Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives

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National Petroleum Technology Office
Bureau of Land Management

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Acronyms and Abbreviations

ADEM	Alabama Department of Environmental Management
AFO	Animal Feeding Operation
AOR	area of review
ARM	Administrative Rules of Montana
Argonne	Argonne National Laboratory
ARS	Agricultural Research Service
BCF	billion cubic feet
bgs	below ground surface
BLM	U.S. Bureau of Land Management
BMP	Best Management Practice
BPJ	best professional judgment
BTU	British thermal unit
bwpd	barrels of water per day
Ca	calcium
CAA	Clean Air Act
CAFO	Concentrated Animal Feeding Operation
CBM	coal bed methane
CD	capacitive desalination
CDPHE	Colorado Department of Public Health and Environment
CDWR	Colorado Drinking Water Division
CEC	cation exchange capacity
CFR	Code of Federal Regulations
CFS	cubic feet per second
CGWA	controlled groundwater areas
CH_4	methane
Cl	chloride
CO	carbon monoxide
CO_2	carbon dioxide
COE	U.S. Army Corps of Engineers
COGCC	Colorado Oil & Gas Conservation Commission
CWA	Clean Water Act
CWQCD	Colorado Water Quality Control Division
DEQ	Department of Environmental Quality
DGGS	Division of Geological & Geophysical Surveys
DO	dissolved oxygen

Acronyms and Abbreviations (Continued)

DOE	U.S. Department of Energy
DNRC	Department of Natural Resources and Conservation (Montana)
DPHE	Department of Public Health and Environment (Colorado)
dS/m	deciSiemens per meter
DWB	Drinking Water Bureau (New Mexico)
EA	Environmental Assessment
EC	electrical conductivity
ECMA	East-Central (coal bed) Methane Area
EDR	electrodialysis reversal
EIS	Environmental Impact Statement
ELG	effluent limitations guideline
EPA	U.S. Environmental Protection Agency
ESP	exchangeable sodium percentage
ET	evapotranspiration
FR	Federal Register
FTE	Freeze-Thaw/Evaporation
GIS	geographical information system
gpm	gallons per minute
GRI	Gas Research Institute
GTI	Gas Technology Institute
GWIC	Ground-Water Information Center
GWPC	Ground Water Protection Council
GWPRF	Ground Water Protection Research Foundation
HOCL	hypochlorous acid
H_2S	hydrogen sulfide
ip	initial production
kW	kilowatt
LEPA	Low Energy Precision Application
MBMG	Montana Bureau of Mines & Geology
MBOGC	Montana Board of Oil & Gas Conservation
MCA	Montana Code Annotated
MCF	thousand cubic feet
MCLG	maximum contaminant level goals
MCL	maximum contaminant level
MDEQ	Montana Department of Environmental Quality

Acronyms and Abbreviations (Continued)

Mg	magnesium
mg/l	milligrams per liter
MIT	mechanical integrity test
MMB	Minerals Management Bureau
MMCFD	million cubic feet per day
MPDES	Montana Pollutant Discharge Elimination System
MOA	Memorandum of Agreement
mS	millisiemens
µS	microsiemens
MWRB	Montana Water Resources Division's Water Rights Bureau
Na	sodium
NDGS	North Dakota Geological Survey
NDSU	North Dakota State University
NEPA	National Environmental Policy Act
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMOCD	Oil Conservation Division
NMSA	New Mexico Statutory Authority
NMWQCC	New Mexico Water Quality Control Commission
NO_2	nitrogen dioxide
NOAA	National Oceanic & Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NRCS	Natural Resources Conservation Service (USDA)
PCP	Progressing Cavity Pump
ppm	parts per million
PRB	Powder River Basin
PS	Point Source
psi	pounds per square inch
psig	pounds per square inch gauge
RCRA	Resource Conservation and Recovery Act of 1976
RO	reverse osmosis
ROD	Record of Decision
RWRCC	Reserved Water Rights Compact Commission
SAR	Sodium Adsorption Ratio
SCF	standard cubic feet

Acronyms and Abbreviations (Continued)

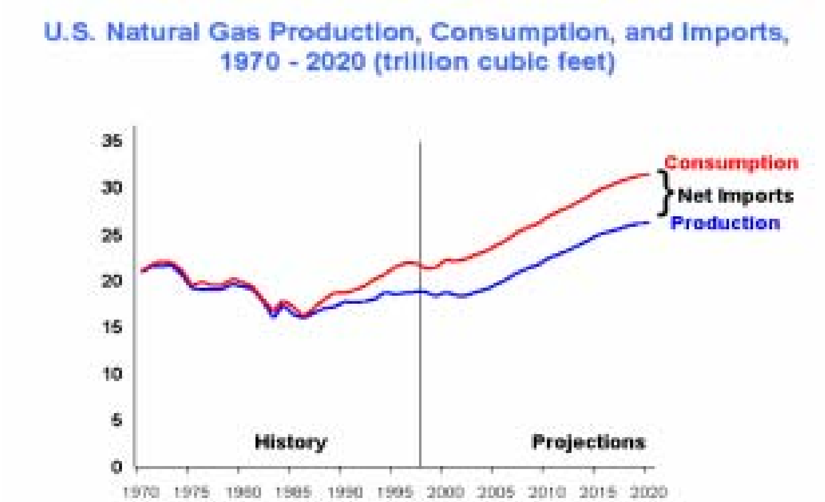
SEO	State Engineers Office
SDWA	Safe Drinking Water Act
SIC	Standard Industrial Codes
SJB	San Juan Basin
SOGC	State Oil and Gas Commission
SP	specific conductance
SWQATR	Surface Water Quality Analysis Technical Report
SWPPP	Storm Water Pollution Prevention Plan
TCF	trillion cubic feet
TDS	total dissolved solids
TMDL	total maximum daily load
TOC	total organic carbon
UDEQ	Utah Department of Environmental Quality
UDOGM	Utah Division of Oil, Gas and Mining
UIC	underground injection control
U.S.	United States
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDI	U.S. Department of the Interior
USDW	Underground Source of Drinking Water
USFS	U.S. Forest Service (USDA)
USGS	U.S. Geological Survey (USDI)
UV	ultraviolet
WAC	weak acid cation
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WIS	Western Interior Seaway
WPD	Water Permits Division
WQS	water quality standards
WQD	Water Quality Division
WOGCC	Wyoming Oil and Gas Conservation Commission
WSEO	Wyoming State Engineers Office
WYDEQ	Wyoming Department of Environmental Quality
ZOEI	zone of endangering influence

Chapter 1
Purpose and Overview

Introduction

Natural gas use in the United States has risen significantly over the past decade and is expected to continue to be a prime source of energy for industrial power and heating, as well as residential use for heating and cooking. The nationwide demand for electricity is steadily increasing and has fueled the need for natural gas to power electrical generating plants across the United States (Figure 1-1). This increased need for natural gas has prompted an increase in the exploration and production of coal bed methane (CBM) resources nationwide, as CBM represents a significant new source for natural gas production. Figure 1-2 shows coal deposits throughout the United States and estimated reserves for each coal basin. As development of CBM has broadened into many new areas, such as the Powder River Basin of Wyoming and Montana, CBM development has gained increased attention by regulators, local governments, land and resource management agencies, special interest groups, ranchers and irrigators, and landowners. This heightened awareness of CBM production has involved concerns largely related to water, ranging from the basic framework of CBM development which requires the withdrawal of significant amounts of groundwater from targeted coal seams to the potential wasting of high-quality water resources. With the volumes of produced water from underground coal seams expected to grow as CBM development increases, a resource manual will be beneficial to assist all stakeholders in effectively managing produced water in an environmentally sound manner. This need is essentially the basis of this handbook as conceived by the Ground Water Protection Research Foundation (GWPRF) and contributing technologists facing the complexity of water management issues in conjunction with CBM development.

Figure 1-1
Natural Gas Production, Consumption, and Imports
Figure shows the difference between production and consumption.

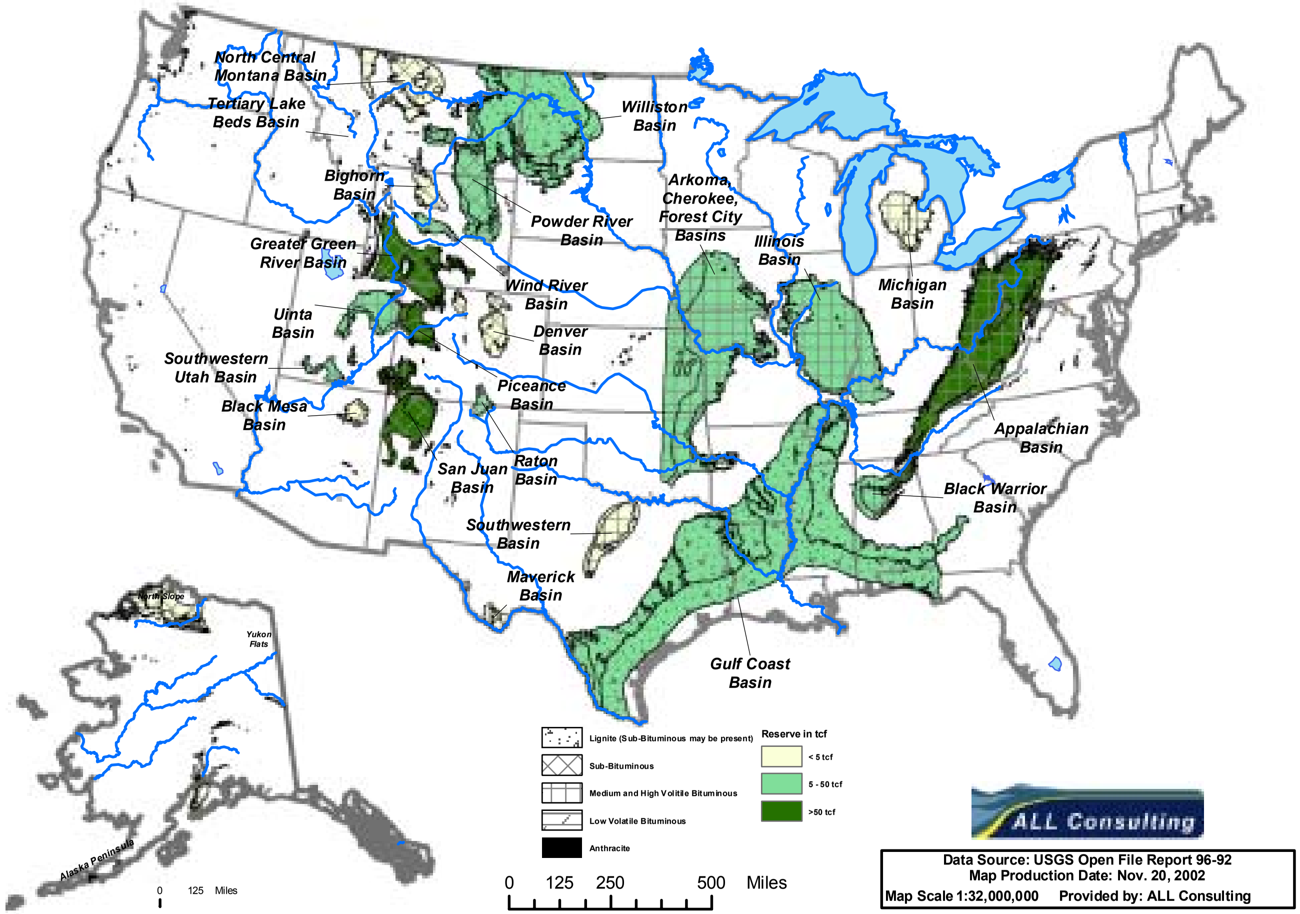


Source: Mariner-Volpe, 2000.

Figure 1-2

U.S. Map of Coal basins

Figure shows coal deposits throughout the U.S. and Est. reserves for each coal basin.



Note: Project focus includes Powder River Basin and San Juan Basin.

Purpose for Handbook

The purpose of this document is to serve as a resource for planning, understanding and implementing environmentally sound water management practices with an emphasis on the beneficial use of CBM produced water. The GWPRF intends this document to be used by a broad range of technical specialists and managers, perhaps including government agencies at the federal, state and local levels; industry representatives involved with the development of CBM resources and associated produced water; and landowners, resource users (e.g., ranchers, irrigators, municipalities, etc.), and special interest groups. Although the document has been prepared as a technical resource, managers and others that do not necessarily have a technical background should find the handbook helpful in gaining further insight to the development of CBM as it relates to water resources and demand, as well as water management practices, and the beneficial uses of produced water as a resource and not a waste byproduct.

This resource manual is intended to have multiple uses, which include:

- Guidance document for the preparation of National Environmental Policy Act (NEPA) documents and Water Management Plans;
- Toolbox for regulators for the review and approval of NEPA documents and CBM development plans;
- Reference and guidebook for permitting agencies, land resource managers, landowners, and operators;
- Technical resource for CBM operators and landowners for development planning; and
- Information source for industry and investors for promotion and development of CBM.

In addition to these uses, the handbook is intended to provide information on past and ongoing CBM research and case studies to assist stakeholders in evaluating the feasibility of various produced water management options for various areas of the United States. This manual is not designed or intended to provide area-specific plans, but is intended to be a resource or toolbox for developing plans for management of produced water as a valuable resource. The document will not provide information such as rankings for the individual issues/alternatives or water budgeting for individual basins.

Research Project Team

This research was conducted under the direction and guidance of the GWPRF with funding provided by the United States Bureau of Land Management (BLM), and the United States Department of Energy's (DOE) Office of Fossil Energy – Tulsa Office[1]. The GWPRF is the research arm of the Ground Water Protection Council (GWPC). The GWPC is made up of organizations and individuals who have a stake in groundwater protection, including federal, state and local government agencies; citizens groups; industry; consultants and researchers; and

[1] The DOE's Office of Fossil Energy serves at the National Petroleum Technology Office, part of the National Energy Technology Laboratory.

others interested in topics dealing with the Safe Drinking Water Act, Clean Water Act, and land and resource management.

The GWPRF board of directors is made up of the following individuals:

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- **Mr. Mike J. Focazio** – US Geological Survey
- **Mr. Del Fortner** – US Bureau of Land Management
- **Mr. Richard Watson** – US Bureau of Land Management
- **Mr. Chi Ho Sham, Ph.D.** – Cadmus Group

The lead researchers for the project include BLM; United States Forest Service (USFS); DOE; various state oil & gas agencies[2]; ALL Consulting (lead technical researcher); and Ft. Lewis College (Durango, Colorado). Assistance, data, and input were also provided by several CBM producers, the United States Geological Survey (USGS) and other groups and individuals. The BLM, USFS and DOE provided invaluable assistance in coordinating the collection of data from contributors and other researchers.

The project team consisted of a core team of project personnel that lead the direction of research and preparation of the document. The core project team had routine meetings to discuss the

[2] Participating states included Alaska, Arkansas, Colorado, Kansas, Montana, New Mexico, Utah, and Wyoming.

preparation of the document and to develop the direction and scope of the research that went into the document. In addition to this core project team, a group of project participants also contributed time and data to the preparation of the document. Listed below are the core project team and the project participants.

Core Project Team

Matt Janowiak	BLM, Durango, CO
Dan Arthur	ALL Consulting, Tulsa, OK
Gary Gianniny	Ft. Lewis College, Durango, CO
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Mike McKinley	BLM, Buffalo, WY
Melody Holm	USFS, Golden, CO
Brian Bohm	ALL Consulting, St. Louis, MO
Bruce Langhus	ALL Consulting, Tulsa, OK
David Winter	ALL Consulting, St. Louis, MO
Greg Casey	ALL Consulting, Houston, TX
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Participating Organizations

ALL Consulting
Bureau of Indian Affairs, Montana
Bureau of Land Management
- Buffalo, WY Field Office
- Colorado State Office
- Farmington, NM Field Office
- Price, UT Field Office
- San Juan Public Lands Center
- Washington, D.C.

CBM Industry
- Anadarko Petroleum
- BP Amoco
- CDX Gas
- ConocoPhillips
- Evergreen Resources
- Fidelity E&P
- Golder & Associates
- J.M. Huber
- Marathon/Pennaco
- Williams

Crow Indian Tribe
Environmental Community
- San Juan Citizens Alliance

Ft. Lewis College
Ground Water Protection Research Foundation

Southern Ute Indian Tribe
State Agencies
- Colorado
- Kansas
- Montana
- New Mexico
- Wyoming

US Dept. of Energy – Fossil Energy
US EPA
US Forest Service
- Colorado
- Montana
- Utah
- Washington, D.C.

The project team worked in groups to prepare the various portions of the document. Integrated case studies were prepared by CBM operators in collaboration with ALL Consulting. Ft. Lewis College conducted research for the project team and provided the project team with valuable data and statistics needed for preparation of the document. ALL Consulting managed and provided technical and research specialists for the project in collaboration with many contributors that are too numerous to mention.

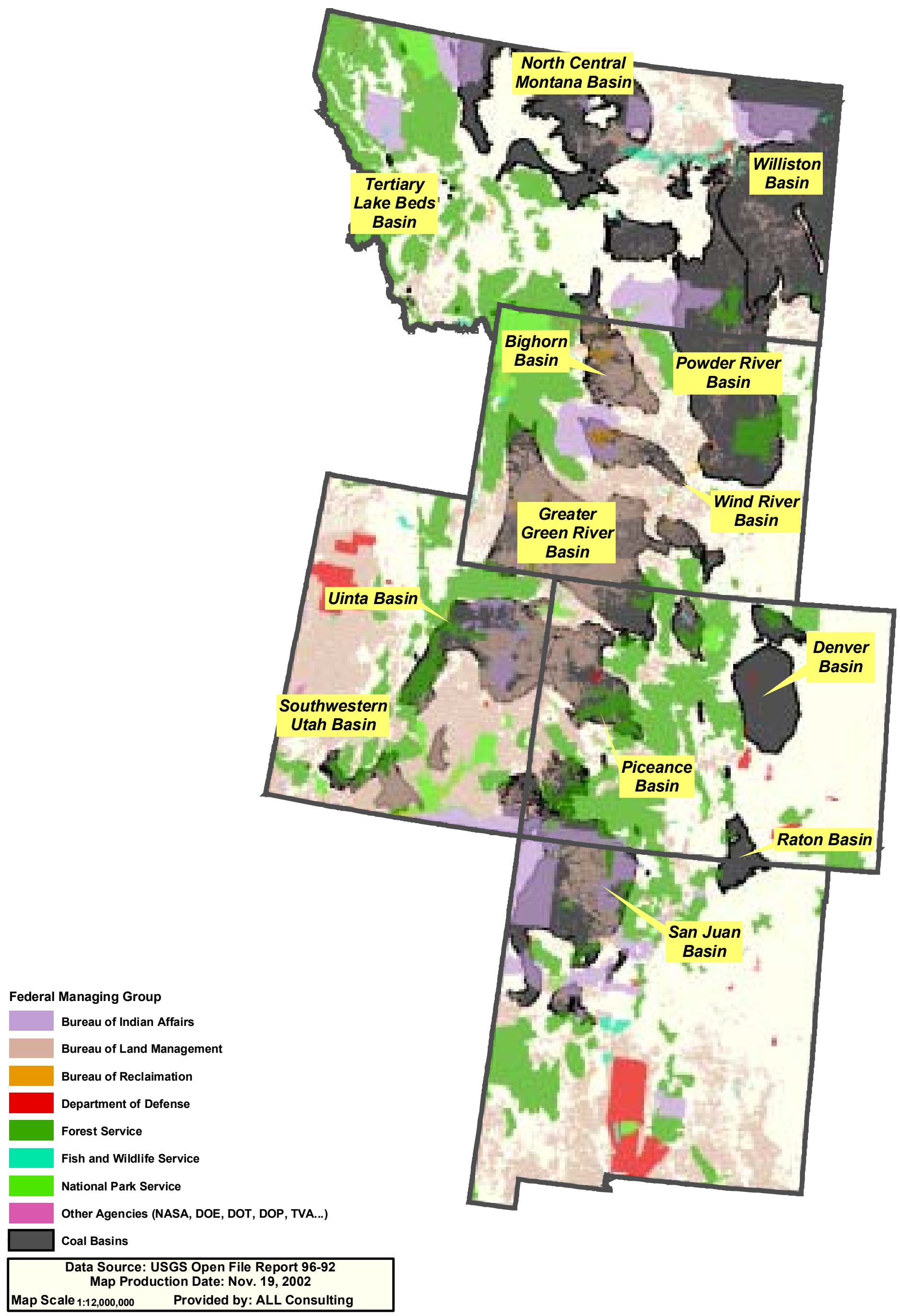
Overview of Research

This beneficial use and produced water management document aligns with the research goals and objectives established by the GWPRF, BLM, DOE and ALL Consulting. A short summary of the research activities conducted is presented below.

Study Area

The research and study area includes current and potential CBM development areas of United States. Emphasis has been placed on western states, including the Rocky Mountain region stretching from New Mexico northward to Montana. A particular emphasis has also been placed on the Powder River and San Juan Basins due to the maturity of CBM development in those areas combined with vast high-quality water resources and high demands for the beneficial use of CBM produced water. Although CBM produced water in areas like the Illinois Basin, the Appalachian Region, and producing areas in Alabama, Arkansas, Kansas, Oklahoma, and Texas typically has high concentrations of chlorides and other dissolved solids, even those areas may find utility in the contents of this document. For instance, surface discharge is currently used to manage produced water in the Black Warrior Basin of Alabama, the Gulf Coast, and areas of West Virginia. As the view toward managing produced water as a resource and not as a byproduct develops, opportunities to modify current management practices in many areas may increase.

Figure 1-3
Five-State Map of Study Area
Figure shows coal basins within study area and land ownership disposition



Source: USGS Open File Report No. 96-92; Produced by ALL Consulting.

Data Collection and Field Reconnaissance

Data collection and field reconnaissance efforts conducted for this document were primarily performed by ALL Consulting and Ft. Lewis College. However, data and information was contributed by a broad group of project cooperators. Some of the data collection and field reconnaissance activities included:

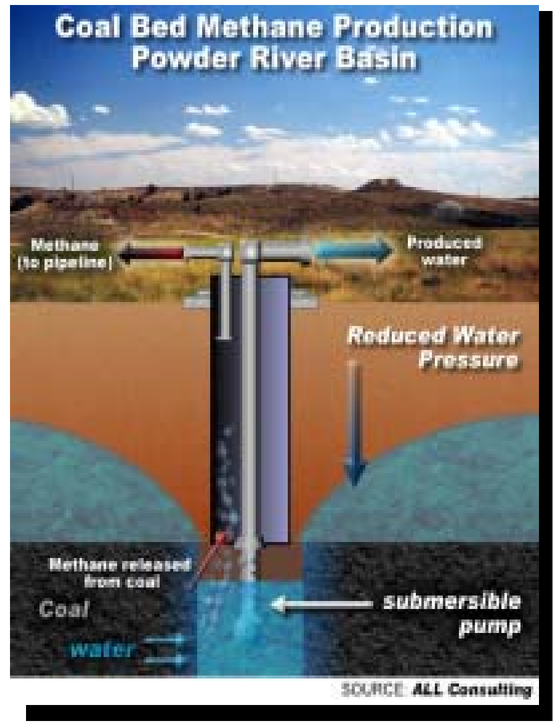
- **Determination of Water Management and Beneficial Use Alternatives:** Early in the project, a broad array of project team members and cooperators developed the outline of the manual, including the specific water management and beneficial use alternatives to consider as part of this research effort. The group also developed a strategy for practical applications of produced water treatment methods to be considered for the research effort.
- **Collection and Compilation of Existing Data Resources:** Upon initiating this research effort, it was evident that growing amounts of data and information existed with relation to the research topic. However, little public research has been performed relative to the management and beneficial use of water produced from oil and gas wells (including CBM). As such, data was both collected and compiled into a usable format for the subject research effort. For instance, CBM produced water quality is collected by several producers for operational purposes (e.g., pipeline corrosion). This data was accessed from producers, compiled into a useable format, and used in this research effort;
- **Leveraging other Research Efforts:** Crucial to the success of this project has been the ability to leverage off of other research efforts. There have been several other research efforts that have been instrumental to this effort, not to mention the various NEPA documents and supporting studies that have been prepared relative to CBM development in Colorado, Montana, New Mexico, Utah, and Wyoming.
- **Industry Data and Support:** Perhaps the most significant aspect of this research has been the data and support provided by CBM producers. Many producers have research ongoing in virtually all of the water management and beneficial use alternatives presented as well as the many treatment technologies considered. Raw data pertaining to the quality of underground coal seams, the feasibility of various alternatives, and the technical details associated with virtually every aspect of this research effort is only possible because producers forged ahead with development and data collection using many innovative strategies for managing water. Without the data and information provided by producers, this research would not have been possible.
- **Field Reconnaissance:** Field reconnaissance activities included visiting CBM development sites in several areas of the country. Researchers witnessed the application of several produced water management activities that are included in this document.

Overview of Coal Bed Methane Production and Produced Water Management

Coal bed methane production involves the production of methane gas from shallow coal seams. In some areas such as the Powder River Basin, these coal seams typically contain fresh to brackish groundwater. Water contained in the coal seam must be pumped from the coal in order to release the methane that is trapped by the groundwater pressure in the coal. A series of production wells are drilled into the coal so that groundwater can be pumped to surface to reduce the hydrostatic pressure in the coal seam (Figure 1-4). The water production from CBM wells typically starts at a high volume, but generally falls dramatically over time as the coal seam becomes depressurized in the producing area. Once the fluid pressure is lowered in the coal seam, the methane is released and available for production through the wells.

The water produced from CBM wells can vary in quality from very high quality (meeting state and federal drinking water standards) to having very high total dissolved solids (TDS) concentration (up to 180,000 parts per million TDS) which is not suitable for reuse. Currently, the management of CBM produced water is conducted using various water management practices depending on the quality of the produced water. In areas where the produced water is relatively fresh, the produced water is handled by a wide range of activities including direct discharge, storage in impoundments, livestock watering, irrigation, and dust control. In areas where the water quality is not suitable for direct use, some operators are using treatment prior to discharge and injection wells to dispose of the fluids.

Figure 1-4
Coal Bed Methane Well
Schematic of CBM well that shows reducing hydrostatic pressure by producing water.



Planning Methods for Produced Water Management

Produced water management is becoming a major issue with the public and regulators due to the high volumes of the groundwater production and disposal operations in CBM development areas. With the most prolific CBM production areas located in very arid parts of the United States, questions arise concerning the "wasting" of groundwater through the production and disposal of groundwater for CBM production. This document attempts to address this issue by providing a summary of alternatives for the effective management of water produced during the development of CBM resources. These alternatives can be implemented by regulators and operators to conduct a holistic review of proposed CBM development to determine the best method(s) for handling the water produced from underground coal seam aquifers.

The implementation of these alternatives will require additional planning to properly implement the best method for each particular development area. Additional data gathering and analysis will be necessary to provide the input necessary to evaluate the alternatives. Water management plans will need to be modified to include the alternative(s) chosen for each area. Personnel must be trained to use the information available to them in this document and other sources to plan the development of CBM resources. The background and professional discipline of the personnel on the planning team will need to be more diverse than is typically found on a conventional oil and gas development project. Biologists, hydrogeologists, hydrologists, soil conservation experts, cultural resource specialists are just a few of the types of personnel that may be needed to plan for CBM development in these arid climates. With the high profile nature that CBM development has evolved into, everyone involved with the planning and development of CBM will need to work together and with landowners to achieve successful and environmentally friendly results.

Overview of Manual

This manual of produced water management practices and beneficial use alternatives is structured to be a resource for understanding the development of CBM resources and provides an array of alternatives for the large volumes of groundwater that may be produced from coal seams. The handbook includes:

- information on the water supply and demand within existing and potential CBM development areas;
- an introduction to CBM development;
- a summary of water classifications and rights;
- presentation of produced water treatment technologies;
- detailed discussion of water management and beneficial use alternatives; and
- case studies for existing CBM water management projects.

Chapter 2
Introduction to Coal Bed Methane

Introduction

Coal bed methane (CBM) is an important facet of the nation's energy mix. While currently supplying approximately seven percent of the nation's natural gas, CBM is expected to increase in importance (EIA, 2001). Natural gas is a clean-burning energy source well suited as a boiler fuel, vehicle fuel, and heating residences as well as large structures. CBM is a non-conventional hydrocarbon fundamentally different in its accumulation processes and production technology. The paragraphs below detail the formation of coal and CBM and the technologies being used to produce the commodity.

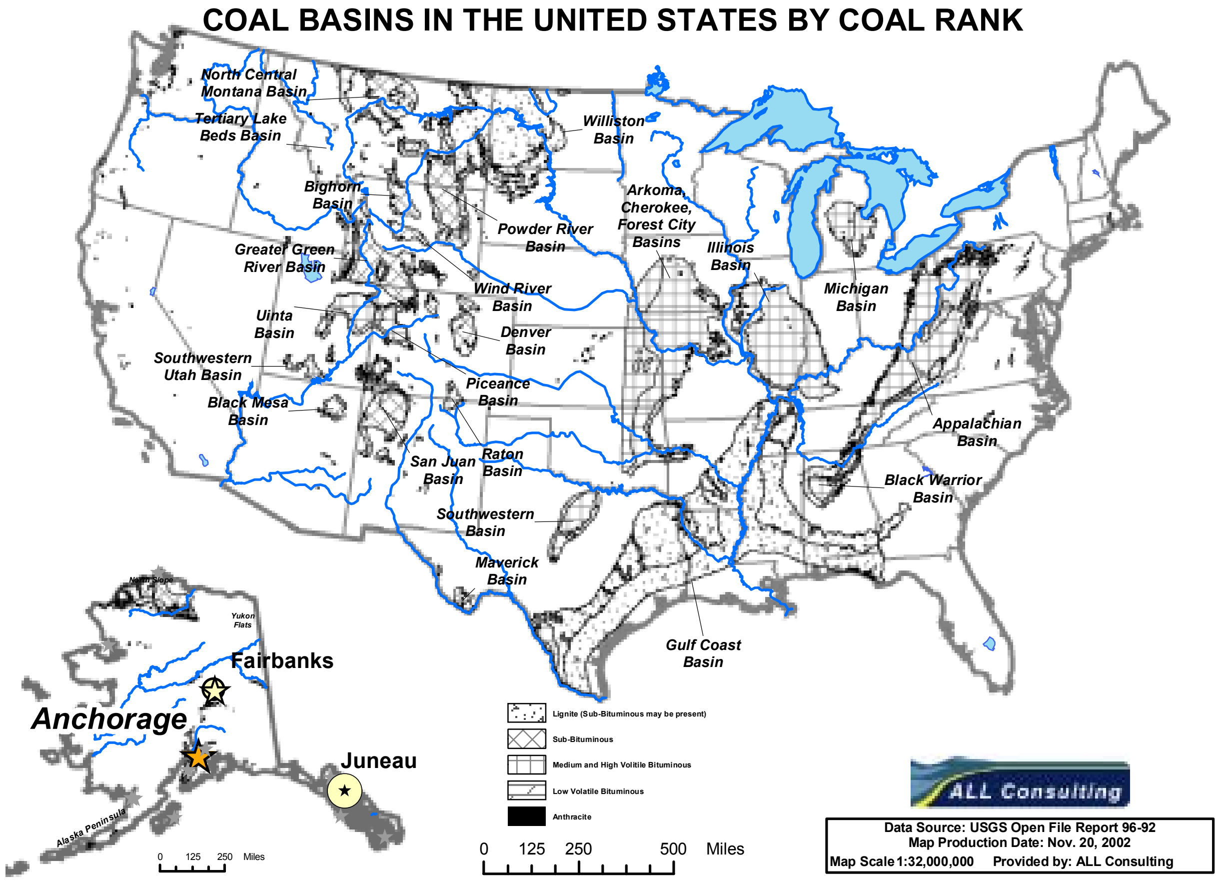
What is Coal Bed Methane?

CBM is a natural gas containing virtually 100% methane (CH_4) produced from coal seam reservoirs. CBM is often produced at shallow depths and is often produced with large volumes of water of variable quality. CBM is natural gas that is sourced and reservoired in a coal seam. It is often produced through a borehole that allows gas and water to be produced to the surface. Shallow aquifers, if present, need to be protected, but in the western United States the producing coal bed is often an underground source of drinking water (USDW). CBM resources represent valuable volumes of natural gas within and outside of areas of conventional oil and gas production. Many coal mining areas support current CBM production; other areas containing coal resources are expected to produce significant volumes.

Significant reserves of coal underlie approximately 13% of the United States landmass as shown below in Figure 2-1. Of the coal regions shown, several currently produce CBM while exploration is active in others. CBM was produced as long ago as 1926 (Cardott, 1999) in Oklahoma, and 1951 in the San Juan Basin. The greatest increase in development, however, began in approximately 1988. This was due to tax incentives being put in place by Congress to boost domestic exploration into alternative sources for energy. CBM production continues to advance across North America as operators develop new techniques for drilling and producing coal seams of different rank and quality and the demand for natural gas continues to increase.

Worldwide, coal is present in most sedimentary basins that are Devonian to Tertiary in age. Coal deposits in the eastern and central United States are Mississippian and Pennsylvanian; in the western United States and Gulf Coast the coals are younger Cretaceous and Tertiary. This diversity of age has given rise to two different types of CBM basins. The eastern hard coals are higher rank and thinner. They contain less water within the coal seam and require fracture enhancement to increase the productivity. The water contained within the coals is typically low quality which does not lend itself to many beneficial uses. The western soft coals are lower in rank, but very thick. These coals may contain prodigious amounts of water that requires removal to initiate production. The produced water is typically high- to medium-quality water that lends itself to many beneficial uses. Table 2-1 provides a summary of the coal reserves across the United States.

Figure 2-1
Coal Resources of the United States
Coal resource areas and CBM potential.



Note: Coal Resources Areas and CBM potential.

Table 2-1
Coal Reserves by State
Coal reserves by state in billions of tons and as a percent of United States' Reserves

State	Tons (billions)	Percent of U.S.
Montana	120	25.4
Illinois	78	16.5
Wyoming	68	14.4
West Virginia	37	8.0
Kentucky	30	6.3
Pennsylvania	29	6.1
Ohio	19	4.0
Colorado	17	3.6
Texas	13	2.7
Indiana	10	2.1
Other States	51	10.9
Total Coal Reserves	**472**	**100.0**

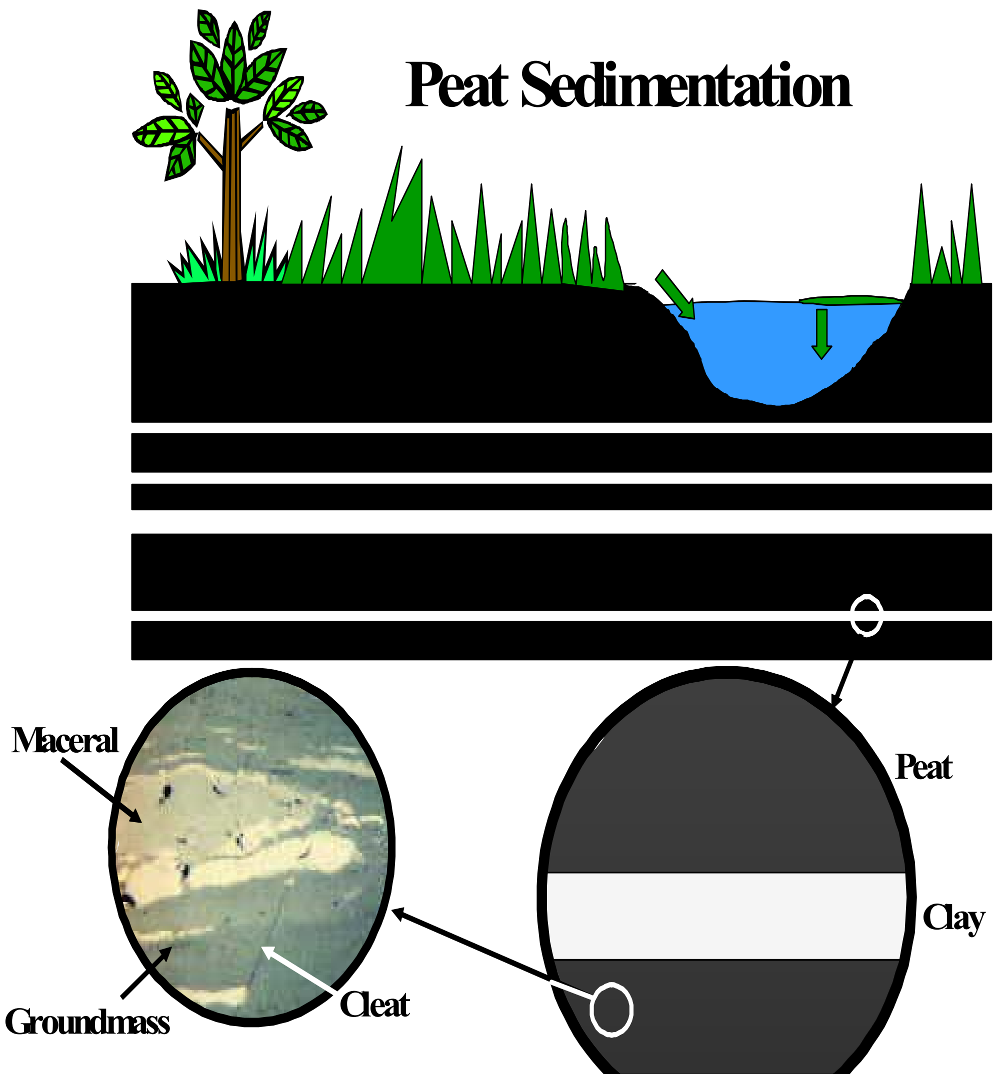
Source: COAL: Ancient Gift Serving Modern Man; American Coal Foundation, 2002.

What is Coal and Where Does It Originate?

Coal is a sedimentary rock that had its origin as an accumulation of inorganic and organic debris. Coal is predominantly organic plant material, in particular, wood, leaves, stems, twigs, seeds, spores, pollen, and other parts of aquatic and land plants. When the debris first begins to pile up it is termed peat; the younger sediment rests on older material, causing it sink ever deeper into the sedimentary pile. Layers of peat may be separated by clay and sand deposited during times of flood or other breaks in the accumulation of peat. As the peat accumulates, organic processes begin to break the plant debris down, both physically and chemically. Physically, small insects, worms, and fungi break the fragments into smaller pieces; as the peat solidifies, the small fragments are termed macerals that can be identified microscopically as coming from plants. At the same time, the peat is squeezed by overlying material, driving out its water and compacting the plant trash into rock. Chemically, the plant material is slowly converted into more simple organic compounds ever richer in carbon. This process is called sedimentation and is illustrated in Figure 2-2 below. The peat is buried more deeply while pressure and heat build up. It is the heat and pressure that slowly transforms the peat into coal through the process of coalification.

Coals are deposited over a narrow range of sedimentary environments; in all cases the fresh, organic plant material needs to be buried quickly and protected from oxidation. In order for the organic matter to be preserved, the plant debris must accumulate in a local area of restricted oxygen supply. Coal-forming environments are often called mires. Mires can be either marine-connected, termed paralic, or freshwater connected termed limnic. Paralic mires are persistently low areas such as lagoons or submarine inter-distributary depressions where terrestrial or marine plant debris can accumulate, and where water circulation is restricted resulting in low dissolved oxygen content. Limnic mires are low-lying terrestrial areas such as lakes or abandoned river channels where strictly terrestrial plant material can accumulate. Local growing conditions will determine whether the mire fills with chemically resistant woody debris, or with leafy material with large quantities of waxes and plant liquids that will readily be transformed into hydrocarbons. In both kinds of mires, water chemistry and plant type will influence the eventual coal type, maturational path, and hydrocarbon generation.

Figure 2-2
Peat Sedimentation
Sedimentation and burial of plant material and the formation of peat.



Within each mire, coals themselves can be of two depositional types: humic coals and sapropelic coals. Humic coals are accumulations of heterogeneous organic debris deposited in-situ, in a more or less oxygen restricted environment. They are the more common type of coal often seen to have mixtures of organic matter from tree limbs to leaves. A contemporary example of a future humic coal is a swamp that sees the quiet accumulation of broken branches, dead leaves, grasses, aquatic weeds and grasses that grow in and around a swamp. Sapropelic coals are redeposited, winnowed accumulations of organic debris that have been sorted by hydraulic action. A modern example may be a portion of the swamp that mostly receives wind-blown pollen and small leaves especially rich in plant liquids that are easily transformed to hydrocarbons. They are mostly minor stratigraphic components within major coal sequences, but can be economically important in that they will often source liquid hydrocarbons and may offer pathways of extraordinary permeability.

In addition, coals contain variable amounts of inorganic material, collectively termed ash, that often consists of clay, sand, and silt. Interbeds predominantly composed of this material are termed bone. These thin strata can affect the fluid movement within a thick coal bed. In some cases, the bone bed may be extensive enough that the coal above should be exploited separately from the coal below. Disseminated ash will retard the development of fractures in the coal.

Where Does CBM Come From?

CBM is naturally occurring methane (CH_4) with small amounts of other hydrocarbon and non-hydrocarbon gases contained in coal seams as a result of chemical and physical processes. These processes start as plant material and are converted from peat to coal. As the peat is buried by younger sediments to increasing depths, heat and pressure increase, causing chemical and physical changes to the plant material. It is this application of the heat and pressure that transforms the peat into coal, driving water and other volatile constituents out of the organic compounds and concentrating the carbon. Transformation of peat to coal is a gradual process termed maturation, which includes many intermediate points as described in Table 2-2.

Table 2-2 lists physical and chemical characteristics of plant debris and coals as they increase in rank or maturation. Maturation is most often measured as vitrinite reflectance. Vitrinite is a common coal grain or maceral that is abundant in most coals. As vitrinite is subjected to maturation, its carbon content increases, its volatile content decreases, and it becomes harder and "shinier". Its reflectance increases as it matures. While shininess is subjective, reflectance can be easily measured. Vitrinite reflectance is a measurement of how reflective the coal is, and in turn, the rank of the coal can be determined. In Table 2-2, coal rank, maturation, and vitrinite reflectance all in ascending order.

As burial and maturation proceeds, organic compounds give off water, CO_2, methane, and other gases. Physically, the material loses porosity because of compaction and maturational changes. Porosity is measured in the table as moisture – plant debris having over 75% porosity and hard coals having 1% or less. The reduction in porosity happens because of compaction and deformation of coal grains or macerals.

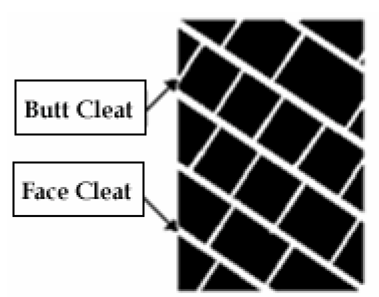
Table 2-2
Coal Maturation
Coal maturation is gradual process characterized by stages.

Rank Stages	Carbon (percent)	Volatile Matter (percent)	Specific Energy (gross in MJ/kg)	In-Situ Moisture (percent)	Vitrinite Reflectance (percent)	
					Random	Max
Wood Debris	50	>65	-	~90	-	-
Peat	60	>60	14.7	75	0.20	0.20
Brown Coal	71	52	23	30	0.40	0.42
Sub-Bituminous	80	40	33.5	5	0.60	0.63
High Volatile Bituminous Coal	86	31	35.6	3	0.97	1.03
Medium Volatile Bituminous Coal	90	22	36	<1	1.47	1.58
Low Volatile Bituminous Coal	91	14	36.4	1	1.85	1.97
Semi-Anthracite	92	8	36	1	2.65	2.83
Anthracite	95	2	35.2	2	6.55	7.00

What Controls CBM Production?

The rate of CBM production is a product of several factors that vary from basin to basin – fracture permeability development, gas migration, coal maturation, coal distribution, geologic structure, CBM completion options, and produced water management. In most basin areas, naturally developed fracture networks are the most sought after areas for CBM development. Areas where geologic structures and localized faulting have occurred tend to induce natural fracturing which increases the production pathways within the coal seam (Figure 2-3). Natural fracturing like that shown in Figure 2-3 can reduce the cost of bringing the producing wells on-line.

Figure 2-3
Coal Cleat Orientation
Orientation of natural fractures in coal.



Cleat (Fracture) Development

Coal contains porosity but very little matrix permeability. In order for fluids to be produced out of coal seams into a well-bore, the coal must possess a system of secondary permeability such as fractures. Fractures allow water, natural gas, and other fluids to migrate from matrix porosity toward the producing well. Cleat is the term for the network of natural fractures that form in coal seams as part of the maturation of coal. Cleats form as the result of coal dehydration, local and regional stresses, and unloading of overburden. Cleats largely control the directional permeability of coals and, therefore, are highly important for CBM exploitation through well placement and spacing.

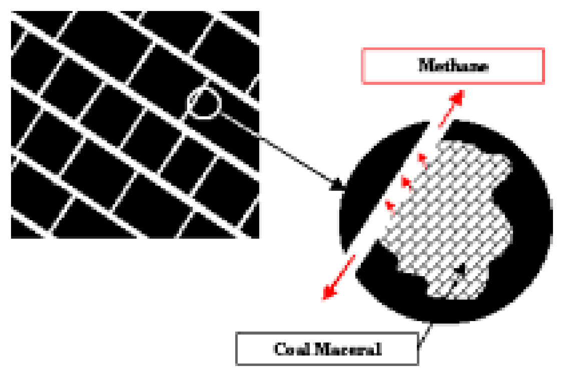
Two orthogonal sets of cleats develop in coals that are both perpendicular to bedding (Figure 2-3). The face cleats are the dominant set that are more continuous and laterally extensive; face cleats form parallel to maximum compressive stress and perpendicular to fold axes. The butt cleats are secondary and can be seen to terminate against face cleats. Butt cleats are strain-release fractures that form parallel to fold axes.

Cleat spacing is related to rank, bed thickness, maceral composition, and ash content. Coals with well-developed cleat sets are brittle. In general, cleats are more tightly spaced with increasing coal rank. Average cleat spacing values for three coal grades include: subbituminous (2 to 15 cm), high-volatile bituminous (0.3 to 2 cm), and medium- to low-volatile bituminous (<1 cm) (Cardott, 2001). Cleat spacing is tighter in thin coals, in vitrinite-rich coals, and in low-ash coals.

Natural Gas Migration

In coal seams, most gas is absorbed on the microscopic laminations and micropores within coal macerals. As hydrostatic pressure is decreased by water production, gas desorbs and moves into the cleat system where it begins to flow towards the producing well, as diagrammed in Figure 2-4.

Figure 2-4
Methane Migration Pathways
Natural gas migrates along open fractures within the coal.

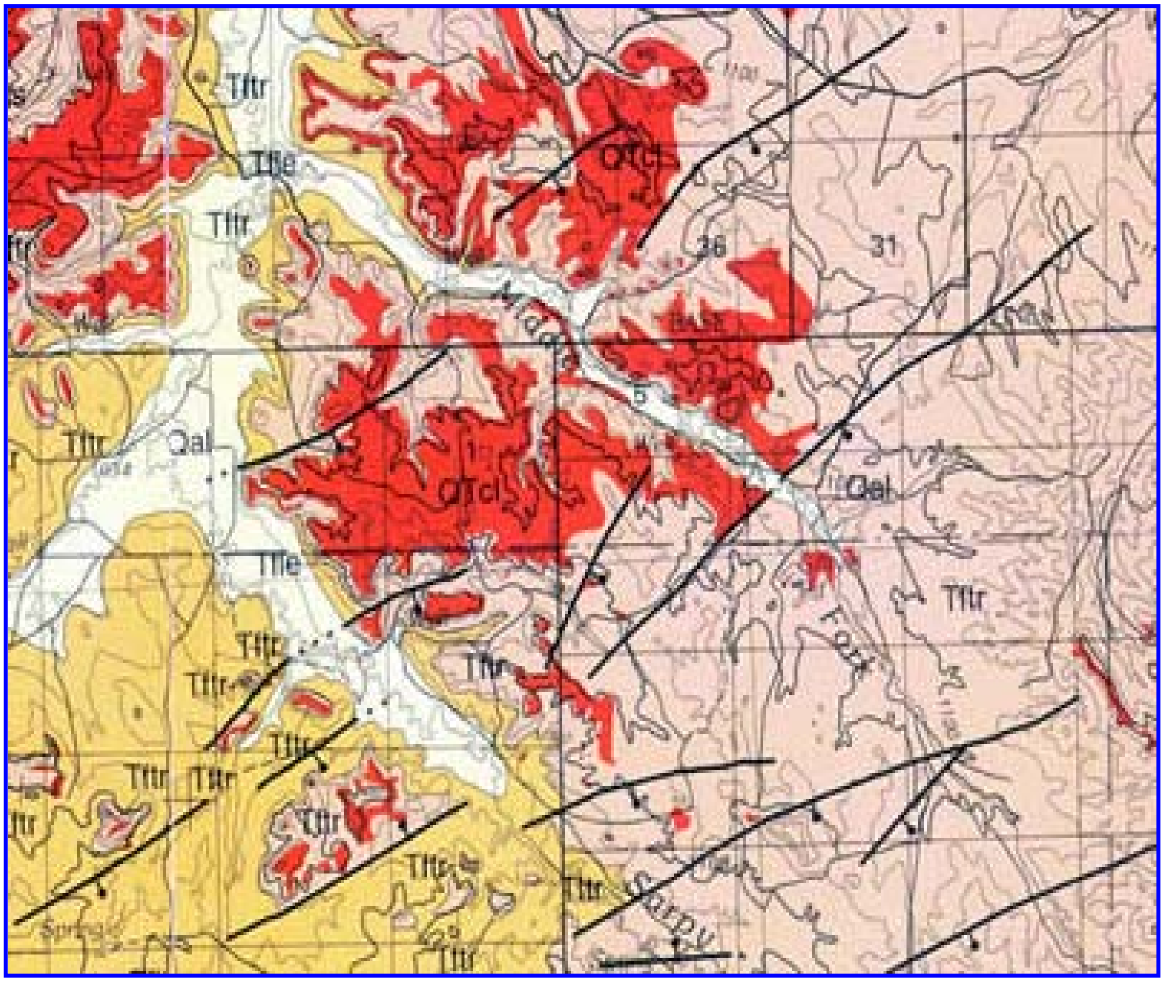


Natural gas can also migrate through more wide-spread fracture sets related to faults and tectonic jointing. The geological map in Figure 2-5 shows a set of these faults that can be seen at the surface. The map shows how these faults have had vertical displacement and have terminated geological units due to movement. As shown on Figure 2-5, some of the geologic units shown in red end at the fault signifying that the fault has been active in the past. The faults can be seen to persist over several miles. These faults can be a source of geologic movement and structure that can enhance the migration pathways for the methane in the subsurface.

Hydrocarbon and Other Fluid Development

As coals mature from peat to anthracite, their associated fluids transform as well. Low rank peat and lignite have high porosities, high water content, low temperature biogenic methane and few other fluids. As coals mature into bituminous types, water is expelled, porosity decreases, and biogenic methane formation decreases because temperatures rise above the most favorable range for bacteria. At the same time, heat breaks down complex organic compounds to release methane and heavier hydrocarbons (ethane and higher). Inorganic gases can be generated by the thermal breakdown of coals. As the coal matures to anthracite, less methane is generated and little porosity or water remains in the matrix. The chart in Figure 2-6 lists the steps in the maturation of coal from peat to anthracite and the fluids generated and expelled during the maturation process. Peat, largely unaltered plant debris, and lignite ("brown coal") can give rise to biogenic methane produced by methanogenic bacteria. Minor production of CBM has been reported from lignite in North Dakota and Louisiana. CBM production in most of the western United States comes from sub-bituminous and bituminous coals. CBM in the eastern United States originates in higher rank coals.

Figure 2-5
Faults in CBM Production Area
Map showing faults in CBM production area.



Evaluation Methods

Coals can be analyzed for adsorbed gas content using standardized techniques that mechanically disaggregate the core samples. The gas content figures range from several hundred standard cubic feet (SCF) per ton of coal to less than 50 SCF per ton of coal. The numbers cannot be equated with ultimate recoverable CBM reserves since not all the gas can be desorbed and produced from the coal. Methane content values in producing basins range from around 800 SCF per ton in Oklahoma, to 450 SCF per ton in the San Juan basin, to an average of 40 SCF per ton in the Powder River Basin (PRB). Table 2-3 shows the results of a survey of CBM content for coals in the state of Virginia. The analyses shown in Table 2-3 include the identification of the samples, methane content, ash content, and coal rank. It also shows some of the variability that can be seen between difference coal beds as well as within coal beds.

Figure 2-6
Coal Maturation Diagram
Thermogenic and biogenic coal maturation plus byproducts.

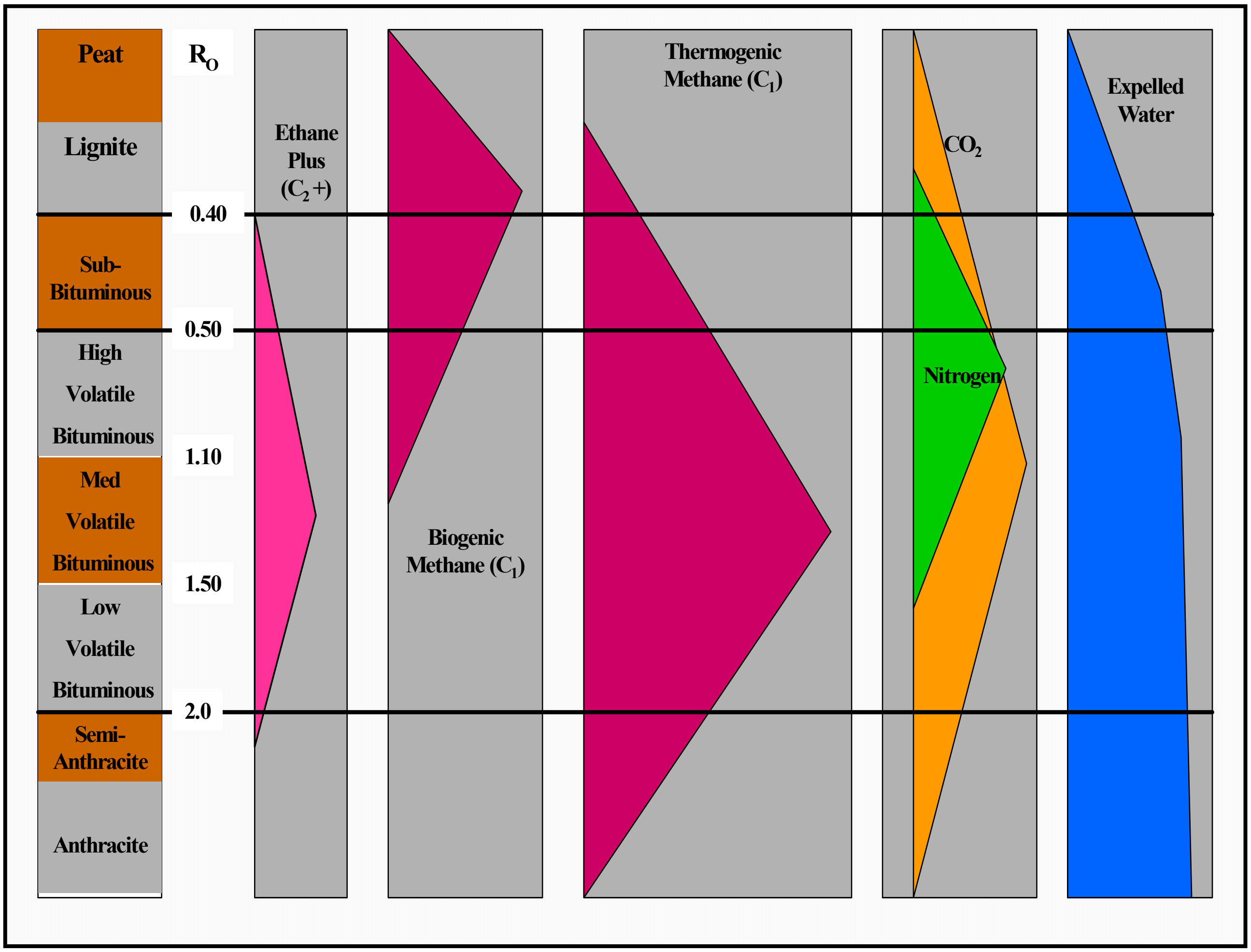


Table 2-3
Methane in Coal
Methane content of coals in Virginia and West Virginia.

Coal bed	County	Depth (ft.)	Total SCF/Ton	Ash Percentage
Jawbone	Dickenson	678	278.31	3.6%
Jawbone	Dickenson	680	278.31	6.6%
Jawbone	Dickenson	431	281.51	7.1%
Jawbone	Dickenson	431	156.75	35.6%
Pocahontas No. 3	Buchanan	1,430	435.06	?
Pocahontas No. 3	Buchanan	1,518	463.86	?
Pocahontas No. 3	Buchanan	2,143	339.09	?
Pocahontas No. 3	Buchanan	1,737	348.69	?
Pocahontas No. 3	Buchanan	1,845	351.89	?

Source: US Bureau of Mines, 1986.

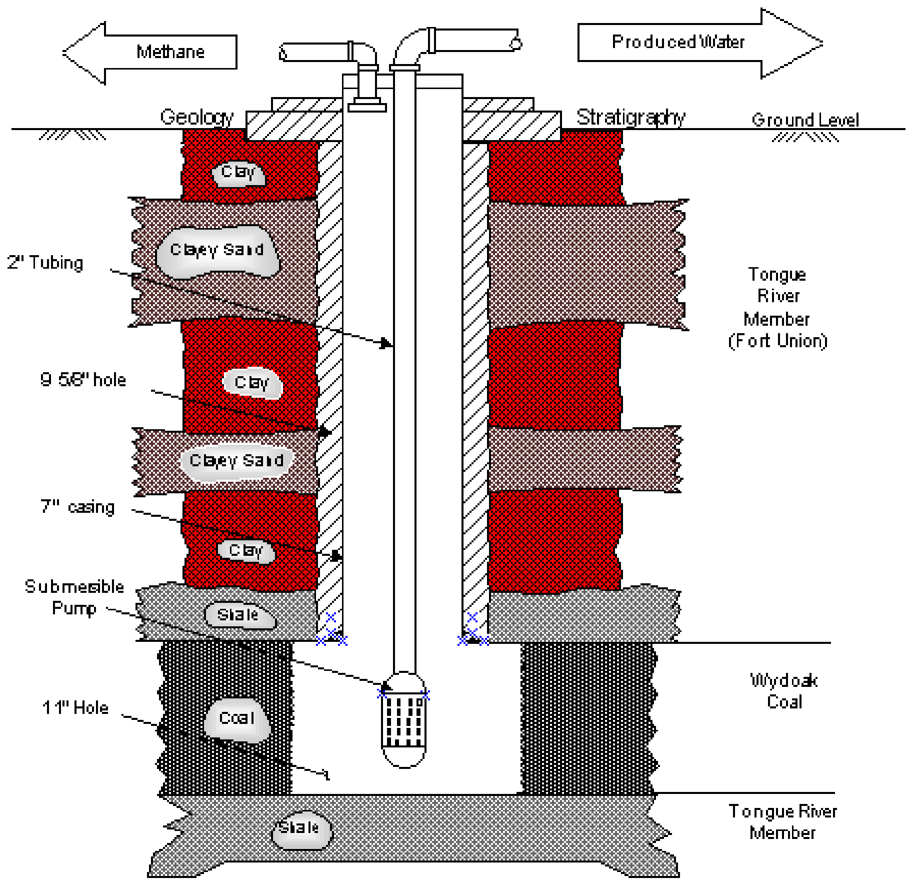
CBM Completion Methods

CBM wells are completed in several ways, depending upon the type of coal in the basin and fluid content. Each type of coal (sub-bituminous to low-volatile bituminous) offer production options that are different due to the inherent natural fracturing and competency of the coal seams. The sub-bituminous coals are softer and less competent than the higher rank low-volatile bituminous coals and therefore are typically completed and produced using more conventional vertical well bores. The more competent higher rank coals lend themselves to completions using horizontal and vertical well bores.

Western Soft Coals

Many of the coals found in the western United States are sub-bituminous in rank and, although competent enough to be completed and produced using open-hole techniques, they are often too soft to allow the use of a horizontal wellbore with any major success to date. However, deviated drilling techniques have been used in the San Juan Basin where more conventional completion techniques have been successful. Figure 2-7 shows a completion diagram of a typical CBM well in the PRB. Within the PRB, a typical well is drilled to the top of the target coal seam and production casing is set and cemented back to surface. The coal seam is then drilled-out and under-reamed to open up more coal face to production. The borehole and coal face is then cleaned with a slug of formation water pumped at a high rate (water-flush). In areas where the cleat or natural fracture system is not fully developed, the coal may be artificially fractured using a low-pressure stimulation technique or cavitation.

Figure 2-7
CBM Wellbore Diagram
Example from the Powder River Basin.

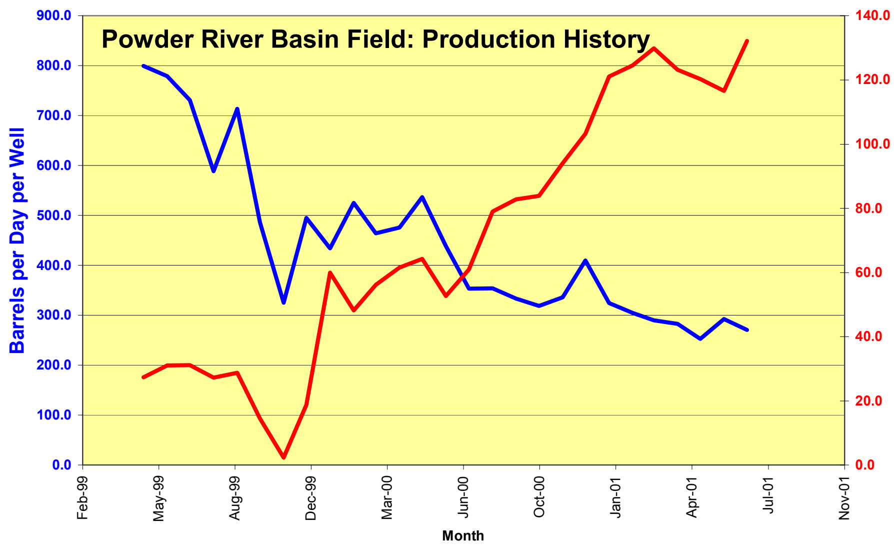


Note: Data used for this exhibit was derived from several CBM developers.

Once the well is completed, a submersible pump is run into the well on production tubing to pump the water from the coal seam. The submersible pump is needed to pump the water from the coal seam in order to desorb (release) the methane which is held in place by formation water pressure and initiate production. The methane flows up both the casing and tubing of the well and is sent via pipe to a gas-water separator at the compression station. The methane is then compressed for shipment to the sales pipeline. In most areas only one coal seam is produced in each well. Attempts at producing more than one coal seam per well have been mostly unsuccessful due to the inherent problem of lowering the water level in each coal seam independent of each other. Size constraints of the production equipment and use of submersible pumps make the use of a dual completion complicated and expensive. With these production wells being so shallow, it is less expensive and less complicated to drill wells into each coal seam independently than to use dual or triple completion well systems.

As water is pumped off the coal aquifer, increasing amounts of methane are produced from the CBM wells. This relationship is shown in the production plot (Figure 2-8) from the Montana portion of the Powder River Basin. The figure details the field-wide average water and gas production over time from the date of first production. Figure 2-8 illustrates how the water production is very high during the initial stages of production, but declines as the water table is lowered in the coal seam. The gas production then increases as new fractures are dewatered and the methane is released.

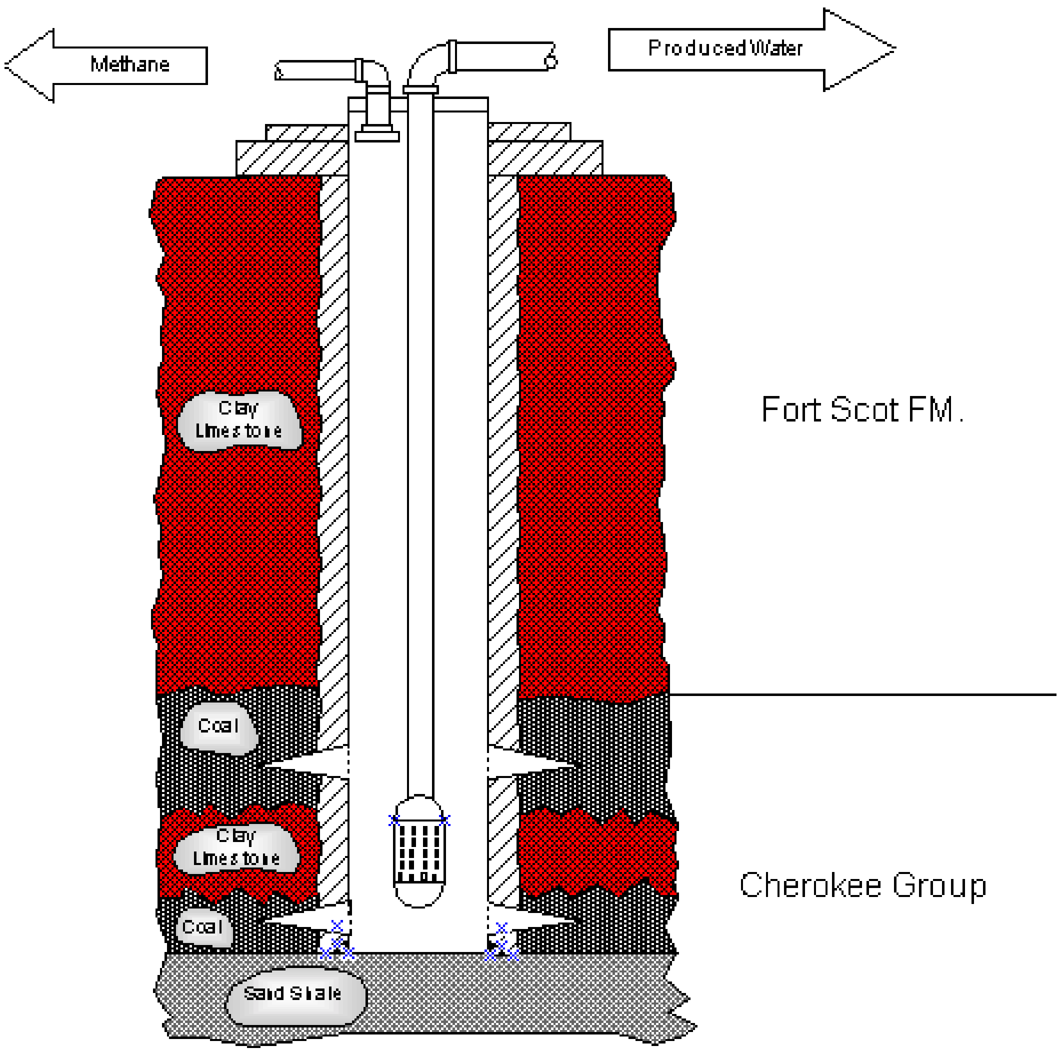
Figure 2-8
CBM Production History
CBM production history in the Powder River Basin field.



Eastern Hard Coals

The coals found in the eastern portions of the United States are often higher-rank medium- to low-volatile bituminous coals. While these coals are very competent and can be completed open hole, these coals are often drilled and cased to total depth to maintain the wellbore after fracturing treatments. Wells are then perforated and stimulated to remove damage caused by drilling and to enhance fracturing near the wellbore. Many of the eastern coals do not have significant water to be removed from the coal to initiate methane production. As such, several coal seams are often perforated in a single borehole. Figure 2-9 provides an example of vertical well bore completed in multiple coal seams from the Cherokee Basin in Oklahoma.

Figure 2-9
CBM Drilling Example
Vertical wellbore example drilled into multiple coal seams in the Cherokee Basin.

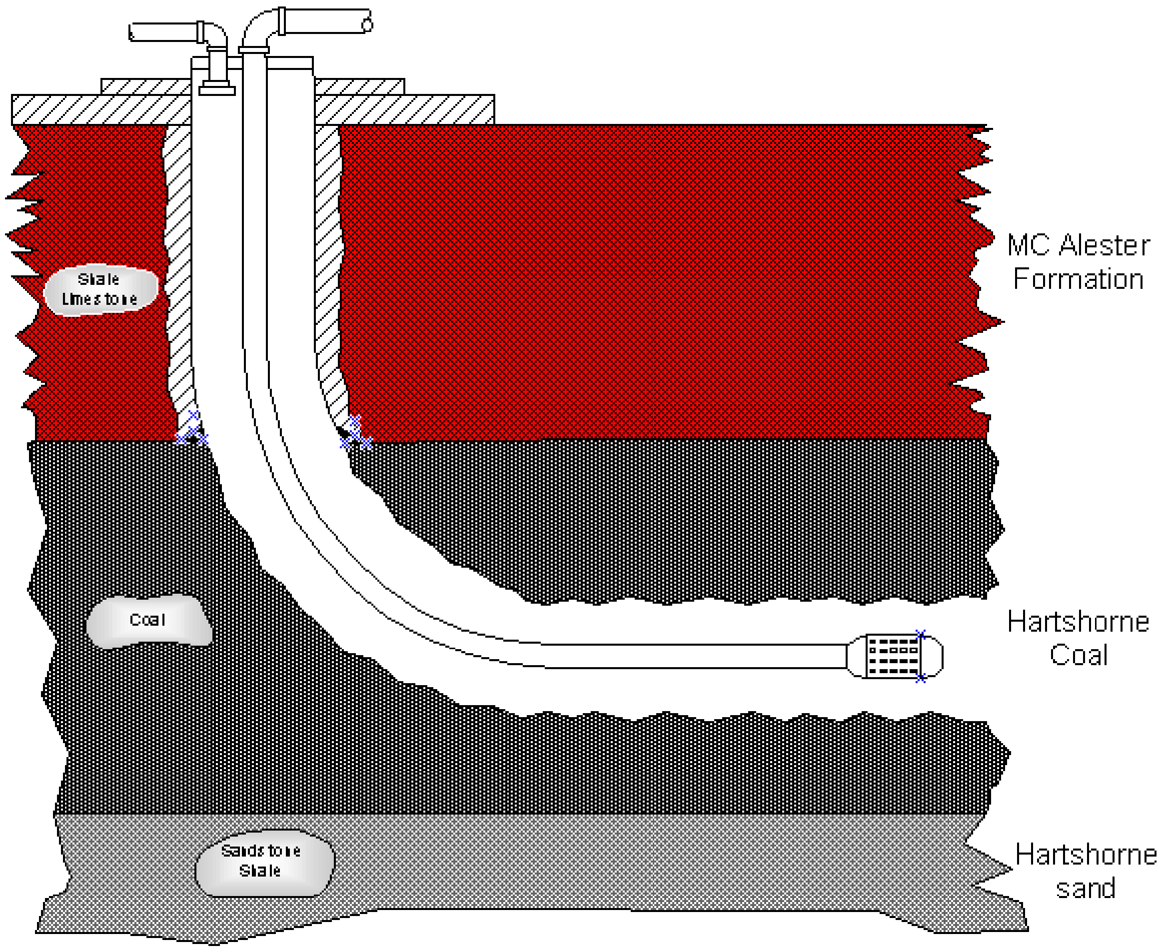


Note: Data used for this exhibit was derived from several CBM developers.

Eastern hard coals are often exploited by way of horizontal drain-holes from a single bore-hole. Each individual well may have up to 3,500-feet of lateral extent within a single coal seam (Figure 2-10). Several laterals can be drilled from a single wellbore to exploit several seams, or to take advantage of several cleat (fracture) trends. Each leg would not necessarily be horizontal, but would closely follow the dip of the individual seam. Many of the coal seams are often less than 5 feet thick, requiring the drilling contractor to exercise great care in steering the drill bit.

Operators in Alabama, Arkansas, Oklahoma, and Virginia have made use of horizontal laterals to enhance CBM production in a manner similar to that shown in Figure 2-10.

Figure 2-10
CBM Drilling Example
Horizontal wellbore example from Arkoma Basin.



Note: Data used for this exhibit was derived from several CBM developers.

The production of CBM from eastern coals is similar to the western coals except for the use of horizontal wellbores and extensive use of fracturing to enhance production. With the coals being of higher rank, the methane content per ton of coal is typically higher, but requires additional enhancement to the natural fractures in many areas to maximize production. Production rates of CBM depend upon local gas content of the coal, local permeability of the coals, hydrostatic pressure in the coal seam aquifer, completion techniques, and production techniques.

Chapter 3
Existing and Potential Coal Bed Methane Development and Resources

Introduction

Coal bed methane resources are located in coal bearing areas across the United States including the Appalachian mountain area of the east, the Gulf Coast, and most of the states from the Great Plains to the West Coast. Many of these states are located in very arid environments where rainfall and water resources are scarce. As a result, the groundwater and surface water are protected by state and federal laws to ensure that these water resources are guarded from the impacts of development activities.

CBM development involves the reduction of pore pressure by withdrawal of groundwater from the coal seams to allow the methane gas to be desorbed from the coal. Operators drill wells into the coal seam that is typically pressurized by groundwater, and reduce the pressure within the coal by pumping the water to the surface using pumps. Once the water pressure is reduced in the coal, the methane in the fractures of the coal is released and flows to the surface where it is piped to a compressor station for distribution by pipeline. The produced water is managed by a variety of methods including, but not limited to, impoundment for storage, direct discharge to a local creek or river, and land application via irrigation. As a result, CBM development activities have come under intense scrutiny from landowners, environmentalists, and regulators concerned with the potential wasting of groundwater resources and the impacts of water management practices.

The potential wasting of this groundwater is a major concern in many western states where produced water can be of high quality and can potentially have a number of beneficial uses. In contrast to the high quality water in the West, produced water in the Appalachians, Gulf Coast and central parts of the United States is typically very high in total dissolved solids (greater than 10,000 TDS) and is less suitable for beneficial uses. The western United States climate is also arid and, therefore, water quality impacts and water wasting issues are a greater concern. These areas typically have seasonal water flows in creeks and minimal rainfall during much of the year. Many of the landowners and municipalities rely on groundwater to provide drinking water for themselves and their livestock. The production of coal bed water gives rise to concerns of depleting groundwater supplies and lowering of the water tables which can potentially cause residential and livestock water supply wells to go dry.

Operating coal bed methane wells from CS Ranch Field, Decker, Montana.

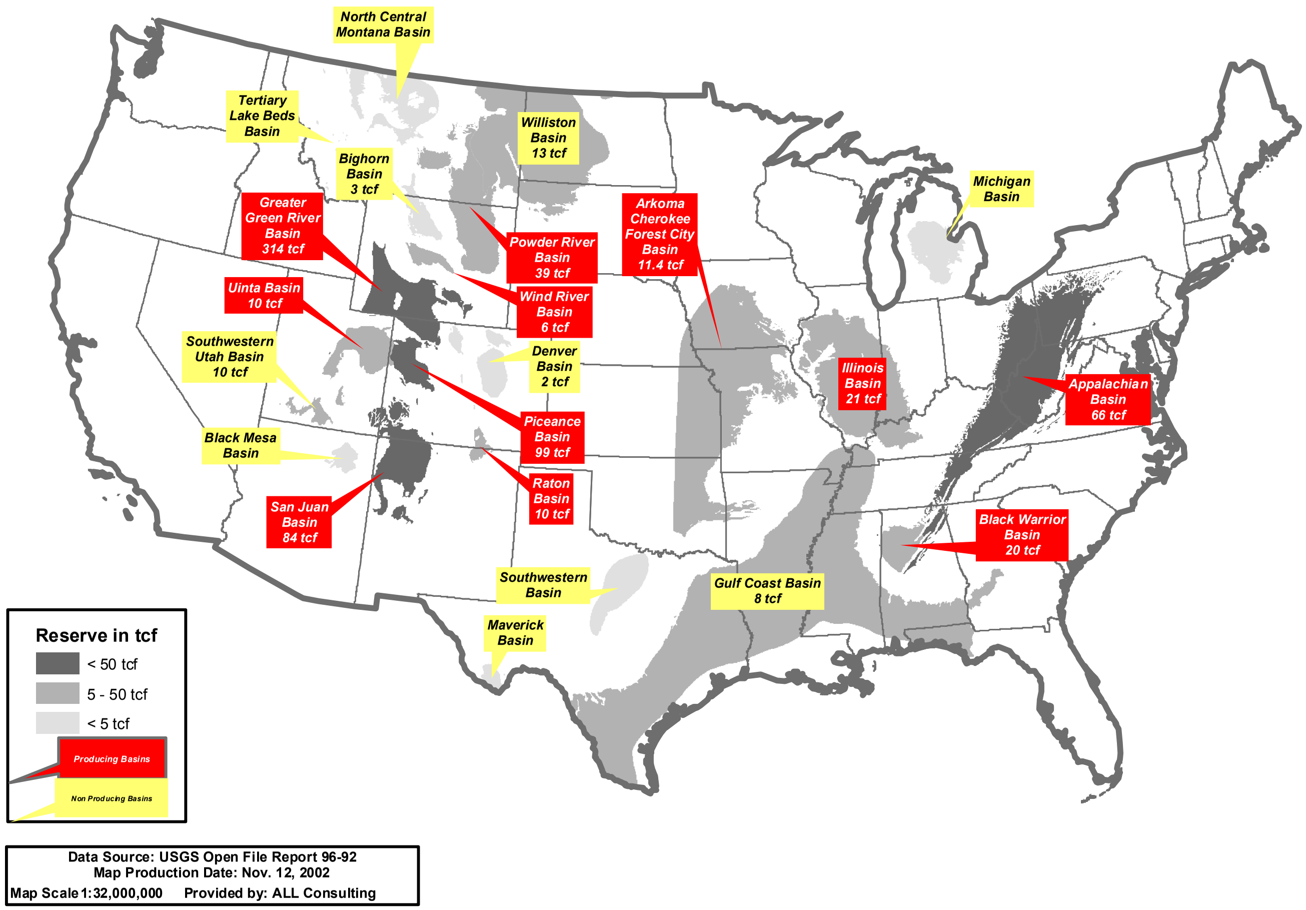
The water produced from many of these coal seams is suitable for use by livestock, agriculture and other industrial uses. To develop CBM resources, developers and resource managers are being requested to find beneficial uses for produced water and to minimize impacts of produced water to the environment. This section provides a summary of current and potential CBM development areas across the United States and the water resources in each of these areas. Table 3-1 and Figure 3-1 provide a summary of historical CBM production information for many of the existing CBM development areas. Each of the areas shown in the table is discussed in detail later in this section. The discussions of these development areas will include, where possible, the amount of CBM development that has occurred and that is projected, the water quality of the produced water, and the supply and demand of groundwater used in the development areas.

