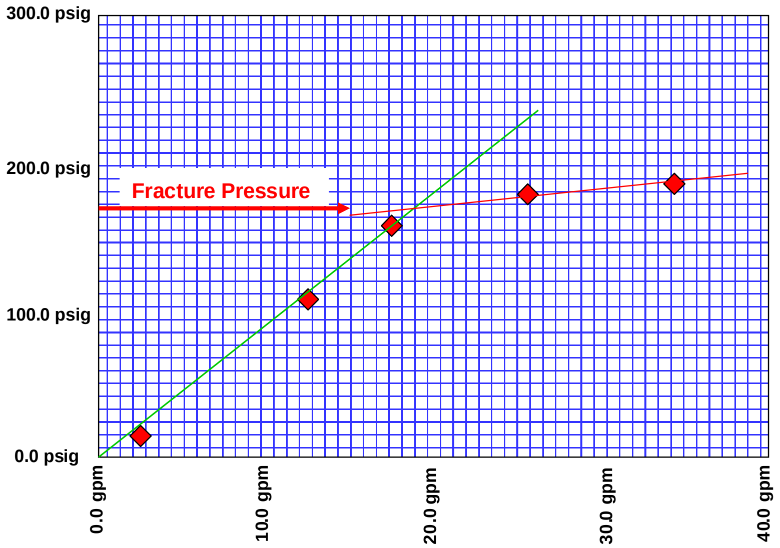
Currently, there are no high-pressure Class V injection wells permitted in the Wyoming PRB. Based on discussions with WDEQ, these wells would require an individual well permit and would be unable to use the General Permits that are in-place for Class V shallow injection. Since this is a new concept, the WDEQ would also need to be convinced that the wells would not degrade other aquifers (Wagner, 2005).

Description: In the conventional oil and gas industry, Class II disposal wells can be used to inject produced water or other liquid wastes into poor quality reservoirs at pressures over the fracture gradient. In this way, the reservoirs will gain new volume that, because it did not previously exist, does not contain formation water and is available for injection. Figure 3 below illustrates the results of a step-rate injection test into a single reservoir. In this case, the operator established five injection rates; the chart records those rates and the surface pressures necessary to maintain those particular rates. The lower pressure portion of the chart establishes the injection gradient utilizing existing pores in the rock. The fracture pressure is the point at which fractures open in the rock and much more fluid can be injected at very little increase in pressure; this is the region of high-pressure injection. In Figure 3 these pressures are shown in terms of surface pressures. The initial pressure at no injection is the original pressure of the aquifer and in this case assumed to be base hydrostatic pressure of the aquifer. This pressure will need to be added to the fracture pressure to express it as a formation (bottom-hole) pressure.

High-pressure Class V injection may occur under several scenarios. Low quality sands may accept several hundred barrels per day of CBNG water at an injection pressure below the point of fracture, but that same sand may accept much more water at high injection pressures. This has been the experience of several operators in the PRB who have used step-rate injection to test Fort Union sands. Another possible scenario is the injection of CBNG water into claystones separated from producing coal seams. Injection over their fracture pressure may allow the operator to dispose of large volumes of water into these claystones. The operator would need to insure that fractures and water would be confined to the claystone but the water would still be available for future uses.

Being able to inject over fracture pressure could result in more aquifers capable of accepting large amounts of injected water. The technique might be able to allow more operators to use Class V injection as a tool for CBNG produced water management.

Figure 3: Step-Rate Injection Test and Fracture Pressure



Potential Benefits: The benefits of high pressure injection include preserving the water resource for future uses and converting poor shallow sand aquifers into capable aquifers that are charged with useable water ready to be tapped by local ranchers and farmers. The chief benefit of this management option is its universality. In theory, the option does not depend on the presence of a highly permeable or depleted aquifer. Although this alternative has not been tested, it theoretically should increase the success rate of wells drilled for injection purposes. This would result in less surface impacts and lesser overall costs than the previous alternative.

Non-Technical Barriers to Implementation: Owners of local water wells and springs may be concerned about the integrity of these sources of water and may protest permit applications. Nearby CBNG producers may also oppose high pressure injection in close horizontal and vertical proximity to their producing coal seams. The fact that no Class V wells in the PRB currently operate over the fracture pressure makes it seem somewhat risky both to regulators, industry and the general public. It can be assumed that the political risks of this management option are somewhat higher than the preceding option of Class V shallow injection under the existing General Permit (Wagner, 2005).

In addition, this practice would require that wells be "hydraulically fractured." The issue of hydraulic fracturing on CBNG wells has been the subject of litigation in Alabama where the practice was believed to be responsible for shallow water well contamination. Overcoming the hydraulic fracturing issue would be considerable and would likely need to be accounted for if this alternative is pursued.

Technical Feasibility: There are currently no Class V wells injecting over the local fracture pressure in the PRB. Several wells have tested the local fracture pressure and measured injection rates in the fracture injection region of the test. Two recent J.M. Huber wells tested the Upper Fort Union sands and experienced injection rates of 1,500 bpd when injecting at low pressures of approximately 200 psig and injection rates over 8,500 bpd while injecting at high pressures of approximately 400 psig (De Lapp, 2005).

As noted above, hydraulic fracturing would likely be a major non-technical and technical feasibility consideration. The major concern for hydraulic fracturing and high-pressure practices is fracture propagation, which could cause uncontrolled water migration. Considering there is an overall lack of data or long-term tests for these types of wells, significant research and testing would be needed to further prove this practice as a feasible alternative.

Economic Feasibility: The economics of high pressure injection have the potential to be more economically attractive than low pressure shallow Class V injection. High-pressure injectors share approximately the same costs as low pressure wells but may have the ability to manage and inject several times more water than low pressure wells. Indeed, costs can be expected to be less if a greater percentage of the wells are successful under high-pressure conditions. However, the practice has not been tested and no economic data exists at the present time.

Environmental Concerns: Perhaps the most significant environmental concern related to this alternative would be uncontrolled migration of injected fluids caused by hydraulic fracturing. Fractures generated by the high injection pressures may be expected to be propagated in a horizontal direction, but there is potential for fractures to be propagated in a vertical direction. If vertical fractures were to occur, these fractures could function as conduits for the injectate to reach aquifers not permitted for injection. Although vertical fractures would not be expected in this area, the practice would need to be proved to be environmentally protective before large-scale use would be allowed.

Potential Volume Capability: High-pressure injection wells may be able to handle several times the water capacity of low pressure Class V wells. Without historical injection data, however, any volumetric estimate would be pure speculation. However, based on discussions with industry representatives, individual well rates could be expected to range from 8,000 to 15,000 bwpd. Further, this type of injection procedure could have a much broader potential use throughout the basin. Of course, actual testing will be required to demonstrate the true feasibility of this alternative.

Timing Issues: The first challenge related to timing for this alternative would be permitting the wells with the WDEQ. Based on discussions with WDEQ and industry, a testing period for a smaller number of wells should be expected before large-scale use would be practical. Therefore, a period of a year or more may be required for testing after which larger scale use could be done, assuming the alterative proves to be feasible. That fact that this alternative is experimental makes it difficult to assess timing for implementation.

3. Class V Re-Injection into Coal Seams

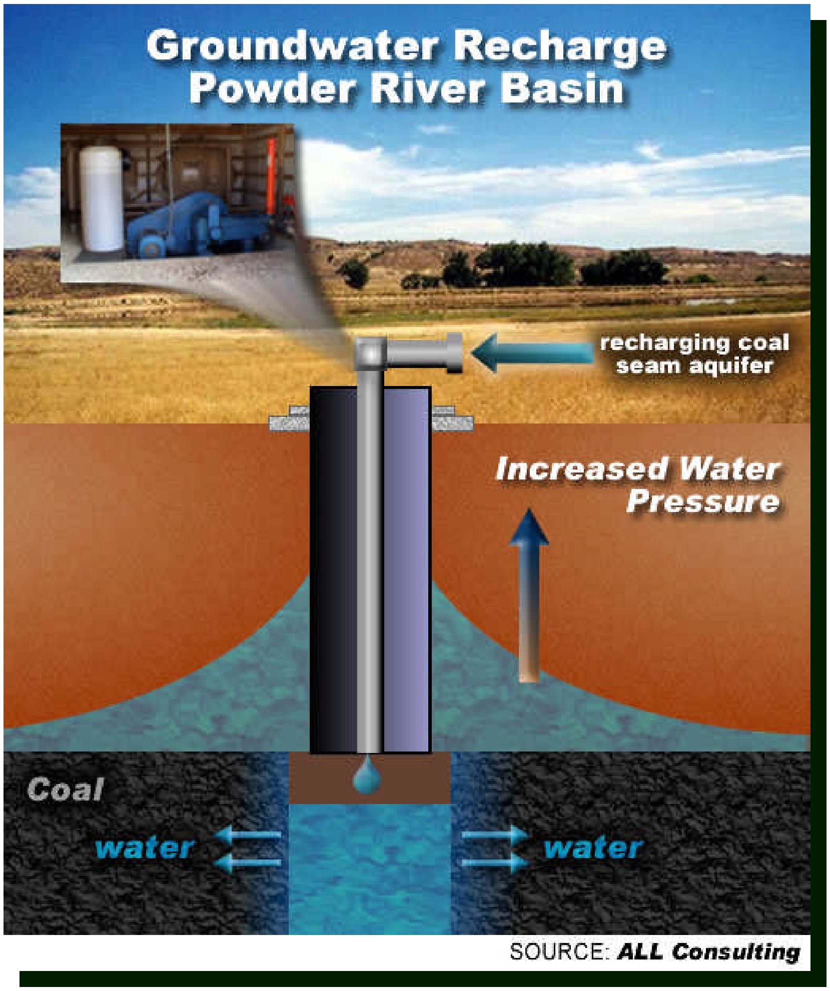
This alternative includes the option of re-injecting CBNG produced water into an underground coal seam. To date in the PRB, coal seam re-injection is not a utilized practice anywhere in the basin. However, the alternative has been tested, although on a very limited basis.

Description: Coal seams serve as water supply aquifers throughout many areas of the PRB. In fact, in some areas coal seams offer the best overall quality and quantity of water for use. Many of the shallow coals in the basin are unconfined and open to the surface, often via clinker zones. Under unconfined conditions, the coal seams are usually not productive of CBNG since the gas has long since seeped out into the atmosphere. Coals can also be present as confined aquifers isolated from the surface by largely impermeable claystones. Confined coals are often productive of water and CBNG. When economic amounts of gas no longer can be produced from these coals, they are economically depleted. Such a coal will usually produce water that will migrate to the well bore by way of lateral recharge. Injection may be possible into non-productive coals as well as depleted coals but each has their own drawbacks and barriers to use.

Figure 4 illustrates a basic Class V coal seam aquifer recharge injection well. Injection into a coal seam could be done using existing CBNG wells after depletion or by drilling new injection wells into non-productive coals.

Non-productive coals are non-productive because the methane has either never generated or has leaked off. If it has leaked off, then the coal seam is an unconfined aquifer whose fluids can reach the surface and discharge onto the surface although the time required to do so may be a few days or many hundreds of years. An unconfined aquifer may be an unsuitable injection zone as the water could be discharged onto the surface and not safely stored underground.

Figure 4: Class V Coal Seam Re-Injection Well



SOURCE: ***ALL Consulting***

A depleted coal seam well may have been produced for a number of months or years and no longer produces CBNG in paying quantities. Such a well probably has a lower reservoir pressure than when the well began producing. If the reservoir pressure has been reduced, the reservoir may be able to accept large volumes of fluid at relatively low injection pressures. It has been reported, however, that methane productive coals irrevocably compact as they are produced. Mazumder et al. (2003) observed permeability reduction by a factor as high as 600 during production. Permeability was largely reduced by the compaction of cleat porosity due to stress changes within the rock-frame, creep effects in the reservoir, and hysteresis. If the coal seam is an injection target, the reduced permeability and porosity during compaction have the tendency to increase injection pressure and decrease injection rate. It is unknown whether these compaction effects will occur to the same degree in PRB coals but if they do, these factors would severely limit the usefulness of depleted coal seams as injection zones.

A coal seam that is depleted in one well or one project may still be productive in an adjacent CBNG project. If an operator applies for a Class V injection permit in a depleted well, an offsetting operator may protest this application with the argument that any injection by the other operator will retard adjacent production, thereby reducing the mineral estate under lease. If the adjacent minerals are not leased, the mineral owner would have the same opportunity to protest the Class V injection well application. It would be difficult to determine the distance beyond which an offset mineral owner's protests would not be legitimate. Even if an arbitrary distance were named, it might not be meaningful if directional joints and fractures could be identified in the vicinity by the protesting operator. The opportunity for offset operators to protest virtually any re-injection application makes this option a high risk alternative (Likwartz, 2005).

Potential Benefits: Coal seams are frequently utilized for drinking water and livestock watering supplies. As such, their use as injection zones could be used to preserve the water for important future beneficial uses. When CBNG produced water is injected into coal seams, the water quality of both is often so similar as to be indistinguishable, assuring that the water will not be wasted. Shut-in CBNG wells might be used as injection wells to save on drilling and completing costs.

Non-Technical Barriers to Implementation: The greatest potential barriers to using re-injection in coal seams are the protests made by offsetting mineral owners and CBNG producers as well as poorly known impacts to the coal resource (Likwartz, 2005). Coal seam re-injection could impact offsetting minerals, delaying or preventing the economic production of natural gas. Class V WDEQ permit applications require public notice and allow for comment and public protest. Protests, hearings, appeals, and subsequent lawsuits will delay permits. Protests that cite the potential for damage to offsetting correlative mineral rights are very powerful arguments for denying injection permits. An outstanding protest from a nearby mineral owner or operator will almost certainly condemn the application. Because of this, successful injection applications will need to be well separated from active CBNG production from the same coals seam. In practical terms, this probably means that operators will be forced to choose injection zones that are non-productive.

In addition, re-injection of water into depleted coals may result in the possible destruction of certain aspects of the coal resource including un-produced methane reserves and in situ bacteria that may be the source of the bulk of the CBNG resource in the basin. When CBNG is produced in the PRB, water is pumped off that allows the natural gas to desorb and come to the surface. Unlike conventional natural gas resources, CBNG operations are estimated to only produce approximately 50 percent of the gas-in-place, leaving the rest still adsorbed to the coal micro-surfaces and dissolved in the pore water. If depleted coals are re-saturated by way of re-injection, those coals will likely never be produced because of poor economics.

Microbes may be present in the coal pore water; these microbes are perhaps responsible for a majority of the CBNG resource in the basin. That is, the natural gas is formed as a byproduct of microbial activity, not thermal cracking of organic material in the rock. Research is yet to reach an answer, but it is possible that the in situ biota might be able to restore the CBNG resource in a reasonable, human-scale timeframe. And, it is probable that re-injected produced water would exterminate the in situ micro-biota. Injectate destined to be pumped into a source of drinking water such as a coal seam must be disinfected so that microbes do not enter the injection zone. Microbes would not only become a potential source of contamination, but would also potentially proliferate to such an extent that they foul the pores of the aquifer and the perforations in the injection well bore. Disinfection is usually accomplished by chlorine treatments, which could carry over into the injection zone aquifer. The loss of this aspect of the coal resource is of unknown importance.

Technical Feasibility: At the present time, there appear to be no wells actively injecting into coals. There are records of at least nine wells that historically injected into shallow non-productive coals. These wells gave varying results from less than 100 bpd to over 2,000 bpd. The receiving coals ranged from 45 to 400 feet bls. There are no records of operators attempting to inject into depleted coal seams (Likwartz, 2005).

Technical parameters will help determine the permitability of injection into coals, including porosity, permeability and injectivity. PRB coals are well known for their high permeability. PRB coals are typically able to produce water at rates ranging from 500 to 1,000 bwpd during the initial phase of production. Permeability in any coal seam is a function of its pore system, local fractures, and its cleat system. Cleat is the largest factor in this equation; cleat is the system of fine-scale fractures that are present throughout the coal seam. Cleat is largely a product of very early de-watering shrinkage of the coal as it is transformed from peat to lignite to bituminous coal. Cleat contains water throughout and it is this water that migrates to the producing well bore. But as this cleat system is de-pressurized, some of the natural gas desorbs from the microscopic coal surfaces and comes out of solution from the remaining cleat-water and pore water. And as more water is pumped out of the coal seam, the cleat system collapses and the coal loses permeability. As seen by researchers (Mazumder et al, 2003), this permeability cannot be restored; therefore, the coal can only accept a small portion of the water withdrawn from it during the production phase. Other researchers (Wolf et al, 2001) have found that injection of CO_2 and N_2 during the phase of de-pressurization has the ability to prop open the cleat system while it displaces natural gas from the micro-surfaces of the coal. CO_2 and N_2 injection has not been attempted in the PRB.