Table 3-1
Coal Bed Methane Historical Production Information
CBM production information for various coal basins throughout the United States

Basin	State(s)	Producing Wells (1996)	Cumulative CBM Production (1981-1996) (BCF)	Typical: Net Coal Thickness (ft)	Typical Gas Content (SCF/ton)	Typical Spacing (acres)	Avg. Production (Mcfd/well)
San Juan	CO, NM	3,036	3,857	70	430	320	2,000
Black Warrior	AL, MS	2,739	728	25	350	80	100
Central Appalachian	WV, VA, KY, TN	814	121	16	na	80	120
Piceance	CO	123	36	80	768	40	140
Powder River	WY, MT	193	17	75	30	80	250
Uinta	UT	72	14	24	400	160	690
Raton	CO, NM	59	8	35	300	160	300

Note: Information used for this table was derived from several industry sources.

Figure 3-1
Map of U.S. Coal Reserves/Basins
U.S. coal reserves and basins



Note: Water quality data is estimated using a variety of data sources, including USGS, industry, and state agencies.

Coal Bed Methane Development Area Discussions

Alaska

Alaska's first exploratory CBM well was drilled in 1994 by the state of Alaska. The project was funded by the state and operated by the Department of Natural Resources, Division of Oil and Gas. Because the project was successful, the state of Alaska implemented a non-competitive shallow gas leasing program in 1999 to encourage increased commercial exploration. The gas will be used to supply roadless rural communities as well as larger urban communities. Figure 3-2 provides an overview map showing the distribution of coal bearing formations across Alaska.

Coal Geology

The majority of the coal resources are in Cretaceous and Tertiary Age sediments spread unequally across the basins with thickness as great as 175 feet at depths less than 6,000 ft (Clough et al, 2001b). The western Colville Basin contains the greatest volume of coal with subcrops of as many as 150 significant coal seams ranging between 5 to 28 feet in thickness. North Slope CBM alone may exceed 800 trillion cubic feet (TCF). Other promising opportunities for CBM include the Cook Inlet, Nenana, Alaska Peninsula, Yukon Flats, Yukon-Koyukuk, and Copper River basins.

Alaska's CBM reserve estimates are as high as one quadrillion cubic feet, but the economically recoverable volumes are unknown at this time (Clough et al, 2001). Alaska coal bed gas markets include urban and rural use and potential commercial export. CBM exploration and development for most basins will be delayed or ignored due to the absence of subsurface coal bed gas and hydrogeologic data, lack of infrastructure, and high exploration costs.

CBM Development and Gas Reserves

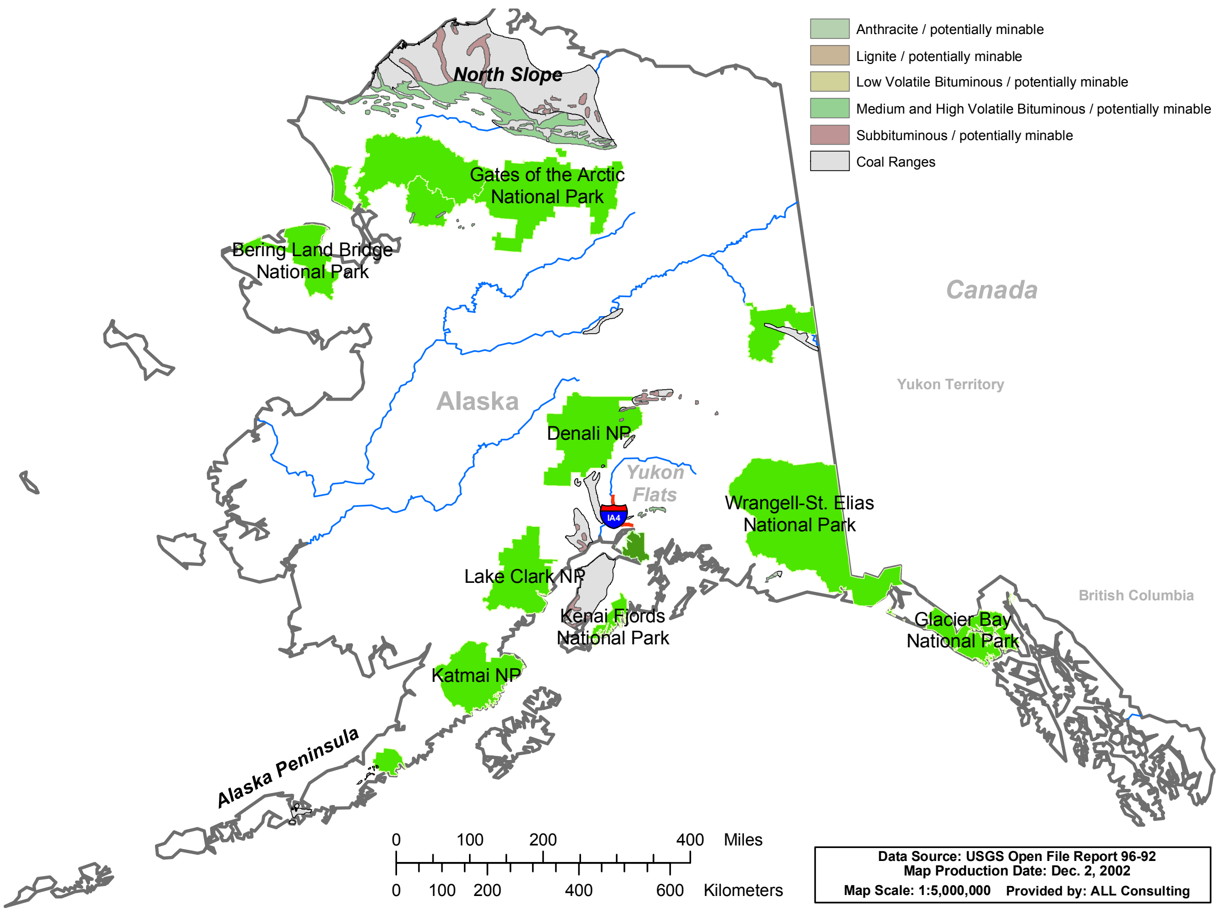
The coal resource varies in rank from bituminous to lignite, and formed in extensive Cretaceous to Tertiary aged basins throughout the state. In 1994, the Division of Oil and Gas drilled the state's first coal bed methane test well near the town of Wasilla, located in the northern portion of Cook Inlet Basin. Eighteen seams of high-volatile C bituminous coal were encountered, with the thickest being 6.5 feet (2 m) and a net coal thickness of 41 feet (12.5 m).

Since that initial drilling activity, there have been thirteen basins identified in Alaska for CBM development. Three of these basins, 1) the western North Slope Basin near Wainwright (northern Alaska), 2) Alaska Peninsula near three Chignik Bay communities (near Anchorage and the southwestern peninsula of Alaska), and 3) the Yukon Flats Basin at Fort Yukon (central Alaska north of Fairbanks) have been identified for potential development to meet the energy needs of rural communities. These areas were identified by the Alaska Division of Geological & Geophysical Surveys (DGGS) for potential development to the meet the energy needs of roadless rural communities (Clough, 2001).

Water Resources

Water supply and demand issues related to CBM production are less of a concern to landowners and producers in Alaska due to the higher precipitation rate and moist climate. Much of Alaska is blessed with ample rainfall and snow to provide adequate surface water supplies for the local population and wildlife. Water disposal issues do require concern due to the inability to discharge to streams during the winter due to low stream flows. Most of Alaska's drinking water producing aquifers are unconfined. The quality is generally good; however, very few of the aquifers have been characterized, or even located and little water quality data is available. Most operators rely on deep disposal wells to dispose of moderate to high TDS content produced water. By using deep disposal wells, the impact from CBM produced water is reduced.

Figure 3-2
Alaska Coal Bed Methane Areas
State of Alaska showing coal types and CBM potential.



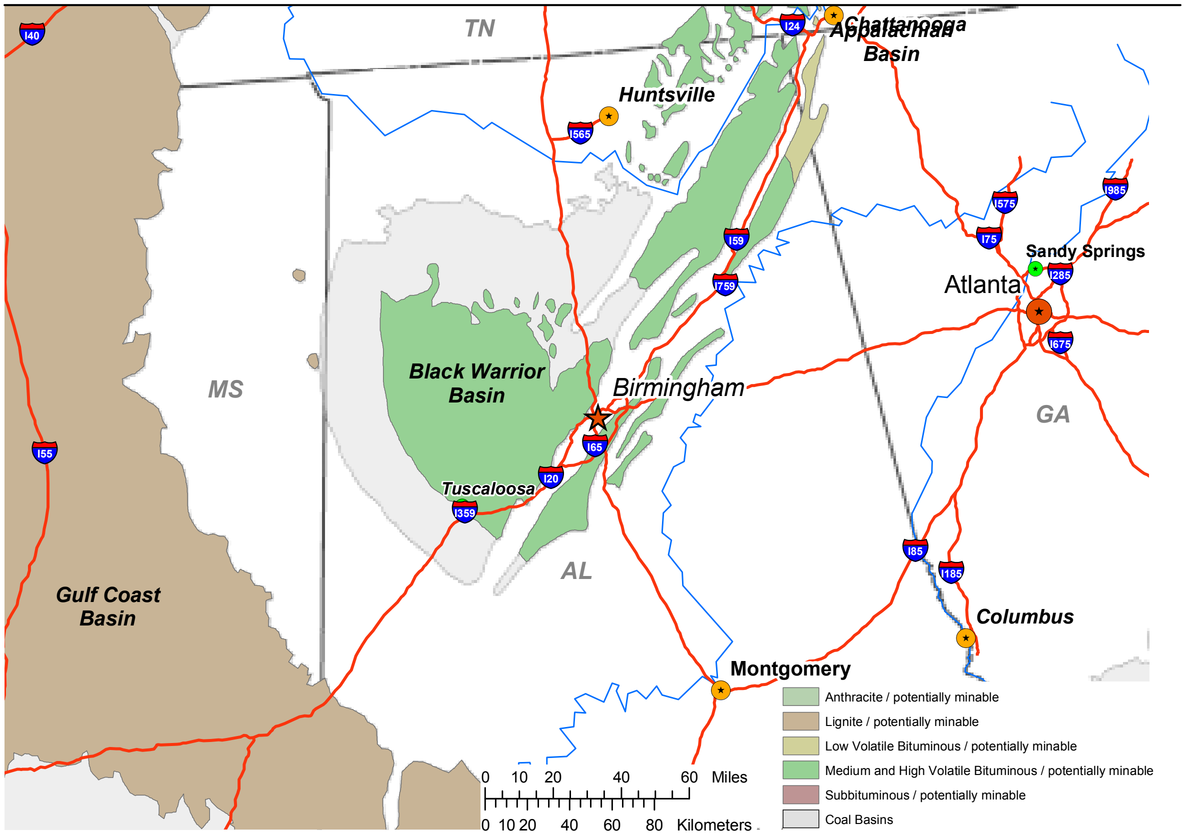
Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

Black Warrior Basin

One of the oldest CBM plays in the United States is the Black Warrior Basin in west-central Alabama. The early investigations into CBM in Alabama were associated with coal mining activities (GSA, 2002). The earliest production of CBM in Alabama was in the Pleasant Grove Field which was the first coal degasification field permitted and established in 1980 (AOGB, 2002). As a result of the rapidly expanding CBM production, the state of Alabama was the first state to establish comprehensive rules and regulations for the drilling and production of CBM in

1983 (AOGB, 2002). Figure 3-3 provides an overview map showing the distribution of coal bearing formations in the Black Warrior Basin.

Figure 3-3
Alabama Coal Bed Methane Areas
State of Alabama showing coal types and CBM potential



Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

Coal Geology

The Black Warrior Basin lies in the area that is currently northwestern Alabama and northeastern Mississippi; part of the southernmost Appalachian Basin. The basin is bounded by the Cincinnati Arch to the north, the Appalachian Basin to the east, the Louisiana- Mississippi Salt Basins to the south, and the Mississippi Embayment part of the Illinois Basin (Ryder, 1995). During the Cretaceous and Tertiary, sediments from the Mississippi Embayment and Gulf Coastal Plain inundated and filled the basin (Ryder, 1995). The Cretaceous section lies unconformably on top of the Lower Pennsylvanian Pottsville Formation. These coal seams are important to CBM development in Alabama.

The upper portions of the Pottsville Formation that contain the coal seams are a series of regressive sequences that coarsen upward from marine mudstone to non-marine mudstone, with thicker sections to the southeast of the basin (Rice and Finn, 1995a). There are five main groups of coals which have shown the greatest development potential they are, in ascending order:

Black Creek, Mary Lee, Pratt, Cobb, and Gwin (Rice and Finn, 1995a). Rice and Finn (1995a) note that the individual coal seams are less than 3 ft thick, but with as many as 40 individual seams in some parts of the basin the net thickness can reach 32 ft in the southeastern part of the Basin at a depth of 4,000 ft or more. The southeastern portion of the basin contains higher rank coals which grade outward in the bulls-eye pattern from low-volatile bituminous to high-volatile C bituminous. Rice and Finn (1995a) note that the high rank coals are associated with the areas of greatest thickness and are approximately 3,000 ft or less deep.

CBM Development and Gas Reserves

The USGS estimates the CBM reserves in the Black Warrior Basin to be approximately 20 TCF with approximately 3.4 TCF technically recoverable. After the first CBM wells were permitted in 1980, CBM production in Alabama steadily increased until 1991, at which time the volume of gas produced nearly doubled the previous years' production (AOGB, 2002). This significant increase in CBM production resulted from an increase in well drilling that started in 1988 and has been attributed to the approaching end of tax incentives (GSA, 2002). Since the end of the tax incentives in 1993, the volume of gas produced from the Black Warrior Basin has stabilized at approximately 110 to 113 billion cubic feet per year (AOGB, 2002). The cumulative production through end of 2001 was 1.3 TCF (AOGB, 2002). A total of 5,600 CBM wells have been drilled in Alabama, with 3,250 still actively producing (AOGB, 2002). There are still wells being drilled in 2002, although numbers have remained relatively low since the end of the tax incentives in 1993.

Water Resources

The volumes of water produced from the Black Warrior Basin are lower on a per well basis than some of the newer CBM basins. The USGS (2000a) reports a per well production volume for the Black Warrior Basin to be approximately 58 Bbl/day, the state of Alabama's Oil and Gas Board's online data shows an average water production volume of approximately 77 Bbl/well/day (data through end of 2001, updated 5/2002). The quality of produced water varies across the basin with TDS in some areas below 2000 mg/L to areas where the TDS is in excess of 30,000 mg/L (Rice and Finn, 1995a). Because of this variation in quality, the water management options within the basin vary from discharge to the Black Warrior River to deep well injection (Stevens, et al 1996).

Alabama has a diverse subsurface environment that contains large quantities of high quality groundwater. The aquifers of Alabama have been characterized and 50% of the population depends on groundwater for drinking water. Recharge areas in Alabama cover 80% of the state, making some aquifers vulnerable to contamination from the surface.

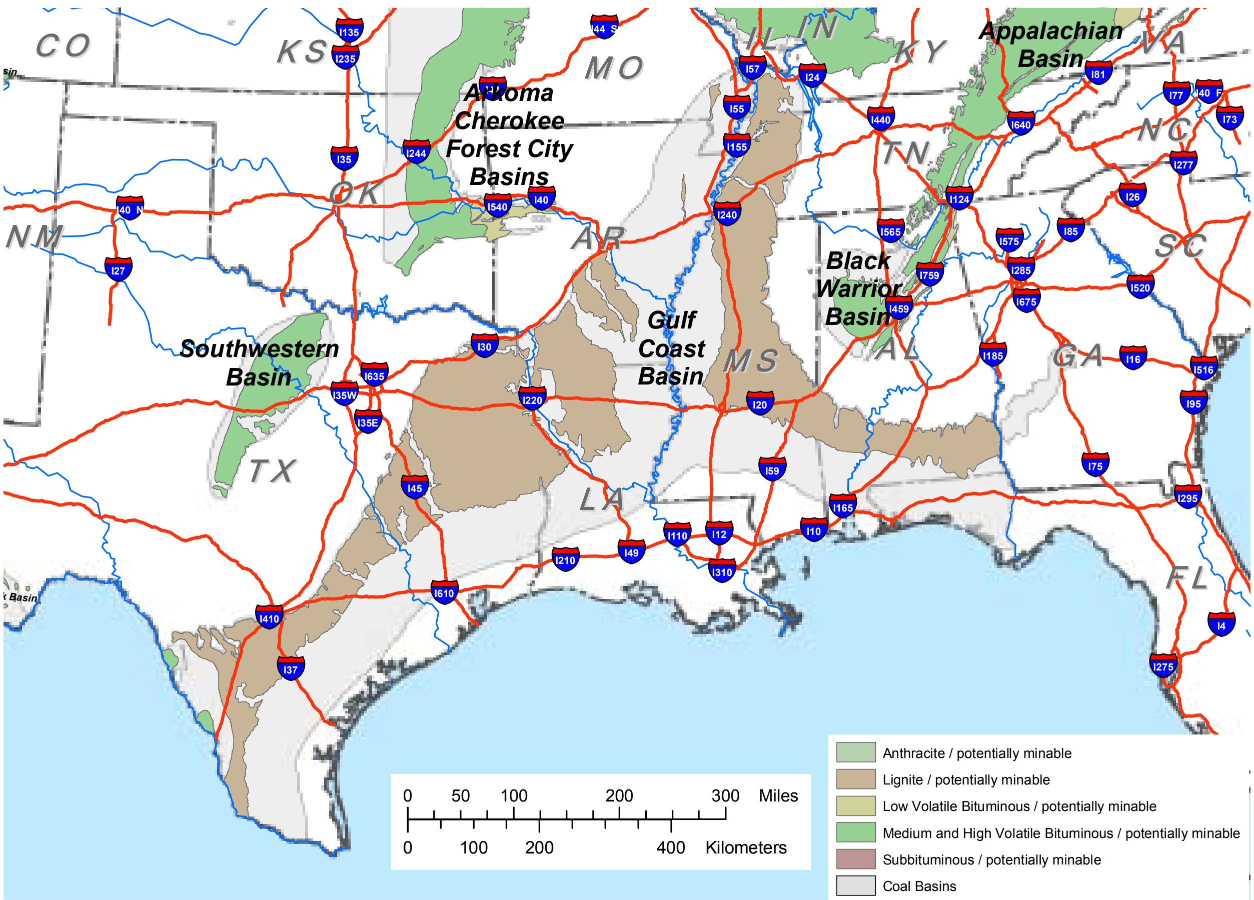
Gulf Coast

The Gulf Coast coal-bearing region is located westward from Alabama and Mississippi, across Louisiana to the northern part of the Mississippi embayment, and then southward to eastern Arkansas, Texas and northern Mexico. Figure 3-4 provides an overview map showing the distribution of coal bearing formations along the Gulf Coast.

Coal Geology

The Gulf Coast Basin is a broad homocline that dips toward the Gulf of Mexico. The region is underlain by Eocene-aged sediments which outcrop across the region, a variety of sandstones interbedded with mudstones, and containing very thin to thick layers of lignites and carbonaceous shales (Middleton and Luppens, 1995). The formations represent a series of marine trangressive-regressive cycles that occurred during the Eocene (Yancey, 1995). The Eocene and some of the underlying older sediments represent the units with the greatest CBM potential in the Gulf Coast.

Figure 3-4
Gulf Coast Coal Bed Methane Areas
Coal bearing formation distribution along the Gulf Coast.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

CBM Development and Gas Reserves

The potential for CBM development in the Gulf Coast exists in coals from the Upper Cretaceous Navarro Group, Cretaceous Olmos Group, Upper Paleocene/Lower Eocene Wilcox Group, Middle Eocene Claiborne Group, and the Upper Eocene Jackson Group (Warwick et al, 2000a). Warwick et al (2000a) identified five CBM prospects across the Gulf Coast region which have the potential to develop CBM out of the Wilcox Group; the five prospects from east to west are the Oak Hill Prospect, North-Central Louisiana Prospect, West Sabine Prospect, East-Central Texas Prospect, and the South Texas Play. The USGS study indicates that gas content within the

Wilcox is greatest in the South Texas Play, but the other plays may contain economically recoverable volumes of gas (Warwick et al, 2000a). The USGS report also indicated that the total reserves are between 4 and 8 TCF, but the amount of recoverable gas is currently unknown (Warwick et al, 2000a).

Several CBM test holes were drilled in Texas and Louisiana prior to 2001, but no economic production is underway. The results of test holes drilled so far have shown low gas yields and researchers are suggesting deeper coals within the Gulf Coast may provide better results (San Filipo et al, 2000; Warwick et al, 2000b). In 2001, the first field in Texas began producing CBM from coal and carbonaceous shales in the Upper Cretaceous Olmos Formation (Warwick et al, 2001c). The Sacatosa CBM Field consists of three production clusters with seven wells each in Maverick County, Texas (Baker et al, 2002).

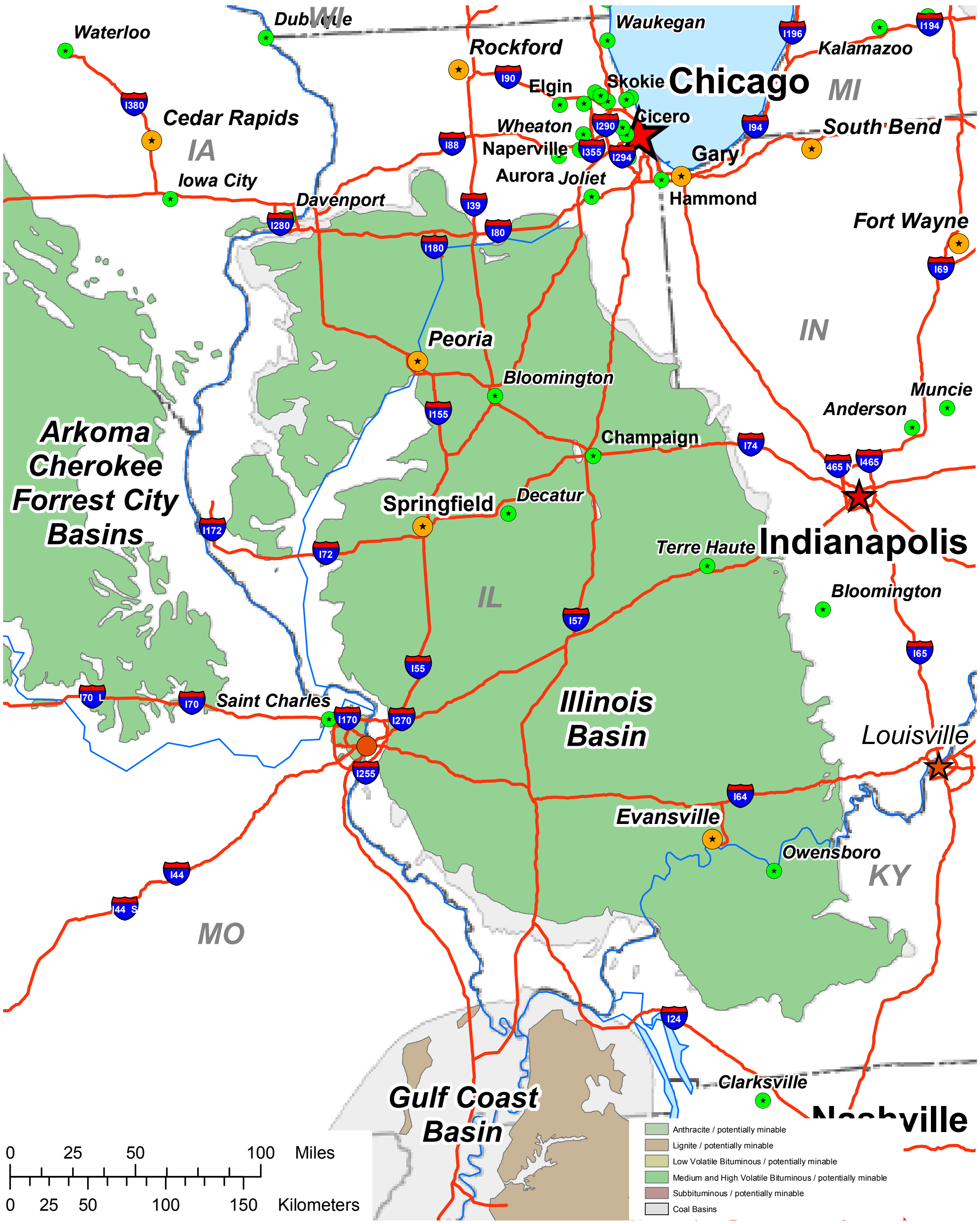
Water Resources
Groundwater quality and use varies significantly across the Gulf Coast area. In the eastern portions of Texas where CBM tests have been conducted, the shallow groundwater is used for drinking water supplies. In south Texas, the groundwater is brackish and used for livestock use only. There is very little information on the quantity or quality of the groundwater produced from CBM wells in the Gulf Coast. As exploration and production activities increase, additional information should become available.

Illinois Basin

The Illinois Basin encompasses northwestern Kentucky, southeastern Indiana, and all but the northern and eastern most portions of Illinois (Figure 3-5). The Illinois Basin is a large sedimentary basin which contains some of the largest bituminous coal basins in the United States (USGS, 1996).

Coal Geology
The Illinois Basin coal beds are contained within the Lower and Upper Pennsylvanian sections; more than 75 different seams have been identified in the basin. The USGS has identified the following coal seams to have the highest potential for CBM: Colchester No. 2, Houchin Creek No. 4, Springfield No. 5, Herrin No. 6, and Danville No. 7 (Rice et al, 1995a). Although the coal seams are less than 54 inches thick, there are multiple-seams present at shallow depths within the basin. Across the basin, coal seams are less than 3,000 feet deep, and over most of the basin the coal resources are at depths of less than 650 feet. The coals in the basin rank as mostly high volatile bituminous.

Figure 3-5
Illinois Basin Coal Bearing Area
State of Illinois showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

CBM Development and Gas Reserves
There have been numerous CBM test wells drilled in Illinois, Indiana, and Kentucky, but currently there is limited commercial production. The test wells in Indiana have been drilled in high volatile bituminous coals (CMCC, 2002). In addition to these wells, other gas production wells in Kentucky and Illinois have been producing from coal seams, but are not identified as CBM wells (Chestnut et al, 1997). The CBM reserves from the Springfield No. 5, Herrin No. 6 and Danville No. 7 are estimated to be as high as 21 TCF (Rice et al, 1995a).

Water Resources
Over 50% of the water used for public water supply in Illinois comes from groundwater (USGS, Warner, 1998). Groundwater in some areas has reached its sustained yield; any further withdrawals will result in groundwater mining. In addition, groundwater provides up to 80% of the base flow to streams in many areas of the state and is essential to watershed ecology (GWPC, 1999). Much of the groundwater is of low quality partly due to degradation or contamination from point and non-point sources throughout the state, especially in the western and southern areas of the state. These groundwater aquifers are located above the coal bearing formations in most of the state. CBM wells in the state produce very little groundwater. The water that is produced is typically of low quality and high in TDS. This water has very little beneficial use due to its high chloride content.

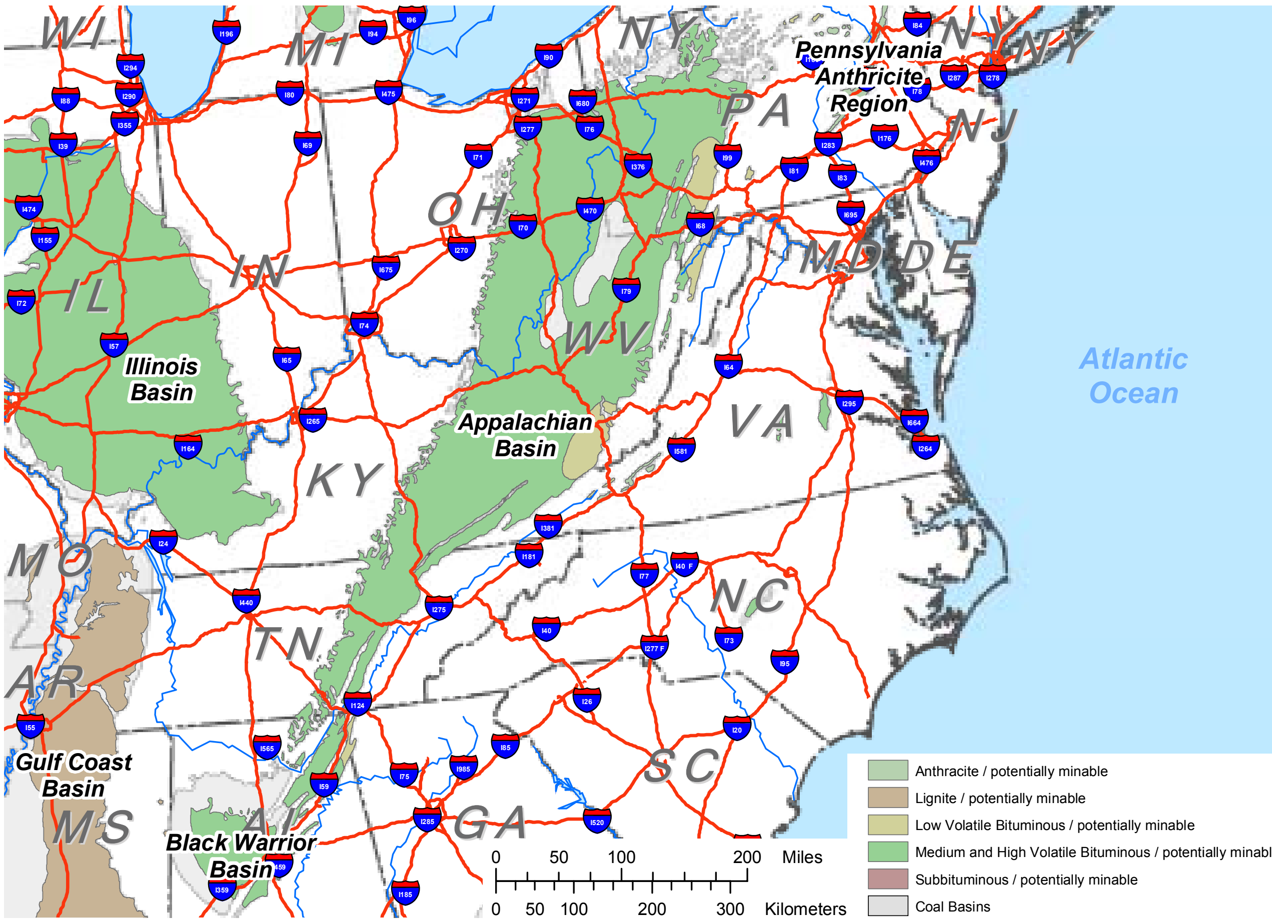
Appalachian Basin

The Appalachian Basin is divided into three basins: the North, Central, and Cahaba Basins (Rice and Finn, 1995b). Figure 3-6 provides a map of the Appalachian Basin. The Northern Appalachian Basin is located across Pennsylvania, West Virginia, Ohio, Kentucky, and Maryland; the Central Appalachian Basin is located in parts of Tennessee, Kentucky, Virginia, and West Virginia; and the Cahaba Basin is located in the Appalachian Thrust Belt of Alabama. The Black Warrior Basin, as previously discussed, is an extension of the southern portion of the Appalachian Basin.

Coal Geology
The Middle and Upper Pennsylvanian coal bearing units of the Alleghany, Conemaugh, and Monongahela groups, as well as the Permian Dunkard Group, all have CBM potential in the Northern Appalachian Basin (Milici, 2002, Rice and Finn 1995b). The following coal seams were identified as the main targets for CBM: Clarion/Brookville, Kittanning, Freeport, Mahoning, Pittsburgh, Sewickly, and Waynesburg coal groups. These groups are composed of several individual coals seams, with the cumulative thicknesses of the groups being relatively thin at 10 to 19 feet. The depth to the coal groups varies within the basin to as much as 2,000 feet, but the seams that show the greatest CBM potential are often 500 to 1,200 feet deep (Rice and Finn, 1995b). Rice and Finn indicate that the coals increase in rank eastward in the basin from high volatile bituminous to low volatile bituminous.

The coals of the Central Appalachian Basin are older (lower and middle Pennsylvanian) and often thicker than those in the northern part of the basin. Areas of commercial CBM production in Virginia occur in three coal bearing intervals: the Pocahontas, Less and Norton Formations, with targeted coal seams deeper (1,500 to 2,500 feet) than in the northern portion of the basin (Rice and Finn, 1995b).

Figure 3-6
Appalachian Basin Coal Bearing Area
Appalachian Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

The coals in the Cahaba Basin are from the same unit as those in the nearby Black Warrior Basin and the Lower Pennsylvanian Pottsville Formation. The depositional difference between the two basins can be identified in the Pottsville Formation, which in the Cahaba Basin is up to 9,000 feet thick with 20 coal zones and as many as 60 individual coal beds. Rice and Finn identified 25 coal beds of economic importance, with individual thicknesses up to 7 feet and cumulative coal thickness that can be 45 feet or more. These coals of economic importance include the Gould, Harkness, Wadsworth, Coke, Cholson, Thompson, Montavello, and Maylene (Rice and Finn, 1995b).

CBM Development and Gas Reserves
There is commercial CBM production within the Appalachian Basin in Pennsylvania (157 wells), Virginia (1,646 wells), West Virginia (115 wells), Kentucky (5 wells), and Alabama (3,195 wells) (Milici, 2002). The majority of the CBM gas produced from the Appalachian Basin is from Black Warrior Basin in Alabama (discussed separately), while other portions of the basin have seen limited field expansion since the early 1990's (Lyons, 1996). In the Appalachian Basin, excluding the Black Warrior Basin, total CBM cumulative production was 266 Bcf in 2001 (Milici, 2002). Reserve estimates of CBM for the Appalachian Basin range from 60 TCF to as much as 76 TCF (Rice and Finn, 1995b; Lyons, 1996).

Water Resources
Groundwater in the Appalachian Basin is variable across the region. In the middle areas of the basin the water is contained in shallow sand aquifers along with fractured bedrock aquifers. In the mountainous area, groundwater flow is restricted to bedrock aquifers that discharge to local streams and creeks. CBM production comes from both drilling into un-mined coal seams and some production from old mine areas where water has filled the mine. The water produced from these coals mines and seams are typically medium to high TDS water that has few if any beneficial uses. There are some areas where the water may be below 10,000 TDS, but due to minerals in the coal is high in metals, sulfur, or arsenic, which makes the water not usable for human or livestock consumption.

Arkoma – Cherokee Basins

Two basins within the Great Plains have potential for CBM development: the Cherokee Platform and the Arkoma Basin. The Cherokee Platform Province covers the southeastern portion of Kansas, southwestern Missouri, and into the northeastern part of Oklahoma. The Arkoma Basin extends from east-central Oklahoma into west-central Arkansas. Figure 3-7 provides an overview map showing the distribution of coal bearing formations in the Arkoma and Cherokee Basins.

Coal Geology
The Pennsylvanian-age coals in the Cherokee Group (Hartshorne, Senora, and Savanna Formations) appear to have the potential for economic CBM development in the Cherokee Platform (Hemish, 2000, and Cardott, 2001). In the Cherokee Platform, the coal seams thickness varies for individual beds and can be as much as 5 feet, with net thickness greater than 15 feet in coal seams between 600 and 1,200 feet deep (Rice et al, 1995b).

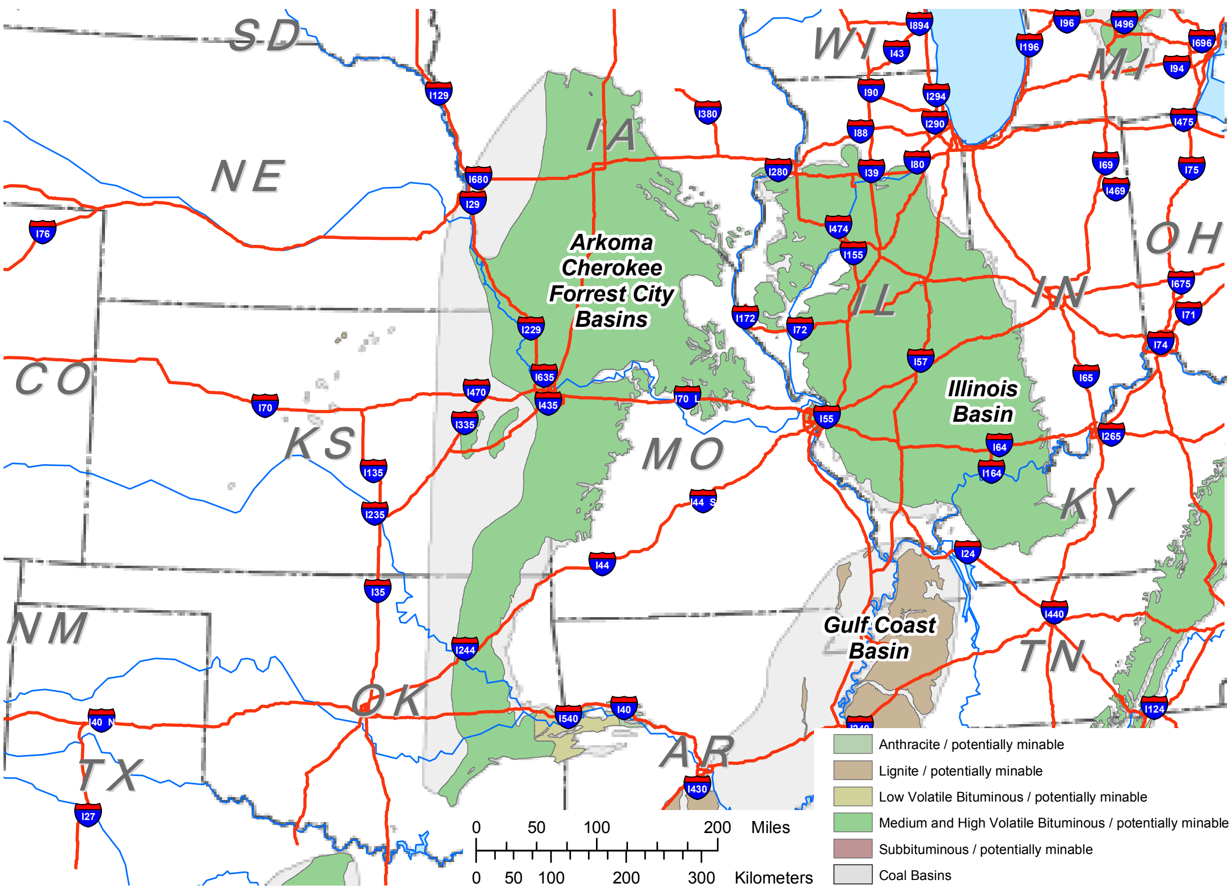
The Middle Pennsylvanian Hartshorne, McAlester, Savanna, and Boggy Formations have been identified to have CBM potential in the Arkoma Basin. The five targeted coal seams for CBM development in Oklahoma are the Hartshorne, McAlester/Stigler, Cavanal, Lower Witteville, and Secor. In Arkansas there are three: the Hartshorne, Charleston, and Paris (Rice et al 1995b). The Hartshorne is the most continuous coal seam with individual bed thickness as much as 10 feet and a depth of 500 to 1,500 feet. The coal rank varies across the basin eastward with higher rank semi-anthracite in the Arkansas part of the basin, which grades over to high volatile bituminous on the Oklahoma side (Rice et al, 1995b).

CBM Development and Gas Reserves
As early as the 1920's, development of "shale gas" from the Mulky coal beds of the Cherokee Group was occurring in southeast Kansas. In the 1980's as a result of the Tax Credit, the

exploration for coal bed gas was occurring in the Cherokee Platform (Rice et al, 1995b). In 1992 there were 230 CBM wells in Kansas; toward the end of 2001 there were 738 CBM wells in the Oklahoma portion of the Cherokee Platform (Rice et al, 1995b and Cardott, 2001). The Oklahoma wells average 947 feet of depth to top of coal, 27 Mcf per day and 60 barrels of water per day (Cardott, 2001).

CBM development in the Arkoma Basin began around 1988 with the target coal seam being the Hartshorne coals. Initial gas production per well was 41 to 45 Mcf per day from the seven wells in the Kinta gas field (Cardott, 1999). By 2001, there were 552 CBM wells completed in seven coal seams in the Oklahoma portion of the Arkoma Basin. The wells average 1,421 feet of depth to top of coal and produced between 106 Mcf per day with most of the wells producing less than 20 barrels of water per day (Cardott, 2001).

Figure 3-7
Arkoma-Cherokee Coal Basin Area
Arkoma—Cherokee Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

Water Resources

CBM wells completed near the top of structure have very little water. As one moves down the structure, the wells require some water removal with pumping rates reaching 40 to 50 barrels per day. The water typically has TDS up to 90,000 mg/L and is mainly injected into the Arbuckle Group.

Powder River Basin

The Powder River Basin (PRB) extends from central Wyoming northward into southeastern Montana. The PRB is bound by the Black Hills Uplift to the east, the Bighorn Uplift to the west, the Miles City Arch and Cedar Creek Anticline to the north, and the Casper Laramie Arch and the Hartville Uplift to the south. Throughout the PRB there are federally owned and managed, state owned, and private and fee mineral estates. Figure 3-8 provides an overview map showing the distribution of coal bearing formations in the PRB.

Coal Geology

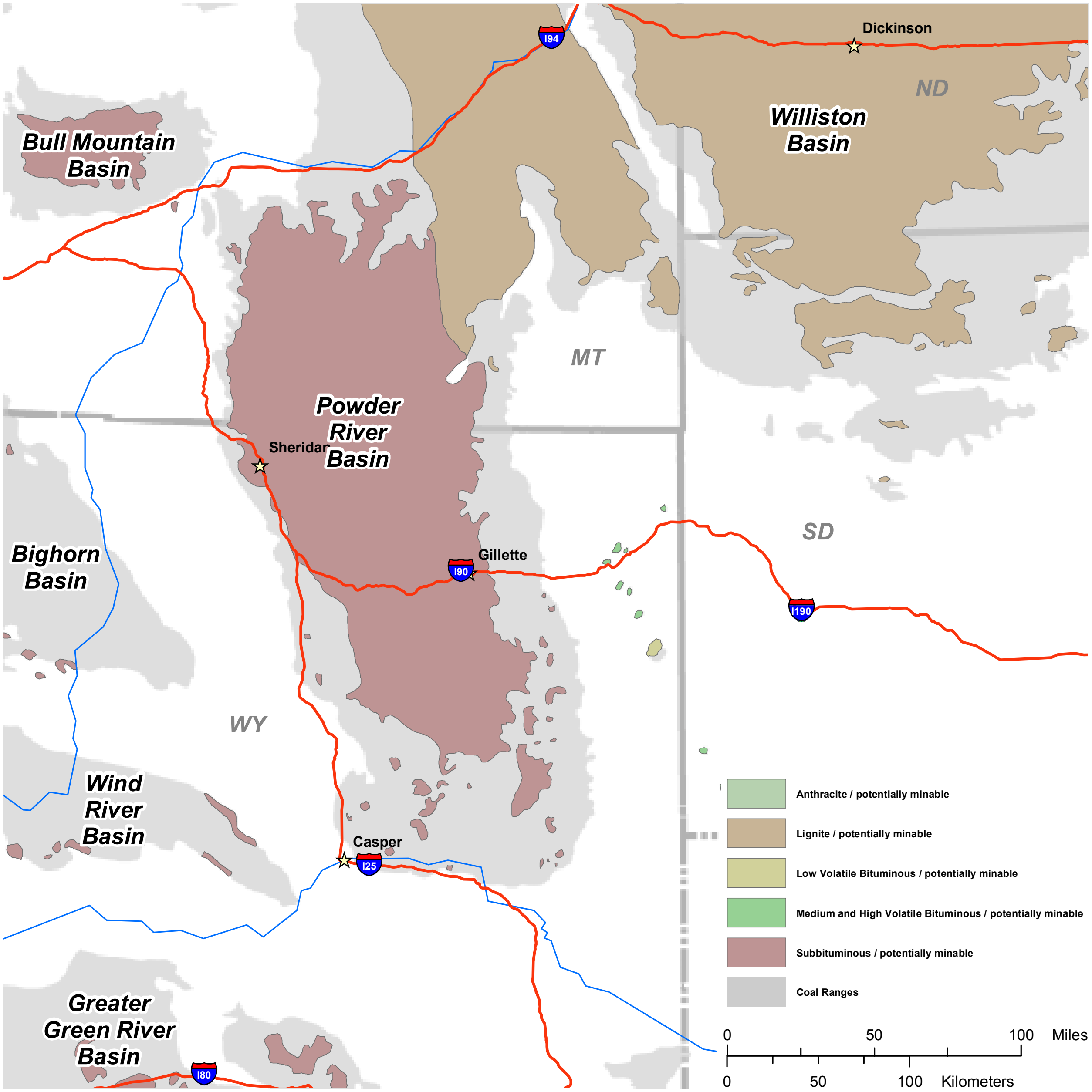
The PRB is filled with several miles of accumulated sediments; these sands, shales, and limestones form the source and reservoirs for fossil energy reserves – crude oil, natural gas, coal and CBM. The sedimentary strata within the PRB extend backward in time from recent aged alluvium found in stream and river valleys, to surface outcrops of Tertiary and Cretaceous strata, and to older sediments corresponding to Laramide tectonism that gave rise to most of the uplifted areas surrounding the PRB (ALL, 2001b). The Tertiary sediments are of particular interest for the potential CBM resources (ALL, 2001b). Of particular interest for CBM in the PRB are the Tertiary Paleocene units from the Tongue River member of the Fort Union Formation. Current CBM production in the Wyoming and Montana portions of the PRB are focused in the three to five coal seams present in the Wyodak Anderson Coal zone within the Tongue River Member.

CBM Development and Gas Reserves

The development of CBM in the PRB started in the late 1980's within the Wyoming portion of the basin and began to slowly expand into the early 1990's. Since early 1999, the number of wells within the Wyoming portion of the basin has increased ten fold from approximately 700 producing wells to nearly 9,000 producing CBM wells in early 2002 (CMCC, 2002). CBM gas production has seen similar increases from approximately 3.5 MMcf per day in 1999 to over 25 MMcf per day in early 2002. Development in the Montana portion of the PRB is behind that of Wyoming with only one active CBM field with approximately 200 active producing CBM wells in 2001 (ALL, 2001b).

The CBM gas reserves within the PRB have been estimated to be as much as 90 TCF in the Montana portion of the PRB (ALL, 2001b). The USGS has estimated the total reserves within the PRB at 30 TCF (Rice and Finn, 1995e). CBM developments in both the Montana and Wyoming sides of the basin are expected to continue to grow once the two Environmental Impact Statements (EISs) being performed by the BLM offices in each state are completed. The Wyoming EIS is projecting as many as 60,000 CBM wells to be drilled in the next 10 to 20 years, while the Montana EIS projects as many as 27,000 CBM wells will be drilled over the same time period. This development rate will be largely dependent on the availability of operators to maintain the necessary number of drilling rigs in the area and economically manage the attendant volumes of produced water.

Figure 3-8
Powder River Basin Coal Bearing Area
Powder River Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

Water Resources
The PRB is one of the areas where data regarding the quantity and quality of groundwater being produced are readily available. The produced water volumes associated with CBM in the PRB show an exponential decline over time. Analysis that has been performed in both the Wyoming and Montana portions of the basin as part of the EISs indicate that initial per well water production rates may be as high as 15 gallons per minute (gpm), but decline rapidly after the first couple of years and that by year six rates of less than 2.5 gpm occur. Depending on the estimated well life, normalized average well lifetime production rates are between 2.5 and 4 gpm (ALL, 2001b; BLM, 2001). As more wells are installed within the PRB the volumes of water produced in order to economically extract CBM from these wells are expected to decrease.

The quality of CBM produced water within the PRB varies across the basin. On the basin margins where fresh water is recharging the coal seam aquifers, higher quality water is produced compared to areas in the basins center. The water produced on the basin margins is often suitable for human consumption, livestock watering, and irrigation purposes. As one moves into the interior portions of the basin the water, although still of sufficient quality for livestock consumption in most cases, becomes unsuitable for human consumption or irrigation by existing practices. This water is often more saline with higher TDS (>3,000 mg/L) and has a high sodium adsorption ratio (SAR) (>8, and up to 40 or 50) which makes it less suitable for irrigation without proper management to prevent damage to soils.

Existing production in the PRB utilizes a variety of options to manage CBM produced water. Deep injection, aquifer storage, surface water discharge (with NPDES permits), land application (irrigation with amendments), livestock watering, and impoundment are all being used to manage produced water.

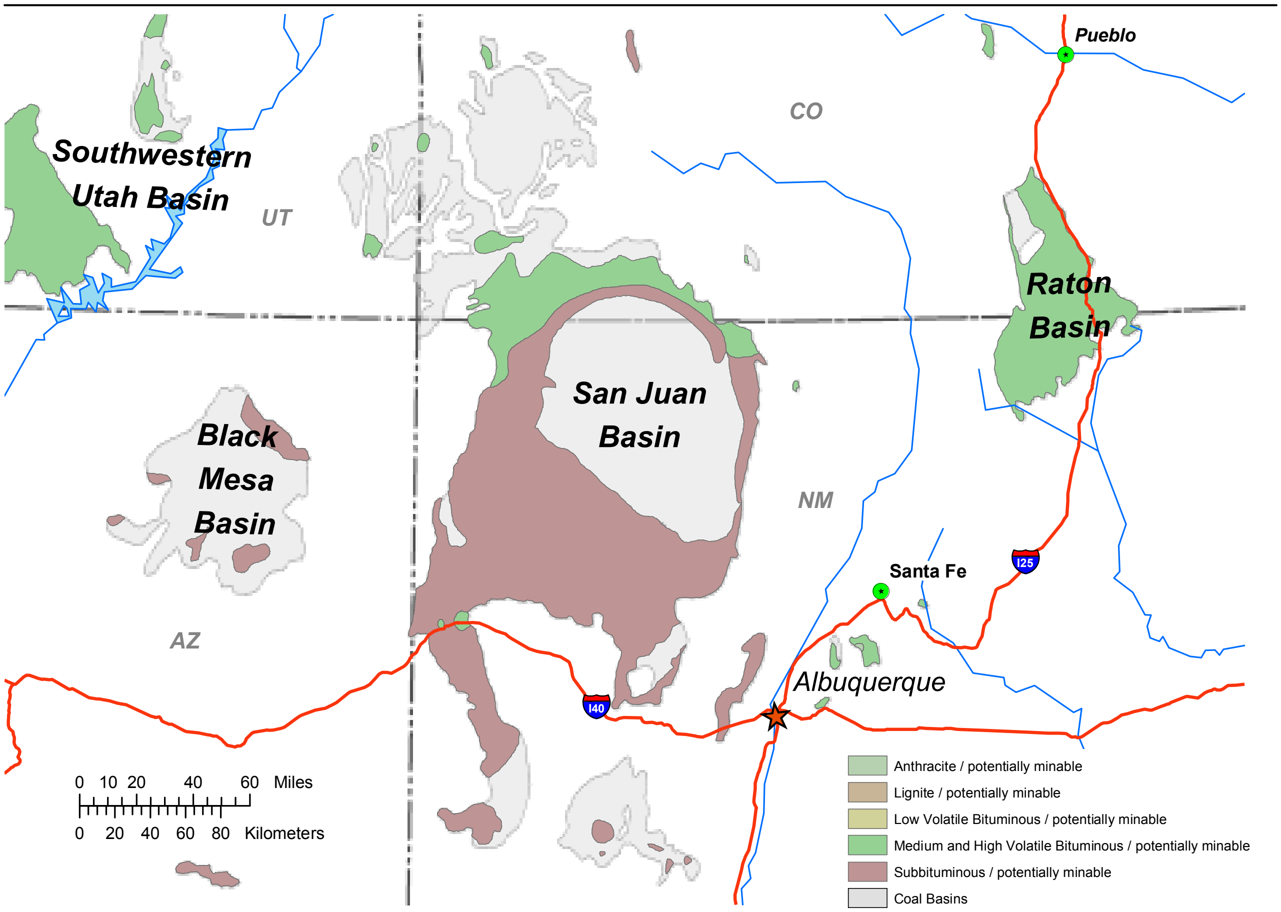
San Juan Basin

The San Juan Basin (SJB) is an asymmetric structural basin along the New Mexico - Colorado border. Within the basin there is a variety of land and mineral ownership including federally managed rights, state owned rights, privately owned rights, and Native American owned rights. Figure 3-9 provides an overview map showing the distribution of coal bearing formations in the SJB.

Coal Geology
The SJB is the result of Laramide tectonic activity that began in the Late Cretaceous after the final regression of the Western Interior Seaway. The basin has since experienced an uplift which resulted in a tilting of the SJB downward to the northwest, followed by a period of subsidence which resulted in the deposition of Paleocene and Eocene sediments; this further enhanced the down warping of the basin center (Fassett, 2002). The Cretaceous age rocks of the SJB, in particular the Fruitland and Menefee Formations, contain substantial coal beds which have been developed for commercial extraction of CBM (BLM, 1999a).

The individual coal seams within the Fruitland Formation vary in thickness with a maximum of nearly 40 feet, while averages in most of the basin are closer to 6 to 9 feet; net thickness can be as great as 100 feet. The Menefee coals are thinner, discontinuous, and more dispersed than those in the Fruitland and are found deeper in the section approximately 6,500 feet, compared to approximately 4,000 feet for the Fruitland (Rice and Finn, 1995c). The Fruitland coals rank from sub bituminous C to medium-volatile bituminous from southwest to northeast across the basin. A similar trend was identified in the Menefee coals, but the Menefee coals rank higher (Rice and Finn, 1995c).

Figure 3-9
San Juan Basin Coal Bearing Area
San Juan Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

CBM Development and Gas Reserves

The methane gas in the formations across the SJB has been identified as an economic resource for nearly 100 years, and has been exploited since the 1940's and 1950's. It was not until the tax incentives associated with the passage of the Crude Oil Windfall Profits Tax Act of 1980 was passed that extensive development of CBM within the SJB occurred (BLM, 1999a). The passage of the Tax Act spurred a drilling boom in the SJB which has resulted in the creation of world's largest CBM field with annual production of 0.9 TCF and cumulative production of approximately 9 TCF (Dugan, 2002).

Water Resources
As of early 2000 there were approximately 3,100 CBM wells in the San Juan Basin producing water at nearly 25 BBLS/day (USGS, 2000b). The BLM has predicted an additional 1,000 CBM infill wells may be drilled on the Colorado side of the SJB (BLM, 1999a). In addition, the BLM's Farmington Field Office has a draft plan that proposed as many as 3,000 wells on the New Mexico side of the SJB (BLM, 2003). Deep injection is the most common water management option in the SBJ.

Approximately 90% of the population of New Mexico depends on the groundwater for drinking water and nearly one-half of the water used for all purposes is groundwater (GWPC, 1999). In many locations, groundwater is the only available water supply. Because of the arid environment and importance of groundwater to the state, New Mexico protects all groundwater with TDS of 10,000 mg/L or less to supply present and potential future use for a domestic and agricultural water supply (GWPC, 1999).

Uinta Basin and East-Central Coal Bed Methane Areas

The Uinta Basin and nearby East-Central (coal bed) Methane Area (ECMA) of Utah are other active areas for CBM production in the western United States. The ECMA includes the Castlegate, Helper, Drunkards Wash, and Buzzard Bench CBM fields of east-central Utah. A portion of these basins fall within what is known as the Ferron Coal Bed Gas Fairway, an 80 mile stretch that is 6 to 10 miles wide that contains between 4 and 9 TCF of recoverable reserves, (BLM, 1999b). These areas are located in Carbon and Emery counties of Utah. The mineral ownership is a composite of federal owned, state owned, and private rights with an approximate split between the federal and state/private ownership. Figure 3-10 provides an overview map showing the distribution of coal bearing formations in the Uinta Basin and ECMA.

Coal Geology
The ECMA is part of the Colorado Plateau physiographic province and lies within the Mancos Shale Lowlands. The Mancos Shale Lowlands are bounded by the Book Cliffs-Roan Plateau to the north, the San Rafael Swell to the southeast, and the Wasatch Plateau to the west (BLM, 1999b). The Mancos Shale Lowlands are characterized by sloping, gravel-covered pediments, rugged badlands, and narrow, flat-bottomed alluvial valleys (Stokes, 1988). The geologic units of interest for current and projected CBM activity are the Cretaceous aged Mesaverde Group and the Mancos Shale.

The methane produced in the active fields of the Uinta Basin is from two formations, the coal-bearing and associated sands of the Blackhawk formation and the Ferron Sandstone Member of the Mancos Shale. The Blackhawk formation is the producing zone for the Castlegate Field and the Ferron Sandstone is the producing zone for the Helper, Drunkards Wash, and Buzzard Bench Fields (Utah Geologic Survey, 2002).

CBM Development and Gas Reserves
CBM exploration began in the early 1980's with production as early as 1987; significant production began in 1992 and is continuing to rise today. In 2001, CBM production comprised approximately 28% of the Utah's total gas production and is expected to become the state's most productive source of gas once the full development potential is reached (Utah Geologic Survey, 2002). There are currently approximately 200 CBM wells within the Uinta Basin with more wells expected upon the completion of an additional EIS by the BLM Utah. The estimated total

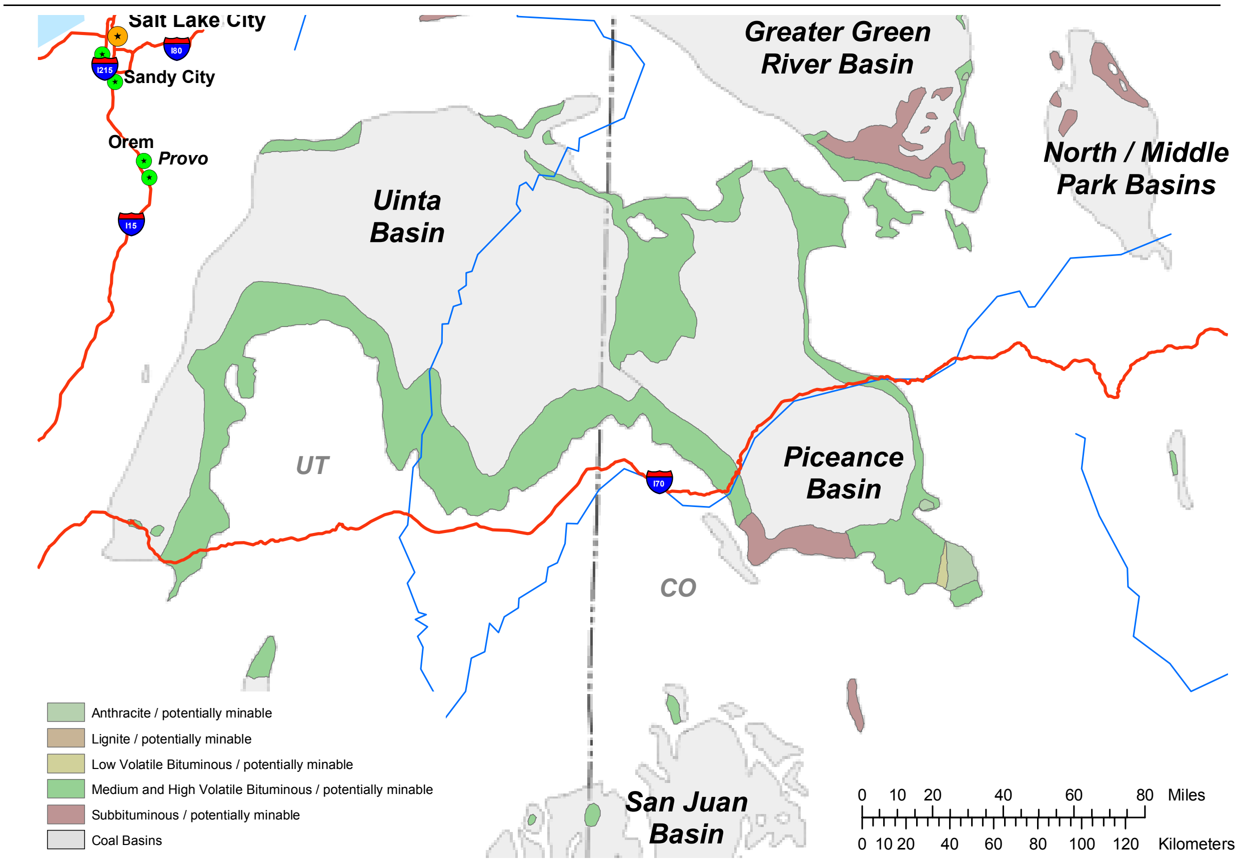
recoverable CBM reserves from this area are approximately 10 TCF (Rice et al, 1995c and GTI 2002). In 2001, the Utah counties of Carbon and Emery had 72 million and 7.3 million MCF of production, respectively.

Water Resources

As of November 2000, 393 CBM wells were operating in the Uinta Basin and were producing an average of 215 barrels of water per day per well (USGSa, 2000). The produced groundwater in the basin had TDS of 6,350 to 42,700 mg/L.

The primary source of water within the Uinta Basin is the streams originating in the Uinta Mountains to the north with lesser contributions from the Wasatch Hinterlands to the west. Approximately 98% of the water is diverted from streams or stored in reservoirs and is used for agricultural, municipal, and industrial uses, as well as secondary uses (Utah DEQ, 2003). As an example, the Uinta River flows south of the Uinta Mountains, providing water to municipal areas through an extensive system of canals and pipelines. The river is dewatered through most of the summer due to the high demands; water flowing in the river during the summer is primarily from run-off from irrigated lands containing high salt contents from percolating through the saline geologic formations (Utah DEQ, 2003). Groundwater is also used to a lesser extent for agricultural, municipal, and industrial uses. The primary recharge for the groundwater is from the Uinta Mountains (Utah DEQ, 2003).

Figure 3-10
Uinta Basin and East Central Coal Bearing Area
Uinta Basin and East Central showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

Colorado Plateau Basins

The Colorado Plateau Basins include the Wind River, Green River, Hanna, Denver, Raton, and Big Horn Basins. The basins have mixed mineral rights which include federally owned and managed, as well as state and private minerals. Figure 3-11 provides an overview map showing the distribution of coal bearing formations in the Colorado Plateau Basins.

Coal Geology

The Colorado Plateau Basins are the result of a combination of Laramide tectonics and the deposition of sediments from the Cretaceous Western Interior Seaway (WIS). The sedimentary rocks which are now exposed at the surface in areas within these basins are the results of deposition along shorelines during the time of the WIS. After the seaway moved out in the Late Cretaceous, various tectonic events of the Laramide Orogeny tilted and deformed these sediments to varying degrees; since then, erosional activities and basin subsidence has produced the forms seen today.

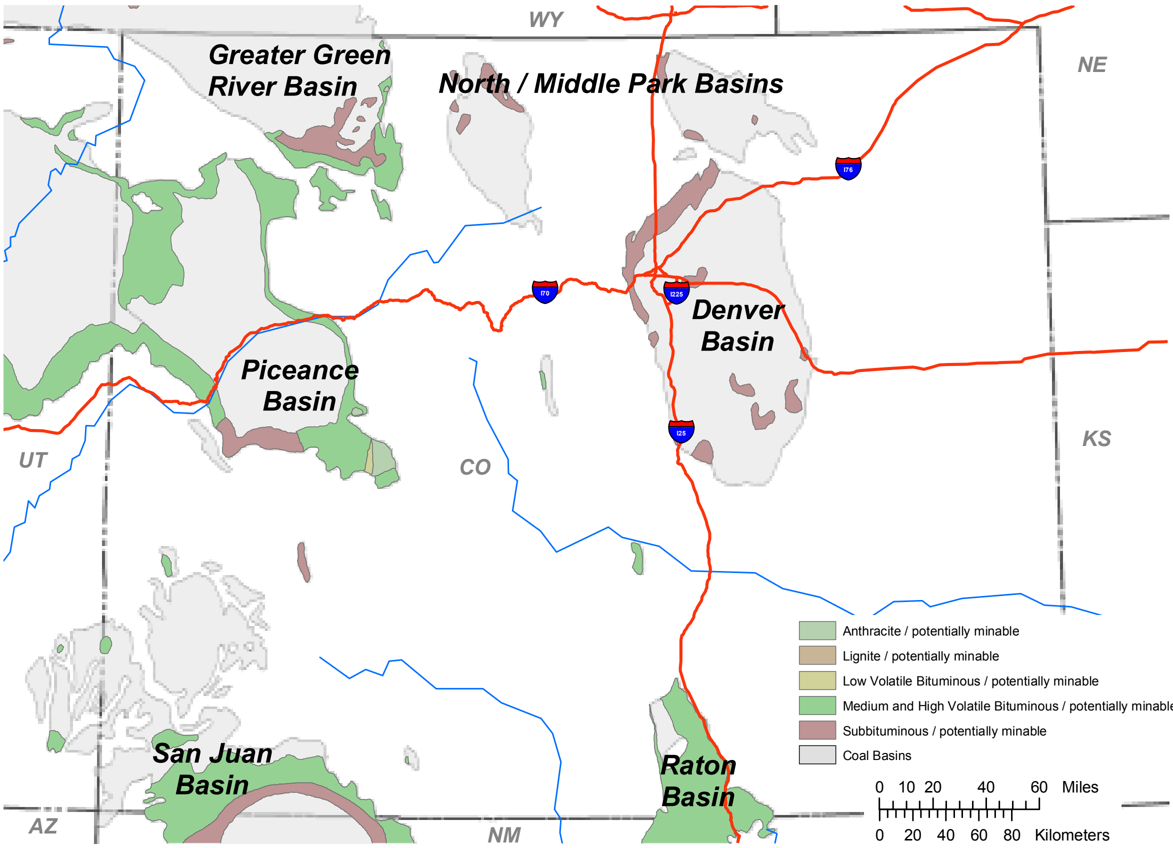
Wind River Basin

The Wind River Basin is located in central Wyoming just to the southeast of the Powder River Basin. The Wind River Basin has the potential for significant CBM development from both the Upper Cretaceous Mesaverde and Meeteetse Formations, as well as the Paleocene Fort Union Formation (Johnson and Rice, 1995a). The coal beds within each of these formations varies with the Mesaverde having cumulative thicknesses as high as 100 ft, while the Meeteetse coals cumulative thicknesses are generally less than 20 ft (Johnson and Rice, 1995a). The Fort Union Formation, which is economically developed for CBM in the nearby PRB, has cumulative thicknesses as high as 100 ft in the western and central portions of the basin (Johnson and Rice, 1995a). The coals vary in rank as well, from lignite near the surface to anthracite at depth for the Mesaverde and Meeteetse, while the Fort Union ranks from sub-bituminous C near the surface to high-volatile A bituminous at depth (Johnson and Rice, 1995a). The estimated CBM reserves within the Mesaverde coal beds of the Wind River Basin range between 2.2 TCF to 6 TCF (Johnson and Rice, 1995a).

Green River Basin

The Green River Basin is composed of five smaller basins located in portions of Wyoming, Colorado, and Utah. The potential for CBM development in the Green River Basin is from coals in the Upper Cretaceous Rock Springs, Almond, Williams Fork, and Paleocene Fort Union Formations (Law, 1995). There are as many as 30 individual coal seams in some beds with four to eight coal beds more common; individual seams can be as thick as 50 ft thick (Law, 1995). The coals grade from sub-bituminous B to high volatile bituminous B with normal cleat development (Law, 1995). There is currently an approval for 200 exploratory wells to be drilled within the Green River Basin, and there is a proposal into the Wyoming BLM for approximately 4,000 additional wells (BLM, 2002b).

Figure 3-11
Colorado Plateau Basin Coal Bearing Area
Colorado Plateau Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

Hanna Basin

The Hanna Basin is small sedimentary basin located in south-central Wyoming. The potential for CBM development in the Hanna Basin is from the Paleocene Ferris and Hanna Formations (USGS, 1999). The coal seams in the Hanna formation are typically 40 to 50 ft thick with a total per well coal interval typically from 60 to 200 ft (BLM, 2002b). The coals in the Hanna Formation are currently being considered for an exploratory development for which the BLM's Rawlins Field Office published an Environmental Assessment in January 2002. The exploration project proposed includes up to nine exploratory wells, but no estimates of total wells for the basin are included (BLM, 2002b).

Denver Basin

The Denver Basin is located in northeastern Colorado and contains rocks of the Late Cretaceous and early Tertiary. The coals of potential CBM importance are located in the Paleocene Denver Formation and present in the upper 300 to 500 ft lignite portion of the formation (Nichols, 1999). The coal beds range from 10 to 30 ft in thickness with maximum thickness of nearly 55 ft in some beds (Nichols, 1999). The coals in the Denver formation rank from lignite A with some thicker beds ranking as high as sub-bituminous C, with the Comanche Bed being identified as the highest quality (Nichols, 1999).

Raton Basin
The Raton Basin is located in southeastern Colorado and extends into northeastern New Mexico. The basin is an asymmetrical arcuate structural trough filled with sedimentary rocks that are steeply tilted, overturned, and faulted on the western edge and gently tilted on the eastern edge (Flores and Bader, 1999). The basin contains Upper Cretaceous and Paleocene coal bearing rocks in the Vermejo and Raton Formations with the potential for CBM development (Rice and Finn, 1995d). The Vermejo Formation has individual coal seams as thick as 14 ft with cumulative coal thickness from 5 to 35 ft; the Raton Formation has net coal thickness from 10 to 120 ft (Rice and Finn, 1995d). Depth to coal varies across the basin, with the northern portion being significantly deeper (4,100 ft) than other portions of the basin where depth to coals are generally less than 1,200 ft (Rice and Finn 1995d). The coals in the Vermejo Formation vary from high-volatile C bituminous along the basin margins to low volatile bituminous in the basins center (Rice and Finn, 1995d). The methane potential of these coal beds has been identified because of coal mining activities in the Morley mine area where coal-gas relief activities have been ongoing (Flores and Bader, 1999). As of 1999, there were 85 CBM wells in the central portion of the Raton Basin producing 17.5 million cubic ft/day mostly from the Vermejo Formation (Flores and Bader, 1999). In 1999, a report in the Oil and Gas Journal indicated a proposed CBM development in the Raton Basin is expected to develop a maximum of 600 additional CBM wells (Flores and Bader, 1999).

There are two available sources of groundwater in the Raton Basin: stream alluvium and bedrock aquifers. While many water wells were drilled near streams until early in the twentieth century, current Colorado water law based on prior appropriation essentially prohibits that activity.

There are two bedrock aquifers: the Cuchara-Poison Canyon and the Raton-Vermejo-Trinidad. The Cuchara-Poison Canyon aquifer provides small, non-sustainable yields to wells. Sandstone and coal layers in the Raton-Vermejo-Trinidad aquifer provide small, sustainable yields. The Raton-Vermejo-Trinidad aquifer is identified as the most reliable water source available. CBM is found in the Raton and Vermejo formations.

Bighorn Basin
The Bighorn Basin is located in north-central Wyoming and south-central Montana. There are coal bearing strata in the Cretaceous Cloverly, Frontier, Mesaverde, Meeteetse, and Lance Formations and the Paleocene Fort Union Formation (Roberts and Rossi, 1999). The thicker more extensive coal beds are in the Mesaverde, Meeteetse, and Fort Union Formations, with the Fort Union having the highest CBM potential (Roberts and Rossi, 1999). The Fort Union coals vary in thickness and lateral continuity across the basin; thickness rarely exceeds 10 ft in the deeper portions, yet cumulative coal thickness can reach 80 ft in other portions of the basin (Roberts and Rossi, 1999). The potential for CBM development in the Bighorn Basin is hampered by the lack of laterally extensive coal beds, and to date, there have been no wells drilled for CBM in the area.

Western Washington

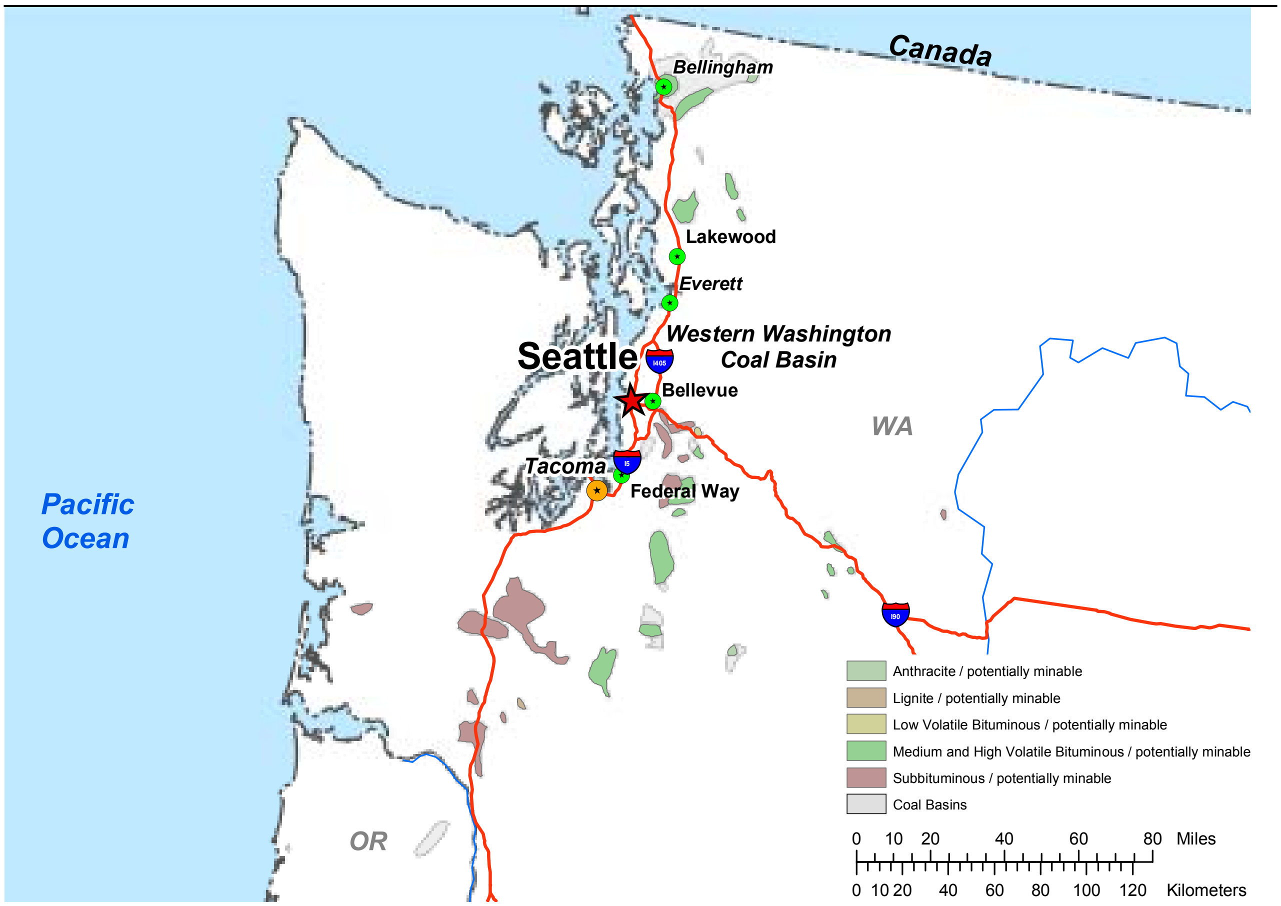
There are several basins within the western portion of Washington state that have the potential for CBM development including Bellingham Basin, Western Cascade Mountains, and Southern Puget Lowlands (Johnson and Rice, 1995b). There are a limited number of CBM test wells that have been drilled within the area, but the potential CBM reserves exceed 24 TCF (ARI, 1998).

Figure 3-12 provides an overview map showing the distribution of coal bearing formations in the Western Washington Basins.

Coal Geology

The three basins of western Washington where CBM has the greatest potential are the result of two predominant geologic activities: volcanism and glaciation. The Cascade Mountain range is the result of an active volcanic arc superimposed on Paleozoic to Tertiary aged sediments (Lasmaris, 1991). Throughout the Holocene, a series of glacial events have carved and shaped the Cascades into their present rugged topography (Lasmaris, 1991). The Puget Lowland is a broad, low-lying region between the Cascage Range and the Olympic Mountains (Lasmaris, 1991). The basin has been carved by as many as four periods of glaciation in the early Pleistocene in addition to late Pleistocene glaciation. The glaciation has exposed sedimentary rocks of Tertiary age that contain significant coal resources (Lasmaris, 1991).

Figure 3-12
Western Washington Coal Bearing Areas
Western Washington showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

The Tertiary sediments from the Eocene have cumulative thicknesses from 10,000 to 20,000 ft, with cumulative coal thicknesses up to 60 to 100 ft (Johnson and Rice, 1995b). There are numerous coal-bearing units in this area including the Puget Group, the Chuckanut, Renton, Carbondo, Spiketon, Skookumchuck, and Cowlitz formations (Johnson and Rice, 1995b). Test wells have been drilled into the coals in the Big Dirty seam of the Skookumchuck Formation. These coal seams are thinner, between 25 to 30 ft (Johnson and Rice, 1995b; MDEQ, 2001).

CBM Development and Gas Reserves

The Montana DEQ CBM webpage shows six CBM wells in Pierce and Thurston counties in Washington completed in the Big Dirty and Little Dirty coal seams of the Skookumchuck Formation (MDEQ, 2001). The six wells range between 468 and 624 ft deep, but no information was found detailing gas production or water production from these wells (MDEQ, 2001).

Water Resources

In the state of Washington, groundwater provides more than 65% of the drinking water and 25% of the total water used for drinking, industrial, commercial, and agricultural purposes (GWPC, 1999). Base flow contribution to streams is estimated to be 70%; therefore, protection of the groundwater resources is vital for maintaining in-stream flows and water quality during summer months (GWPC, 1999).