The loss of cleat permeability is a very important factor for predicting injectivity of depleted CBNG coals but it appears to be less important for non-productive, unconfined coals. Shallow unconfined coals do not contain natural gas but do contain water in their pore space and cleat. It appears that shallow non-productive coals may also have higher porosity within their matrix and cleat systems. In addition to coal, these aquifers often contain clinker beds – coals and adjacent claystones that have been baked by internal heat of oxidation – that have high permeabilities so that these shallow sedimentary packages have the ability to transfer large quantities of water (Wheaton, 2003).

Permeability needs to be carefully determined for any prospective coal injection zone. The measurements need to be done on the depleted coal, not the productive coal seam which may still have its native cleat system intact. The most reliable test would be a pump-test on the prospective coal aquifer to determine permeability and damage near the borehole. Such a test or set of several tests would be more accurate than a core and much less expensive. The pump-test would include a step-rate injection test and a pressure fall-off to determine the ability of the coal to take water and the determination of the fracture pressure.

Regulatory implications of geotechnical factors include connectivity to nearby productive coals and to nearby conduits to the surface. These aspects of a given non-productive or depleted coal seam can be very problematic; it may not be possible to prove connection or isolation of a proposed injection well except over an extended period of time. A 24-hour injection test might show no connection to a producing well or surface spring but in 30 days a connection may be obvious. Designing a relevant and meaningful injection test that will satisfy the regulatory agency may be difficult to arrange.

Economic Feasibility: Capital costs of these injection wells are expected to be quite low, assuming that shut-in CBNG wells will be utilized for the injectors. Average injectivity values are difficult to predict as the historical range is from less than 100 to more than 2,000 bpd. Economics of this option for managing produced water is difficult to predict, but may be in the range of costs for shallow Class V injection which is estimated to be from $0.10 to more than $5.00 per bbl. The cost of transportation of produced water to the depleted coals may be considerable since any depleted coals will be located many miles to the east of the Big George production.

Environmental Concerns: Besides the minor environmental risks of surface water handling facilities, the most significant environmental issue is probably risk of breakout of the water to the surface in nearby springs and under nearby streams or rivers (Wagner, 2005). With the widespread distribution of clinker beds in the basin, water injected into shallow, non-productive coals could migrate long distances within a clinker bed where it could surface in a spring at an outcrop. If enough water migrates to the outcrop, the volume of the spring may be large enough to cause erosion and impacts to local plant communities. In addition to the physical impact of increased spring flow, the migrating injected water could pick up additional dissolved salts as the water passes through various soils and bedrock units. The leaching of salts may result in a high TDS burden when the water exits as a spring. At other locations in the basin, the coal seam may outcrop under a stream or river that may not be apparent or easy to identify. Private citizens or state agencies may be concerned that re-injection into shallow, non-productive coals may represent an unacceptable risk to surface water resources.

Potential Volume Capability: Successful re-injection wells into coal seams are able to accept between 100 and 2,000 bpd while an unknown number of unsuccessful wells take little or no water. For perspective, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George; therefore, if the operator were to depend upon Class V coal seam re-injection, between 75 and 1500 wells or more would be needed.

Timing Issues: While converting shut-in producing wells to injectors will take little time to accomplish, permitting will likely be time consuming because of protests and appeals. It could be estimated that the regulatory problems associated with this management option will be in excess of high-pressure Class V injection discussed above.

4. Class IID Injection into Deep Non-USDW Reservoirs

Class II injections wells that would be typically used for conventional oil & gas operations have the potential to be used for CBNG water disposal. Deep injection wells used for disposal below any USDW are classified by the EPA as Class II wells. Class II injection wells are subdivided as either IID (for disposal) or IIR (for secondary oil recovery).

Descriptions: Class IID permits may be issued for injection into underground reservoirs that are greater than 10,000 mg/L TDS or are an exempted aquifer. Many of the deep aquifers that could be suitable for injection contain less than 10,000 mg/L TDS and would require an aquifer exemption in order to receive a permit. Aquifer exemptions are written in federal EPA regulations and are meant to avoid giving full protection to low quality aquifers that will never be used for public water supply because of the cost of producing and treating the water. It would be risky to put a depth limit or water quality limit on an aquifer before it might qualify for an aquifer exemption; if the aquifer is deeper than 10,000 feet, it is unlikely that it would be an economic source of drinking water for a public water supply. Likewise, an aquifer with over 10 ppm oil and grease or over 5,000 mg/L TDS would be difficult to describe as a source of drinking water (WDEQ, 2005). In the Wyoming portion of the PRB, this might include the Dakota, Lakota, Minnelusa, and Madison Formations. In practical terms, however, this probably only applies to the Madison that might qualify as an exempted aquifer capable of accepting large volumes of CBNG produced water.

The Madison Formation is a thick carbonate with vuggy porosity underlying much of the PRB. The depth to the top of the formation ranges from approximately 8,000 feet at the edges of the basin to more than 14,000 feet at the basin axis. The formation is charged with largely fresh, meteoric recharge water taken up from outcrops at the edge of the basin in the Big Horn Mountains to the west and the Black Hills to the east.

Potential Benefits: These deep Class IID wells are generally expected by industry to be able to inject large volumes of water in an environmentally safe an unobtrusive manner. These injection zones can be very deep and isolated by thick, impermeable confining zones safely confining the injectate away from drinking water aquifers. Wells will be inherently safe, thus providing minimal environmental concerns.

Non-Technical Barriers to Implementation: As with many other water management options, possible protests could prevent widespread use. Citizens may protest the disposal of CBNG water if the water is perceived to have a valuable beneficial use. The WOGCC has recently issued a permit for the disposal of low quality CBNG water, but higher quality produced water may receive more protests. It will be the responsibility of the operator to demonstrate that the produced water has no beneficial uses without treatment.

Technical Feasibility: There is currently one Class II permit for deep injection of CBNG produced water in the PRB. This well's operator is Yates Petroleum and the well is 14,000 feet deep, completed into the Madison Formation, and contains water in excess of 5,000 mg/L TDS. This well has recently been drilled/completed and testing is being done at the present time (George, 2005). A deep permit has been issued to Anadarko Petroleum for several Madison injection wells in the old Salt Creek oilfield. The Madison aquifer in the Anadarko project contains water with TDS less than 5,000 mg/L; therefore, the permit is for Class V injection

(Cline, 2005). The Anadarko wells are injecting over 50,000 bpd into highly fractured and faulted Madison carbonates, a vastly permeable, depleted aquifer that has been a source of water-flood water in this field (Cline, 2005). The Yates well is not on a similar structure and will not, therefore, take advantage of the concentrated fracturing. The Yates well is in a geologic setting that much of the Wyoming portion of PRB is in – rather flat-lying with few nearby faults; it will likely not average as high a rate of injection as the Anadarko wells. It is unclear how much water can be accepted by the Yates well. On the eastern edge of the Montana portion of the PRB are two deep Madison wells used for water supply wells. These wells, approximately 8,000 feet deep, flow Madison water at rates up to 25,000 bpd. It can be expected that these wells would also accept water at that rate under injection conditions.

Class IID deep wells must be demonstrated to be safe and protective of the environment. Mechanical and engineering integrity must be shown prior to the well being used; the injection zone must be isolated from other aquifers and USDWs. The operator must show that the deep injection zone is isolated from other permeable zones away from the borehole and the injection perforations are isolated from the long-string casing in the well. The former – stratigraphic isolation – can be demonstrated by wire-line log cross-sections through the proposed injection well and nearby wells; stratigraphy can illustrate local and regional isolation. It will also be necessary to show that the injection zone will not endanger nearby correlative mineral rights. At the same time, integrity of the injection tubing and packer on top of the injection perforations can be tested by pressuring up on the long-string casing to check for leaks.

Technically feasible injection requires that the injection rate is sufficient for the operator's needs. Prior to use, the injection zone may need to be stimulated by way of acidization or fracturing. This might involve pumping small amounts of weak acid or large volumes of fluid with sand to prop open the fractures in the injection zone.

Technical and permitting feasibility also demands that the operator test the injection zone to verify fracture pressure and injectivity – the injection rate as it is related to the injection pressure. Injection pressure can exceed the fracture pressure in the injection zone but cannot exceed the fracture pressure of the confining zone. This is best determined by step-rate tests.

As demonstrated from the above examples, the technical feasibility for this option can vary significantly. Further, considering that there is only one (1) existing deep injection well in the basin and that well has not yet been tested or used suggests that this alternative still requires much research and analysis before it could be established as a tool for widespread usage. Because of the overall lack of historical data for this alternative, it is considered experimental at the current time.

Economic Feasibility: Capital costs of deep Class IID disposal wells are expected to be quite high. Injection wells drilled to the Dakota Formation, over 10,000 feet deep, will likely cost more than $3 million to drill and complete. A 14,000-foot Madison well will likely cost more than $4 million (George, 2005). This is a large economic risk not knowing the ability of the borehole to accept injected water. A deep injection well is best installed in a newly drilled borehole, but a shut-in deep dry hole could be more economically feasible if its location is ideal for efficiently managing CBNG water.

In addition to well costs, required surface equipment will include high-volume pumps and large tanks in a battery protected by secondary containment. Because the potential water injection rates may be high, 25 to 50 CBNG wells will need to be connected by pipeline into each Class IID well. Further, as water production rates decline, new connections would be required. Transportation costs may be higher than the injection options discussed above. Economics of this option are difficult to predict but will likely be in the range of costs for conventional Class II disposal wells, which is estimated to be from less $0.10 to approximately $1.00 per bbl. However, these economic estimates are largely speculative considering the lack of information relative to this alternative.

Environmental Concerns: Risks are the same as for conventional Class IID wells of which Wyoming has approximately 6,100 (Nelson, 2005). The safety of these wells is exemplary both within the state and across the country. Another environmental concern is the perceived waste of the CBNG produced water resource caused by deep injection. It may be necessary to establish a water quality limit for produced water below which the water has legitimate uses and cannot be injected into deep reservoirs by way of Class II UIC wells.

Potential Volume Capability: Successful deep Class IID wells may be able to accept up to 50,000 bpd while an unknown number of unsuccessful wells will take little or no water. For perspective, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George; therefore, if the operator were to depend upon Class IID coal seam re-injection, between three and 15 wells would be needed.

Timing Issues: Contrary to timing issues for the other types of injection facilities listed above, deep Class IID will likely take several weeks or months to drill, but may be more easily permitted by the WOGCC. A total of 30 to 60 days may be needed to drill and complete one of these wells and less than 30 days be needed to secure a permit. Whenever a deep well is attempted in the PRB, unforeseen drilling and construction delays can happen but these should not be frequent.

5. Class IIR Injection into Secondary Recovery Projects

CBNG produced water has the potential to be used to supply water for injection into Class IIR wells permitted by the WOGCC as part of secondary oil recovery (water-flood) projects. Class IIR injection is done by oil producers to more efficiently produce oil from many kinds of conventional oil fields. Under this alternative, CBNG operators could pipeline their produced water to oilfields being flooded by other operators in an effort to produce additional oil. Injection wells would be permitted by the water-flood operators. Pipelines would likely be operated by the CBNG operator or a consortium of CBNG operators.

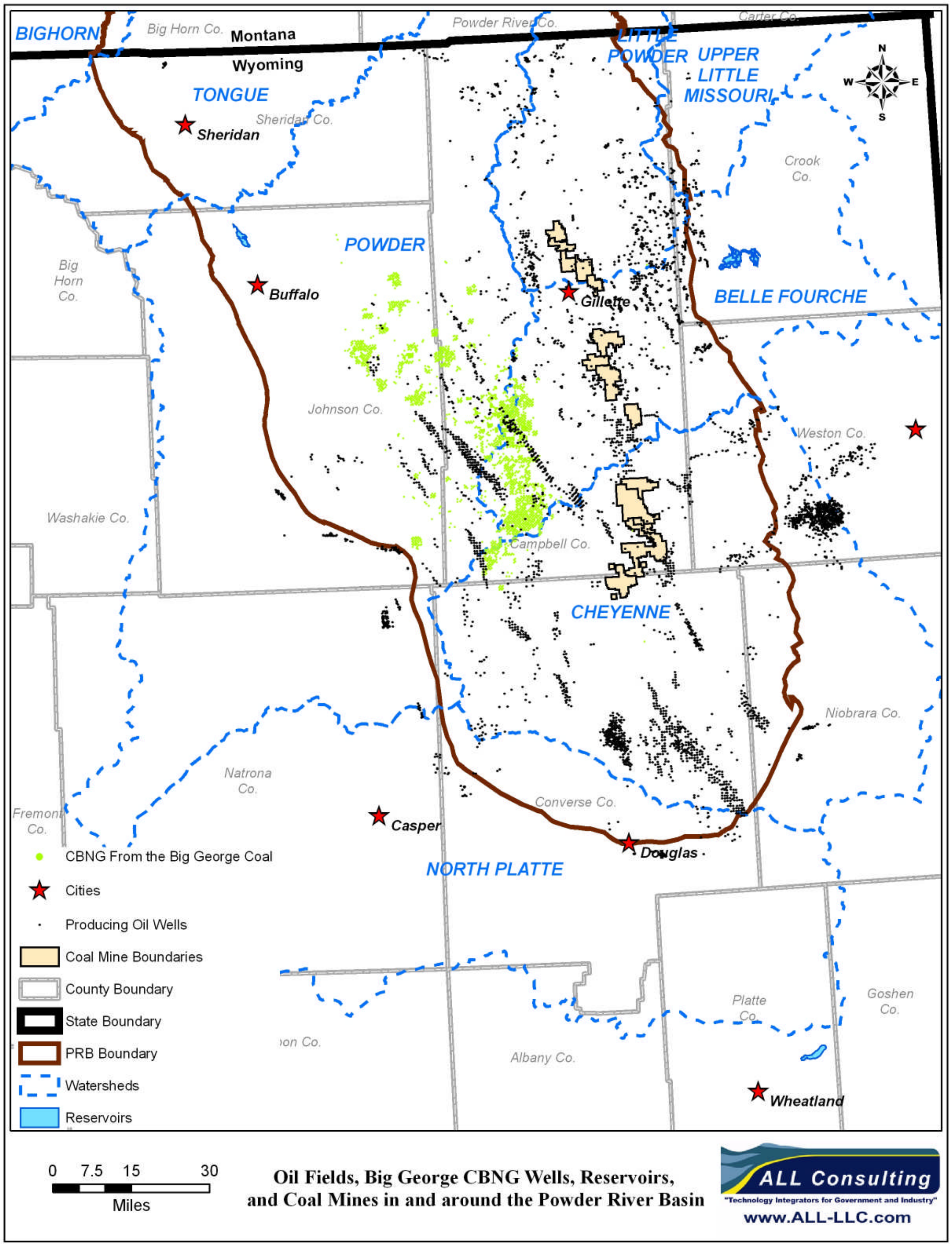
Description: A number of PRB oilfields are being flooded at the present time. Water-floods consist of a number of injection wells in a particular field that are coordinated to move the oil that remains in the target reservoir toward the producing wells in the subject field. A water-flood project can consist of less than a dozen wells or several hundred wells. Each of the operating water floods uses injection wells to inject water back into the oil reservoir in order to maintain reservoir energy and drive more oil toward the producing wells. The injected water can be water produced from the field being water-flooded or it can be "make up" water obtained from another source. In some cases the original field wells do not produce enough water with the oil to support a flood project and in those cases the operator will either postpone the flood project or will find make-up water from nearby production, surface water, or groundwater produced through water supply wells. As the water-flood continues, the reservoir fills up and eventually the injected water and additional oil will be seen at the producing wells. As production continues, the water produced in the oil wells replaces make-up water and the flood becomes more or less self-sustaining and no outside water is needed.

Some new oil fields have not as yet been converted to flood projects. At the present time there are approximately 38 fields totaling approximately 2,300 wells that have not been flooded (Likwartz, 2005). Operators of these fields may or may not be looking for make-up water to begin new water-floods. The cost of securing make-up water will influence the operator to decide when to start the water-flood. A large volume of water may be needed for a successful water-flood operation. A year or more may be required to reach fill up on the water-flood. CBNG may be able to be used as part of the make-up water for the unflooded fields. Oil field locations in relation to Big George production are shown in Figure 5. Many oil fields are within five miles of Big George CBNG production.

During the first phase of the feasibility study, conventional operators were not contacted to ascertain what the specific needs are or may be for utilization of CBNG produced water. Further analysis of this alternative may be considered for the second phase of the study.

Figure 5: Oil Fields and Big George CBNG Production

This map shows the relationship between existing conventional oil fields and the Big George production areas in the western and central portion of the Wyoming Powder River Basin.



Sources: Wyoming Oil & Gas Conservation Commission, ALL Consulting (2005)

Potential Benefits: Water-flood projects have the ability to increase oil recovery at existing fields; oil reserves that would be lost without those projects. This beneficial use of the CBNG water could have an economic benefit to oil producers and to the State of Wyoming.