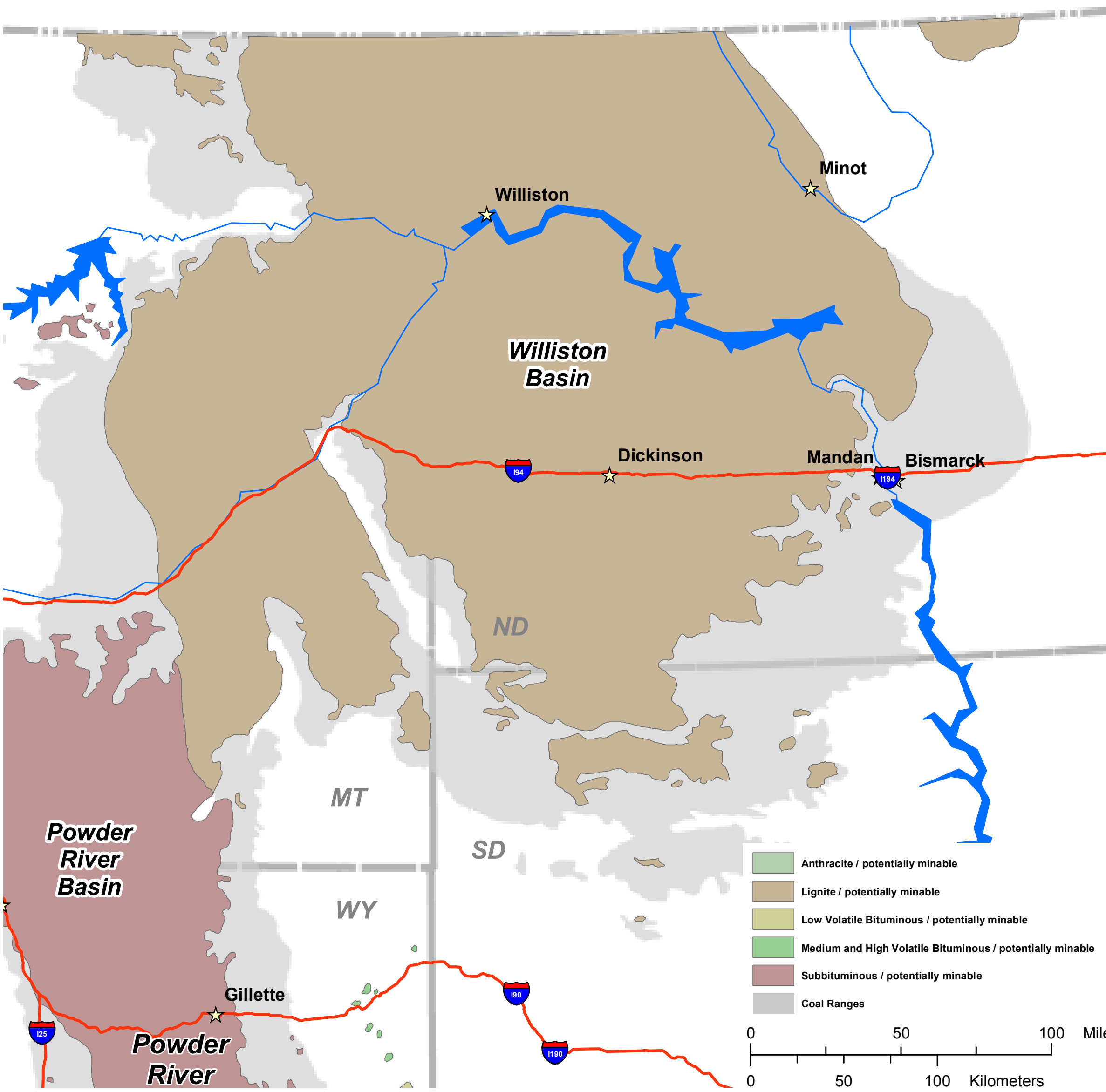
Williston Basin

One of the newest areas of CBM potential is the Williston Basin of North Dakota. The Williston Basin is a large, relatively round depression that extends from northwestern South Dakota through western North Dakota and into eastern Montana, all the way into the Saskatchewan and Manitoba Provinces in Canada (Heck et al, 2002). The Williston Basin is located just east of the PRB and separated from the PRB by the Cedar Creek Anticline and the Black Hills. The Williston Basin is a major source for oil, gas, lignite, and potash (BLM, 2001). Figure 3-13 provides an overview map showing the distribution of coal bearing formations in the Williston Basin.

Coal Geology

The basin is a result of episodic subsidence of the North American Craton that began sometime during the Ordovician period and is continuing today (Heck et al, 2002). Because the basin is a result of gradual subsidence, there is an extensive rock record present. From Cambrian time through the end of the Cretaceous, a series of marine transgressions and regressions have filled and drained the basin over time. Although there are numerous erosional unconformities, sedimentary strata from all epochs are present in the basin (BLM, 2001). The important sediments for the Williston Basin in North Dakota are the Tertiary sediments, which are equivalent to, or the same age as those in the Powder River Basin (Murphy, 2002).

Figure 3-13
Williston Basin Coal Bearing Area
Williston Basin showing coal types and CBM potential.



Note: Data source is USGS Open File Report No. 96-92; produced by ALL Consulting.

The Fort Union Group in the Williston Basin of North Dakota contains sub-bituminous coals. There have been numerous reports by the North Dakota Geological Survey (NDGS) regarding the CBM potential of lignites in the Williston Basin (Murphy, 1998; Murphy and Goven, 1998; Murphy and Goven, 1998; Murphy et al, 1999; Murphy et al, 2000; Murphy et al, 2002). The current evaluations of the shallow lignite deposits in North Dakota do not appear to have the

CBM potential of the Powder River Basin deposits (Murphy, 2002). The NDGS has recommended that operators target deeper lignite seams that have not been targeted previously, are rarely used for water wells, and too deep for mining (Murphy, 2002).

CBM Development and Gas Reserves

There is no existing CBM production in the Williston basin: several test wells have been drilled with limited success (Murphy, 2002). However, the NDGS is continuing to evaluate the CBM potential of the lignites within the Williston Basin and hope to have more detailed information in the near future (Murphy, 2002). In addition, the USFS (2001) finished an RFD for oil and gas in the Dakota Prairie National Grassland and are predicting as many as 60 CBM wells within the area.

Water Resources

Groundwater supplies 60% of North Dakota's domestic water supply needs; furthermore, 94% of the state's incorporated communities rely on groundwater (GWPC, 1999). Groundwater quality varies greatly within the aquifer units, with the deeper units generally considered more saline and the shallower units are saline to brackish to moderately low TDS. The best quality water in the bedrock aquifer units almost always occurs in the shallowest unit at any given location (GWPC, 1999).

Chapter 4
Water Classifications and Rights

Introduction

This section presents a summary of general water planning issues, including water classifications and water rights, as they pertain to CBM produced water. Emphasis is on the states of Colorado, Montana, New Mexico, Utah, and Wyoming, which have a combination of significant existing and/or potential CBM resources; high-quality groundwater in coals; and considerable water needs. These areas are of particular interest because stakeholders are currently struggling with water management issues related to CBM development. Although this section of the handbook includes a detailed discussion relative to five specific states, many of the issues discussed apply throughout the United States (e.g., federal water standards and classifications) or provide examples of water issues that may be applicable in states not specifically discussed.

Both water classification and water rights issues may impact the management and use of produced water. Water rights, classifications, standards, laws, and compacts exist in areas where CBM is, or may be developed. Classifications and standards may impact how water is managed, used, or how it must be protected. Furthermore, because of the importance of water throughout the United States and especially in many water-poor western states, water rights issues may present significant hurdles in beneficially managing and using produced water. In some areas where local or even interstate water concerns have arisen, compacts or area-specific laws have been implemented that may impact water management planning.

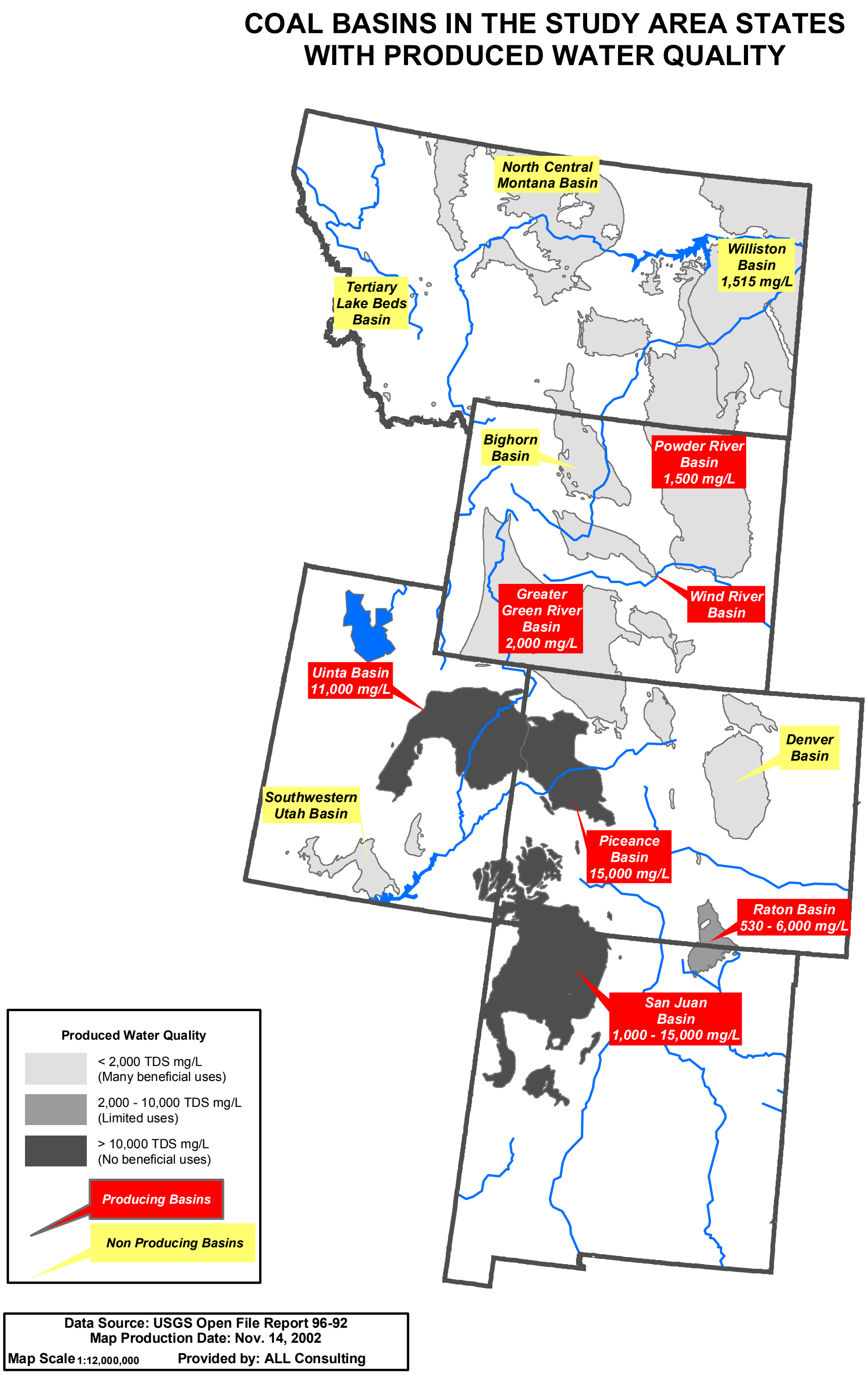
Figure 4-1 is a five-state map of the emphasis area showing order of magnitude water quality data for various basins that have existing or potential CBM production. As depicted in Figure 4-1, coal seams in Montana and Wyoming currently appear to have some of the highest quality water. However, other CBM basins may also have significant high-quality groundwater resources that may provide a broad range of water management options.

Federal Classifications and Standards

The federal government establishes several regulatory classifications and standards. In some regulatory programs, federal classifications and/or standards may also be adopted by applicable state regulatory agencies. This section summarizes the various federal classifications and standards, but the reader should recognize that state standards may vary or may change over time. As always, current regulations pertaining to classifications and standards should be referenced during actual water management planning.

Water can be classified according to its characteristics, use, source, location, as well as other criteria. Water classifications generally take into consideration the use and value of water for public water supplies; protection and propagation of aquatic wildlife; recreation in and on the water; and other potential uses (e.g., agricultural, industrial, municipal). Standards may also be established to maintain the quality of water as well as current and potential beneficial uses of the water. In addition to federal programs, individual states may also have classifications and

Figure 4-1
Coal Basins with Average Water Quality in the Five State Study Area
Map of the select western states showing water quality overlaying coal basins.



Note: Basin average water quality data is presented for comparative purposes. Data is based on available data and may not represent the entire basin.

standards to account for local or regional environmental issues. In some cases, interstate or intrastate water protection programs have been established to protect surface or groundwater resources within and/or between states.

When considering the classification of water, a good example can be observed with respect to the Colville Indian Reservation. The Colville Indians established four classifications for surface water on the Reservation as outlined in 40 CFR 131. Each class has specific requirements relative to bacteriological criteria, dissolved oxygen; total dissolved gas; temperature variations due to human and natural conditions; pH; turbidity; and toxic, radioactive, non-conventional or deleterious material concerns.

For the Colville Indian Reservation, surface water has been separated into four classifications based on the above criteria as well as designated uses. Class I and Class II waters have the same designated uses; however, the water quality criteria are different. The four classes and designated uses are:

Class I – Extraordinary Water:

- Domestic, industrial, and agricultural water supply
- Stock watering
- Fish and shellfish, including migration, rearing, spawning, and harvesting of Salmonid and other fish
- Wildlife habitat
- Ceremonial and religious water use
- Recreation including primary contact recreation, sport fishing, boating, and aesthetic enjoyment
- Commerce and navigation

Class II – Excellent:

- Domestic, industrial, and agricultural water supply
- Stock watering
- Fish and shellfish: migration, rearing, spawning, and harvesting of Salmonid and other fish
- Wildlife habitat
- Ceremonial and religious water use
- Recreation including primary contact recreation, sport fishing, boating, and aesthetic enjoyment
- Commerce and navigation

Class III – Good:

- Industrial and agricultural water supply
- Stock watering
- Fish and shellfish: migration, rearing, spawning, and harvesting of Salmonid and other fish; crayfish rearing, spawning, and harvesting
- Wildlife habitat
- Recreation including secondary contact recreation, sport fishing, boating, and aesthetic enjoyment
- Commerce and navigation

Class IV – Fair:

- Industrial water supply
- Stock watering
- Fish: salmonid and other fish migration
- Recreation including secondary contact recreation, sport fishing, boating, and aesthetic enjoyment
- Commerce and navigation

Considering the complexity of water issues, prudent and effective planning should include a detailed understanding of water classifications, standards, water rights, and any other compacts or laws that may exist.

Drinking Water Standards

Although drinking water standards are not specifically a "classification" of water, water that meets federal drinking water standards is essentially considered to be high quality. It is common for permits under a variety of environmental regulatory programs to reference federal drinking water standards, including shallow injection pursuant to Underground Injection Control (UIC) program. As such, it is important to understand drinking water standards when considering produced water management.

Most Americans get their drinking water from large scale municipal water systems that rely on surface water sources such as rivers, lakes and reservoirs. However, millions of Americans depend on private water sources such as wells and aquifers. In either case, the United States enjoys one of the cleanest drinking water supplies in the world. The EPA regulates the quality of the nation's drinking water by issuing and enforcing safe drinking water standards (EPA, 2002e). These standards essentially set a classification of water that is commonly used to distinguish between high-quality and lower quality waters.

Naturally pure water does not exist in nature, all water contains some impurities. As water flows in streams, sits in lakes, and filters through layers of soil and rock in the ground, it dissolves or absorbs the substances that it touches. Many of these substances are harmless; and in fact, some people prefer mineral water because the minerals give it an appealing taste. Naturally occurring minerals, just like man-made chemicals, are considered contaminants that can make water unpalatable or even unsafe when they occur above certain levels (EPA, 2002e).

Under the authority of the Safe Drinking Water Act (SDWA), EPA sets standards for approximately 90 contaminants in drinking water. For each of these contaminants, EPA sets a legal limit, called a maximum contaminant level (MCL), or requires a certain treatment. Water suppliers are legally required to provide water that meets these standards because water that meets these standards is safe for most people to drink. People with severely compromised immune systems and young children may have special needs that are not met by the drinking water standards.

The MCLs for the primary standards include biologic contamination, disinfectants, organic and inorganic chemicals, and radionuclides (Table 4-2 at the end of the section). These standards are legally enforceable standards that apply to public water systems as outlined in 40 CFR 141. Maximum contaminant level goals (MCLGs) are allowable levels of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.

The SDWA was amended in 1996, adding the secondary drinking water standards. The secondary standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water (Table 4-3 at the end of the section). The secondary standards are outlined in 40 CFR 143.

Clean Water Act

The Clean Water Act (CWA) requires that all discharges of pollutants to surface waters (streams, rivers, lakes, bays, and oceans) be authorized by a permit issued under the National Pollutant Discharge Elimination System (NPDES) to prevent degradation of the waters. Detailed information about the CWA, NPDES, anti-degradation, effluent limitation guidelines, and total maximum daily loads can be found in the Surface Discharge Section.

UIC Program

As directed by Congress, the EPA developed a means to protect groundwater that may currently or potentially be used as a drinking water source. Through the UIC program, EPA established a water classification system to allow categorization of usable quality groundwater as Underground Sources of Drinking Water (USDWs). A USDW is defined in 40 CFR 144.3 as an aquifer that contains less than 10,000 mg/L of TDS; currently supplies or contains a sufficient quantity of groundwater to supply a public water system; and is not an exempt aquifer. This classification provides the basis of the UIC program as implemented nationally in the United States. All federal or state implemented UIC programs are in place to protect any USDW. As such, injection operations must be protective of USDWs, whether injection is occurring below any USDWs or directly into a USDW.

Livestock Watering

Animals are able to ingest a wide variety of different types of water and survive. However, some salts and elements, at high levels, may reduce animal growth and production or may cause illness and death. An abrupt change from water of low salinity to water of high salinity may cause animals harm while a gradual change would not. Animals can consume water of high salinity (TDS) for a few days without harm if they are then given water of low salinity (TDS). Animal tolerance also varies with species, age, water requirement, season of the year, and physiological condition.

The ions of magnesium (Mg), calcium (Ca), sodium (Na) and chloride (Cl) all contribute to the salinity of water, and they may cause toxic effects because of this salinity effect or by interference with other elements. But, these four are not usually considered toxic otherwise.

Table 4-1 lists guidelines of potential uses of waters of various concentrations TDS and electrical conductivity (EC). As is apparent from Table 4-1, as water quality decreases, potential uses for livestock watering diminishes.

Table 4-1
Water Quality Guide for Livestock Use

TDS (ppm)*	Livestock Watering Comments
Less than 1,000 (EC < 1.5 mmhhos/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.

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. Source: NAS, 1974

Irrigation Water Quality Requirements

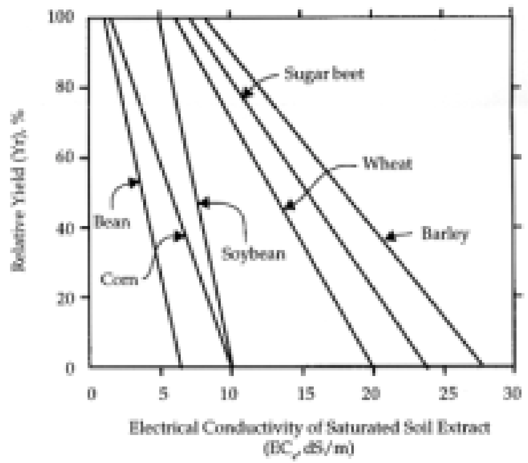
Numeric water quality standards have been adopted in some states for many substances that could affect agricultural uses. However, numeric water quality standards have generally not been adopted for salinity and SAR as well as other substances which might affect irrigation practices. The quality characteristics of CBM water can be compared to generally accepted irrigation water quality requirements (Ayers and Westcot 1985). The three major types of salt related considerations are salinity, sodicity and toxicity.

Salinity: Salinity refers to the total concentration of dissolved salts in the soil or water. Salinity causes reduced crop growth and yield loss because the plant must redirect energy from growing to extracting pure water from the saline water in its root zone. The principal measure of salinity of irrigation water is EC expressed in deciSiemens per meter (dS/m). (Note: 1 dS/m = 1 mmhos/cm). Crops vary in their response to irrigation water salinity as follows:

- < 0.7 dS/m provides no restrictions to crop growth
- 0.7 – 3.0 dS/m provides slight to moderate restrictions to crop growth
- > 3.0 dS/m provides severe restrictions to crop growth

Crops differ greatly in their response to salinity. The most distinct signs of injury from salinity are reduced crop growth and loss of yield. Crops can tolerate salinity up to certain levels without a measurable loss in yield (this is called the salinity threshold). The more salt tolerant the crop, the higher the threshold level. At salinity levels greater than the threshold, crop yield reduces linearly as salinity increases. The relationship between soil salinity and yield for several crops is illustrated in Figure 4-2.

Figure 4-2
Soil Salinity and Crops
Impact of soil salinity on the yield of select crops.

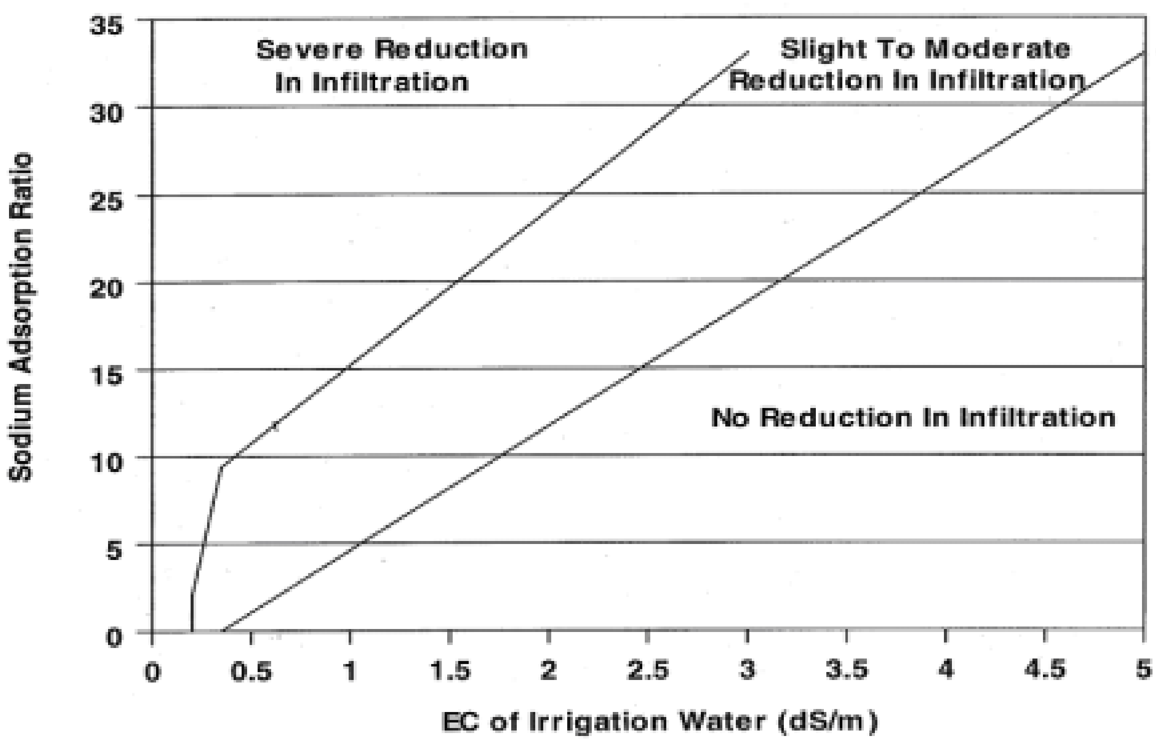


Source: Ayers and Westcot, 1985

Sodicity: Sodicity, the presence of excess sodium, deteriorates soil structure and reduces water penetration into and through the soil. The effect of sodium on soils is related to the abundance, or ratio, of sodium to the abundance of calcium and magnesium. This is called the sodium adsorption ratio or SAR. Generally, increasing levels of SAR create an increasing hazard for infiltration problems. The effects are also directly related to the total abundance of all of the ions. The permissible value of the SAR is a function of salinity. Usually, SAR values below 3.0 are not considered to be a threat to crops and native plants; however, SAR values above 12.0 are considered sodic and may affect soils and vegetation. High salinity levels reduce swelling and aggregate breakdown (dispersion), promoting water penetration. High proportions of sodium, however, produce the opposite effect. Figure 4-3 represents the approximate boundaries where chemical conditions severely reduce infiltration of water into soil, where slight to moderate reductions occur, and where no reduction is expected in most soils. Regardless of the sodium content, water with an EC less than about 0.2 dS/m causes degradation of the soil structure, promotes soil crusting and reduces water penetration. As Figure 4-3 illustrates, both the salinity and the SAR of the applied water must be considered when assessing the potential effects of water quality on soil water penetration.

Toxicity: Certain trace elements in irrigation water can cause toxicity in certain crops. A toxicity problem is different from a salinity problem in that it occurs within the plant itself and is not caused by a water shortage. Toxicity normally results when certain ions are taken up with the soil/water and accumulate in the leaves during water transpiration to an extent that results in damage to the plant. The degree of damage depends upon time, concentration, crop sensitivity, and crop water use, and if damage is severe enough, crop yield is reduced. The usual toxic ions in irrigation water are chloride, sodium, and boron. Each can cause damage, individually or in combination. Ayers and Westcott (1985) present recommended maximum concentrations of trace elements in irrigation water. The Agricultural Beneficial Use Section in Chapter 5 provides more information related to the use of CBM produced water for irrigation.

Figure 4-3
Soil Infiltration Effects
Graph shows the effects of SAR on the ability of water to infiltrate the soil.



Source: Ayers and Westcott, 1985.

Water Rights

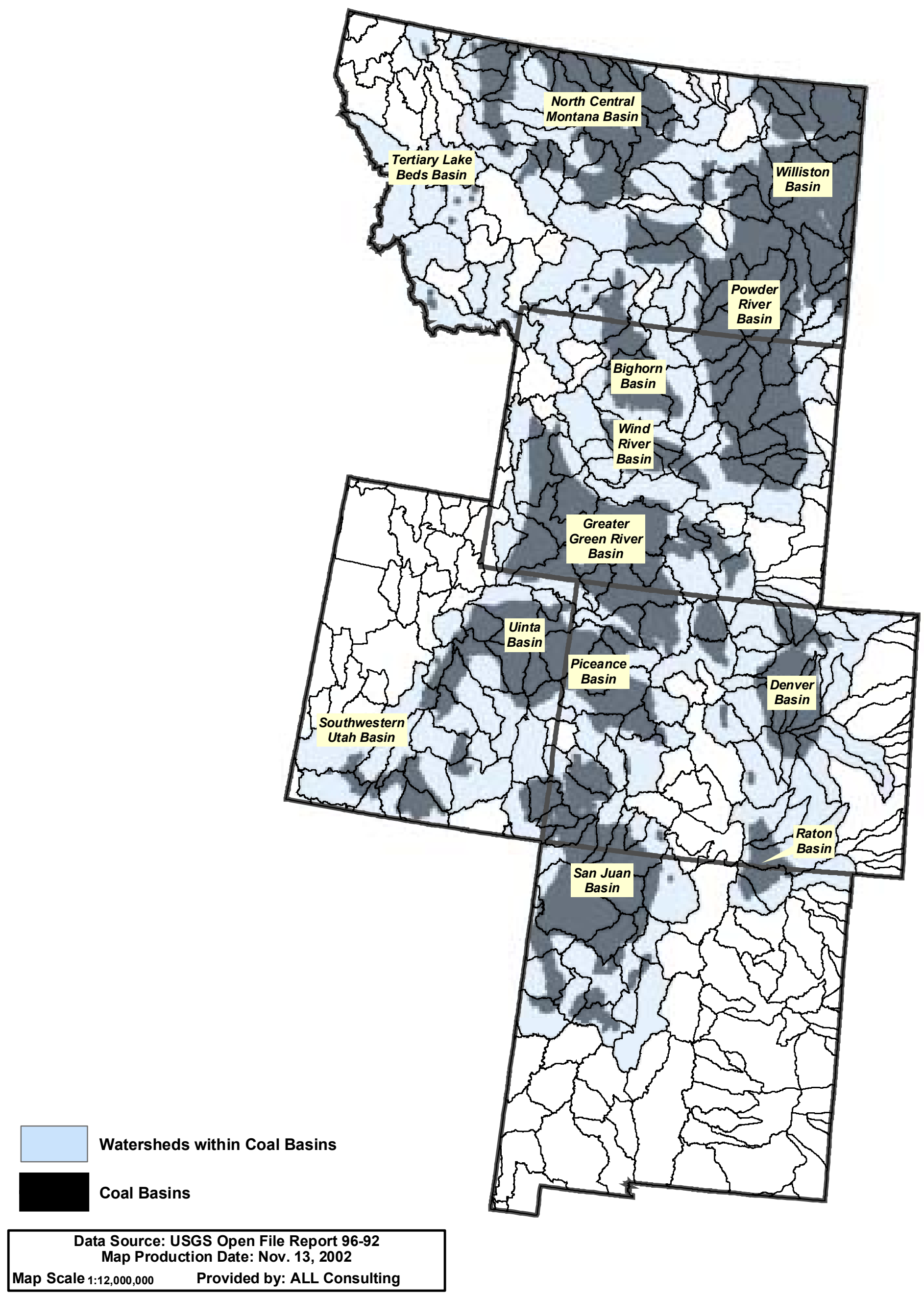
Water rights, with regard to CBM produced water, is a very complex issue that is critical in understanding how states, operators, and the public can maximize beneficial water uses and minimize or mitigate the impact of production. This complexity is due to the fact that water rights are managed to a great extent under state law. Therefore, it is important to have a good understanding of the water rights laws of each individual state and how they apply to CBM. As noted above, this discussion has been generally focused on the five-state emphasis area of Colorado, Montana, New Mexico, Utah, and Wyoming. In this area, the scarcity of water in the region has led to the development of doctrines that guide water rights. Special attention is paid to the states' water rights systems, the application processes, groundwater regulations, the general adjudication processes, and the states' instream flow programs. The basis for the water rights information presented in this section has been largely taken from recent document prepared for the Bureau of Land Management entitled "Western State's Water Laws" by Eric B. Hecox (2001).

Angel and the Bad Man, 1963, John Wayne ultimately persuades the water holder to share some of his water supply with the adjoining neighbors.

Hydrology surrounding a CBM project could consist of surface water flow from several rivers and their associated tributaries, and the production of groundwater from a variety of geological formations—the combination of which comprises the aquifer systems within any specific portion of a project area. CBM development typically involves the necessary and unavoidable production of large volumes of water from coal aquifers and appropriate use or disposal of this produced water. Continuous CBM water production and disposal has the ability to impact both groundwater and surface water rights. Figure 4-4 shows the coverage and reach of watersheds to coal basins in the five-state emphasis area.

Figure 4-4
Coal Basins and Watersheds in the Five-State Study Area
Map of the select western states showing watersheds overlaying coal basins.

COAL BASINS WITH WATERSHEDS IN THE STUDY AREA STATES



Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

Water Rights Doctrines

Water rights doctrines fall generally in three categories 1) riparian, 2) prior appropriation, and 3) federal reserved water rights. Water rights are managed in large part at the state level, thus, it is up to the state to determine which doctrine they will use to manage their rights, or use a combination of rights, such as a hybrid doctrine. The following discusses each of the doctrines.

The Justinian Code of the fifth century enunciated what we recognize today as the riparian doctrine: running water is the property of the public for use by traders and fisherman, whereas the banks of the river are the property of the adjoining landowner. The law of running water was inclusive of a riparian landowner's right to make a de minimus use, or reasonable use, for milling and domestic purposes. Of course, this use was subject to the water's return to the stream without substantial alteration to either its quality or quantity. The riparian doctrine is the basis for most of the eastern United States water rights laws, however due to the scarcity of water in the western region, the doctrine of prior appropriation was developed.

The prior appropriation doctrine, or "first in time – first in right", evolved during the California gold rush when miners in California needed to divert water from the stream to locations where it was needed to process ore. Customs and principles relating to water diversion developed in the mining camps, and disputes were resolved by simple priority rule. According to the rules of prior appropriation, the right to the full volume of water "related back" or had the priority date as of the time of first diverting the water and putting it to beneficial use. In other words, those with earliest priority dates have the right to use that amount of water over others with later priority dates.

Unlike a riparian right, an appropriative right exists without regard to the relationship between the land and water. An appropriative right is generally based upon physical control and beneficial use of the water. These rights are entitlements to a specific amount of water, for a specified use, at a specific location with a definite date of priority. An appropriative right depends upon continued use of the water and may be lost through non-use. Unlike riparian rights, these rights can generally be sold or transferred, and long-term storage is not only permissible but also common.

Historically, there are four essential elements of the prior appropriation doctrine: intent, diversion, beneficial use, and priority. In all states with the prior appropriation doctrine, the acquisition of water requires that the appropriator demonstrate intent to appropriate the water, divert the water, and apply it to beneficial use. Historically, intent was indicated by on-the-ground acts such as site surveys, land clearing, preparation of diversion points, and most importantly posting of notice. Today, however, intent is generally indicated by the application for a permit.

Beneficial use is perhaps the most important characteristic in defining a prior appropriation water right. Beneficial use is used to determine whether a certain use of water will be recognized and protected by law against later appropriations. The justification for beneficial use criteria is to prevent waste. Since water is a scarce resource in the west, states must determine what uses of water are acceptable. Beneficial uses of water have been the subject of great debate, and each western state has an evolving system for evaluating what uses of water is considered "beneficial".

Another essential component of a prior appropriation water right is diversion. Historically, a physical diversion of water was required in order to acquire a water right. This requirement has diminished as states have implemented various in-stream flow programs. A point of diversion, however, is still an essential element of a consumptive use water right.

In western states, there are few restrictions on who can hold an appropriative water right; therefore, both private and public entities hold rights. An appropriative right does not depend on land ownership, but some states do require that the water is appurtenant to the land on which it is used. In general, appropriative water rights are transferable property. There are, however, three major requirements which inhibit the transfer of an appropriative water right: (1) rules prohibiting the severance of water right from the land on which the water is appurtenant to; (2) showing that there will be no injury to other appropriators; and (3) establishing the extent of the water right for transfer.

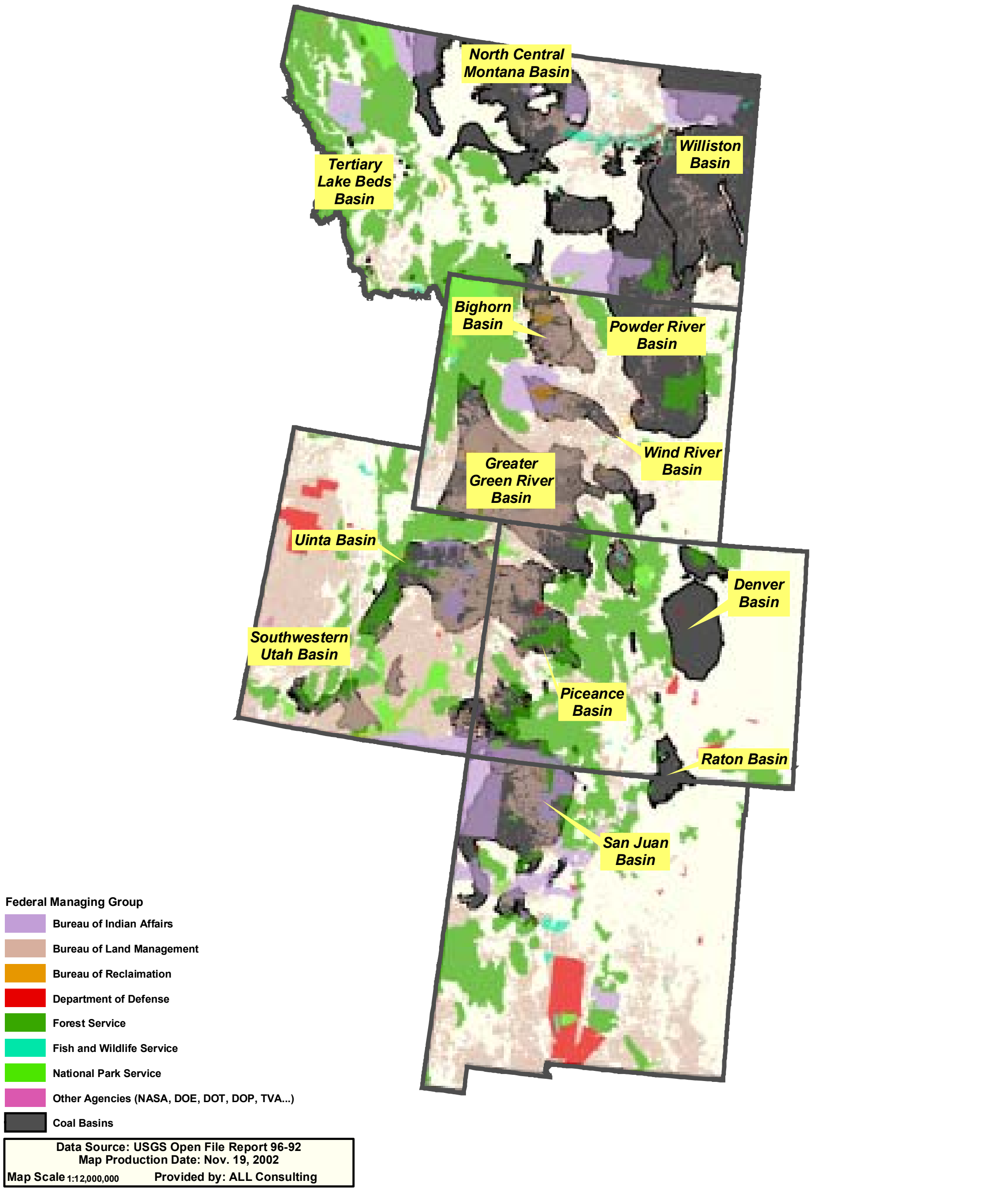
The traditional means of losing appropriative water rights are non-use or abandonment. Loss through abandonment is a consequence of the essential role that "use" plays in the definition of the right. The right does not come into existence without application of water to beneficial use and cannot continue to exist without the continuance of beneficial use. Non-use in itself, however, does not always constitute abandonment. An appropriative right can be lost through non-use when intent to abandon can be demonstrated, or when the water right has not been used for a specified number of years.

Several western states recognize both riparian and appropriative water rights under a hybrid doctrine. In general, states have this dual system because riparian rights were historically recognized, but the state has changed to an appropriative system. Some states have allowed riparian landowners to claim a water right by a certain time and incorporate it into the state's prior appropriation system. The riparian rights tend to be superior to the prior appropriative rights even if the water was not put to beneficial use until much later.

The United States federal government reserves public land for uses such as Indian reservations, military reservations, national parks, forest, or monuments and within that reservation, it also implicitly reserves sufficient water to satisfy the purposes for which the reservation was created. These rights are termed federal reserved water rights and are often senior in priority to water rights established under state law. The date of priority of a federal reserved right is the date the reservation was established. Due to the size of federal reservations throughout the west, the potential impact of federal reserved rights on state water rights holders could be significant. Figure 4-5 shows the federal land boundaries over coal basins in the five-state emphasis area.

The U.S. Supreme Court established the federal reserved water rights doctrine in 1908 in Winters v. United States. In this case, the U.S. Supreme Court found that an Indian reservation (in the case, the Fort Belknap Indian Reservation) might reserve water (of the Milk River in Montana) for future use in an amount necessary to fulfill their purpose, with a priority dating from the treaty that established the reservation. This doctrine establishes that when the federal government reserved public land, water rights were reserved in sufficient quantity to meet the purposes for which the reservation was established.

Figure 4-5
Coal Basins and Federal Lands in the Five-State Study Area
Map of the select western states showing federal lands overlaying coal basins.



Note: Data source is USGS Open File Report No. 96-92; Produced by ALL Consulting

State Profiles

Summaries of water classification and water rights issues for each of the states in the five-state emphasis area are discussed in this section. Discussions for each state are presented in summary format and are not intended as a complete reference.

Colorado

Water Classifications

The state of Colorado has established five classifications for groundwater. The classifications are on use, quality, and other information as necessary, and include:

- Domestic use – quality
- Agricultural use – quality
- Surface water quality protection
- Potentially usable quality
- Limited use and quality

Surface water is divided into four classes:

- Aquatic life
- Water supply
- Recreation
- Agriculture

Each of the classes contains different subclasses.

Water Rights System

Colorado water law is based upon the doctrine of prior appropriation, or "first in time – first in right", and the priority date is established by the date the water was first put to a beneficial use.

Responsible Agency

Colorado does not have a single state agency responsible for issuing water rights. Water rights in Colorado are established through a water court system. There are seven water courts corresponding to each of the major river basins which adjudicate water rights throughout the state. The State Engineer administers and distributes the state's waters. The State Engineer is also responsible for issuing and denying permits to construct wells and divert groundwater, but these permits do not constitute rights to groundwater. The Groundwater Commission is a regulatory and an adjudicatory body authorized to manage and control designated groundwater resources. The Colorado Water Conservation Board oversees conservation in the state and is responsible for the state's in-stream flow program.

Application Process

Water rights in Colorado are established through a water courts system. Every water right application must go through the water courts, and must be handled by an attorney.

In order to obtain a right for either surface or groundwater, an application must be filed with one of the seven water courts in the state. The types of applications are:

- Application for surface water right
- Application for groundwater right

- Motion to Intervene—A legal motion
- Application for change in water right
- Application for approval of plan for augmentation
- Statement of opposition—A legal motion

Water rights in Colorado (both surface and groundwater) can be either absolute or conditional. An absolute right is water that has been diverted and put to a beneficial use. A conditional right is a right that will be developed in the future. A conditional right maintains its priority until the project is complete. The owner must file an application for a finding of reasonable diligence every six years with the Water Court proving that they have been diligently pursuing completion of the project. Upon completion, the owner of a conditional right may file for an absolute water right, and that absolute water right contains the appropriation date for which the conditional right was awarded.

Point of Diversion – Change of Use
Appropriations of water are made when an individual physically takes the water from a stream and transports it to another location for beneficial use. The use of water directly from a stream, such as by wildlife or livestock drinking, is considered a diversion in Colorado. A point of diversion is required for all water rights in Colorado except for in-stream flow. In-stream flow rights, however, can only be held by the Colorado Conservation Board.

The point of diversion, location of use, and type of use of a water right can be changed through an application with the appropriate water court. In order to change a water right, the applicant must provide evidence that the change will not injure the vested water rights of other users.

State Recognized Beneficial Uses
Beneficial use in Colorado is statutorily defined as "the use of that amount of water that is reasonable and appropriate under reasonably efficient practices to accomplish without waste the purpose for which the appropriation is lawfully made". Specific uses are not described but previous categories have included:

- Aesthetics and Preservation of Natural Environments
- Irrigation
- Augmentation
- Livestock
- Commercial
- Minimum Flow
- Domestic
- Municipal
- Fire Protection
- Power
- Fishery
- Recreation
- Geothermal
- Silvicultural
- Groundwater Recharge
- Snowmaking
- Industrial
- Wildlife Watering
- Wildlife Habitat

Groundwater
Colorado uses a modified form of prior appropriation to govern the establishment and administration of groundwater rights. Colorado groundwater uses are governed by the Groundwater Management Act of 1965, which was adopted to allow the full economic development of water resources while protecting the rights of senior appropriators. Colorado considers all water within the state to be tributary to a surface stream, unless the water applicant

can prove otherwise in water court. The test for establishing a non-tributary source of water is very rigorous. The proposed diversion cannot deplete surface streams more than 1/10 of 1% of the proposed diversion volume in any single year for up to 100 years. When a non-tributary aquifer is established by law, the water in the aquifer is allocated based on the percentage of land owned on the surface above the aquifer. If the applicant cannot establish non-tributary groundwater, then the use of groundwater falls under the prior appropriation system and water rights must be obtained through the court system described above.

Water Rights

Water rights in Colorado can be held by any legal entity. In other words, an individual, group of individuals, organization, corporation, government agency, etc can hold a water right. The only restriction to who can hold a water right concerns in-stream flow rights with can only be held by the Colorado Conservation Board.

Water rights in Colorado are considered real property and they can be bought, sold, and leased to other entities. Although water is considered to be the property of the state, a property right exists in the priority to the use of water. The transfer of a water right requires filing a change of water right application with the appropriate water court. As with a change of use or point of diversion application, the applicant must provide evidence that the transfer will not injure the vested water rights of other users.

A conditional water right can be considered abandoned if the holder fails to show diligence to complete the necessary project. Any water right can be considered abandoned if it is not used for a period of ten years. Abandonment, however, must include the finding of intent to abandon; as a result, water rights in Colorado cannot be forfeited without proof of intent.

Adjudications

Water rights in Colorado are adjudicated by the district water courts. Colorado has a process of individual adjudications where each right is adjudicated as it is approved. There are no general or basin wide adjudications in Colorado

In-stream Flows

In 1973, Colorado adopted legislation that recognized the maintenance of in-stream flows as a beneficial use of water. This legislation said that in-stream flow could be used "to preserve the natural environment to a reasonable degree", and it removed the requirement of a diversion to appropriate water. This established Colorado's in-stream flow program, and the Colorado Water Conservation Board has the exclusive responsibility for the protection of in-stream flows.

The Board is the only entity that may hold in-stream flow rights. They can apply for new appropriations through the state water courts. In order to do this, the Board must ensure that a natural environment exists and will be preserved by the water available for appropriation. The Board then submits an application to the state water court, and the priority date for the in-stream right is the application date.

Recognized Beneficial Uses for In-stream Flow

In-stream flows in Colorado must be used to preserve the natural environment. Although the law authorizes a wide range of uses for in-stream flow, to date the Colorado Water Conservation Board has acted only to protect streams that support fisheries.

Holdership of In-stream Flow Water Rights
The Colorado Water Conservation Board is the only entity that can hold an in-stream flow right. Other entities, however, can acquire an existing right and transfer it to the board for in-stream flow.

Montana

Water Classifications

The state of Montana has established groundwater classifications as described in the Administrative Rules of Montana (ARM). The purpose of groundwater classification is to establish the maximum allowable changes in groundwater and is the basis for limiting discharges into groundwater. The classifications are based on the natural specific conductance (SP) of the water and are defined as:

- Class I, SP less than 1,000 microSiemens/cm at 25°C
- Class II, SP between 1,000 and 2,500 microSiemens/cm at 25°C
- Class III, SP between 2,500 and 15,000 microSiemens/cm at 25°C
- Class IV, SP greater than 15,000 microSiemens/cm at 25°C

The state of Montana has nine classifications for surface water, as determined by its use and quality as described in the ARM. The classifications are:

- Class A-Closed, suitable for domestic use with simple disinfection; access restrictions to protect public health may limit use
- Class A-1, suitable for domestic use after conventional treatment, recreational use, fish and wildlife, and agricultural and industrial use
- Class B-1 through B3, suitable for domestic use after conventional treatment, recreational use, fish and wildlife, and agricultural and industrial use
- Class C-1 & C-2, suitable for recreational use, fish and wildlife, and agricultural and industrial use

The state of Montana has established the surface water classification system in order to maintain the quality of water for the uses described.

Montana Controlled Groundwater Area

Montana has the authority to control or close river basin and groundwater aquifers to certain types of water appropriations because of water availability problems, water contamination problems, and a concern for protecting existing water rights (Montana Water Resources Division, 2001). Montana has established five different types of closures, of which the controlled groundwater areas (CGWA) are addressed here.

The Department of Natural Resources and Conservation (DNRC) has the authority to designate or modify CGWAs. In addition, other state or local agencies and individual users can petition for a CGWA. The DNRC lists the following reasons for ordering a CGWA:

- groundwater withdrawals in the area are greater than recharge of the aquifer;
- excessive groundwater withdrawals are likely to occur in the near future;
- there are significant disputes involving groundwater rights in the area;
- groundwater levels or pressures in the area have been or are declining excessively;
- excessive groundwater withdrawals would cause contamination migration;
- groundwater withdrawals are or will adversely affect groundwater quality; and,
- water quality in the groundwater area is not suited for a specific beneficial use.

In a CGWA, anyone wishing to drill a well must first apply for and receive a Permit for Beneficial Water Use (Montana Water Resources Division, 2001). This applies to any size and type of appropriation, including wells to be used at less than 35 gpm and less than 10 acre-feet per year (Montana Water Resources Division, 2001).

Controlling and closing a basin can impact CBM production. For example, the Powder River Basin is a CGWA for all formations above the Lebo member in the Fort Union Formation. The CGWA applies only to wells designed and installed for the extraction of CBM and requires all CBM wells to follow the standards for drilling, completing, testing, and producing as adopted by the Montana Board of Oil and Gas Conservation (MBOGC). The CGWA in the Powder River Basin requires CBM operators to offer water mitigation agreements to all owners of water wells and natural springs within one-half mile of the CBM operation, or within the area that the operator reasonably believes may be impacted by the CBM operation, whichever is greater. The area will automatically be extended one-half mile beyond any well adversely affected. The DNRC will also designate a Technical Advisory Committee to oversee groundwater characteristics and monitoring, and reporting requirements.

Water Rights System

Water rights in Montana are guided by the prior appropriation doctrine. Montana law establishes that the state's water resources are the property of the state of Montana and are to be used for the benefit of the people. Montana has closed some of its river basins to certain types of new water appropriations due to water availability problems, over appropriation, and a concern for protecting existing water rights. Montana water law authorizes the closure of basins to certain new appropriations through the adoption of administrative rules and the negotiation of reserved water right compacts.

Responsible Agency

The district court and the Water Resources Division of the Montana DNRC share authority for water rights decisions.

Application Process

New appropriation of water or a new diversion, withdrawal, impoundment, or distribution requires the filing of an Application for Beneficial Water Use Permit. A beneficial water use permit is also required before appropriating groundwater of more than 35 gpm and 10 acre-feet per year. Permits are not required for groundwater uses of less than 35 gpm, but a Notice of Completion must be filed in order to acquire the water right. Upon receipt of an application, the regional office reviews the application and publishes the notice; additionally, an environmental review is also made to determine whether the proposed project will have significant environmental impacts and whether an environmental impact statement is needed.

The following criteria are considered when a new appropriation of water is requested in Montana:

- Is water physically available at the proposed point of diversion in the amount that the applicant seeks to appropriate?
- Can water reasonably be considered legally available during the period in which the applicant seeks to appropriate and in the amount requested?
- Will the water rights of a prior appropriator under an existing water right, a certificate, a permit, or state water reservation be adversely affected?
- Are the proposed means of diversion, construction, and operation of the appropriation works adequate?

- Is the proposed use of water a beneficial use?
- Does the applicant have possessory interest, or the written consent of the person with the possessory interest, in the property where the water is to be put to beneficial use?

If valid objection pertaining to water quality is received, an applicant must also prove that:

- the water quality of a prior appropriator will not be adversely affected;
- the proposed use will be substantially in accordance with the classification of water set for the source of supply pursuant to 75-5-301(1), MCA, or
- the proposed use will not adversely affect the ability of a discharge permit holder to satisfy effluent limitations in accordance with Title 75, Chapter 5, Part 4.

Types of Applications:

- Application for Beneficial Water Use Permit
- Application for Extension of Time
- Notice of Completion of Groundwater Development
- DNRC Water Right Ownership Update
- Well Log Report
- Water Right Dispute Options
- Application for Provisional Permit for Completed Stockwater Pit or Reservoir
- Objection to Application
- Application for Change of Appropriation Water Right
- Notice of Completion of Permitted Water Development
- Notice of completion of Change of Appropriation Water Right
- Notice of Water Right

The estimated processing time for an application that is correct and complete is 210 days.

Point of Diversion – Change of Use
A holder of a water right, permit, certificate, or water reservation may change the point of diversion, place of use, purpose of use, and place of storage by obtaining prior approval from the DNRC. An application of Change of Appropriation Water Right must be submitted to the DNRC.

State Recognized Beneficial Uses
Beneficial use in Montana means "a use of water for the benefit of the appropriator, other persons, or the public". Recognized uses have previously included, but are not limited to:

- Agriculture
- Municipal
- Commercial
- Navigation
- Domestic
- Power
- De-watering
- Pollution Abatement
- Erosion control
- Recreation Uses
- Fire Protection
- Sediment control
- Fish
- Storage
- Fish Raceways
- Stock water
- Geothermal
- Waterfowl
- Industrial
- Water Leased
- Irrigation
- Wildlife

- Mining

Groundwater

Groundwater use regulations are different within Controlled Groundwater Areas than outside of these areas. Controlled Groundwater Areas may be proposed by DNRC on its own motion, by petition of a state or local public health agency, or by a petition signed by at least 20 or one-fourth (whichever is less) of groundwater users where the petitioners feel a Controlled Groundwater Area is necessary. One or more of the following criteria must be met in order for DNRC to declare an area a Controlled Groundwater Area:

- groundwater withdrawals are in excess of recharge to the aquifer;
- excessive groundwater withdrawals are very likely to occur in the near future because withdrawals have consistently increased in the area;
- there are significant disputes within the area concerning priority of rights, amounts of water being used, or priority of type of use;
- groundwater levels or pressures are declining or have declined excessively;
- excessive groundwater withdrawals would cause contaminate migration;
- groundwater withdrawals adversely affecting groundwater quality are occurring or are likely to occur; and/or
- water quality within the groundwater area is not suited for a specific beneficial use.

The nine Controlled Groundwater Areas that are designated in Montana are:

1. The South Pine controlled Groundwater Area
    - No new appropriations of groundwater may be made except by permit request.
    - No presently inactive well may be used except with the approval of DNRC.
    - No presently active well may increase its flow rate except with the approval of DNRC.
2. The Larson Creek Controlled Groundwater Area
    - Controlled Groundwater Area for the shallow aquifer from the surface of the ground to a depth of 70 feet.
    - The shallow aquifer is closed to further appropriations except for applicants for a Permit for Beneficial Water Use who:
        - Prove the criteria of Section 85-2-311, MCA by clear and convincing evidence, and
        - Submit a plan for water augmentation of Larson Creek or prove that augmentation is not necessary.
        - Wells deeper than 70 feet deep must be constructed so that the controlled aquifer is sealed off.
3. The Hayes Creek Controlled Groundwater Area
    - Permanent Controlled Groundwater Area which includes both the shallow alluvial and deep fractured bedrock aquifers.
    - New groundwater appropriations in this permanent Controlled Groundwater Area require a Permit for Beneficial Water Use.

4. The Warm Springs Ponds Controlled Groundwater Area
    - This Controlled Groundwater Area was contaminated in the shallow aquifer to a depth of 40 feet.
    - DNRC cannot accept any applications for a Permit for Beneficial Water Use to divert water from 0 to 40 feet in depth.
    - Wells deeper than 40 feet must be constructed to include a casing maintained to a depth of 40 feet.
    - The EPA may rescind or modify the current requirements for a water well ban.
5. The Rocker Controlled Groundwater Area
    - This controlled groundwater area was created due to contamination in three aquifers:
        - The Rocker Timber Framing Treatment Plant Operable Unit Superfund Site,
        - A small portion of the Streamside Tailings Operable Unit Superfund Site, and
        - A ¼ mile buffer zone radius around the contaminated groundwater area.
    - This area is closed to all new appropriations of groundwater.
    - Once the determination is made that the Rocker plume has been effectively mitigated to halt the threat of further migration, a re-petition to the DNRC will be made to remove the controlled groundwater area designation.
6. The Bozeman Solvent Site Controlled Groundwater Area
    - Drilling and installing water wells within this Controlled Groundwater Area is prohibited without receiving an interim permit from the DNRC.
    - Permits will not be issued by DNRC for the following conditions:
        - The well is located within the zone of highest contamination.
        - Groundwater pumping from the individual well or in combination with nearby wells is likely to induce or redirect contaminated groundwater plume migration.
        - City of Bozeman municipal water supply system is, or will soon be available.
        - The proposed well has a design capacity of 100 gpm or greater.
    - If there is ever evidence that part of the controlled groundwater area is not contaminated and will most likely never be contaminated, procedures may be initiated to remove that part from the Controlled Groundwater Area.
7. The Old Butte Landfill/Clark Tailings Controlled Groundwater Area
    - Drilling and installation of water wells is prohibited without first obtaining a permit from DNRC.
    - Wells will be permitted or excluded based on the requirements of the four zones.
    - All new wells must be sampled and analyzed for constituents as defined in EPA guidelines.
    - New wells permitted for human consumption must produce water that meets all applicable WQB-7 water quality standards or other updated human health standards.
8. U.S. National Park Service – Montana Compact Yellowstone Controlled Groundwater Area
    - The Controlled Groundwater Area was established to regulate groundwater development adjacent to Yellowstone National Park in an effort to preserve its natural hydrothermal features.

- Groundwater appropriations must be made using a Permit for Beneficial Water Use.
- Permit applications must include a statement of whether the proposed water used will be a temperature of 60º Fahrenheit or more.
- New appropriations are required to use meters provided by DNRC and reported annually.
- Additional special requirements must be met based on the temperature of the water in the well.

9. The Powder River Basin Controlled Groundwater Area

- Applies only to wells designed and installed for the extraction of CBM.
- CBM development must follow the standards for drilling, completing, testing, and production of CBM wells as adopted by the MBOGC.
- CBM operators must offer water mitigation agreements to owners of water wells or natural springs within one-half mile of a CBM operation or within the area that the operator reasonably believes may be impacted by the CBM operation, whichever is greater. This area will automatically extend one-half mile beyond any well adversely affected.

Outside of Controlled Groundwater Areas, a Permit to Appropriate Water is required before any development can begin. Obtaining the permit involves the application process described above.

Water Rights
An individual, group of individuals, organization, corporation, government agency, etc., can hold a water right in Montana. Water rights are attached to the piece of land on which they are used. If a piece of land is transferred, any water right attached to that land passes along with it unless specifically stated otherwise. A water right may be severed from the land and sold, or retained independently from the land. If the water right alone is transferred to a new owner, an ownership update must be filed with the department.

A water right under a permit can be abandoned if it is not used and there is an intent to abandon. If an appropriator ceases to use all or part of an appropriation with the intention to abandon, the right is considered abandoned. Additionally, a right is considered to be abandoned if it is not used for ten consecutive years.

Adjudications
In 1979, the Montana legislature passed a bill amending the adjudication procedures originally established by the Montana Water Use Act. The legislature opted for a comprehensive general adjudication of the entire state's 85 drainage basins, rather than adjudication existing water rights one basin at a time. Existing water rights are defined as those that originated before July 1, 1973. The Reserved Water Rights Compact Commission (RWRCC) was created to negotiate compacts with federal agencies and Native American tribes to quantify their reserved water rights in Montana. These negotiated compacts are incorporated into Montana's adjudications.

In-stream Flows
In-stream flow rights in Montana can be established through new appropriations or through water transfers. New appropriations for in-stream flow can be established through the water reservations system.

Recognized Beneficial Uses for In-stream Flow

Beneficial Uses for in-stream flows are vaguely defined in Montana. The decision of what constitutes a beneficial in-stream flow use is at the discretion of the DNRC. Most in-stream flow uses to date have been to benefit fisheries and to maintain water quality, but in-stream flow uses are not necessarily limited to these uses.

Holdership of In-stream Flow Water Rights

Federal agencies and any political subdivision of the state may apply for and hold in-stream flow reservations (from new appropriations). With some restrictions, private or public entities may lease water rights for in-stream flow.

Federal Reserved Water Rights

A Reserved Water Rights Compact Commission has been established in Montana to negotiate compacts with federal agencies and Native American tribes in an effort to quantify federal reserved rights.

New Mexico

Water Classifications

The state of New Mexico does not have a detailed groundwater classification system but chooses, instead, to protect all water with TDS less than 10,000 mg/L (Hanning, 2002). New Mexico does have a surface water classification system based on the types of fish the water will support. The classifications are:

- *High quality cold water fishery* - a perennial surface water of the state in a minimally disturbed condition which has considerable aesthetic value and is a superior coldwater fishery habitat.
- *Cold water fishery* - a surface water of the state where the water temperature and other characteristics are suitable for the support, or propagation, or both of coldwater fishes.
- *Marginal cold water fishery* - a surface water of the state known to support a coldwater fish population during at least some portion of the year, even though historical data indicate that the maximum temperature in the surface water of the state may exceed 20°C (68°F).
- *Warm water fishery* - means a surface water of the state where the water temperature and other characteristics are suitable for the support, or propagation, or both of warm water fishes.
- *Limited warm water fishery* - means a surface water of the state where intermittent flow may severely limit the ability of the reach to sustain a natural fish population on a continuous annual basis, or a surface water of the state where historical data indicate that water temperature may routinely exceed 32.2°C (90°F).
- *Intermittent stream* - means a stream or reach of a stream that flows only at certain times of the year, such as when it receives flow from springs, melting snow, or localized precipitation.
- *Interrupted stream* - means a stream that contains perennial reaches with intervening, intermittent, or ephemeral reaches.

Water Rights System
New Mexico's water law is based on the doctrine of prior appropriation, or "first in time – first in right". All waters in New Mexico are declared to be public and subject to appropriation for beneficial use. There are five basic components of a water right in New Mexico:

- Point of Diversion (or constructed work),
- Place of Use,
- Purpose of Use,
- Owner, and
- Quantity.

Although these factors are statutorily required, past court decision, legal opinions, and the discretion of the State Engineer allow flexibility in the interpretation of these basic requirements.

Responsible Agency
The State Engineer, appointed by the governor and confirmed by the state senate, has broad authority over the supervision, appropriation and distribution of New Mexico's surface and groundwater. This office is responsible for supervision, measurement, appropriation, and distribution of the state's water. The State Engineer performs these duties according to state statute and according to the adjudication of the courts.

Application Process
Apart from water rights acquired before 1907 and small scale stock watering (10 acre-feet or less), a permit from the State Engineer is required to appropriate water, change the point of diversion, change the location of wells in declared basins, divert or store water, or change the place or purpose of water use. New Mexico has 11 types of applications for groundwater rights, 12 applications for surface rights, and five applications for miscellaneous.

When considering an application for permit, the State Engineer considers: the existence of unappropriated waters; if the application will impair existing water rights; whether granting the application would be contrary to the conservation of water within the state; and if the application will be detrimental to the public welfare. The State Engineer can then issue a permit either in whole, in part, or conditioned to ensure non-impairment of water rights.

Point of Diversion – Change of Use
Statutory law states that beneficial use in New Mexico requires a diversion of water from its natural path to a place where that water produces revenue or sustains human life. Court rulings, however, have found that this requirement does not apply to all beneficial uses; for instance, in-stream flow for recreational use does not require a point of diversion.

State Recognized Beneficial Uses
The state of New Mexico does not have an official list of approved beneficial uses. The recognition of a beneficial use is at the discretion of the State Engineer. According to state statute, a beneficial use in New Mexico requires a diversion of water from its natural path to a place where the water will produce revenue or sustain human life. Recent court decisions, as stated above, have changed this allowing for beneficial uses without a diversion requirement. The State Engineer has broad authority in considering what constitutes beneficial use in New Mexico. Recognized beneficial uses in the past have included:

- Agriculture
- Recreational Uses
- Commercial
- State Conservation Goals
- Domestic
- Stock watering
- Industrial

Groundwater

The New Mexico groundwater code was enacted in 1931. Groundwater procedures closely parallel those for surface water, with several important differences. A permit to drill a well and appropriate water is not required in areas outside of declared "underground water basins". Within underground water basins, however, the State Engineer regulates use. The State Engineer has the authority to establish these basins when regulation is necessary to protect prior appropriations, ensure water is put to beneficial use, and to maintain orderly development of the state's water resources. There are currently 33 declared underground water basins throughout New Mexico.

Water Rights

Water rights in New Mexico can be held solely, jointly, collectively, or in the name of a corporation, organization, or government agency, except the State Engineer. All water appropriated for irrigation (unless otherwise stated) is appurtenant to the land upon which it is used and it cannot be transferred to other lands, or used for other beneficial purposes unless the water right is separated from the land. A water right can be severed from the land through an application to the State Engineer.

Water rights in New Mexico can be transferred from one entity to another, but a change application must be filed and approved by the State Engineer. Water rights in New Mexico are considered real property and they may be bought or sold. A water right can be conveyed as part of a piece of property or separately (as long as that water right has been severed from the land by an approved application through the State Engineer).

A water right in New Mexico can be lost by forfeiture. When all or any part of appropriated water is not put to beneficial use for a period of four consecutive years, the State Engineer issues a notice of non-use. If the failure to beneficially use the water persists for one more year, the unused water is forfeited and becomes part of the public domain. Forfeiture does not occur, however, if the reason for non-use is beyond the control of the owner.

Adjudications

New Mexico has adjudicated water rights since 1907. Adjudication is through a program of hydrographic surveys and suits. The State Engineer is required to conduct surveys of every stream system in the state. During a survey, data is collected to help the court determine the amount of water to be awarded to each claimant. In an adjudication suit, each claimant has an opportunity to present evidence of the water right to the court. The completion of adjudication results in a court decree outlining the priority, amount, purpose (determination of use), periods, and place of water use.

In-stream Flows

New Mexico does not have a legislated in-stream flow program, and in-stream flow in not a recognized beneficial use. Recent case law, however, has allowed the development of an in-stream flow program within the state. The legal opinion determined that in-stream uses such as recreation and fish and wildlife habitat are beneficial uses, and that transfers of existing water rights to in-stream flows are not expressly prohibited. Prior to this opinion, New Mexico was the only state that did not recognize in-stream flow as a beneficial use.

Recognized Beneficial Uses for In-stream Flow
In-stream flow in itself is not recognized as a beneficial use. It appears, however, that water can be dedicated to in-stream flow for the purpose of recreation and fish and wildlife habitat.

Holdership of In-stream Flow Water Rights:
The Attorney General's opinion does not explicitly address the issue of ownership of in-stream flow rights.

Utah

Water Classifications

Utah groundwater classification is primarily based on its TDS. Utah has established seven classes of groundwater, which are:

- Class IA, Pristine groundwater – water with less than 500 mg/L TDS
- Class IB, Irreplaceable groundwater – source of water for a community public drinking water system
- Class IC, Ecologically important groundwater – source of groundwater discharge important to the continued existence of wildlife habitat
- Class II, Drinking water quality groundwater - water with TDS between 500 mg/L and 3,000 mg/L
- Class III, Limited use groundwater - water with TDS between 3,000 mg/L and 10,000 mg/L
- Class IV, Saline groundwater - water with greater than 10,000 mg/L TDS

Surface stream classifications in Utah are based on existing uses. Different reaches of the same stream can fall under different classifications. Utah has six water classes of surface water plus subclasses, as follows:

- Class 1, Culinary raw water source
- Class 1C, Domestic use with prior treatment
- Class 2, In-stream recreational use and aesthetics
- Class 2A, Primary human contact: swimming
- Class 2B, Secondary human contact: boating, wading, etc
- Class 3, In-stream use by aquatic wildlife
- Class 3A, Habitat maintenance for cold water game fish, water-related wildlife, and food chain organisms
- Class 3B, Habitat maintenance for warm water game fish, water-related wildlife, and food chain organisms
- Class 3C, Habitat for non-game, water-related wildlife, and food chain organisms.
- Class 3D, Habitat for waterfowl, shore birds, water-related wildlife, and food chain organisms.
- Class 4, Agricultural-livestock and irrigation water.
- Class 5, Great Salt Lake general use: primary and secondary human contact, water related wildlife, and mineral extraction
- Class 6, General use restricted and/or governed by environmental and health standards and limitations

Water Rights System
The prior appropriation doctrine is the basis of water appropriation in Utah. State statutes provide that all water is the property of the public, and a water right is the right to the use of water based upon quantity, source, priority date, nature of use, point of diversion, and physically putting water to beneficial use. The basis of all water rights in Utah is beneficial use. A water right is defined by the point of diversion, place of use, amount diverted, purpose of use, and period of use. Much of the state of Utah is closed to new appropriations of water; so new projects and allocations will require obtaining existing rights and amending them for new purposes.

Responsible Agency
The State Engineer through the Division of Water Rights is responsible for the administration of water rights, including the appropriation, distribution, and management of the state's surface and groundwater. The Utah State Engineer's Office was created in 1897, and the State Engineer is the chief water rights administrative officer.

Application Process
The establishment of a new water right or changing an existing right requires the filing of an application with the State Engineer. Applications can either be processed under formal or informal administrative procedures. The predominate difference between the two procedures relates to the appeal process. Under the formal procedures, an appeal is reviewed based upon the existing record, whereas under the informal proceedings, the appeal is handled as a new trial.

Once the project is complete and the water has been placed to beneficial use, the applicant is required to file proof of appropriation with the State Engineer. Upon filing of proof, the State Engineer then issues the "certificate of appropriation" and the status of the application is referred to as "perfected".

Point of Diversion – Change of Use
A point of diversion is required in order to obtain a water right in most cases. Certain beneficial uses (such as in-stream flow), however, do not require diversion. Both the point of diversion and the purpose and place of use can be changed.

State Recognized Beneficial Uses
Utah recognizes the following beneficial uses:

- Agriculture
- Power
- Culinary
- Stock watering
- Domestic
- Industrial
- Irrigation
- Manufacturing
- Milling
- Mining
- Storage—irrigation, power generation, water supply, aquatic culture and recreation
- In-stream flow—fish, recreation and the reasonable preservation or enhancement of the natural stream environment
- Municipal

Groundwater
The State Engineer is responsible for administering both surface and groundwater. The process for obtaining a groundwater permit (either a new application or a change application) requires the same forms and process as that for surface water. Groundwater policy, however, is different than surface

water; therefore the criteria used to evaluate the groundwater application may be different. Utah is divided into groundwater areas and policy is determined by area. In general, groundwater policy in Utah consists of "open", "restricted", and "closed" designations.

Utah also regulates the drilling of wells. Any well drilled to a depth of 30 feet or greater must be constructed by a licensed Utah Water Well Driller. The State Engineer is responsible for licensing requirements and well construction criteria, and the development and publication of the Administrative Rules for Water Well Drillers.

Water Rights

Water rights in Utah can be held by any legal entity, thus they can be held solely, jointly, collectively, or in the name of a corporation, organization, or government agency. Water rights can be transferred from one entity to another, but a change application must be filed and approved by the State Engineer. Water rights can be bought and sold, as means for transfer, but approval by the State Engineer is still required. An unapproved or approved application is considered personal property, whereas a certificated application or "perfected" water right is considered real property. Since applications for a new water right are considered personal property, they may be bought and sold using a conveyance or assignment. When water rights are perfected, they are considered real property; therefore, they must be conveyed by deed to the new owner.

A water right in Utah can be lost by either abandonment or forfeiture. Abandonment is determined by the intent of the water user and does not require a statutory time period. A water right is lost by forfeiture if the right is not used for five years. Water lost through abandonment or forfeiture reverts back to the public and is subject to future appropriation.

Adjudications

An adjudication of water rights is a state action addressed in district court to determine the water rights on the source or in the area involved in the action. The State Engineer is a party to the action with the statutory responsibility to prepare a "Proposed Determination of Water Rights" which serves as the basis for the court's decree on the water rights in the area.

In-stream Flows

In 1986, Utah enacted an amendment to its water code recognizing in-stream flows as a beneficial use not subject to diversion requirements. Utah's in-stream flow laws allow the Utah Division of Wildlife Resources or the Division of Parks and Recreation to file for temporary or permanent changes for in-stream flow rights. The law specifically states that unappropriated water cannot be appropriated for in-stream purposes.

Although the above-mentioned Divisions are the only entities allowed to hold in-stream flow rights, the State Engineer has the legal power through the application approval process to preserve water for natural flows. Utah water law empowers the State Engineer to withhold approval or reject applications that would unreasonably affect public recreation or the natural stream environment.

Recognized Beneficial Uses for In-stream Flow

Either Division may file applications for permanent or temporary changes for the purpose of providing water for in-stream flows within a designated section of a natural stream channel or altered natural stream channel for the propagation of fish, public recreation, or the reasonable preservation or enhancement of the natural stream environment.

Holdership of In-stream Flow Water Rights
Although the Division of Wildlife Resources and the Division of Parks and Recreation are the only two entities that may hold in-stream flow rights, individuals may acquire an existing right and transfer it to these agencies to hold as an in-stream flow right.

Wyoming

Water Classifications:
The state of Wyoming has seven classes of groundwater based on the major groundwater uses (WDEQ, 1993). The classifications are:

- Class I, suitable for domestic use
- Class II, suitable for agricultural use where soil conditions and other factors are adequate
- Class III, suitable for stock use
- Class Special (A), suitable for fish and aquatic life
- Class IV, suitable for industry
- Class V, groundwater found closely associated with commercial deposits of hydrocarbons or considered a geothermal resource
- Class VI, groundwater that may be unusable or unsuitable for use

Groundwater uses in the Powder River Basin include domestic, agricultural, municipal/public water systems, and industrial uses, including CBM production, coal mining, secondary oil recovery, and uranium mining and processing.

The state of Wyoming also has four classes of surface water, including several subclasses. Except for Class 1 waters, each classification is protected for its specified uses plus all the uses contained in each lower classification. Class 1 designations are based on value determinations rather than use support and are protected for all uses in existence at the time or after designation. The classes are designated as follows:

- Class 1, Outstanding Waters
- Class 2, Fisheries and Drinking Water
- Class 3, Aquatic Life Other than Fish
- Class 4, Agriculture, Industry, Recreation, and Wildlife

Water Rights System
Wyoming water law is founded on the doctrine of prior appropriation, or "first in time, first in right". The Wyoming constitution states that all natural waters within the boundaries of the state are property of the state. The State Engineer is charged with the regulation and administration of the state's water resources.

Responsible Agency
The State Engineer's Office is the water rights administrator and is responsible for the appropriation, distribution, and management of the surface and groundwater throughout the state. Wyoming is divided into four water Divisions for administration purposed. A Superintendent who administers the waters of each water division heads each of these Divisions. These four Superintendents and the State Engineer comprise the Wyoming Board of Control. The Board of Control meets quarterly to adjudicate water rights and to consider other matters pertaining to water rights and water appropriation. The Board of Control is also responsible for any requests for

changes in point of diversion, change in use, change in the area of use, or abandonment of a water right pertaining to adjudicated rights.

Application Process

Since statehood, the only way to obtain a surface or a groundwater right is by filing an application with the State Engineer. The types of applications that can be filed in Wyoming are:

- transporting water through ditch or pipelines,
- storage in reservoirs,
- storage in smaller (under 20 acre-feet of capacity and a dam height less than 20 feet) reservoir facilities for stock water or wildlife purposes,
- enlargements to existing ditch or storage facilities, and
- in-stream flow purposes.

The date the application is filed establishes the water right's priority date. For both surface and groundwater, the State Engineer has the authority to approve or reject the application after reviewing and evaluating for any interference with any existing rights or harm the public welfare. In approving an application, the State Engineer can impose conditions or limitations on the application to protect existing water rights, further define the extent of the application, and address any other issue deemed necessary. An appeal process is available if the applicant disputes the findings.

If the State Engineer approves an application, the application achieves the status of "permit". The permittee is then given a specified time period (usually one year) within which to commence any necessary construction, and an additional time period (usually five years) within which to complete the project and put the water to beneficial use. When the notice of completion is received, a proof of completion is prepared. The proof is sent to the appropriate Water Division Superintendent for field inspection and advertised for public comment. For groundwater rights, the State Engineer, not the Superintendent, verifies the information through field inspections. Protests can be brought against the permit, and these protests can lead to public hearings.

Once adjudicated and a certificate is issued, the water right is permanently attached to the specific land or place of use described on the certificate, and it cannot be removed except by action of the Board of Control. Any disputes with the Board of Control can be appealed to District Court.

Point of Diversion – Change of Use

A point of diversion is required for all water rights (except for in-stream flow rights which require the identification of the appropriate stream segment). Any changes in point of diversion, conveyance, or use are done through a petition. The petition goes to the Board of Control for adjudicated rights or to the State Engineer if the water right is inchoate. Changes of use are only granted if the quantity of transferred water does not exceed historic consumptive use or diversion rates, does not decrease the amount of historic runoff, and does not impair other existing rights.

State Recognized Beneficial Uses

Wyoming recognizes the following beneficial uses categories. These categories apply to both surface and groundwater; the definition may be different when pertaining to surface as opposed to groundwater.

- Irrigation
- Stock
- Municipal
- Domestic
- Industrial
- Pollution control
- Power generation
- In stream flows
- Recreational
- Miscellaneous

Water rights holders are limited to withdrawals necessary for the beneficial purpose, and these limits are established for each use (for example, irrigators are allowed to divert up to 1 CFS for each 70 acres under irrigation).

Groundwater

In Wyoming, surface and groundwater are treated as hydrologically separate. If, however, a user protests that ground and surface water appear to be part of the same source, the state will investigate (using monitoring wells). If a hydrologic connection is found between established groundwater and surface water are assumed to be separate. Additionally, springs producing more that 25 gpm are treated as surface water, and those producing less that 25 gpm are treated a groundwater. Groundwater rights can only be obtained through the State Engineer. Groundwater rights are issued for the same beneficial uses as for surface water rights.

Water Rights

Any entity or group of individuals including a federal agency, state board, corporation, district, or individual may hold a water right in Wyoming (with the exception of in-stream flows which can only be held by the state). A water right in Wyoming is considered a property right, but it is a right which is attached to the lands or to the place of use specified in the permit. Wyoming water law expressly prohibits the sale of water rights—since water rights are attached to the land they cannot be sold separately from that land, but can be included in the sale of land.

A water right in Wyoming can be lost by abandonment. The three ways that abandonment can be initiated are: 1) voluntary abandonment by the water right holder; 2) another water user can claim that the reactivation of an allegedly abandoned water right would injure their right; 3) the State Engineer can initiate it if it is felt water has not been put to beneficial use for five consecutive years and a reallocation would be in the public interest. Water lost through abandonment reverts back to the public and is subject to future appropriation.

Adjudications

Once a certificate is issued by the Board of Control, the water right is adjudicated and listed in the tabulation of adjudicated rights. The primary reason for general adjudications in Wyoming is the determination and integration of tribal and federal water rights. An adjudicated right exists in perpetuity and can only be lost through abandonment.

In-stream Flows

Only the state of Wyoming may hold a right for in-stream flow, but no single agency has sole responsibility for the in-stream flow program. If approved by the State Engineer, an in-stream flow right is established. Water for in-stream flow can come from new appropriation, or through the transfer of existing rights. The transfer of existing water rights, however, can only be done by voluntary transfer or gift.