Non-Technical Barriers to Implementation: Few barriers have been mentioned when researching this option. Residents near the CBNG production could protest that the CBNG produced water is being lost forever by its injection into an oil reservoir. But, it could perhaps be argued that the water-flood is indeed a valid beneficial use helping the industry and the economy of the State of Wyoming.

Technical Feasibility: The most important technical issues standing in the way of using CBNG water in a water-flood is its chemical compatibility with the particular oil reservoir. Compatibility tests can be run prior to installing necessary pipelines to deliver the water. In order to be reliable, the test will require sidewall or full-hole cores of the reservoir; these are usually obtained when an oil operator is beginning to exploit a new field. Important aspects of a compatibility test will be pore-throat size range to determine the filter system and the presence of clays and other mineral grains that can react, swell, or become mobile when exposed to the injected water. If incompatibility is discovered, the testing contractor will be able to recommend a chemical additive that may prevent the reaction.

Water-floods can inject large volumes of water if the oil reservoir is thick and porous; in some cases over 50,000 bpd could be handled. Other floods are small and might involve less than 1,000 bpd (Doll, 2005). The only permits needed for this option pertain to the Class IIR injection wells; these permits will be the responsibilities of the oil operator.

Economic Feasibility: Pipelining costs at particular Big George CBNG fields could argue against using this alternative. Water pipelines can be expected to cost approximately $43,000 per inch-mile. Operating costs are expected to only include pumping costs. Economics of this option are difficult to predict but will likely be in the range of costs for conventional water-floods, which is less than $0.10/bbl (Jackson and Myers, 2002).

Environmental Concerns: Environmental risks usually only involve releases from the pipeline and surface equipment such as manifolds and tanks.

Potential Volume Capability: A water-flood will be able to accept between 1,000 and 50,000 bpd of make-up water. For perspective, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George; therefore, if the operator were to depend upon water supply to water-floods, between three and 150 flood projects would be needed. It is likely that most oil fields likely to be successful water-floods have already been flooded (Likwartz, 2005).

Timing Issues: Installation of the pipeline from CBNG project to water-floods will be of varying length and difficulty but its installation will be routine for the PRB. The NEPA requirement for crossings on BLM land may pose a delay unless anticipated and planned for in a project's schedule. Few other risks to the project timetable will be expected.

6. Treatment and Discharge

In general, CBNG produced water is characterized by elevated levels of sodium, barium, bicarbonates, EC, and iron. The concentrations of each of these constituents will vary for any given water source and in some cases will require treatment prior to beneficial use. There are a variety of potential beneficial uses for CBNG produced water that can be implemented by CBNG operators to manage this resource, but the quality of the produced water can be a deciding criterion for what option is chosen. The potential also exists for this water to be treated by a variety of technologies to improve the its quality and allow for increased beneficial use or discharge.

Description: This option involves treating produced CBNG water to acceptable quality for discharge or beneficial use. Typically, water treatment technologies are limited to treating specific constituent types concentrated in water, e.g., dissolved solids, organics, conductive ions, etc. Depending on the eventual use of the water and the desired constituent concentrations, treatment processes may be coupled together to achieve required water use objectives. Treated water is either discharged directly to surface water (Tongue and Powder River) or beneficially used for irrigation by landowners, or to provide water for livestock and wildlife use.

Operators currently employing water treatment to handle CBNG produced water include Pinnacle Gas Resources, Inc., J.M. Huber, Anadarko Petroleum Corporation, Lance Oil and Gas, and Black Diamond Energy (Beels, 2005). Marathon has tried water treatment in the past but currently does use treatment as a management option (Searle, 2005).

Potential Benefits: Treating produced CBNG water provides quality water for landowners in arid regions where good quality water is in short supply for irrigation and other beneficial uses. Water treatment may be the only option for produced water in areas where infiltration, storage or irrigation are not appropriate or allowed by landowners. Direct discharge of Big George water is virtually impossible but can be permitted after treatment.

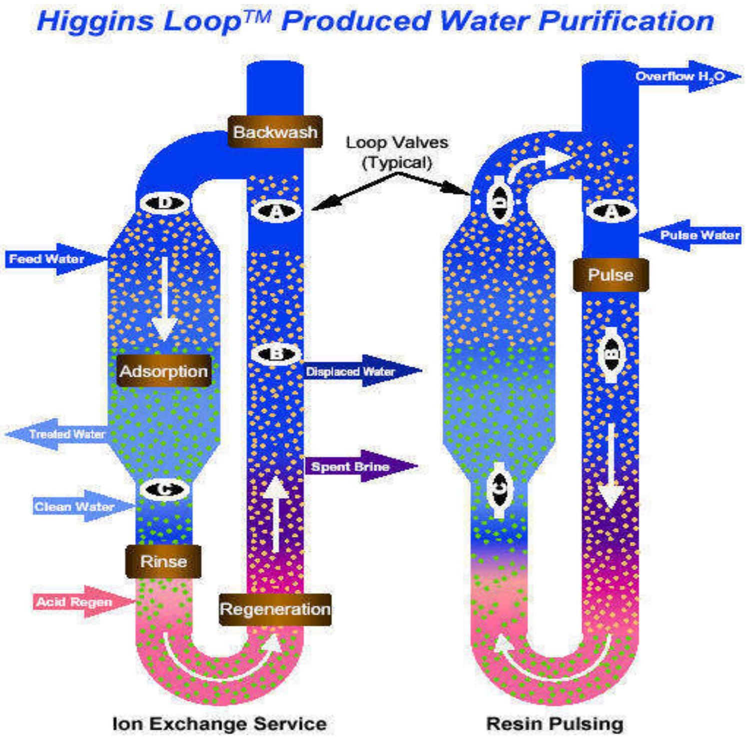
Non-Technical Barriers to Implementation: WPDES permitting may be time consuming, especially if down stream water users do not wish to have additional volumes of water in the stream. Additionally, if no live surface water is present and there are no irrigable lands in close proximity, there may be very few uses for the treated water. New treatment technologies require a pilot permit under which operation can begin. After at least a year's operation, the permit can be converted to a state-wide construction permit. Discharge permits are also required and are received separately (Thomas, 2006).

Technical Feasibility: Treatment processes are dependent both on treatment goals and influent water quality. Continual adjustments to treatment processes may be required if influent water quality varies from the expected quality. There are several important technical aspects of CBNG produced water that reduce feasibility of this option. Variability of the produced water stream – in terms of both quantity and quality – presents a daily challenge to the treatment plant operators to fine-tune their technologies to the water stream. Two constituents in some CBNG waters must be removed prior to the treatment process are oil and grease and iron bacteria (De Lapp, 2005). Both constituents foul the resins within the ion exchange process or foul the membranes in the reverse osmosis process. Some of the most common types of treatment systems are described below:

The primary treatment process currently used in the PRB to treat CBNG water is ion exchange. The ion exchange process effectively removes arsenic, heavy metals, nitrates, radium, salts, uranium, and other elements from the produced water. Ion exchange is a reversible chemical reaction wherein positively or negatively charged ions present in the water are replaced by similarly charged ions present within the resin. The resins immersed in the water are either naturally occurring inorganic zeolites or synthetically produced organic resins. When the replacement ions on the resin are exhausted, the resin is recharged with more replacement ions.

The Higgins Loop^{TM} Continuous Ion Exchange method is currently being used in Wyoming by Pinnacle Gas Resources, Inc, Black Diamond Energy, and Lance Oil and Gas to treat CBNG produced water. The Higgins Loop is a vertical cylindrical loop containing a packed bed of strong acid ion exchange resin that is separated into four operating zones by butterfly (loop) valves. These operating zones – Adsorption, Regeneration, Backwashing and Pulsing-function like four separate vessels. A schematic diagram of the system is shown below in Figure 6 (Beagle, 2005).

Figure 6: Higgins Loop Schematic Diagram



(Source: Severn Trent Services)

The Higgins Loop treats liquids in the adsorption zone with resin while the ions are being removed from loaded resin in the regeneration zone simultaneously. Intermittently, a small portion of resin is removed from the respective zone and replaced with regenerated or loaded resin at the opposite end of that zone. This is accomplished hydraulically by pulsing of the resin through the loop. The result is continuous and countercurrent contacting of liquid and resin. The cations (Ca^+, Na^+ etc.) are replaced by hydronium (H^+) ions from resin beads. The hydronium ions are released in the treated water, which lowers the pH of the water. Cations are stripped from the resin in the regeneration zone concurrent with ion exchange in the adsorption zone. Dilute hydrochloric acid is injected into the loop and moves counter-current to the resin and the spent brine discharge, leaving the resin restored to the hydronium form.

Concentrated brine volumes average approximately 1.0% of the total Loop feed volume, depending on the cation loading that is removed from the treated water. Excess brine that is not recycled to other beneficial uses is proposed to be transported offsite by truck for disposal injection into a permitted Class I, deep disposal well located in Wyoming.

The Loop operation is followed by calcium addition to adjust pH, balance SAR and increase calcium concentration. The process removes sodium as well as other ions from the produced water; the reduction of SAR is a combination of the Higgins loop and adding back calcium and magnesium. SAR reduction is a delicate balance between the removal of ions and the enrichment of calcium and magnesium ions so that SAR is reduced and TDS is kept low. Gypsum and zeolite ion exchange is also being used in the basin with limited success for sodium removal.

Another treatment technology being attempted in the Powder River Basin is reverse osmosis. This method uses a semi-permeable membrane to remove dissolved cations and anions. The CBNG water must be pumped through the membrane. Fouling of the membrane is common and pre-treatment of influent waters is required for significant volumes of water. Pre-treatment may include clarification, filtration and pH adjustment. A brine waste stream is also produced with reverse osmosis, with the volume being approximately 10 percent of the influent volume.

Although the above treatment alternatives have the potential to greatly improve the quality of CBNG produced water, the feasibility of these options relative to Montana’s proposed new water quality regulations presents challenges that these methods may not be able to meet on a consistent or economically feasible basis. None of the current treatment systems have been used to treat water to the levels proposed by the State of Montana. Further, the treatment methods needed to meet these standards have yet to be established.

Several technical concerns arise when considering using treatment and discharge in accordance with the new standards. First, treatment systems would need to be upsized to meet the new standards. Many operators are concerned that costs to meet the new standards may not be achievable or may be so expensive that they would not be economically feasible. Further, upsizing may greatly increase waste volumes generated from the plants, which would present additional environmental concerns.

Economic Feasibility: Costs to treat water under existing standards are variable and have been noted to range from less than \$0.25/bbl to well over \$2.00/bbl. These costs include capital costs of the treatment facility, operating expenses, brine disposal, monitoring expenses, and regulatory (permitting) expenses. Estimated total cost reported by several operators is approximately \$1.00/bbl under current conditions. Costs relative to the new standard are unknown and may be as much as an order of magnitude greater than current costs for treatment and discharge.

Environmental Concerns: Primary concerns associated with treatment processes include waste stream transport and disposal, process chemical transport and storage, and impact to surface water systems. Direct discharge of high quality treated water into the Powder River, for example, must be managed to minimize impact to the existing stream conditions and to the indigenous biota. Often the treatment outflow must be adjusted according to existing stream flow. Several outfalls may be required for the discharge from one treatment facility to disperse the treated water into the system for minimal disruption to aquatic biota.

Important secondary environmental issues include possible leakage from the associated storage ponds, increased truck traffic, and visual impact of the facilities. If water treatment were the only solution for produced water, the number of treatment facilities would have to increase by a factor of a hundred, causing increased stream flow in areas where irrigation is not suitable. Even when treated water is used for irrigation, the water must be directly discharged or stored during the non-irrigation season.

Potential Volume Capability: Successful ion exchange treatment facilities in the Powder River Basin have a maximum throughput of approximately 8,000 bpd. At least one operator is proposing a 100,000 bpd plant to begin operations in spring of 2006. In order to handle variable quantities of water, some operators are exploring using two or more smaller capacity units and bringing on line the number of units to handle the capacity as needed instead having one large capacity unit (Searle, 2005).

Timing Issues: Discharge permitting via the WDEQ can pose delays to treatment schedules. The permitting process involves agency review as well as public comment periods. Other delays may be caused by system start-up difficulties as well as upsets during treatment cycle due to influent water quality fluctuations.

7. Dust Control and Other Process Water at Coal Mines

Coal mines in the PRB use large volumes of water for dust control. Across the PRB dust is a powerful issue (Shiffer, 2005). The coal mines within the PRB need to control fugitive dust and virtually every mine is looking for more water (Murphree, 2005). CBNG produced water can be used at local coal mines for control of dust, equipment washing, and other uses. The coal mines are shown in geographic relation to Big George production on Figure 7. Big George production is separated by several miles from the coal mines. CBNG produced water will need to be transported to the active mines for this option to be feasible.

Description: PRB coal mines are some of the world's largest. In 2004, Wyoming's coal mines produced over 395 million tons of coal, most from the PRB. A single PRB mine can supply up to 200,000 tons of coal per day (WMA, 2005), almost all of it shipped out by rail car. The coal rests in the ground in seams 40 to 60 feet thick or thicker. A mechanical shovel scrapes it out of the seam and drops the coal into trucks that transport the coal to a processing facility for sizing and carefully controlled loading onto rail cars. Since several pits may be active at any one time in each mine, truck traffic is heavy as coal travels on as much as 15 miles of gravel road in each mine (Hutchinson, 2005). As this is done, loaded trains leave for power plants as far south as Mississippi while empty trains arrive at the loading dock. All of this activity goes on around the clock, all year long and almost all of this activity generates copious amounts of fugitive dust. CBNG produced water can be used to control dust on roads and in mines. It can also be used for washing trucks and other large equipment.

Peabody Coal reports the water needs of a single large mine to be between 2,400 bpd and 84,000 bpd, depending upon the season (Murphree, 2005). Arch Coal reports water needs at large mines of approximately 25,000 to 100,000 bpd (Hutchinson, 2005). Other mine operators had similar reports. Virtually every mine in the PRB is looking for more water for dust control (Murphree, 2005).

Fugitive dust is a well known environmental concern in the PRB. Dust originates in and around coal mines, around CBNG projects, and various county gravel roads. With sharply increased coal production at basin mines and sharply increased CBNG activity, fugitive dust levels are high. Some areas are facing dust levels that may require curtailment of mining and other industrial activity. New industries that generate dust are being discouraged from establishing in the PRB portion of Wyoming. As reported in ***The Billings Gazette*** on 11/14/05:

> *George Parks, executive director of the Wyoming Association of Municipalities, said Monday that improvements to local government infrastructure are necessary to ensure that Wyoming's energy development can continue.*
>
> *"An example is the county roads in the Powder River Basin, where the coal-bed methane is creating a lot of dust," Parks said. "It's possible we could run into an air-quality limitation on the amount of coal-bed methane if the county there and the industry doesn't do an adequate job of controlling that dust."*

This impression is shared by many members of the State Legislature and private citizens (Shiffer, 2005).

Coal mines require more water for dust control during the dry periods of the summer and fall. During other times, water can be stored on-site in pits and settling ponds. A typical large coal mine can have storage approaching 5.0 million bbls (Murphree, 2005).

Potential Benefits: Helping area coal mines control dust can benefit the mining sector. Reducing regional dust levels can help all industrial interests in the basin and can improve air quality issues in the PRB in Wyoming. Reducing dust with the help of CBNG produced water will give CBNG operators a low-cost, year-round option for managing the water.

Non-Technical Barriers to Implementation: Few barriers were mentioned when researching this option. Residents near the Big George CBNG production could protest that the CBNG produced water is being lost by the beneficial use of dust control. But it could be argued that dust control is badly needed in the region and that this is a valid beneficial use helping residents and the economy of the State of Wyoming.

Technical Feasibility: Several CBNG operators have historically supplied water to numerous mines in Wyoming and Montana. The Spring Creek mine near Decker, Montana, receives between 200 and 800 gpm from the CX Ranch CBNG field in the area (Williams, 2005). Several mines near Gillette received small amounts of water from adjacent CBNG fields (Stearns, 2005), but at the present time, these Wyoming CBNG fields produce very little water and none is delivered to the mines.

Technical aspects of this option involve water quality requirements that may limit usage. However, there are differing impressions of the quality limits for dust control water applied to roads. Some operators are concerned about the buildup of salt at the side of coal mine roads and have a self-imposed limit of 10 SAR (Murphree, 2005). Other companies have a corporate (Rio Tinto) policy about using high quality water for dust control and emphasize the use of poor quality water (Stearns, 2005). Other companies (Arch) add MgCl to any dust control water so they are unconcerned about water quality for dust control (Hutchinson, 2005).

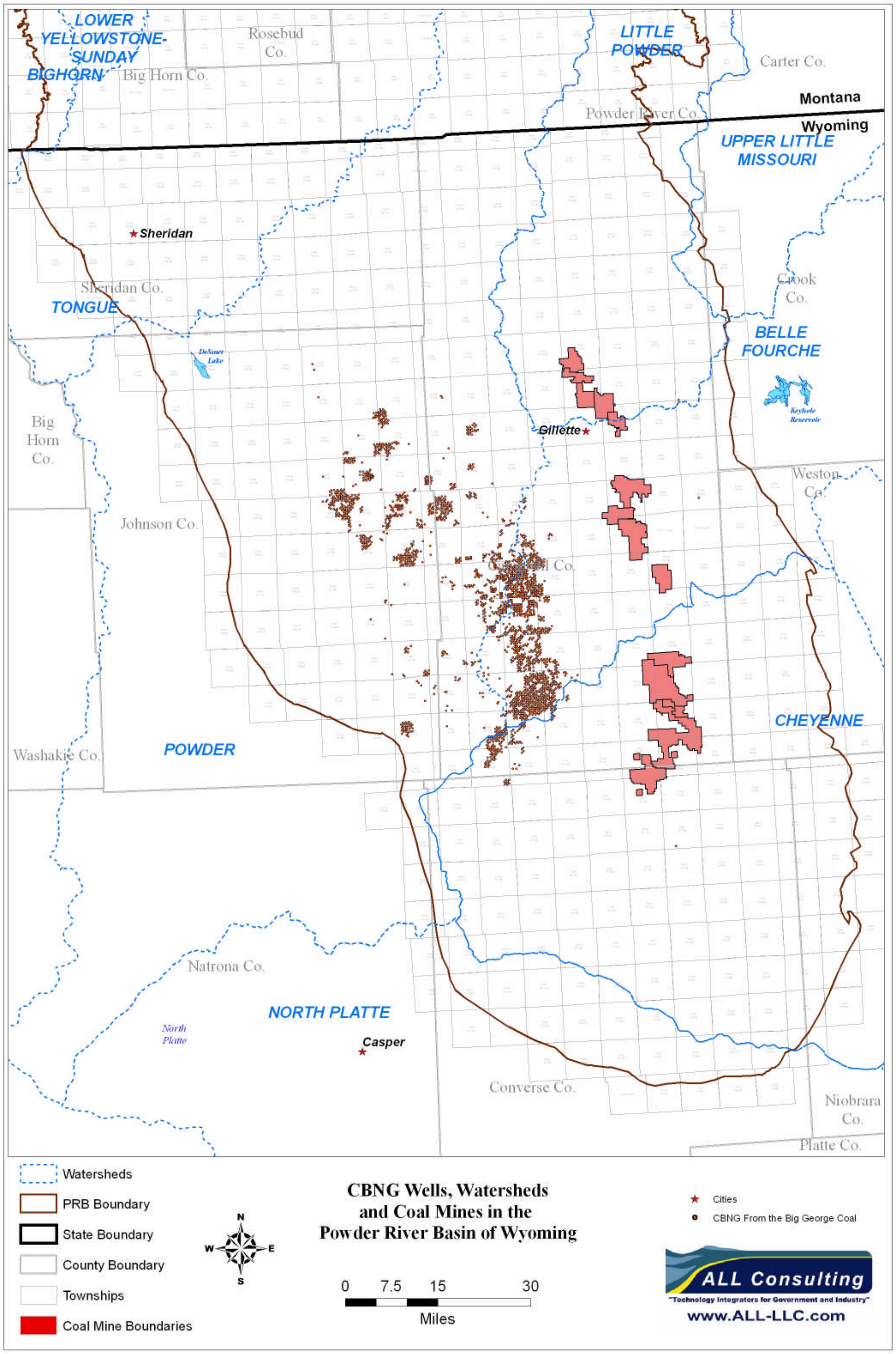
WDEQ and WOGCC entered a Memorandum of Agreement on July 9, 1999 placing control of road application of CBNG water in the hands of the WOGCC. This agency permits road applications of oil and gas wastes under its Form 20. Additional Federal permits may also be required on a site-by-site basis.

Economic Feasibility: Capital costs of pipelining CBNG water to operating coal mines is expected to vary depending on the distance. Pipeline costs can be expected to average approximately $43,000 per inch-mile (Skinner, 2005). The diameter of the pipeline will be determined by the volume of water to be transported. Operating costs are expected to only include pumping costs. Economics of this option are hard to predict, but will likely be less than $0.10/bbl (Jackson and Myers, 2002).

Environmental Concerns: Environmental risks involve typical concerns of pipelines to the mines and saline build-up along roads.

Figure 7: CBNG Elements and Coal Mines in the Powder River Basin

This map shows the relationship between locations of CBNG wells and coal mines in the PRB.



Potential Volume Capability: A large coal mine will require between 20,000 and 100,000 bpd of dust control water depending upon the size of the mine and the season of the year. For perspective, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George; therefore, if the operator were to depend upon pipelining water to coal mines, between two and seven coal mines would be sufficient.

Timing Issues: Installation of the pipeline from CBNG project to coal mines will be of varying length, but its installation will be routine for the basin. The NEPA requirement for crossings on BLM land may pose a delay unless anticipated and planned for in a project's schedule. Few other risks to the project timetable will be expected.

8. Cooling Tower Water at Power Plants

Electric generating power plants can have a considerable need for water to use for cooling. Nationally, water availability has been a limiting factor in the development of new power plants. With the current and projected over-abundance of produced water from CBNG development in the Wyoming portion of the Powder River Basin combined with existing and potential future power plants in the state, consideration of using produced water for cooling at power plants is reasonable.

Description: There are six (6) existing power plants located in the general area of the PRB. These plants have the capacity to individually generate between 80 and 2,110 MW. Power plants in the PRB area are generally coal fired and used to provide electric power locally and for export outside of Wyoming. As an integral part of the power generating process, the plant must employ water, air, mist, or a combination of these for cooling. The need for cooling provides a potential opportunity for beneficially using CBNG produced water.

Water usage volumes vary widely among plants in the area, with ranges from approximately 20,000 bpd to more than 400,000 bpd (Schultz, 2005). However, plants are generally designed to accommodate cooling water of a relatively high and consistent quality. These issues are of particular concern with respect to CBNG as water varies by coal and by area providing considerable variations in both quality and consistency of quality and volume. These issues would need to be considered and addressed when further pursuing the use of CBNG produced water for cooling at power plants.

Currently, two new power plants are under construction and permitting. Basin Electric's Dry Forks Plant will be located near Gillette, Wyoming and is being designed to use air cooling. This 375 MW plant has a need for approximately 20,000 bpd of water on a long-term basis. At the present time, Basin Electric has permitted several water supply wells into the Fox Hills aquifer (Shultz, 2005). Had they designed the plant as being water-cooled, this would have required the long-term supply of approximately 170,000 bpd of water. During the planning phase of the plant, Basin Electric spoke with several CBNG operators, including Williams Production, and discovered that very little excess produced water existed in the vicinity of the plant (Shultz, 2005). These discussions lead Basin Electric to forego consideration of CBNG produced water for cooling.

Basin Electric also operates the large Laramie Station Plant near Wheatland, Wyoming. Designed as a water-cooled facility, this plant has a capacity of 1,650 MW and requires approximately 400,000 bpd of water for cooling. Currently its water comes from the Grey Rocks Reservoir on the North Platte watershed. This reservoir does not have an adequate supply of water to support its cool water fishery. Further, the entire watershed lacks sufficient water to support irrigation and to fulfill commitments to the Platte River Compact (Lawson, 2005). This shortage in water volume creates a potential opportunity for beneficially using CBNG produced water for several purposes, including power generation. However, the Greyrocks Reservoir is approximately 160 miles from center of the area where CBNG is produced from the Big George coals.

Potential Benefits: The beneficial use of CBNG produced water for cooling at power plants could be a strategic significance to the state of Wyoming. Having a water surplus could allow power plants to avoid costly air cooling, potentially reducing overall power generation costs. Further, the presence of a water surplus could be used to attract power generating facilities for exporting power outside of Wyoming. In the case of the Greyrocks Reservoir, additional benefits could be realized relative to maintaining the cool-water fishery, providing water to the North Platte watershed, and providing supplies for agricultural uses such as irrigation.

Non-Technical Barriers to Implementation: Non-technical barriers to this alternative appear to be minimal, although water rights issues were not evaluated as part of this study. Further, this alternative could include the transport of water from producing areas within the PRB to usage areas outside of the basin (e.g., Greyrocks Reservoir). Inter-basin transfer of water was an issue raised by multiple state agencies as a potential barrier applicable to CBNG produced water usage (Besson, 2005). Inter-basin transfer involves complex water ownership issues that may delay or restrict the implementation of this alternative.

In order for this alternative to be feasible, CBNG water must be available to the power plant for a length of time sufficient to enable the power plant owner/operator to engineer the water source. Although Big George coals seem to decline less rapidly than other coals, this management alternative may not be able to supply water for enough time to make it worth the power plant's effort.

Technical Feasibility: Technical feasibility of supplying water to power plants hinges on several issues. These include water quality, water quantity, consistency of water quality and quantity, distance from the producing area to the usage area, water transportation issues, and the length of time the water would be available.

The six (6) existing power plants in the general area of the PRB are shown on Figure 8. These plants vary in distance from Big George CBNG production from 15 miles to 160 miles. Further, many of the nearby plants have either designed the plants to minimize water needs or have made arrangements to meet water supply demands. This leaves plants located at greater distances from CBNG production as those in need of any significant volumes of water for cooling (Lawson, 2005).

To date, there has been some small-scale usage of CBNG produced water for cooling by power plants. This usage has been short-lived and minor from the standpoint of the power plants (Stafford, 2005). In all of the historical cases where produced water has been used, the usage point was very close to the CBNG production area, thus minimizing transportation costs. Unfortunately, due to rapid water production declines, the cases evaluated were unable to meet plant quantity requirements for an extended time, thus forcing the plant to seek cooling water from alternative sources. The issue of a single operator being able to commit to long-term supply needs of a power plant has been challenging (Cline, 2005). Therefore, to meet short- and long-term water supply demands, it is likely that a consortium of operators would need to cooperate for this alternative to be feasible.

Different power plants are designed for using differing quality of waters for cooling. For instance, the plant at Laramie Station is designed for using water from the Greyrocks reservoir. Water quality in the Greyrocks reservoir and within the North Platte watershed varies with the season of the year (Wagner, 2005). Produced water from the Big George coal varies considerably and water quality was a concern specifically expressed by Basin Electric (Shultz, 2005). Therefore, it may be necessary to incorporate treatment of produced water by the producer or user for produced water from the Big George to be used for power plant cooling.

Economic Feasibility: Cost for this alternative will include significant up-front capital costs for water transportation pipelines. For example, a 24-inch pipeline from the Big George producing area to the Greyrocks Reservoir would involve the construction of a 160 mile pipeline (approximately). This pipeline alone could cost approximately $170 to $200 million (Skinner and Tomlinson, 2005). This pipeline could transport up to 400,000 bpd of water. The operation of a pipeline of this length would likely require pump stations and ongoing maintenance throughout its use. Further, if a single general use pipeline were constructed for use by multiple operators, individual operators would still need to construct local gathering lines to connect to the larger general use line.

Considering the large capital cost of this alternative combined with ongoing maintenance, the per-barrel price of this alternative can vary greatly. If the pipeline were to receive usage and cost sharing among the majority of Big George producers, it may be reasonable to assume that per-barrel water management costs could be reduced to as low as $0.10 to $0.30 per barrel over a total period of perhaps 10-15 years. However, the per-barrel water management costs for this alternative have the potential to be significantly higher depending on the quantity of water transported in a particular pipeline, the duration water is able to be transported, and whether treatment would be required by the end user.

This alternative has many unknowns and challenges that would require involvement from the State of Wyoming to successfully facilitate this as a reasonable and feasible alternative.

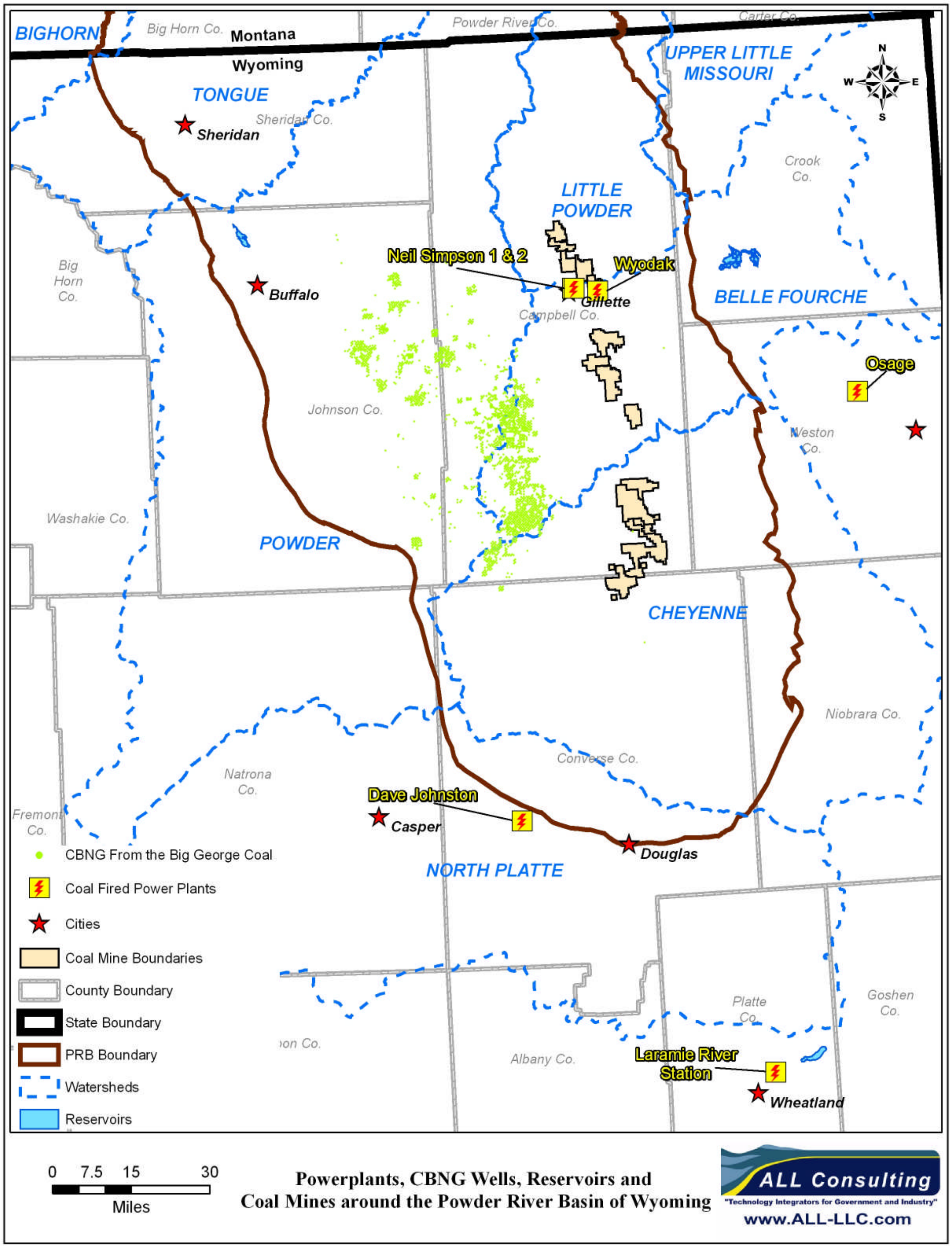
Environmental Concerns: Discharges to Greyrocks Reservoir will have to be kept below the point of degradation in order to protect the resources within the reservoir and downstream waters. The mix of produced water entering the pipeline will determine the final quality at the discharge point. It well be necessary to plan this mixture and monitor the quality of the resulting stream in order to assure compliance with WPDES discharge permits. Preliminary research by Basin Electric suggests that large volumes of Big George produced water could be discharged to the Greyrocks Reservoir (Shultz, 2005).

Potential Volume Capability: A coal-fired power plant will require between 20,000 and 400,000 bpd of cooling water depending upon the size of the plant, the cooling design, and the season of the year. For scale, a 100-well CBNG project may start by producing 150,000 bpd of water from the Big George; therefore, if the operator of a new project were to depend upon pipelining water to power plants, between one and seven power plants would be sufficient to manage all of the produced water.

Timing Issues: Timing and timing variability will depend on pipeline location and length. A 10 to 15-mile pipeline can be permitted and constructed in a short time while a 160-mile pipeline may have a great deal of variability in the time it takes to acquire right-of-way, permit, and construct.

Figure 8: Power Plants in the Powder River Basin

This map shows the relationship between locations of CBNG wells, coal mines and coal fired power plants located in the PRB.