Recognized Beneficial Uses for In-stream Flow
In-stream flow rights in Wyoming may only be used to establish or maintain new or existing fisheries. Other uses commonly associated with in-stream flow (recreation, aesthetics, water quality, etc.) are not defined a beneficial use under Wyoming water law.

Holdership of In-stream Flow Water Rights
Only the state of Wyoming may apply for and hold an in-stream flow right. Other entities, however, may request that an in-stream flow right be applied for. Additionally, the state can accept water rights as a gift and convert it to in-stream flow (as long as the purpose is to support fisheries).

Table 4-2
Table of Primary Drinking Water Standards

Microorganisms	**MCLG[1] (mg/L)[2]**	**MCL or TT[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
Cryptosporidium	zero	TT [3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and fecal animal waste
Giardia lamblia	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste
Heterotrophic plate count	n/a	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment
Legionella	zero	TT[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and *E. Coli*)	zero	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E. coli* only come from human and animal fecal waste.
Turbidity	n/a	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Viruses (enteric)	Zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste

Disinfection Byproducts	**MCLG[1] (mg/L)[2]**	**MCL or TT[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
Bromate	zero	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	0.8	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5)	n/a[6]	0.060	Increased risk of cancer	Byproduct of drinking water disinfection
Total Trihalomethanes (TTHMs)	none[7] ---------- n/a[6]	0.10 ---------- 0.080	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection

Table 4-2 (Continued)

Disinfectants	**MRDL[1] (mg/L)[2]**	**MRDL[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
Chloramines (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2)	MRDLG=0.8[1]	MRDL=0.8[1]	Anemia; infants & young children: nervous system effects	Water additive used to control microbes

Inorganic Chemicals	**MCLG[1] (mg/L)[2]**	**MCL or TT[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronicsproduction wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[8]; Action Level=1.3	Short term exposure: Gastrointestinal distress;long term exposure: Liver or kidney damage; People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits

Table 4-2 (Continued)

Inorganic Chemicals	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[8]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities; adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Table 4-2 (Continued)

Organic Chemicals	**MCLG[1] (mg/L)[2]**	**MCL or TT[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
crylamide	zero	TT[9]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene (PAHs)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1,1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories

Table 4-2 (Continued)

cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories
1,2-Dichloropropane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	0.4	General toxic effects or reproductive difficulties	Discharge from chemical factories
Di(2-ethylhexyl) phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD)	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	zero	TT[9]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	zero	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories

Table 4-2 (Continued)

Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories
Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories

Table 4-2 (Continued)

Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

Radionuclides	**MCLG[1] (mg/L)[2]**	**MCL or TT[1] (mg/L)[2]**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
Alpha particles	none[7] ---------- zero	15 picocuries per Liter (pCi/L)	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation
Beta particles and photon emitters	none[7] ---------- zero	4 millirems per year	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation
Radium 226 and Radium 228 (combined)	none[7] ---------- zero	5 pCi/L	Increased risk of cancer	Erosion of natural deposits
Uranium	zero	30 µg/L as of 12/08/03	Increased risk of cancer, kidney toxicity	Erosion of natural deposits

Notes:
1 - Definitions
• Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
• Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
• Maximum Residual Disinfectant Level Goal (MRDLG) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
• Maximum Residual Disinfectant Level (MRDL) - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
• Treatment Technique (TT) - A required process intended to reduce the level of a contaminant in drinking water.
2 - Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million (ppm).
3 - EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:
• *Cryptosporidium* (as of1/1/02 for systems serving >10,000 and 1/14/05 for systems serving <10,000) 99% removal.
• *Giardia lamblia*: 99.9% removal/inactivation
• Viruses: 99.99% removal/inactivation
• *Legionella*: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
• Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
• HPC: No more than 500 bacterial colonies per milliliter
• Long Term 1 Enhanced Surface Water Treatment (Effective Date: January 14, 2005); Surface water systems or (GWUDI)

systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (e.g. turbidity standards, individual filter monitoring, Cryptosporidium removal requirements, updated watershed control requirements for unfiltered systems).
• Filter Backwash Recycling; The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.
4 - No more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or *E. coli* if two consecutive TC-positive samples, and one is also positive for *E.coli* fecal coliforms, system has an acute MCL violation.
5 - Fecal coliform and *E. coli* are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.
6 - Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:
• Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.3 mg/L)
• Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L)
7 - MCLGs were not established before the 1986 Amendments to the Safe Drinking Water Act. The standard for this contaminant was set prior to 1986. Therefore, there is no MCLG for this contaminant.
8 - Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.
9 - Each water system must certify, in writing, to the state that when it uses acrylamide and/or epichlorohydrin to treat water, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows: Acrylamide = 0.05% dosed at 1 mg/L (or equivalent); Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent).

Table 4-3
Table of Secondary Drinking Water Standards

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	Noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Chapter 5
Beneficial Use Alternatives

Introduction

Production of CBM, as well as conventional oil and gas, can be accompanied by the production of large volumes of produced water. The United States generates an estimated 340 million barrels or billions of gallons of produced water every year (Argonne National Laboratory, 2002). Therefore, identifying and implementing appropriate beneficial uses for this produced water would provide overwhelming benefits for local communities or ecosystems, while in conjunction provide operators with flexible, cost-saving water management options. The intent of this section is to discuss and identify traditional technologies, along with new or innovative applications of existing technologies (or combinations of the two) that may allow for the beneficial use of produced water.

Typically, applicable regulations, produced water quality, and cost will dictate potential beneficial use of produced water. In some cases poor quality water will require treatment before a particular use is implemented. For this reason, conventional and emerging water treatment technologies are also discussed in this section. Water of poor quality has traditionally been disposed of via deep well injection to prevent environmental impacts to the surface. New treatment technologies, however, have become an attractive solution for operators pumping from geologic formations containing poor water quality to facilitate uses other than disposal.

Beneficial use alternatives discussed within this section are either currently being implemented, or are considered feasible options for the near future. Discussion of the alternatives addresses the applicability of the technology and ecological or environmental regulatory constraints that may limit a producer's options for managing produced water. Beneficial use alternatives discussed in this section are sub-categorized into six beneficial use groups: Underground Injection, Impoundments, Surface Discharge, Agricultural, Industrial, and Domestic and Municipal Use

Produced Water and Treatment Technologies

Water produced in association with both oil and natural gas production comprises 80 percent of the oil and gas industry's residual waste requiring management and disposal, ultimately contributing to the overall costs of energy production (GTI, 2002). Management costs associated with water disposal can potentially impact realized profits of the natural gas industry, and possibly halt production operations. Approximately 60% of water produced with conventional oil and gas is disposed of via deep well injection at a cost of $0.50 to $1.75/bbl in wells that cost $400,000 to $3,000,000 to install (Argonne National Laboratory, 2002).

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 are often coupled together to achieve required water use objectives. For this reason, an integral aspect of the treatment process is the performance of water analysis to ascertain the presence of specific constituents for any given water source. This step provides various entities such as, government agencies, oil and gas companies, or land owners the ability to choose a treatment technology (or technologies) best suited to achieve their required water quality objectives for beneficial use.

Two different methods of water quality testing are applied to produced water. The first method tests for individual constituents and contaminants; whereas, the other method takes into account the cumulative effects of individual contaminants. Water quality testing of domestic wells and surface water generally utilizes the first method. National Pollutant Discharge Elimination System (NPDES) permits for produced water requires the performance of both methods.

Coal Bed Methane Produced Water

The following table (Table 5-1) represents CBM produced water data collected in the PRB by the Marathon Oil Company (Hodgson, 2001). This data does not necessarily reflect produced water quality levels for other regions or natural gas facilities.

In general, CBM produced water is characterized by elevated levels of sodicity, sodium, barium, bicarbonates, EC, and iron. The concentrations of each of these constituents will vary for any given water source depending on certain factors such as coal seam depth, peat metabolism processes, aquifer recharge, etc., and in some cases will require treatment prior to beneficial use. According to a Rocky Mountain News article regarding water produced from the wells of a Las Animas County operator, 80% of the produced water met federal drinking water standards (Frazier, 1999). This point illustrates the importance of conducting proper water analysis on produced waters prior to treatment and beneficial use designation.

Water disposal and treatment costs are an important aspect of the CBM industry since the volume of water produced is significant, especially during initial production operations. To help alleviate growing concern for rising water management costs, various treatment technologies are being researched and/or developed that may provide cost-effective practical options for produced water use. Many of the treatment technologies described below are not specific to the treatment of CBM produced water. These technologies should only be considered suitable treatment options upon thorough treatment research, analysis of cost effectiveness, water quality assessment, and identification of beneficial use goals.

Table 5-1
Typical Powder River Basin CBM Produced Water Constituents and Concentrations

Constituent	Concentration
Sodium	619 mg/L
Potassium	7 mg/L
Calcium	25 mg/L
Magnesium	12 mg/L
Carbonate	0 mg/L
Bicarbonate	1920 mg/L
Chloride	18 mg/L
Sulfate	4 mg/L
Nitrite + Nitrate as N	< 0.05 mg/L
Fluoride	1 mg/L
Total Potassium Hydrocarbons	< 1 mg/L
Total Dissolved Solids	1750 mg/L
Specific Conductance	2730 μmhos/cm
pH	7.5 Std. units
SAR	25.5
Alkalinity as $CaCO_3$	1580.0 mg/L
Hardness, as $CaCO_3$	6.5 grn/gal
Arsenic	0.05 μg/L
Barium	700 μg/L
Iron	2080 μg/L
Boron	100 μg/L
Manganese	20 μg/L

Treatment Technologies

The quality of water that is produced in association with CBM development will vary from basin to basin, within a particular basin, and over the lifetime of a CBM well. There are a variety of potential beneficial uses for CBM produced water that can be implemented by CBM 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 quality of this water and allow for increased beneficial use. The following section presents a discussion of some of the treatment options that may be utilized. However, this list is not all-inclusive nor is it intended to show preferred treatment methods. Instead, this section is intended to provide a description of several treatment technologies that are currently being evaluated or utilized for the treatment of CBM produced water prior to beneficial use.

Freeze-Thaw/Evaporation

The Freeze-Thaw/Evaporation (FTE) process involves lowering the freezing point of water containing salts or other constituents below the freezing point of pure water (32°F). Partial freezing of the solution results in the formation of higher quality ice crystals than the water from which it was derived, and the concentration of the higher density dissolved solids and other constituents in the unfrozen liquid. The ice crystals can then be collected and thawed, providing a source of high quality water with more management options, or in appropriate regions, the crystals can be allowed to evaporate. This process can be repeated until the more concentrated effluent is of a manageable volume. The smaller volume of effluent, though more concentrated, can be more easily disposed of and/or discharged with an appropriate NPDES permit, if necessary.

Ice buildup on framework of freezing pad.
Source: Boysen et al, 1997.

The FTE water treatment process is currently being practiced in Alaska, Colorado, and Wyoming to reduce the concentration of total dissolved solids in produced water. Since 1992, research has been sponsored by Amoco Production Company (Amoco), the U.S. Department of Energy, and Gas Research Institute (GRI), now known as Gas Technology Institute (GTI) to develop a commercial, natural FTE purification process for produced waters. The FTE process has been shown to produce water of suitable quality for various beneficial uses by effectively reducing concentrations of organic chemicals, heavy metals, and particulates in aquifers (Harju and Hayes, 1997).

Performance of the FTE treatment process, in general, is not significantly affected by water constituents concentrated in the water or by freezing conditions (Collins, Dempsey, and Parker, 2000), which may allow for successful implementation of the process in varying climatic conditions. However, prior studies have indicated there is a definite economic advantage over conventional evaporation technology in climates with seasonal subfreezing ambient temperatures. When natural processes of crystallization and evaporation are coupled, an increase in the throughput capacity of evaporation ponds results and water treatment economics are improved (Harju, 2002).

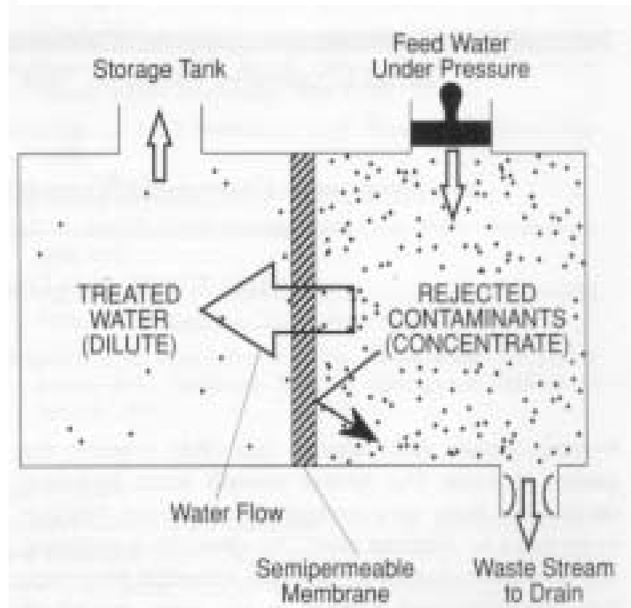
The Amoco Production Company conducted a test in New Mexico's San Juan Basin at an evaporation facility associated with a coal bed methane production facility. During the winter of 1996-97, 8,000 bbls of produced water with a TDS concentration of 12,800 mg/L were treated using the FTE process. As a result of the treatment, water requiring disposal was reduced by 80%. Of the original produced water volume, only 1,612 bbl or 20% remained with a final TDS concentration of 44,900 mg/L. The remaining produced water was either evaporated or purified to a level of 1,010 mg/L. The projected costs of using the FTE process to treat and dispose of the produced water were 24 cents and 32 cents/bbl, respectively.

Research sponsored by the City of Grand Forks, North Dakota and the U.S. Bureau of Reclamation, focused on the natural freeze/thaw process from aquifer supplied water to economically produce suitable water quality for reuse. The research indicated the FTE process is technically feasible for treating the Dakota Aquifer to produce water for augmentation of the Grand Forks municipal water supply. The process simulation yielded 72.6% of high quality water (292 mg/L TDS concentration) and detailed chemical analysis of the water supported the reuse premise. The researchers concluded filtration or disinfecting FTE-treated water would still be necessary to utilize the water as a potable water source, but the overall economic benefits of the process could be significant (Harju, 1997).

Reverse Osmosis

Reverse Osmosis (RO), or hyperfiltration, is a proven treatment process for the removal of TDS and other constituents such as arsenic. RO water treatment has been used extensively to convert brackish water/seawater or brine to drinking water, reclaim wastewater, and recover dissolved salts from various industrial processes. The RO treatment process separates dissolved solids or other constituents from water by passing the water solution through a semi-permeable cellophane-like membrane (Figure 5-1). Most RO technologies utilize a cross-flow process to allow the membrane to continually clean itself. As some of the solution passes through the membrane, the remaining fluid is flushed down stream to remove constituents away from the membrane.

Figure 5-1
The Reverse Osmosis Process
Reverse osmosis is used to lower TDS.



Source: Water Treatment Notes, Cornell University.

The RO process requires energy, most commonly pressure supplied from a pump, to force the solution through the membrane. As the pressure increases the concentration of solution passing along the membrane is also increased. The subsequent buildup of dissolved solids along the membrane requires continual increases in energy to pass the pure water through the membrane. In general, the RO process is capable of filtering or treating bacteria, salts, dissolved solids, proteins, and other constituents having a molecular weight greater than 150 to 250 daltons (Osmonics, 2002a).

Pretreatment is typically required to insure stable, long-term RO system performance and membrane life. In general, surface, sea, and wastewaters require more pretreatment than well water supplies (Ionics, 2002). Pretreatment may include clarification, filtration, ultrafiltration, pH adjustment, and removal of free chlorine. The efficiency of the membrane to collect particles is based on constituent concentrations and chemical properties, membrane type, temperature, and general operations. RO systems can be used to treat produced water and concentrate constituents into an effluent that is smaller in volume and more easily disposed. The higher quality water resulting from the RO process could be available for many beneficial uses.

Data collected from a wastewater treatment facility in Orange County (Water Factory #21) California indicates the RO treatment process is capable of treating TDS, sodium, magnesium, calcium, barium, alkalinity, and hardness for potable use (Committee on Groundwater Recharge, 1994). Depending on certain parameters such as equipment, initial water quality, membrane characteristics, etc., RO is able to effectively remove 95 to 99% of the dissolved salts, TOC, and silica from water supplies. Based on technology developed by Ionics, the RO process can effectively reduce salt concentrations between 50 to 95%, feed water salinities to 100 to 12,000 ppm, and concentrate salinities up to 120,000 ppm with a water recovery rate up to 94% (Ionics, 2002). Information provided by the Marathon Oil Company indicated the RO process, when coupled with other treatment techniques, could reduce waste streams by 80% at a cost of 8 to 10 cents/bbl of feedwater treated when deep injection of the waste stream is practical (Hodgson, 2001). Eighty percent of the feedwater stream would be available as high quality freshwater for beneficial use.

Ultraviolet Light

Ultraviolet (UV) sterilization is a proven technology for the treatment of water and the removal of unwanted free-floating constituents. UV light is a form of energy located in the electromagnetic spectrum region of shorter wavelength, high-energy light. UV light exists in a region between visible light and x-rays, occupying a spatial spectrum between 1 to 400 nanometers (1 nm = 10^{-9} meters). UV energy absorbed by bacteria, viruses, fungi, algae, and protozoa disrupts nucleic acids found in their cells preventing the cell's ability to multiply (Muskoka-Parry South Health Unit, 2002). The amount of UV light necessary to kill microbes depends on the type of microbe, but the minimum recommended dosage considered acceptable for treatment is 16,000 microwatts per second at a wavelength of 253.7 nm at maximum flow (Muskoka-Parry Sound Health Unit, 2002).

The performance of UV light water treatment on constituents in raw water is affected by the concentration of germs, bacteria, suspended solids, soluble molecules, and mineral concentrations. The effectiveness of UV light treatment is not affected by pH, temperature, alkalinity, or total inorganic carbon (Muskoka-Parry Sound Health Unit, 2002). Raw water containing more than 1,000 total coliforms per 100 mL or more than 100 faecal coliforms per 100 mL would not be effectively treated by UV light (Muskoka-Parry Sound Health Unit, 2002). Certain molecules are capable of absorbing UV light, such as humic acids and iron, thus decreasing the overall energy availability necessary to kill microbes. Pre-filtering these types of molecules would be necessary prior to treating the water using UV light.

Water hardness is related to the concentration of certain minerals in water and over time (Commission of Geosciences, Environment, and Resources, 2000). Minerals such as manganese, iron, calcium, and magnesium can precipitate out of solution, slowly reducing the intensity of the UV light. Typically, raw water containing these types of minerals (>140 mg/L) would also need to be pre-treated prior to UV light treatment.

UV light does not effectively remove dissolved constituents from water. Shadows created by the suspended solids also disrupt the performance of UV light to kill microbes and thus, as with other water constituent types, raw water containing large concentrations of suspended solids would need to be pre-filtered (Muskoka-Parry Sound Health Unit 2002).

Water that has been exposed at the surface is required to be sterilized before it can be re-injected into an aquifer. The use of UV sterilization would achieve this requirement. Produced water used for groundwater restoration, aquifer storage and recovery, or aquifer recharge could be sterilized prior to re-injection using this treatment technology.

The use of ultraviolet light in combination with ozone has been shown to enhance the reactivity of ozone with certain chemical constituents (GTI, 2002). Ozone is a form of active oxygen that is commonly produced by exposure to UV light or high voltage electric arc. Ozone is highly reactive, with a short half-life (120 minutes in distilled water), and is a popular treatment option for more than 140 water utilities to remove algae and biological growth prior to water processing. The use of ozone as a primary disinfectant is considered a much more effective disinfectant than chlorine from a financial and functional perspective, even though residual levels of disinfectant are lost once the molecule is converted to normal oxygen. Chemical oxidation/UV has been shown to achieve the following percent reductions from the aqueous phase (GTI, 2002):

- 99%+ removal of VOCs;
- Between 50 and 99+% removal of PAHs;
- Between 10 and 99+% removal of phenolics;
- Between 20 and 90% removal of cyanide; and
- Between 20 and 99% removal of sulfide.

In terms of wastewater treatment, the EPA researched UV light versus chlorination for small-scale water treatment plants and discovered unfavorable results due to higher costs, lower reliability, and lack of residual disinfection (Turner, 2002). The EPA has estimated the capital cost for a UV light system at a 1.5-MGD plant is $200,000.00, which translates into a unit cost of $0.13/gpd of capacity. Operations and maintenance cost associated with this system is estimated at 1.5 cents/1,000 gallons of water treated (Parrotta and Bekdash, 1998).

Research sponsored by the American Water Works Association Research Foundation recently provided details on the formation of bromate, a suspected human carcinogen, when utilizing ozone to purify water (Barlow, 1995). Since then the EPA has proposed a bromate MCL in drinking water at 10 micrograms per liter. The catalysis of bromate formation is hypobromous acid, which results when bromide is oxidized by ozone (Barlow, 1995). Given the average concentration of bromide in most U.S. drinking water sources is near 100 micrograms per liter, the use of ozone as a disinfectant should be limited to areas where bromide concentrations are low or can be controlled.

Chemical Treatment

Chlorination – Chlorine has been the principal water disinfectant of public water supplies, sewage, and industrial effluent for several decades. The active form of chlorine present in treated water is a hydrolysis product, hypochlorous acid (HOCL), which is formed when chlorine and water molecules interact (Committee on Groundwater Recharge, National Research Council. 1994). Chlorination effectively removes disease-causing bacteria, viruses, protozoa, and other organisms, and can be used to oxidize iron, manganese and hydrogen sulfide so these minerals can be filtered from the water. Other treatment technologies, such as UV light and RO, are often used in tandem with the chlorination process.

Public health is the main benefit associated with this treatment process. Relative to other treatment technologies, chlorination provides a residual disinfection effect. For example, water treated with UV light becomes susceptible to contamination once the water has been removed from the treatment facility, whereas chlorine will continue to disinfect to the tap (Turner, 2002). Additional advantages associated with chlorination include prevention of algae and slime growth in pipes and storage tanks. Chlorination systems are cost effective, safe to use, and require minimum maintenance.

In instances where produced water could be used for beneficial human consumption, storage, or injection into aquifers, it may be necessary to chlorinate the water. Chlorine treated water would reduce environmental degradation caused by the discharge of produced water and provide an alternative water supply in areas with low water supplies. In addition, the chlorination process prevents the accumulation of toxic microorganisms in fish, shellfish, and other wildlife species.

Iodine – Iodine water treatment is commonly used to remove pathogens, with the exception of cryptsporida, from water. Iodine is less sensitive to pH and the organic content of water, is safe for long-term exposure, and is considered effective in lower doses. Experts however, are reluctant to recommend iodine for long-term use because the average American iodine intake (0.24 to 0.74 mg/day) is higher than the recommended daily allowance (0.4 mg/day) (Turner, 2002).

Silver – The use of silver to kill water pathogens has been considered, but because of the EPA's establishment of 50 ppb MCL limit on silver, its use for water treatment has been very limited. The MCL was established to prevent argyrosis, a silver specific disease characterized by staining of the eyes, skin, and mucous membranes.

Additional chemicals used to treat water include potassium permanganate, hydrogen peroxide, and coagulation/flocculation agents. Historically these reagents have been used on a very limited basis because of potential health concerns and/or cost efficiency. For the purpose of this study, as with iodine and silver, these chemicals are not considered a practical solution for treating produced water for beneficial uses.

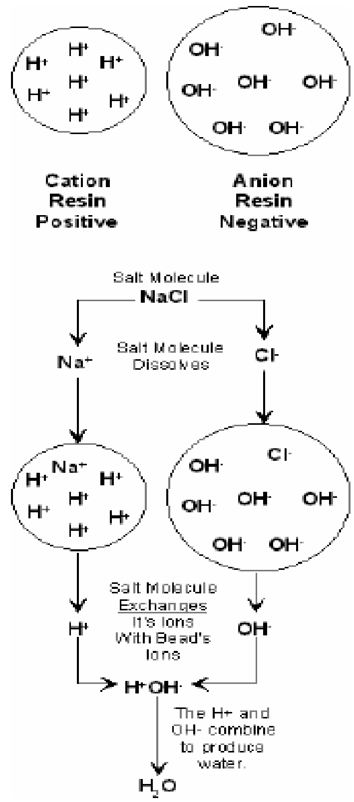
Ion Exchange

The process of ion exchange historically has been used to soften water for residential purposes by replacing hardness ions such as calcium and magnesium with Na^+ and Cl^- ions (Filters, Water & Instrumentation, Inc., 2002). Ion exchange is also commonly used to deionize water by replacing ions, such as conductive salts (desalination), with H^+ and OH^- when extremely pure water is required. The ion exchange process works by charging resins with the replacement ions, e.g., Na^+, Cl^-, H^+ or OH^- (see Figure 5-2). Ions in the water are attracted to the resin and attach themselves to the resin, replacing the ions that are already attached. Once the replacement ions are exhausted, the resin is regenerated with a concentrated solution of the replacement ions. This process removes the ions concentrated in the water and effectively regenerates the resin (Osmonics, 2002b).

When coupled with other treatment technologies, such as RO, the ion exchange process can potentially reduce waste streams to about 5% of the feedwater volume (Hodgson, 2001). The advantage of some ion exchange processes is that secondary pollutants and waste shifting from one media to another is usually avoided. The process is also considered non-polluting and requires low energy. The effectiveness of the ion exchange process is dependent on the initial constituent concentrations and the role of the treated water's reuse, but in general requires additional chemical treatment. The ion exchange process can effectively remove salts, heavy metals, radium, nitrates, arsenic, uranium, etc., from raw water, but is unable to effectively remove organics (Owens, 1985). Because divalent ions are removed preferentially to sodium, SAR (sodicity) adjustments must be made after treatment.

Hydrometrics has developed a treatment process referred to as the HYDRO treatment process (patent-pending) designed to treat constituents concentrated in CBM produced water. The constituents of concern, namely sodium, hardness and certain metals, could be reduced in a manner that would potentially minimize capital and operating costs. The HYDRO treatment process is a four tiered treatment process with a secondary RO treatment to reduce residual sodium sulfate solution. The four-step HYDRO process is described below.

Figure 5-2
Ion Exchange Process
Softens water by replacing hardness ions.



Source: Filters, Water & Instrumentation, Inc., 2002.

Step 1: Weak Acid Cation (WAC) Ion Exchange: WAC removes sodium and hardness associated with alkalinity and releases acidity. Other cations (such as ammonia, strontium, barium, iron, manganese and zinc) are also removed. Treated water is slightly acidic. Under acidic conditions, the bicarbonate alkalinity in the water is converted to carbon dioxide. The TDS is reduced accordingly.

Step 2: Forced Draft Decarbonization: After the WAC ion exchange treatment, the water is passed through a counter current air stripper to remove the carbon dioxide created in the WAC process. This inexpensive step neutralizes the pH and prevents calcium carbonate formation in the next step.

Step 3: Lime Addition: Lime is used to increase the calcium content of the treated water and reduce the SAR.

Step 4: Ion Exchange Regeneration: Several WAC ion exchange vessels are employed to reduce TDS. Normally one vessel is in regeneration, or stand-by, while the others are in service. After an individual WAC ion exchange vessel treats approximately 45,000 gallons of produced water the resin is exhausted and requires regeneration. Regeneration is accomplished in two steps.

First, the resin is regenerated by passing a stream of 5% sulfuric acid through the resin bed. The sulfuric acid removes the sodium and hardness from the resin and replaces it with hydrogen ions. The sulfuric acid stream is converted to sodium sulfate in the process.

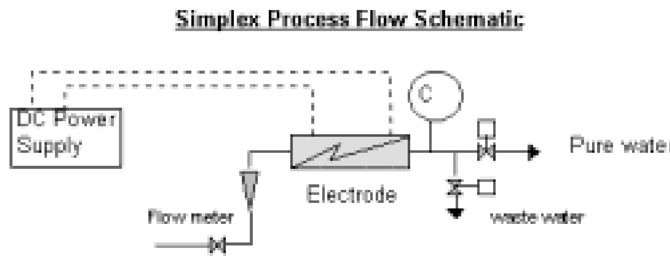
Second, the residual sodium sulfate solution remaining in the resin bed is rinsed out using additional produced water. The rinse water containing the residual sodium sulfate solution is then treated by reverse osmosis to concentrate this waste stream and reduce its volume. This softened waste stream can be easily treated by RO. The concentrated waste stream from the RO (the reject) is blended with the first sodium sulfate regenerate waste stream. The treated RO water (the permeate) can be combined with the treated water from the ion exchange treatment for discharge to the environment.

The result of this treatment process is an approximate 4 to 10% waste stream that may be evaporated or injected underground (Hodgson, 2001). The treated water can be released to the environment or put to beneficial use.

Capacitive Desalination (CD) or Deionization

According to the inventor, Joe Farmer, this relatively new high water recovery treatment process has the potential to use one-thousandth to one-hundredth the energy required by typical distillation methods. Water with concentrations of salts, heavy metals, and/or radioactive isotopes is pumped through thin sheets of carbon aerogel. Each porous aerogel sheet is 3 in^2 with the effective surface area of a football field (600 to 900 m^2/g) (Envirosense, 1996). Non-polluting electricity is applied to the aerogel sheets (electrodes) trapping ions and allowing pure water to pass through. Since the capacitive deionization process does not require the regeneration of ion exchangers with acids and bases, as with the conventional ion exchange process, any associated secondary waste would be eliminated (Lawrence Livermore National Laboratory, 1994b).

Figure 5-3
Capacitive Desalination
A distillation process that traps ions.



Source: Atlas, Sabrex of Texas, Inc., 2002

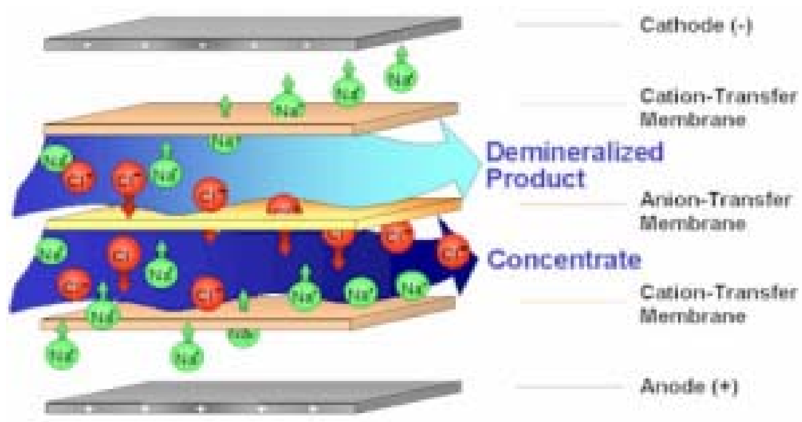
The expected applications of this treatment process include deionizing water for boilers of fossil-fueled and nuclear power plants, RO pre-treatment, wastewater treatment, and the desalination of water for dry, heavily populated areas. The high cost of the technology has limited its widespread use to small-scale use or by energy rich countries (Lawrence Livermore National Laboratory, 1994a). Active development of this process is ongoing and should reduce energy and capital requirements to possibly 5 to 10 cents/bbl (Lawrence Livermore National Laboratory, 1994a).

Similar capacitive desalination technology utilizing activated carbon electrodes developed by Biosource Inc. and licensed to Sabrex and Alamo Water Refiners produces deionized quality water by electronically removing dissolved salts. Considerable testing on this new treatment process has been performed on San Antonio City Water. Based on a volumetric average, over 75% of the dissolved salts in the water were removed with a substantial improvement to regeneration time (15 minutes per cycle), while only using 1.7 watt-hours of electricity per gallon of water purified. TDS limits for this technology is 2,500 PPM, but future technology is being developed that will potentially allow effective operation at TDS levels of 15,000 PPM.

Electrodialysis Reversal (EDR)

Traditionally, electrodialysis treatment of water has been used to desalt brackish water to produce higher quality water (Damien (Solarweb), 1998). The basic principles of this treatment process are similar to ion exchange in that ions will dissolve in water and will posses either a positive charge (cation) or negative charge (anion) and will be attracted to electrodes of an opposite electrical charge. Electrodialysis differs from a normal ion exchange process by utilizing both cation and anion selective membranes to segregate charged ions from a water solution (AWWA, 1996). These membranes are arranged alternatively (cation and anion) to selectively collect charged ions. The arrangement of two membranes creates spaces of concentrated and diluted solutions and collectively is referred to as a cell (Shuler and Kargi, 1992). A typical dialysis system consists of hundreds of adjacent cells with electrodes on the outside and is referred to as a membrane stack (Damien (Solarweb), 1998). As with RO, energy, such as a small pump, is required to move the water through the membranes.

Figure 5-4
Selective Membranes
Cation and anion selective membranes are used to remove ions from water.



Source: Ionics, 2002.

The EDR process was developed in the 1970's and operates on the same basic principles of the conventional electrodialysis process with the exception that the resulting product effluent channels (brine and purified water) are constructed in an identical manner. The polarities of the electrodes are reversed periodically so that the brine channel becomes the water channel and the water channel becomes the brine channel (Damien (Solarweb), 1998). The reverse in polarity results in opposite movement of the ions across the selective membranes. The reversal process aids in the prevention of slime and other buildups and lowers the amount of pretreatment chemicals necessary to produce predetermined water quality objectives (and/or prevention of membrane fouling).

The EDR process is considered low energy and pressure, and is expected to achieve removal efficiencies of 80% (EPA, 1999a). Because of the process's self-cleaning characteristics, this treatment technique has the potential to function more efficiently for longer periods of time. Coupled with other treatment technologies the EDR process can reduce the volume of waste streams which will contain the arsenic and other dissolved solids to approximately 12% of the feedwater volume (Hodgson, 2001). The EDR process, however, is not effective at lowering the SAR without additional chemical treatment.

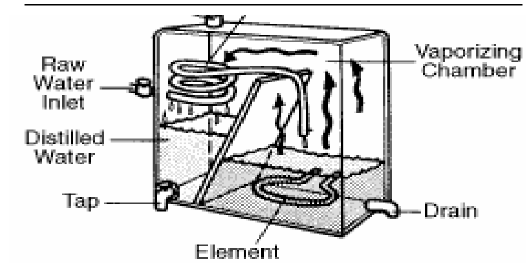
Based on information reported by the GTI, laboratory tests performed by the Argonne National Laboratory showed that electrodialysis can partially demineralize produced water economically to within NPDES permit requirements. ThermoRetec treated 15 batches of produced water and collected analytical results for 12 of the 15 batches. Five of the batches were treated to a TDS water quality of 1,000 mg/L, four were treated to 2,500 mg/L, and three were treated to 5,000 mg/L TDS water quality. Removal efficiency was low for the 5,000 mg/L TDS final water quality, but the efficiency was better than that of the 2,500 mg/L and 1,000 mg/L final treatment endpoint batches. Electrical costs for the treatments ranged from \$0.006/bbl to \$0.064/bbl of produced water treated (GTI, 2002).

A second experiment associated with this project was performed to ascertain costs and membrane integrity issues by placing the electrodialysis unit in a continuous mode. The electrical costs of continuous partial demineralization ranged from \$0.02/bbl to \$0.64/bbl of produced water treated. Total treatment costs for the deoiling, dissolved organics removal and partial demineralization system was estimated to range from \$0.27 to \$0.40/bbl depending on the final TDS water quality. This estimate did not include capital cost of the system. These costs are much higher than Ionics estimated for a proposed Powder River Basin CBM facility (GTI, 2002).

Distillation

The distillation process is capable of removing 99.5% of the impurities concentrated in raw water (Derickson, et al 1992). The distillation process is commonly used to remove nitrates, bacteria, sodium, hardness, dissolved solids, many organics, heavy metals, and in some cases, radioneucleides. Distillation involves boiling water into steam, which is then passed through a cooling chamber and subsequently condensed into a purified form (see Figure 5-5). The boiling process segregates water impurities from the purified product for collection and disposal. Constituents having similar boiling points of water are not effectively removed during the distillation process. Such impurities include many volatile organic contaminants, certain pesticides, and volatile solvents (Derickson, et al, 1992).

Figure 5-5
The Distillation Process
Removes impurities by boiling water to produce steam.



Source: North Dakota State University Extension Service, 2002.

Rapid Spray Distillation is a new technology developed by Aquasonics International that uses a rapid spray system to eject salt contaminated water at high velocities to create water droplets of specific size and nature. Depending on various parameters, liquid is converted to vapor within milliseconds of ejection, allowing for solids to be flashed or separated from solution. The resulting pure vapor is condensed and collected with 95% recovery. This technology is projected to reduce by one-eighth the treatment cost relative to other treatment technologies, e.g., RO (Aquasonics International, 2002).

Artificial Wetlands

Constructed wetlands were developed approximately 40 years ago to exploit the biodegradation ability of plants (Shutes, 2001). The advantage of these systems includes low construction and operation costs (Cooper, et al., 1996), approximately 1 to 2 cents/bbl, although relative to other wastewater treatment technologies these systems have a slow rate of operation.

Constructed Artificial Wetland

For organic waste treatment the

average lifespan of a constructed wetland is approximately 20 years (Shutes, 2001).

Wetland treatment systems reproduce the natural filtering aspects observed in wetland settings by removal of organic matter (carbon, nitrogen, and phosphorus), suspended matter, and certain pathogenic elements. Traditionally, artificial wetland systems have been constructed based on two natural water filter principles: vertical flow or horizontal flow. In a vertical flow wetland system, wastewater seeps from the surface to the subsurface, usually consisting of soils containing a mixture of sand and gravel. The vertical system is an aerobic process used primarily to remove BOD, phosphorus, and to oxidize nitrogen. The horizontal wetland system is a facultative aerobic or anaerobic process, depending on the time and frequency of inundation, where water flows from one side of the system to the other. This type of constructed system is typically used to remove BOD, to disinfect, to filter finely, and remove specifically by precipitation, ionic exchange, and/or adsorption. Vertical systems or subsurface flow systems, in general, are more efficient at filtering or treating water and/or soil because of an increase in the presence of bacteria, and there subsequent ability to degrade pollutants in an aerobic environment.

Reed grasses (Phragmites) are commonly used in wetland treatment systems because of their large biomass, underground rhizome system, and ability to assist in the breakdown of certain pollutants (Cooper, et al., 1996). Rootzone Soil Filters, or Reed Bed wetland systems are commonly used in Australia and worldwide to treat heavy wastewaters including those derived from chemical and heavy industries, landfill sites (tip leachate), wineries, mining operations, aquaculture, etc. (Adcock, 2000). Many types of pollutants are not treatable during anaerobic (inundated) conditions and tend to accumulate in subsurface soils by adsorption, poisoning subsurface bacteria necessary to degrade certain compounds, e.g., NH4. Reed grasses provide oxygen to the root zone allowing for aerobic respiration and treatment of pollutants. The grasses are capable of some nutrient transfer of pollutants but, in general, only account for 2 to 5% of the total pollutant removal (Adcock, 2000). At a pig farm in Germany, a study utilizing Reed Bed technology for the treatment of waste sludge reached net reductions of 87% to 99% in select compounds (Table 5-2).

Information reported by RSA Consultants (1995) in Quebec on a filterable phytophil wetland system indicated wetlands are most useful for the treatment of wastewater for small municipalities or industries. In general, wetlands are limited to $400 m^3$/day to $750 m^3$/day, depending on the season, or approximately the effluent output from 1,000 residents. Wetlands can receive and filter maximum concentrations of BOD and PO_4 of 1,000 and 10 mg/1 respectively (RSA Consultants, 1995). Performances of these systems are influenced by size, length to width ratio, water depth, and loading rates (Shutes, 2001). In general, these systems can remove 90% of disease causing microorganisms and 80% organic material and suspended solids (Shutes, 2001).

Research sponsored by Marathon Oil Company in 2000 involved construction of an artificial sedge wetland system to treat CBM produced water. The purpose of the project was to determine if constituents concentrated in CBM produced water, mainly SAR, Fe, and Ba, could be treated cost-effectively. The wetland system load for the study was designed for approximately 30 to 40 gallons of water per minute. Results after one year of operation indicated the wetland system could effectively treat iron and possibly barium, but not SAR (Sanders, et al., 2001).

Table 5-2
Results from Reed Bed Treatment on Waste Sludge

Compound	Affluent	Effluent	Net Reduction (%)
Total N	1573.80	173.80	88.9
NH_4	1363.60	92.70	93.2
NO_3	34.10	2.30	93.2
PO_4^{3-}	133.51	0.49	99.6
K^+	884.60	116.50	86.8
Cu^{2+}	1.14	0.08	93.0

Source: Adcock. 2000.

Initial iron concentrations of 270 µg/L and initial barium concentrations of 300 µg/L were reduced to 100 µg/L and 200 µg/L, respectively. SAR increased from 12.1 to 14.1 during the initial year; a fact investigators attributed to calcite precipitation without the associated soil dissolution of calcium and magnesium (Sanders, et al., 2001). Researchers in the study concluded an increase to iron and barium loading rates received by the wetland system would be necessary to ascertain the system's filtering potential. They also concluded reduction of SAR is not a useful wetland function based on one year treatment data results. A report by Montanan State University further supported these results, concluding "clean water" is needed to supplement sodicity and saline treatment by vegetation and soil (Bauder, 2002).

A monitoring study was performed by UNLV personnel from the Harry Reid Center and Environmental Studies Department in the Nature Preserve at Clark County Wetlands Park, Nevada (Pollard and Kinney, 2002). Water quality monitoring activities were conducted to evaluate adverse environmental effects on natural wetlands by creation of the preserve and associated water treatment plant. Water samples were collected between October 2000 and December 2001 at inflow points, middle points, and outflow points relative to the wetland system. Sampling data results collected on October 18, 2001, for the three points are presented in Table 5-3.

Based on data collected throughout the entire sampling period (15 months) the natural wetland filtering process did not affect water conductance, dissolved oxygen, chloride concentrations, alkalinity, hardness, turbidity, and total suspended sediment (Pollard and Kinney, 2002). Moderate reductions to pH, sulfate, and nitrate were observed, but in terms of water quality, the reductions are considered negligible.

Table 5-3
Clark County Wetland Park Water Quality Partial Data for Three Wetland System Points

Sampling Point	DO (mg/l)	Temp. (°C)	Conductance (µS/Cm)	Turbidity (NTU)	Phosphorus	NH_3-N	$N0_3$-N
Inflow	10.74	17.5	5270	8	0.11	0.27	15.5
Middle	9.38	17.8	5160	7	0.09	0.31	12.5
Outflow	10.79	17.5	5260	9	0.08	0.25	12.4

Source: Pollard and Kinney, 2002

Summary

As stated above, water quality levels for CBM produced water will vary depending on certain factors and in some cases may require treatment prior to beneficial use. Water treatment technologies are generally limited to treating specific water constituent types, and depending on the eventual use of the water and desired constituent concentrations, treatment processes are often coupled together, e.g. RO and chlorination. The following table (Table 5-4) reflects common constituent types present in CBM water versus the discussed treatment processes' ability to effectively treat each. Again, the relative effectiveness for each treatment process will vary depending on the produced water's initial water quality and associated beneficial use.

Table 5-4
Treatment Technologies and their Effectiveness on Reducing Certain Constituent Types Present in CBM Produced Water

Treatment Technology	Heavy Metals	SAR	TDS	Ba	Fe	EC	Organics	Na	HCO_3	Bio
FTE	√		√	√	√	√		√		
RO	√	√ [2]	√	√	√	√		√	√ [1]	
UV Light							√ [3]			√
Chemical										√
Ion Exchange	√	√ [2]		√	√	√		√	√ [1]	
CD	√	√ [2]		√	√	√		√	√ [1]	
EDR	√	√ [2]		√	√	√		√	√ [1]	
Distillation	√		√	√	√	√	√ [3]	√		√
Wetlands	√		√	√	√	√				√

Source: ALL Consulting
√ - indicates treatment process can reduce constituent type.
1 - pH adjustment would be required prior to treatment
2 - water adjustment by addition of calcium and magnesium would be required.
3 – limited to certain organics based on volatility, boiling point, chemical composition, etc.

Underground Injection

Introduction

The production of CBM is often accompanied and facilitated by the production of groundwater. One management option for produced water is to inject it underground in accordance with state and federal regulatory programs. Injection wells are currently used in conventional oil and gas and CBM fields across the country as a necessary and critical water management tool. Without the use of injection, CBM development would not be possible in many areas of the country rendering these valuable resources unattainable. Injection is dependant upon several variables, including, but not limited to the availability of a receiving formation(s); the quality of water being injected; the quality of water in the receiving formation; and the ultimate storage capacity of the receiving formation(s). These factors will influence what type of injection well can be used as a tool for managing water produced in association with CBM.

From a process viewpoint, injection is generally viewed as the emplacement of water into an aquifer or reservoir by pumping the water into an injection well[3] completed in a zone or formation that is capable of receiving and storing water. Injection wells are regulated by the Underground Injection Control (UIC) program, which was initiated under the Safe Drinking Water Act (SDWA) to prevent contamination of underground sources of drinking water (USDWs). The UIC program is overseen by the EPA and allows states to have primary enforcement responsibility when the states promulgate regulations that meet the minimum standards set and approved by the EPA.

UIC Program

UIC History & Regulations

The primary purpose of the UIC program is to prevent contamination of USDWs during and after injection activities. USDWs are defined in 40 CFR 144.3 as an aquifer that contains less than 10,000 mg/L of TDS, currently supplies or contains a sufficient quantity of groundwater to supply a public water system, and is not an exempted aquifer. In 1974, Congress passed the SDWA, giving the EPA the authority to control underground injection to protect USDW (SDWA, Part C, Sections 1421-1426). In 1980, EPA published the regulations for the UIC program, which set the minimum standards that state programs must meet to have primary enforcement responsibility (primacy) under the UIC program. In 1981, Congress amended Section 1425 allowing states to have primacy over oil and gas related injection wells. The amendment also strengthened Section 1421(b)(2), stating that EPA can interfere with the production of oil and gas only when protecting drinking water sources.

In order to be granted primacy, a state must develop and implement regulatory programs that meet the EPA requirements as either a 1422 or 1425 program. Section 1422 of the SDWA allows states and Indian Tribes to have primacy of the UIC Program. In order for states to receive primacy, the states must implement a UIC program that meets the minimum requirements established in 40 CFR §§144-147. The state must then apply to the EPA, give reasonable notice to the people of the state, provide public hearings concerning the

[3] A well is defined by the EPA as any man-made hole that has a depth greater than its largest surface dimension, an improved sinkhole, or any man-made subsurface fluid distribution system.

implementation of the state UIC program, and receive approval from EPA. Upon accepting primacy, states are required to keep records and report the activities of the state UIC program to the EPA. The state is further required to meet any revised or added requirements that may be amended to the current regulations. Once each state has qualified for and received primacy, the state will be listed in the Federal Register. Approval as a 1422 primacy program essentially is done by adopting federal UIC regulations. Under Section 1425, a state may develop its own regulations, but must demonstrate the effectiveness of the subject regulations. Most state delegated Class II UIC programs are 1425 programs.

Conversely, states that do not implement the UIC program as either a 1422 or 1425 program are "Direct Implementation" states. In Direct Implementation states, EPA implements the UIC program directly. Through direct implementation, injection well operators are required to meet federal regulatory requirements relative to the UIC program, including applying for permits, submitting injection monitoring reports, and being subject to the full regulatory authority of the EPA, which includes being subject to federal enforcement in cases of non-compliance with the federal program. If a state does not obtain primacy for all or some of the well classes, then EPA implements the program directly through one of its ten Regional offices.

State agencies that have not applied for and received delegated authority over the UIC program do not have regulatory authority to implement or enforce the federal UIC program. Although the EPA has full authority to implement the federal UIC program, it does not preclude states from implementing other regulatory programs that do not conflict with the federal program. It is common for all states, whether primacy or Direct Implementation, to collect information on all wells drilled in the state as part of in-place regulations. However, it would be very uncommon for a state to implement requirements that conflict with the federal UIC program.

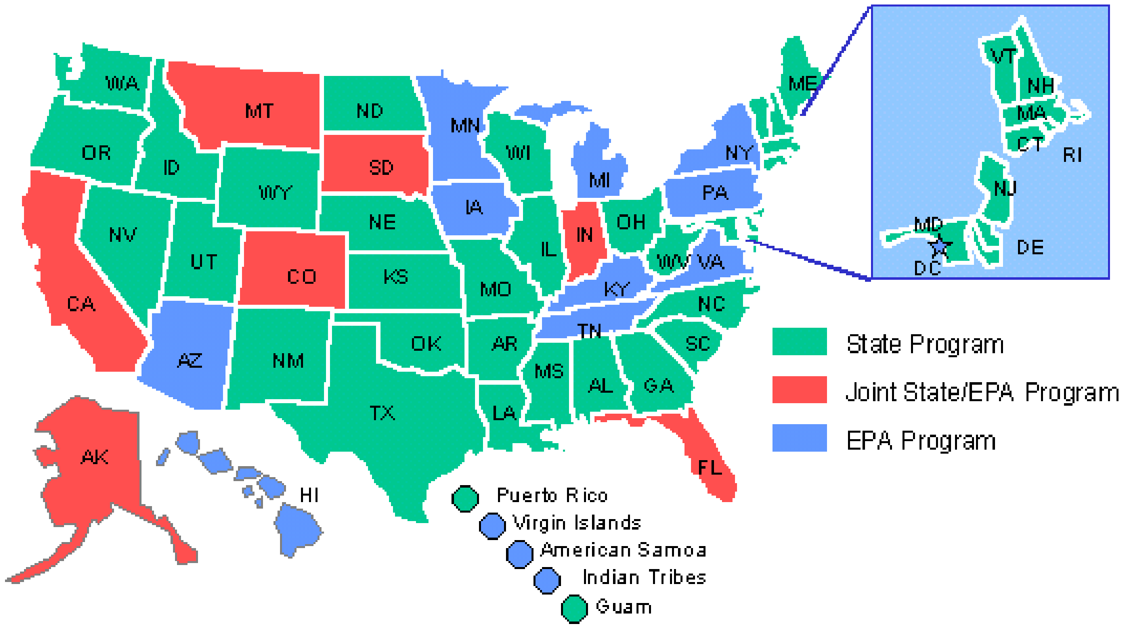
EPA has delegated primacy for all well classes in 34 states; it shares responsibility in six states, and directly implements the program for all well classes in ten states. EPA provides grant funds to all delegated programs to help pay for program costs. States must provide a 25% match on EPA funds. Figure 5-6 shows the breakdown of responsibility for the UIC program throughout the United States.

Section 129 of Public Law 110-1660 requires underground injection activity on federal lands to follow EPA and state guidelines. When the federal lands are located in a state with UIC primacy, they are under state UIC jurisdiction; when the federal lands are in a direct implementation state, they are under EPA jurisdiction. Indian Lands are primarily direct implementation sites; however, EPA has acknowledged tribal jurisdictional responsibility according to the Indian Policy established in 1984 by William Ruckelshaus, and reaffirmed in 2001 by Christine Whitman. The tribal jurisdictional responsibility allows tribal governments to apply for and receive UIC primacy under the same guidelines as states.

Well Classification

Within the 40 CFR, EPA has provided definitions that divide injection wells into five general classes of wells. EPA's definition relative to well classification depends on several criteria, including purpose, characterization or quality of the injectate, relative location of the receiving zone to USDWs, along with others. A summary of the five classes of injection wells is provided below:

Figure 5-6
Regulatory Control of the UIC Program
UIC Program responsibility and control nationally.



Source: US EPA, 2002

- Class I wells are technologically sophisticated facilities that are used to inject hazardous and non-hazardous industrial wastes into well-confined and permeable formations below all USDWs.
- Class II wells are used to inject fluids associated with oil, natural gas, and geothermal energy production (including CBM), or to inject liquid hydrocarbons for storage purposes. Injection is generally into a permeable formation that is not a USDW or, if containing groundwater having TDS concentrations less than 10,000 mg/L, is an exempted aquifer. Class II injection wells have been further divided into three subclasses: enhanced recovery, disposal, and hydrocarbon storage and extraction wells. Enhanced recovery (Class II-R) wells are used to inject water or other fluids into producing horizons to increase oil and/or natural gas production. Disposal (Class II-D) wells are used to inject produced fluids into zones other than producing horizons for disposal purposes. Hydrocarbon storage and extraction wells (Class II-H) are used to inject and store oil or natural gas in the subsurface for later extraction and use.
- Class III wells are wells that are used to inject water or unsaturated brine, super-heated steam, or other fluids into formations (including bedded and domal salt deposits) in order to extract minerals through a solution mining process. After injection, fluids are pumped to the surface for disposal or mineral extraction.

- Class IV wells are used to inject hazardous or radioactive wastes into or above USDWs. These wells are banned under the UIC program except when involved in an authorized remediation program to remove previously injected hazardous or radioactive wastes.
- Class V wells are injection wells that are not included in the other classes. Some Class V wells are technologically advanced wastewater disposal systems used by industry, but most are "low-tech" wells, such as septic systems and cesspools. The simple construction of the low-tech wells provides little or no protection against possible groundwater contamination, so it is important to control what materials are allowed to enter into them. Class V wells are primarily used to inject fluid above or into a USDW, and are regulated to protect the groundwater aquifer. The minimum requirements for a Class V injection well have been set by 40 CFR §§144-147. The wells used to manage CBM produced water are categorized as aquifer recharge wells and aquifer storage and recovery wells.

Figure 5-7, taken from an EPA publication, is a characterization showing various Classes of injection wells in relation to each other and the base of the lowermost USDW. It is important to note that in each of the examples shown in Figure 5-7, injection occurs into a discrete geologic interval and is typically well confined from any USDW. However, in some cases, injection may occur into or above a USDW, depending on the circumstance and quality of the injection fluid. Fluids injected into a USDW, perhaps for storage and recovery in the future, may be required to meet high water quality standards and/or pre-treatment (e.g., chlorination).

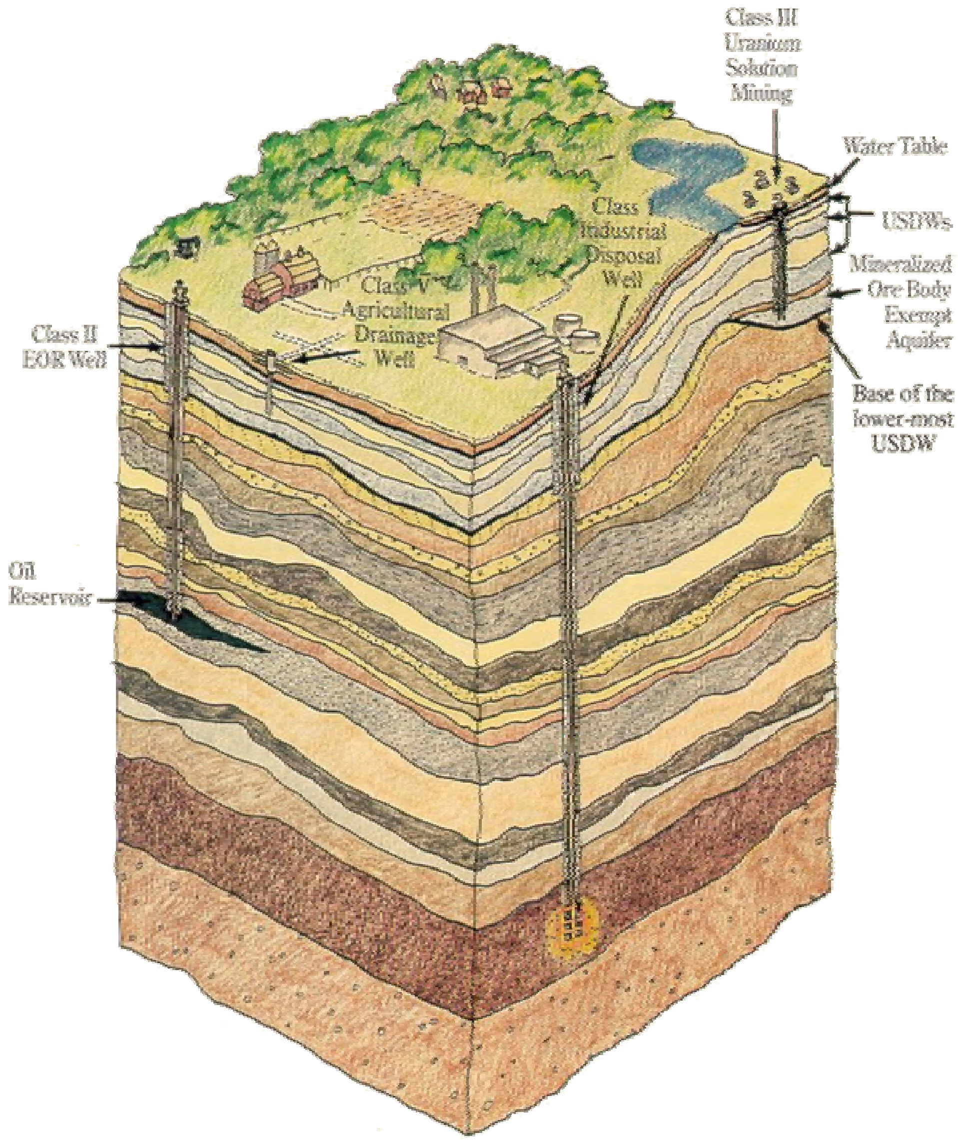
Regulatory Framework and Applicability

Injection activities associated with CBM development activities may involve a variety of water management practices and the use of more than one type of injection well. Depending on the circumstances, it is conceivable that water produced in association with CBM production could be injected into any one of the five well classes described earlier. If used for industrial purposes, later disposal of the subject water could be required via a Class I injection well. Considering that solution mining does occur in several CBM development areas (e.g., Wyoming), CBM water could be used for solution mining purposes and therefore injected into a Class III injection well. Although unlikely, CBM produced water could be used as part of a remediation process making injection as a Class IV well conceivable.

Regardless of the possibilities, it is likely that the two most appropriate injection options for managing CBM water are either Class II or V wells. Because the feasibility of using wells other than Class II or V wells is believed to be remote, the focus of this section will generally be limited to the discussion of these well classes. However, circumstances may warrant the use of injection well types other than Class II or V, especially if the produced water is first used in an industrial process.

As noted above, regulatory authority for injection activities in a particular area will be implemented by either the EPA or a state regulatory agency. As such, regulatory requirements and burdens of the federal UIC program as well as selected state programs are presented and discussed.

Figure 5-7
Injection Well Classes and Relationship to USDWs.
This figure shows the relationship of USDWs to different classes of injection wells.



Source: US EPA, 2002.

Technical Considerations

Utilization of underground injection as a tool for managing produced water includes both technical and regulatory considerations. Technical considerations may include such things as geologic, economic, and engineering considerations. The valuation of both engineering and economic considerations can vary significantly by operator and location; there are, however, a set of issues that must be considered relative to the hydrogeology of any proposed injection well, including:

- *Formation Suitability:* Selection of a suitable injection zone may include several criteria, potentially including reservoir characteristics; depth; relative location to producing wells and USDWs; 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 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, 1991a) 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, 1975). 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.
- *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. For instance, a permeable unit that has 10% porosity, is 20 feet thick, and is homogenous and regionally extensive would have a storage capacity of 2 million bbls if the injectate front extended for ¼ mile.
- *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 injected fluids.
- *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.

Federal UIC Program

EPA has established federal regulations relative to all classes of injection wells, including Class II and V type wells in 40 CFR §144-147. The primary purpose of the federal UIC program for injection wells (40 CFR §144.82) is to prohibit the movement of fluid containing any contaminant into a USDW that might cause a violation of the primary drinking water standards under 40 CFR §141, or that might cause endangerment. Individual states have set additional guidelines to prevent groundwater contamination. Some of the more significant requirements for Class II and V injection wells are presented below:

- *Permitting:* The federal UIC program establishes permitting requirements for all classes of injection wells. Although the federal program requires most wells to be permitted, EPA continues to allow some types of Class V injection wells to be permitted by rule – meaning that a permit is not required, although regulatory requirements apply. Currently, all Class II injection wells must be permitted, although not all Class V wells are required to be permitted. Class II and V permits can be written as individual permits covering a single well, or area permits that cover an area of surface land and will apply to all wells within the area. Class V well permits may be required when:

- the owner/operator fails to comply with the prohibition of the fluid movement standard;
- if the well is a Class V large-capacity cesspool, or a Class V motor vehicle waste disposal well;
- required inventory information has not been submitted; or
- the UIC Director requires a permit.

- *Area of Review Analysis:* An important aspect of the federal UIC program requires that the permitting authority determine, within an "area of review" (AOR), whether a proposed injection operation has the potential for contaminating USDWs through wells, faults, or other pathways that penetrate an injection zone (EEI, 1985). The AOR can also be referenced in relation to the zone of endangering influence (ZOEI) for a well. The ZOEI includes the area surrounding an injection well or injection well pattern in which the increased pressure due to injection would cause the migration of fluids out of the injection zone and into a USDW. The AOR can be determined analytically using the Theis or similar equation, or as an arbitrarily defined area set by regulation. The available completion and plugging records for all wells within the AOR must be reviewed to determine if conditions or pathways exist that might allow the migration of formation or injected fluids out of the injection zone. Any such conditions must be corrected or preventive action must be taken before using the injection well.
- *Aquifer Exemptions:* The primary purpose of the federal UIC program is to prohibit the movement of fluid containing any contaminant into USDWs; however, the program is not required to protect aquifers that are not reasonably expected to be used in the future as a USDW (Freeman and Arthur, 1995). An aquifer, as defined by 40 CFR 146.04, is not reasonably expected to be used as a USDW if the aquifer is:
    - mineral, hydrocarbon, or geothermal energy producing;
    - too contaminated for use;
    - located at a depth or location making use of the aquifer technologically and economically impractical; or
    - located over a Class III mining area subject to subsidence or collapse.

  An aquifer with less than 10,000 mg/L TDS can be exempted (under 40 CFR 144.7 and 146.4) with minor or major exemptions, allowing Class II injection well completion within the aquifer. A minor exemption is any exemption of an aquifer containing between 3,000 and 10,000 mg/L TDS and is not reasonably expected to supply a public water supply system. An aquifer containing less than 3,000 mg/L TDS must have a major exemption before a Class II well can be completed in it. Major exemptions require EPA rulemaking procedures and are made with Federal Register publication; minor exemptions do not require Federal Register publication, but do require public notice and an opportunity for a hearing in all cases (Freeman and Arthur, 1995).

- *Construction:* Federal requirements relative to construction are generally focused toward assuring the protection of USDWs. Requirements for Class II wells and some Class V wells include constructing the well in such a manner to prevent movement of fluids into a USDW using effective drilling and completion procedures, with emphasis on casing and cementing practices. This is done by allowing injection only into a formation that is vertically and laterally separated or otherwise confined from USDWs. Borehole geophysical logs and other information are required to assure USDWs are protected. For applicable Class V injection wells, injection may occur into a USDW and construction practices would likely need to assure that injection fluids are properly placed and stored in the permitted injection interval.
- *Operation and Monitoring:* Injection wells must be operated in such a fashion as to assure that injection fluids reach the permitted injection interval and are confined. Operating requirements typically state that injection pressures at the wellhead not exceed a predetermined maximum so that new fractures will not be formed and old fractures will not be further propagated through the confining zones. Operators are commonly required to monitor several parameters on a routine basis, including flow rates, pressures, mechanical integrity, injection fluid quality, and other operational statistics. For Class V injection wells, other requirements may also apply, including monitoring quality of the injection fluid as well as other operational data and information.
- *Waste Water Classification:* The classification of the waste is vitally important because primary hydrocarbon exploration and production wastes are exempt under RCRA Subtitle C Regulation. Exempt wastes are the only wastes that can be injected into Class II wells. CBM water is usually an exempt waste unless it has been treated, used, or mixed with a non-exempt waste. Class II injection wells may also be considered to manage the concentrated re-injectate produced from other CBM water management options. CBM water management options including RO treatment, evaporation, and freeze-thaw will produce concentrated re-injectate in the treatment process. Some regulatory agencies may classify re-injectate as primary hydrocarbon wastes and others may classify it as industrial waste; the first would be an exempt waste eligible for injection in a Class II well, while the second will not be eligible. Specifically, CBM re-injectate can be argued to be exempt because it consists of "constituents removed from produced water before it is injected or otherwise disposed of" (EPA, 1995). When the concentrated brine water is classified as an exempt waste, the water can legally be disposed of by injection into a Class II well with appropriate regulatory documentation. When the concentrated brine is classified as industrial wastes, however, it will need to be disposed of as industrial wastes, which will need to be considered when writing water management plans and forecasting costs.
- *Testing:* The federal UIC program establishes testing criteria to assure that injection wells are mechanically sound and protective of USDWs. Mechanical Integrity Tests (MITs) are performed on injection wells on a routine basis to assure the integrity of the wells' internal components (i.e., casing, tubing, and packer) and that the well has external integrity (i.e., fluid movement external to a well's casing into a USDW is not occurring). Several standard tests are approved for use by EPA for both internal and external mechanical integrity demonstrations.

- *Reporting:* The EPA has established minimum reporting requirements for all classes of injection wells, including Class II wells. Reporting requirements range from submitting routine monitoring reports to reporting well failures or other well-specific activities (including workovers or corrective action). Reporting is required for submittal of injection monitoring data as well as instances where a well may fall out of compliance. For instance, if a well were to experience a failure in mechanical integrity, EPA has established emergency reporting requirements and subsequent procedures that must be followed to assure USDWs are protected.
- *Financial Assurance:* Operators must maintain bonds or other financial assurance instruments to assure that once a well is no longer needed, it can be plugged and abandoned in an environmentally protective manner. Several financial assurance mechanisms are allowed under the federal UIC program.
- *Plugging and Abandonment:* After an injection well has served its usefulness, it must be plugged and abandoned in an environmentally prudent manner assuring that all USDWs at the well are protected. Although federal regulations do not provide specific procedures for plugging and abandonment, several EPA regions have guidelines established and minimum requirements to assure protection of USDWs.

Select State UIC Programs

In addition to the minimum standards established by the EPA and as noted above, the UIC program in a particular state may be the responsibility of a particular regulatory agency. Because of this, underground injection well regulations can vary slightly from state to state. For purposes of this manual, the regulations of the primary CBM producing states of Colorado, Montana, New Mexico, Utah, and Wyoming are summarized in this handbook and presented below:

Colorado

Authority over the UIC program in the state of Colorado is shared between the EPA and the Colorado Oil & Gas Conservation Commission (COGCC). The EPA in Region VIII directly implements the UIC program in accordance with applicable sections of 40 CFR for all injection well classes other than Class II wells, except on Indian Lands where EPA also implements the Class II UIC program. The COGCC has primacy over the state's Class II UIC program, except on Indian Lands as noted above. The COGCC's Class II UIC program encompasses all Class II injection wells on private, state and federal lands within Colorado.

The Class II UIC program is implemented in accordance with the COGCC Rules and Regulations, Series 300 and 400. Like the federal UIC program, the Colorado Class II UIC program has similar requirements for permitting, conducting AOR analyses, assuring the protection of USDWs, and requiring operators to maintain financial assurance for all Class II wells.

Existing COGCC Rules and Regulations (COGCC, 2001) require operators to obtain permits prior to drilling a new injection well or converting an existing well to injection. Requirements that must be submitted as part of the permit application include description information for the well; a detailed AOR analysis; detailed locations of wells within the AOR; design plans and specifications for the proposed well or well system, including the surface facility; applicable geologic and geophysical information; casing and cementing details; location of USDWs; and other information specified in the rules or required by the UIC Director.

COGCC Rules and Regulations (COGCC, 2001) define the AOR as ¼ mile for all oil and gas, domestic, and irrigation wells. Unlike many other states, however, the location of all oil and gas wells within ½ mile that are currently producing from the proposed injection formation must also be analyzed as part of the AOR evaluation in the permit application. In addition, the COGCC (2001) requires design plans for injection systems, including a complete diagram of the surface facility showing all pipelines and tanks associated with the well system; a list of all leases connected directly to the system by pipelines; and a list of all sources of water, by lease and well, to be injected into the well (COGCC, 2001).

In addition to the above, the owner/operator is required to complete a notification process during the permitting of any Class II injection well. The purpose of the notification process is to provide relevant information to surface owners, mineral owners, and others that may be affected by the proposed well, and an opportunity to comment or protest on the application prior to action by the COGCC.

Colorado will exempt an aquifer under the same protocols as EPA. To exempt an aquifer, the Director of the COGCC must publish a notice of the proposed designation in a newspaper of general circulation in the area where the aquifer is located.

Montana

Authority over the UIC program in the state of Montana is shared between the EPA and the Montana Board of Oil and Gas Conservation (MBOGC). The EPA in Region VIII directly implements the Class V and other UIC programs other than Class II wells. The MBOGC has primacy over the state's Class II UIC program, except on Indian Lands where the EPA has jurisdiction. The MBOGC's Class II UIC program encompasses all Class II injection wells on private and federal lands; approximately 2,000 wells within the state of Montana.

The Class II UIC program in Montana is implemented in accordance with the MBOGC's General Rules and Regulations contained in Title 36, Chapter 22 of the Administrative Rules of Montana (ARM). Like the federal UIC program, the Montana Class II UIC program has similar requirements for permitting, conducting AOR analyses, assuring the protection of USDWs, and requiring operators to maintain financial assurance for all Class II wells (MBOGC, 2000).

Like many Rocky Mountain states, geology and groundwater quality varies substantially throughout Montana. In fact, many oil and gas producing formations contain groundwater that is of relatively high quality, and in many cases may have concentrations of TDS less than 10,000 mg/L. In addition to this, Montana has an anti-degradation policy that further stresses the importance of groundwater in the state. The proximity of high-quality groundwater and oil and gas resources requires that proposed injection project applications include detailed groundwater quality analyses. In many instances, minor aquifer exemptions are required before a Class II injection well permit or Class II area permit can be approved. Requirements for aquifer exemptions are included in ARM 36.22.1418, and the MBOGC has developed a guidance document relative to the aquifer exemption process and requirements in Montana (MBOGC, 1997).

ARM 36.22 details requirements for Class II injection well applications. Similar to the federal UIC program, Class II injection applications must provide the location and mechanical condition of all oil and gas wells that penetrate the injection zone within the AOR, including abandoned wells, drilling wells, dry holes, etc. The permit must also contain the location of all pipelines that will be used to transport fluids to the proposed well for storage and injection (MBOGC, 2000). To aid operators in the preparation of Class II permit applications, the MBOGC has developed a guidance document for permit applications that can be obtained from the MBOGC upon request.

In addition to the above, the owner/operator is required to complete a notification process during the permitting of a Class II injection well when the injection well is not in a field already approved by public hearing. The notification process allows surface owners, mineral owners, and others that may be affected by the proposed well an opportunity to comment or protest on the application prior to action by the MBOGC.

As an information resource, the MBOGC has developed and deployed information tools that are accessible from the Internet. The two main tools of significance are the On-Line Data Access Tool and the WebMapper application. The On-Line Data Access Tool allows visitors to obtain detailed information for wells throughout the state. This system can be used to obtain well location, completion, production, and a variety of other information from an easy-to-use web-based interface. The WebMapper tool is an Internet-based Geographical Information System (GIS) that was developed to allow detailed analysis of management practices relative to CBM in the Montana portion of the PBR. From this tool, users have the ability to conduct spatial analyses (including AOR analysis) and perform detailed visual and statistical analysis using geospatial data.

New Mexico

Authority over the UIC program in the state of New Mexico is shared between the EPA, New Mexico Energy, Minerals, and Natural Resources Department, Oil Conservation Division (NMOCD), and the New Mexico Environment Department (NMED). The EPA in Region VI has Direct Implementation authority over the UIC program for all injection wells on Indian Lands. For private, state and federal lands, the NMOCD has primacy over the UIC program for Class II injection wells and the NMED has primacy over the UIC program for Class V injection wells within New Mexico.

The Class II UIC program is implemented by the NMOCD in accordance with the Oil and Gas Act as set forth by the New Mexico Statutory Authority (NMSA), 1978, in the New Mexico Administrative Code (NMAC). The Class V UIC program is implemented by the New Mexico Water Quality Control Commission (NMWQCC) under the authority of the Water Quality Act, NMAC.

The permitting requirements of the Oil and Gas Act are defined in Title 19, Chapter 15 of the NMAC. In New Mexico, state permits are not required on federal land, but injection wells must be approved by the BLM. Permitting is required on all private and state land. Requirements that must be submitted as part of the permit application include descriptive information for the well; a detailed AOR analysis; detailed locations of wells within the AOR; design plans and specifications for the proposed well or well system, including the surface facility; applicable geologic and geophysical information; casing and cementing details; location of USDWs; and other information specified in the rules or required by the UIC director.

In addition to the permitting requirements, the owner/operator is required to complete a notification process during the permitting of any Class II injection well. All property owners and lease holders within ½ mile of the proposed site must be notified by certified or registered letter. The purpose of the notification process is to provide surface owners, minerals owners, and others that may be affected by the proposed well an opportunity to comment or protest on the application prior to action by the NMOCD.

Existing NMWQCC Regulations for the Class V UIC program are similar to the EPA program requirements.

Utah

Authority over the UIC program in the State of Utah is shared by the EPA, Utah Division of Oil, Gas and Mining (UDOGM), and the Utah Department of Environmental Quality (UDEQ). The EPA in Region VIII directly implements the UIC program in accordance with applicable sections of the 40 CFR for all injection well classes on Indian Lands. The UDOGM has primacy over the Class II UIC program and the UDEQ has primacy over the Class V UIC program.

The Class II UIC program is implemented in accordance with the rules established under the Oil and Gas Conservation General Rules, R649-5. Like the federal UIC program, the Utah Class II and Class V UIC programs have similar requirements for permitting, conducting AOR analyses, assuring the protection of the USDWs, and requiring operators to maintain financial assurance for all Class II wells.

Existing UDOGM General Rules require operators to obtain permits prior to drilling a new injection well, or converting an existing well to injection. Requirements that must be submitted as part of the permit application include description information for the well; a detailed AOR analysis; detailed locations of wells within the AOR; design plans and specifications for the proposed well or well system, including the surface facility; applicable geologic and geophysical information; casing and cementing details; location of USDWs; and other information specified in the rules or required by the UIC Director.

The General Rules require an AOR of ½ mile from the injection site identifying all proposed injection wells, active wells, and abandoned wells. The General Rules also allow monthly monitoring during injection to replace pressure testing of the injection well.

In addition, the owner/operator is required to complete a notification process during the permitting of any Class II injection well. All operators, owners, and surface owners within ½ mile of the injection site must be notified of the proposed injection well. A copy of the notice must be sent to all parties involved, including government agencies. The purpose of the notification is to provide surface owners, mineral owners, and others the opportunity to comment or protest the application prior to action by the NDOGM.

Class V wells are regulated by the UDEQ and are authorized by permit. UDEQ also allows wells to be permitted on an area basis rather than individually permitting wells. The Class V UIC permit application requires information similar to what is required by the UDOGM for Class II wells, with some differences.

The AOR for Class V wells extends one mile beyond the property boundary. The AOR must include any intake and discharge structures; any hazardous waste, treatment, storage and disposal facilities; injection wells; and all wells, springs, surface body waters, and drinking water wells listed in the public records or otherwise known. The number or name and location of all producing wells, injection wells, abandoned wells, dry holes, surface bodies of water, springs, mines (surface and subsurface), quarries, water wells, residences, roads, faults (known or suspected), and any other surface features of public record must also be included. The well information should include a description of all wells in the area of review, including the well type, construction, date drilled, location, depth, record of plugging and/or completion, any available water quality data, and any additional information that may be required.

The owner/operator is also required to provide a list of all activities conducted by the applicant which require a permit, along with a list of up to four Standard Industrial Codes (SIC) codes that describe the activities; a brief description of the nature of the business; a list of state and federal environmental permits or construction approvals received or applied for; and other relevant environmental permits.

The owner/operator is required to complete a notification process during the permitting of Class V injection wells, similar to the notification process for Class II injection wells. The purpose of the notification is to provide surface owners, mineral owners, and others that may be affected by the proposed well an opportunity to comment or protest the application prior to action by the UDEQ.

Wyoming

Authority over the UIC program in the state of Wyoming is shared by the EPA, the Wyoming Oil and Gas Conservation Commission (WOGCC) and the Wyoming Department of Environmental Quality (WDEQ). The EPA in Region VIII directly implements the UIC program in accordance with applicable sections of the 40 CFR for all injection well classes on Indian Lands. The WOGCC has primacy over the state's Class II UIC program and the WDEQ has primacy over the state's Class V UIC program.

The Class II UIC program is implemented in accordance with the rules established under the Wyoming Conservation Act. Like the federal UIC program, the Wyoming Class II and Class V UIC programs have similar requirements for permitting, conducting area of review analyses, assuring the protection of the USDWs, and requiring operators to maintain financial assurance for all Class II and V wells.

Existing WOGCC rules require operators to obtain permits prior to drilling a new injection well or converting an existing well to injection. Requirements that must be submitted as part of the permit application include description information for the well; a detailed AOR analysis; detailed locations of wells within the AOR; design plans and specifications for the proposed well or well system, including the surface facility; applicable geologic and geophysical information; casing and cementing details; location of USDWs; and other information specified in the rules or required by the UIC Director.

WOGCC defines the AOR as the area within ½ mile of the proposed well, including all disposal wells, abandoned wells, drilling wells, dry holes, as well as all lease operators, owners, and surface owners. All wells within ¼ mile of the injection site that have penetrated the proposed injection zone must have their mechanical condition evaluated. In addition, any fresh water flows detected during drilling must be reported to the WOGCC on the next business day.

Aquifer exemptions for Class II injection wells follow the same regulations as EPA with one difference: the aquifer must have TDS between 5,000 and 10,000 mg/L. If the Class II injection well is being used to inject into an exempted aquifer, the owner/operator must determine and describe the depth and areal extent of all USDW underlying the proposed exemption area. The owner/operator must also provide a reference to the WOGCC order exempting the aquifer.