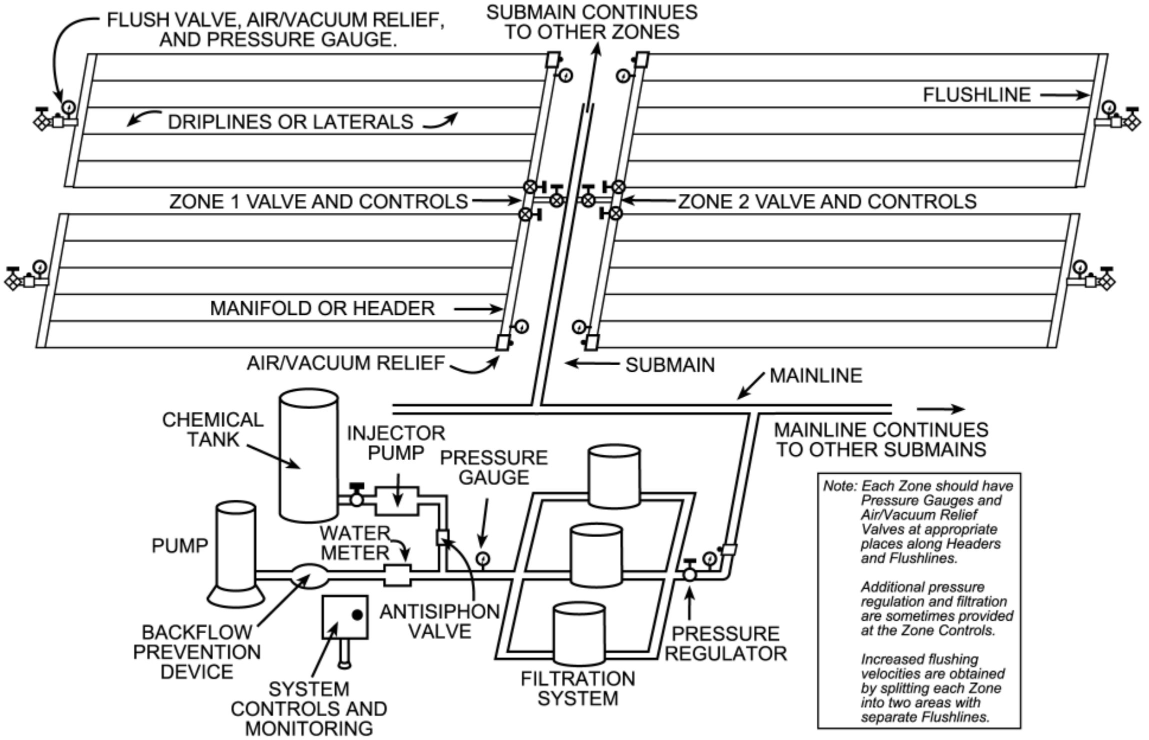


9. Subsurface Drip Irrigation

Irrigation is one of the common and proven beneficial uses of CBNG produced water in the PRB. Good sources of water for irrigation are not abundant except near rivers and reservoirs; therefore, good sources of usable water are desirable for farmers and ranchers for irrigation use. Some of the problems associated with typical surface irrigation include soil crusting on the surface, dispersion, and salt accumulation in the root zone. Subsurface Drip Irrigation (SDI) supplies water to crops by a system of hoses and pipes buried in a network of trenches under the field. The water enters the soil below the soil surface avoiding these problems.

Description: Subsurface drip irrigation is a method of irrigation where water is applied to the crop root zone below the soil surface by small emission points (emitters) that are in a series of plastic lines typically spaced between crop rows. A typical section of a SDI system is shown in Figure 9. SDI is currently being used by CBNG producers in Wyoming to irrigate alfalfa and refined grasses. JM Huber currently has two systems, one 115 acres in size in production and another 220 acres in size (permitted, but not in production) (Zupancic, 2005). They are currently planning additional systems for use in the PRB. Subsurface drip irrigation has also long been used in Israel and Australia with high quality and saline water (KSU, 2005).

Figure 9: Diagram of SDI System



Note: Each Zone should have Pressure Gauges and Air/Vacuum Relief Valves at appropriate places along Headers and Flushlines.

Additional pressure regulation and filtration are sometimes provided at the Zone Controls.

Increased flushing velocities are obtained by splitting each Zone into two areas with separate Flushlines.

(Source: KSU, 2005)

Potential Benefits: With SDI, water is applied beneath the soil surface, therefore, eliminating the possibility of surface soil crusting and dispersion that may occur when irrigating with sodic water with surface type irrigation such as sprinkler and furrow irrigation. When irrigating with waters that have high SAR and/or sodicity, the water is applied below the root zone where possible accumulations of salts will cause less harm to plants and soils. Current SDI applications in Wyoming have been successful and have not shown any subsurface soil structure or infiltration problems during their initial use. The soils at these sites are mixed alluvium and colluvium, and have a high porosity. In order to increase water flow in the soils, the operators sometimes increase electrolyte levels in the irrigation water since infiltration rates generally increase as salinity (measured by the EC) increases (Zupancic, 2005). However, soil hydraulic properties degrade with increasing SAR, no matter the salinity; therefore, limits need to be applied to the quality of irrigation water applied to prevent infiltration problems, along with proper leaching and amendments. Other soil types with higher clay content may require different irrigation management to prevent subsurface soil dispersion and infiltration problems.

SDI allows enhanced crop production without negative environmental impacts associated with leaching or runoff. Water can be applied year-round instead of just during the typical growing season of most crops, therefore, allowing for more water to be beneficially used, and reducing or eliminating the need to store produced water during winter months. SDI application of water during non-growing months may not represent irrigation but may be seen as a beneficial use in the aid of the soil and subsoil, flushing the salts below the root zone. An added benefit is an increase in crop production for the surface landowner.

Non-Technical Barriers to Implementation: Subsurface drip irrigation is considered as Class V injection in Wyoming and a WDEQ 5C5 UIC permit is required (Passehl, 2005). The WDEQ has been requiring a cultural survey of the irrigated area prior to the granting of a permit; this survey can add considerable time to the permitting process. The permitting process can add to the time required before the operator can start using SDI irrigation with CBNG produced water and can add to the cost of implementation.

Technical Feasibility: SDI appears to be one of the most suited types of irrigation available for use with CBNG produced water. Some of the drawbacks of other types of irrigation such as sprinkler and furrow are field shape and topography. With SDI, there is increased flexibility in matching field shape and field size and its pressure compensating systems are not as limited on slopes as surface irrigation. For example, if one CBNG project produces little water, water from these wells could be applied to small, carefully selected sites, resulting in successful SDI projects. Irrigation water is applied subsurface, therefore operators can pump water several months longer, even during winter months; field operations can occur during irrigation; less irrigation equipment is exposed to vehicular damage; there is no surface soil crusting; any salt accumulation is below the root zone; there is less or no runoff into streams; and reduced weather-related application constraints (especially high winds and freezing temperatures). Other advantages include decreased energy costs as compared to other irrigation systems; improved in-field uniformities can result in better control of the water, nutrients and salts; and the SDI system can be easily and economically sized to the available water supply.

Some of the drawbacks of SDI include: water filtration is a critical issue in ensuring proper system operation and system longevity; tillage options may be limited; fewer visual indicators of system operation; subsurface repairs are more difficult; shorter design life than alternative irrigation systems (usually 10-12 years); salinity may be increased above drip-line, increasing salinity for small germinating crops; and root intrusion into drip-line can occur. Compared to conventional surface drip systems, concentration of salts on or near the surface causing germination and other problems tends to be reduced under properly designed and managed SDI systems. However, salinity may still be a problem with SDI in arid and semi-arid areas since any leaching above the tubing occurs only as the result of rain. Thus, salts may accumulate in this area during the season as the plants extract water and leave the salts behind.

Crop selection is also important with the use of SDI. Perennial crops are the most suited for SDI, with alfalfa and refined grasses as some of the better candidates. Alfalfa, a forage crop, has high crop water needs and, thus, can benefit from highly efficient irrigation systems such as SDI. In some regions, the water allocation is limited by physical or institutional constraints, so SDI can effectively increase alfalfa production by increasing the crop transpiration while reducing or eliminating soil evaporation. Since alfalfa is such a high-water user and has a very long growing season, irrigation labor requirements with SDI can be reduced relative to less efficient alternative irrigation systems that would require more irrigation events. Currently, SDI is used to irrigate alfalfa at the Perry Ranch in Wyoming and it is estimated that about 60 inches of water can be applied annually, with the crop using 40 inches of that water through evapotranspiration (Zupancic, 2005). Continuation of irrigation reduces the amount of water stress on the alfalfa and thus can increase forage production, which is generally linearly related to transpiration. Salt tolerant or moderately tolerant grass species or mixes of grass should be chosen for use with SDI.

Economic Feasibility: Costs for this alternative will include the capital costs of the irrigation equipment and surface equipment, installation costs, power to pump the water, operating expenses, monitoring expenses, and regulatory expenses. Estimated costs for equipment installation are around \$1500-\$4000/acre with an estimated life of 10 years. Lifetime costs for the system installation and design are around \$0.004 to \$0.01 per barrel, \$0.04 to \$0.06 per barrel for soil amendments, and \$0.02 to \$0.04 per barrel for operations and monitoring for a total cost of \$0.06 to \$0.11 per barrel (De Lapp, 2005). These costs will be influenced by water chemistry, soil chemistry, water volume, irrigation season limitations, and land management practices. These costs do not include costs for establishing a crop or the sale of any crops.

Environmental Concerns: There is a potential for salt accumulation below the root zone if appropriate leaching is not performed during irrigation. Leaching will flush the salts below the root zone where they are not harmful by applying more water than the plant needs. Leaching often occurs with rainfall. In other cases, irrigation water beyond the crop's water requirement may need to be applied. Gypsum can be used to help reduce SAR in the soil by replacing sodium cations with Ca^{++}.

If the groundwater in alluvial aquifers is shallow, there could be a possibility that saline water could affect the aquifer. In order for groundwater to be impacted by SDI systems, saturated flow must exist through the soil/unsaturated zone to the point where water is moving in a continuous wetting front under gravity to the groundwater table. If CBNG produced water is applied in accordance with crop needs, soil water holding capacities, climatic characteristics, soil infiltration rates, and leaching requirements, the aquifer should not be affected. It may be necessary to perform modeling to avoid this situation, especially if the water is applied on a continual basis throughout the year.

Potential Volume Capability: Current SDI systems in use in Wyoming have applied up to 60 inches of water per acre per year. This was accomplished on a 115 acre alfalfa field in fairly porous alluvium and colluvium soils, and applied continuously for 365 days a year (Zupancic, 2005). This equates to about 38,800 barrels of water per acre per year, or about 106 bpd per acre. This amount of CBNG water can vary depending on the field size, soil type, and crops grown.

Timing Issues: There are several aspects to SDI that can affect the successful use of the technology. More serious are the unknown delays associated with the WDEQ permitting process. A WDEQ 5C5 UIC permit is required for SDI in Wyoming. General permits are often handed down within 60 days, but during the period of public notice, outside objections can be received. Offsetting CBNG operators and any citizen can protest the granting of a Class V permit; if a hearing is needed, several weeks or months may be consumed in the permitting process. Past experience has shown that permits for SDI have taken from 60 days to 8 months to be granted (Wagner, 2005).

10. Cattle Feedlots

Livestock watering is one of the most common and proven beneficial uses of CBNG produced water in the PRB. Most range and pasture use for livestock watering would require relatively minute quantities compared to the amounts of water produced in the basin; therefore, to support a feedlot where large numbers of beef cattle are confined and fed would be a more feasible option.

Description: This option involves the use of CBNG produced water for the water needs at cattle feedlots. These water needs could include consumption for cattle, irrigation of forage crops, and waste management. Most of Wyoming's cattle feedlots are concentrated in the southeastern corner of the state because of their proximity to grain supplies in neighboring Nebraska and a more favorable climate. Figure 10 shows the current number of feedlots with NPDES permits on a county basis (NPDES permits are required for facilities with more than 1,000 head capacity). Of the 59 permitted feedlots, 32 are located in the three most southeast counties (Platte, Goshen and Laramie counties). In the Powder River Basin, there are currently only about five feedlots with NPDES permits. Figure 11 shows the distribution of all cattle throughout Wyoming by county. This figure indicates that there are a fair number of cattle in counties located in the Powder River Basin where most CBNG production is located, but these totals include all types of cattle including grazing and cow/calf numbers. One of the major drawbacks to locating additional feedlots in this area would be providing an adequate source of feed and grain. If sufficient CBNG water were available, additional water can be used to irrigate hay and grain crops adjacent to the feedlot, providing a source of feed.

Potential Benefits: One of the larger needs of cattle feedlots includes water for livestock. The quality of almost all of the CBNG produced water in the PRB is acceptable for livestock drinking, therefore, eliminating the need or any water treatment.

Non-Technical Barriers to Implementation: During construction of new feedlot facilities, owners of nearby water wells and springs may protest surface discharge permits. Cattle feedlots with more than 1,000 animal units are regulated through Wyoming's Department of Environmental Quality's (DEQ) point source program and must get a NPDES permit. All existing confined animal feeding operation (CAFO) NPDES permits are scheduled to expire on December 31, 2006. Effective January 1, 2007, new state and federal CAFO requirements will be phased into NPDES permit requirements. Feeding operations, regardless of size, are subject to potential litigation from neighbors, nearby towns, and sportsman's groups on the basis of pollution or nuisance odors. If a complaint against a feeding operation is filed with DEQ, an investigation will follow. If the investigation reveals that site is a significant contributor of pollution, a permit will be required.

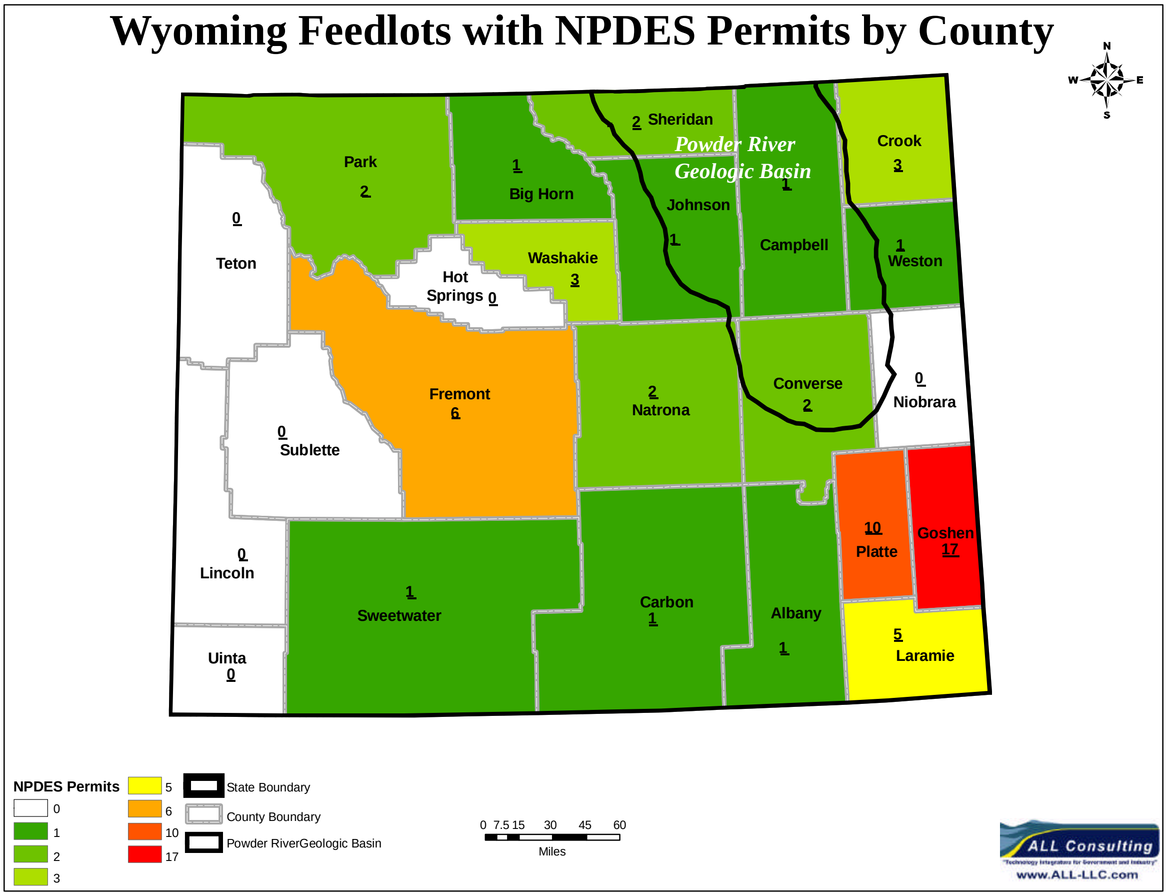
Technical Feasibility: The quality of a majority of the CBNG produced water in the PRB is acceptable for livestock drinking without any treatment. Table 2 below shows the acceptable quality of water for livestock. Water with a TDS below 10,000 mg/L (EC <16 mmhos/cm) is generally considered acceptable.

Most of Wyoming's cattle feedlots are concentrated in the southeastern corner of the state because of its proximity to grain supplies in neighboring Nebraska and a favorable climate. If the CBNG field is located many miles from the feedlot, the CBNG operator would likely not choose to pursue this particular management option.

Since good sources of feed and grain supplies are not located close to the CBNG fields, there would not be much enticement for construction of feedlots of any significant size in close proximity to the sources of CBNG produced water (Magagna, 2005). This condition could be changed by the application of CBNG water to nearby fields for growing hay and grain. In this way, the feedlot operator would have the option of being a vertically integrated beef producer.

Figure 10: Feedlots by County in Wyoming

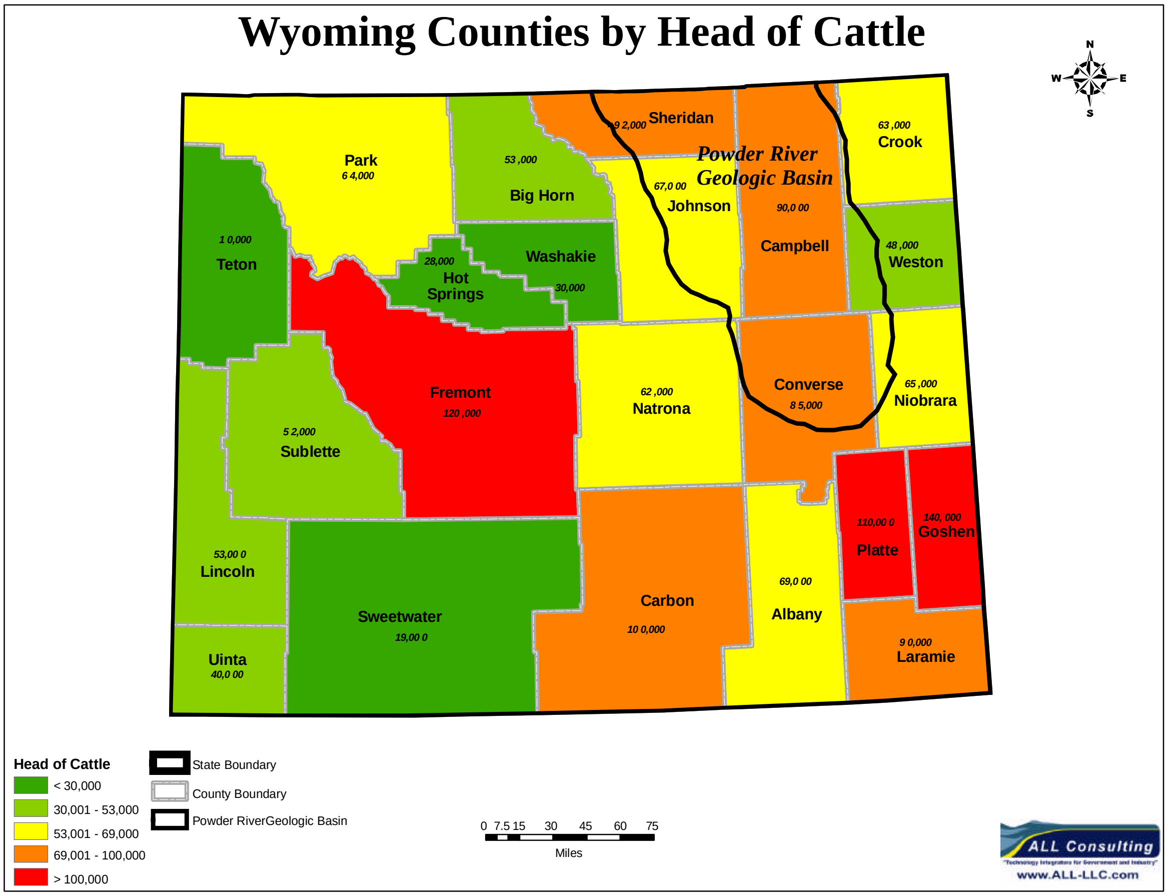
This map shows the number of cattle feedlots by county that have NPDES permits in Wyoming.



(Source: WDEQ, 2005)

Figure 11: Distribution of Beef Cattle in Wyoming

This map shows the distribution of the total number of cattle by county in Wyoming.



(Source: WBC, 2002)

Transporting the water from the CBNG producing areas to the feedlots would be the most difficult technical aspect of this option. Either trucking the water or building pipelines would be the most feasibly solutions, but cost may be prohibitive, depending on the distances.

The issue of a single operator being able to commit to long-term supply needs of feedlot could be challenging. Therefore, to meet short- and long-term water supply demands, it is likely that a consortium of operators would need to cooperate for this alternative to be feasible.

Table 2: Water Quality Guide for Livestock Use

TDS (mg/L)*	Livestock Watering Comments
Less than 1,000 (EC < 1.5 mmhos/cm)	Excellent for all classes of livestock.
1,000 to 2,999 (EC = 1.5-5 mmhos/cm)	Very satisfactory for all classes of livestock. May cause temporary and mild diarrhea in livestock not accustomed to them.
3,000 to 4,999 (EC = 5-8 mmhos/cm)	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them.
5,000 to 6,999 (EC = 8-11 mmhos/cm)	Can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. Avoid use for pregnant or lactating animals.
7,000 to 10,000 (EC = 11-16 mmhos/cm)	Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10.000 (EC > 16 mmhos/cm)	This water is considered unsatisfactory for all classes of livestock.

(Source: NAS, 1974)

Note: Electrical conductivity (EC) expressed in micromhos per centimeter at 25°C can be substituted for total dissolved solids without introducing a great error in interpretation.

Economic Feasibility: Current feedlot operators will already have sources of water; therefore, water would have to be provided at a very low cost for this to be economically feasible for them. Costs associated with the beneficial use of produced water for feedlots would mainly include transporting the water to the feedlot facility. Most feedlot facilities are currently located in the southeastern portion of the state; therefore, transportation of the relatively small quantities of water there would most likely be cost prohibitive. Capital costs for new facilities will be fairly high. Costs for construction of new feedlot facilities are beyond the scope of this exercise, but estimates from university sources give construction costs for conventional concrete based feedlots at $166,000/acre (Chugh, 2004) and typical pen stocking densities between 150 ft^2 and 300 ft^2 per animal (Davis, et al, 2004). There would not be any treatment costs associated, as long as the TDS of the water is below 10,000 mg/L. If new feedlots were constructed to take advantage of the CBNG produced water, they would most likely be located in close vicinity to the production fields. Transportation costs for the water would be by truck or pipeline, which are fairly well known (see other alternative discussions) and should be less than $0.10/bbl.

Environmental Concerns: There would be very few if any environmental concerns for the actual use of the CBNG produced water for consumption by cattle at feedlots. If the water is stored in impoundments, the concerns would be the same as for typical CBNG impoundments. Other environmental concerns related to feedlots in general do exist, however. Feedlots have the potential to be a source of nitrate and bacteria contamination if groundwater is shallow, or a pathway into groundwater is present. A public hearing is held if there is "sufficient public interest," according to state regulations, in which case public notice of the hearing is provided. Operations smaller than 1,000 animal units fall under the voluntary non-point source program. The DEQ may require smaller facilities to obtain a permit if the state determines that they pose a threat of polluting the waters of the state.

Many cattle feedlots are clustered along the North Platte River in Wyoming which supplies drinking water to several communities in southeastern Wyoming. Citizen groups have long been concerned that feedlots in this area might be polluting the river. Major pollution threats include polluted runoff from animal waste, erosion of riverbanks trampled by cattle, and cattle waste stockpiled or spread on nearby fields. Officials at the Wyoming DEQ say they have found nitrates in the North Platte River above natural background levels, but not in sufficient quantities to pose a health or environmental threat.

Potential Volume Capability: Finishing cattle consume from 8 to 20 gallons of water per day, depending on the time of year and outdoor temperature (Guyer, 1977). For a larger feedlot handling 5,000 head, this would require a maximum volume of about 100,000 gallons, or 2,380 bpd of drinking water. The average size feedlot in the Great Plains is about 500 head (Davies and Widawsky, 1995); therefore, water use for livestock drinking would be about 240 bpd for an average size feedlot. Water requirements for waste management would increase this amount slightly. If CBNG water were to also supply irrigation for hay and grain adjacent to the feedlot, much more water would be required.

Timing Issues: Supplying water to current feedlot facilities could commence as soon as the supply could reach that facility. If that includes trucking, it could be immediately, but if pipelines are required, it would rely on factors involved with construction of the pipelines, which has been discussed in other options of this study. There are no known permitting requirements for the actual use of the water by the feedlots for animal consumption. If new feedlot facilities are to be constructed, timing would rely on the actual design and construction of the facilities. If the facility is larger than 1,000 animal units, a NPDES permit would be required for the facility, which could be obtained during construction.

11. Public Water Supply

Public water supplies can be a limiting factor in both residential and industrial development. While public water supplies do not appear to be at risk of running low in the near future, they could become so if growth accelerates (WDC, 2005). CBNG water can be used as input for public water supply; the water can be used to insure continued growth of development.

Description: Towns and cities of Wyoming use surface water and/or groundwater for their supply. Groundwater aquifers may be located in the Fort Union or deeper units. The City of Gillette, lacking surface water resources, uses wells completed into sands of the Fort Union and the Fox Hills. Sheridan, on the other hand, relies on Twin Lakes for its water supply. The City of Buffalo uses both surface resources and water wells. The Towns of Wright and Arvada use groundwater (WDC, 2005). The City of Sheridan is looking at its reserves of water and sees a possible shortage if the metropolitan area grows as much as the front-range area between Denver and Fort Collins (Dixon, 2005). The abundance of CBNG produced water in the PRB could be seen as a viable source of public water supply. CBNG produced water may not, however, be of sufficient quality to use in a public water supply without treatment. But Big George CBNG produced water may be of sufficient quality to use as "raw water" and piped separately to high-volume, non-drinking users such as golf courses, and industrial facilities (Boyce, 2005). Marathon has in the past supplied CBNG water to the City of Gillette for use on golf courses; this water was, however, higher in quality than typical Big George water, which may not be suitable for such a use (Searle, 2005). Figure 12 illustrates the geographic locations of Big George production and public water supply wells. Big George production is within ten miles of municipal water facilities in Gillette and Wright but is farther from other facilities such as Buffalo and Sheridan.

Potential Benefits: CBNG produced water could reduce costs to municipalities who might otherwise be forced to drill deep, expensive wells or buy water from nearby cities. At the same time, the enhanced water supply may enable the town to expand its residential area, add industries, or reduce environmental stresses on local fisheries in reservoirs or streams.

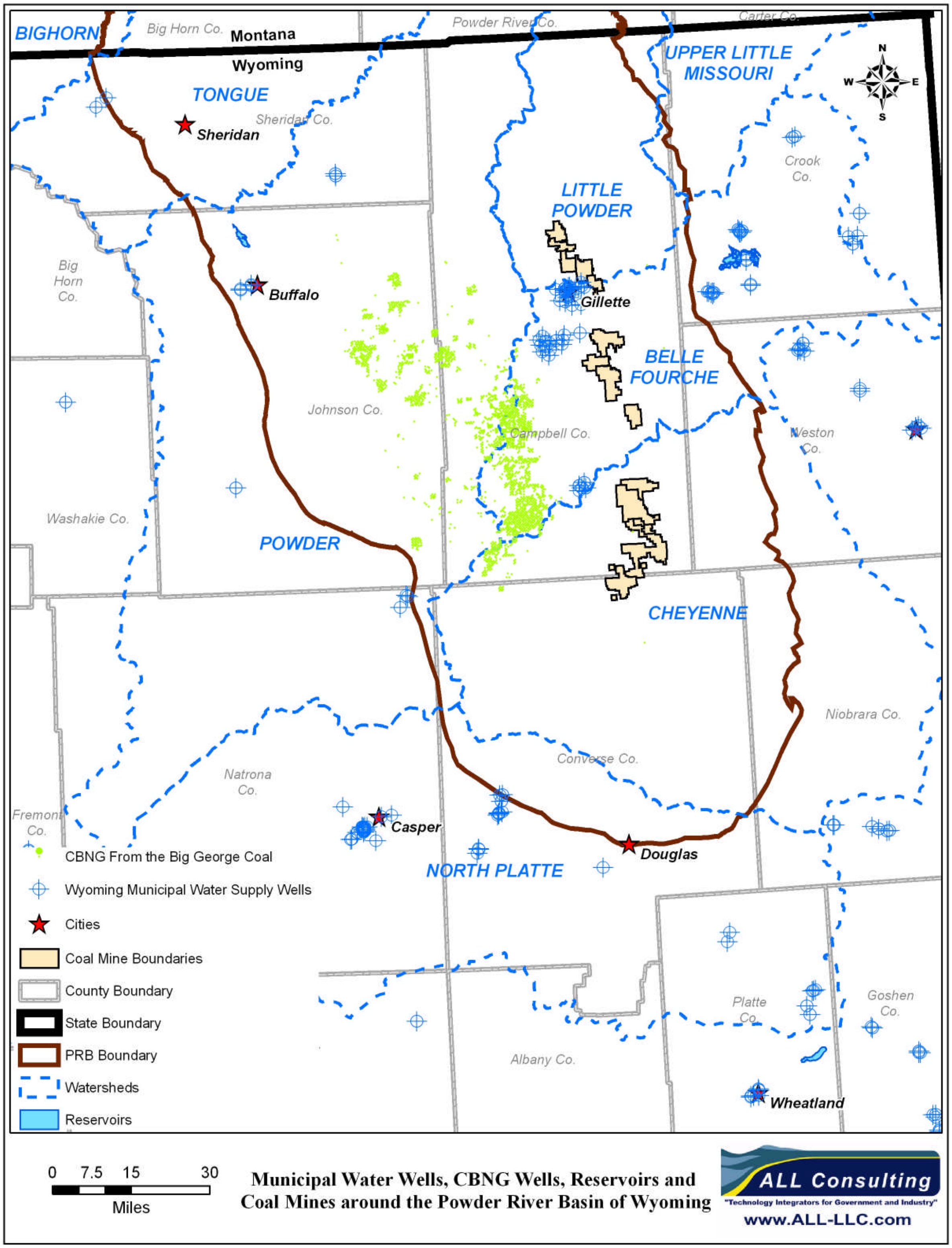
Non-Technical Barriers to Implementation: If the pipeline connecting CBNG project to city or town needing water were to cross from one watershed to another, residents of the former may protest the removal of the water from their resource base.

Technical Feasibility: Research for this feasibility study has not shown any evidence that CBNG water has been used to directly supply a public water system (excluding aquifer recharge). It is possible that some cities have used CBNG produced water as "raw water" for municipal uses such as parks and grounds but the records are not known (Boyce, 2005).

Big George water quality is low for CBNG water and exceeds the national secondary standard for TDS (250 mg/L). Big George water would need to be desalinized for it to be suitable for drinking water. Technologies and costs involved in the various treatment techniques are detailed in the treatment and discharge option above.

Figure 12: Big George CBNG Production and Public Water Supply Wells

This map shows the relationship between locations of CBNG wells and public water supply wells in the PRB



There is an extensive regulatory burden placed upon public water suppliers because they can have a direct bearing on the health of thousands of people. The regulations would be the same whether the water supply would be from groundwater wells or CBNG producing facilities. The regulatory burden, however, would be upon the municipality, not the CBNG operator.

Economic Feasibility: Capital costs for transportation are expected to be approximately $43,000 per inch-mile. Operating costs are expected to only include pumping costs. Economics of this option are difficult to predict but will likely be less than $0.10/bbl (Jackson and Myers, 2002).

Environmental Concerns: Few environmental risks are seen to this option.

Potential Volume Capability: The City of Gillette uses an average total of 100,000 bpd in its system. The Town of Buffalo uses an average total of 20,000 bpd. It is unlikely, however, that either city would use Big George CBNG produced water to supply all their water needs. Big George produced water would need to receive costly treatment. Rather than replace the entire needs of the municipality, any volume over 10% would likely be seen as not being economically feasible.

Timing Issues: Installation of the pipeline from CBNG project to the water plant will be of varying length but its installation will be routine. The municipal water department will likely require additional time to plan for storage and treatment prior to usage. Few risks to the timetable will be expected.

12. Discharge to Reservoirs

The area around the Powder River Basin is home to three public reservoirs – De Smet, Keyhole, and Greyrocks. CBNG water can be transported directly to public reservoirs if they are in need of water for other uses including the building of the minimum pool.

Description: There are several reservoirs within and around the PRB; in some ways all of these reservoirs have been impacted by the prolonged drought (Lawson, 2005). In some cases the reservoirs have reduced in size so that allocated resources such as fisheries, municipal water, and irrigation water have not been available to their allotted volume. Water is needed within those reservoirs. CBNG can be a source of that reservoir-fill if the produced water is compatible with the water in the reservoir.