WDEQ has primacy over the Class V UIC program under the provisions of the Wyoming Water Quality Act and Chapter 16 of the Wyoming Water Quality Rules and Regulations. The WDEQ has written three general Class V injection well permits (5C5-1, 5C5-2, and 5C5-3) for CBM operators in Campbell, Johnson, and Sheridan counties. The general Class V permit allows the operator to:

- inject all CBM produced water, but not drilling fluids, spent oilfield chemicals, other industrial wastes, or hazardous wastes in any quantity;
- 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 this permit;
- fully characterize the class of use of the receiving aquifer's water and the CBM water to be injected. No CBM produced water will be injected into an aquifer with a better classification than the CBM produced water;
- inject CBM 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 is not degraded by the injection; and
- operate injection wells that comply with the standards for the permit. If the injection violates groundwater standards, injection is not allowed under individual permit, the general permit, or any form of rule authorization.

Existing WOGCC Rules and Regulations require permit applications to include description information for the well; a detailed AOR analysis; detailed locations of wells within the AOR; design plans and specifications for the proposed well or well systems, including the surface facility; applicable geologic and geophysical information; casing and cementing details; location of USDWs; and other information specified in the rules or required by the UIC Director.

Information to be included in the AOR includes all property boundaries and adjacent property land use within ½ mile of the point of injection as well as all water wells, surface water bodies, and springs.

An owner/operator covered by a general permit may apply for and obtain an individual permit; the individual permit will eliminate the coverage of the general permit. The individual permit will be required when the owner/operator does not meet the following four primary standards of the general permit:

- the classification of the CBM produced water and the aquifer into which it is being injected is not in dispute;
- the injection wells are properly installed with cement casing and the mechanical integrity of the system has been proven;
- the injection zone is several hundred feet deep and the injected water will not be resurfacing; and
- the pressure of injection is controlled to less than 0.7 psi per foot at the top-most perforation.

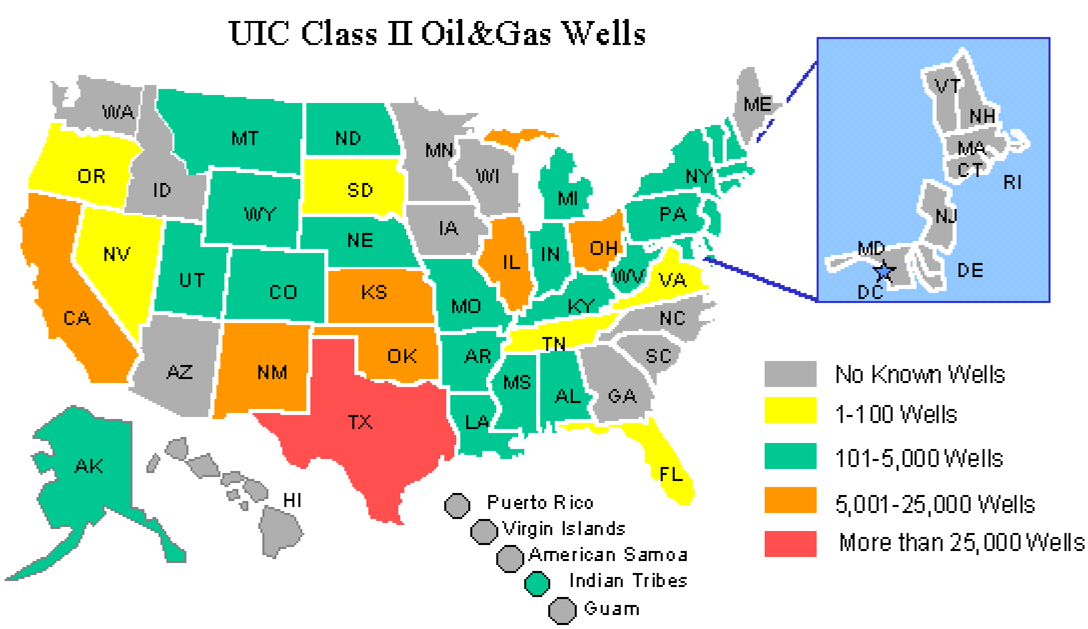
In addition, the owner/operator is required to complete a notification process during the permitting of any Class II and V injection well. The purpose of the notification is to provide surface owners, mineral owners, and others that may be affected by the proposed well an opportunity to comment or protest the application prior to action by the WOGCC.

CBM Injection Alternatives

Managing produced water is a necessary and critical component of CBM exploration, development and production. Injection wells are currently used in conventional oil and gas and CBM fields across the country as a water management tool and have proven to be an environmentally safe and economically responsible option. EPA estimates there to be approximately 167,000 Class II injection wells used by the petroleum industry to manage produced water. Figure 5-8 presents general location information for Class II injection wells throughout the United States.

Injection wells have proven to be economical in many instances and provide an environmentally safe alternative to manage produced water. Without the use of injection wells, conventional oil and gas and CBM development would not be possible in many areas of the country, rendering these valuable resources unattainable. Injection wells are currently used by many CBM operators as a sound produced water management option.

Figure 5-8
Class II Injection Wells in the United States
This figure shows the general well density of Class II injection wells throughout the United States.



Source: US EPA, 2002.

Applicability

In most CBM producing areas, there may be several options relative to the use of injection as a water management practice. Potential injection zones may be present above producing coals, between producing coals, below the producing coals, or even the producing coals themselves. In some areas of the country, injection wells are being drilled and completed into zones several thousands of feet below the deepest coal seam or they may be completed into very shallow permeable formations. Regardless of the alternative considered, the operator must be careful that correlative mineral rights are respected. Injection within or outside an active project is dependant upon several variables, including, but not limited to the production operations in the area; the availability of a desirable receiving formation(s); the quality of water being injected; the quality of water in the receiving formation; the ultimate storage capacity of the receiving formation(s); and existing regulatory restraints. These factors will influence where the water can be injected and what type of injection well can be used to manage the produced water.

Water management options relative to injection, for the purpose of managing CBM produced water, can essentially be grouped into two general categories. These include injection into a coal seam aquifer or injection into a non-coal seam aquifer. These groupings have been structured to align with considerations relative to CBM produced water management to facilitate discussion. These groups do not necessarily align with specific regulatory or technical criteria. Details of these general alternatives are discussed below:

Alternative 1 – Injection into a Coal Seam Aquifer

The injection of CBM produced water back into the coal seam aquifer from which it was extracted is called aquifer re-injection. Coal seam re-injection is perhaps most commonly thought to occur within a single active CBM project. This process may also be identified by producing and transporting water from one active project to another for disposal into a single regionally extensive coal seam. However, coal seam injection may take several forms. Produced water can be injected into non-productive coal seams that lie above or below a producing coal deposit, or perhaps laterally separated and possibly isolated from hydraulically affecting an active project. Any option involving injection into a coal requires serious evaluation of technical, legal, and regulatory issues. Various types of coal seam injection are presented below:

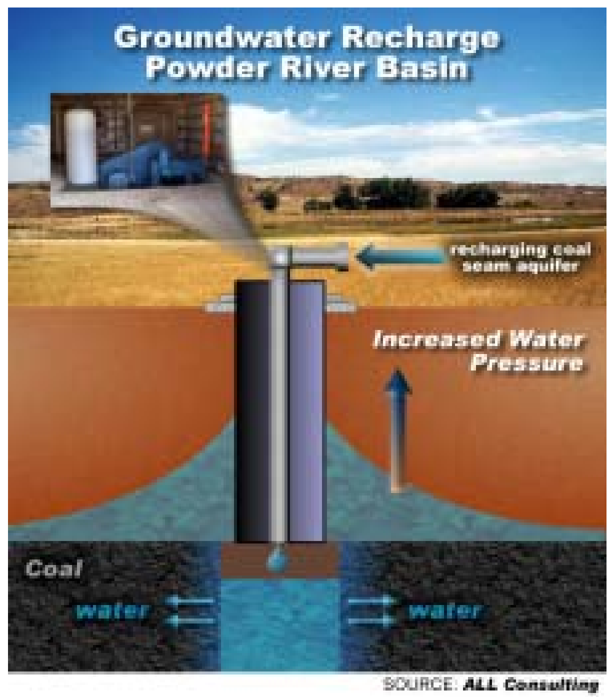
- *Coal Seam Re-Injection:* As noted above, coal seam re-injection is generally considered as the practice of re-injecting CBM produced water into the same coal seam aquifer from which the water was produced. Although the re-injection of produced water back into the source (coal) aquifer may initially appear to be a desirable solution, the feasibility of this alternative is difficult to ascertain. The production of methane gas from CBM wells most typically requires a reduction in the hydrostatic pressure of the coal seam (Cox, 2001; Lamarre, 2001; Ayers, 2002). The hydrostatic pressure of the coal seam is reduced by producing water; therefore, re-injection, especially during active production of methane, would likely result in increased hydrostatic pressure which would result in decreased gas production, increased water production, increased costs, and possibly a waste of the natural gas resource.

  Aquifer re-injection is also affected by the properties of the producing formation. Water is removed from the producing coal to decrease the hydrostatic pressure, and as the water is removed, the producing formation can undergo a one-time compaction event in which the formation releases water (Lofgren and Klausing, 1969). The compaction event causes the volume of the aquifer to decrease so that the aquifer can no longer store the same amount of water (Lofgren and Klausing, 1969). Because the concept of coal seam re-injection has not been thoroughly studied, it may be some time before the feasibility of this option is determined.

- *Coal Seam Injection:* As an alternative to re-injection, CBM produced water could be injected into other coal seams that occur either above or below CBM production. Injection into a non-producing coal aquifer may likely avoid detrimentally affecting production in a producing coal by not increasing the hydrostatic pressure caused by injection in the producing coal. Since the hydrostatic pressure in the producing coal would not be influenced, the potential gas production within the field should not be hindered. The non-producing coal aquifer could also be a productive coal seam aquifer that has already been depleted. Once the productive life of a CBM field has ended, the wells may be converted into recharge/re-injection wells. The converted wells can be used to inject water from other productive fields to restore the hydrostatic pressure within the depleted coal seams, or the coal seams can be used to store water for later use.

Currently in the Powder River Basin, CBM producers are studying the feasibility of transporting CBM produced water from active fields in the western portion of the basin to depleted areas in the eastern edge of the basin that were the initial sites for CBM production. This proposal would essentially involve aquifer re-injection, although not within a single active project. However, this alternative has not been fully tested relative to technical or economic feasibility.

Figure 5-9
Groundwater Recharge Schematic
Figure shows effects on groundwater due to CBM groundwater recharge.



There may also be other circumstances when coal seam injection may be considered. In some areas, such as the Powder River Basin, similar coal deposits may be hydraulically separated, either through faulting or other geologic circumstance. In some cases, it may be feasible to consider coal seam injection into an isolated fault block or area within an active project when hydraulic separation can be demonstrated. However, the risk of detrimentally impacting injection may preclude even this option from having a reasonable feasibility.

In some very specific circumstances, there could be a desire to increase coal seam hydrostatic pressure in an effort to prevent drainage of methane and/or groundwater resources. Increasing the hydrostatic pressure of a coal seam aquifer that has not been produced could be done in a fashion to create a hydraulic barrier between a producing area and areas where production is not desired. Although the concept of actively creating a hydraulic barrier has not yet been attempted; it has been considered relative to the protection of Indian Trust Resources in Montana.

Alternative 2 – Injection into a Non-Coal Aquifer

The injection of CBM produced water into a non-coal seam aquifer is a proven technology in several areas of the country, including, but not limited to, areas such as the Arkoma, Powder

River, and San Juan Basins. Most injection wells used in relation to CBM production operations are Class II injection wells, although the use of Class V injection wells has gained momentum by the producing industry in recent years. Various types of non-coal seam injection are presented below:

- *Coal Sequence Injection:* Many coal-bearing formations, like the Fort Union Formation in Montana and Wyoming, contain multiple permeable zones that are hydrologically separated from adjacent zones by aquitards. In many areas the coal seams are interbedded with sand seams forming a series of discontinuous lenses of coal and sand within the claystone sequence. Despite the discontinuity of the coals and sands, sets of interbedded layers can be hydrologically separated by either 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 non-coal formations provides an opportunity for various types of injection, potentially including disposal, aquifer storage/recovery, and possibly aquifer recharge.

- *Non-Coal Sequence Injection:* The most commonly used injection alternative relative to CBM production operations is disposal into formations that are well below coal deposits. In these cases, injection is managed using Class II disposal wells. The use of this type of injection technology is most common in areas where CBM 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 several issues, including quality of the produced water and aquifer as well as the desired purpose for a proposed injection project. If the desire is to beneficially use the water, options such as aquifer recharge or aquifer storage/recovery should be considered. Aquifer recharge could be considered to replenish depleted non-coal aquifers that may have experienced several years of pumping, potentially including an aquifer used for domestic or municipal supply. Disposal may be considered into coal sequence aquifers, but may be highly dependant upon quality of the produced water and the receiving aquifer.

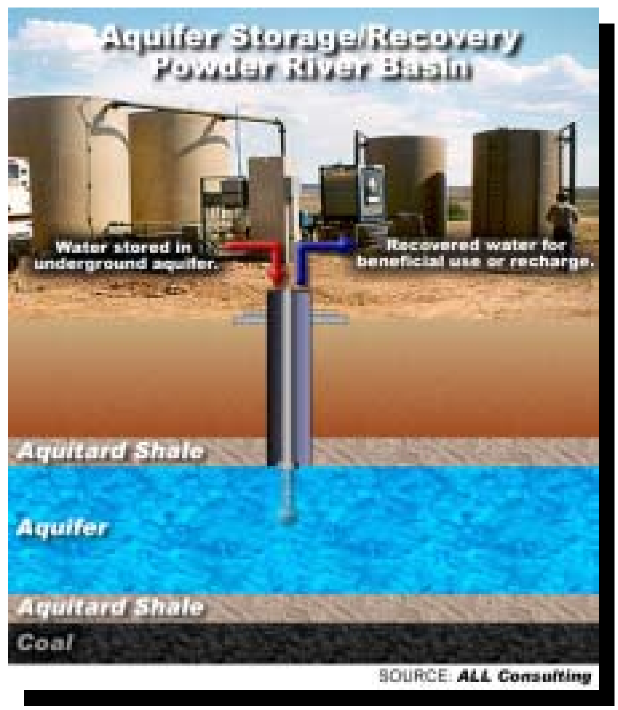
Aquifer Storage/Recovery (ASR) wells can be used to manage CBM produced water. ASR is the process of injecting water into an aquifer for storage and subsequent recovery for beneficial use, using the same well (see Figure 5-10). Beneficial uses include, but are not limited to, public drinking water, agricultural uses, future recharge of a coal seam aquifer, 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, 1999c).

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 UIC 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.

Constraints

There are several constraints relating to the use of injection as a CBM produced water management alternative, including:

Figure 5-10
Aquifer Storage/Recovery
Water is injected into an aquifer and later recovered for beneficial use.



- *Potential Impacts to CBM Production:* CBM operators will be especially careful to avoid any management practices that will economically impact their project, especially practices that will impact production. Injection into zones that are either geographically or stratigraphically close to producing coal seams will need to be watched for any pressure communication with the producing coals.
- *Post-Production Compaction:* Once-productive coal seams may be used as injection zones for produced water. The act of CBM production, however, may have caused irreversible compaction of the coal seam, making injection difficult or impossible.
- *Injection May Lead to Waste of Resources:* Injection in close proximity to a productive coal seam may, despite close scrutiny by the operator, result in a loss of CBM resource. The loss would be a waste of valuable resources and may have repercussions beyond the loss of an injection zone. The owners of the wasted minerals as well as adjacent minerals may have cause to sue the operator for the waste of resources.

Data Needs

Data needs specific to injection are generally outlined in state and federal UIC program regulations. Some that should be given special attention relative to the beneficial use of produced water including the following:

- *Aquifer Characteristics:* The operator will be best served by collecting data on the horizontal and vertical distribution of reservoir characteristics such as porosity, permeability, continuity, geochemistry, pressure, fracturing, structure, and thickness. Other specialized parameters may also prove to be locally important. This data may be necessary for permitting, testing, and well analysis. Sands and carbonate reservoirs can be adequately characterized by wireline logs, although permeability data is largely lacking. Coals are more difficult to characterize although recent hybrid wireline logs are available from several vendors for the purpose of logging coals. Shales and other confining beds can be accurately measured by wireline logs although exact vertical and horizontal permeabilities are difficult to determine.

Reservoirs can best be measured by injection tests to determine the ease of injection and response of the reservoir to pressure. The test data can be analyzed to give injectivity values, permeability, skin damage, secondary permeability, and fracture pressure.

Full-hole cores can be useful for determining the directionality of fractures, presence of shale partings, and for retrieving formation water samples.

Injection well facility in the Powder River Basin

- *Injectate Characteristics:* The chemistry and volume of produced water should be closely defined. If wells from several coals seams are to be managed by a single injection well or network of injection wells served by a single water system, the range of water chemistry can vary greatly. Having an accurate knowledge of these characteristics can be critical when beneficial use options are considered.

  Produced water may need to be filtered to remove entrained coal fines that could plug the receiving formation in the injection well. This is usually a routine process, although more filtration may be required. Scaling may need to be controlled with the continuous application of anti-scaling chemicals. Chemical interactions can take place between the injectate and the in-situ formation water or rock matrix. These reactions are best discovered beforehand through tests using actual injectate and samples of the injection zone water and rock.

- *Permit Requirements:* In order for the water management project to go forward, a number of agreements and permits may need to be in-place. Appropriate leases and damage agreements will need to be negotiated with the surface and mineral owners to accommodate injection wells and pipelines. State, Tribal, and federal permits may also be necessary.

- *Water Rights Requirements:* If produced water is consumed in beneficial uses, water rights will need to be secured with the relevant agencies. Water rights are discussed further in the Water Rights section of this document.

Economics

Injection of CBM produced water is a viable and popular alternative for managing water. It is not feasible everywhere, however, largely dictated by economic realities. Several important factors can influence the economics of injection including depth of the injection zone, injection pressures, needs for transportation of water, and regulatory burden.

- *Depth of the injection zone:* The greatest determinant in the cost of an injection well, whether new drill or re-completion, is the depth of the well. Actual costs will vary from area to area depending upon drilling time, availability of suitable rigs, and other associated costs.
- *Injection pressure:* The reservoir quality and pressure will determine the required pumping pressures needed at the surface of the injection well. In some cases, the well will take water on a vacuum while in other areas, expensive triplex pumps are needed to overcome the lack of permeability and high residual pressures.
- *Transportation:* Long-distance trucking or pipelining may need to be done to bring the water from the producing wells to the injection facility. These costs will need to be considered in the management plan.
- *Regulatory burden:* Regulatory compliance consists of permitting and continuing reportage. Permitting costs will be directly dependent upon application complexity and agency review time; complex forms will require a great deal of operator time, extra analytical detail, and a long time for agency evaluation and approval. Class II permits are usually simple and easily approved. Some Class V permits must be awarded by the EPA, which can require over 12 months for review and approval. Once permitted, the injection facility will require monitoring and reportage at least at monthly intervals; in order to fulfill the requirements written into a permit, periodic lab analyses may also be required.

These factors will add up to a site-specific cost-per-barrel figure that may be much less than other available options, or may prove to be higher.

Regional Summaries of Injection Usage

The Black Warrior, Arkoma-Cherokee, Powder River, San Juan, and Uinta Basins are addressed in this section along with the East Central CBM Area and the Colorado Plateau Basins. The information discussed includes the quality of water being produced, the producing formation, the availability of Class II and Class V wells, and currently used and potential receiving formations for the injection wells.

Black Warrior Basin

The Black Warrior Basin is in west-central Alabama. CBM water has been produced from the Pottsville Formation at depths ranging from 450 to below 4,100 feet, with TDS varying from less than 1,000 mg/L to more than 43,000 mg/L. To date, the primary disposal of water has been by surface discharge (USGS, 2000a). Since 1991, less than 5% of the produced water has been injected using Class II wells; currently all produced water is being disposed of by surface discharge. Formations previously used for subsurface injection into Class II wells have included: sandstone at the base of the Pottsville Formation, fractured chert and limestone of Devonian age, and fractured dolomite near the top of the Knox Group of Cambrian-Ordovician age (GSA 2002). Class II wells that have been in operation were completed in the depth range 4,300 to 10,900 feet.

Arkoma-Cherokee Basins

The Arkoma-Cherokee Basins are in Oklahoma, Arkansas, Missouri, and Kansas. The methane and water are produced primarily from the Hartshorne coals at a depth from 500 to 1,500 feet, with TDS of up to 90,000 mg/L in the Cherokee Basin (Rocky Mountain Oil Company, 1993).

The production wells in the Arkoma Basin produce less than 0.5 Bpd and the wells in the Cherokee Basins only produce about 10 Bpd. The water is mainly injected into the Arbuckle Group carbonates at an average depth of 2,000 feet using Class II injection wells. The Arbuckle Carbonate group is an excellent receiving zone capable of accepting water at rates between 10,000 and 20,000 Bpd from a Class II injection well (Kansas Corporation Commission, 2002).

Powder River Basin

The Powder River Basin is located in Montana and Wyoming. The methane and water is produced from the Wyodak Anderson and other coals zone in the Tongue River Member of the Fort Union Formation. The average depth of production is between 200 feet and about 2,500 feet, with TDS ranging from 250 mg/L to greater than 3,000 mg/L with a mean of 850 mg/L. To date, the primary disposal of the water is by surface discharge (USGS, 2000a). Some of the produced water is being managed with aquifer storage and recovery (Class V wells).

The PRB has several permeable zones below the Fort Union that may be suitable injection zones. WDEQ has issued general permits for more than 250 Class V wells to be used to inject into the Fox Hills, Lance, Wasatch, and Fort Union Formations (Lucht, 2002). The Montana portion of the Powder River Basin may support deep Class II injection; it has more than 280 abandoned boreholes deeper than 6,000 feet that are potentially available for re-entry as injection wells (MBOGC, 2002).

San Juan Basin

The San Juan Basin is located in Colorado and New Mexico. The methane and water is produced from the Fruitland Formation at an average depth of 2,500 feet and from the Menefee Formation at an average depth of 6,500 feet. The produced water typically has TDS greater than 10,000 mg/L with lower TDS around the basin edge. The primary disposal of produced water is by Class II injection wells completed into the Entrada Formation.

Uinta Basin & East Central Coal Bed Methane Area

The Uinta Basin and East Central Coal Bed Methane Area (ECMA) are located in Utah and produce methane and water from two formations. The Uinta Basin is producing methane from the Blackhawk Formation and the Ferron Sandstone Member of the Mancos Shale. The ECMA is producing from the Mesaverde Group and also the Mancos Shale. TDS ranges from 5,000 to 10,000 mg/L and the water is being managed primarily by injection into Class II wells. In the Uinta Basin, the produced waters are injected into the Mesaverde Formation. Near Price, Utah, just southwest of the Uinta Basin, existing Class II injection wells being used to inject into the Navajo Formation (BLM, 1999b). The Wingate Formation has also been proposed as an injection zone (BLM, 1999b).

Colorado Plateau Basins

The Colorado Plateau includes the Wind River, Greater Green River, Hanna, Denver, Raton, and Bighorn Basins. Several of the basins are in the early exploration process and have not begun producing or injection.

Wind River Basin

The Wind River Basin is located in central Wyoming with the coal located in the Mesaverde, Meeteetse, and Fort Union Formations. Historically, the formations have had TDS values ranging from 1,000 to 6,000 mg/L (Zelt, et al., 1998). Class II injection wells are currently active in several different fields in the Wind River Basin in Fremont and Natrona counties, Wyoming.

The Greater Green River Basin

The Greater Green River Basin consists of the Green River, Great Divide, and Washakie Basins and is located in Wyoming, Colorado, and Utah. The potential for CBM development is in the Rock Springs, Almond, Williams Fork, and Fort Union Formations. The Rock Springs Formation has TDS of 1,000 to 2,000 mg/L with some samples greater than 2,000 mg/L. The Almond Formation has TDS less than 2,000 mg/L. The Fort Union Formation has TDS ranging from less than 500 mg/L to greater than 2,000 mg/L. In southern Wyoming, a good permeable zone for aquifer storage and recovery is the Lewis sands within the Lewis Formation (BLM, 2002d). The Lewis sands are confined above and below by shale aquitards; the injected water will flow westward, following the regional dip and flow patterns (BLM, 2002d). The coal in the Hanna Basin is located in the Ferris and Hanna Formations. A limited number of CBM wells have been drilled in the Hanna Basin and are producing water with TDS of less than 3,000 mg/L (BLM, 2002d). One Class V well, owned by Double Eagle Petroleum, has been permitted in the Hanna Basin and is currently shut-in (Lucht, 2002). Class II injection wells are active in multiple fields within the Greater Green River Formation.

Denver Basin

The Denver Basin is located in Colorado with the potential for CBM development being in the Denver Formation. TDS in the Denver Formation is less than 2,000 mg/L. The Denver Basin is composed of sections of nine counties. Active Class II injection wells are located in the following four counties: Adams, Arapahoe, Elbert, and Weld. These Class II injection wells support conventional oil and gas production, but could be used for CBM produced water management.

Raton Basin

The Raton Basin is located in Colorado and New Mexico. CBM development is in the Vermejo and Raton Formations. The Raton Formation has TDS less than 6,000 mg/L with the primary disposal being injection. A limited number of injection wells are located in Huerfano and Los Animas Counties, within the Raton Basin.

Bighorn Basin

The Bighorn Basin is located in Montana and Wyoming. The potential for CBM development is in the Cloverly, Frontier, Mesaverde, Meeteetse, Lance, and Fort Union Formations. The Cloverly, Meteetse, and Lance Formations have TDS less than 3,000 mg/L; the Mesaverde and Fort Union range from about 600 to over 5,500 mg/L; and the Frontier ranges from 300 to 10,000 mg/L (Zelt, 1998). Class II injection wells are actively being used to inject oil and gas produced water in Bighorn, Park, and Washakie counties in the Bighorn Basin, Wyoming. Injection zones include the Cody, Muddy, Embar, Frontier, Tensleep, Curtis, Jefferson, Big Horn, Dinwoody, Phosphoria, Darwin, and Madison Formations.

Impoundments

Introduction

A surface impoundment is an excavation or diked area that is typically used for the treatment, storage, or disposal of liquids (EPA, 1991b) and can vary from less than one acre in size to several hundred acres. Impoundments are usually constructed in low permeable soils, with the possible exception of recharge ponds, to prevent or decrease raw water loss due to subsurface infiltration or percolation. Based upon an EPA national impoundment survey which characterized over 180,000 impoundments, the oil and gas industry is considered one of the largest users of this technology. A breakdown of applied impoundment uses by this industry includes, storage (29%), disposal (67%), and treatment (4%) (EPA, 1991b).

The impoundment of produced water from CBM production can be an option utilized by operators as part of their water management practices. In some producing basins, such as the PRB, impoundments play a large role in water management practices, while in other basins impoundments may only be used during drilling operations. The impoundment of CBM water is the placement of water produced during operations at the surface in a pit or pond. There are a variety of ways in which operators can impound produced water at the surface. Impoundments can be constructed on- or off–channel, and the regulatory authority in some states varies based on whether the impoundments are off- or on-channel.

Impoundments can be used for a variety of water management options including: disposal by evaporation and/or infiltration; storage prior to another water management option including injection or irrigation; or for beneficial use such as a fishpond, livestock and wildlife watering ponds or a recreational pond. The impoundment of water can be performed in any area where there is sufficient construction space.

Impoundments can be constructed to provide a single management option, or a combination of management options that include livestock and wildlife watering from wetlands, fisheries and recreational ponds, recharge and evaporation ponds, or other combinations. Although the discussions included here address the different types of impoundments individually, most practical applications will include a combination of uses.

The purpose of the discussion in this section is to provide an overview for the management of CBM produced water via impoundments by identifying technology specific applications, regulations, and limitations associated with each impoundment type. The intent of this discussion is to present information in a manner that emphasizes the far-reaching potential of this technology, while at the same time recognizing regional limitations derived naturally from insufficient water quality, climate, or methane production.

Specific regulations as they pertain to CBM produced waters and impoundment use, are provided for the states of Montana, New Mexico, Wyoming, and Colorado because of their current CBM production levels, suitable water quality, and current interest in impoundment use. Operators, landowners, or other entities interested in the use of impoundments to receive CBM produced water should contact their appropriate state authority, including Departments of Environmental Quality, State Engineer's Office, Oil and Gas Commission, and Fish and Wildlife for additional information, pertinent statutes or clarification of the information provided within. It is also important to note that the rules and regulations relating to impoundments and the CBM industry in several of these states are changing, existing regulations are being modified, and new regulations are being drafted.

Regulations

The number and complexity of applicable regulations, permit requirements, and water right issues that can apply to impoundments for the beneficial use of CBM produced waters can be overwhelming, and in some cases may cause operators and landowners to hesitate in using available technologies in water management. An understanding of the applicability for the issues associated with each regulatory program is critical prior to implementing various produced water uses. Regulatory programs vary for any given state or region, and as is often the case, agencies can exercise some discretion when applying their programs. Therefore, it is essential for operators and landowners to have an understanding of the regulations to make informed decisions as it relates to which beneficial use will best serve their needs within the regulatory environment. Included in the discussion below is a summary of federal, state and/or regional regulations that may impact the beneficial use of CBM produced waters.

EPA Regulations

40 CFR 435, the Oil and Gas Extraction Point Source Category, Subpart C Onshore Subcategory, establishes there shall be no effluent discharge of produced waters. However, Subpart E-Agricultural and Wildlife Water Use, allows the discharge of produced water for agricultural or wildlife watering use if the facility is located west of 98th meridian. Under this subpart, the water must be of good enough quality to be used for wildlife, livestock, or agricultural use and that the water be put to such use during periods of discharge.

40 CFR 435 is only applicable when state authorities deem CBM produced water as an oil and gas produced water. The state of Alabama, for example, does not consider CBM produced water as an oil and gas extracted water and thus, is not regulated by this standard. Currently the EPA does not have CBM specific produced water effluent limitations since 40 CFR 435 was promulgated prior to initiation of current CBM operations. Section 307 (a)(1) of the Federal Water Pollution Control Act, as amended, however, does require a list of toxic pollutants and effluent standards for cyanide, cadmium, and mercury when applicable. Produced water from the oil and gas industry is exempt from EPA RCRA rules and standards, and is therefore not subject to 40 CFR, Part 264, which establishes performance standards for hazardous waste landfills, surface impoundments, land treatment units, and waste piles. If state authorities do, or were to classify produced water as a hazardous waste and also deem the water as a non-by-product produced by the oil and gas industry, the above mentioned standard would apply.

As authorized by the Clean Water Act, the NPDES permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States. The Water Permits Division (WPD) within the U.S. Environmental Protection Agency's Office of Wastewater Management manages the NPDES permit program in partnership with EPA Regional Offices, states, and tribes. NPDES permitting requirements for produced water will vary from state to state, but in general would largely depend on the quality of water and eventual use of the water. Appropriate state water quality authorities would need to be contacted to ascertain their permitting requirements.

BLM Regulations
Water produced by oil and gas wells located on federal or Indian leased/owned lands, and its subsequent disposal, is regulated by BLM under 43 CFR Part 3160, Onshore Oil and Gas Operations. On-lease water disposal, when approval is requested for disposal of produced water in a lined or unlined pit, requires operators to submit a Sundry Notice, Form 3160-5. This statute requires operators to comply with all applicable BLM standards for pits. The same requirements are established when approval is requested for removing water that is produced from wells on leased federal or Indian lands and is to be disposed of into a lined or unlined pit.

When approval is requested for removing water that is produced from wells on leased federal and/or Indian lands and is to be disposed of into a pit located on state or privately owned lands, BLM requires the operator to submit a Sundry Notice, Form 3160-5 and a copy of the permit issued for the pit by the state or any other regulatory agency, if required. The permit will be accepted unless it is determined the approval will have adverse effects on the federal/Indian lands or public health and safety.

BLM also has authority over design, construction, reporting, maintenance, and reclamation requirements for pits, which will vary depending on project specific parameters, and water analysis. BLM requires water analysis be taken at the current discharge point. A reclamation plan detailing the procedures expected to be followed for closure of the pit and the contouring and re-vegetating is required prior to pit abandonment.

Colorado
Water rights issues are also important in the impoundment of CBM produced water in Colorado. Although the water is considered contaminated by both the Department of Public Health and Environment and Division of Water Resources-Water Rights, beneficial uses can be applied if water rights can be obtained. The Division of Water Resources-Water Rights allows three uses of produced water without submitting augmentation plans and permits; dust control, dumped into stream system, and evaporation ponds. The Colorado Department of Public Health and Environment considers CBM produced water to be contaminated water and requires all discharges to impoundments to be permitted unless the impoundment can be shown to have no discharge. The COGCC have regulations for produced water including permit requirements for impoundments designed for water disposal via evaporation ponds.

The COGCC requires evaporation impoundments to be lined when there is a potential to impact an area determined to be environmentally sensitive for water quality. The impoundments are not allowed to discharge to the surrounding environment unless a discharge permit is obtained from the Colorado Department of Public Health and Environment’s Water Quality Control Division.

Water disposal or evaporation pits must also be permitted by COGCC and are lined only when they are in an area determined to be environmentally sensitive for water quality. Produced water may only be discharged to state waters if a discharge permit is obtained from the Colorado Department of Public Health and Environment's Water Quality Control Division. This requirement also applies to water disposal or evaporation pits that discharge water to the surrounding environment. The COGCC requires permits (Permit Form 15) to be submitted prior to the construction of unlined production pits and special purpose pits outside sensitive areas, excluding those pits permitted in accordance with Rule 903.a.(2).B. The following pits must have permit Form 15 submitted within 30 days following construction:

- lined production pits outside sensitive areas,

- unlined production pits outside sensitive areas receiving produced water at an average daily rate of five (5) or less barrels per day calculated on a monthly basis for each month of operation,
- lined special purpose pits, and
- flare pits where there is no risk of condensate accumulation.

Montana

The MDEQ, MBOGC, and Montana Water Resources Division's Water Rights Bureau (MWRB) have, or are in the process of adopting regulations for impoundment of CBM produced waters within the state of Montana. Currently, the MBOGC has regulations for the impoundment of produced water associated with the oil and gas industry. The MWRB regulations relate to water rights and the capture of storm water runoff, which may reduce the volume of water available for downstream irrigation use. The MDEQ has proposed a CBM Produced Water General Discharge Permit, which will regulate discharges of CBM produced water to impoundments for specific beneficial uses.

The MBOGC has established rules for the disposal of water in ARM Sub-Chapter 12 – 36.22.1226 based on the quality of produced water. Produced water containing 15,000 ppm or less TDS can be retained and disposed of in a lawful manner that does not degrade surface waters, groundwater, or cause harm to soils. Produced water containing greater than 15,000 ppm TDS can be disposed by Class II injection, into board-approved earthen pits at a rate of less than 5 barrels per day on a monthly basis, or can be temporarily stored in storage tanks or board-approved pits prior to injection. The board requires all discharges of produced water to comply with all applicable local, state, and federal water quality laws and regulations.

The MBOGC has construction and maintenance regulations requiring all production facility ponds to be permitted prior to construction; all permitted ponds must comply with regulations in ARM 36.22.1227. The earthen pits and ponds construction regulations for ponds receiving 15,000 ppm TDS or more in volumes greater than 5 barrels per day on a monthly basis should:

- be constructed in cut material or at least 50 percent below original ground level;
- be lined with an impermeable synthetic liner, or, if the bottom of the pit or pond is underlain by porous, permeable, sharp, or jagged material, the pit or pond must be lined with at least 3 inches of compacted bentonite prior to setting the impermeable synthetic liner;
- be constructed above the high water table;
- not be located in a floodplain as defined by ARM 36.15.101, or in irrigated cropland;
- be bermed or diked and have at least 3 feet of freeboard at all times between the surface of the water and the top of the banks, berms, or dikes of the pit or pond;
- be fenced, screened, and netted in accordance with ARM 36.22.1223; and
- not be used for disposal of hazardous wastes or hazardous or deleterious substances.

The board may impose more restrictive requirements to prevent degradation of water or harm to soils. These rules do not apply to emergency pits (as allowed by ARM 36.22.1207), nor do certain rules apply to temporary pits approved by the board unless the ponds are not closed within 12 months after drilling or completion operations have ended.

The two other state agencies in Montana that have, or are in the process of implementing regulations for impoundments have rules that are related to water rights and beneficial uses. The MWRD Water Rights Bureau states that impoundments cannot be constructed in a manner where storm water runoff is captured, preventing downstream water rights uses including irrigation use. The MDEQ currently considers CBM produced water to be unaltered state water and permits are not required if the water meets the numerical water quality standards established in circular WQB-7 guidelines. The CBM produced water general discharge permit currently proposed by the MDEQ authorizes regulated discharges to impoundments for specified beneficial uses, such as livestock or wildlife watering. However, the final permit approved by the state may be altered to include other beneficial uses.

New Mexico

Impoundments are regulated in the state of New Mexico by the State Engineer's Office, Water Rights Division, the Energy, Minerals, and Natural Resources Department, and the Department of the Environment, Surface Water Quality Bureau. As authorized by the State Engineer's Office, the impoundment of surface waters by the construction of dams is governed under section 72-5-32 of the NMSA 1978, as amended in 1997. The 1978 statute did not require permitting if dams did not exceed 10 feet in height and were less than 10 acres in size. Permitting was required, however, for any impoundment of water for beneficial use, with the exception of livestock ponds. In the New Mexico Court of Appeals, a decision was reached that did not limit the use of impoundments for beneficial use as long as the impoundment did not exceed the above-mentioned volume and size. Section 72-5-32 was amended in 1997 to remove the Court of Appeals exemption requiring all persons to obtain a permit for appropriate water prior to impoundment construction, unless the surface water use was for stock watering, sediment control, or flood control.

The New Mexico Energy, Minerals and Natural Resources Department, Oil Conservation Division, regulates disposal management facilities, not beneficial uses, and requires discharge permits for water supplying impoundments from oil and gas facilities under Title 19, section 710 and 711 of the state's statutes. A surface waste management facility is defined as any facility that receives for collection, disposal, evaporation, remediation, reclamation, treatment or storage any produced water, drilling fluids, drill cuttings, completion fluids, contaminated soils, bottom sediment and water, tank bottoms, and waste oil.

Under Title 19, surface water impoundment water quality must be as good as the groundwater located below the impoundment, and may not be disposed on the surface in a manner which will constitute a hazard to any fresh water supplies. Delivery of produced water to a disposal facility is not construed as hazardous if the produced water is placed in tanks or other impermeable storage at such facilities. Facilities are not governed by this rule if underground injection wells are utilized. Any modifications to existing facilities or new facilities require a permit, Form C-137, with the Santa Fe Office of the Division and one copy with the appropriate Division district office.

The New Mexico Department of the Environment, Surface Water Quality regulations are applicable for interstate and intrastate surface waters being used for livestock watering and wildlife habitat. Under NMAC Title 20.4.4.900 when a discharge creates water which could be used by livestock or wildlife in ephemeral surface water of the state, such water would be protected for the uses by this standard. Designated uses of such water is limited to livestock watering and/or wildlife habitat only when the water does not enter a classified surface water of the state with criteria which are more restrictive than those necessary to protect livestock watering and/or wildlife habitat, except in direct response to precipitation or runoff.

When water of this type, except in direct response to precipitation or runoff, enters a classified surface water of the state with criteria which are more restrictive than those necessary to protect livestock watering and/or wildlife habitat, the numeric standards established for the classified surface water of the state shall apply at the point where water enters the classified surface water of the state. If discharge of the waters ceases or is diverted elsewhere, all uses adopted under this section, or subsequently under additional rulemaking, are deemed no longer designated, existing, or attainable.

Wyoming

In the state of Wyoming the State Engineers Office (SEO), DEQ, and Oil and Gas Conservation Commission regulate impoundments. The WDEQ requires NPDES permits for the discharge of produced water to off-channel ponds to ensure the quality of the discharge will protect designated uses and the waters of the state. There are two types of permits available: general permits created specifically for CBM discharges to off-channel containment ponds and individual permits that are site-specific. WDEQ requires off-channel ponds to be designed and constructed so that there is no subsurface connection of the impounded water to the surface waters of the state. If there is the potential for the degradation of a groundwater aquifer, the WDEQ may require a Chapter 3 construction permit, however WDEQ relies on WOGCC and the BLM siting and permitting requirements for the protection of groundwater resources.

Wyoming water rights issues regarding impoundments are similar to Montana's in that natural surface flows must be allowed to continue down stream. Wyoming regulations are separated based on whether the impoundment is on-channel or off-channel. The SEO has regulations for on- and off-channel ponds, while the WOGCC has regulations for off-channel ponds used for retention of produced water and reserve pits.

The Wyoming SEO requires that prior to drilling, all CBM wells are permitted. In the permit application the operator must identify the intended beneficial use of produced water for the well. The state currently assumes the beneficial use of the produced water to be the production of coal bed methane gas, with no other implied use. If additional beneficial uses are intended for the produced water stored in an impoundment, a reservoir permit must be obtained prior to the construction of that pit. A reservoir permit for impoundments falls into two categories:

- Impoundments with a capacity of 20 acre-feet or less AND with a dam height of 20 feet or less.
- Impoundments with a capacity in excess of 20 acre-feet OR with a dam height exceeding 20 feet.

The application process is different for each impoundment type: (a) a USGS Quadrangle map is ufficient to serve as the permit map, (b) requires the permit application to be accompanied by a certified, blackline, mylar, or linen map certified by either a Wyoming-licensed professional engineer or land surveyor; if the impoundment has a dam height greater than 20 ft or storage capacity of 50 acre-feet or more, then only the Wyoming-licensed professional engineer can certify the map.

The SEO requires all on-channel ponds to have a storage permit prior to construction or the modification of any existing impoundment. All existing impoundments must be properly authorized prior to receiving CBM discharge. The following requirements must be included in any new on-channel impoundment built to store CBM water:

- The pond must be equipped with a controllable, low-level outlet pipe to allow for proper regulation, with a minimum diameter of 12 inches in the low-level outlet pipe.
- The pond may not capture natural runoff from the drainage unless that runoff exceeds the average annual peak runoff event. This requires a self-regulating runoff by-pass facility that prevents flows up to and including the average annual peak runoff event from being captured.
- In lieu of this regulation, an application for a permit for on channel ponds must be accompanied by a water administration plan that demonstrates the proposed pond will not negatively impact the drainage it was built upon and show how runoff will be made available to downstream drainage regardless of existing downstream development or channel conditions.

The WOGCC and the SEO permit off-channel impoundments. The WOGCC permits apply to ponds constructed for the disposal of produced water (fluids) associated with oil and gas exploration and production prior to an NPDES discharge point. The impoundment will be approved if it is reasonably demonstrated that there will be no contamination of surface water or groundwater, and no endangerment of human health or wildlife. The following information is required for produced water pits according to the WOGCC rules:

- a standard water analysis, (Form 17) to include oil and grease;
- maximum and average estimated inflow;
- size of pit;
- freeboard capacity;
- origin of pit contents;
- method of disposal of pit contents;
- maximum fluid level above average ground level;
- distance to closest surface water;
- depth to groundwater;
- subsoil type; and
- type of sealing material.

A plan view map and topographic map of sufficient size and detail to determine surface drainage system and all natural waterways and irrigation systems, if applicable, must be attached. The Commission may request additional information it deems necessary.

In addition, the SEO requires off-channel ponds to be constructed where the potential to capture surface runoff is minimal, or include a by-pass facility to prevent surface runoff from entering the pond. Off-channel ponds that collect no direct surface runoff are not required to have an outlet. Any pond that captures runoff must have the capability to pass this water to downstream senior appropriators.

Impoundment Design and Construction Considerations

As stated above, the EPA under 40 CFR, Part 264, has established performance standards for hazardous waste surface impoundments which, in most cases, would not be applicable to impoundments receiving CBM produced water. However, in an EPA technical resource document published in 1991 entitled "Design, Construction, and Operation of Hazardous and Non-Hazardous Waste Surface Impoundments" the EPA does discuss general impoundment design and construction guidelines that are applicable to this study. The discussion below briefly summarizes certain design and construction components of the document that include: on-channel versus off-channel; topography; surface and subsurface hydrology; geology and subsurface; climate; and construction and component design. Design considerations specific to each surface impoundment type, when available, are presented within the appropriate impoundment section. For additional information on general guidelines for surface impoundment design and construction, it is recommended the above-mentioned EPA technical resource document be reviewed.

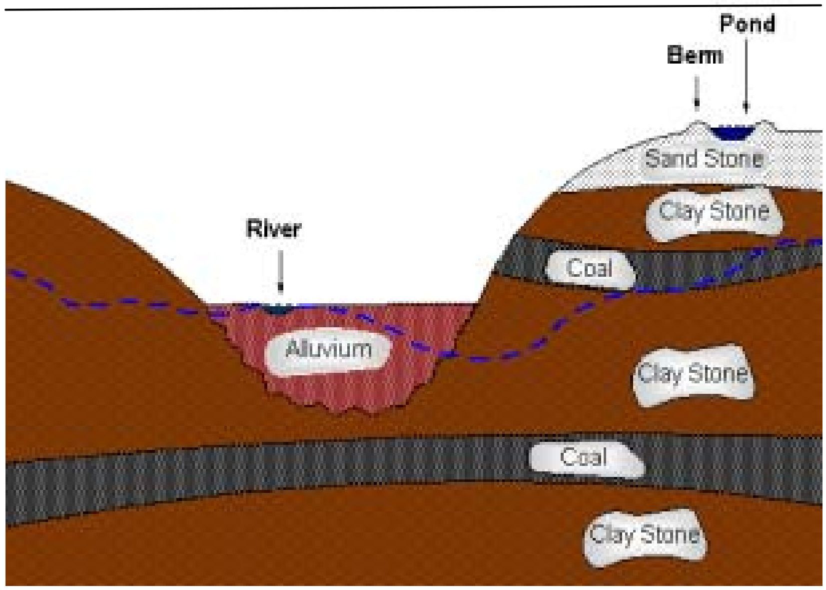
On-Channel and Off-Channel Surface Impoundments

The distinction between off-channel and on-channel impoundments is important in this study because the regulatory authority in many states changes depending on which impoundment type is used. The reason for different regulatory agencies having control over the two impoundment types usually involves two matters: surface water rights and discharge potential. On-channel ponds have the potential to affect downstream water rights by capturing flow that would otherwise continue down the channel and have the potential for discharges from the impoundment to flow into downstream surface water bodies, which would require NPDES permits in most situations. Because of these two factors, a state's engineering office or department of environmental quality usually regulates on-channel ponds since the state's engineering office generally oversees water rights issues, and surface water quality issues are managed by NPDES permits. The state's oil and gas division usually regulates off-channel impoundments for CBM produced water.

Off-channel impoundments are constructed in areas that have the potential to collect and store minimal surface runoff. Off-channel impoundments are usually located away from natural drainages of perennial and intermittent streams and coulees, and are constructed to prevent surface runoff from entering the ponds with either by-pass facilities or berms (Figure 5-11). The only input into off-channel ponds other than discharged CBM produced water is precipitation. Off-channel ponds are generally used to reduce the effects produced water can have on surface waters by preventing the water from contacting or influencing surface water flows. Off-channel impoundments can be used for evaporation ponds, wildlife watering, and aquifer recharge ponds.

On-channel impoundments are constructed by damming a natural drainage area where water runoff occurs at least part of the year, including intermittent stream channels, coulees, or lowland areas. On-channel ponds are generally designed to take advantage of natural drainage patterns as part of water management practice. This may include allowing the water to infiltrate into the alluvium, or discharge down the channel. On-channel ponds can also be designed to allow surface flow through or around the impoundment to ensure continued flow of surface water to downstream areas in order to minimize affects on downstream water rights. On-channel impoundments can be used for a variety of applications including alluvial recharge, wetlands, fishing, and recreational ponds.

Figure 5-11
Off-Channel Impoundment
Schematic diagram of off-channel impoundment.



Source: ALL Consulting

Topography

Physical characteristics of land can influence development, implementation, and management strategies for impoundments, and should be closely considered prior to commencement of construction. Identifying the ideal surface topography would require operators to delineate locations that would minimize physical modifications to the land. Suitable topography would also help alleviate area erosion events, environmental impacts, and overall construction costs. Areas of low relief above the 100-year flood elevation would be generally considered an ideal location for impoundment construction, although basin topography or design will vary to some degree depending on specific uses. For example, moist soil impoundments or wetlands should have basins with a gradient less than 1 percent (less than 1-ft elevation in 100 ft distance) with flooding depths from 2 to 12 in (USACE, 2001). These design specifications would not be appropriate for recharge or detention ponds that, from a functional perspective, would require greater flooding depths.

Subsurface and Surface Hydrology

In general, areas with high water tables or low aquifers can potentially interfere with impoundment construction or function and should be avoided when possible. Clay zones or non-mineral soils enclosing low relief areas can help reduce water infiltration to the groundwater system and should be an important consideration prior to choosing and impoundment's location. Other important considerations include:

- presence of a perched water table,
- depths to uppermost saturated zones,

- groundwater flow rates and direction,
- effects of climate on groundwater flow, and
- vertical components of groundwater flow.

Geology and Subsurface
Geology and subsurface properties requires close consideration since these properties can significantly influence impoundment design. Seismically areas and/or porous rock can potentially compromise the integrity of the structure and should be avoided. As stated earlier, clay soils are most desirable, whereas coarse-grained soils and shallow water tables are least desirable. Freezing and thawing events, especially in northern states, can often times change the chemical and physical properties of soils. Proper engineering controls, such as protective liners, may be required to assure the integrity of the system.

Other important considerations include:

- character, thickness, and distribution of soil;
- zones of saturation;
- pertinent engineering properties;
- identification of unstable conditions;
- ground response to excavation practices; and
- suitability of on-site soil materials for construction of dikes and berms.

Climate
In general, climate would have the least influence on impoundment application or selection, but would likely play an important role in determining size. Design considerations for impoundments should account for the system's ability to maintain stored water during normal and extreme climatic conditions. As such, regions with the potential to receive excessive heavy rainfall/snowmelt would require additional engineering controls. Impoundment size could also be affected by air circulation and ambient temperature, which typically influence evaporation rates. Reduced evaporation rates observed in colder climates would limit the size of the impoundment if evaporation were critical to the overall function of the facility.

Construction and Component Design
Construction and operation for most impoundments will largely depend on beneficial uses, landowner requirements, pertinent regulations, water quality, and could vary significantly for each state or region. Local authorities should be contacted to determine pertinent engineering requirements and applicable regulations.

If the produced water supplying impoundments does not meet state or federal water quality standards for discharge, pit liners are typically an acceptable design consideration to help prevent the migration of unwanted constituents to subsurface soils, groundwater, and surface water. Many styles of liners are commercially available; choosing the appropriate one would depend on the quality of water and general use of the impoundment. In any case, the EPA recommends inspecting liners for damage during construction and then weekly thereafter, especially after storms or sudden drops in water level. In some cases a professional engineer may be needed to certify the integrity of the liner and impoundment dike.

Other construction considerations would include:

- dikes and foundation,
- geomembranes,
- water level controls,
- inflow and outflow,
- protective coverings,
- secondary containment systems,
- surface water management, and
- construction quality assurance.

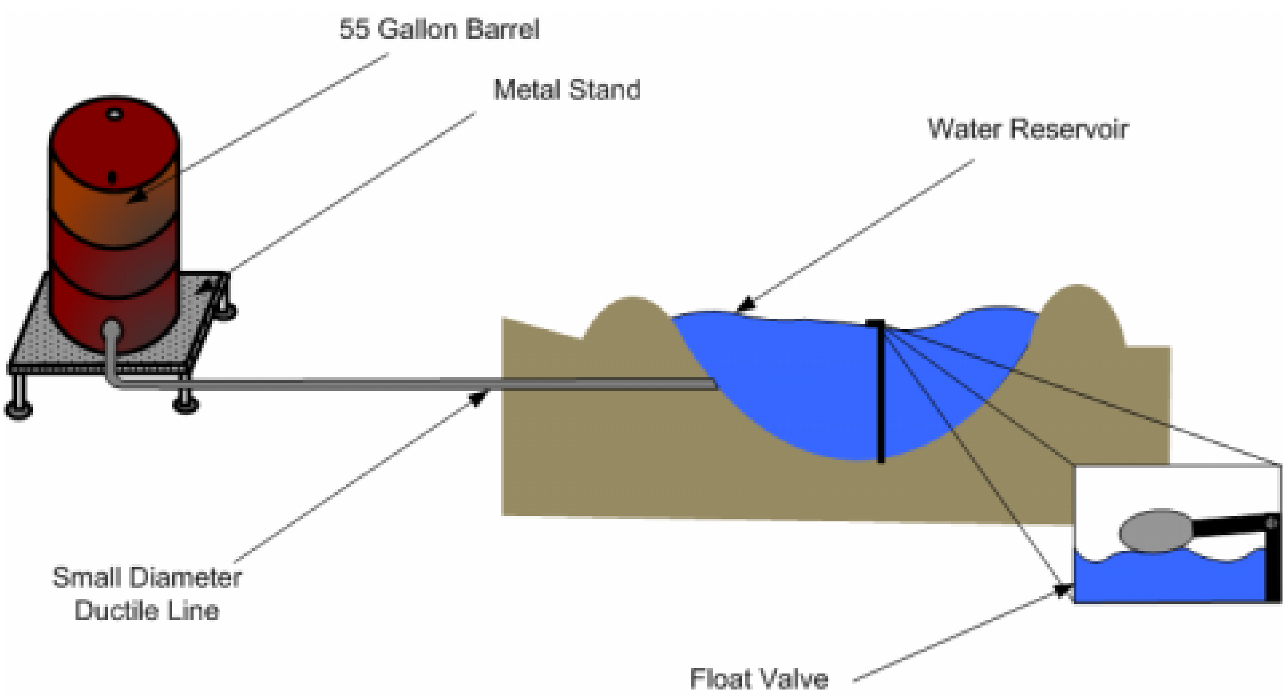
Alternative 1 - Wildlife and Livestock Watering Impoundments

Wildlife watering ponds are typically small off-channel reservoirs that are used to help supplement wildlife or livestock water demands in semi-arid to arid regions. There are many types of watering facility designs available. Choosing the correct one would depend on proper evaluation of the situation to ensure landowner needs are satisfied. Watering facilities can have simple designs, such as PVC pipe facilities capable of holding four gallons, or relatively complex designs like asphalt impregnated fabric catchment systems capable of supporting large herds or wildlife species (Figure 5-12). The Natural Resource Conservation Service (NRCS) provides nationwide standards and technical guidelines for wildlife watering facilities (Ponds – Planning, Design, Construction, Agriculture Handbook 590) to help facilitate the decision process and assure proper recommendations are presented to land owners. State NRCS offices in some cases have customized these standards to meet the demands or requirements for their particular region.

Surface impoundments for wildlife use should have gentle slopes to reduce erosion and suspended solids (Rumble, 1989). The surface area and depth of the pond would depend on the climate and the species expected to utilize it. Ponds expected to sustain waterfowl populations should have a surface area of 0.4 to 4.0 ha (Proctor et. al., 1983) and at least 25% of the pond should have a depth of three meters (Rumble, 1989). Watering ponds of this size and depth could also be used to sustain populations of shore and upland birds and fish. Ponds with a surface area less than 0.4 ha would likely not be able to support fish populations without management (Marriage and Davison, 1971).

Wildlife watering ponds function to improve, or enhance watering places and systems for wildlife, to provide adequate drinking water during drought periods, to create or expand suitable habitat for wildlife, and in some cases to improve water quality. Wildlife watering ponds are commonly constructed in areas of the western United States to enhance wildlife habitat limited by water supplies. In some areas, watering ponds provide wintering areas for migrating waterfowl, neotropical birds or other transient species. In severe drought conditions, watering ponds are used to provide water to mule deer, coyotes, bobcats, badgers, and other wildlife (U.S. Fish and Wildlife Service, 2002). The presence of constructed or artificial watering ponds, especially in arid environments, could increase wildlife populations and in general, community function, as a result of increased water availability and habitat diversity.

Figure 5-12
Watering Facility
Drawing of simple drum with float design.



Source: Natural Resource Conservation Service

CBM production facilities are often located in isolated geographic regions and, as in the case of the Powder River Basin, in arid environments with limited water sources. There is growing concern CBM operations may impact wildlife habitat and cause population displacement. The construction of watering ponds in the Powder River Basin, for example, could provide additional wildlife habitat, as well as increase water availability to wildlife, and overall help reduce wildlife displacement.

Designs of wildlife watering ponds can be simple or complex depending on certain factors such as landowner needs, wildlife ranges, territory size, wildlife distribution, travel distance, and geography. General design guidelines have been established by the Natural Resources Conservation Service (NRCS-Colorado State Office, 1999) and include:

- depending on land owner needs, the ponds should be fenced to provide protection from larger wildlife species or livestock;
- the use of plastic and PVC materials should be minimized - rodents and UV light can damage these materials;
- in colder temperate areas, provisions should be made to drain or shut-off the water supply to prevent damage caused by hard freezes;
- a maintenance program should be developed and implemented to monitor equipment function and integrity; and
- the facility should be located in shade when possible to prevent build-up of algae.

Watering ponds should be located in habitats that can provide food and shelter for as many wildlife species as possible and should include water level control devices or a means for escape to prevent drowning (Greatplains.org, 2002). Other important considerations include aesthetics, accessibility for periodic maintenance, and the control of noxious weeds. In some cases, natural watering areas can be improved to function in the same manner as constructed watering ponds. Natural watering areas are often found where run-off water accumulates in depressions. These areas can be improved by deepening the catchments, by trenching run-off waters to the basin, or developing the springs and seeps (Greatplains.org, 2002).

Applicability

Wildlife watering ponds could be used to provide additional or improved watering areas to increase the range of wildlife distributions. In arid regions where water is the limiting component or in cases where wildlife populations have been displaced, watering ponds could provide critical resources necessary to sustain community structure and increase certain wildlife distributions, such as amphibians. If properly maintained, watering ponds could effectively function for many years and help alleviate long-term wildlife impacts resulting from CBM operations. The use of wildlife watering ponds to enhance habitat(s) could be applied nationwide, but may have limited functional use in regions with seasonal sub-freezing temperatures.

In South Carolina, Bald Eagle populations appear to be increasing due in part to old and new reservoirs located throughout the state (Bryan et al, 1996). Nest territories associated with these reservoirs increased from one in 1982 to 29 in 1993. The survey indicates there was a significant rate of increase relative to territories not associated with reservoirs. Reservoir territories also produced significantly more fledglings per nest than a sample of non-reservoir territories (Bryan et al, 1996).

In general, livestock watering, when not utilizing ponds, has occurred by allowing livestock direct access to stream channels. The consequences of this watering practice has led to destabilized bank systems and streambeds, increased sediment load, contaminated waters due to manure (Iowa Department of Natural Resources, Undated), increased nutrient availability, and subsequent algae bloom and depleted oxygen levels (Kentucky Department of Fish and Wildlife, Undated). Off-channel impoundments serving as livestock or wildlife watering ponds would provide additional water in water limited areas and prevent or reduce livestock related impacts to naturally occurring water systems. The quality of CBM produced water in most cases would be sufficient for this beneficial use.

Potential Constraints

Wildlife watering ponds supported by produced waters effectively function as temporary facilities, since wildlife needs would persist upon discontinuation of CBM operations. The conclusion of CBM operations and subsequent loss of artificially constructed habitat would require wildlife acclimation to pre-existing CBM conditions, unless other sources of water were used.

The Montana Department of Environmental Quality currently classifies CBM produced water as "State Water" (non-pollutant). Therefore, permitting prior to impoundment use is not required, although discharges are not allowed into state waters. Under the newly proposed "Coal Bed Methane Produced Water General Discharge Permit," the state of Montana will be authorized to regulate discharges of CBM produced water to impoundments for the specific beneficial use of livestock or wildlife watering. The state of New Mexico, Department of the Environment, Surface Water Quality, also has permitting regulations which pertain to this specific beneficial use.

Data Needs

The long term benefits of watering ponds on disturbed wildlife populations and community structure requires further study since successful implementation of this technology will vary for each project specific situation. Prior to the implementation of CBM operations, which include reservoirs for livestock and wildlife, data should be collected regarding the following variables:

- Topography and Land Use: Local topography and existing land use are both important to identify when constructing an impoundment for livestock and wildlife watering. Identifying areas with existing or potential forage for livestock will help in determining locations for livestock ponds. If the pond is constructed to provide additional wildlife habit, it is important to consider the surrounding landscape and determine if there are hazards or activities that will limit the approach and use of the pond for wildlife.
- Produced Water Quality: The quality of the produced water will determine the extent to which it can be used for wildlife and livestock watering. There are national guidelines for livestock water quality which would have to be met for this option to be applicable. This option would require the testing of water quality parameters as established in those guidelines.
- Wildlife Distributions: The determination of the distribution of local wildlife will assist in the placement of wildlife watering ponds. Data needs may include identifying seasonal habitat, breeding grounds, population density, and species diversity.
- Landowner Relations: Communication with the landowner and identifying landowner needs are also important to this option. Many ranchers may be willing to accept as much water as their current herd can consume; for others, the additional supply of water may open new grazing land that was previously unavailable.

Economics

Costs to implement this technology will primarily depend on the complexity of the pond design, construction, water transportation and associated maintenance requirements. Watering ponds are inherently self-sustaining, low operating cost systems that require minimum maintenance. Relative to normal operating costs for CBM operations, costs associated with wildlife watering ponds should be negligible. Pond type, equipment, and travel distance will likely be the primary factors associated with construction and design costs.

Alternative 2 - Fisheries

Constructed fisheries are on- or off-channel water catchment systems designed to sustain healthy fish and other aquatic organism populations. Fishponds are typically small to medium sized privately owned reservoirs that are stocked by state agencies or individual landowners for recreational use. Designs for such ponds are simple and often depend on the water source and volume, topography (Missouri Department of Conservation, 1995), climate (temperature), and specific use. Commercial fisheries are, in general, large, complex aquaculture facilities designed to sustain large fish or other aquatic organism populations for resale and consumption. The operation of a commercial fishery requires significant investment capital, time, and management skills.

Although there are many facets to be considered prior to developing a fishpond, location is one of the more important aspects (Helfrich and Pardue, 1995). Choosing an appropriate location requires thorough research that may include volume of available water and quality, water level control options, a survey of the watershed to determine soil and vegetation density and quality, and the area's erosion and flooding potential (Montana Department of Fish, Wildlife and Parks, 1994). This background information should allow for more informed decisions to determine both the physical and economical practicability of pond construction.

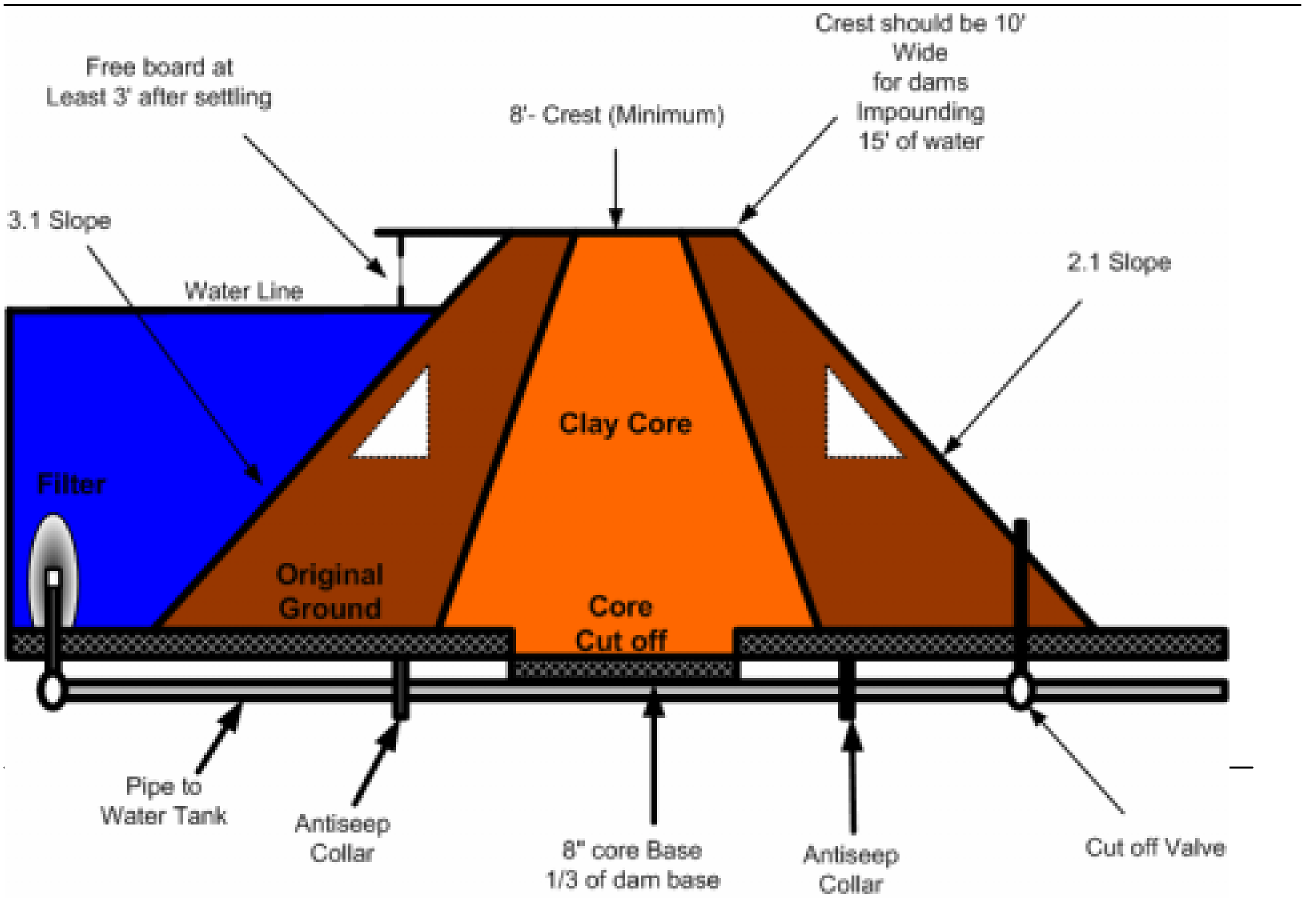
Fishponds should be constructed in soils characterized by at least 20% clay (Helfrich and Pardue, 1996), and for optimal function, have a surface area of at least 1 acre (Ashley et al, 2002). Review of available literature found conflicting data for maximum water depths and cut bank ratios, but in general ranged from 10 to 25 feet and 2:1 to 3:1, respectively (Figure 5-13). Other factors to consider include:

- level topography;
- water supply should be able to maintain a constant water level;
- will a spillway be needed and if so, what capacity is required;
- the area should be grassed immediately to prevent erosion;
- pond should be fenced to prevent livestock access; and
- inlets should be constructed in a manner to control inflow (Helfrich and Pardue, 1996).

States will typically recommend appropriate fish species for a particular area depending on the geographic area and associated climate, landowner requirements, and the population status of native species. In general, coldwater ponds are stocked with hardy trout species; whereas, warmer waters are stocked with bass species.

The importance of fisheries to the U.S. economy cannot be overstated. Currently, BLM manages over 85,000 miles of fishery habitat on public lands. In the Pacific Northwest alone, there are approximately 173,000 acres of fishery reservoirs that include 58 million pounds of anadromous fish with an estimated market value of 40 million dollars (BLM, 1989). It is also estimated that 3.5 million days of recreational fishing take place on public lands nationwide per year-estimated value at 56 million dollars (BLM, 1989).

Figure 5-13
Fish Pond
Schematic of a multi-purpose pond.



Source: Missouri Department of Conservation.

Many streams and lakes nationwide suffer from dewatering due to existing industrial, commercial, or irrigation uses, which through the years has caused increasing difficulties in maintaining healthy fish habitats (Kaufman et al., 1993). For this reason, the use of produced water supplies could have a critical role in the development and creation of new habitat for fish populations. Landowners may also have future plans for property that could benefit from this impoundment type.

Management practices for fisheries can be complex depending on the general objectives of the pond and the geographic location. Relative to privately owned stock ponds, commercial fisheries, including streams or large water systems, may have stringent requirements associated with them, which may lead to higher maintenance and monitoring costs. Privately owned ponds are typically constructed for recreation uses, and with the exception of water right or applicable permit issues, habitat maintenance is often the only issue facing the landowner. Proper water management techniques for either situation can help decrease future expenses and sustain viable long-term fish populations by sustaining functional habitat. Management techniques generally include, but are not limited to periodic water sampling to assure permit requirements are conformed with; establishing guidelines to prevent erosion events and any subsequent sedimentation build-up; and practices to control surface (aquatic) vegetation and prevent local distribution of exotic fish and noxious weeds (Montana Department of Fish, Wildlife and Parks, 1994).

Applicability

In many cases the type of water and its availability will determine the size and quality of the pond (Montana Department of Fish, Wildlife and Parks, 1994). Water rights and water quality requirements are normally important considerations to take into account prior to fisheries implementation and will vary depending on regional or state stipulations. Produced waters can vary in quality and may dictate the success of the constructed pond. To assure survivability and overall pond function, water quality analysis of the produced water would be essential. The two critical water elements for fish are dissolved oxygen (DO) and nutrient content (Lamaire, 2002; Holeton, 1980).

As a result of the methane extraction process, DO levels in CBM produced waters are typically low, but will vary to a certain extent based on aquifer charge sources and the prominence of aerobic or anaerobic conditions at the extraction point. When produced water is stored or transported for some beneficial use, DO levels may increase as a result of surface agitation or some other form of aeration. The increased DO levels could provide suitable conditions to sustain many types of fish species, assuming these DO levels could be consistently supplied. The levels of DO could be a limiting factor when determining pond size, species, and population sizes and would need further consideration prior to pond development.

Many fish species are susceptible to high or elevated levels of phosphates, heavy metals, salts, and pH (Eisler, 1991). The level of these constituents in produced water would be another contributing factor when assessing the water's usability for fishponds. Phosphates and heavy metals can bio-accumulate in fish and over time, reach deleterious concentrations that could potentially cause reproductive, developmental, and survivability issues (Eisler, 1991). Produced waters containing elevated constituents of this type would have marginal fisheries use without prior treatment. In situations where ponds exhibited low pH values resulting from bicarbonates, lime could be used to restore the water to natural conditions (Ashley et al, 2002).

Non-treated CBM produced water is currently being used to sustain privately owned fishponds in some states, including Wyoming. Water quality levels have been sufficient to support healthy populations of rainbow trout, blue gill, small-mouth bass, etc. In a related issue, the state of Wyoming discontinued fish stocking programs in certain ponds due to a general lack of available water volume needed to sustain the system. CBM produced waters are now being beneficially used to supplement these ponds, allowing for continuation of the State's stocking program.

As stated by the Recreational Fisheries Policy, recreational fishing provides substantial benefits to Americans derived from maintaining healthy and robust fish populations and related habitats. CBM produced waters could be used to support and enhance federal and state sponsored sport fishing programs by constructing additional fisheries in arid regions normally lacking in fish sustainable waters or in areas with declining fish populations due to over fishing. The application and success of this use would depend on applicable state guidelines, public demand, water quality, drainage, and geographic region.

Potential Constraints
Most states will require fishpond permits in order to legally stock ponds. Although not necessarily a constraint, most permit applications of this type will require water quality analysis, beneficial use designation, expected volume, and various other parameters that may require additional investigation. Sufficient time to collect this data should be incorporated into any management plan.

Before a pond can be constructed, many states, including Montana, require a water right. The water right, in general, requires the water be used only in a beneficial manner and require assessment of water availability and determination if the "water use" will interfere with other water users. The definition of beneficial use will vary from state to state and in most cases, beneficial use applications will depend on the quality of water. Water right issues will also vary from state to state and would require additional research.

The efficiency of methane extraction during CBM production can often times dictate the volume of water, which is pumped from the aquifer. Because of this, the volume of water available for beneficial use may fluctuate. The uncertain volume of supplied water to fisheries could make it difficult to properly maintain DO and nutrient levels, and also replace water lost to the system as a result of evaporation, infiltration, or biologic use. Design considerations, especially during initial CBM production activities, would need to account for this issue. As with wildlife watering ponds, CBM produced water would only be available for a relatively short period. After conclusion of CBM operations, fish ponds supplied via produced water would require an alternate water supply, e.g., wells or springs, or be confronted with potentially expensive closure fees.

Data Needs
When considering the construction of fisheries for the management of produced water data needs could include:

- Produced Water Quantity and Quality: The variance of produced water volumes available for supply may determine the cost-effectiveness of constructing fisheries that are developed and sustained for long periods of time. Available produced water volumes over time to supply the fisheries may determine if this option is sustainable, or would be a short-term opportunity. Water quality data would also need to be collected to determine levels of phosphates, heavy metals, salts, and pH, all of which can be toxic to certain fish species, as well as determining if adequate levels of DO can be maintained within the ponds.
- Water Rights: Water rights rules and regulations vary by state; it is important to determine local water rights as they apply to this management option.

Economics
Fisheries can have a considerable cost associated with the construction and maintenance activities required to keep the ponds suitable for certain species in commercial settings, but can be relatively inexpensive if construct for private landowner use. A small fishing pond constructed for a landowner could be maintained relatively inexpensively if stocked with local native fish species. Larger commercial fisheries will be more expensive to maintain, but cost could be offset by the commercial profits associated with sport fishing. The long-term expenses associated with a commercial fishery would increase once local CBM production ends and the

produced water is no longer available to replenish water lost from evaporation. Additional costs may be associated with obtaining water rights to supply larger commercial operations.

Alternative 3 - Recharge Ponds

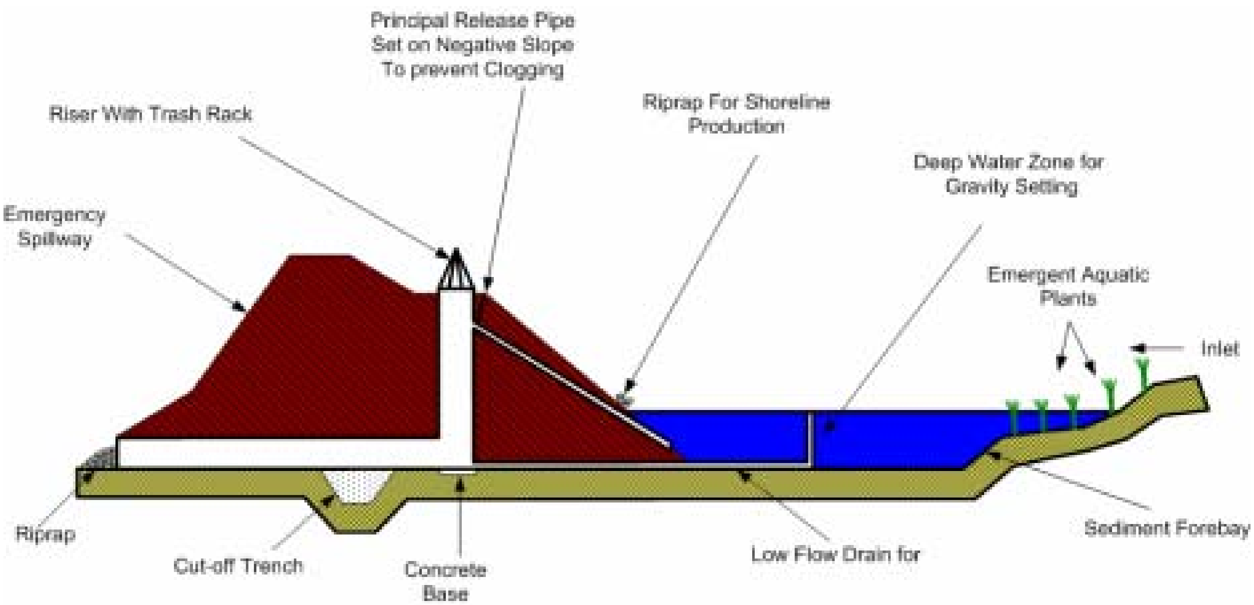
Recharge ponds, also known as storm water ponds, retention ponds, or wet extended detention ponds, are constructed off- or on-channel reservoirs typically containing a permanent pool of water, especially during regional wet seasons (Stormwatercenter.net, 2002). Recharge ponds are traditionally used to restore depleted groundwater sources by water infiltration into subsurface aquifers, whereas retention ponds are permanent pools constructed to improve water quality, attenuate peak flows, and minimize flooding (Kantrowitz and Woodham, 1995). Recharge ponds also have some treatment function to lower TDS by a settling removal mechanism (Stormwatercenter.net, 2002) or by water infiltration through a pre-fabricated pond liner. Nutrient uptake is also possible through various biological processes that could facilitate additional uses.

Design considerations for recharge ponds are generally divided into five categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping (Stormwatercenter.net, 2002). The pretreatment aspect of the recharge pond involves filtering or settling coarse sediment out of the water prior to main pool arrival. This particular step helps reduce the overall pond maintenance costs. In general, the treatment process removes additional pollutants at various efficiencies based on the length of time the source water remains in the pond. Rates of removal can be controlled by pond size, flow path, flow volume, and speed of infiltration. Conveyance refers to controlling water flow to and from the pond. Spillways are typically constructed to control water outfalls to prevent downstream erosion events. The amount of maintenances activities per recharge pond is directly related to design considerations, which lower costs and ease maintenance requirements. Design considerations to prevent potential clogging, which may include reverse sloping pipes or weir outlets (Stormwatercenter.net, 2002), can significantly reduce maintenance issues. Lastly, proper landscaping of the pond can enhance community aesthetics and increase the efficiency of pollutant removal. A greenbelt buffer adjacent to the pond can provide additional local habitat for wildlife, reduce floodwater runoff, protect the banks from erosion, and reduce pollutant uptake observed by the pond resulting from overland flow.

Design options for recharge ponds could be dictated by recharge rates, (which will vary significantly depending on the region), the volume of source water and available lands, flooding patterns, soil types, groundwater, regional characteristics, e.g., topography and climate, and the specific pollutants to be treated. As an example, wet detention ponds (Figure 5-14) combine the concepts of dry retention ponds and wet ponds, making them suitable treatment and storage facilities for many types of conditions.

The volume of water split between the permanent pool and retention pond results in efficient pollutant removal in relatively less space. In situations where space is the limiting factor, "Pocket Ponds" are commonly used (Stormwatercenter.net, 2002). Pocket ponds drain from smaller areas and thus require additional water sources to maintain and supplement the permanent pool. In most cases groundwater sources are used to achieve this, although this results in less efficient pollutant removal relative to other recharge pond types (EPA, 1999d).

Figure 5-14
Recharge Pond
Schematic diagram of wet detention pond.