Potential Benefits: CBNG produced water may allow reservoir managers the latitude of releasing more water to downstream users of can allow the retention of more water in the reservoir to maintain valuable fisheries or other aquatic life. Reservoir storage can benefit many rural and urban citizens and businesses.

Non-Technical Barriers to Implementation: If the pipelines connecting the CBNG production to a particular reservoir were to cross from one watershed to another, residents of the former may protest the removal of the water from their resource base. This is very likely to cause public concern for water rights and water ownership (Yates, 2005 and Lawson, 2005). Water ownership issues may be straightened out by involvement of state governmental authorities or public outcry may prove to be more powerful (Besson, 2005).

Water ownership issues can be very important in a regulatory scheme. This is especially true with Big George water, which is often produced on BLM-managed lands (Beels, 2006). If federally-owned produced water is involved, the planning documents are required by the National Environmental Protection Act (NEPA) including Environmental Assessments (EA) and Environmental Impact Statements (EIS). Any discharge of federal water will involve NEPA.

Technical Feasibility: CBNG discharge to reservoirs does not seem to have occurred in the Wyoming PRB but is happening in adjacent areas. Just to the north in the Montana portion of the basin, CBNG is being discharged to waters that drain into the Tongue River Reservoir where a small amount of untreated CBNG water is allowed under a MPDES discharge permit (Williams, 2005). And in Carbon County Wyoming, the Seminoe Reservoir receives a small amount of CBNG discharge from Green River Basin production (Lawson, 2005).

The ability to discharge CBNG water into public reservoirs is a function of the compatibility of the water quality in both the particular reservoir and the CBNG discharge stream. At the same time, the volume of the permitted discharge is a function of flow rate in the stream. The watersheds containing the reservoirs will determine how much, or if any water can be discharged. The Belle Fourche watershed contains the Keyhole Reservoir. The North Platte watershed contains the Greyrocks Reservoir. The De Smet Reservoir empties into the Powder River watershed. It will be the responsibility of the CBNG operator to demonstrate that each of these watersheds can accept a meaningful flow of produced water without degradation in beneficial use of the reservoir water.

Economic Feasibility: Capital costs of this option are high, requiring the construction of a pipeline to the particular reservoir. Figure 1 illustrates the location of the three reservoirs and the Big George CBNG production. Big George production is widely separated from all three reservoirs. Pipelines to transport the CBNG produced water are expected to average approximately $43,000 per inch-mile, but actual costs may vary. Permitting and construction costs for the pipeline will depend on the location of the CBNG producing wells and the particular reservoir. Economics of this option are hard to predict but will likely be in the range of $0.10/bbl to $0.20/bbl (excluding transportation).

Environmental Concerns: The discharge of CBNG water, especially Big George water, may be deleterious to some forms of biota indigenous to the particular reservoir. The De Smet reservoir is very high quality water although quality does vary with depth, location, and season of the year (Yates, 2005). Reservoir water quality will need to be thoroughly documented prior to receiving the WPDES discharge permit. Discharge will be limited by the WDEQ to those days when discharge will not degrade the water in the reservoir (Wagner, 2005). In addition, discharge volumes will be a concern. Increased outflow below the reservoir, even though it is required for allotted irrigation use, could result in changes to the riparian ecosystem and may prevent the reservoir managers from accepting the CBNG produced water (Yates, 2005). The benefits and costs of discharge to the particular reservoir will need to be analyzed in terms of environmental protection.

Potential Volume Capability: The capacity and needs of each reservoir will differ from the others but as an example, the entire Platte River drainage is short of water by between 25,000 AF and 125,000 AF (500,000 bpd to 2.6 million bpd) (WDC, 2005). Lake De Smet discharges approximately 22,000 AF (170 million bbls) every year to irrigators (Yates, 2005); just to replace that amount of water would require approximately 470,000 bpd from CBNG production into Lake De Smet. These volumes are many times that projected from the hypothetical Big George field of 100 wells and 150,000 bpd of water production.

Timing Issues: Installation of the pipeline from the CBNG project to the reservoir will take time in relation to the length of the line, but its installation will be routine for cross-country pipelines. Permitting is expected to be more drawn out than permitting for a similar natural gas line. Delays are certainly possible when the pipeline crosses federal holdings. The more important factor is the potential for extended delays caused by the public perception that water is leaving one watershed and being delivered to another; this inter-basin transfer of water will be likely to have political implications.

13. Coal Slurry Pipeline

The option of using CBNG produced water as a transport media in coal slurry pipelines was suggested by the feasibility study committee. The concept of coal slurry pipelines has been around for some time with a large feasibility study being performed in 1978 by the Office of Technology Assessment (OTA, 1978). This study was used to develop an alternative to transporting coal long distances by railroads. Included in the study were four proposed pipeline systems, including one that transported coal from Wyoming coal mines to power plants near Houston, Texas. The study identified several barriers and hurdles that would need to be overcome. The main ones included political and legal issues involved with water rights, limited water supplies, eminent domain, right-of-way, and high costs of construction. This option was considered for this feasibility study, but was not considered a very viable option because of all of these issues. Conversations with cooperators also led to this not being a practical option at this time.

Description: Coal slurry pipelines transport coal from mine to power plant, often over very long distances. The coal is ground to the size of granulated sugar and mixed with an about equal amount of water; the resulting slurry is then pumped through a buried pipeline (from 4 inches to 3 ft in diameter), with pumping stations every 50 to 150 miles, depending on the pipe diameter and the terrain. At the destination, the slurry is "dewatered;" the coal can be stored, transported by other means, or introduced directly into a power plant or other user's system. The water, too, can be used at the receiving end, for example, as coolant for the same power plant.

Potential Benefits: CBNG water used in coal slurry pipelines could provide a very large source of beneficial use for the water. The pipelines would require large quantities of water that the CBNG industry could help provide. The water could also be used at the receiving end by the power plants for cooling or other beneficial uses.

Non-Technical Barriers to Implementation: Pipelines connecting CBNG projects to coal mines and the coal slurry pipelines will need to be permitted and constructed to safely convey the water and slurry. If the pipeline were to cross from one watershed to another or to another state, residents of the former may protest the removal of the water from their resource base, and water rights issues will need to be resolved for interstate transfer of the water. This would most likely need to be resolved through the state and federal regulatory process. Under the prior appropriation system for water allocation in many Western States, slurry pipelines, like any new applications of water, are accorded a lower priority relative to existing rights. The use of the power of eminent domain may cause problems and delays for accessing property and right-of-way for the coal slurry pipeline infrastructure. The extremely high cost for construction of the pipeline would also be a prohibitive factor, along with whom or what entity would own and operate the pipeline.

Technical Feasibility: Technologically, slurry pipelines are proven. The Black Mesa pipeline from the Four Corners area across the breadth of Arizona to the southern point of Nevada is already operating and is the only coal slurry pipeline in operation in the US. The pipeline is a 273-mile, 18-inch diameter coal slurry pipeline that originates at a coal mine in Kayenta, Arizona. The coal slurry pipeline transports crushed coal suspended in water. It traverses westward through northern Arizona to the 1,500-megawatt Mohave Power Station located in

Laughlin, Nevada. The coal slurry pipeline is the sole source of fuel for the Mohave Power Station, which consumes an average of 4.8 million tons of coal annually.

Normal slurry pipeline design and construction would be used, which is well known. If saline water were to be used in a coal slurry pipeline, the main problem for the system itself would be increased corrosivity in the presence of high-dissolved solids concentrations. Increased use of corrosion inhibitors may be required. Suspension of finely divided coal in water with high sodium concentrations may cause, through an ion exchange, an increase in sodium bound to the coal surface, resulting in fouling problems when the coal is burned (OTA, 1978).

Since coal slurry pipelines require large volumes of water, alternate sources of water would need to be acquired and planned for, especially as the volume of CBNG produced water declines over time. Once the water reaches the power plants, there will be the problem of determining how to use, treat or dispose the transport water.

Economic Feasibility: Capital costs of this option are very high, requiring the construction of a pipelines from the CBNG fields to the coal mines and from the coal mines to the power plants, which will most likely be in different states such as Texas, as proposed by the OTA. Permitting and construction costs for the pipeline will depend on the location of the CBNG producing wells and the target power plants. Economics of this option were not developed since this option is not thought to be feasible.

Environmental Concerns: Compliance with NEPA will be triggered if pipeline construction involves any major federal action which significantly affects the environment, which would involve an EIS. Other concerns would be those related to typical pipelines, such as leaks and spills.

Potential Volume Capability: Based on the OTA (1978) proposed Wyoming-Texas pipeline, transporting 35 million tons of coal per year from eastern Wyoming by pipeline would require up to 19,000 acre-feet of water per year, or about 400,000 bpd.

Timing Issues: Installation of the pipeline from CBNG projects to the power plants will take considerable amounts of time to plan and construct. It is estimated to take at least three years to construct a pipeline such as the one from the PRB to Texas, and at least eight to ten years in the legal system prior to construction.

III. SUMMARY AND CONCLUSIONS

A total of thirteen (13) water management options have been evaluated relative to their feasibility for use in managing CBNG produced water in the Wyoming portion of the PRB. The analysis performed has been aimed primarily towards current and future production from the Big George coal seam (currently 470,000 bwpd) and also existing and future CBNG production from other coals. Current water production in the Wyoming portion of the basin amounts to approximately 550 million barrels of water per year and could increase if development is able to continue.

The 13 management alternatives discussed herein have a wide range of costs (capital and operating), technical and non-technical barriers, benefits, and timing factors. Some of the options are used today in the PRB; others may have been attempted by individual operators, while still others have yet to have been attempted. Many of the options considered in this feasibility study are not being used or have not been attempted for a variety of reasons, including such factors as high capital costs, long-term water supply requirements, or technical feasibility concerns.

Table 3 presents a summary of findings that describe each of the various alternatives evaluated as well as the concept large-scale pipelines that could be used by multiple operators. For summary purposes, feasibility details for each alternative have been generally defined for a series of categories. Because the alternatives considered are largely unproven on a large-scale basis, Table 3 serves to compliment detailed discussion presented in Section 2 while providing a comparison of each of the various alternatives considered.

Table 3: Comparison of Water Management Alternatives

This table presents a summary of findings resulting from the feasibility study of water management alternatives in the Wyoming portion of the PRB.

Management Option	Technical Feasibility	Non-Tech Feasibility	Potential Individual Capacity	Potential Overall Capacity	Capital Costs	Pipeline Costs	Operating Costs	Timing
Class v Injection Shallow Sands	Low	High	Low	Low	Low	Low	Med	< 6 mo
High Pressure Class V Injection	Unknown	Med	Unknown	Unknown	Low	Low	Med	< 1 yr
Class V Re-Injection into Coals	Unknown	High	Unknown	Unknown	Low	High	Med	> 1 yr
Class IID Injection	High	High	Med	Low	High	High	Med	> 1 yr
Class IIR Injection	High	High	Med	Low	Med	High	Med	> 1 yr
Treatment	Low	High	Low	Low	High	Low-Med	High	< 1 yr
Dust Control	High	High	High	High	Low	High	Low	> 1 yr
Cooling Water	High	High	High	High	Low	High	Low	> 1 yr
Subsurface Drip-Irrigation	Med	Med	Low	Med	Med	Low	Med	< 1 yr
Feed Lots	Med	Med	Low	Low	Med	Unknown	Unknown	Unknown
Public Water Supply	Med	Low-Med	Med	Low	Med	High	Varies	> 3 yr
Public Reservoirs	High	Med	High	High	Med-High	High	Low	> 3 yr
Coal Slurry Pipelines	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

The factors shown in Table 3 and the others discussed above can be used to rank the options. For example, if timing is the most important factor, shallow Class V injection may be one of the most attractive options – even through this option has limited capacity. Conversely, those options which appear to have the greatest potential to manage large volumes of water (e.g., cooling at power plants, dust control at coal mines, reservoirs, etc.) also take the largest amount of time to implement. Further, large capacity options generally include large capital investment, the need for multi-operator coordination, high transportation costs (e.g., large-scale pipelines), significant non-technical barriers (e.g., inter-basin transfer of water), and other issues that could further extend the time required for implementation.

Findings from the study suggest that volume is the most important consideration in evaluating the feasibility of alternatives considered. Currently there is approximately 550 million barrels of water per year requiring management and that figure could increase if development expands. Of the total water produced in Wyoming portion of the PRB from CBNG development, approximately 30 percent originates from Big George coals in the western and central portion of the basin. Considering current and future water production volumes combined with Montana's proposed new rules, three options stand out as having the feasibility to meet Wyoming's current and future water management needs. These options include dust suppression at coal mines, cooling water for power plants, and discharge to public reservoirs.

Each of the three options noted above require pipelines of considerable length – from areas of Big George production to coal mines in the east part of the basin, to power plants near the coal mines, and to public reservoirs. The concept of constructing and implementing large-scale pipeline systems would be a considerable task, perhaps taking years to put in-place. Long pipelines in the PRB may cross flat and rugged terrain. In addition, streams and rivers may need to be crossed. All of these issues will affect the costs of particular pipelines. As an estimate, representatives from Marathon and Williams provided rule-of-thumb cost estimates for area pipelines, which was approximately $43,000 per inch-mile (Skinner, 2005 and Tomlinson, 2005). This rule-of-thumb figure compares closely with detailed costs estimates performed by Anadarko Petroleum Corporation for a 49 mile pipeline proposed from their County Line project to the Salt Creek oilfield near Midwest, Wyoming (Cline, 2005). Although Anadarko's pipeline is not yet built, using the rule-of-thumb figures provided by Marathon and Williams appears reasonable.

Using the above referenced rule-of-thumb estimate, large-scale pipelines could range in cost from $150 million to well over $200 million, depending on size and length. A pipeline from the Big George production area to the Greyrocks Reservoir would require a pipeline approximately 160 miles in length at a construction cost of approximately $170 million. However, this cost does not include design, environmental permitting, any federal issues that would have to be addressed, water rights issues, water treatment (if required), costs of individual operator water gathering lines, management and maintenance of the pipeline, public outreach, and a host of other issues and challenges that would likely be required to make a pipeline such as this a reality.

In addition to the high-volume options discussed above, there are two other little-used options that appear to be worth pursuing on a state-wide basis. These alternatives include high pressure Class V injection and subsurface drip irrigation. Both options are new to the basin and new to the CBNG industry. Both options are regulated as Class V injection systems and appear to be permitable with existing WDEQ regulations. Although obtaining individual permits from the WDEQ may be time-consuming, these options have the potential to be put in-place in less time than the high-volume alternatives discussed above. In order to make these options more feasible to the CBNG industry, a general permit format could be considered by the state. Further analysis of a general permitting option for injection could be considered in the second phase of this study.

IV. RESEARCHERS

ALL Consulting served as the researcher for the subject feasibility study. Lead researchers involved in the study are presented below, although several staff members from ALL Consulting and many individuals and companies contributed to this study.

J. Daniel Arthur, P.E. is Managing Partner of ALL Consulting and the Project Manager of the Feasibility Study. Mr. Arthur earned a Petroleum Engineering degree from the University of Missouri-Rolla and a registered Professional Engineer in Wyoming as well as other states. He has been involved in CBNG projects since the late 1980s.

Bruce Langhus, Ph.D., C.P.G. is the Chief Geologist at ALL Consulting and founding member of the firm. He is a Geologist with 40 years experience with oil and gas and environmental issues. He has been the lead Geologist/Hydrogeologist on CBNG research issues regarding the beneficial use of CBNG produced water as well as on many issues dealing with NEPA and federal access issues.

David Epperly, Ph.D., P.E. is a partner in ALL Consulting and a Senior Project Engineer. He earned his degrees in Agricultural Engineering from Oklahoma State University with experience in irrigation systems, soil science, managed irrigation, water resources management and environmental engineering.

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VI. APPENDIX

I Groundwater Classification

Section 4. Quality Standards Prescribed; Groundwaters of the State Classified.

(a) Standards are prescribed to protect the natural quality of underground water:

(i) Receiving pollution or wastes directly from a subsurface discharge or by migrating water or fluid of a discharge;

(ii) Invaded by underground water of inferior quality as a result of well or exploration hole drilling or completion practices;

(iii) From pollution which may result from aboveground facilities capable of causing or contributing to pollution;

(iv) From pollution which may result from surface mining operations.

(b) Groundwaters of the State are classified in order to apply standards to protect water quality. Groundwaters of the State are classified by use, and by ambient water quality.

(c) Waters which are known sources of supply and appropriated for uses identified in W.S. 35-11-102 and 103(c)(i) are classified herein as: Domestic water; Water for fish and aquatic life; Water for agriculture; Water for livestock; and, Water for industry. A discharge or activity that impacts an underground source of water for existing uses identified in W.S. 35-11-102 and 103(c)(i) shall not make the affected water unsuitable for its intended use or uses, at any place or places of withdrawal or natural flow to the surface.

(d) Unappropriated waters are classified by ambient water quality.

(i) Class I Groundwater of the State – This water is suitable for domestic use. The ambient quality of underground water of this suitability does not have a concentration in excess of any of the standards for Class I Groundwater of the State (see Table I, page 9).

(ii) Class II Groundwater of the State – This water is suitable for agricultural use where soil conditions and other factors are adequate. The ambient quality of underground water of this suitability does not have a concentration in excess of any of the standards for Class II Groundwater of the State (see Table I, page 9).

(iii) Class III Groundwater of the State – This water is suitable for livestock. The ambient quality of underground water of this suitability does not have a concentration in excess of any of the standards for Class III Groundwater of the State (see Table I, page 9).

(iv) Class Special (A) Groundwater of the State - This water is suitable for fish and aquatic life. The ambient quality of underground water of this suitability does not have a concentration in excess of any of the standards for Class Special (A) Groundwater of the State (see Table I, page 10).

(v) Underground water of Class I, II, III or Special (A) shall not contain biological, hazardous, toxic or potentially toxic materials or substances in concentrations or amounts which exceed maximum allowable concentrations based upon information of the EPA in the Federal

Register for December 24, 1975 (Part IV), Water Programs, National Interim Primary Drinking Water Regulations; and in the Federal Register for March 13, 1978 (Part II), Water Programs,Hazardous Substances. In addition, underground water of Class I, II, III or Special (A) shall not contain any biological, hazardous, toxic or potentially toxic materials or substances in concentrations or amounts which, based upon the latest available scientific information and as determined by the Administrator, will impair this water for its use suitability or which may contribute to a condition in contravention of groundwater quality standards or to any toxic or hazardous effect on natural biota.

(vi) A discharge into an aquifer containing Class I, II, III or Special (A) Groundwater of the State shall not result in variations in the range of any parameter, or concentrations of constituents in excess of the standards of these regulations at any place or places of withdrawal or natural flow to the surface. A discharge which results in concentrations in excess of standards shall be permitted if post-discharge water quality can be returned to a quality of use equal to, or better than, and consistent with the uses for which the water was suitable prior to the operation.

(vii) Class IV Groundwater of the State – This water is suitable for industry. The quality requirements for industrial water supplies range widely and almost every industrial application has its own standards.

(A) Class IV (A) Groundwater of the State has a total dissolved solids concentration not in excess of 10,000 mg/L.

(B) Class IV (B) Groundwater of the State has a total dissolved solids concentration in excess of 10,000 mg/L.

(C) A discharge into an aquifer containing Class IV (A) or IV (B) Groundwater of the State shall not result in the water being unfit for its intended use.

(D) A discharge into an aquifer with Class IV (A) or IV (B) Groundwater of the State shall not result in oil and grease concentrations in excess of 10 mg/L or a lesser amount if a concentration in excess of the lesser amount is determined to be toxic; or oil and grease in excess of background concentrations of the underground water, whichever is greater, at any place or places of withdrawal or natural flow to the surface.

(E) A discharge into an aquifer with Class IV (A) or IV (B) Groundwater of the State shall not result in radioactivity concentrations or amounts which exceed the standards for Class I through III and Special (A) Groundwaters of the State; or in concentrations or amounts which exceed background concentrations of the underground water, whichever is greater, at any place or places of withdrawal or natural flow to the surface.

(F) A discharge into an aquifer with Class IV (A) or IV (B) Groundwater of the State shall not result in biological, hazardous, toxic or potentially toxic materials or substances including pesticides, insecticides or herbicides in concentrations or amounts which exceed maximum allowable concentrations, based upon information of the EPA in the

Federal Register for December 24, 1975 (Part IV), Water

Programs, National Interim Primary Drinking Water Regulations, and in the Federal Register for March 13, 1978 (Part II), Water Programs, Hazardous Substances; or which exceed background concentrations of the underground water, whichever is greater, at any place or places of withdrawal or natural flow to the surface. In addition, a discharge shall not result in any biological, hazardous, toxic or potentially toxic materials or substances, in concentrations or amounts which, based on the latest available scientific information and as determined by the Administrator, will impair the quality of ambient groundwaters of the State of this Class; or which may contribute to a condition in contravention of groundwater quality standards or cause, allow or permit any deleterious effect on natural biota.

(viii) Groundwater of the State found closely associated with commercial deposits of hydrocarbons and/or other minerals, or which is considered a geothermal resource, is Class V (Hydrocarbon Commercial), Class V (Mineral Commercial) or Class V (Geothermal) Groundwater of the State.

(A) A discharge into a Class V (Hydrocarbon Commercial) Groundwater of the State shall be for the purpose of the production of oil and gas and shall not result in the degradation or pollution or waste of other water resources.

(B) A discharge into a Class V (Mineral Commercial) Groundwater of the State shall be for the purpose of mineral production and shall not result in the degradation or pollution of the associated or other groundwater and, at a minimum, be returned to a condition and quality consistent with the pre-discharge use suitability of the water.

(C) A discharge into a Class V (Geothermal) Groundwater of the State shall be for the purpose of the production of geothermal resources and shall not result in the degradation or pollution or waste of other water resources.

(ix) Class VI Groundwater of the State may be unusable or unsuitable for use:

(A) Due to excessive concentration of total dissolved solids or specific constituents; or

(B) Is so contaminated that it would be economically or technologically impractical to make the water useable; or

(C) Is located in such a way, including depth below the surface, so as to make use economically and technologically impractical.

Section 5. Classification for Groundwater of the State Affected by a Discharge; Classification by Aquifer and Area.

(a) Classification of groundwaters of the State shall be based on the water quality standards of this chapter; excepting, a Class I Groundwater of the State shall be classified by ambient water quality and the technical practicability and economic reasonableness of treating ambient water quality to meet use suitability standards.

(b) Underground water quality shall be classified for an aquifer which is or may be affected by a subsurface discharge or other activity identified in Section 4.a. of these regulations.

(c) Classification shall be made:

(i) Whenever there is pollution or the threat of pollution to a groundwater of the State; or

(ii) The physical, chemical, radiological or biological properties of any groundwater of the State are or may be altered by man's action.

(d) Classification shall be for a water in a specified locally defined area by named and described aquifer or receiver. Any aquifer or receiver in its regional setting may have one or more classifications by defined area or areas.

(i) The name shall be a recognized geologic name whenever possible;

(ii) The description shall include a lithologic description.

(e) The lateral and vertical limits of an aquifer or receiver, for purposes of classification, shall be based on existing water use, ambient water quality and geologic and hydrologic characteristics of the aquifer or of the receiver.

(f) An underground water may be reclassified if new or additional data warrant reclassification.

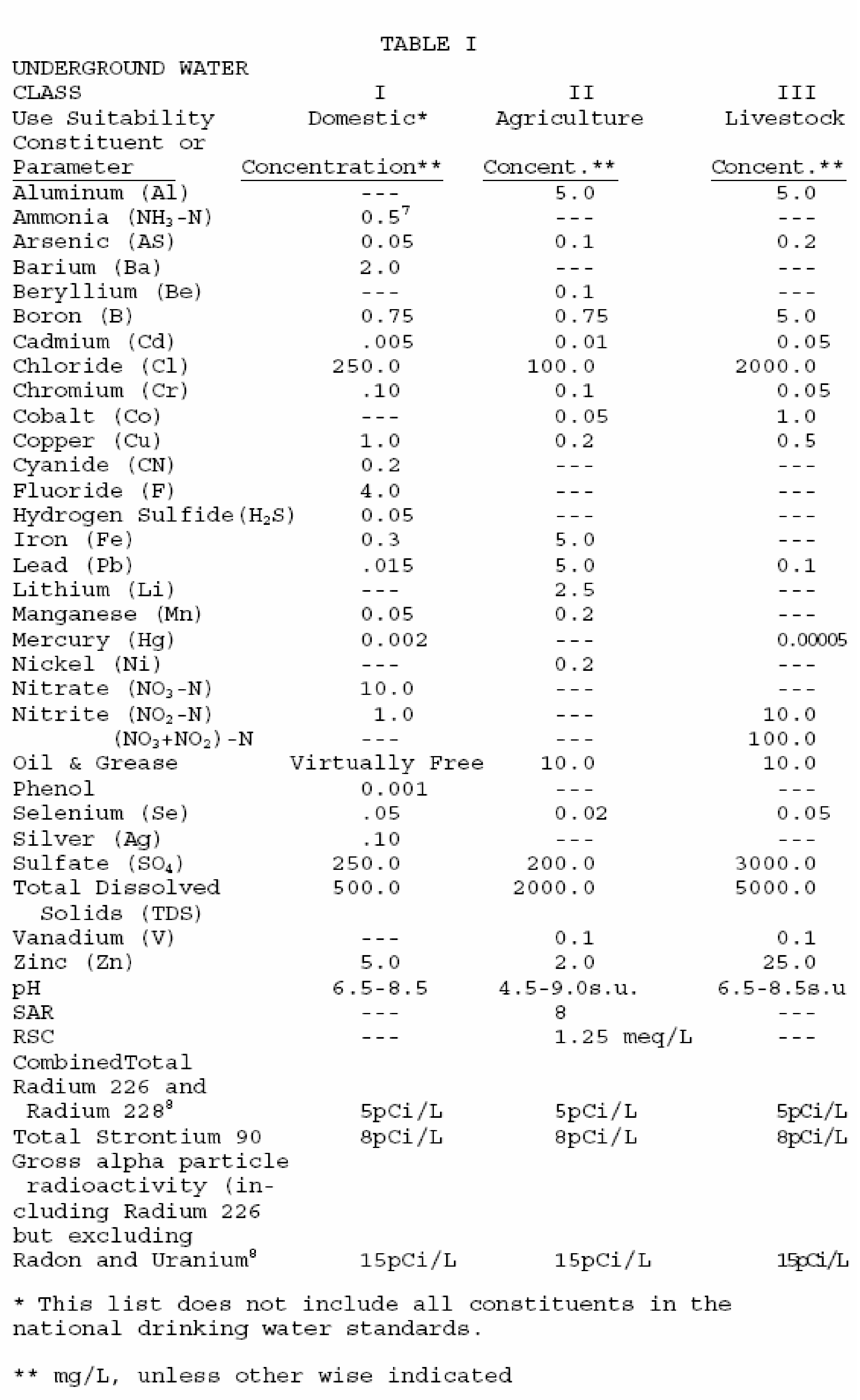

TABLE I

UNDERGROUND WATER CLASS	I	II	III
Use Suitability	Domestic*	Agriculture	Livestock
Constituent or Parameter	Concentration**	Concent.**	Concent.**
Aluminum (Al)	---	5.0	5.0
Ammonia (NH_3-N)	0.5[7]	---	---
Arsenic (AS)	0.05	0.1	0.2
Barium (Ba)	2.0	---	---
Beryllium (Be)	---	0.1	---
Boron (B)	0.75	0.75	5.0
Cadmium (Cd)	.005	0.01	0.05
Chloride (Cl)	250.0	100.0	2000.0
Chromium (Cr)	.10	0.1	0.05
Cobalt (Co)	---	0.05	1.0
Copper (Cu)	1.0	0.2	0.5
Cyanide (CN)	0.2	---	---
Fluoride (F)	4.0	---	---
Hydrogen Sulfide(H_2S)	0.05	---	---
Iron (Fe)	0.3	5.0	---
Lead (Pb)	.015	5.0	0.1
Lithium (Li)	---	2.5	---
Manganese (Mn)	0.05	0.2	---
Mercury (Hg)	0.002	---	0.00005
Nickel (Ni)	---	0.2	---
Nitrate (NO_3-N)	10.0	---	---
Nitrite (NO_2-N)	1.0	---	10.0
(NO_3+NO_2)-N	---	---	100.0
Oil & Grease	Virtually Free	10.0	10.0
Phenol	0.001	---	---
Selenium (Se)	.05	0.02	0.05
Silver (Ag)	.10	---	---
Sulfate (SO_4)	250.0	200.0	3000.0
Total Dissolved Solids (TDS)	500.0	2000.0	5000.0
Vanadium (V)	---	0.1	0.1
Zinc (Zn)	5.0	2.0	25.0
pH	6.5-8.5	4.5-9.0s.u.	6.5-8.5s.u
SAR	---	8	---
RSC	---	1.25 meq/L	---
CombinedTotal Radium 226 and Radium 228[8]	5pCi/L	5pCi/L	5pCi/L
Total Strontium 90	8pCi/L	8pCi/L	8pCi/L
Gross alpha particle radioactivity (including Radium 226 but excluding Radon and Uranium[9]	15pCi/L	15pCi/L	15pCi/L

* This list does not include all constituents in the national drinking water standards.

** mg/L, unless other wise indicated

TABLE I

UNDERGROUND WATER CLASS Use Suitability Constituent or Parameter	Special (A) Fish/Aquatic Life Concentration*
Aluminum (Al)	0.1
Ammonia (NH_3)	0.02[1]
Arsenic (As)	0.05
Barium (Ba)	5.0
Beryllium (Be)	0.011-1.3[3]
Boron (B)	---
Cadmium(Cd)	0.0004-0.015[3]
Chloride (Cl)	---
Chromium (Cr)	0.05
Cobalt (Co)	---
Copper (Cu)	0.01-0.04[3]
Cyanide (CN)	0.005
Fluoride (F)	---
Hydrogen Sulfide (H_2S)	0.002[2]
Iron (Fe)	0.5
Lead (Pb)	0.004-0.15[3]
Lithium (Li)	---
Manganese (Mn)	1.0
Mercury (Hg)	0.00005
Nickel (Ni)	0.05-0.4[3]
Nitrate (NO_3-N)	---
Nitrite (NO_2-N)	---
(NO_3+NO_2-N	---
Oil & Grease	Virtually free
Phenol	0.001
Selenium(Se)	0.05
Silver(Ag)	0.0001-0.00025[3]
Sulfate (SO_4)	---
TotalDissolvedSolids(TDS)	500.0[4]-1000.0[5]-2000.0[6]
Uranium (U)	0.03-1.4[3]
Vanadium (V)	---
Zinc (Zn)	0.05-0.6[3]
pH	6.5s.u.-9.0s.u.
Combined Total Radium 226 and Radium 228[8]	5pCi/L
Total Strontium 90	8pCi/L
Gross alpha particle radioactivity (including Radium 226 but excluding Radon and Uranium[8]	15pCi/L

*mg/L, unless other wise indicated

Explanation for Superscripts Used in Table I

[1] Unionized ammonia: When ammonia dissolves in water, some of the ammonia reacts with water to form ammonium ions. A chemical equilibrium is established which contains unionized ammonia (NH_3), ionized ammonia (NH_4^+) and hydroxide ions (OH^-). The toxicity of aqueous solutions of ammonia is attributed to NH_3; therefore, the standard is for unionized ammonia. (Note: 0.02 mg/L NH_3 is equivalent to 0.016 NH_3 as N.)

[2] Undissociated H_2S: The toxicity of sulfides derives primarily from H_2S, rather than from the dissociated (HS) or (S) ions; therefore, the standard is for the toxic undissociated H_2S.

[3] Dependent on hardness: The toxicity of metals in natural waters varies with the hardness of the water; generally, the limiting concentration is higher in hard water than in soft water.

[4] Egg hatching

[5] Fish rearing

[6] Fish and aquatic life

[7] Total ammonia nitrogen

[8] Requirements and procedures for the measurement and analysis of gross alpha particle activity, Radium 226 and Radium 228 shall be the same as requirements and procedures of the U.S. Environmental Protection Agency, National Interim Primary Drinking Water Regulations, EPA-570/9-76-003, effective June 24, 1977.

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Section 6. Standards for the Underground Management of Hazardous or Toxic Wastes. The underground management of wastes includes the temporary storage and the ultimate disposal of all hazardous or toxic wastes in below-surface receivers. The following standards apply to any underground storage or disposal of hazardous or toxic wastes.

(a) The below-surface receiver:

(i) Is an extensive sedimentary rock stratum or strata free of complex faulting and folding and distant from any underground water recharge area;

(ii) Is adequately separated from aquifers both above and below;

(iii) Has normal or low formation pressure and is capable of accepting the discharge without necessitating excessive discharge or injection pressure;

(iv) Has slow movement of ambient formation fluid under the natural horizontal gradient and is not in an area of underground water discharge for the receiver;

(v) Is located areally and stratigraphically so that an escape of waste to useable water resources would not be anticipated due to:

(A) Seismic risk;

(B) Abandoned holes; or

(C) Mineral exploration or other drilling,

or mineral development.
(b) The underground water in the receiver;
(i) Is not an economically available source of water or is unusable;
(ii) Is confined by strata overlying and underlying the receiver; and
(iii) Is classified as class IV groundwater by this chapter.
(c) The discharge or waste:
(i) Will not create or result in a hazard to health or impair existing rights, and is not prohibited from subsurface disposal by Federal or State law or regulation;