Source: Maryland Department of the Environment.

Typical maintenance activities can prolong the life and function of a recharge pond and include:

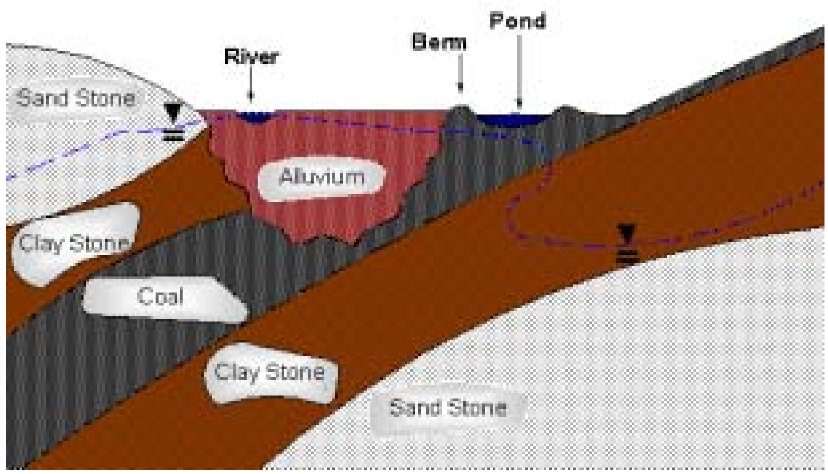
- inspect for damage and hydrocarbon build-up,
- monitor sedimentation accumulation and clean as necessary,
- inspect inflow and outflow devices for potential clogging,
- repair eroded areas,
- maintain greenbelts for optimal overland run-off protection, and
- periodic water analysis.

Applicability

Potential impacts resulting from pumping water from coal bed seams could include the reduction of water from local aquifers that support agriculture uses. Coal bed aquifers will be drawn down during CBM production, potentially affecting springs and streams used for irrigation, drinking and livestock wells, and as a source of baseflow or recharge to perennial streams and rivers (Warrence and Bauder, 2002). The use of recharge ponds to replenish depleted aquifers would be extremely site specific and would require extensive evaluation (Committee on Groundwater Recharge, 1994).

Recharge ponds could be applied in most regions of the United States to receive produced water. These ponds could be used to recharge surficial aquifers, or built over clinker zones to provide recharge to depleted coal seams (Figure 5-15). This technology would have limited use in colder climate conditions without utilizing certain design considerations (see below). In areas with limited water supplies, produced waters could be used to continuously supply ponds and help alleviate excessive sediment load and water loss resulting from evaporation. This technology would be most applicable in areas with critical water demands resulting from declining groundwater systems to help supplement various uses, such as livestock watering or irrigation.

Figure 5-15
Coal Seam Aquifer Recharge
Schematic diagram of coal aquifer recharge pond.



The quality of water would have important implications on a recharge pond's operation and overall reclamation use. Water characteristics that could affect the operational aspects of the pond include suspended solids, dissolved gases, nutrients, biochemical oxygen demand, (Commission on Geosciences, Environment and Resources, 1993) and SAR. The volume of water needed to sustain a recharge pond will vary depending on size and location. In a semi-arid region of Texas, a study performed by Saunders and Gilroy (1997) concluded 2.6 acre-feet per year of supplemented water were needed to maintain a permanent pool of only 0.29 acre-feet. Typically, the volume of CBM produced waters could meet this demand. However, because the volume of produced water decreases in the later stages of CBM production, recharge ponds would likely require additional future water sources, or the overall size of the ponds could be reduced.

In traditional wet detention ponds, treatment of water occurs via a gravity settling process, which separates sediment and liquids (EPA, 1999e). The separated liquid is removed by evaporation, outflow, or infiltration while the remaining solids are typically removed by dredging the basin. In Pinellas County, Florida, the U.S.G.S. performed a local study to determine the efficiency of a multi-purpose wet storm water detention pond (designed to retain water during non-storm periods) in reducing certain constituent loads in urban storm water (Kantrowitz and Woodham, 1995). In essence, by comparing inflow and outflow water, results of the study indicated the pond was effective at reducing heavy metals (including aluminum, chromium, copper, lead, and mercury), nutrients, suspended solids, and biochemical and chemical oxygen demand, but not chloride, bicarbonate, and dissolved solids. The National Pollutant Removal Performance Database for the treatment of storm water by a recharge (wet) pond indicated the following results (Winer, 2000).

Although the quality of CBM produced waters will vary and typically contain different constituent types relative to storm water, the treatment effectiveness of recharge/retention ponds on these same constituents concentrated in CBM produced waters is likely applicable (Table 5-5).

Table 5-5
Recharge Pond Pollutant Removal Efficiency

Pollutant	Removal Efficiency (%)
TSS	80 (± 27)
Total Phosphorus	51 (± 21)
Total Nitrates	33 (± 20)
Metals	29-73
Bacteria	70 (± 32)

Groundwater recharge management plans are becoming both increasingly common and valuable for communities located in arid or semi-arid regions as a result of new technologies and increased public water, irrigation, and wildlife demands, respectively. In general, recharge ponds can be incorporated into water management plans to improve basin water quality, potentially provide communities with water banking options, flood control, remove certain pollutants, and protect riverine channels (Watershed Management Institute, 1997). As in the case of CBM produced water, recharge ponds for beneficial use could potentially function to control the quality of water recharging the groundwater supply (Figure 5-16), ultimately providing communities with increased long-term groundwater resources.

Given the right situation, recharge ponds could also be used to provide additional wildlife and fish habitat and usable water, especially in water-deprived environments. As an example, tiger salamander populations are decreasing in western regions as a result of lost habitat. In Liverstone, California, tiger salamanders are using additional habitat provided by constructed recharge ponds for breeding purposes (Garcia, 1998). The presence of these ponds may help alleviate urban advancement on wildlife habitat or at a minimum, provide agencies with additional time to develop and implement mitigation plans.

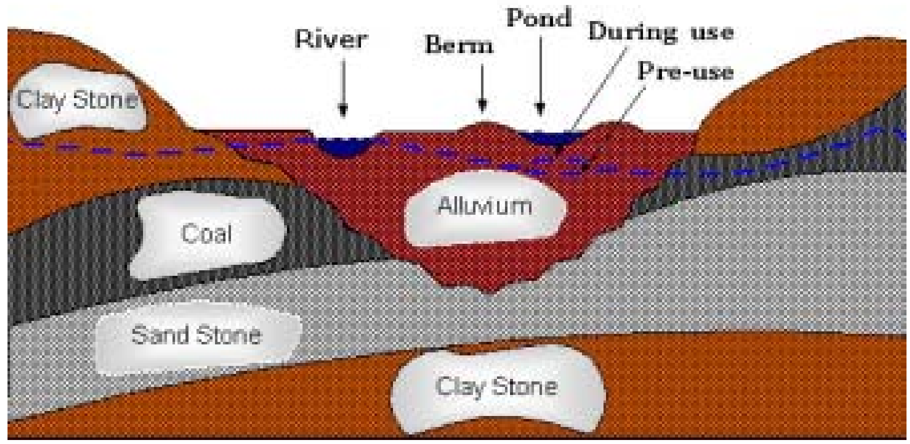
As with watering ponds, recharge ponds receiving produced water in remote or arid regions could reduce wildlife displacement and increase wildlife ranges. The warmer water stored in permanent ponds could provide suitable wintering habitat for waterfowl or other transient species. A new permanent water source could help sustain additional or larger wildlife populations.

Potential Constraints

Additional pond design measures would be required in colder climates as a result of accumulated pollutants present in snowmelt runoff. Pollutants in snowmelt can overload pond systems causing a significant reduction of water quality being infiltrated to local aquifers. The pollutant increase would also limit surface uses for wildlife. Snowmelt may also cause excessive overland runoff leading to increased erosion and sediment buildup. Design measures to alleviate such issues commonly entail construction of spring specific retention ponds to collect excessive snowmelt. Additional issues associated with colder climates include freezing of water transport piping and inflow and outflow devices.

The rate of water infiltration relative to inflow is typically greater in a recharge pond system. When also considering the evaporative process, the accumulation of certain constituents is likely. A variance in water quality could limit the ponds functional use and increase costs associated with management practices. During flooding events, discharges could impact adjacent soils, greenbelts, and wetland systems thus, resulting in unsuitable or degraded wildlife habitat. Also, the discharge of warmer waters present in ponds could potentially harm coldwater systems critical for some fish. Depending on the volume of received water, initial water, and pond size, pre-treatment applications may be necessary. In certain situations salt tolerant plants could be used to reduce some of the above-mentioned impacts.

Figure 5-16
Recharge of an Alluvial Aquifer
An alluvial aquifer recharge pond showing pre- and post-use water levels



As with any impoundment type, habitat conversions for pond use could affect available water for agricultural use and overall farm budgets. Many state water right programs prohibit the obstruction of natural water flows. This requires channel construction or some other engineering control to divert storm water runoff from impoundments. Construction and maintenance costs would need consideration prior to pond implementation.

Data Needs
Recharge ponds supplied by produced waters will likely require the collection of additional data related to the following:

- Geologic Data: In determining the appropriate location for a recharge pond, geologic and hydrogeologic data will provide important data. Soils data will need to be collected at prospective locations to determine infiltration rates from the pond. The identification of coal outcrop areas would assist in determining areas where recharge pond could be located for coal aquifer restoration.

- Existing Groundwater Quality: In addition to the produced water quality information, additional water quality data from the shallow groundwater system that will be receiving produced water is important.

Economics
The constructions costs for recharge ponds are relatively inexpensive, but depend on the size of the pond and permit requirements. Other factors which may affect construction cost include location of the ponds (on-channel vs. off-channel, and alluvial vs. coal seam aquifer recharge).

The annual costs of maintenance of recharge ponds based on the costs of storm water ponds would be between 3t o 5% of the overall construction costs (Stormwatercenter.net, 2002). Ponds can provide economic benefits to landowners by increasing property values. The EPA in 1995 concluded that owning pond front property could increase the selling price of new properties by approximately 10%.

Alternative 4 - Recreation

Traditionally, artificial lakes have been created to augment urban and industrial water supplies; uses for recreation have been considered a secondary benefit (Bennett, 1962). The conceptual use of artificial lakes has changed through the years, however, and is now commonly used in the Midwest for fishing, swimming, and boating. CBM produced water could be used to supply artificially constructed surface impoundments for recreational use. Depending on the quality of water, size of the production facility, and subsequent volume of pumped water, available lands could be converted into large artificial lakes and used for boating or canoeing. The lakes could also be stocked with native warm and possibly cold-water fish to increase local populations and/or used to accentuate camping grounds by providing swimming areas for local residents.

The addition of a large water body to an ecological community could provide additional habitat for resident and migratory birds, including waterfowl, and possibly provide resting and nesting sites for raptors (Bryan et al, 1996). An increase of waterfowl populations in the area could help support the local hunting community and potentially deter illegal hunting due to limited population sizes. The lake would effectively function as a watering pond or wetland system, potentially increasing wildlife ranges and populations as a result of an increase to the overall dynamics observed by the local ecosystem.

Two-acre impoundment design for multiple use recreation, Lake Hashawha, Maryland.

An increase to wildlife and vegetative diversity to the area could provide unique opportunity for study. The constructed impoundment could facilitate outdoor classrooms for school children use or provide local agencies with the basis to initiate various wildlife programs. Pause points could also be constructed near the lake to provide local residents with bird watching or nature study opportunities.

Applicability
According to the second national water assessment by the U.S. Water Research Council, less than one-fourth of the surface waters in the continental U.S. are accessible and useable for recreation because of pollution or other restrictions (Harney, undated). The application of artificial lakes supplied by CBM produced water could potentially have widespread use depending primarily on available lands, water volume, and quality. Many areas of the country are overwhelmed with overcrowded or limited recreational facilities as a result of overpopulation and urban encroachment, respectively. The development of artificial lakes could provide additional recreational opportunities within these areas while at the same time promoting community involvement and habitat improvement. In colder climates, artificial lakes could also provide ice fishing or ice skating opportunities.

Potential Constraints
The large volume of produced water needed to sustain an artificial lake system, especially in arid or semi-arid regions, may be the limiting factor contributing to the overall success of the system. As with other impoundment types, an artificial lake could be susceptible to fluctuations in water levels resulting from changes in pumped water demands. This factor alone could limit both the size of the impoundment and any associated beneficial uses.

Produced water would no longer be available to support artificially created lakes upon conclusion of CBM production. From a functional perspective, the use of the lake system would likely regress to pre-existing conditions without additional water sources supplying the area. The resulting loss of recreational opportunity and its effects on local communities, including economic impacts, is uncertain. Feasibility and environmental assessment would be critical in reducing observed impacts if additional water sources could not be found.

Construction of an artificial lake could require sizeable lands. Depending on private landowner needs and capabilities, available lands may hinder this impoundment's application. This particular impoundment type may best be suited for application to federally or state owned lands. The management and liability implications commonly associated with recreational use areas could be overwhelming for many private landowners and, in general, may have more practical uses for the water.

Data Needs
Community benefits associated with constructing artificial lakes for various recreation uses have been well documented and, therefore, have few data needs. Additional information gathering would be necessary prior to implementation to assure the development would meet the demands of local residents. Additional information related to the volume of produced water and duration of the supply will be necessary in determining the long-term sustainability of this option.

Economics
The costs of construction and maintenance of a recreation pond will vary depending upon the size of the pond, permit requirements, design, and supply of water once CBM produced water is no longer available. Large community recreation ponds can include considerable design costs, and construction costs would increase with the complexity of the pond design. In addition, the water rights permits and associated costs of the replenishment of water once CBM operations have ceased would add additional expenses for this option.

Alternative 5 - Evaporation Ponds

Evaporation ponds are usually off-channel; constructed impoundments designed to store water at the surface so that natural evaporative processes can move the water from the land surface into the atmosphere. As evaporation occurs, "pure" water is removed from the pond resulting in an increase in the TDS for the remaining water. Over time as more water is lost to the atmosphere, the water remaining in the pond can become more concentrated brine. Depending on the quality of the water in the pond, the bottom and toe areas may be lined to prevent concurrent infiltration of the water. In other geologic settings, the ponds may be placed on natural confining layers such as bentonite rich clay soils, or exposed shales that prevent the downward migration of the groundwater. If the evaporation pond is constructed solely for evaporative loss (no infiltration), the ponds are generally designed to be broad shallow pools that maximize the surface area allowing for increased evaporation rates. Additional consideration is given to exposure; areas with high winds and few natural windbreaks would provide additional evaporative potential, which would include finding areas with low-level vegetation.

Applicability

The potential for evaporation ponds is greatest in arid areas where high natural evaporation rates occur. Average annual lake evaporation rates vary considerably across the western United States from less than 30 in/yr to nearly 80 in/yr as shown in Figure 5-17 (United States National Weather Service, 2000). In some of the areas of interest for CBM development such as the PRB of Montana and Wyoming and the SJB of Colorado, evaporation rates between 28 and 40 in/yr have been historically recorded, while areas in Utah have evaporation rates between 40 and 52 in/yr. The Gulf Coast region of Louisiana and Texas has average evaporation rates between 48 and 70 in/yr. Thus in the areas where future CBM development is expected to occur, the potential exists for evaporation to result in a significant amount of managed water loss.

Although some portions of these states have considerable annual evaporation, seasonal variations should be taken into account. The National Oceanic & Atmospheric Administration (NOAA) provided the following diagrams to demonstrate regional average evaporation rates for the months of January (Figure 5-18) and July (Figure 5-19) for the years 1971 to 2000. If evaporation is zero in more than one year during 1971-2000, the ranking percentile is undefined and, therefore, not shown in the map.

Constraints

There are several conditions, which can constrain the effectiveness of evaporation ponds. The existing landscape or topography, landowner considerations, natural runoff or flooding of a pond, seasonal variations including cold winter climates, and vegetation can all affect evaporation ponds by reducing the evaporation rate or by increasing the volume of water within the pond.

Figure 5-17
Average Annual Lake Evaporation Rates for Five State Study Area
Map of the select western states showing lake evaporation rates.

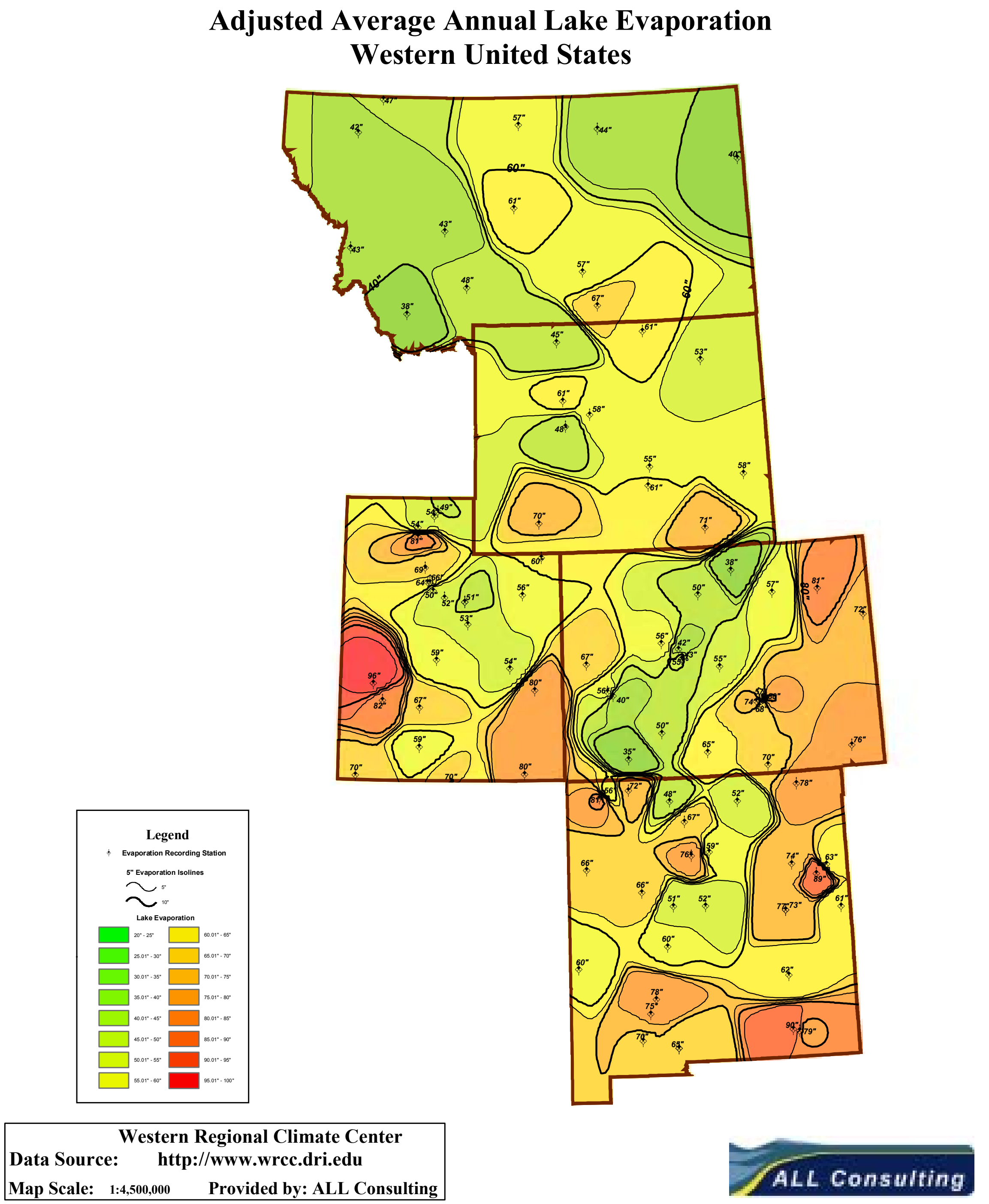
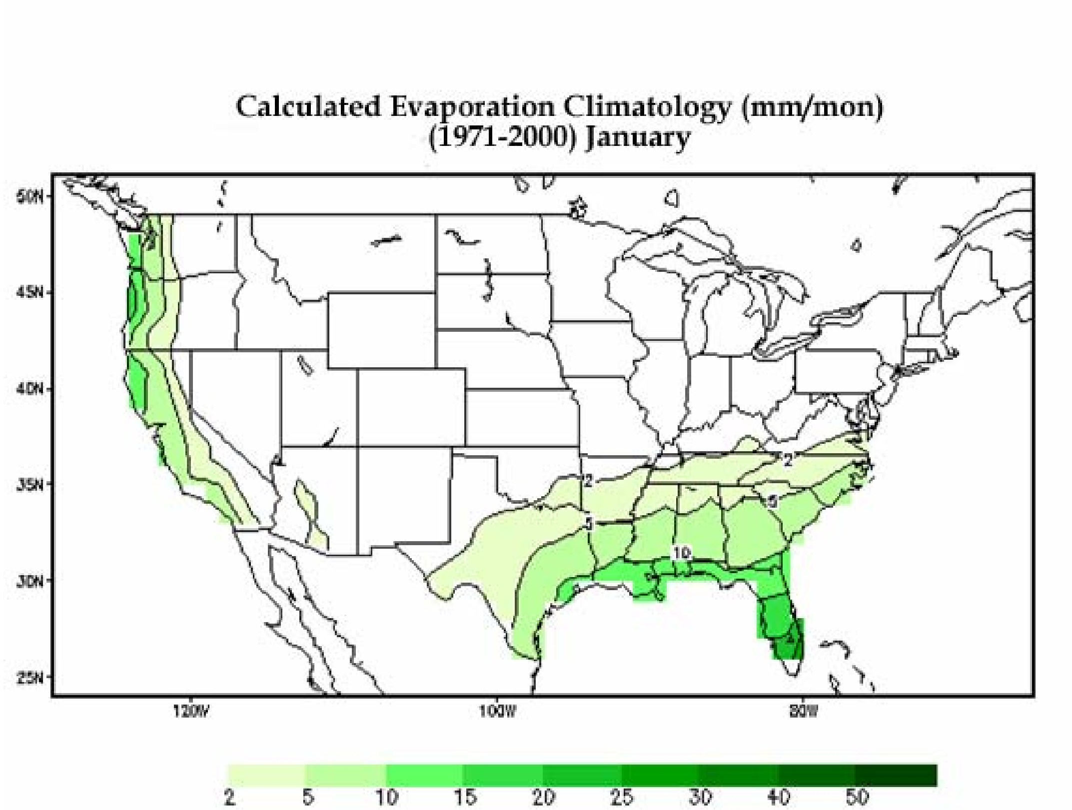


Figure 5-18
Calculated January Evaporation
Map of United States showing calculated average evaporation rates for January.

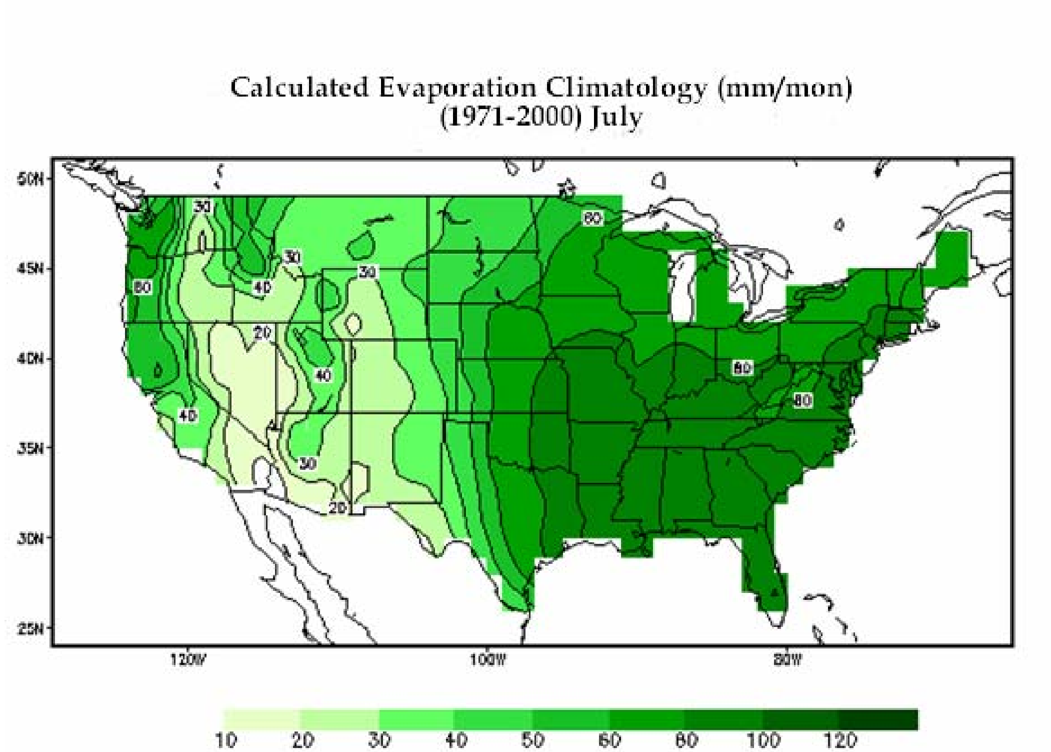


Landscape and topography are important in siting the location of an evaporation pond. It is important when constructing an evaporation pond that the amount of surface area exposed to the atmosphere be maximized. Evaporation ponds are typically designed to be shallow pools with large surfaces in order to store considerable volumes of water while maximizing the area exposed to the atmosphere. Topography can limit the areas where evaporation ponds can be constructed as hilly areas or areas with limited available land are less desirable for this type of pond.

Landowners may also have desires that constrain the use of evaporation ponds. Some landowners may not wish to have large areas of their land disturbed for the placement of an evaporation impoundment. CBM operators should consult with landowners to ensure that the location and size of impoundments are agreed upon prior to construction.

Runoff from precipitation events or flooding counteracts intended purpose of the evaporation pond. Siting, designing, and constructing the ponds to minimize the volume of water that is able to enter the pond from natural runoff or flooding can minimize these affects.

Figure 5-19
Calculated July Evaporation
Map of United States showing calculated average evaporation rates for July.



Many of the areas in the western United States which future CBM development is expected to occur have considerable seasonal variations, including subfreezing temperatures during the winter months. The cold temperatures of these regions would reduce the effectiveness of evaporation ponds during portions of the year while CBM water production would continue to occur. However, this alternative could be combined with the Freeze/Thaw Treatment Alternative discussed previously.

Although low lying vegetation would be beneficial to reduce erosion around the ponds, trees, and other tall vegetation would act as a wind barrier and reduce the rate of evaporation around the pond. A pond located near a forested area with a developed canopy would have reduced evaporation rates.

Data Needs
Evaporation ponds supplied by produced waters will likely require the collection of additional data related to the following:

- Water Quality and Soil Composition: Water quality needs will be important to evaporation ponds as with any of the beneficial uses listed. In addition, data will need to be collected on the soils over which the pond will be constructed prior to the discharge of CBM produced water into the ponds. This data will be important in order to determine if the ponds need to be lined and to determine the impact that the brine may have on the soils under the pond.

- Water Quantity and Evaporation Rates: The volume of CBM produced water placed in the pond and measurements of evaporation rates will be important in determining if the pond is losing water solely by evaporative processes, or if there is additional water being lost via infiltration.

Economics

The construction costs for evaporation ponds can vary depending on the conditions which underlie the area where the pond is being constructed. If the pond is designed for evaporation only and overlies a permeable stratum such as a sandy alluvium, additional costs for lining the pond would be incurred. If the pond is constructed over a less permeable stratum such as a bentonite rich clay or shale, the cost would be less since only the toe and berms around the pond would need to be lined. Maintenance costs for evaporation ponds will vary depending on the quality of the produced water; higher TDS produced waters will result in more concentrated brines, which may increase the disposal and reclamation costs associated with the closing of the pond.

Alternative 6 - Constructed Wetlands

The U.S. Army Corps of Engineers (USACE) and the EPA define wetlands as areas that are inundated or saturated by surface or groundwater at a frequency and duration to support vegetation adapted for life in saturated soil conditions. According to USACE (1987), wetlands are characterized by three criteria: vegetation, soils, and hydrology.

Hydrophilic vegetation is defined by the USACE as "macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present." Wetland hydrology is present when it influences vegetation and soil due to anaerobic and reducing conditions. This commonly occurs in areas that are seasonally, semi-permanently, or permanently flooded for a consecutive number of days during the growing season or have soil saturation to the surface for a sufficient period of time. Wetland hydrology is considered present if the soil is saturated to the surface for more than 12% of the growing season. If soil saturation is estimated to occur between 5 to 12 percent of the growing season, wetland criteria is only met if other hydrology indicators are present; this includes drift lines, sediment deposits, and drainage patterns. When soil saturation is present for less than 5% of the growing season, the area does not meet the hydrology criteria for a wetland.

As defined by USACE, soils consist of unconsolidated, natural material that supports, or is capable of supporting life. Soil must be able to support plant life and must consist of a least one of several wetland indicators that are used to define a hydric soil. These indicators include histosols, histic epipedons, sulfidic material, aquic moisture regimes, reducing soil conditions, soil colors (gleyed soils and mottling), organic streaking, and organic pans.

Wetlands occur in every state in the nation and vary in size, shape, and type because of differing climate, vegetation, soils, and hydrologic conditions (Dahl, 1990), and are considered by most experts to be the most productive ecosystems in the world. Construction of a wetland system to receive produced waters could increase wildlife distributions, reduce displacement, and enhance diversity by improving quality habitat.

Proper construction of a wetland system requires consideration of site-specific characteristics such as water source, soil type, and topography (Fredrickson and Taylor, 1982; Lane and Jensen, 1999). The primary water source supplying the system should be dependable in both quality and quantity (USACE, 2001). Suitable soil conditions are essential to assure efficient function. Silt, clay, loams, and fine sands are able to hold water well versus coarse sand or gravel, which are more likely to facilitate erosion events or subsurface water seepage (USACE, 2001). Irregular topography within an impoundment can provide diverse microhabitat features important to a variety of wildlife species (Reid et al. 1989). Wetland systems consisting of aggregated areas (surface impoundments) or complexes with varying successional stages, water depths, and topographic relief can increase habitat diversity (Fredrickson, 1991).

Initial Planting, June 2000,
Marathon Oil Company.

Impoundment basins should have a gradient less than 1 percent (less than 1-ft elevation in 100 ft of distance), with flooding depths from 2 to 12 in. The optimal size of a wetland system is approximately 5 to 100 acres (Fredrickson, 1991). In an artificially created ecosystem, water levels can be manipulated to accommodate a variety of species that may forage in varying water depths (USACE, 2001). Many dabbling duck species feed in water up to 10 in deep, whereas wading birds prefer water depths up to 5 in. Common snipe (Gallinago gallinago) use shallow waters up to 1 in deep (Lane and Jensen, 1999).

Same Planting Area, August 2001,
Marathon Oil Company.

Many species of birds and mammals rely on wetlands for food, water, and shelter, especially during migration and breeding. Available food resources in wetlands would attract many animal species, including small aquatic insects, shellfish, small fish, larger predatory fish, reptiles, amphibians, birds, and mammals. Wetlands systems can also increase the overall function in the ecology of the local watershed (EPA, 2002b). Wetlands provide natural nutrient recycling and sediment filtration during high water or flooding periods, which may help improve the water quality of neighboring water systems. Furthermore, wetland plant communities and soil store available carbon preventing release of carbon dioxide into the atmosphere and, thus help to moderate the global climate (EPA, 2002b).

Increased vegetation within wetland-associated riparian zones facilitates the assimilation, filtering, and retention of nutrients that are eventually recycled back into a water system. Rain that runs off the land can be slowed and stored in leaves, limbs and roots and, in essence, reduce water runoff. Functioning riparian buffers would also help control non-point source pollution and through the process of "denitrification"; bacteria in the forest floor would convert harmful nitrate to nitrogen gas (EPA, 2002b).

Applicability

Information from the USGS (Dahl, 1990) has indicated that 22 states have lost 50% or more of their original wetlands. California has lost the largest percentage of original wetlands within the state (91%), whereas Florida has lost the most acreage, 9.3 million acres, (Dahl, 1990). Only recently the value of wetland systems was recognized for their important role in providing fish and wildlife habitats; for maintaining groundwater supplies and water quality; for protecting shorelines from erosion; for storing floodwaters and trapping sediments that can pollute waterways; and for modifying climatic changes (Dahl, 1990). The loss of wetland systems has had profound impacts to the country's natural resources.

Constructed or reclamated wetlands receiving CBM produced waters could be used to create new habitat, restore altered systems, or potentially serve as state mitigation banks for future developments. These types of impoundments could potentially have widespread application, with the exception of arid regions, to provide the above-mentioned benefits. Successful implementation of constructed wetland systems will ultimately depend, in general, on proper design, management practices, climatic conditions, topography, and community or landowner needs and requirements. Close evaluation of these parameters would be necessary prior to implementation.

The advantage of the addition of produced water wetland systems to most ecological communities would be greater that any associated negative impacts. Recent research funded by the Marathon Oil Company (Sanders, Gustin, and Pucel, 2001) suggests CBM produced waters would be sufficient to support wetland systems. In the study, an artificial sedge wetland system was created to treat CBM produced waters. Although the wetland system failed to effectively treat many constituent types, the wetland system flourished within a year's time. The wetland system load for the study was designed for approximately 30 to 40 gallons of water per minute. Within one year, hydric vegetation present in the system was approximately 100%. (Data was not available to reflect characteristics of the wetland system in a more mature form: + 1 year.)

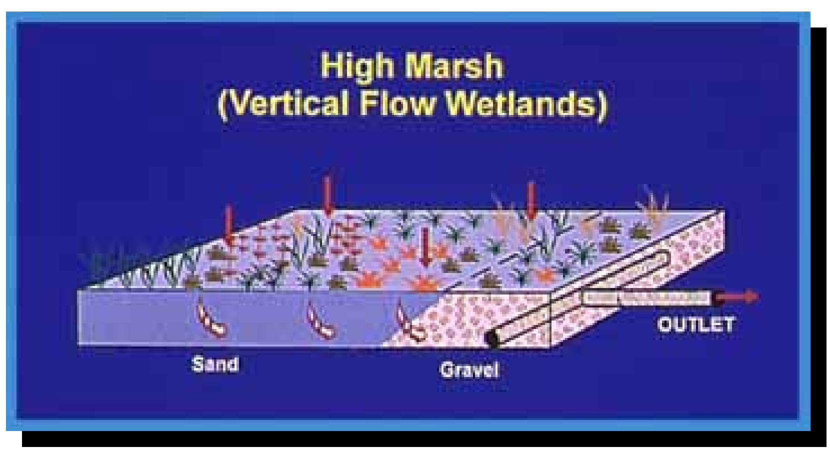
Many vegetative species known as halophytes are able to tolerate elevated salt levels or alkalinity. Reed grasses, salt grasses, saltbush and shore grasses, for example, are able to accumulate sodium, potassium, and chloride ions with no deleterious effects on the plants survivability (University of California: Los Angeles, 2002). Several common mangroves distributed in salt marshes go one step farther by secreting salts from their leaves. Although these plants are not likely able to counter the effects of SAR on soil, or alkalinity on water quality, they would help sustain wetland systems for many years.

In order to maximize water conservation, many communities are incorporating wetlands into their wastewater treatment program for the purpose of augmenting local water supplies. Not only does this reclamation process create additional habitat, it also significantly lowers water demands on existing water sources (Schwartz and Olsen, 1996). A reclamation program in Florida was designed to provide 60 to 100 million gallons of water to the Everglades during the dry season, while at the same time satisfying urban water supply demands. CBM produced waters received by wetlands could be used in a similar manner to recharge depleted aquifers and increase groundwater availability for beneficial use.

From an industrial perspective, constructed wetlands have historically been created to supplement wastewater treatment technologies. Although the wetland treatment process is less efficient when compared to conventional treatment processes, the application of this technology is widespread because of low costs and associated wildlife benefits (Schwartz and Olsen, 1996). Wetland treatment systems reproduce the natural filtering aspects observed in wetland settings by removal of organic matter (carbon, nitrogen, and phosphorus), suspended matter, and certain pathogenic elements. Traditionally, artificial wetland systems have been constructed based on two natural water filter principles: vertical flow or horizontal flow.

In a vertical flow wetland system, wastewater seeps from the surface to the subsurface, usually consisting of soils containing a mixture of sand and gravel (Figure 5-20). The vertical system is an aerobic process used primarily to remove BOD, phosphorus, and to oxidize nitrogen. The horizontal wetland system is a facultative aerobic or anaerobic process, depending on the time and frequency of inundation, where water flows from one side of the system to the other. This type of constructed system is typically used to remove BOD, to disinfect, to filter finely and remove specifically by precipitation, ionic exchange, and/or adsorption. Vertical systems or subsurface flow systems, in general, are more efficient at filtering or treating water and/or soil because of an increase in the presence of bacteria, and their subsequent ability to degrade pollutants in an aerobic environment. In general for organic waste treatment, the average lifespan of a constructed wetland is approximately 20 years (Shutes, 2001).

Figure 5-20
Vertical Flow Wetland
Diagram of a vertical flow wetland.



Source: Water Recycling, 1997.

Many studies unrelated to CBM produced waters have indicated wetlands can effectively treat for heavy metals, total dissolved solids, and biological. In the above-discussed Marathon oil study, results after one year of operation indicated the wetland system could effectively treat iron and possibly barium, but not SAR. Initial iron concentrations of 270 µg/L and initial barium concentrations of 300 µg/L were reduced to 100 µg/L and 200 µg/L, respectively. SAR increased from 12.1 to 14.1 during the initial year, a fact investigators attributed to calcite precipitation without the associated soil dissolution of calcium and magnesium (Sanders et al, 2001). Researchers in the study concluded an increase to iron and barium loading rates received by the wetland system would be necessary to ascertain the system's filtering potential. They also concluded reduction of SAR is not a useful wetland function based on one year treatment data results. A report by Montanan State University further supported these results, concluding "clean water" is needed to supplement sodicity and saline treatment by vegetation and soil (Bauder, 2002).

Potential Constraints

If CBM produced water is discharged into pre-defined upland areas, the USACE does not have jurisdictional authority under section 404 of the Clean Water Act. The USACE does have authority, however, if CBM discharges are used to enhance and/or restore a pre-existing wetland system, or if the produced water is used to supply a constructed wetland system located in bottomlands, which is characterized as a wetland. Pertinent state programs under Section 401 parallels jurisdictional authority granted by Section 404 of the Clean Water Act.

The location of the wetland system would need comprehensive evaluation prior to commencement of any development. The created wetland system would be susceptible to water level fluctuations being caused especially in semi-arid regions by changes in pumped water demands during the CBM extraction process. Fluctuations in water levels would adversely impact hydric vegetation and reduce the system's ability to uptake nutrients and filter sediment. Ultimately, this loss of function would result in unusable habitat for various terrestrial and aquatic wildlife species. Additional water sources may be necessary to sustain certain systems if the wetland is not constructed in a hydric favorable environment.

Upon cessation of CBM operations the wetland system would stop receiving produced waters. Again, additional water sources would be required to sustain an impoundment of this type. The construction of the wetland near naturally occurring, unutilized springs or streams could help alleviate this issue. In situations where additional water sources were not available, limiting the size of the pond to reduce future impacts observed by the wildlife community may be necessary.

The discharge of untreated CBM produced waters caused during flooding or heavy rain events would be limited since wetlands are able to naturally retain floodwaters. Nonetheless, discharges to adjacent lands or water bodies are possible and would need further consideration. Proper damming techniques or water control devices in regions with frequent flooding events could be utilized to reduce potential discharges.

The long-term effects of SAR on soil permeability could hinder wetland function. The accumulation of certain constituents present in CBM produced waters could reach toxic levels if not properly controlled. Depending on the climate and local soil type(s), the addition of calcium and magnesium to the system may be necessary. Deep tillage, although not practical, could also be used to reduce SAR levels. The addition of lime may also be required to counter the effects of carbonates.

Data Needs

Constructed wetlands will likely require the collection of additional data related to the following:

- Water Chemistry: The effects of SAR and carbonates on wetland systems may not adversely impact long-term function. The impacts, if any, would depend on water quality, the type of wetland, topography, local soil types, and other variables. Additional data is needed to properly address long term constituent exposures as they relates to wetland function.

- Water Quantity: As with other constructed wildlife use impoundments, the eventual loss of produced waters could significantly hinder the wetlands long-term function. One possible solution to this problem would be to locate impoundments near unutilized water sources for future use. Additional research and data collection by local authorities would be necessary to evaluate the feasibility of the premise. Limiting the size of the pond, and therefore lowering water demands, may also help reduce function loss. The applicability of this concept is unknown and would require additional data.

Economics

The construction costs for artificial wetlands have been well documented nationwide. However, costs can vary depending on landowner requirements and site characteristics such as topography, geology, hydrology, and climate. If the wetland is constructed in areas with appropriate soil and hydrology disposition, construction costs should be reduced, whereas, site conditions requiring amendment of soils or hydrology enhancement would accrue higher construction costs. Pre-treatment, if necessary, and maintenance costs will vary depending on the quality of water supplying the system. Produced water containing high TDS, SAR, bicarbonates, etc. values would likely require pre-treatment and, thus, increase the overall costs for operating and maintaining the impoundment.

Secondary Impoundment Uses

The potential to use impoundments for secondary or multiple water management uses would largely depend on the principle objectives of the impoundment type, landowner needs, pertinent regulations, and the quality of the supplied water. Project specific evaluations for each situation would be critical prior to impoundment construction and implementation. The matrix below indicates potential secondary beneficial uses for primary impoundment types highlighted in this document (Table 5-6).

The primary use of a constructed pond receiving produced water in most cases would have specific disposal or discharge permitting requirements. Secondary uses associated with that pond may or may not be covered under the authority of that permit. For example, the Montana Department of Environmental Quality through the proposed CBM Produced Water Discharge Permit would be authorized to permit CBM produced water specifically used for livestock or wildlife watering. In the event these wildlife-watering ponds were also functioning, for example, as fisheries, wetlands, or recharge ponds, either by natural or artificial design, other permitting requirements from other state agencies would need consideration.

The quality of CBM produced water will vary depending on the source and may dictate primary and secondary uses. Evaporation ponds receiving low quality produced water would require impermeable lining to prevent water infiltration to the groundwater system. In this particular situation, secondary uses would be limited. Given the appropriate situation, however, evaporation ponds receiving high quality produced water could potentially function as recharge ponds to re-supply depleted coal seam aquifers.

Wetlands are considered by most to be highly productive, flexible ecosystems, and providing suitable water, if available, would likely have the greatest potential to offer secondary beneficial uses. Wetlands throughout the country are being utilized as recharge ponds to help alleviate increasing public water demands. When considering these systems are naturally capable of supporting viable fish, waterfowl, and other wildlife populations, they could provide significant benefit to many comminutes while at the same time functioning in multiple capacities.

Consideration should be made to including multiple uses when designing and constructing impoundments. Impoundments with multiple uses serve not only to benefit operators by increasing the volume of water that could be potentially managed, but also by benefiting landowners and local population with uses. In some cases, multiple uses could potentially conflict with one another resulting in decreased operation and function. Surface impoundments used for evaporation or flood control, for example, could also function as a wetland and irrigation supply system, respectively, without impacting certain functions.

Table 5-6
Impoundment Beneficial Use
Primary impoundment types versus secondary beneficial use.

Impoundment Type	Wildlife Watering	Fisheries	Recharge Ponds	Recreation	Evaporation Ponds	Wetlands
Wildlife Watering	√	√	√			√
Fisheries	√	√		√		√
Recharge Ponds	√		√	√	√	√
Recreation		√	√	√		√
Evaporation Ponds			√		√	
Wetlands	√	√	√	√		√

Surface Discharge

Introduction

Surface discharge involves release of produced CBM water onto the earth's surface, either to surface water or surface soil. Surface discharge is a water management option that that allows CBM water to augment stream water flow. Increasing stream water flow will enhance the entire riparian area and provide additional water resources to support agriculture. Releases to surface water resources must be carefully managed to maintain the water quality standards and to avoid excessive riparian erosion. The specific amount of CBM water that can be managed by surface discharge will depend upon the existing character of the stream and the quality of the CBM water.

Surface discharges may occur in a variety of ways; however, three basically different alternatives have been selected for this analysis, as follows:

- *Direct discharge to surface waters*. By this alternative, CBM water is delivered to a stream by pipeline or dry drainage where it mixes with existing stream flow.
- *Discharge to surface soil with possible runoff to surface water.* This alternative involves release and management of CBM water through different irrigation techniques. Specific management and site conditions will determine the rate of CBM water that can be discharged to the surface, as well as the possibility of any runoff and subsequent discharge to surface water. If irrigation and runoff rates are high, significant volumes of CBM water can enter and mix with surface water.
- *Discharge to surface impoundments with possible infiltration into the subsurface and surface water.* In this alternative, CBM water is managed through evaporation and infiltration into subsoil and bedrock aquifers. When CBM water enters a shallow aquifer, the water could migrate to surface water.

Management of the three alternatives defined above allows operators to discharge significant volumes of CBM water that will be available for beneficial use, with minimal impact on the environment.

Regulatory and Legal Background

Federal and state regulations affecting surface discharge are in place to safeguard surface water resources. Regulatory programs vary for any given state or region; and, as is often the case, agencies can exercise some discretion when applying their programs, provided that relevant regulatory requirements are met. The following discussion is a summary of federal and state regulations that may impact the surface discharge of CBM produced waters.

Clean Water Act

Growing public awareness and concern for controlling water pollution led to enactment of the Federal Water Pollution Control Act Amendments of 1972. As amended in 1977, this law is commonly known as the Clean Water Act (CWA). The CWA established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave EPA the authority to implement pollution control programs, including wastewater standards for industry. The CWA also continued previously established requirements to set water quality standards for all contaminants in surface waters, making the discharge of any pollutant from a point source into navigable waters illegal, unless a permit was obtained under its provisions.

NPDES Permit

The CWA requires that all discharges of pollutants to surface waters be permitted under the NPDES. The Water Permits Division (WPD) within the EPA's Office of Wastewater Management manages the NPDES permit program in partnership with EPA Regional Offices, states, and tribes. Individual NPDES permits can be issued to specific facilities or general NPDES permits can be issued that cover all similar facilities within a geographic area. Most states have been delegated the authority to administer the NPDES program; consequently permits must follow not only the federal regulations, but also any relevant state requirements. Discharge permits covering Indian lands are frequently administered by the EPA. NPDES permitting requirements for CBM produced water will vary from state to state, but in general would largely depend on the quality of water and eventual use of the water.

Types of NPDES Permits

A permit is typically a license for a facility to discharge a specified amount of waste water into a receiving water body under certain conditions. The two basic types of NPDES permits issued are individual and general permits.

Individual Permit

An individual permit is a permit specifically tailored to an individual facility. Once a facility submits the appropriate application(s), the permitting authority develops a permit for that particular facility based on the information contained in the permit application (e.g., type of activity, nature of discharge, receiving water quality). The authority issues the permit to the facility for a specific time period (not to exceed five years) with a requirement that the facility re-apply prior to the expiration date.

General Permit

A general permit covers multiple facilities within a specific category. General permits may offer a cost-effective option for permitting agencies because of the large number of facilities that can be covered under a single permit. According to the NPDES regulations in 40 CFR Section l22.28, general permits may be written to cover categories of point sources having common elements, such as:

- storm water point sources;
- facilities that involve the same or substantially similar types of operations;
- facilities that discharge the same types of wastes or engage in the same types of sludge use or disposal practices;
- facilities that require the same effluent limits, operating conditions, or standards for sewage sludge use or disposal; and
- facilities that require the same or similar monitoring.

General permits, however, may only be issued to operators within a specific geographical area such as city, county, or state political boundaries; designated planning areas; sewer districts or sewer authorities; state highway systems; standard metropolitan statistical areas; or urbanized areas.

By issuing general permits, the permitting authority allocates resources in a more efficient manner to provide timelier permit coverage. For example, a large number of facilities that have certain elements in common may be covered under a general permit without expending the time and money necessary to issue an individual permit to each of these facilities. In addition, using a general permit ensures consistency of permit conditions for similar facilities. Some states have issued general permits for discharge of CBM waters, as discussed later in this section.

Primacy Process

EPA allows states, Indian tribes, and territories to have "primacy" to operate specific programs in accordance with federal law. To receive primacy or delegation, states must adopt state regulations that are at least as stringent as the federal regulations, and assume responsibility for ensuring compliance with federal and state requirements. The state must also demonstrate that the state agency administering and enforcing the program has appropriate statutory authority. Additionally, the state must enter into a memorandum of understanding with the EPA to assume primacy. The federal requirements are contained in section 402 (b) of the CWA and 40 CFR Part 123. Currently (2003), all but six states (Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico) have primacy for the NPDES program.

States requesting authorization to administer the NPDES program must submit a letter from the state's governor to EPA requesting review and approval, a Memorandum of Agreement (MOA), a Program Description, a Statement of Legal Authority, and the underlying state laws and regulations. The EPA will then render a decision to approve or disapprove the program.

The NPDES Program consists of various components, including:

- NPDES Base Program for municipal and industrial facilities,
- federal facilities,
- general permitting,
- pretreatment program, and
- biosolids.

A state may receive authorization to administer and enforce one or more of the NPDES Program components. For example, if the state had not received authorization for federal facilities, EPA would continue to issue permits to federal facilities (e.g., military bases, national parks, federal lands, etc.) and the state would administer the other components.

The process of authorization includes a public review and comment period, and a public hearing. If EPA disapproves the program, EPA remains the permitting authority for that state, tribe, or territory. If EPA approves the program, the state assumes permitting authority in lieu of EPA. All new permit applications would then be submitted to the state agency for NPDES permit issuance. Certain permits issued prior to authorization may continue under EPA administration as set in the MOA. Even after a state receives NPDES authorization, EPA continues to issue NPDES permits on tribal lands (if the tribe is not administering its own approved NPDES Program).

Other NPDES Permit Conditions

Individual facilities are generally responsible for demonstrating compliance with NPDES permit limits. Permits instruct each facility operator on the frequency for collecting wastewater samples, the location for sample collection, the pollutants to be analyzed, and the laboratory procedures to be used in conducting the analyses. Detailed records of these "self-monitoring" activities must be retained by the facility for at least three years. Facilities are required to submit the results of these analyses to the EPA or state agency (with primacy) on a periodic basis. For most facilities, the reporting frequency is monthly or quarterly, but in no case may it be less than once per year. Failure to meet the permit limits can result in fines or loss of the permit.

NPDES permits may also include operational or environmental effects monitoring requirements. Examples of these include preparing best management practices plans or spill prevention plans; conducting additional monitoring of the discharges, sediments, or fish tissues; and restrictions on the rate of discharge based on the receiving water flow.

Effluent Limitations Guidelines

The heart of a NPDES permit, whether EPA or state-administered, is its numerical effluent limits describing what pollutants must be monitored and what is an acceptable discharge of these pollutants. Effluent limits are established after considering both (a) technology-based limits developed to comply with applicable effluent limitations guidelines (ELGs) and (b) water quality-based limits. ELGs are national technology-based minimum discharge requirements developed by the EPA on an industry-by-industry basis and represent the greatest pollutant reductions that are economically achievable by that industry sector. Selection of ELGs involves consideration of available technologies, economic impacts, and other associated environmental impacts. ELGs are applied uniformly to every facility within the industrial sector, regardless of where in the country the facility is located or the condition of the water body receiving the discharge.

For the oil and gas industry, the EPA developed ELGs in 1979 and compiled them into 40 CFR Part 435. Three subcategories of Part 435 deal with onshore activities.

- ***Subpart C*** establishes that no discharges of produced water are permitted while the other two subparts provide exceptions.
- ***Subpart E*** is the agricultural and wildlife water use subcategory. This applies to facilities located in the continental United States west of the 98th meridian, for which produced water is clean enough to be used for wildlife and livestock watering or other agricultural uses. The 98th meridian extends from near the eastern edge of the Dakotas through central Nebraska, Kansas, Oklahoma, and Texas. Produced water with a maximum oil and grease limit of 35 mg/L may be discharged from such sites. One caveat to this subcategory is that the produced water must be of good enough quality to be used for wildlife or livestock watering or other agricultural uses, and must actually be put to such use during periods of discharge.
- ***Subpart F*** is the stripper subcategory that applies to facilities that produce 10 barrels per day or less of crude oil. The EPA has published no national discharge standards for this subcategory, effectively leaving any regulatory controls to states or EPA regional offices, depending on which has NPDES primacy. The EPA's decision to provide an exception for small oil wells reflects the economic burden that an across-the-board zero discharge standard would impose. The stripper subcategory is inconsistent in that it applies only to oil wells and not to marginal gas wells (typically defined as producing 60 mcf per day or less). In the absence of any regulatory exception for marginal gas well discharges, such discharges are apparently prohibited by the general onshore standards of 40 CFR 435.

Permit writers may face situations in which no ELGs have been developed for specific industries, industry segments, or particular waste streams. In these circumstances, the permit writer must use their best professional judgment (BPJ) to develop an ELG-equivalent technology-based limit. Under a BPJ permit, the permit writer can start from scratch or can borrow limits from other ELGs that have some relevance to the situation under consideration (Veil, 2002).

Anti-degradation

The 1972 amendments to the CWA include Section 303(d) requiring states to develop lists of water bodies that do not meet water quality standards and to submit updated lists to EPA every two years. Water quality standards, as defined in the Code of Federal Regulations, include beneficial uses, water quality objectives (narrative and numerical), and anti-degradation requirements. The Regional and State Board develop impaired water body lists in a public process. EPA is required to review impaired water body lists submitted by the state, approve or disapprove all or part of the list, and add additional water bodies. The EPA approval process is a public process, allowing the public to comment.

The CWA also requires states to protect their high quality waters from further degradation. To meet that goal, the CWA mandates that states adopt anti-degradation policies to prevent any further lowering of water quality in high quality rivers, streams and wetlands unless facilities are first able to satisfy a stringent cost/benefit analysis and open public review.

Tongue River, Wyoming

Each state must develop and adopt an anti-degradation policy that is consistent with the federal policy. The anti-degradation policy can be identical to the federal policy, or it can be more specific and more protective, but it must not be any less specific or protective. States must also develop a system for implementing the policy. This system should ensure that the state's major programs, decisions, and day-to-day activities affecting water quality and aquatic ecosystem health will be consistent with all tiers of its anti-degradation policy.

Streams are placed into one of three or four "tiers" of protection, depending on the state (most have three tiers). Each tier has specific criteria for protection. For example, streams protected under Tier 3 receive very strict reviews. Water in these Tier 3 streams cannot be degraded and discharge activities in these watersheds will be closely scrutinized. Streams receiving Tiers 1 and 2 designations will not be so restrictive in discharge effluent limits, but activities causing discharges into these streams will still be carefully reviewed.

Total Maximum Daily Loads

The Clean Water Act requires each state to develop a list of impaired streams, rivers, and lakes which do not currently meet the water quality standards necessary for their designated category.

Such impaired waters are placed on the 303(d) list and are targeted as waters that must be given a pollutant load reduction plan, or total maximum daily loads (TMDL). The TMDL is a pollution reduction plan which allocates amounts of pollutants that may be discharged from a point or non-point discharge source to reduce the total amount of pollutant in the stream.

Entities holding NPDES permits may be given lower effluent limits to reduce the total amount of pollutant in the stream from that source. TMDLs must document the nature of the water quality impairment, determine the maximum amount of a pollutant which can be discharged and still meet standards, and identify allowable loads from the contributing sources. The elements of a TMDL include a problem statement, description of the desired future condition (numeric target), pollutant source analysis, load allocations, description of how allocations relate to meeting targets, margin of safety, and a program of implementation, including monitoring.

Water Rights

Surface discharge regulations are intimately intertwined with water rights issues. CBM produced water can sometimes be permitted through state or federal agencies to discharge into water bodies or to land surface. After discharge, the water often becomes part of the "waters of the state" or "waters of the nation", the use of which may require permitting through a new or existing water right. Water management by way of surface discharge techniques, therefore, may involve both discharge permits and water rights.

CBM water discharge regulations are often tied to water quality determinations, but water rights are connected to other legal concepts of property ownership and appropriation. In some states, water rights are of two separate categories – riparian and prior appropriation. Landowners on either side of a river may be automatically entitled by state law to use a part of the river's flow volume for their own uses, depending upon the amount of riparian area owned. Riparian ownership determines the right to water withdrawal from the river or stream; however, riparian water rights are not usually involved in CBM issues.

Many arid western states have water rights that derive from prior appropriations, based upon the water doctrine of "first in time – first in right". The prior appropriation doctrine states that those individuals with the earliest priority dates have the primary right to use a given volume of water and those with later priority dates have secondary rights. Prior use can be defined in terms of several elements, the most important of which is beneficial use. Beneficial use requires proof by the water right applicant that the water will not be wasted. Beneficial use further requires the applicant to show that the water will be dedicated to a specific use defined by the individual state as an acceptable use that is recognized and protected by law. Beneficial uses of water have been the subject of debate and each western state has an evolving system for defining which uses are considered "beneficial."

Federal water rights can be reserved for future uses and, therefore, the priority date is the date of the reservation, not the date of first use. Future use is often quantified in terms of the primary purpose of the water reservation and then only for minimum requirements. Federal water rights can be very important when considering CBM discharges (see the Water Classifications and Rights section) on federal reservations. Many federal reservations were created during the settlement of the western United States, including Indian, military, national parks, forests, and monuments, making up a large portion of the land in the western United States.

Indian Lands

Under the *Winters*[4] doctrine of Indian water rights, water was implicitly reserved for tribal use whenever lands were set aside as reservations. Congress amended the CWA in 1987 to allow tribes to be "treated as states" for most purposes of the federal statute (CWA Section 518, 33 U.S.C. Section 1377(e)) when the tribes meet certain statutory requirements. Using the programs of the CWA, tribes may take primacy for setting water quality standards in reservation waters.

Tribes may regulate the discharge of pollutants from point sources located within the reservation by taking primacy for the NPDES permit program and issuing discharge permits for point sources within the reservation. Tribes may also regulate point source discharges indirectly under the Section 401 program. In general, if a tribe does not take primacy for the NPDES program, the EPA will issue discharge permits for point sources within the reservation; however, under Section 401, the tribe may review the federal permits for compliance with tribal water quality standards and either certify the permitted discharge, certify it with conditions, or refuse certification.

Tribes also have a voice in the regulation of off-reservation point sources located upstream of tribal territories. If the EPA issues NPDES permits within a state, the permit limitations must protect the water quality standards of downstream tribes[5]. Even if the state itself issues NPDES permits, the state is required by the CWA to consider the water quality standards of downstream tribes in setting effluent limitations. The state must provide notice to downstream tribes, and either accept or explain its rejection of any written recommendations provided by the tribes. If a downstream tribe is dissatisfied with the upstream state's decision, it may protest the state-issued NPDES permit.

State Specific

Regulations and water rights are the subject of differing agencies within the states where surface discharge of CBM water is likely to occur. Surface discharge regulations and attendant water rights are discussed below on a state-by-state basis for a limited number of states.

Alabama

In Alabama, CBM production began as a mine safety effort rather than as a mechanism to recover methane. Research in Alabama in the mid-1970s indicated that methane could be drawn out of coal seams by dewatering the seams. In the early 1980s, a group of Alabama producers petitioned the EPA for relief from the oil and gas ELGs (Veil, 2002). The producers argued that if the same coal bed was mined through conventional mining methods, the water associated with the seam could be discharged under a NPDES permit reflecting the coal mining ELGs. The EPA concurred with this position and further noted that when it had developed its onshore oil and gas ELGs, it had not performed a technical or economic analysis of the CBM sector. Therefore, at least for Alabama, CBM produced water was not considered to be regulated under Part 435, and operators could discharge the produced water.

The Alabama Department of Environmental Management (ADEM) began issuing NPDES permits that were based on the coal mining ELGs and added other water quality-based limits.

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4 *Winters v. United States*, 207 U.S. 564 (1908).

5 *City of Albuquerque v. Browner*, 97 F.3d 415 (10th Cir. 1996).

The following paragraph summarizes portions of a May 1993 publication entitled "Coalbed Methane Produced Water Management Guide Treatment and Discharge to Surface Waters: Black Warrior Basin, Alabama."

> "In Alabama, the construction and operation of CBM wells are regulated by the State of Alabama Oil and Gas Board and CBM discharge permits are handled by the Water Division, Mining and Non-point Source Section of ADEM. Initial permits were based on total dissolved solids (TDS), and discharges were limited to an in-stream TDS concentration of 500 mg/l. As the number of CBM wells increased sharply in the mid to late 1980s, ADEM began to enact more stringent discharge requirements to protect the water quality of the Black Warrior River. In 1988, EPA published an Ambient Water Quality Criteria for chloride which established a National Chloride Criterion of 230 mg/l and ADEM then adopted rules whereby applicants were permitted to release produced waters into surface streams if the in-stream concentration of chloride beyond a mixing zone would not exceed 230 mg/l. However, because of the perceived difficulty in enforcing this standard the state developed a total loading criterion for CBM operations at the point of discharge. The allocation for each CBM operator was based on a calculated loading beginning at a point above the discharge, with additional allocations permitted downstream because of additional tributary waters provided dilution for additional chlorides. This procedure calculated the allowable mass loading [the number of pounds per day] for chlorides that will not exceed an in-stream concentration of 230 mg/l. These permits were later referred to as Tier I permits. To allow growth while still protecting aquatic resources, CBM operators and ADEM jointly developed guidelines for in-stream monitoring of chloride concentration as the basis for additional NPDES permits. These permits were called Tier II permits and were issued with in-stream chloride concentration limits rather than the mass limits used in Tier I permits."

Information collected in 1997 (Veil, 1997) indicates that ADEM uses a baseline permit that can be customized for discharges to small streams. The permit is detailed, containing numerical limits for pH, iron, manganese, biochemical oxygen demand, oil and grease, and dissolved oxygen; additional monitoring requirements for conductivity, chlorides, and effluent toxicity are included. Dischargers are required to install a diffuser on the end of their discharge pipes and to implement a best management practices plan.

Colorado

CBM produced water in Colorado is typically of poor quality, cannot be used for any beneficial use, and is considered a waste product by the state of Colorado. Only recently has some of the produced water been of sufficient quality for limited beneficial uses. Multiple agencies regulate and monitor different aspects of produced ground water, yet no agency oversees and integrates all aspects. Each agency has its own jurisdiction as established by state laws. At least three different agencies, the Colorado Oil and Gas Conservation Commission (COGCC), Colorado Drinking Water Division (CDWR), and Colorado Water Quality Control Division (CWQCD), have authority as it relates to the withdrawal, use, and/or disposal of water from a CBM well. The relationships between the constitutional provisions, statutory language, and various rules are extremely complex. CDWR is aware of overlapping jurisdictional issues between the COGCC and CWQCD. COGCC has authority over all oil and gas operations, including the generation, transportation, storage, treatment, or disposal of exploration and production wastes. The Colorado Department of Public Health and Environment (CDPHE) rules provide that no person shall discharge CBM produced water into waters of the state without first having obtained a permit from CWQCD for such discharge. The CDPHE and CWQD have currently issued 12 NPDES permits for CBM discharges (Veil, 2002).

<u>Allowed Beneficial Uses and Restrictions of Groundwater</u>

The following uses have been recognized as beneficial uses by CDWR: agriculture, mining, domestic, manufacturing, stock watering, wildlife watering, irrigation, industrial, mechanical, commercial, municipal, recreation, minimum stream flows, fire protection, and dust suppression (Wolfe and Graham, 2002). CDWR has jurisdiction over appropriations of water; an appropriation is defined as the application of a specified portion of the waters of the state to a beneficial use pursuant to the procedures prescribed by law. Waters of the state in this context means all surface and underground water tributary to natural streams, except groundwater designated by the CGWC.

The statutory and case law vests CDWR with jurisdiction over water withdrawn from a CBM well that is beneficially used. If an operator or another person wants to beneficially use water from a CBM well, that operator or person must comply with the Water Right Determination and Administration Act and the Ground Water Management Act (Water Rights Acts). The person can apply for a water right in water court and/or file for a well permit. If the person applies for a well permit for water from a CBM well, that water is presumed tributary, but the person may submit evidence such as engineering documentation that the water is nontributary. Regardless of whether the water withdrawn from a CBM well is nontributary or tributary, there are certain statutory requirements that the water user must meet before obtaining a well permit and/or a water court decree.

Any water discharged into waters of the state (as defined by the Water Quality Control Act) is subject to appropriation under the Water Rights Acts. CBM wells are not “wells” as defined in the Water Rights Acts, and operators do not need to obtain a permit from CDWR to withdraw water from these wells as part of the CBM extraction process. However, if water from a CBM well is put to beneficial use other than those uses allowed under COGCC Rule 907 (see below), then CDWR has certain jurisdiction over the water and the well, and the well is subject to the *Rules and Regulations for Water Well Construction, Pump Installation, and Monitoring and Observation Hole/Well Construction (2CCR 402-2).*

<u>COGCC Rule 907</u>

Colorado statute grants authority to COGCC to promote oil and gas conservation, and rescinds the authority of any other agency as it relates to the conservation of oil and gas. CBM produced water is considered a waste product by operators and must be properly disposed of to prevent adverse environmental impacts. Pursuant to COGCC rules, an operator may dispose of water from a CBM well in any of the following ways:

- inject it into a disposal well;
- place it in a properly permitted lined or unlined pit for evaporation and or percolation;
- dispose it at a permitted commercial facility;
- dispose of it by road spreading on lease roads outside sensitive areas for produced waters;
- discharge it into waters of the state in accordance with the Water Quality Control Act and the rules and regulations promulgated thereunder;

- reuse it for enhanced recovery, recycling, and drilling; or
- mitigation to provide an alternate domestic water supply to surface owners within the oil and gas field (Wolfe and Graham, 2002).

Ground Water Permitting by CDWR

Under Colorado law, CBM operators are not required to obtain a permit from the State Engineer when withdrawing nontributary water unless the produced water is put to a beneficial use. The State Engineer has authority to issue permits outside designated basins in accordance with Section 37-90-137(7), Colorado Revised Statutes (2002), which is restated as follows:

> In the case of dewatering of geologic formations by removing nontributary ground water to facilitate or permit mining of minerals: (a) No well permit shall be required unless the nontributary groundwater being removed will be beneficially used; and, (b) In the issuance of any well permit pursuant to this subsection (7), the provisions of subsection (4) of this section shall not apply. The provisions of subsections (1), (2), and (3) of this section shall apply; except that, in considering whether the permit shall issue, the requirement that the state engineer find that there is unappropriated water available for withdrawal and the six-hundred-foot spacing requirement in subsection (2) of this section shall not apply. The state engineer shall allow the rate of withdrawal stated by the applicant to be necessary to dewater the mine; except that, if the state engineer finds that the proposed dewatering will cause material injury to the vested water rights of others, the applicant may propose, and the permit shall contain, terms and conditions which will prevent such injury. The reduction of hydrostatic pressure level or water level alone does not constitute material injury.

In the context of this section, the State Engineer considers CBM gas a mineral. As stated above, if groundwater produced from a CBM well is determined to be non-tributary, the amount of water claimed is not based on overlying land ownership. If nontributary groundwater is produced to the surface and discharged, it may be subject to CWQCD regulation. For water rights purposes, all groundwater in Colorado is presumed to be tributary unless there has been a ruling by the water court or a permit issued by the State Engineer that groundwater from a certain aquifer in a specific area is declared nontributary. Any use of tributary groundwater is subject to section 37-90-137(1) and (2), CRS (2002).

Summary

Due to the complex and overlapping regulatory authority of state agencies in Colorado, many companies are collaboratively working with local residents, concerned citizens, and state agencies to minimize impacts of CBM production. The CDPHE, COGCC, and the CDWR have only recently coordinated efforts to understand the conflicts in regulatory authority and decision-making. These efforts have resulted in many public awareness meetings that include both the general public and legislative committees on oil and gas, resulting in the COGCC adopting new rules and regulations to clarify jurisdictional issues of CBM produced water.

Montana

Surface discharge of CBM produced water in Montana is regulated by the Montana Board of Oil and Gas Conservation (MBOGC) and the Montana Department of Environmental Quality (MDEQ), with the EPA overseeing Indian Lands. Prior appropriations water rights dating from before June 30, 1973, are adjudicated by the Montana Water Court, a division of state district court. Appropriations dating from that date forward are the jurisdiction of the Water Resources Division of the Montana Department of Natural Resources and Conservation (DNRC).

The MBOGC regulates surface discharge of produced water under Annotated Rules of Montana (ARM) 36.22.1226 *Disposal of Water* "(1) Produced water containing 15,000 parts per million (ppm) or less total dissolved solids (TDS) may be retained and disposed of in any manner allowed by law that does not degrade surface waters or groundwater or cause harm to soils." Surface discharge of produced water must be via permit in accordance with ARM 36.22.1227 *Earthen Pits and Ponds*. CBM operators are usually producing water considerably less than 15,000 mg/L, which is the MBOGC threshold for lined impoundments. As such, the permit will require construction of the impoundment to adequately protect surface and groundwater resources. The application to the MBOGC for construction of the impoundment will include a topographic map and construction details to demonstrate protection of surface water resources in the area. The application and permit will also specify that the impounded water cannot be used for a beneficial use except watering of livestock. Under Montana Water Law as stated in the 2001 Montana Code Annotated (MCA) 85-2-306 (3), an impoundment on any source other than a perennially flowing stream of less than 15 acre-feet in size is exempt from water right application if its only beneficial use is livestock watering. Any other use will require an MDEQ surface discharge permit and an application and award of a Beneficial Water Use Permit and Certificate of Water Right.

When there is discharge of CBM water where beneficial use is to be allowed, the MDEQ will permit the facility and an applicable water right must be applied for and awarded. On federal, state, and fee lands where the MDEQ has authority, adherence must be paid to the state's Nondegredation Policy as spelled out below:

> **75-5-303. Nondegradation Policy.**
> (1) Existing uses of state waters and the level of water quality necessary to protect those uses must be maintained and protected.
> (2) Unless authorized by the department under subsection (3) or exempted from review under 75-5-317, the quality of high-quality waters must be maintained.
> (3) The department may not authorize degradation of high-quality waters unless it has been affirmatively demonstrated by a preponderance of evidence to the department that:
>
> > (a) degradation is necessary because there are no economically, environmentally, and technologically feasible modifications to the proposed project that would result in no degradation;
> >
> > (b) the proposed project will result in important economic or social development and that the benefit of the development exceeds the costs to society of allowing degradation of high-quality waters;
> >
> > (c) existing and anticipated use of state waters will be fully protected; and
> > (d) the least degrading water quality protection practices determined by the department to be economically, environmentally, and technologically feasible will be fully implemented by the applicant prior to and during the proposed activity.
>
> (4) The department shall issue a preliminary decision either denying or authorizing degradation and shall provide public notice and a 30-day comment period prior to issuing a final decision. The department's preliminary and final decisions must include:
>
> > (a) a statement of the basis for the decision; and

(b) a detailed description of all conditions applied to any authorization to degrade state waters, including, when applicable, monitoring requirements, required water protection practices, reporting requirements, effluent limits, designation of the mixing zones, the limits of degradation authorized, and methods of determining compliance with the authorization for degradation.

(5) An interested person wishing to challenge a final department decision may request a hearing before the board within 30 days of the final department decision. The contested case procedures of Title 2, chapter 4, part 6, apply to a hearing under this section.

(6) Periodically, but not more often than every 5 years, the department may review authorizations to degrade state waters. Following the review, the department may, after timely notice and opportunity for hearing, modify the authorization if the department determines that an economically, environmentally, and technologically feasible modification to the development exists. The decision by the department to modify an authorization may be appealed to the board.

(7) The board may not issue an authorization to degrade state waters that are classified as outstanding resource waters.

(8) The board shall adopt rules to implement this section.

Discharge point on the Tongue River, Montana

Permits for surface discharge are regulated under the Montana Pollutant Discharge Elimination System (MPDES) whose purpose is to establish and implement a common system for issuing permits controlling point sources discharging pollutants into state waters. MPDES is intended to allow the Montana Board of Environmental Review and the MDEQ to administer a pollutant discharge permit system which is compatible with the NPDES as established by EPA, controlling discharges to the waters of the state. Approximately 24 existing discharge permits have been issued to conventional oil and gas operators to discharge produced water to surface impoundments under ARM 17.30.1341(f) General Permits Sort Form C. This general permit allows operators to discharge produced waters to the land surface. Permit conditions are closely defined in terms of discharge rate, discharge water quality, and receiving facility.

CBM operators can also discharge under the MPDES program. At the present time, CBM produced water must be the subject of an individual permit, but a Draft General Permit Application has been issued. The general permit allows the operator to discharge CBM water to an impoundment that is sufficiently protective of surface and groundwater resources. The Draft General CBM Discharge Permit Application contains the following preamble:

> "In compliance with Section 75-5-101 et seq., MCA, and ARM Title 17, Chapter 30, Subchapters 6, 7, 12, and 13. Owner or operators of coal bed methane point sources are authorized to discharge produced water resulting from natural gas production wells to holding ponds for the purpose of the prescribed beneficial use. Discharges to other any other state water is not authorized except in conformance with the terms and conditions of this permit and an accompanying letter of authorization. The use of holding ponds for the prescribed beneficial use shall be in accordance with effluent limitations, monitoring requirements, and other conditions set forth herein. A written authorization letter from the Department is required before an applicant is authorized to discharge under the Coal Bed Methane Produced Water-General Permit."

Wyoming

The Wyoming Department of Environmental Quality, Water Quality Division (WDEQ/WQD); the Wyoming State Engineers Office (WSEO); the Wyoming Oil and Gas Conservation Commission (WOGCC); and the BLM regulate surface discharge of CBM produced water in Wyoming.

The state of Wyoming obtained primacy for water quality from the EPA in 1974; therefore, the WDEQ's WQD established a NPDES Point Source Program. In order to commence discharging wastes into the waters of the state (which includes all permanent and intermittent defined drainages and lakes, reservoirs, and wetlands which are not manmade retention ponds used for the treatment of municipal, agricultural, or industrial waste), Chapter 2 of WQD's Rules and Regulations requires the operator to file a NPDES permit application and obtain a NPDES permit. Before a NPDES permit can be issued, the proposed permit must be published as a 30 day public notice to allow for public comment. Discharges of pollutants, including CBM produced water, to areas such as fields or roads, which are not considered to be waters of the state, are not regulated under the NPDES program, but are deferred to the WOGCC.

The WDEQ has issued individual NPDES permits and general NPDES permits that cover many similar discharges in the same geographic area. Currently, the WDEQ has issued approximately 600 NPDES permits for CBM discharges covering nearly 3,000 different discharge points (Veil, 2002). WDEQ first issued a statewide general permit that had relatively stringent limits. So far, only five to ten companies have applied for coverage under this general permit and most companies have sought individual permits.

Within the general NPDES permitting process, there are two categories: temporary and off-channel containment units. The temporary permit allows for the collection of information to be included in the application for individual permits and shall not exceed five days. The NPDES permit authorizes discharge to the surface, as long as the effluent quality is in compliance with Wyoming's produced water criteria (Chapter 7, Rules and Regulations) and Water Quality Standards. A wildlife or agricultural beneficial use must be stated or a NPDES permit will not be issued because individual permits rely on EPA's agricultural and wildlife use subcategory ELGs as the technology basis. The individual permit is site-specific and is determined by CBM water quality and proximity of downstream irrigation use.

In order for a NPDES permit to be issued, a representative water sample must be submitted and pass the effluent limitations established by the WDEQ. Different requirements are established for discharge to on-channel and off-channel structures. The WDEQ regulates surface discharge of CBM produced water under Wyoming Surface Water Quality Standards, Implementation

Policies for Anti-degradation, Mixing Zones, Turbity, and Use Attainability Analysis effective November 28, 1975. Safeguards for storm water and construction related activities state that changes in water quality will be limited to temporary increases in turbidity and that increases will be limited to those allowed in Section 23 of Chapter 1, Water Quality Rules and Regulations. Currently, if greater than 5 acres of land have surface disturbance during construction of an oil and gas project, a Storm Water Permit and a Storm Water Pollution Prevention Plan (SWPPP) are required. The area of disturbance was reduced to 1 acre in January, 2003, which means that almost all oil and gas and CBM projects will be required to have a Storm Water Permit and an SWPPP.

The WSEO is responsible for water rights associated with groundwater and surface water. When a water well is registered, groundwater rights are appropriated as determined by 'beneficial use'. The WSEO has different criteria for beneficial use than the WDEQ, which sees beneficial use as pertaining to wildlife or agriculture (per EPA definition). The WSEO classifies beneficial use as also including dust suppression, fisheries, land application, aquifer recharge, etc. WSEO standards dictate that as soon as the groundwater encounters the ground surface it becomes surface water, i.e. waters of the state, and is appropriated through the surface water division of the WSEO. The WSEO also permits all on-channel water containment structures and off-channel containment structures having beneficial use. If there is no associated beneficial use, other than methane production, the WSEO does not require permits for off-channel containment structures, nor does it issue any associated water rights. If a containment structure has the intended use of treatment of CBM-produced water, then the WSEO requires that the beneficial use be filed as Industrial Pollution Control and a Form SW-3 must be submitted.

In order to discharge into off-channel containment structures, a construction permit is also required from the WOGCC for fee and state leases, and the BLM for federal leases where federal action has been initiated, i.e. right-of-way or production of federal CBM water. The off-channel structures must be designed by a registered professional engineer in the state of Wyoming, bonded for remediation/closure at the end of CBM water production, and constructed such that the CBM-produced water does not enter 'waters of the state'. An 'umbrella' document outlining the "Permitting Requirements Associated with Off-Channel Containment Pits" was finalized by the WDEQ on October 14, 2002. Another article titled "Off-Channel, Unlined CBM Produced Water Pit Siting Guidelines for the Powder River Basin, Wyoming", accepted August 6, 2002, includes siting criteria that recommends that CBM operators collect hydrogeologic information at each site to determine the following:

- the classification of shallow, unconfined groundwater (where present) as determined from existing use or ambient quality, or both, in accordance with Chapter 8 of WDEQ's WQD Rules and Regulations;
- ability of the produced water to diminish the use (i.e. suitability) of shallow, unconfined groundwater (where present);
- ability of the produced water to re-surface, or reach surface waters; and
- ability of the produced water pit to infiltrate into the subsurface.

The WDEQ primary concern is to insure that the class of use is not diminished and the secondary concern is water quality.

Technical Considerations

Discharge design, discharge permit applications, and discharge monitoring all require technical sophistication equal to the tasks of characterizing CBM discharge water, existing stream water, and the issues that are involved with mixing the solutions. Technical considerations include characterization, assimilative capacity, and total maximum daily load, described briefly here and in more detail later within this section. The technical considerations are important in order to maximize the volume of CBM water to be managed.

Characterization: Accurate characterizing and detailing the quantity and quality of stream water will enable the operator to discharge maximum volumes of produced water without exceeding water quality standards and degrading surface water resources.

Assimilative Capacity: This is a measure of the volume of contaminants that can be discharged to a stream without exceeding relevant standards or limits.

Total Maximum Daily Load: TMDL is a summation of the various pollutant loadings to a stream segment.

Surface discharge to stream
Powder River Basin

Common Terms

In order to better understand some of the discussion presented throughout this section, various parameters and terms are defined below.

1Q10: A statistical measure of the lowest daily flow rate expected to occur in a stream segment every ten years.

7Q10: A statistical measure of the lowest flow rate expected to occur in a stream segment over seven consecutive days every ten years.

Assimilative Capacity: The ability of a body of water to effectively degrade and/or disperse chemical substances. If the rate of introduction of pollutants into the environment exceeds its assimilative capacity for these substances, then adverse effects may result to habitat and wildlife (NDWR, 1999).

Base Flow: (1) The flow that a perennially flowing stream reduces to during the dry season. Flow during the dry season is from groundwater seepage into the channel. (2) The fair-weather or sustained flow of streams; that part of stream discharge not attributable to direct runoff from precipitation, snowmelt, or a spring. Discharge entering streams channels as effluent from the groundwater reservoir. (3) The volume of flow in a stream channel that is not derived from surface run-off. Base flow is characterized by low flow regime (frequency, magnitude, and duration daily, seasonally, and yearly), by minimum low flow events and in context of the size and complexity of the stream and its channel (NDWR, 1999).

Biota: Various components of the biological environment.

Electrical Conductivity and Total Dissolved Solids: Electrical conductivity (EC) is commonly used to estimate the amount of total TDS, or the total amount of dissolved ions in water. EC is defined as "the reciprocal of electrical resistance in ohm (Ω), in relation to a water cube of edge length 1 cm at 20ºC ". The specific EC unit is given in siemens per cm (S/cm), where S = Ω^{-1}. In practice, EC is often expressed in terms of millisiemens (mS) and microsiemens (μS) where:

$$S/cm = 10^3\ mS/cm = 10^6\ \mu S/cm$$

EC does not give specific information about the chemical species present in water, but it infers the TDS, which is a common indicator of relative water quality.

Erosion: Erosion is a potential planning issue that should be considered when soils or bedrock are friable and easily eroded. Under such conditions of vulnerability, discharge should be managed so as to avoid significant erosion.

Flow-Based Discharge: NPDES permits can be written to allow discharge rates that vary with flow in the stream. When flow rate is high then discharge rate can be high.

Infiltration: CBM water discharged to dry drainage may infiltrate into soil and bedrock. Coals, clinker beds, and sands, all present in the Fort Union Formation of the PRB and adjacent basins, often have sufficient porosity and permeability to accept water. The infiltrated water can enter the bedrock and migrate through the subsurface toward an aquifer or toward a spring.

Meteoric Water: Water derived primarily from precipitation.

Point Source: For purposes of the Clean Water Act, "Point Source" means any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill, leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agriculture storm water runoff.

National Pollutant Discharge Elimination System (NPDES): Program established by the *Clean Water Act (CWA)* that requires all *Point Sources (PS)* of pollution discharging into any "waters of the United States" to obtain a permit issued by the *U.S. Environmental Protection Agency (EPA)* or a state agency authorized by the federal agency. The NPDES permit lists permissible discharge rates and other operating, monitoring, and reporting requirements (NDWR, 1999).

Non-Point Source: Non-point sources are less obvious, more diffuse and challenge the traditional way of thinking about pollutants. They do not come from a specific point, but rather are comprised of runoff from city and suburban streets, construction sites, mining, logging, and agriculture. The pollutants may consist of sediments, nutrients, pathogens, oil, grease, and chemicals. Unlike point source discharges, accurately determining the extent and the source of non-point runoff is difficult.

Rate-Based Discharge: NPDES permits can be written to allow a single discharge rate throughout the year.

Sodium Adsorption Ratio: Sodium Adsorption Ratio (SAR) is the proportion of sodium (Na) ions compared to the concentration of calcium (Ca) plus magnesium (Mg) on a milliequivalent basis. The actual formula is as follows:

$$SAR = \frac{[Na^+]}{\sqrt{1/2\,([Ca^{2+}]+[Mg^{2+}])}}$$

Snowmelt: (1) The runoff from melting snow; (2) The net decrease in water equivalent of the snowpack after allowing for increases due to precipitation. It does not include water which refreezes or is retained as liquid water within the snowpack (NDWR, 1999).

Stream Type: Streams and rivers can be classified as perennial, intermittent, or ephemeral.

- *Perennial Streams* flow water from source to mouth throughout the year in most years.
- *Intermittent Streams* carry water only part of the time, generally in response to periods of heavy runoff either from snowmelt or storms; a stream or part of a stream that flows only in direct response to precipitation. It receives little or no water from springs or other sources. It is dry for a large part of the year, usually more than three months. Flow generally occurs for several weeks or months in response to seasonal precipitation, due to groundwater discharge,
- *Ephemeral Streams* flow for a few hours or days following a single storm. These streams frequently have a well-defined stream channel, flow only in direct response to precipitation, and thus discontinues its flow during dry seasons. Most of the dry washes of more arid regions may be classified as ephemeral streams. These features frequently do not have a defined stream channel (NDWR, 1999).

Data Sources

Several different types of data are relevant to the management and permitting of surface discharges. In today's high-tech environment, many data sources are publicly available and accessible via the Internet. Although this is not always the case, Internet data acquisition can often be a good starting point for research. Some important sources for environmental water quality are described below.

USGS:

Existing surface water quality is best documented through the USGS archives. The USGS maintains historical and real-time records on many surface water and groundwater monitoring stations throughout the fifty states. Much of this data is available on their website. Several different kinds of information are especially useful:

- Historical stream-flow data dating from the establishment of the gauging station. This data is useful for establishing monthly mean values in a particular stream segment.
- Water quality data is valuable for determining the monthly average quality data on a number of relevant parameters. Parameters will vary by the location. Physical and chemical parameters can be tied to stream-flow conditions in order to derive high-flow and base-flow characteristics.
- Real-time stream-flow data are automatically collected and made available for selected gauging stations. This data is valuable for managing a flow-based discharge plan whose discharge rate is tied to current stream-flow in the receiving stream.
- Groundwater data is also available through the USGS to determine groundwater depth, distribution, and quality. Occasionally, real-time groundwater levels are also available.

- Historical water-use statistics are available for several states.

State Agencies:
State agencies maintain various water files that contain information useful to the planning and management of surface discharge of CBM water.

- The Ground-Water Information Center (GWIC) at the Montana Bureau of Mines and Geology (MBMG) is the central repository for information on the ground-water resources of Montana. The data include well-completion reports from drillers, measurements of well performance and water quality based on site visits, water-level measurements at various wells for periods of up to 60 years, and water-quality reports for thousands of samples. The databases at GWIC are continually updated with new data from driller's logs, MBMG research projects, and research projects from other agencies.
- The MBOGC maintains two separate online data systems. These systems provide access to conventional oil and gas and CBM data, including production. The separate Internet GIS system provides access to spatial data sets.
- The Colorado Oil and Gas Conservation Commission maintains a database of produced water quality. The database also contains limited amounts of water well data. The COGCC also maintains oil and gas data in tabular and spatial formats.
- The Utah Division of Oil, Gas, and Mining maintains an on-line oil and gas data in tabular and GIS formats.
- The Wyoming Oil and Gas Conservation Commission maintains a database of produced water organized by formation and location.

Existing Surface Water Characterization
When planning surface discharge, site specific details of the quantity and quality of existing stream water must be considered. Knowledge of existing stream flow is also vital for planning surface discharge. Stream quantity and quality varies considerably across the country, from New York to Alaska; some rivers have strong base-flow throughout the year while other streams have limited base-flow and can go from strong flow to dry because they are driven by precipitation or perhaps snowmelt. Stream flow characterization parameters are tailored to individual streams in order to describe locally important aspects of the existing stream flow. Some rivers are highly seasonal in terms of water quantity and quality, when precipitation is also highly seasonal. Other streams carry important chemical constituents such as suspended sediments, dissolved salts, and volatile organic compounds that are supplied by local runoff or local industrial activity. Water managers will consider these and other characteristics of surface waters. Some aspects of surface water characterizations that are particularly important when planning surface discharge include flow rate, water quality, and assimilative capacity.

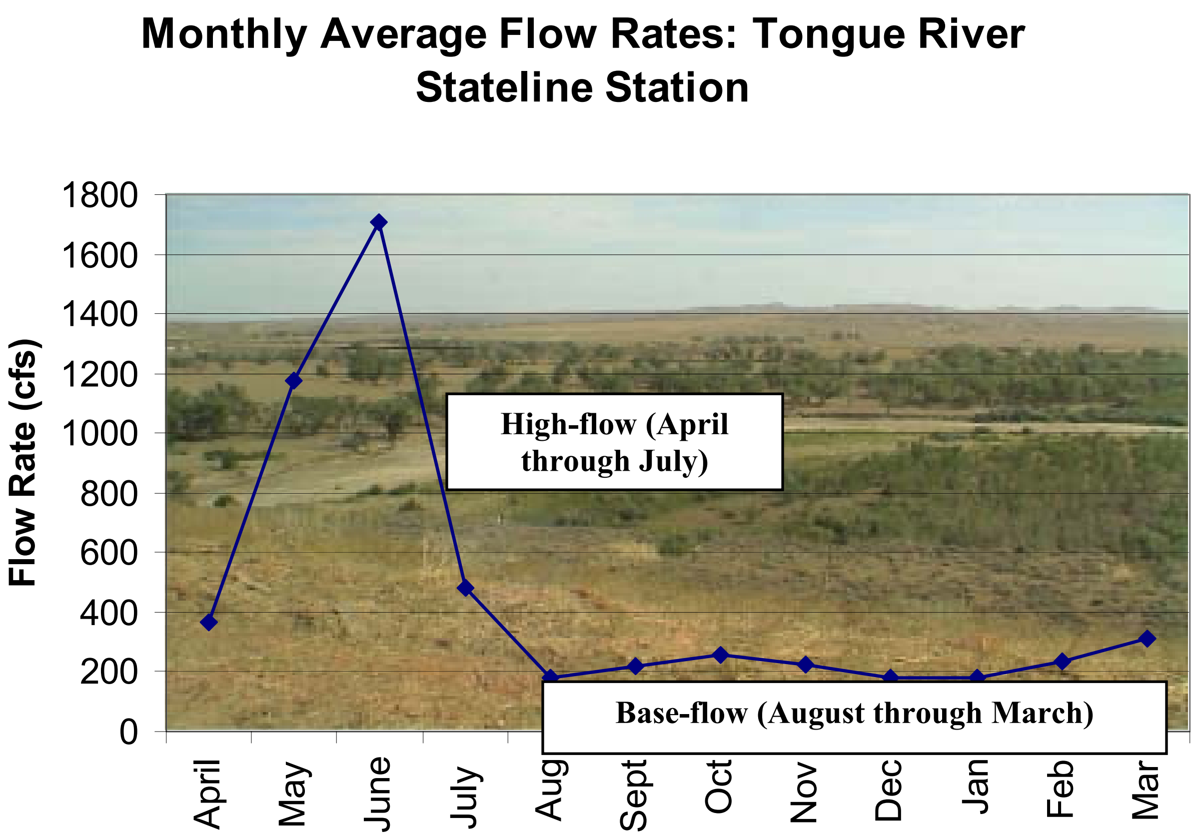
Flow rate is often measured in cubic feet per second. Stream flow may be stable or variable depending upon whether it is a permanent, ephemeral, or intermittent stream. Across the five-state emphasis area, rivers can vary from a wide, powerful and navigable flow of more than 100,000 cfs to a fordable stream of less than 100 cfs. A single river might also range from over a thousand cfs to zero depending upon rainfall. In addition to the instantaneous data points of measured flow rate, the data can be analyzed to give historical monthly averages and two statistical measures – 1Q10 and 7Q10. The 1Q10 is the lowest one-day rate that can be expected every ten years. The 7Q10 is the lowest rate averaged over seven consecutive days that can be expected every ten years. The lowest historical rate value can also have some interest. An example of seasonal variation in the flow rate of a river can be illustrated using the Tongue River that begins in the Bighorn Mountains and flows north through parts of Wyoming and Montana and feeds into the Yellowstone River. Monthly average flow rates were calculated from approximately 40 years of USGS stream-gauge data and are plotted in Figure 5-21. The annual average flow at the Montana Stateline Station is approximately 453 cfs while the monthly averages vary from 1670 to 178 cfs. High flow and base flow are clearly illustrated on the monthly mean flow rate plot of the flow data from the Stateline gauging station near Decker, Montana, on the Tongue River.

The months of April through July frequently have snow-melt and spring rains resulting in high flow rates in excess of 1000 cfs. The months from August through March contain small, scattered showers or snowfalls that do not melt until the spring. During these months the river is largely fed by base flow from shallow aquifers resulting in average flow rates less than 400 cfs.

Water quality can be documented in terms of suspended sediment, concentration of chemical constituents, biologically available oxygen, various constituent ratios, and other measurements or classifications. Surface discharge can affect a river; for example, rivers may contain plant and animal life that is sensitive to suspended sediment. Other rivers carry a significant load of dissolved salts and, when surface discharge with increased salts are added to the existing water, the water quality may become impaired to the point that existing uses such as irrigation can no longer be continued. Other rivers have a water chemistry that may be either impaired or improved by mixing with CBM water. Determining water quality information for both the water being discharged and the receiving water is particularly important because of the potential positive and negative impacts.

Existing contaminant load can be determined for a variety of constituents or ratios such as TDS.

Figure 5-21
Historical Average Flow Rates
Graph of Average flow at Stateline Station of the Tongue River near Decker, Montana.



Source: USGS, 2002

Assimilative Capacity

Assimilative capacity is an important aspect to the characterization of particular streams is the ability of that stream to accept pollutants while maintaining water quality. Assimilative capacity is defined as the maximum load of a specific constituent (such as sodium) or a parameter (such as sodium adsorption ratio) that can be carried by a stream without causing violations of a water-quality standard or criterion. Assimilative capacity will depend upon existing stream water quality and upon relevant standards whether they are numerical or narrative standards. An individual stream segment is likely to have several measures of assimilative capacity based upon different constituents. Likewise, there may be wide differences in assimilative capacity due to seasonal stream variations; that is, a stream may have very low assimilative capacity during periods of base flow but have considerable capacity during high flow. Assimilative capacity is one of the key controlling factors for discharging CBM water. Knowing assimilative capacity along with resulting flow rate, CBM operators can calculate and plan for potential effects and impacts to receiving water bodies. If a stream is in base-flow, it has less capacity to dilute any CBM water that might be discharged to it. During high-flow periods, which could be several hundreds of times greater in volume, the stream may be able to assimilate larger volumes of

CBM discharge without significant impact to water quality. Regulatory agencies and operators may adapt to seasonal assimilative capacity by writing discharge permits that will allow very little water discharge during base-flow, but higher discharge during high-flow periods. Permits of this type will insure that a certain level of assimilation will always occur within the stream.

Examples of Assimilative Capacity

The Decker, Montana station on the Tongue River can be used again to give an example of existing water quality characteristics, trends and their influence on assimilative capacity. EC is commonly used to estimate total dissolved solids in area streams by regulatory officials, irrigators, land owners, and the oil and gas industry. Electrical conductivity is an important parameter used to predict usability of water for irrigation. Water with high values of EC can severely limit crop productivity if used for irrigation by local ranchers. In order to preserve irrigation practices, stream EC must be effectively managed. Many USGS gauging stations sample for EC and this parameter can be plotted with stream flow to determine seasonal variations.

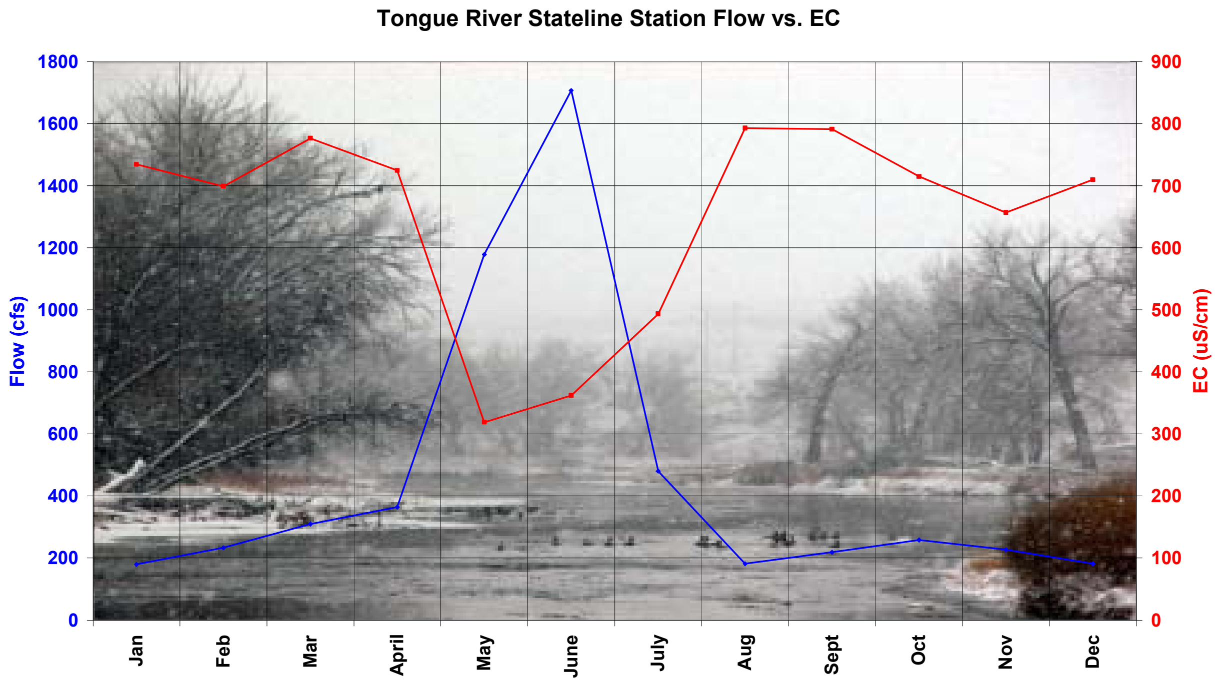
Figure 5-22 below shows the average monthly flow rate and EC values during the 40-year history of the Tongue River Stateline gauging station. The graph illustrates the quality of base-flow water and the change brought by runoff during high-flow months. While base-flow water quality (as measured by EC) varies from 650 to 800 µS/cm, high-flow water quality is between 300 and 400 µS/cm. High-flow periods correlate with periods of greater assimilative capacity for CBM produced water that may have EC values that exceed that of Tongue River water during base flow.

Flow rate and EC values for the existing stream can be used to calculate the EC of specific, proposed mixtures of CBM discharged waters and existing stream water to determine compliance with existing guidelines, standards, or limits. For example, if this segment of the Tongue River has a relevant EC limit of 2500 µS/cm, the quality of the mixed water can be judged against that limit. If the limit remains the same across the year, then the assimilative capacity of the Tongue River at Decker will vary from month to month because of seasonal changes in water quality. For example, during the month of July, the Tongue River averages 470 cfs and the water averages an EC of 474 µS/cm. If the CBM water to be discharged averages 5000 µS/cm, the assimilative capacity can be determined from the following formula:

> (Stream flow x stream EC) + (discharge flow x discharge EC) = (combined flow) x (EC limit)
>
> or
>
> (470 x 474) + (discharge flow x 5000) = (470 + discharge flow) x (2500 discharge flow)
>
> Therefore, discharge flow can be solved for and in this case equals 381 cfs.

The assimilative capacity in terms of EC of the Tongue River at the Stateline Station in July, therefore, allows up to 381 cfs of CBM water discharge during that month. There may be additional relevant limits for other constituents that allow less discharge. Other methods and approaches can also be used to calculate the assimilative capacity from more complex models.

Figure 5-22
Monthly Average Flow Rate and EC in the Tongue River
Graph shows flow and EC at the Stateline Station near Decker, Montana



Source: USGS, 2002

Total Maximum Daily Load

Total Maximum Daily Load (TMDL) is another way of looking at assimilative capacity and is an important factor used to characterize streams and rivers. The TMDL process is an essential element of the water quality-based approach to watershed management that analyzes the capacity of a stream segment to carry a specific pollutant given inputs from point sources and non-point sources. The process links the development and implementation of control measures to attainment of water quality standards. Through the establishment of TMDLs, pollutant loadings from all sources are estimated, including both point-source and non-point source. Allowable pollutant loads can be allocated to each source and appropriate control mechanisms can be established so that water quality standards can be achieved (EPA, 2002d).

The maximum allowable pollutant load is the sum of the following, along with considerations for a margin of safety, seasonal variation, and allowances for future growth:

- *Waste-load allocations for point sources.* Point-sources of pollution are those that discharge through a discrete conveyance – a pipe or drainage. These sources are relatively easy to identify and monitor. Waste-load allocations are calculated on the basis of permit conditions including constituent concentrations and parameter averages.

- *Load allocations for non-point sources.* Non-point sources are less obvious and more diffuse. They do not issue from a specific point, but are comprised of runoff from streets, construction sites, mining, logging, and agricultural sources. Unlike point source discharges, accurately identifying and monitoring the extent and the source of non-point runoff is difficult.

Once TMDLs are established for a watershed, CBM production facilities with individual or general NPDES discharge permits will likely be required to receive individual waste-load allocations and would have existing permits modified to a TMDL basis. Permit limits based on TMDLs are water quality-based limits and the permit limits must be consistent with any applicable waste-load allocations contained in the TMDL for that watershed/pollutant combination. Discharge limits are commonly expressed as numerical restrictions on discharges (e.g., not to exceed 4.83 cfs @ 1500 μC/cm EC, or not to exceed 200 lbs of sodium per day) or as best management practices (BMPs) when numerical restrictions are unfeasible.

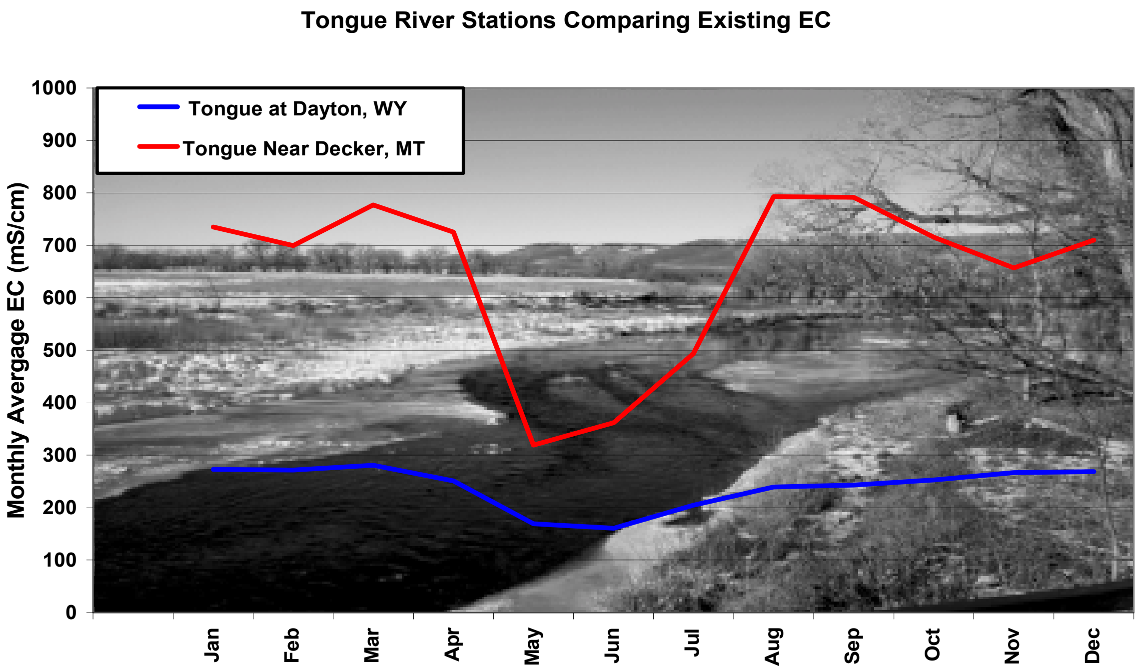
TMDLs involve an additional step of watershed protection, moving beyond the point-source permits under the NPDES program. TMDLs require management of point sources and non-point sources, because as states move from NPDES and endangered streams to a TMDL basis, non-point sources will play a part in the process. For example, irrigated land can give rise to non-point source discharge into streams; however, currently available data do not generally allow a calculation of the load allocation assignable to irrigated cropland.

The setting and need for TMDLs can be illustrated in an area where CBM activity will continue to be important as in the Tongue River of the PRB. Figure 5-23 graphically demonstrates the differences between the water quality at Dayton, Wyoming and the water quality approximately 25 miles down stream at Decker, Montana. The station at Dayton is directly downstream from the Bighorn Mountains, the source of the Tongue River; and there is little agriculture and no CBM activity upstream of Dayton. Water quality in the Tongue at Dayton is very different as is evidenced by Figure 5-23 and mirrored in other parameters. Downstream at Decker, Montana, the water quality is still high but notably degraded.

The main difference between the two stations is the poor quality of the Decker base-flow, possibly caused by natural leaching from shallow Fort Union aquifers, by runoff from irrigated fields (approximately 14,000 acres under irrigation between the two locations), as well as other industrial and municipal activities.. A TMDL approach to the segment of the Tongue River between Dayton and Decker would involve the assignment of waste-load allocations for specific discharges and other point-source discharges, as well as load allocations from irrigated fields, from natural leaching, and other non-point sources. These load determinations go together to form the maximum allowable pollutant load allocation for the stream segment. This sum of waste load plus non-point-source load plus future growth plus margin of safety can be implemented and managed under another key aspect of the TMDL program.

The management of maximum allowable pollutant load allocation levels is the subject of the TMDL implementation plan, which is specific to each TMDL. The plan is to include the implementation, enforcement, and monitoring steps needed to attain and manage the TMDL. At minimum, the TMDL implementation plan must include the following (EPA, 2002d):

Figure 5-23
Monthly Average EC values at Dayton, Wyoming and Decker, Montana.



- a description of the control actions and/or management measures which will be implemented to achieve the waste load allocations and load allocations, and a demonstration that the control actions and/or management measures are expected to achieve the required pollutant loads;
- a time line, including interim milestones, for implementing the control actions and/or management measures, including when source-specific activities will be undertaken for categories and subcategories of individual sources, and a schedule for revising NPDES permits;
- a description of the legal and regulatory authorities under which the control actions will be carried out;
- a monitoring and/or modeling plan designed to determine the effectiveness of the control actions and/or management measures and whether allocations are being met; and
- a description of measurable, incremental milestones for the pollutant for which the TMDL is being established for determining whether the control actions and/or management measures are being implemented and whether water quality standards are being attained.

In the case of the Tongue River and other rivers in the PRB as well as the five-state CBM emphasis area, TMDLs are to be established in the future for EC, SAR, and other parameters in order to safeguard the beneficial uses of the streams including fisheries and irrigation. The

TMDLs are meant to lead to the revision of NPDES and similar state permits for facilities in both states as well as controls on other sources of relevant pollution, including runoff from irrigation.

Analysis Methods

When planning discharge to the surface, quality of produced water, quality of the receiving water, and/or character of the receiving soil are all important. Not only is the chemical character of these media important, but the characteristics of the mixed media are also important. Predicting the character of the mixture prior to actual discharge is a difficult problem for water management.

The discharge permit application addresses the question of resulting water quantity and quality after mixing in the river. The permit application also determines the parameters of interest. Parameters might include some or all of the following water quality and quantity aspects:

Discharge in cfs: Is measured according to an appropriate schedule. Increases and decreases in the volume of water can affect the erosion of the stream channel, the organisms in the water, and the banks of the stream.

Total Dissolved Solids: TDS is the measure of dissolved solids in water, usually inorganic salts. Water with high TDS often has taste problems, water hardness problems, and/or changes in the chemical nature of the water. TDS affects the biological inhabitants within an aquatic environment as well as the agricultural uses of the water.

Electrical Conductivity: EC is an approximation of TDS in the water.

Dissolved Oxygen: The concentration of free oxygen dissolved in the water and available to fish and other organisms. The dissolved oxygen is affected by the dissolved solids and the temperature of the water. The temperature of the water has the strongest impact on the amount of dissolved oxygen: small temperature changes in the water cause significant changes in the amount of dissolved oxygen.

pH: pH measures the acidity and basicity of an aqueous solution. The pH influences the presence and concentration of many dissolved chemical constituents found in water. Biological processes including growth, distribution of organisms, and toxicity of the water to organisms may also influenced by the pH.

Temperature: Temperature of the water affects the type of organisms that can live in the water. Cooler water supports different organisms than warmer water.

Total Alkalinity as $CaCO_3$: Total alkalinity is defined as the capacity to neutralize acid; closely related to pH.

Total Hardness as $CaCO_3$: Total hardness is the total dissolved salts in water. Water high in total hardness will have salts precipitate out easily, especially in the presence of soap. $CaCO_3$ is the principal hardness and scale-causing compound in water.

Phenols: A group of organic compounds that produce taste and odor problems in water in very low concentrations and are toxic to aquatic life in higher concentrations. Phenols can be naturally occurring or can be byproducts of petroleum refining.

Total Petroleum Hydrocarbons: Hydrocarbons are chemical components that consist entirely of hydrogen and carbon. They can originate in refined petroleum or in crude oil, natural gas and coal.

Chloride: A negative ion found naturally in some surface and ground waters, especially in waters high in TDS.

Fluoride: Fluoride combines with tooth enamel to make it less soluble in acidic environments. Fluoride is commonly added to public drinking water to prevent tooth decay.

Nitrate + Nitrite as N: Generally used as fertilizers and can lead to excessive growth in aquatic plants and serious problems with drinking water.

Selenium: An inorganic element found primarily in soils as well as water and air in lesser extents. Selenium is a necessary nutrient in small amounts but is toxic in high doses.

Lead: A toxic heavy metal present in air, food, soil, and water. Lead can cause damage to circulatory, digestive, and central nervous systems. Children under six years old are considered very susceptible.

Other parameters to be considered include:

	Nickel
Sulfate	Zinc
Calcium	Iron
Magnesium	Manganese
Potassium	Antimony
Sodium	Arsenic
Aluminum	Barium
Cadmium	Beryllium
Chromium	Thallium
Copper	Bicarbonate as HCO_3
Mercury	Carbonate as CO_3
Silver	Hydroxide as OH

All these parameters can be calculated and reported on an annual basis or, if the stream shows significant seasonal variation, the parameters can be displayed as monthly averages with statistical measures.

Simple Mixed and Component Mixed Methods

Calculated ratios can be charted on a monthly basis by taking simple weighted averages of the constituent parameters; however, in the case of some calculated parameters such as SAR, the results would be erroneous. For SAR calculations, the components (Na, Ca, Mg) need to be individually calculated from stream concentrations and CBM water analyses, and the resulting SAR values computed. The difference between the two methods is shown below in Figure 5-24.

Figure 5-24
Calculated SAR Values from Simple Mixed and Component Mixed Methods
Graph shows data from Tongue River Stateline Station near Decker, Montana

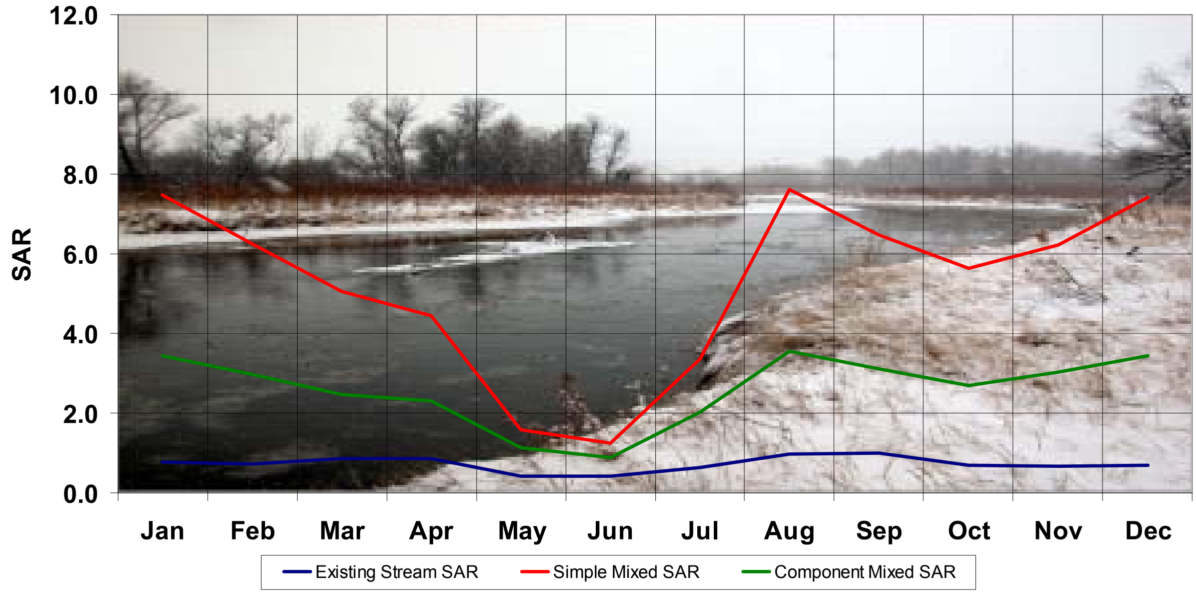


Figure 5-24 is calculated from a projected number of CBM wells discharging produced water to the river. This number of wells is taken from the latest Montana EIS (BLM, 2002b), which specifies 1,948 wells in the Wyoming portion of the watershed and 530 wells in the Montana portion. Each of these wells would be forecast to discharge a volume of water to the Tongue River. For the Wyoming wells, no direct discharge is expected to occur, but approximately 15% of the water production is expected to reach the Tongue River through indirect means such as leakage of impoundments. From Montana, only 120 CBM wells are expected to discharge into the Tongue River and the potential volume of discharged CBM water is assumed to have the composition of water from nearby existing production in both states.

Using the individual components (Ca, Na, and Mg), averaging gives a predicted mixed SAR that is approximately one-half the value predicted by simple averaging of SAR. For the three high-flow months (May, June, and July), the simple mixed SAR average was 2.07 while the component mixed SAR average was 1.36. For base-flow months the effect is even more pronounced with the simple mixed average SAR at 6.29 and the component mixed SAR average was 3.00. The difference in the predicted SAR values could result in erroneous and grossly conservative discharge limits for any permit; therefore, component averaging and subsequent calculation is the preferred method. On the basis of calculating assimilative capacity, the correct methodology would result in a permitted discharge of almost 200% of the erroneous calculation.

Constant Discharge Based Rate and Flow Based Rate

With streams that have meager assimilative capacities, discharges can be managed in two basic ways: as a constant discharge-based rate, then calculated and analyzed in the method above in the Assimilative Capacity Examples section; or as a variable rate based on the flow of the receiving stream. A constant discharge-based rate is sufficient when the assimilative capacity of the stream is sufficiently high to accommodate the CBM water throughout the year. Constant rate discharge permits typically have one rate of discharge year round, are easier to manage, and require less monitoring. The total volume of produced water that can be released in constant discharge, however, is usually more restrictive, based on a worst case, lowest discharge scenario.

If the stream has a lower assimilative capacity, either due to lesser quality or lesser flow rate, a flow based discharge plan may be necessary. Flow based discharge can be used to decrease the quantity of water discharged to receiving streams during times of low flow. The lower flow discharge occurs when the potential for degradation of surface water quality is greatest. Flow based discharge is designed to maximize the dilution potential of the receiving stream by controlling the volume of water discharged relative to the flow rate of the receiving stream. During times of low flow in the receiving stream when the dilution potential is lowest, produced water is stored rather than released. Stored water is then discharged when flow in the receiving streams has been increased, usually due to increased precipitation and/or snowmelt. Flow based discharge requires more management than constant rate discharge; extra management includes the continuous monitoring of produced water and water in the receiving stream

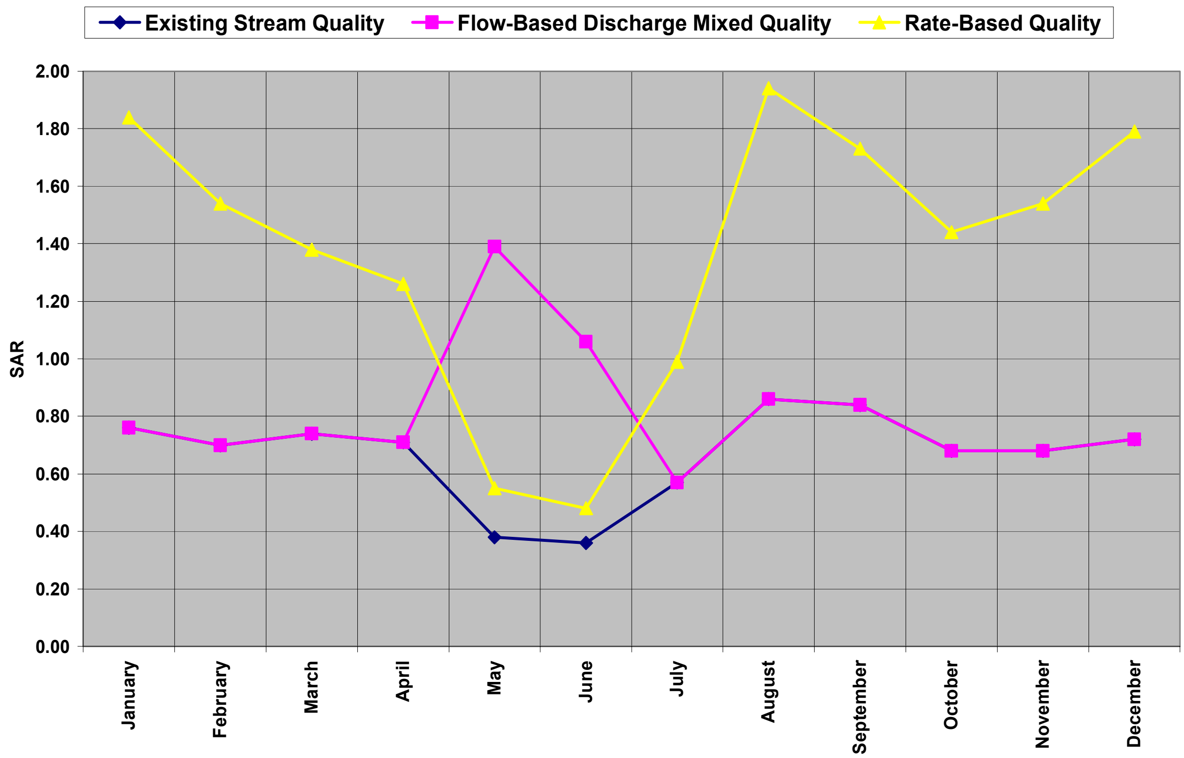
An example of flow based discharge can be illustrated using the parameters discussed above in the Assimilative Capacity Section. Rather than at a constant year-round rate of approximately 4.8 cfs, the same volume of CBM water could be discharged only during the months with the highest flow rate (May and June). That is, no discharge would happen from July through April, and then CBM water would be discharged at approximately 29 cfs, a rate six times higher than the constant rate. The SAR of the mixed water under both discharge scenarios is displayed in Figure 5-25. The SAR levels in the river under the flow based discharge are consistently well below those levels reached during some base-flow months under conventional rate based discharge. Flow-based discharge may be helpful to the operator under some existing conditions as a way of utilizing seasonal variations in assimilative capacity.

Surface Discharge Alternatives

Operators can choose from an almost infinite variety of ways to discharge produced water; for purposes of this study, however, we have grouped alternatives into three general categories including discharge to surface water, discharge to land surface with possible runoff, and discharge to land surface with possible infiltration into subsurface aquifers and surface water. Following is a discussion of these three alternatives, their applicability, constraints, and economics.

Direct discharge of CBM water to the surface waters of the Tongue River.

Figure 5-25
SAR Water Quality
Graph shows example of SAR Analyses for the Tongue River, Montana



Alternative No. 1 - Direct Discharge to Surface Water

Discharge of CBM produced water can bolster seasonal flows of local rivers and accommodate more beneficial uses. Various discharge scenarios can be considered based on the quantity and quality of the produced water and the receiving water. Discharge directly to surface waters, such as streams and rivers, can be accomplished by the use of pipelines. The pipeline method avoids erosion and the incorporation of suspended sediments, which can impact stream water quality. Pipeline use prevents interaction of produced water with local soil and bedrock. The photo above shows direct discharge to the surface waters of the Tongue River. At this discharge point produced water is discharged over a rocky surface to minimize erosion of the stream bank.

Applicability

During discharge planning, site-specific issues dealing with water quantity changes due to discharges, including increased erosion, infiltration into the local bedrock, and changes to biota along the drainage will generally need to be examined.

Water management provides the opportunity to mix discharged CBM water with existing stream water in a manner that will safeguard surface water quality while augmenting surface water resources. Stream water serves life within and near the stream, and supplies water for uses including wildlife support, municipal water systems, crop irrigation, and/or livestock. Beyond the discharge point, mixing occurs to dilute the CBM water, leading to a stable mixture whose characteristics can be calculated from analyses of the two water volumes. The amount of dilution will depend upon the rate of discharge and the flow of water within the stream; both of these flow rates can vary considerably over time.

Riparian zones along streams are complex, sensitive environments that are some of the most biologically productive areas in the western United States. Many species of plants fill niches from within the stream to some distance beyond the bank onto dry land. Each plant has adapted to the amount of available water and the water chemistry within its particular niche. Associated with the different plants are a series of insects, invertebrate animals, and larger reptiles and mammals. Discharge of suitable CBM water can add to the riparian environment by supplying sorely needed water during drought periods and by diluting poor quality water supplied by subsurface aquifers during seasonal base-flow periods. CBM surface discharge management can support the existing biota or can result in increased riparian plant cover and associated wildlife.

Direct Surface Discharge
Powder River Basin, Wyoming

Potential Constraints

The assimilative capacity of some streams for some parameters may be a limiting factor for management of produced water discharge. Depending upon water management priorities and water quality, surface discharges may be curtailed or eliminated as a management option. Water quality issues in conjunction with assimilative capacity may constrain discharge. Relevant standards will be set to preserve beneficial uses that might include agriculture, industry, and wildlife. Assimilative capacity will be derived from these relevant standards and may be revised by TMDLs. Assimilative capacities will be used to derive proposed discharge rates for specific waste waters. The proposed rates will be used to determine the most limiting constituent and to calculate the permitted rates for individual projects or facilities.

Discharge to streams can lead to significant changes brought about by increased flow volume either seasonally or throughout the year. The site-specific vulnerabilities of the stream can constrain or even prevent such discharges. Certain important factors connected to discharge volume and erosion should be considered when planning discharges.

- *Stream Bank Erosion:* Increased flow volumes could lead to erosion and deposition along the stream valley. The increased flow level and velocity may remove alluvial material including clay, silt, sand, and perhaps gravel, as well as plant debris from those places and deposit them where the flow velocity drops. The erosion may be greater where bedrock and/or alluvium are sandy and unconsolidated; in these areas, erosion may proceed quickly and deeply. The resulting gullies could be deep enough to impede the passage of cattle and other domestic animals and prevent the movement of farm vehicles. Riparian erosion could also impact buried utilities such as electric lines and pipelines. Where sedimentation occurs, valuable riparian and pasture plants could be covered and killed. Discharge of CBM water can be coordinated with seasonal flow rates to minimize or eliminate increases in stream bank erosion.

- *Water Crossings:* During episodes of increased flow, bridges and culverts could be destroyed or weakened enough to make them unusable. The resulting disruption could be significant to local agriculture. Discharge of CBM water can be engineered and timed to significantly reduce threats to water crossings.
- *Riparian Plants and Wildlife:* Riparian erosion could destroy streamside vegetation including important pasture land and animal food sources. Grasses that have adapted to irregular doses of water could be swept away, leaving bare ground that would take years or generations to re-vegetate. These grasses may be the best forage available to livestock and wildlife. The erosion could destroy large cottonwood trees growing at the stream edges. The loss of these trees would be significant in terms of loss of aesthetics, loss of wildlife habitat, and loss of erosion control. Managing CBM water discharges will avoid significant amounts of erosion and damage to riparian vegetation.

Data Needs

Discharge planning and permit applications require sufficient data to effectively evaluate how a watershed will react to discharge of CBM produced water. If more than one coal seam is produced, then discrete samples and analyses will need to be provided to cover the range of water types. Other analytes may be required by regulatory agencies in order to determine compliance with water quality standards.

In addition, a forecast of the volume of CBM water to be produced from the project will be needed. Water production can be calculated from the forecast number of wells in the field and the projected water decline curve.

Economics

Surface discharge to water can be one of the cheapest methods of CBM produced water management (Rice, 2002; Hodgson, 2001). Flow pipelines can be installed to transport water to the discharge point. For newly installed wells, trucking produced water may be necessary until pipelines are installed. Filtering and treatment may be required by the permitting agency, which can add to costs and operating expenses. Permitting agencies may also require characterization of the effluent stream in terms of both rate and characteristics. If the discharge is by way of a flow-based permit, the agency may require monitoring of the receiving stream to record flow rate and quality. The resulting monitoring may require sensors and automatic shut-down in the event of sensor failure; this will prevent the discharge of produced water during times of unknown conditions. If automated shut-down valves are mandated, the operator will need to plan other management options that are available to dispose of or store produced water during periods of shut-down. These back-up systems will represent necessary redundancies that will add to management costs and operating expenses but will significantly decrease any negative impact on the environment.

Direct discharge economics will depend on the layout of the proposed project, the available utility routes, and the proximity to suitable receiving streams. In many cases, however, direct discharge to surface waters will be the most attractive option for managing produced CBM water.

Alternative No. 2 - Discharge to Land Surface with Possible Runoff
This management option involves the discharge of CBM produced water directly to the land surface by way of irrigation methods. The common methods of irrigation include center-pivots, side-rolls, and fixed or mobile water-guns. The management option under discussion assumes that there can be runoff that reaches surface water. Surface runoff from irrigated land can be managed and controlled to avoid or minimize discharge to streams and rivers.

The direct discharge of water to the land surface can be a viable practice for CBM operators, depending upon site-specific conditions. Under this alternative, water is discharged to fields and pastures in order to support plant growth and to manage the disposal of produced water through evaporation, transpiration by way of plant tissue, and infiltration into the soil. These factors will effectively reduce the volume of discharged water but depending upon local conditions, some portion of the discharged water may eventually reach water-bodies down-gradient. Factors such as the quality of produced water, existing land uses, landowner's future plans for use, soil type, vegetative cover, and other factors all affect the land's ability to accept surface discharge produced water.

Applicability
The feasibility and applicability of discharge to land surface will depend on many of the same factors that controlled the discharge to surface water. Discharge to dry meadows or pastures draining into streams may allow the water to take up ions from the soil. Depending upon local conditions, this activity could improve the SAR of the water. If Ca and Mg (but not Na) ions are leached from the soil, SAR would decrease; but if the runoff encounters soils or bedrock strata rich in salt, the discharged water could become even higher in SAR. Traveling down the drainage slope, some of the water will be lost to evaporation as well as infiltration into the soil and sub-soil. These conveyance losses will be site-specific, with the calculation of conveyance losses detailed in the data needs section below. Discharge to surface soil has been effective in several settings.

Discharge to upland pastures may produce higher rates of plant growth and support grazing by livestock and wildlife. Some upland areas can have high slopes that will encourage and concentrate runoff into dry drainages; discharge can be managed to avoid significant amounts of runoff that may produce soil erosion and may reach live streams. Discharge to areas with steep slopes could cause increased runoff water velocity leading to higher erosion potential.

Discharge can also be directed to bottom-land pastures and fields in order to grow hay, crops, or pasturage. These fields are typically quite flat, without topographic relief that encourages runoff. On the other hand, these fields are adjacent to live streams; therefore, any runoff of irrigated water can enter the surface waters. Discharge onto and around the fields will be need to be closely managed to minimize runoff to surface waters.

Potential Constraints
Many of the same constraints listed above for direct discharge to surface water apply to land surface discharges. Additionally, soil erosion could be a problem with this type of discharge, which would be affected by soil type, surface vegetation, land slope, water volume, and other factors. In areas with surface soils consisting of fine textures (clayey), the soil would likely be susceptible to increasing sodicity when applied with discharge water having a high SAR. If sodic water is discharged onto these soils, the probability of soil dispersion (deflocculation) is high, causing decreased infiltration and increased runoff. CBM water discharge could have the cumulative effect of encouraging the establishment and proliferation of non-native and noxious

weed species. Flow volume impacts can be a significant constraint, even when the CBM water quality is high.

Data Needs

The potential constraints described above can usually be mitigated by management techniques available. In order to design the appropriate mitigation, however, site-specific data is required. The data needs required to describe the quality of the produced water that will be discharged for surface water discharge would also apply to land surface discharge.

Discharge Point, CBM Field in Wyoming

Soil Properties

Soil properties need to be determined in areas where water is to be discharged to the land surface in order to maintain adequate infiltration of water into the soil and to prevent soil dispersion and erosion. As stated above, the NRCS publishes detailed soil maps of many areas of the western United States. NRCS soil maps can be reviewed to provide a general indication of the soil types, erosion potential, and drainage characteristics present in a project area. Following this initial review, a more detailed characterization of physical and chemical properties of soil and drainage characteristics can be obtained from a soil sampling and analysis program. Soil pits could be excavated and samples collected for analysis of texture and potential clay mineralogy. Preventative treatments can also be employed including soil amendments and treatment of irrigation water prior to discharge.

Discharge Volume and Conveyance Losses

Discharge volume is an important constraint for discharge to dry fields and drainages, especially as it leads to runoff volumes of water that may reach live streams. In some settings, surface discharge may lead to managed runoff volumes; in these cases the runoff volume may need to be mitigated. Although irrigation return water to perennial streams is exempt from the CWA, monitoring would have to be performed on a voluntary basis. If land application of CBM-produced water exceeds the 'agricultural rate' and has the potential in low-lying alluvial areas to enter waters of the state through subsurface recharge adjacent to perennial streams, some monitoring may be required. Forecast flow volume will need to be accurately calculated in order to predict and manage any impacts. Operators will need to calculate runoff flow rates and mixed flow characteristics after conveyance losses have been computed for the runoff. Conveyance losses are the localized summations of all losses within a flow: evaporation from the water's surface, transpiration from the plant life in contact with the runoff water, and infiltration into the soil or bedrock or alluvium. Conveyance losses can be estimated through several steps:

- In several states, the Office of the State Engineer has published average conveyance loss figures for watersheds. The Wyoming OSE has established the loss of 1.0% per mile of stream flow. This figure can be used to successively remove the CBM discharge volume after it has been added to the stream. For instance, if Antelope Creek contains only one discharge point, its contribution will reduce by 1.0% every mile of travel, regardless of flow from groundwater or other tributaries. The conveyance loss will, of course compound so that at the end of the first mile, 99% will remain, at the end of the second mile, 98.01% will remain.
- NRCS publishes detailed soil maps of many areas of the western United States. The maps will frequently include infiltration rates for soil types. Infiltration losses can be accumulated from map information.
- Some stream reaches have detailed water budgets worked out by local researchers. The Wyoming BLM has assembled some of this data for the Powder River in Wyoming.

Economics

Often dry pastures and drainage ways are widely distributed in CBM project areas, and could be utilized as discharge sites with little or no extra cost. Erosion control measures may need to be implemented prior to, and during discharge of CBM-produced water to the land surface. Costs associated with resulting soil erosion, such as filling in eroded channels and gullies, reclaiming sodic/dispersed soils, and replanting vegetation may be incurred during production and post-production periods.

Alternative No. 3 - Discharge to Surface Impoundments with Possible Infiltration and Subsurface Discharge to Surface Water

CBM produced water is often discharged to surface impoundments, especially in the Powder River Basin. Untreated CBM water is typically carried by pipeline from the producing facilities to impoundments that are located to maximize water management and to satisfy the needs of the land owner. Impoundments are often located on the land surface where infiltration is the dominant agent of water movement instead of evaporation and transpiration. Infiltration is effectively managed where water is confined to an unlined impoundment that can be situated in two ways: on-channel and off-channel.

- *On-Channel Impoundment Discharge*. Discharge to ponds situated on dry drainages are managed to encourage infiltration into the alluvium filling the channel. In this position the fate and transport of the infiltrated water can be monitored.
- *Off-Channel Impoundment Discharge.* Discharge to off-channel, containment structures is intended to reduce the volume of produced water through infiltration and evaporation, with the remaining water being used for applicable beneficial purposes.

In Wyoming, the WDEQ regulates CBM produced water into the off-channel containment structure with a NPDES permit. The off-channel containments is considered a class 4C surface water of the state. The produced water may infiltrate downward and may reach the uppermost aquifer. If the CBM water quality is greater than or equal to that of the receiving aquifer, no monitoring is required. However, there must be reasonable assurance that there is no direct subsurface hydrologic connection between the produced water pits and surface waters of the state.

Discharge planning examines site-specific issues dealing with water quality and quantity, soil chemistry and physical properties, and the potential for infiltration and soil degradation. CBM water discharged to structures may accumulate inorganic elements and compounds in the sediment along the bottom of the containment structure. As salts separate out, denser saline solutions may sink into lower soil and bedrock zones. Evaporation also increases the salinity of water in the containment structure. The Surface Water Modeling Technical Report (SWQATR) for the Powder River Basin Oil & Gas EIS (covering both Montana and Wyoming) discusses non-point sources such as infiltration via shallow impoundments and land application.

Potential Constraints

Discharge of CBM produced water to containment structures may potentially affect the water quality in the shallow overburden aquifer. However, in the PRB the upper aquifers in the Wasatch sands tend to be of 'poor' water quality with a TDS of 2500 to 3500 μg/L. In this case, the CBM-produced water may improve the water quality of the receiving aquifer, depending on the contribution of leached constituents. Water management by surface discharge to impoundments can maximize this disposal option while protecting surface water resources. Management mechanisms may involve monitoring wells in the area of the impoundment and monitoring surface water in the vicinity of the impoundment. After CBM production has ended and the impoundment is closed, the site will be remediated.

Data Needs to Support Discharge to Impoundments

Discharge planning requires sufficient data to insure that soil chemistry and surface water quality is not adversely affected. The type of data needed to determine possible effects to soil and water include baseline soil sampling analysis, installation of shallow monitoring wells down gradient of containment structures and adjacent to perennial streams and rivers, and follow-up soil chemistry sampling. A more detailed discussion is given in the Impoundments portion of this section.

Economics

Discharge to containment structures can provide a considerable volume of water for subsequent stock watering, crop and range enhancement, and even for providing fish habitat. Filling impoundments with CBM water can be a valuable water source for local ranchers that will allow them to run cattle on remote, dry pastures. The increased economic impact from the abundance of discharged water, however, is a short-lived event that will depend upon the producing characteristics of the CBM field.

Agricultural Use of CBM Produced Water

Potential for Beneficial Use in Agriculture

The water provided by CBM discharge is a temporary and potentially valuable resource for agriculture, particularly in arid regions. CBM produced water has the potential for beneficial use in agricultural livestock and irrigation applications, depending on the quality. Beneficial uses can also be realized in the areas of improved riparian habitat and increased wildlife habitat. Livestock benefits have been realized with increased cattle density, increased weight gain in cattle, and a subsequent increase in range utilization as water is made available over a much greater area as a function of the aerial distribution of wells and new stock tanks.

The physiography and climate of many arid regions largely restricts the cultivation of crops to dry land farming techniques. Water sources in these areas are the result of direct rainfall and runoff events that fill ephemeral streams with a temporary supply of water following spring snow melt and isolated storm events. Historically, irrigation has been achieved by flood irrigation using spreader dikes constructed across the channels of ephemeral streams or through water storage in large reservoirs.

Arid landscapes often have sparse vegetation and rocky ground.

Water from previously undisturbed coal beds can vary in quality. CBM experience to date indicates that water has been utilized extensively for stock watering in many of the CBM plays in the U.S., but its use for irrigation has mainly been limited to operations in the Powder River Basin, with some experimentation taking place in the San Juan Basin. Accordingly, the irrigation component of this chapter focuses primarily on the Powder River Basin experience gained during the three drought years between 2000 and 2002, and thus the water types associated with operations in that region.

This section summarizes various irrigation technologies; the applicability of this technology based on water quality, soil type, and land management strategies; the potential constraints and data requirements for these methods; and the economics associated with these technologies. Flood irrigation has also been employed on a limited basis by landowners who chose to divert CBM produced water to their native grass fields.

Areas of Greatest Potential

A major beneficial use of CBM produced water has been realized in the area of livestock watering and, to a lesser degree, through irrigation. The two issues are connected by virtue of the fact that increased irrigation of range land results in an increased herd size and broader utilization of the land. The agricultural benefits of CBM produced water need to be considered in the context of flow, or volume of water used over time, as well as the infrastructure needed to implement an irrigation system.

Beneficial use of CBM produced water for agriculture (generally irrigation or stock watering) is dependant on the quality of the produced water and the types of soil present in the project area. CBM produced waters tend to be high in sodium but comparatively low in calcium and magnesium, and may have relatively high concentrations of other metals such as iron, manganese or barium. Accordingly, the SAR of the waters can have a potentially deleterious affect on the permeability of certain soil types as discussed in detail below.

Crops in arid lands require significant irrigation; one possible source of water is CBM produced water.

The second factor governing the use of CBM produced water for irrigation is the salinity. Salinity is typically measured by the EC or TDS in the water. Water high in TDS will be relatively conductive, while distilled water has a very low conductivity. For example, sea water has an EC of approximately 50,000 µmhos/cm (Hem, 1992) and a corresponding TDS of approximately 35,000 mg/L (ppm). When irrigation water is high in TDS, the ability of the plant root to incorporate water is diminished and the plant may exhibit decreases in yield that correspond to the salinity of the soil pore water.

Because of the limitations presented with EC and SAR, the ideal situation for irrigating with CBM discharge water would be in an area characterized by widespread coarse-textured soils and incorporating the cultivation of salt tolerant crops. Although the use of CBM produced water for stock watering can affect area soils in a similar manner, the actual areas influenced by this method are generally confined to a much smaller area (i.e. drainage channels and soils adjacent to tire tanks or stock ponds).

Alternative 1 - Stock Watering

The layout of many CBM projects is particularly conducive to stock watering because CBM wells are spread out on 80 acre spacing, or greater. Stock watering may be handled in several ways, including discharge to reservoirs and stream drainages, or discharge to small containment vessels, such as tire tanks. In either case, overflow of water from the containment ponds or tanks can provide water to livestock over a distance. Water impounded at the head of a drainage, if allowed to overflow from a small tank or reservoir, distributes water over a larger linear distance, potentially up to several miles. The result is an improved distribution of the herd, and ultimately an improved utilization of the grazing lease or ranch. Loss of the water in this scenario is largely a function of infiltration through the streambed and consumption by plant species along the banks, rather than direct consumption by livestock and wildlife.

Stock Watering can use
CBM produced water to water stock.

Although incorporating stock water use into CBM water management strategies is a viable management component, the method alone is severely limited by the volume of water a stock watering system can handle without creating copious channel flow that could potentially impact downstream properties. Therefore, this method is generally used in concert with other management options (i.e. seasonal containment, irrigation). Guidelines for uses of waters of various concentrations of TDS and EC for livestock consumption is provided in Chapter 4 in Table 4-1.

Costs associated with this management method are typically minimal and the CBM operator may explore suitable ways to direct discharging wells to areas beneficial to the landowner and livestock. However, due to the numerous uncertainties associated with this option, costs have not been included in the economic comparison provided herein.

Discussions with several ranch owners in the Powder River Basin suggest that the introduction of CBM produced water into this arid region has provided many positive benefits. For example, the 7 Ranch near Gillette, Wyoming indicated that the ranch has utilized CBM produced water for stock and irrigation purposes for over three years (Cox, 2002). Approximately 3,300 head of cattle were present on the 43,000 acre ranch and CBM produced water was provided through the use of rubber tire tanks and small reservoirs. This ranch also irrigates up to 120 acres of land using “big gun” sprinkler application. The introduction of these waters has benefited the ranch in the following areas (Cox, 2002):

- Generally the stock consumes approximately 15 gallons of CBM produced water per day per head and the ranch has realized an average weight gain of approximately 1.5 pounds per head per day.
- The discharge of CBM produced water to rubber tire tanks keeps the stock water much cleaner and colder than traditional methods.
- The increase of water distribution has allowed the use of approximately 40% more of ranch lands including less cattle friendly areas (i.e. mesa tops), effectively dispersing the stock and limiting cattle herds to 50 to 100 head, thus lessening impacts on area soils and trails.
- The ranch has noticed a dramatic reduction in stock related sicknesses and stock hair quality has increased.

- The ranch has been able to change stock rotations and areas historically holding only spring runoff water can be utilized later in the year.
- There has been an increase in area wildlife due to reservoir impoundment of CBM produced water and a resulting increase in groundwater recharge.
- Irrigation has expanded and improved grazing areas.
- Yearling numbers have increased thereby increasing revenue from grazing fees (typically $12 to $15 per head).

Stock Watering Ponds can be replenished using CBM water during dry seasons and times of drought.

Alternative 2 - Irrigation

Although CBM produced water is considered potable and has been utilized extensively for human consumption and stock watering in the PRB of Wyoming, irrigation practices utilizing CBM water has only a recent history within the region. The experience with irrigation using CBM discharge waters has been gained with various types of sprinkle irrigation through the use of center pivots, lateral roll systems, and high pressure, large flow rainbird-style sprinklers ("big guns"). In addition, flood irrigation has been employed on a limited basis by landowners who chose to divert CBM produced water to their native grass fields. A discussion of each potential irrigation technology is summarized in the following sections which were supplemented by several resources (Scherer, 1998; Broner, 1991; Evans, 1996; UN, 1997).

Center Pivot

The center pivot irrigation system is a self-propelled continuous move machine that rotates around a central, fixed pivot point. The propulsion system may be oil hydraulic, water hydraulic, or electric. The current trend is toward 240 or 480 volt electric drive assemblies. Electric motors of 0.5 to 1.5 horsepower are mounted on each tower with a drive shaft from the motor to a gear box on each wheel.

The lateral line on which the sprinklers or spray nozzles are located are 5- to 10-inch outside diameter (OD) galvanized steel pipe, painted steel pipe, or aluminum pipe. The lateral line is supported by "A" frames spaced 90 to 200 feet apart. Guide wires or trusses help support the pipe at 8 to 16 feet above the ground. Rubber tires, metal wheels, tracks or skids are mounted under each "A" frame to move the machine. The system can be fitted with a variety of sprinkler applicators conducive to CBM operations, from raised fine mist heads (which will maximize evaporation and drift), to oscillating "Rain Bird" type sprinkler heads which capitalize on the radius of throw, to Low Energy Precision Application (LEPA) spray–type nozzles. Pivots are best adapted to flat terrain, but units are being used satisfactorily on slopes up to 15%. Sloping terrain may require towers to be located closer together so that the lateral line can more closely follow the topography.

A center pivot irrigation system is a self-propelled irrigation system that rotates around a central, fixed pivot point.

Pivots are available as low (<35 psi), medium (35 to 50 psi) and high pressure (>50 psi) units, depending on the required application rate, sprinkler pressure and/or area of coverage desired. Flow rates for a typical system within a square 160 acre field range from approximately 600 to 800 gpm. For CBM applications the calculation of an appropriate discharge rate is paramount in limiting runoff during irrigation operations. These calculations are based on the following inputs and can typically be performed by the system manufacturer using a computer based program:

- soil type (infiltration rate),
- system size (length),
- sprinkler head type and capacity (spray nozzle or oscillating),
- area of coverage (throw),
- elevation gain/loss (head differential from the pivot point to the end of the system),
- water pressure (pump capacity),
- speed of rotation (actual time for one revolution), and
- peak daily evapotranspiration (ET).

The center pivot design should also include initial sizing using an aerial photograph followed by a ground survey to determine the optimal pivot point location and identify any obstacles that may need to be removed or bridged for adequate system operation. Infrastructure requirements for the center pivot system can include the following:

- an appropriate cement pad for anchoring the pivot;
- pump(s), regulator(s) and piping to route CBM water from the containment reservoir or well head(s);
- power units (hardwired or internal combustion) to drive the pumps and electric-drive wheel units; and
- main pivot control panel with safety controls to monitor system alignment (automatic shut-down features)

Although the center pivot system requires substantial start up costs, the system can be automated and operational costs following start up can be minimal. A comparison of center pivot capitol, and operation and maintenance costs are discussed relative to the other irrigation options later in this section.

Side (Wheel) Roll System

The side roll is essentially a hand line system which consists of a lateral moving unit mounted on 4- to 10-foot diameter wheels with the pipe acting as an axle. Common pipe diameters are 4- and 5-inch. Typically the side roll system irrigates an area 60 to 90 feet wide. When the desired amount has been applied to a set area, the system is drained and a gasoline engine located at the center is used to move the side roll to the next irrigation set. The sprinklers are generally mounted on weighted, swiveling connectors to remain perpendicular to the ground surface regardless of topographic irregularities. However, the side roll system is not recommended for slopes greater than 5%. The system is considered a medium pressure unit (35 to 50 psi) and utilizes standard oscillating impact sprinkler heads. Flow rates for a typical system irrigating a square 160 acre field are approximately 800 to 950 gpm (four systems @ 200 to 250 gpm each). It should be noted that, when not in use, side rolls have been susceptible to damage from high winds.

Wheel Moving Irrigation System can be used to distribute CBM water with a hand line system that moves laterally, where the pipe is the axle.

Infrastructure requirements for the side roll system can include the pump(s), regulator(s), and piping to route CBM water from the containment reservoir or well head(s). The piping from the CBM produced water source(s) should be flexible hose or a network of fixed pipe able to deliver water to the side roll at each watering station.

For CBM applications, the side roll requires a much greater amount of operational attention (than the center pivot option) which includes draining the system, moving the system to a new location and visual monitoring for soil saturation and runoff. Generally, four side roll systems would be required to cover an area similar to a typical center pivot system. A comparison of side roll capitol, and operation and maintenance costs relative to the other irrigation options are presented in a later section.

Big Gun System

The big gun (rainbird-style) system uses a large capacity nozzle (0.75 to 1.5-inch diameter) and high pressure (90 to 125 psi) to throw water at a 175 to 350 foot radius. Big guns come in two configurations: hard hose or flexible hose feed. With the hard hose system, a hard polyethylene hose is wrapped on a reel mounted on a trailer. The trailer is anchored at the end of the section to be irrigated. The wheel mounted gun is pulled across the application area as the hose is wrapped up on the reel.

Big Gun Irrigation System is a high pressure, large capacity nozzle that can be used to throw CBM water in a 175 to 300 foot radius.

Several options exist with the flexible hose system including the gun mounted on an automated four-wheel cart or a manual wheeled unit. Water is supplied to the gun by a flexible hose from the CBM water source. The automated system includes a winch cable on the cart which pulls the unit through the application area. Most automated big gun systems have the cable winch and power unit mounted directly on the big gun cart. The power unit may be an internal combustion engine or a water drive. According to an NDSU evaluation (Scherer, 1998), flow rates for a typical system irrigating a square 160 acre field are approximately 950 gpm (two guns @ 475 gpm each). However, actual CBM irrigation operations have utilized much lower flows (70 to 125 gpm).

Infrastructure requirements for the big gun system can include the pump(s), regulator(s) and piping to route CBM water from the containment reservoir or well head(s). The piping from the CBM water source(s) should be flexible hose or a network of fixed pipe able to deliver water to the big gun at each watering station.

For CBM applications, the big gun requires a much greater amount of operational attention than the center pivot option, including continually moving each gun to a new location and visually monitoring for soil saturation and runoff. Generally, two to four big gun systems would be required to cover an area similar to a typical center pivot system, depending on the use of an automated or manual system and the number of field personnel dedicated to the irrigation operation.

Flood Irrigation

The physiography and climate of arid regions largely restricts the cultivation of crops to dry land farming techniques. Irrigation water is derived from direct rainfall and occasional runoff events following spring melt (typically early March) and storm events. Historically, irrigation has been

Flood Irrigation uses spreader dikes to capture CBM water and irrigate crops by spreading the runoff.

achieved by flood irrigation using spreader dikes constructed across the channels of ephemeral streams.

The greatest advantage of flood irrigation is the relatively low cost. This affords smaller-scale farmers the opportunity to make a profit with their agricultural practices without incurring the energy costs associated with pressurized systems. The most common criticism associated with flood irrigation is the waste of water, but proper design and construction can maximize water use. Traditional flood irrigation involved releasing water onto a field with minimal water management. Improved techniques include surge flooding where water is released at prearranged intervals, which reduces unwanted runoff. Another method of improved flood irrigation technology involves capture of the runoff in ponds and pumping it to the upgradient end of the field where it is reused for the next cycle of irrigation. Although flood irrigation is a viable irrigation technique, costs associated with this method are difficult to itemize for the widely varying conditions and, therefore, have not been included in this discussion.

Assessing the Irrigation Suitability of CBM Produced Water

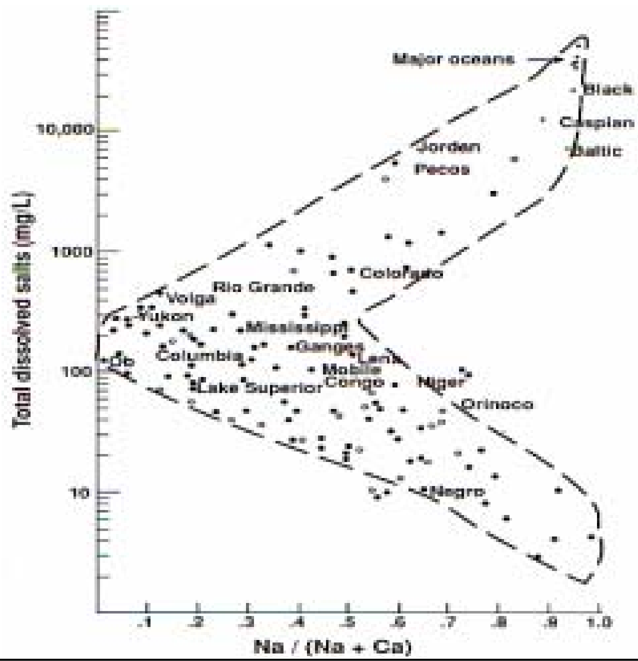
CBM produced water is of generally high quality and meets the majority of regulations governing its use and discharge. CBM produced water is often considered potable and has been utilized for over 100 years for human consumption and stock watering in Campbell and Sheridan counties (Wyoming), as evidenced by the density of wells completed in coal that have sustained ranching operations for three and four generations. The water has not, however, been utilized extensively for irrigation.

The suitability of CBM produced water for use in agricultural irrigation is largely governed by the quality of the water and the physical and chemical properties of the irrigated soils. The quality of the CBM produced water should be evaluated with respect to salinity (EC) and sodicity (SAR) to provide an initial indication of the general suitability for irrigation. In addition, trace constituents should be evaluated to identify any potential affects to irrigated soils and plants. These factors should be considered with respect to characteristics inherent to the irrigated soil, such as texture, drainage, and chemistry. Only a limited number of studies and field experiments utilizing CBM produced water for irrigation have been conducted and the results are discussed below. However, saline and/or sodic irrigation waters are commonly used in various agricultural contexts worldwide and can represent a valuable resource if appropriate management practices are employed.

Figure 5-26 provides a general comparison of the salinity and sodicity of various major surface water bodies.

This section provides an overview of the factors influencing the irrigation suitability of CBM produced water and includes a comprehensive list of references on the agricultural use of saline/sodic waters to consult for additional information on this topic.

Figure 5-26
Salinity and Sodicity of Major Surface Water Bodies



Source: Gibbs, 1970.

Affect of Saline Irrigation Water on Plant Growth

As discussed above, CBM produced water is often characterized by elevated salt concentrations that should be considered when evaluating the suitability for beneficial use in agricultural irrigation. Irrigation water with an EC > 3 dS/m is generally categorized as saline (Hansen et al., 1999). A classification index for soil salinity and sodicity is shown in Figure 5-27. As discussed later in this section, the salinity and sodicity of soils will be greater than the corresponding irrigation water due to processes including evaporation, transpiration, and sorption.

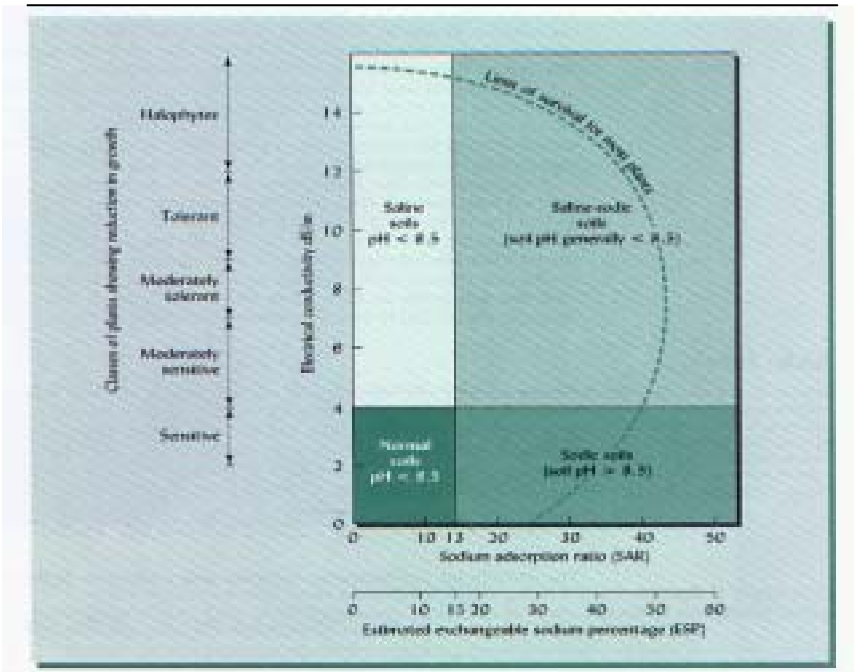
The irrigation suitability of saline water is dependent on numerous factors, including the type and relative abundance of ions in solution, soil texture and mineralogy, sensitivity threshold and growth stage of individual plant species, and the amount of water applied during each irrigation event.

The detrimental affect of elevated soil salinity on plant productivity has been well established (Maas and Hoffman, 1977). Increased salinity in the soil pore water reduces the availability of water for plant use. Therefore, plants must expend more energy to extract water from the soil when elevated concentrations of soluble salts are present in the root zone (Western Fertilizer Handbook, 1995; Barbour, 1998; Bauder and Brock, 2001). The increase in energy required to extract water results in decreased plant productivity in soils with elevated concentrations of soluble salts. While all plants exhibit decreased productivity with increasing concentrations of soluble salts, the threshold and degree to which salinity affects crop yield varies between species (Maas and Hoffman, 1977). The sensitivity of different agricultural crops to increases in soil salinity is shown in Figure 5-28.

Saline water has the potential for use in agricultural irrigation if appropriate management practices are employed. Therefore, irrigation practices should be managed to maintain the soil salinity in the root zone below the threshold concentrations specific to each crop species.

Plant transpiration and evaporation will result in salt concentrations in the soil which exceed that of the irrigation water. Due to these processes, the soil salinity (measured from the saturated paste extract) can often increase to

Figure 5-27
Soil Salinity and Sodicity
Classification index for soils showing the limit of survival of most plants.

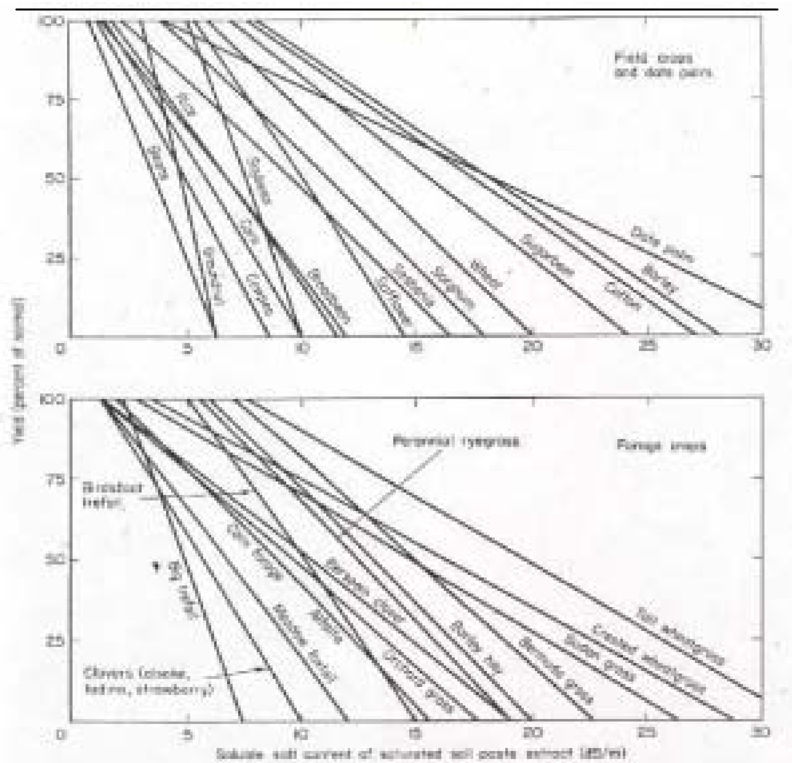


Source: Brady and Weil, 1999.

concentrations approximately 1.5- to 3-fold higher than the salinity of the irrigation water (Ayers and Westcot, 1976; Western Fertilizer Handbook, 1995). Therefore, a sufficient amount of irrigation water must be applied to the soil to leach accumulated salts from the root zone. This is represented by the leaching fraction, which is the relative quantity of the applied irrigation water that leaches below the root zone (Figure 5-29).

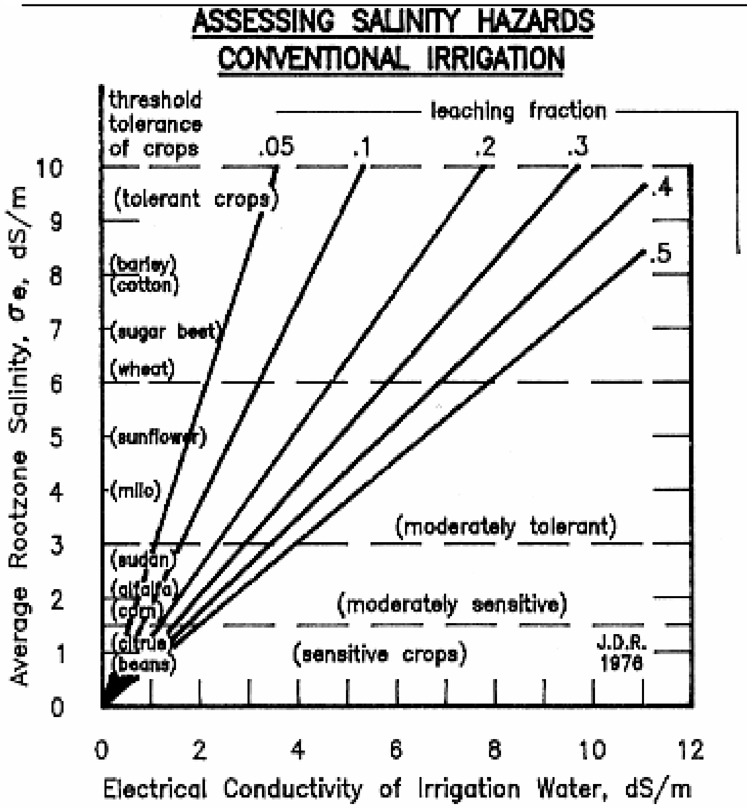
With high leaching fractions, salts that have accumulated in the root zone will be leached through the soil profile with the irrigation water (Figure 5-30). The concentration of soluble salts remaining in the root zone is a function of the salinity of the irrigation water and the rate

Figure 5-28
Crop Sensitivity and Salinity
Graph comparing the sensitivity of different crops to increases in soil salinity.



Source: Miller and Donahue, 1995.

Figure 5-29
Threshold Tolerance of Crops
The threshold tolerance of crops is compared to the salinity and electrical conductivity of soil.



Source: Tanji, 1996; based on Rhoades, 1982.

at which it percolates through the soil profile relative to evaporation and transpiration. However, it should be noted that while soluble salts will leach through the soil profile, sorption of cations on exchange sites in soils is also important in governing the relationship between EC and SAR.

Managing the application of irrigation water to maintain appropriate leaching fractions is particularly important during growth stages in which plants are most sensitive to elevated soil salinity. For example, alfalfa seedling emergence has been shown to be influenced by elevated soil salinity (Bauder et al., 1992).

While elevated soil salinity can have detrimental affects on crop yield, it should be noted that elevated soluble salt concentrations can also have beneficial affects on soil physical properties (Quirk and Schofield, 1955; McNeal, 1968; Oster and Schroer, 1979; Shainberg and Letey, 1984). Elevated concentrations of soluble salts in the soil pore water can enhance the aggregation (or flocculation) of clay particles and subsequently maintain soil permeability. Hansen et al. (1999) stated that flocculation is enhanced when the salinity of the irrigation water is greater than 0.5 dS/m, resulting in a soil pore water salinity of approximately 1.5 dS/m. The flocculation of clays in saline soils is governed by the combined influences of total salinity and the amount of sodium, as discussed below.

Affect of Sodic Irrigation Water on Soil Properties

In many project areas, CBM produced water contains higher levels of sodium than calcium or magnesium. The ratio between sodium and calcium + magnesium is typically expressed by SAR (Richards, 1954), which is defined as follows:

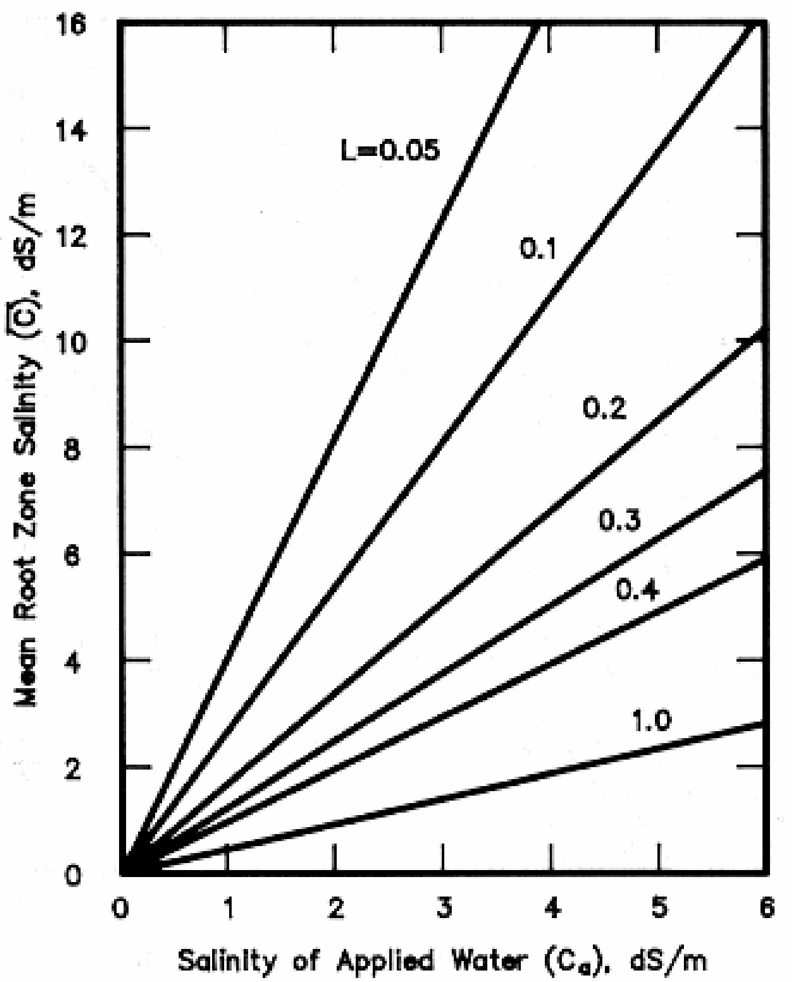
$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca]+[Mg]}{2}}}$$

where concentrations in square brackets are expressed in meq/L.

Irrigation water with an SAR > 12 is generally categorized as sodic (Hansen et al, 1999).

Irrigation water characterized by an elevated SAR has the potential to swell and disperse clays in the soil, which can result in decreased pore size and soil permeability (Buckman and Brady, 1967; Shainberg and Letey, 1984; Ayers and Westcot, 1985; Miller and Donahue, 1995). The dispersion of clays occurs due to a difference in the electrical attraction forces of sodium and calcium (or magnesium) ions that maintain the aggregation of soil clays. When concentrations of sodium sorbed on clay exchange sites increase relative to calcium, the attractive forces between clay platelets are decreased and the platelets begin to swell and disperse. The point at which dispersion may occur can be estimated based on knowledge of the clay mineralogy of a soil and the exchangeable sodium percentage (ESP). The ESP, defined below, is an expression of the fraction of sodium adsorbed to soil exchange sites in comparison to the total number of exchange sites.

Figure 5-30
Salinity of Applied Water and Soil
Accumulated salinity in the soil is compared to the salinity of the applied water.



Source: Hoffman and van Genuchten, 1983.

$$ESP = \frac{[Na - X]}{CEC}$$

where Na-X is exchangeable sodium concentration and CEC is cation exchange capacity.

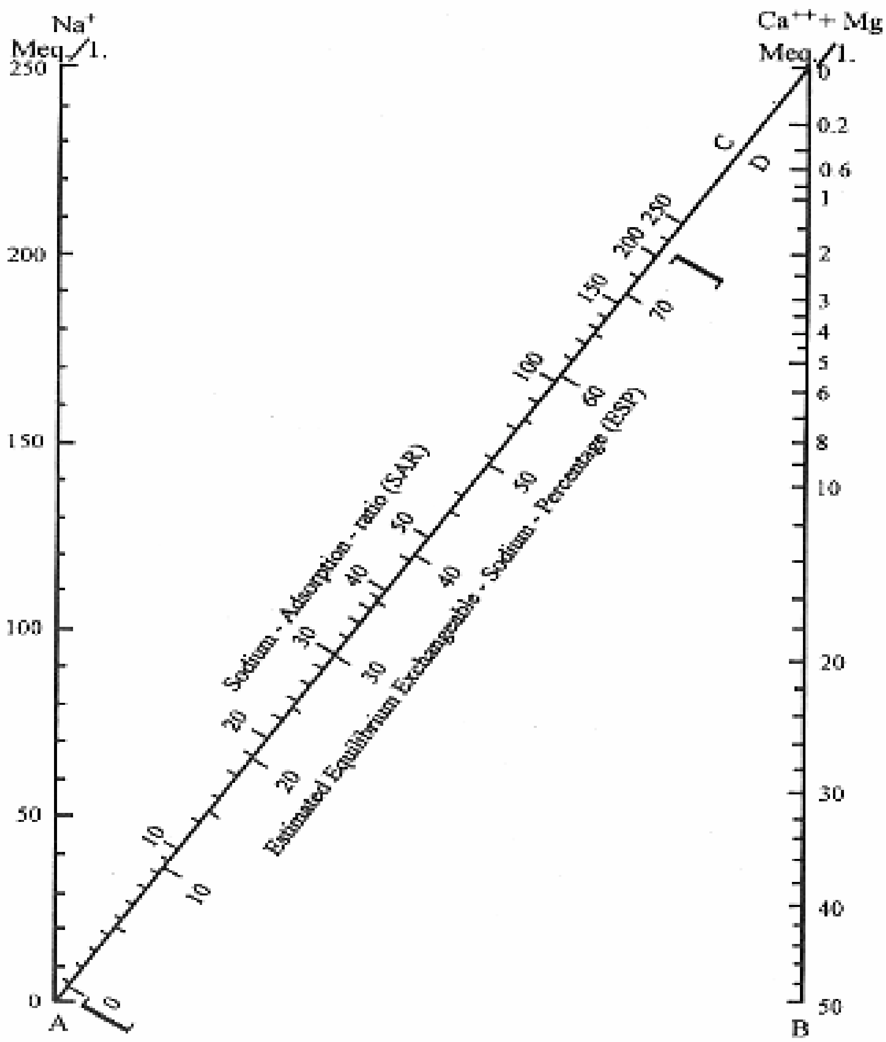
As described above, elevated concentrations of soluble salts in the soil pore water can decrease the risk of clay dispersion. Figure 5-31 demonstrates the relationship between the soil ESP value in equilibrium with the SAR of the soil saturated paste extract.

Recent academic, government, and industry review and research relative to the irrigation suitability of CBM produced water has focused on the relationship between SAR and EC. The primary discussions have revolved around the relationship between EC and SAR presented by Ayers and

Westcott (1985). Their research (based on previous work by others including Rhoades, 1977; and Oster, and Schroer, 1979) provides a risk-based evaluation of SAR and EC with respect to soil permeability.

Figure 5-32 demonstrates the risks posed to soil permeability that can be rapidly assessed based on the irrigation water quality. It should be noted that this relationship has not been developed for soils in many CBM project areas, but it offers a reasonable reference to guide initial planning efforts. In addition, the relationship between SAR, EC, and soil permeability is influenced by soil pH, which will affect the precipitation of calcium and magnesium, and subsequently, SAR. The affect of carbonates on this process is discussed in greater detail below.

Figure 5-31
Exchangeable Sodium Percentage
The exchangeable sodium percentage affects the ability of water to infiltrate soil by causing clay dispersion, which changes the pore size and soil permeability.



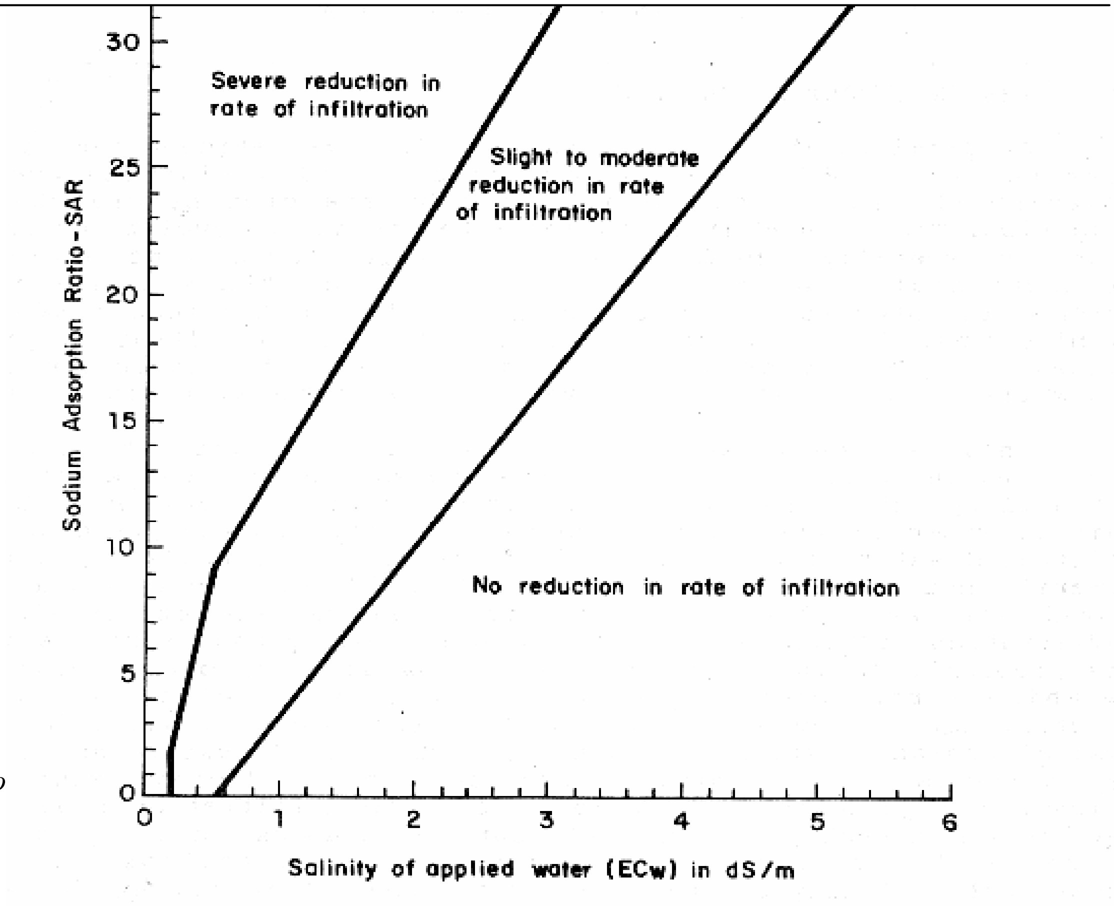
Source: G.J. Levy (1999), based on USSL Staff (1954).

Change in CBM Produced Water Quality During Storage

Many irrigation strategies using CBM produced water involve the storage of water in impoundments prior to land application. It is important to note that this temporary storage can alter the water chemistry, due to the abundance (and instability) of bicarbonate in the water. The CBM produced water is under pressure in the coal seams and when brought to the surface is generally oversaturated with respect to bicarbonate. Therefore, the bicarbonate will reach equilibrium with atmospheric conditions according to the following reactions:

Figure 5-32
Risk of Soil Permeability
The Sodium Adsorption Ratio is compared with the salinity of the applied water to determine the risk of reduction in the rate of infiltration of water into the soil

So



Source: Ayers and Westcot, 1985.

$CO_2(g) + H_2O = H_2CO_3°$

$H_2CO_3° = H^+ + HCO_3^-$

$HCO_3^- = H^+ + CO_3^{2-}$

As shown above, this increases the pH of the system, which can result in an increase in SAR due to the precipitation of $CaCO_3$, through the reaction shown below:

$Ca^{2+} + CO_3^{2-} = CaCO_3$

A recent study by Sessions and Bauder (2002) evaluated the change in chemistry over time with five CBM produced waters shown in Table 5-7. An increase in pH was observed due to the equilibration of CBM produced water with atmospheric CO_2 and a concomitant increase in SAR was observed due to precipitation of $CaCO_3$.

Table 5-7
Changes in Water Chemistry after Impoundment
Table shows the changes in water chemistry for five water qualities after 12 days of storage in impoundments, prior to land application, and minimal evapoconcentration.

	Initial pH	Final pH	Initial EC	Final EC	Initial SAR	Final SAR	% Change EC	% Change SAR
WQ1	7.77	8.5	1.67	1.38	3.1	6.51	-17.37	110.00
WQ2	7.58	8.09	3.21	3	2.19	3.25	-6.54	48.40
WQ3	7.94	8.64	3.02	2.92	9.49	14.67	-3.31	54.58
WQ4	7.53	8.3	3.8	3.62	8.69	13.51	-4.74	55.47
WQ5	7.39	8.87	6.87	6.73	16.98	24.98	-2.04	47.11
					Average % Change (Excluding WQ1)		**-4.16**	**51.39**

When considering the irrigation suitability of CBM produced water, it is important to determine the change in water chemistry over time. In addition, the chemistry of the CBM produced water should be considered relative to the chemistry of the irrigated soils. For example, irrigation water with a relatively low SAR may present a permeability risk to irrigated soils if the soils have abundant carbonate concentrations or a high pH, which may precipitate calcium and increase the apparent SAR.

The occurrence of trace metals in CBM produced water should also be evaluated when considering the suitability for agricultural use. Constituents such as iron, manganese, and boron are not uncommon in CBM produced water. However, the concentrations of these constituents should be considered relative to the specific use of the produced water.

Evaluation of Irrigated Soils
The physical and chemical properties of irrigated soils are important in determining the suitability of CBM produced water for irrigation.

Physical Properties

Understanding the physical properties of irrigated soils in addition to the drainage characteristics is critical to establishing the potential for irrigation with saline and/or sodic irrigation water. Soil profiles should be characterized and the texture of each horizon should be evaluated to determine whether adequate drainage is present to facilitate leaching of soluble salts through the root zone. In addition, the textural characteristics will provide an indication of the potential for upward salt migration in the soil profile due to capillary rise. A coarse determination of soil texture and drainage characteristics can be often be obtained from Natural Resource Conservation Service

(NRCS) soil maps. This information will not permit a detailed assessment of the suitability of irrigation with a given water quality; however, the information is useful to guide initial planning efforts.

Another important factor governing the suitability of saline and/or sodic water for irrigation is the fraction and type of clay in the soil. Fine textured soils have lower hydraulic conductivities and poorer drainage characteristics. Since the ability to leach accumulated salts through the root zone is critical to achieving sustainable irrigation practices with saline and/or sodic waters, more intensive management practices must be employed if finer textured soils are present. In addition, soils with higher fractions of clay are more sensitive to dispersion, and irrigation suitability should be determined based on the relationship between EC and SAR discussed above. In soils with higher fractions of clay, evaluating the mineralogy is important in determining the response of the clay to sodic irrigation water. For example, montmorillonitic clays are at a greater risk to dispersion when irrigated with sodic waters in comparison to illitic or kaolinitic clays. Characterizing the clay mineralogy of a soil can be costly; therefore, an initial evaluation of candidate areas for irrigation with CBM produced water should focus on locating sandy sites, if possible. If finer textured soils are considered for irrigation with CBM water, determination of clay mineralogy can be informative in evaluating the risk of dispersion and guide the design of appropriate land management strategies.

Chemical Properties

The chemistry of irrigated soils should also be determined to evaluate the suitability of CBM produced water for use in agriculture. The existing salinity of the soils should be characterized with depth in the soil profile. This will provide an indication of baseline conditions in addition to trends such as salt leaching.

The sodicity of soils should be evaluated by sampling and analysis of exchangeable ions and cation exchange capacity (CEC). As discussed above, this information can be used to calculate the ESP.

A concern of irrigating with saline/sodic waters is the affect of precipitation on dispersion of clays in the soil. As discussed above, the risk of dispersion of sodic soils is minimized in soils with elevated concentrations of soluble salts. However, when salts are leached through the soil profile by precipitation, the salinity of surface soils will decrease and subsequently increase the risk of dispersion, since sodium will remain adsorbed to exchange sites. Although, a recent study indicates that saline/sodic soils high in clay content may exhibit a buffering affect against decreases in EC following irrigation with "clean" water (Robinson and Bauder, 2002).

Land Management Options for Irrigation with CBM Produced Water

The potential for the beneficial use of CBM produced water in agriculture is also governed by the commitment of landowners and/or operators to design and implement appropriate land management practices. Various land management strategies can be designed to increase the suitability of CBM produced water for use in irrigation. These involve increasing the suitability of CBM produced water for agricultural use by amending the soil and/or water. In addition, recent research has demonstrated the potential value of using plant species that have inherent properties that minimize the impacts of saline and/or sodic irrigation water to soil permeability and crop yield. These plant species may facilitate the use of saline and/or sodic irrigation water, and have been used in the bioremediation of salt-affected soils.

The PRB of Wyoming and Montana is in an arid region with abundant use of land for hay production and grazing. Consequently, there has been a considerable effort to evaluate the potential for CBM produced water, if used for irrigation, to impact the growth of native grasses, alfalfa, and other crops located in flood irrigated pastures in this area. Since the irrigation suitability of CBM produced water has been widely explored in the PRB, many of the examples of amendment strategies discussed below are from this region.

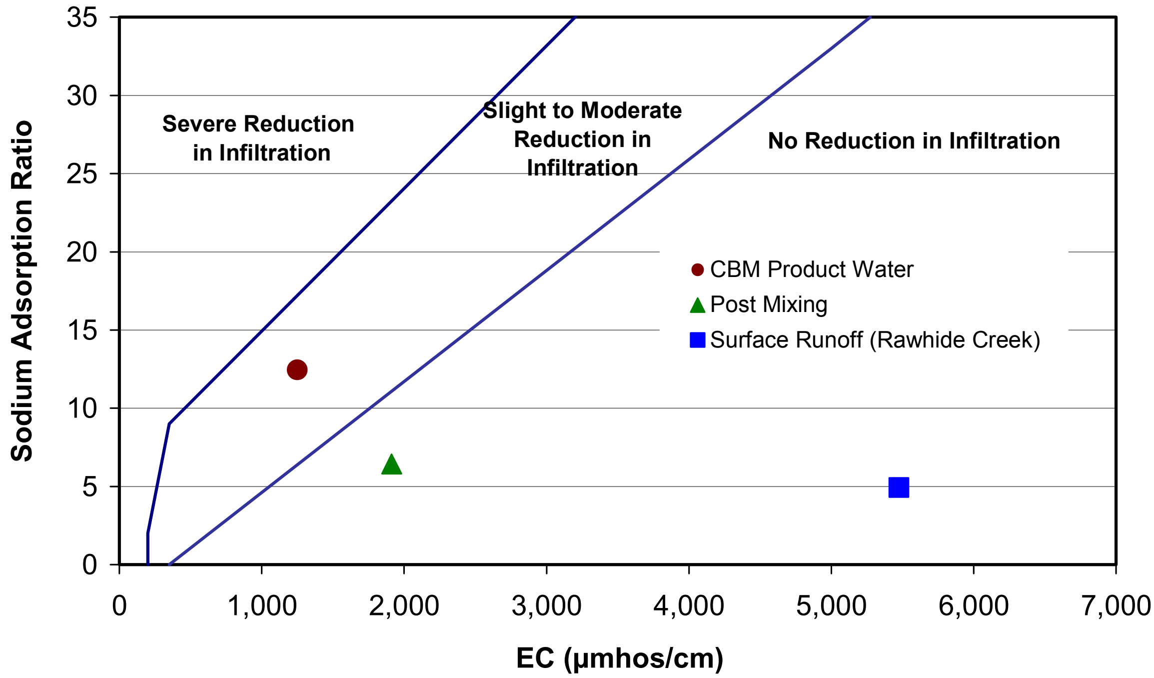
Amending CBM Produced Water to Increase Suitability for Irrigation

As discussed above, the pH of CBM produced water will often increase during storage and transit as bicarbonate concentrations in the water reach equilibrium with atmospheric conditions. The increase in pH and subsequently SAR (due to calcite precipitation) increases the risk of swelling and dispersion when applied to soils with a high fraction of clay. To increase the suitability of the water for irrigation, the water can be chemically amended to decrease the pH and increase the concentration of calcium. Various acids can be used to achieve the reduction in pH, and sulfuric acid has been often considered due to the abundance of sulfate in natural surface waters of the PRB. In addition, formic acid has been utilized in laboratory studies as a potential amendment, since the organic acid will be degraded by soil microorganisms and therefore minimizes the increase in soil salinity in comparison to other acids. Once the pH of the CBM produced water has been decreased, amendment of the water with calcite, dolomite or other calcium-bearing minerals can be conducted to decrease the SAR of the water. It should be noted that these treatment strategies may require prior regulatory classification of impoundments as treatment basins.

Mixing of CBM produced water with natural runoff and/or groundwater should be evaluated in addition to the use of chemical amendments to increase irrigation suitability. In many areas of the PRB, the soils and surface water are rich in calcium and magnesium. The natural runoff is therefore characterized by a relatively low SAR and elevated EC in comparison to CBM produced water. In contrast, CBM produced waters can have a relatively low EC and moderate to very high SAR, which is often elevated due to very low concentrations of calcium and magnesium, rather than very high concentrations of sodium. Therefore, when CBM produced water is mixed with natural runoff, the resulting water may be more suitable for agricultural use than either of the parent waters. This relationship is demonstrated in the mixing calculation in Figure 5-33, in which CBM produced water (approximately 15 acre-feet) is hypothetically mixed with natural runoff from Rawhide Creek (approximately 2.5 acre-feet) an ephemeral stream in northeast Wyoming (based on average water quality data from Rawhide Creek prior to CBM development in this region; Wyoming Department of Environmental Quality, 2001).

Figure 5-33 shows the water quality resulting from mixing of CBM produced water (EC of 1,250 μmhos/cm, SAR of 12.5) with natural runoff from Rawhide Creek (EC of 5,475 μmhos/cm, SAR of 4.9). Since the natural runoff in this region has elevated sulfate concentrations (and subsequently elevated salinity), mixing with CBM produced water results in a decrease in the salinity of the mixed water. A slight increase in SAR from the natural runoff was calculated; however, based on the criteria presented above, the resulting water would not cause a reduction in infiltration.

Figure 5-33
Amended CBM Water
CBM water can be mixed with non-CBM water to decrease the salinity and increase the permeability of the water applied to the land.



Soil Amendment Strategies
In addition to amending irrigation water prior to land application, various soil amendment strategies are available to minimize impacts of sodic irrigation waters to sensitive soils. These amendments are also geared towards maintaining relatively low levels of soil pH and ESP to minimize decreases in soil permeability. J.M. Huber incorporated soil amendments to facilitate the use of CBM produced water for irrigation of hay meadows and improved rangeland in Sheridan County, Wyoming. The produced water quality at the site had an SAR of 53 and an EC of 2,100 µmhos/cm. To maintain the permeability of the irrigated soils, gypsum (4 tons/acre) and disintegrating sulfur (600 lbs/acre) were amended to the soils at quantities that were based on the sodium content of the CBM produced water (Fehringer, 2002). The use of gypsum is designed to provide a slow-release source of calcium to the irrigated soils. Disintegrating sulfur is elemental sulfur that has a very high surface area, which is oxidized through microbial activity to form sulfuric acid and aid in the maintenance of relatively low soil pH conditions. This amendment strategy was designed to reduce the risk of clay dispersion and minimize the precipitation of calcite.

Laboratory testing was performed to determine the decrease in SAR following mixing of the gypsum with the CBM produced water and to evaluate the quality of various sources of gypsum.

Soil Amendments can be added to decrease the affects of CBM water with a high SAR.

Table 5-8 below shows monitoring data for soil chemistry of four fields amended with gypsum and disintegrating sulfur to facilitate the use of CBM produced water for irrigation. The gypsum was applied at 4 tons per acre at approximately $38/acre, and approximately 600 pounds of sulfur applied per acre at $0.11/lb. Based on these quantity estimates, the average material costs for amendments ranged from approximately $150 to $200 per acre in addition to irrigation infrastructure costs.

As shown in the Table 5-8 below, an increase in soil salinity was observed during irrigation with CBM produced water. However, the resulting soil salinity was below the threshold values of many crops as described earlier. The amendments were designed to maintain a relatively low SAR and a corresponding EC that will maintain soil permeability while maintaining sufficient crop yield. In addition, the soil amendments were applied in excess of those necessary based on the amount of applied CBM produced water to provide a residual source of calcium and acidity after irrigation with CBM produced water is complete. This will aid in the maintenance of soil permeability when the primary source of moisture in the soil is either natural runoff or direct precipitation, which may be of lower salinity than the CBM produced water.

Evaluating the Selection of Plants

When utilizing CBM produced water for irrigation, it should be understood that increases in soil salinity may occur, even with appropriate management practices. Therefore, crop selection should be based on the salt tolerance of the species under consideration, as discussed above.

In addition to tolerating saline soil conditions, many plant species have physiological attributes that minimize the detrimental affects of saline and/or sodic irrigation water on soil physical and chemical properties. Recent research has focused on identifying plant species that produce acid or accumulate sodium and may be used in addition to, or in place of soil amendments discussed above. For example, Bauder and Brock (1992) reported that sorghum and barley had positive affects on the maintenance of soil structure during irrigation with saline/sodic water and

Table 5-8
Soil Test Data
Soil salinity increases with the application of CBM produced water; however, the resulting soil salinity is below the threshold values of many crops.

J.M. Huber Soil Test Data

Baseline Geochemical Soil Analyses & Soil Analyses Following CBM Water Application

Field/(Crop)	*Depth*	*Soil Test Timing*	*Soil Texture*	*pH*	*% CaCO3*	*%Organic Matter*	*EC mmhos/cm*	*Ca meq/l*	*Mg meq/l*	*Na meq/l*	*SAR*	*Water Applied*
Peterson Sideroll (Established alfalfa)	0-6"	Baseline	CL	7.2	1.7	2.52	0.85	6.28	2.43	0.31	0.15	n/a
		1st Yr	CL	7.5	2.6	2.88	4.33	11.10	4.89	29.50	10.40	
	6-24"	Baseline	CL	7.4	-	-	0.89	5.70	3.02	0.53	0.25	
		1st Yr	CL	7.5	-	-	1.45	5.02	2.82	7.52	3.80	
Trembath Pivot (Hay barley)	0-6"	Baseline	CL	7.5	5.1	3.32	0.80	5.14	1.90	0.30	0.16	n/a
		1st Yr	CL	7.5	6.7	2.29	4.75	25.80	8.98	31.40	7.53	
	6-24"	Baseline	SiCL	7.6	-	-	0.67	3.77	1.73	0.57	0.32	
		1st Yr	SiCL	7.5	-	-	2.94	15.20	9.72	11.90	3.36	
Taylor Pivot: W1/2 (Established alfalfa)	0-6"	Baseline	CL	7.4	-	-	0.98	6.08	2.95	1.05	0.49	n\a
		1st Yr	CL	7.1	1.2	2.19	2.09	13.40	5.87	16.70	5.39	9"
		2nd Yr	CL	7.2	1.5	2.95	3.48	17.50	7.62	17.00	4.79	
	6-24"	Baseline	CL	7.8	-	-	0.78	3.11	2.48	2.74	1.61	
		1st Yr	CL	7.4	-	-	0.74	3.18	2.32	2.13	1.26	
		2nd Yr	CL	7.6	-	-	1.99	5.77	3.83	9.74	4.45	
Taylor Pivot: E1/2 (Established alfalfa)	0-6"	Baseline	SCL	6.9	-	-	0.66	4.35	2.00	0.75	0.42	n/a
		1st Yr	SCL	7.1	1.1	1.83	2.74	15.10	4.99	11.40	3.58	10"
		2nd Yr	SCL	7.0	0.9	2.26	4.22	24.30	7.88	20.50	5.11	
	6-24"	Baseline	SCL	7.2	-	-	0.73	3.43	2.10	1.43	1.14	
		1st Yr	SCL	7.3	-	-	0.89	4.97	2.18	2.10	1.11	
		2nd Yr	SCL	7.2	-	-	2.76	9.46	8.54	11.80	4.17	
Pilch Sideroll (New alfalfa in 2002)	0-6"	Baseline	CL	7.2	1.7	2.52	0.85	6.28	2.43	0.31	0.15	n/a
		1st Yr	CL	7.4	4.1	2.95	3.61	24.10	6.14	18.50	4.76	
	6-24"	Baseline	CL	7.4	-	-	0.89	5.70	3.02	0.53	0.25	
		1st Yr	CL	7.4	-	-	1.11	7.31	3.33	2.19	0.95	

Notations:
1. "-" indicates sample not tested for that parameter.
2. Taylor pivot baseline was sampled and analyzed by B & C Ag Consultants of Billings, MT.
3. All others sampled by Neal Fehringer, Certified Professional Agronomist, C.C.A., and analyzed by Energy Labs, both of Billings.
4. Table compiled by Neal Fehringer, Certified Professional Agronomist, C.C.A. on 11/15/02.

performed statistically better than any of the chemical amendments tested. Table 5-9 lists several plant species that have the ability extract ions from the soil and accumulate salts in the plant biomass or excrete salts on the leaf surface. Many of these species not only tolerate saline soil conditions, but have also been successfully used in the bioremediation of saline and/or sodic soils.

Salt tolerant plants can also be incorporated into the design of impoundments to maximize the consumptive use of CBM produced water. For example, the sidewalls and areas upgradient of impoundments can be seeded with salt tolerant plants and irrigated with stored CBM produced water to maximize evaporation and transpiration. This strategy can also be used to design wetlands that will maximize the plant consumption of CBM produced water. The resulting water stream will be more saline and of a lower volume than the produced water, and may increase the cost-effectiveness of alternative management strategies such as water treatment or injection.

Table 5-9
Bioremediation of Saline or Sodic Soils
Plants can be used to minimize the detrimental affects of saline and/or sodic irrigation water on soils. This table identifies plants that may be used in addition to or in place of soil amendments.

Common Name	Scientific Name	Function
Amshot Grass	Echinochloa stagninium	ion accumulator
Suada vera Forsk	Suaeda fruiticosa	ion accumulator
Rice	Oryza sitiva	ion accumulator
Sunflower	Selianthus annuus	ion accumulator
Sharp-leaved rush	Juncus acutus	ion accumulator
Samaar morr	Juncus rigious	ion accumulator
Salt Cedar	Tamarix L.	ion extractor
Goosefoot	Chenopodium spp.	ion extractor
Summer Cypress	Kochia spp.	ion extractor
Salt Wort	Salicornia spp.	ion extractor
Russian Thistle	Salsola spp.	ion extractor
Seablite	Suaeda spp.	ion extractor
Sorghum-sudan grass	Sorghum-sudanese	pore size enhancer
Barley	Hordium spp.	limited ion accumulator
Wheat	Triticum spp.	limited ion accumulator
Cotton	Gossypium spp.	limited ion accumulator
Sugarbeet	Heterodera spp.	limited ion accumulator

Source: Phelps and Bauder, 2002.

Other Considerations for Agricultural Use of CBM Produced Water

It is important to note that the duration of the irrigation season will be variable depending on the location of the project area. In many areas, the climate necessitates that the water cannot be used for irrigation during long periods in the winter. Therefore, a comprehensive water management plan should be designed to include options such as the storage, surface discharge, or re-injection of produced water to accommodate seasonal considerations. The species and use of crops may also require the periodic interruption of irrigation to allow for planting and harvesting.

Data Needs

This section describes the information required to determine the suitability of CBM produced water for agricultural use. As discussed above, the factors influencing the irrigation suitability of CBM produced water include water quality, soil characteristics, and land management practices. This section provides recommended sampling parameters for soil and water; however, decisions on the use of CBM water for irrigation should also be based on land management practices.

Analysis of CBM Produced Water

The discussion of the irrigation suitability of CBM produced water presented above focused primarily on the evaluation of EC, SAR and pH. However, other analytes and parameters should be evaluated when characterizing CBM produced water in a new project area, including the following:

General Parameters
- pH
- EC
- TDS
- Alkalinity
- Hardness

Soluble Ions
- Calcium
- Magnesium
- Sodium
- Potassium
- Bicarbonate/Carbonate
- Sulfate
- Chloride
- Fluoride

Trace Constituents
- Iron
- Manganese
- RCRA 8 (As, Ba, Cd, Cr, Pb, Hg, Se, Ag)

It should be noted that alternative sources of irrigation water in a project area should also be characterized with respect to irrigation suitability. For example, a water management plan may include the use of natural runoff and/or groundwater to mix with, or supplement, CBM produced water. Therefore, these sources should also be analyzed for the parameters described above.

Analysis of Irrigated Soils

Irrigated soils should be characterized to determine the potential for swelling and/or dispersion when irrigated with CBM produced water. As discussed above, the potential for dispersion of soils is based on the quantity and type of clay present. The detail to which the physical characteristics of the soil should be evaluated is dependent on the size and stage of the project. For example, NRCS soil maps can be reviewed to provide a general indication of the soil types and drainage characteristics present in a project area. Following this initial review, a more detailed characterization of soil physical and chemical properties and drainage characteristics can be obtained from a soil sampling and analysis program. Soil pits should be excavated and samples collected from discrete horizons for analysis of texture and potentially clay mineralogy. Drainage characteristics of the soil should be evaluated based on field observations described during soil pit excavation and laboratory analysis.

The soil samples collected during soil pit excavation should also be submitted for laboratory chemical analysis of the following parameters:

General Parameters

- pH
- EC
- CEC
- Alkalinity
- Hardness
- $CaCO_3$ content

Soluble Ions (Saturated Paste Extract)

- Calcium
- Magnesium
- Sodium
- Potassium
- Bicarbonate/Carbonate
- Sulfate
- Chloride
- Fluoride

Exchangeable Ions (Ammonium Acetate Extraction)

- Calcium
- Magnesium
- Sodium
- Potassium
- Fluoride

Potential Constraints

The benefit of utilizing CBM water for irrigation has been realized in arid regions such as the PRB. However, various constraints exist within many CBM projects that may affect the potential for agricultural use of CBM produced water. These issues require careful scrutiny during the early stages of a CBM project timeline and include the following:

- *Permitting.* State agencies including the Department of Environmental Quality (DEQ), State Engineers Office (SEO) and the State Oil and Gas Commission (SOGC) require a specific permitting process for CBM exploration/exploitation. These agencies may require, based on the requested CBM discharge/containment option (i.e. on-channel containment versus off-channel), formal documentation of the proposed water management plan for pre-approval.
- *Landowner.* Most CBM governing bodies stress the importance of cooperation between the CBM operator and surface rights landowner. The two parties must be able to explore suitable ways to handle CBM produced water in a mutually beneficial way. Also, if the agreed water management option has the possibility of affecting adjacent lands (i.e. discharge waters moving across ownership boundaries by means of surface flow or subsurface flow) these other parties must be in agreement to the proposed option, or steps must be taken to manage water without crossing property boundaries.
- *Environmental.* CBM produced water chemistry and soil texture and mineralogy of the irrigable area play a major role in determination of a successful water management option. Protection of the environment should be paramount when considering CBM water management options.
- *Agricultural.* Salt tolerance and growth stage of individual plant species within the irrigable area.

- *Meteorologic.* Drought versus wet weather conditions will play a considerable role in the ultimate ability of an irrigable area to provide acceptable soil and water chemistries by adequately infiltrating or diluting CBM produced water.
- *Topographic.* The topographic setting of an area will have a major roll in determining the suitability of an irrigation option.
- *Geologic.* Unstable geologic conditions (slide areas, sinks, etc.) may eliminate some water management irrigation options.

Economic Evaluation

This section presents a comparison of costs associated with the irrigation systems previously discussed excluding the flood irrigation and stock watering options. Table 5-10 has been modified from an analysis presented by the North Dakota State University (NDSU) Extension Service (Scherer, 1998) on selection of an appropriate irrigation system. The discussion has also been fortified with pertinent information on actual equipment usage, soil amendment materials, and labor costs realized by existing CBM PRB operators (Huber, 2002). Several line items on Table 5-10 have been modified to more accurately represent CBM operational needs based on actual operational data.

Per NDSU, the purpose of the original evaluation was to provide a per-acre comparative cost of irrigation options based on the following criteria:

- The irrigation area is a square, 160 acre field.
- The water source is delivered near the center of the field.
- The water supply is adequate for any sprinkler system.
- The soils are suitable for the system application rate.

The comparative costs presented by NDSU have also been modified to include best estimate costs for the manual big gun system option currently used in CBM operations in the PRB.

Capital Costs

Start-up costs to implement the identified irrigation systems range from approximately $20,000 to $58,000 with the manual big gun system as the least expensive and the center pivot system the most expensive. Based on NDSU's 160 acre test plot, this equates to a per-acre capitol cost of $446.15, $348.10, $350.32, and $127.39 for the center pivot, side roll, automated big gun, and manual big gun systems, respectively. The per-acre costs provide a relational approximation of the necessary infrastructure and number of systems required to effectively irrigate the test area in a similar application rate and time frame. For example, it would require about four side roll irrigation systems to irrigate an area comparable to a standard size center pivot system. Several variables exist that could influence capitol costs and include the following items:

- topography and access restrictions
- use of existing utilities or an internal combustion generator for power
- proximity to existing utilities
- shape and size of the irrigable area

- required flow rate for a system
- soil properties compatibility with system design
- the amount of time and labor available to operate the system
- distance from the CBM water source
- system depreciation, interest on investment, and insurance

Table 5-10
Capital Costs
Table showing costs of CBM operational needs.

CAPITAL COSTS	*Center Pivot System*	*Side Roll System*	*Automated Big Gun System*	*Manual Big Gun System*** (estimated)*
Number of Systems Required	1	4	2	3
Acres Irrigated (in 160)	130	158	157	157
Max Flow Rate (gpm, cumulative for multiple units)	780	948	942	1413
Approximate Equipment Cost	$50,000	$40,000	$40,000	$5,000
Pump, Motor and Piping from CBM Source Water*	$5,000	$5,000	$5,000	$5,000
Pipe, Meter, Valves for Irrigation Station Set-up	$3,000	$10,000	$10,000	$10,000
TOTAL CAPITAL COSTS	***$58,000***	***$55,000***	***$55,000***	***$20,000***
CAPITAL COSTS PER ACRE	$446.15	$348.10	$350.32	$127.39
OPERATING COSTS (Per ACRE)				
Electric Power***	$20.30	$26.88	$40.05	$7.50
Labor (@ $10.00/hr)****	$7.50	$25.00	$20.00	$100.00
Maintenance (@ 1.5% of New Cost)	$6.69	$5.22	$5.25	$1.91
Total Annual Operating Costs	***$34.49***	***$57.10***	***$65.30***	***$109.41***

*Initial costs by NDSU included well installation. This line item has been modified to include a best guess estimate on costs for the Pump, Motor and Piping of CBM waters from the source area to one discharge point near the center of the property.

**Estimated costs for the Manual Big Gun System were not included in the NDSU Comparison. This category and estimates have been included based on a best guess estimate by Golder.

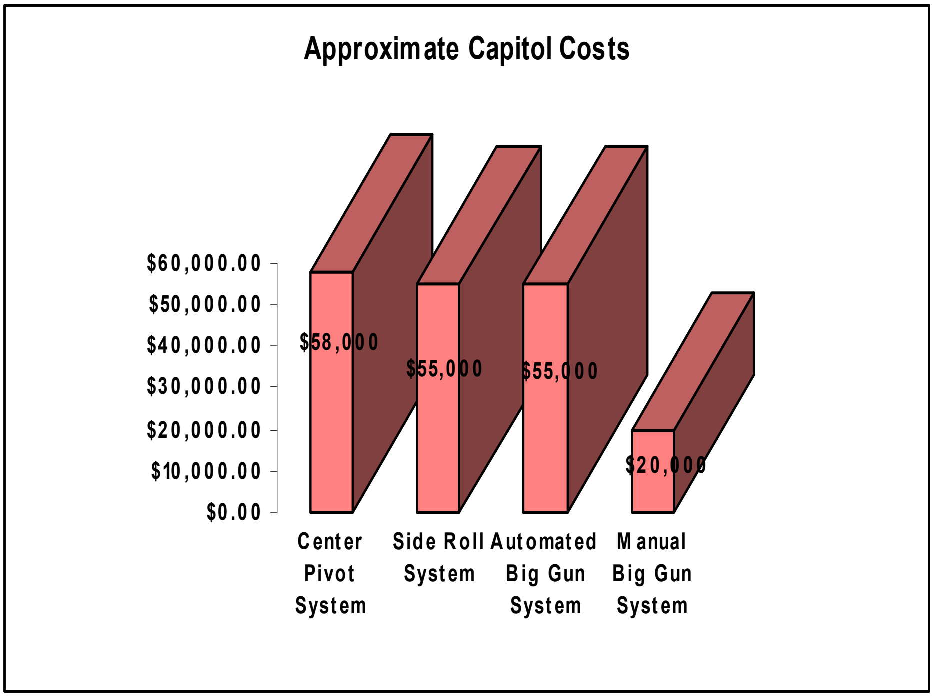
***Power usage costs based on an electric rate of 4.5¢ per Kilowatt-hour (KWH), an electric demand charge of $9.00 per KW per month (4 moths of operation) and 1050 hours of pump operation per irrigation season

****Initial labor costs were estimated at $7.00/hour by NDSU. This has been modified to $10.00/hour.

Source: Huber, 2002

Capital costs presented above are broken down into several components: 1) costs for the irrigation system infrastructure and setup; 2) costing to route CBM source water to a central location on the property, including the pump, motor and piping; and, 3) costs for the piping, metering and valves to setup irrigation stations for mobile systems. These costs are provided as a general comparative tool and do not take into account other considerations such as construction of a CBM containment reservoir to store produced waters prior to pumping to the irrigation system (up to $100,000 for a 50 acre-ft off channel pond). Therefore, very significant uncertainties are inherent in these estimates.

Figure 5-34
Capital Cost of Irrigation Systems
Chart shows initial start-up costs of irrigation systems that use CBM water.

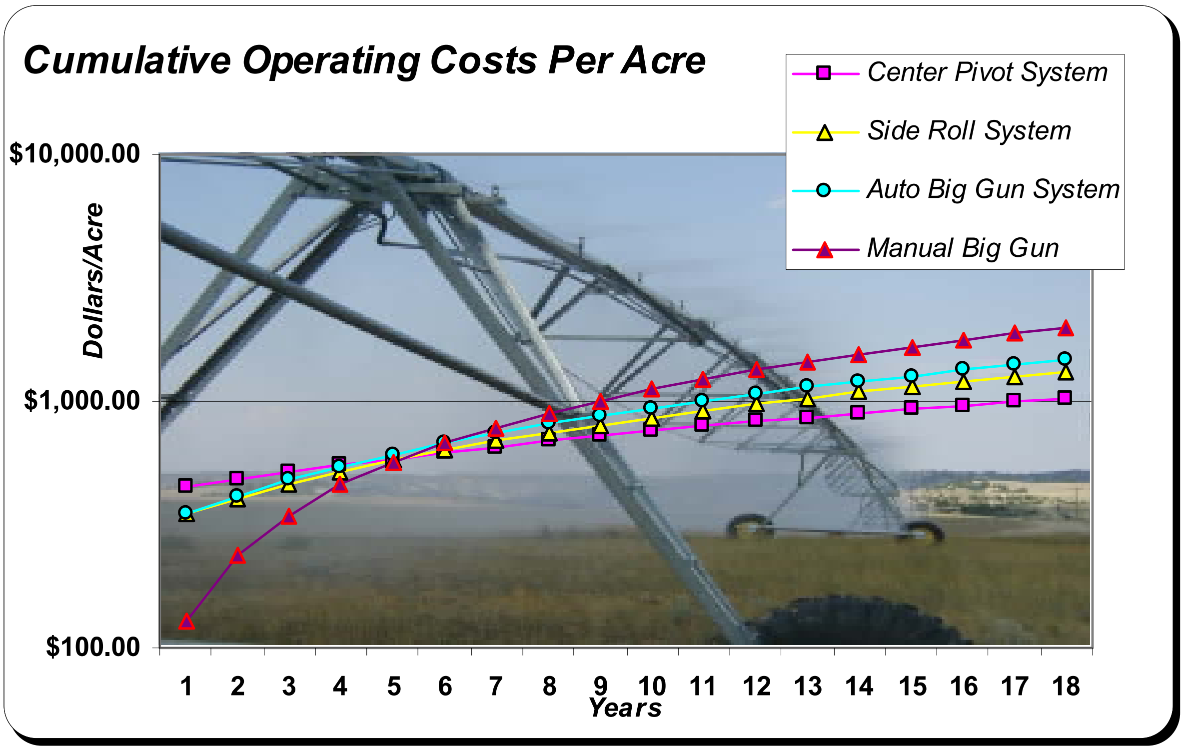


Operating Costs

Operating costs for each irrigation option are based on electric power usage, labor and maintenance. Variability of these operating costs may depend on several factors including:

- power demand (electric or diesel),
- application rate,
- irrigable area configuration (ease of system mobilization),
- labor effort requirements (mobilization, monitoring, system breakdown), and
- length of irrigation season.

Figure 5-35
Cumulative Operating Costs per Acre
The operating costs for each irrigation option, based on electric power usage, labor, and maintenance.



As suggested by Table 5-10, labor costs are the major factor influencing overall operating costs for potential CBM irrigation operations. Based on actual PRB operational data supplied by J.M Huber, the labor costs per acre presented in the NDSU summary are extremely conservative for the mobile systems (side roll, auto big gun, and manual big gun) used in CBM applications.

Figure 5-35 suggests that during the life span of an irrigation system the center pivot would provide the most cost effective option despite requiring the greatest startup capitol.

For example, after the first year of operation the cumulative operational costs per acre (including the one-time capitol investment) would be approximately $480.65, $405.20, $415.62, and $236.80 for the center pivot, side roll, auto big gun and manual big gun systems, respectively. This equates to a first year cost of about $480,000, $400,000, $410,000, and $237,000, respectively for an irrigable area of approximately 1,000 acres. However after ten years of operation, the typical lifespan of a producing CBM field, the center pivot option becomes the more economic system with respective cumulative costs of $791.06, $919.10, $1003.32 and $1221.49 per acre, or approximately $790,000, $920,000, $1,000,000 and $1,220,000 in total operational costs over a 1,000 acre area. Again, these costs are provided only as a general comparative tool for each irrigation option and very significant uncertainties are inherent.

Industrial Use

Introduction

Other water management options for CBM produced water include the supply of CBM water to other industries for use in operational activities. A variety of existing industries could benefit from this water supply including: coal mines, animal feeding operations, cooling tower water for various industrial applications, car wash facilities, commercial fisheries, enhanced oil recovery, and fire protection. Industrial applications which may be less commonly considered but would still have the potential for the use of CBM produced water include: sod farming, bottled drinking water, brewery water, and solution mining of minerals. Each of the existing industries and emerging industrial applications would use produced water of varying quantities and quality.

Alternative 1 - Coal Mine Use

Coal mining in the United States is generally at or near the land surface. Mining related activities which require water include: dust suppression, slurry activities, and post mining restoration efforts. Dust has a variety of sources around coal mining operations including:

- drilling and blasting;
- road surfaces disturbed by vehicles;
- materials handling and transporting e.g. hoppers, conveyor belts, crushing and grinding;
- mine waste piles (overburden, tailings etc);
- unrestored mine sites; and
- spontaneous combustion.

In some mining operations, coal is slurried during transportation either from the mineshaft or during transportation to minimize additional dust. In some surface and subsurface mining operations, the extractable coal is below the existing water table and requires a reduction in the water table prior to mining. After mining has been completed, coal mine operators are required to restore these shallow aquifers.

Applicability

CBM developed initially as an effort to degas coal seams prior to mining activities. The supply of CBM produced water for coal mining use can be a significant water management option in many existing and evolving basins. Surface coal mining activities exist around many of the basins where there is potential for additional CBM development.

Most coal mines collect the water they remove during dewatering in order to access mineable coal seams; however, this water does not always provide sufficient quantities of water for the mines' use. Additional water is supplied to coal mines from a variety of supplies including the damming of surface waters and extraction of groundwater from other aquifers. CBM produced water could be supplied to the mine during active mining to use for dust suppression activities. Once mining activities have been completed additional volumes of CBM produced water could be supplied to the mines for their restoration efforts including the use of water to restore drawdown aquifers and for irrigation of reclamation plantings.

CBM water can be used by water truck to spray roadway to suppress dust.
Source: Envirotac.com

Constraints

There are several constraints for the use of CBM produced water in coal mining including:

- *Water Quality:* Although the majority of the water used in association with coal mining activities is used for dust suppression, water quality is still a concern. Water that is applied for dust suppression can cause environmental impacts which may make subsequent reclamation of the mine area more difficult in the future. Poor quality water can impact the soils resulting in increased erosion and salt accumulation which would increase the work necessary in future reclamation activities.
- *Timing:* Significant volumes of produced water could be used over the lifetime of a coal mine for dust suppression, but additional water is also needed for aquifer restoration activities after the mine has been reclaimed. In some areas, existing mines will continue to operate after CBM water production has declined significantly. This timing issue may be critical in determining how much CBM water is used for coal mining operations, causing coalmines to store significant volumes of water produced during the early stages of CBM development for later use.
- *Transportation:* The transportation of the produced water could also constrain the amount of produced water that is used by coalmines. As CBM development moves further away from existing coal mining operations the methods of transporting the produced water become more expensive. Transportation will be a bigger factor in areas where other supplies of water are readily available for the mines to use; however, in

water scarce areas the limits associated with transporting water greater distances should be lessened.

Data Needs

The data needs for this management option are to identify the location of mines, then to establish the volume and quality of produced water that could be used.

- *Locations:* Many of the basins which have the potential for CBM development have existing coal mines and coal leases for future mining activities. The identification of these areas prior to field scale development would allow operators an opportunity to construct water management facilities in areas where the mines could have easy access to the water.
- *Water Quantity and Quality:* Once the mines that need water have been identified, operators need to determine how much produced water and what quality of produced water are needed. Some larger mines may need as much produced water of any quality that can be supplied to them, while other mines may only need high quality water for aquifer restoration efforts. Communication between the CBM operator and mining company could identify methods to meet the needs of both party's water management issues.

Alternative 2 - Animal Feeding Operations

CBM produced water could be supplied to Animal Feeding Operations (AFOs) and Concentrated Animal Feeding Operations (CAFOs) for livestock watering and the management of animal wastes. Livestock watering applications in a CAFO would be similar to that previously discussed in the Agricultural Use section of this chapter. Additional detail regarding CBM produced water quality and how it relates to livestock water can be found there. In addition to livestock watering at CAFOs, produced water could be used to assist in waste management activities. This could include using the water to dilute animal waste prior to discharge. The EPA, as defined in 40 CFR 122.23, Appendix B, regulates NPDES permitted discharges from CAFO's for animal waste if:

- More than the numbers of animals specified in any of the following categories are confined: (1) 1,000 slaughter and feeder cattle, (2) 700 mature dairy cattle (whether milked or dry cows), (3) 2,500 swine each weighing over 25 kilograms (approximately 55 pounds), (4) 500 horses, (5) 10,000 sheep or lambs, (6) 55,000 turkeys, (7) 100,000 laying hens or broilers (if the facility has continuous overflow watering), (8) 30,000 laying hens or broilers (if the facility has a liquid manure system), (9) 5,000 ducks, or (10) 1,000 animal units; or
- More than the following number and types of animals are confined: (1) 300 slaughter or feeder cattle, (2) 200 mature dairy cattle (whether milked or dry cows), (3) 750 swine each weighing over 25 kilograms (approximately 55 pounds), (4) 150 horses, (5) 3,000 sheep or lambs, (6) 16,500 turkeys, (7) 30,000 laying hens or broilers (if the facility has continuous overflow watering), (8) 9,000 laying hens or broilers (if the facility has a liquid manure handling system), (9) 1,500 ducks, or (10) 300 animal units;

Concentrated Animal Feeding Operation in Illinois.
Photo source: Grace Factory Farms

- In addition, either one of the following conditions must be met: pollutants are discharged into navigable waters through a manmade ditch, flushing system or other similar man-made device; or pollutants are discharged directly into waters of the United States which originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the animals confined in the operation. Provided, however, that no animal feeding operation is a concentrated animal feeding operation as defined above if such animal feeding operation discharges only in the event of a 25 year, 24-hour storm event.

The term animal unit means a unit of measurement for any animal feeding operation calculated by adding the following numbers: the number of slaughter and feeder cattle multiplied by 1.0, plus the number of mature dairy cattle multiplied by 1.4, plus the number of swine weighing over 25 kilograms (approximately 55 pounds) multiplied by 0.4, plus the number of sheep multiplied by 0.1, plus the number of horses multiplied by 2.0. The term manmade means constructed by man and used for the purpose of transporting wastes.

The EPA's NPDES general permits are required for discharges associated with CAFOs, however most states have primacy over the general permit program with the exception of Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico which are not authorized to implement the NPDES program. Oklahoma is delegated to implement the NPDES program, however; Oklahoma does not issue a general NPDES permit specifically for CAFOs and is in effect unauthorized to administer the CAFO portion of the NPDES program. Oklahoma CAFOs should apply for coverage under the general NPDES CAFO permit issued by U.S.EPA Region 6 (See 63 FR 53002).

Applicability
When the animal waste (manure) from CAFOs is discharged to nearby streams and rivers, high concentrations of nutrients including nitrogen, phosphates, and organic matter causes utrification within the water body. CBM produced water could be used for washing confinement areas, can be discharged above or below CAFOs, or used to dilute the animal waste prior to discharge.

Constraints
The constraints to the use of produced water around CAFOs are the volume and quality of produced water. When applied or discharged, the produced water needs to be of sufficient quantity and quality to reduce the effluent concentrations to below permitted limits. If insufficient volumes of produced water are available or the produced water is of lower quality, the permitted effluent limits may be exceeded.

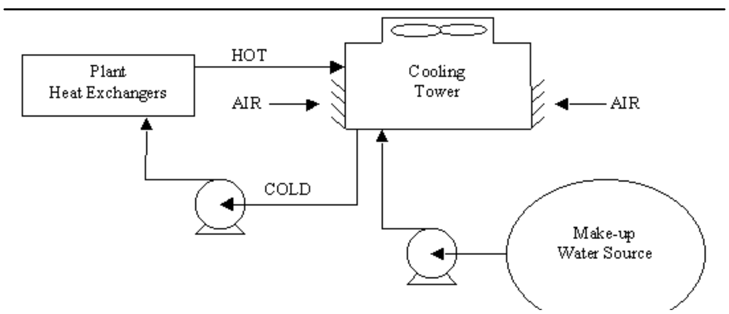
Data Needs
The data needs for this water management option are:

- *Location:* The proximity of CAFOs to the CBM producing field must be identified and means to transport produced water to the facility identified.
- *Water Quantity and Quality:* The volume and quality of produced water and the water needs of the CAFOs operation must both be identified. The water needs of the CAFOs include identifying how much water the operation can use, whether the volumes change from year to year, and the quality of produced water needed to obtain the CAFOs discharge permit.

Alternative 3 - Cooling Tower Water

Numerous industrial activities and chemical plants use water as a cooling agent. Towers are a common means of removing heat from cooling water that has been heated through thermal exchange. Figure 5-36 is a diagram of a closed loop cooling system; the diagram shows the flow of water through an industrial cooling system. Cold water enters the plant's heat exchanger which causes a thermal exchange of heat from within the plant to the water in the cooling loop; this water is then sent to the cooling tower where it flows over fill surfaces. As the water flows over the fill surfaces, air is passed through the tower either by natural flow or by electric fans, cooling the water by contact with the air. Once the water is cooled, it is recycled through the system; make-up water is usually added due to losses

Figure 5-36
Cooling Tower
Closed loop cooling tower system.

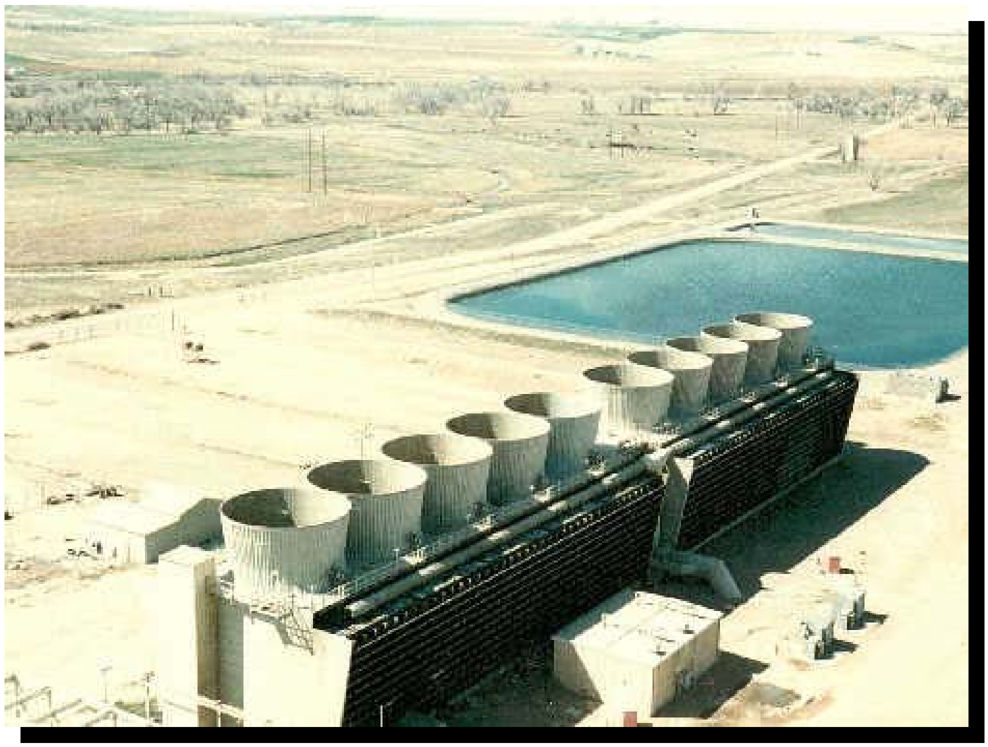


Source: www.chemeresources.com

from evaporation. High quality CBM produced water can be used as make-up water in a cooling tower system. The produced water would need to be low TDS water because mineralization generally leads to clogging of the cooling system.

Applicability

The use of CBM produced water for make-up water in a cooling system can be applicable in many areas where CBM development is likely. Industrial applications that use cooling tower systems include chemical plants and power plants. Numerous coal-fired power plants are located in areas near CBM producing fields and have the potential to use CBM produced water for cooling tower water. In addition to the power plants, various chemical plants and other industrial applications use cooling towers throughout the United States where CBM water can be used as make-up water.



Power plant cooling tower.
Source: Tom Kennedy

Constraints

The quality of the produced water will be the principal constraint for the use of CBM water in cooling tower make-up water. Water with high TDS can cause significant problems when used in cooling tower applications because minerals can be deposited within a closed system. Mineralization within a cooling system can cause problems with flow and heat exchange.

Data Needs

The data needs for this option are similar to most industrial uses: identifying the location of potential users of produced water, and identifying both quantity and quality needs. This data will be important in determining the effectiveness of this water management option.

Alternative 4 - Field and Car Wash Facilities

Construction activities and other land disturbing activities are a concern because vehicles accessing land with noxious plants can cause them to spread. The problems associated with spreading noxious weeds include making site reclamation more difficult, as well as impacts to ecosystems, farmland and grazing land. One way to reduce the spread of noxious weeds is to wash vehicles and equipment before and after entering these areas. The construction of field equipment wash facilities and rural car washes supplied with produced water reduces the potential for distribution of noxious weeds by vehicles and equipment. These temporary wash facilities constructed near CBM development could be supplied with produced water. The field wash facilities are temporary and used to clean vehicles and equipment entering and leaving construction sites, recreational off road vehicles, farm and ranch equipment, and oil and gas equipment. Many state and federal agencies (for instance USFS, BLM) recommend these facilities as part of their Best Management Practices for controlling the spread of noxious weeds.

Applicability

Field wash facilities for equipment and vehicles that are accessing off-road areas could be supplied with CBM produced water. During CBM and other oil and gas development, equipment including drill rigs, crew vehicles, bulldozers, etc. are moved from project to project. Other vehicles including work over rigs, repair crew vehicles, portable treatment trucks and trailers are also moved from one operational field to another. In addition, recreational vehicles can come into contact with noxious weeds. The availability of a field wash facility supplied with CBM produced water would reduce the spread of noxious weeds from one area to the next, making reclamation efforts easier, reducing impacts to wildlife ecosystems, and reducing potential damage to farming and grazing lands.

Constraints

The constraints for the use of produced water for field wash facilities are associated with timing and quality of produced water:

- *Timing:* When new construction activities first begin within a CBM field, no supply of produced water exists for initial field washes; however, as the field expands, produced water can be supplied for these facilities. Initial washes could be supplied with water from previous operations and transported with the equipment for the initial washes. Also at the end of a CBM field life, the volume of water produced has decreased significantly and the supply of produced water for a field wash would also be diminished unless water is stored and retained for this purpose.
- *Water Quality:* Produced water quality could also limit the use of CBM water for field wash applications because this water would generally be disposed onsite or discharged. Water with high sodicity or high SAR could also be detrimental to the soils and increase the reclamation effort for these areas.

Data Needs

The data needs for this application include identification of produced water quality, determining soil and drainage characteristics for proposed field wash areas, and identifying areas used to access these remote areas to help in determining the most beneficial site to locate a field wash facility.

Alternative 5 - Enhanced Oil Recovery

Another management option of CBM produced water is to inject the water into a secondary or enhanced recovery well into conventional oil producing horizons. Primary recovery of oil is driven by the natural energy of the reservoir and can be supplemented by pumping. When primary recovery ends, secondary recovery begins and may be followed by enhanced recovery. Secondary and enhanced recovery is the process of injecting a fluid into a reservoir creating a waterflood that displaces the oil causing it to flow to the producing well (Collins and Carroll, 1987). Water is the fluid most commonly used in secondary and enhanced recovery of oil in non-CBM fields; CBM produced water could, therefore, be of beneficial use in secondary and enhanced oil recovery.

Applicability
In many of the regions where CBM development is occurring, other oil and gas operations produce from conventional reservoirs. Most of these areas have fields that have or are nearing the end of the primary recovery life and beginning secondary recovery operations. For some of these operations, secondary or enhanced oil recovery includes the use of waterfloods to facilitate the recovery of oil. Waterfloods are a relatively common practice that can be performed with varying quality water, and may be able to use even the poorest of quality CBM produced water.

Constraints
The constraints for the use of produced water in enhanced oil recovery options would be transportation, water quality, and volume:

- *Transportation:* The transportation of produced water for enhanced oil recovery should not constrain this option because CBM produced water in most areas has nearby conventional oil development and it should be relatively easy to transport the water.
- *Water Quality:* Water quality may limit this option, as other beneficial uses may be preferred if the produced water is of high quality.
- *Volume:* The volume of produced water used in this option may be a constraint for larger water producing fields, as most waterfloods do not consume the quantity of water that can accompany years of CBM production.

Data Needs
The data needs for this option include the identification of fields and reservoirs near CBM development which are in the secondary or enhanced oil recovery stage and produced water quality data. The information on fields in the enhanced recovery stage should be obtainable through state oil and gas commissions.

Alternative 6 - Fisheries

Commercial fisheries in the western United States could also benefit from available CBM produced water supplies. These fisheries have to obtain water rights to divert water into their operational ponds for surface waters; therefore, CBM produced water could be used in place of diverted surface water or groundwater. Produced water could also be used during dry summer months or droughts to supply water when traditional surface supplies have been drained or are dry.

Applicability
The applicability of this option is dependant upon the location of nearby fisheries to CBM operations and the quality of the produced water. Commercial fisheries that are located in or near CBM fields where water can be easily transported or accessed through natural drainage would benefit most from this option.

Constraints
The constraints for using CBM produced water for fisheries are poor water quality and distance of transportation of the water and water rights. If the produced water quality is such that it is toxic or hazardous to fish, this water could not be used without some treatment. The

transportation of large quantities of produced water over great distances is not very cost effective and may limit this option. Finally, it would have to be determined if state law allows for the beneficial use of produced water for supplying fisheries.

Data Needs

The data needs for this option would include produced water quality, location of fisheries, and identification of water rights.

Alternative 7 - Fire Protection

In municipal areas, fire hydrants and sprinkler systems are supplied with drinking quality water from municipal supply systems. In areas where CBM development is near a municipality, produced water could be used to supply both fire hydrants and sprinkler systems. Fighting fires does not require high quality water and could benefit from the use of produced water by not depleting drinking water supplies. Wildfires in the western United States are becoming larger

Air-crane collecting water from lake for fire suppression
Source: Erickson Air-Crane

and more dangerous during the current drought conditions that exist in many states. The normal supplies of water that are used for fighting fires are also being depleted by the drought. The supplies of CBM produced water stored in impoundments could provide an accessible option for fighting fires in remote areas in states such as Colorado, Wyoming, New Mexico, Montana, and Utah.

Applicability

During the summer of 2002 as wildfires were encroaching on Durango, CO, CBM produced water from the SJB that was stored in impoundments allowed for quicker turn around times for air tankers fighting the fires. Although planning the placement of impoundments for preparation of future wildfires is difficult, this option has proven to be beneficial for emergency use during recent wildfires.

Constraints
The constraints of using CBM produced water for fire protection involve having an available supply in a location that is easily accessible during times of need. Having sufficient supplies of CBM produced water in the right area may be more a matter of chance for fighting wildfires than something that can be readily planned and coordinated; however, the option of using produced water for fighting wildfires provides additional options during emergencies.

Data Needs
Information that would be beneficial under this option includes: produced water quality, historical wildfire distributions, and areas with extensive fire hazards.

Alternative 8 - Other Industrial Uses

Aside from those uses listed above which are either currently in practice or have been researched to show potential as a use for produced water, other options which have been considered, but not analyzed in detail, are included in this document. Some of these potential uses include options that have the potential to use large quantities of produced water. The potential industrial uses which are being mentioned here and discussed briefly include: sod farming, solution mining for minerals, bottled drinking water, and brewery water.

The use of produced water for sod farming is currently being experimented with in the SJB. An experimental plot of sod is being irrigated with produced water from a CBM operation in the area. The research is in the early stages and little information is currently available, but this does appear to be a viable water management option for CBM produced water.

Within the state of Wyoming there are several uranium mines that use Class III injection wells for the in-situ solution mining of uranium ore. In addition there are mines in Nebraska, Texas, and Oklahoma that have operation permits for this type of uranium mining (EPA, 1995). Injection wells could be supplied with CBM produced water that has been treated to aid in the leaching process.

Another potential use for CBM produced water is creating a water bottling facility within the basin. Produced water in some basins is high in sodicity and SAR but is still drinking water quality, “soft water”. Some of the produced water is near the quality of water that is sold in convenience stores and grocery stores or could be treated to be of that quality.

The last alternate water use option considered for this project was the use of produced water in a brewery application. CBM produced water could be used not only in the manufacturing end of a brewery, but could also be used as irrigation water for the barley, hops, and other grains used in the manufacturing process.

Domestic and Municipal Water Use

Introduction

Produced water associated with CBM development can be a valuable commodity, especially for arid regions in the western United States. CBM produced water is of greater value when it meets drinking water standards, or is near drinking water quality, because of the broad variety of uses high quality water provides. This water management alternative includes the use of CBM produced water for domestic (e.g., public or residential) and municipal (e.g., city or county) water use and supply. Figure 5-37 is a population distribution map for select states with CBM potential. The map shows county-by-county population within the five states plotted over known coal zones. The figure shows some states have a more rural population in which individual landowners would benefit from the residential supply of CBM produced water, while other states have large municipalities located in or near existing and potential CBM development which could benefit from this water management alternative. Alternatives under this water management group include: the supply of high quality water from CBM production areas to rural landowners and municipalities; the use of lesser quality CBM produced water for reclaimed water systems; make-up water; and other residential non-potable water uses.

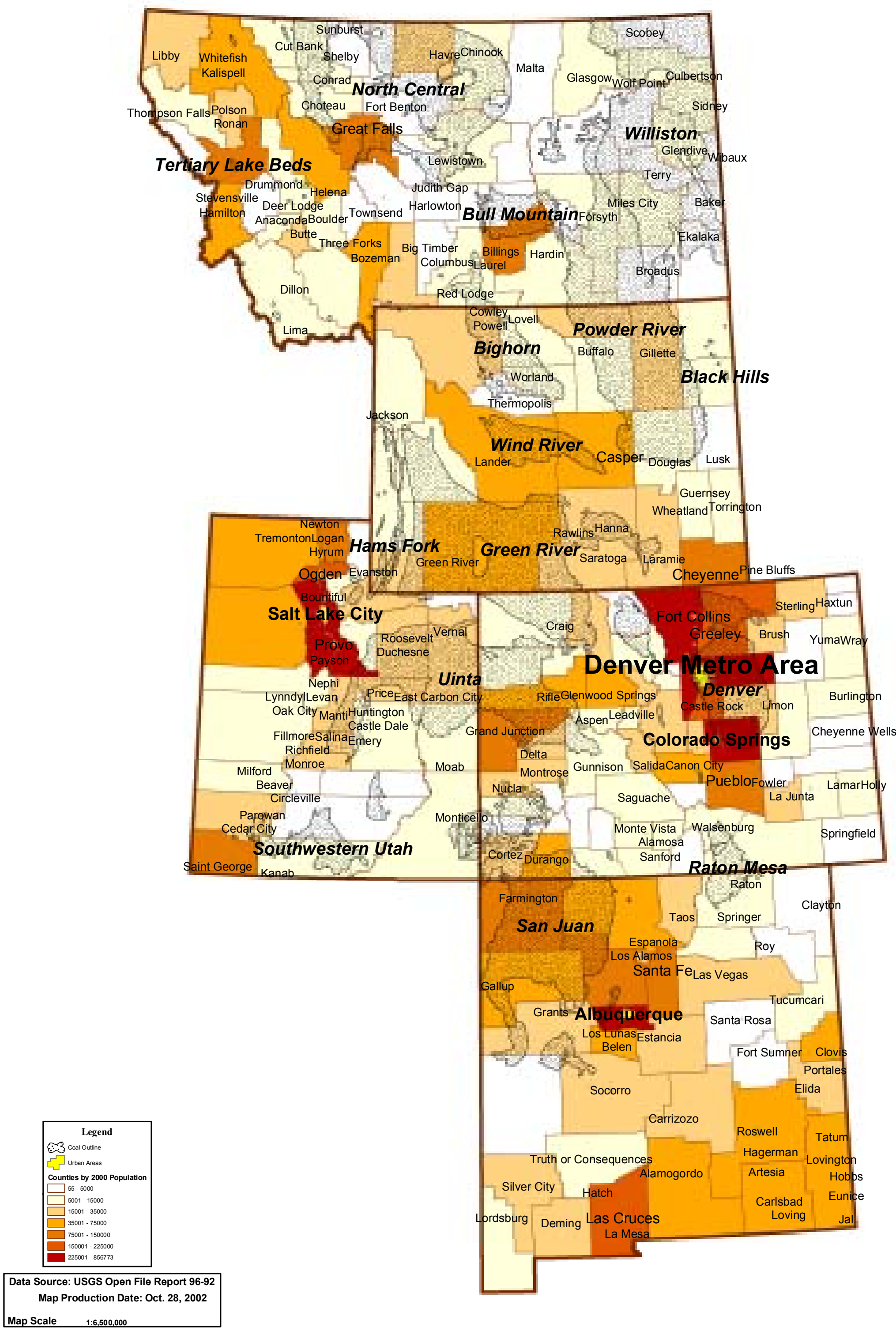
Domestic water supplies are typically individual wells designed to supply a single family residence the necessary water for daily activities. In most rural areas, individual family dwellings are supplied by a well drilled to relatively shallow depths in the local alluvium or shallowest groundwater aquifer with high quality water. A single supply of water is used for drinking, cooking, bathing, washing of clothes/dishes, lawn watering, toilet flushing and other activities. These domestic supplies typically have their own wastewater disposal system, often a septic tank and drain field or similar system. In more populated areas such as towns and cities, water is supplied by a municipal water supply system.

Municipal water supply systems obtain their water from a variety of sources including surface waters (lakes, reservoirs and rivers), groundwater, or a combination of surface water and groundwater. The water supplied from municipal water systems must be treated to meet state and federal drinking water standards. The level and type of treatment will vary depending on the quality of the water obtained. Once the water for municipal supply has been treated, it is distributed in most areas to businesses and households via an underground system of pipes. Municipal water systems also have return water systems (sewers), which collect wastewater that is treated prior to disposal.

Under this water management alternative, CBM produced water would serve to replace or augment rural wells and springs, augment municipal water supplies that are already strained from over appropriation and reduced because of drought conditions, replace residential wells of lesser quality water, or perhaps supplement other surface or groundwater sources. For municipal water supplies, produced water could be used to augment traditional supplies. This alternate supply of water could help to promote aquifer recharge and reduce demands on other more traditional water supplies from both surface and groundwater sources. CBM produced water that may be of a slightly lesser quality, but still of high enough quality to be usable, could be used as make-up water in wastewater treatment activities, used for non-potable purposes, or used in reclaimed water reuse applications instead of using drinking quality water.

Figure 5-37
Population Density and Coal Beds

Map of county population relative to the location of coal beds in the five state study area.



The supply of CBM produced water for residential use could include water for drinking, with lesser quality water used for non-potable uses (e.g., lawn watering, bathing, vehicle wash, etc.). In North Dakota and some other western states, many rural homes rely exclusively on groundwater from underground coal seams as their sole water source, including water for drinking.

Also integral to this alternative is the producer's view of water as a resource and not a waste product. The feasibility of beneficially using produced water for domestic and municipal uses requires a change in mindset that takes into account operational needs and a stringent regulatory framework put in-place to protect public water supplies and the individuals using and consuming water. Using produced water may require a more rigorous sampling and analysis program than many producers are used to. Further, pre-treatment of the produced water prior to being introduced for domestic or municipal use may be required. Pre-treatment may be as simple as chlorination, or as complex as reverse osmosis, depending on site-specific circumstances. Close coordination with the various stakeholders will also be critical to the success of this water management alternative.

Regulations

Numerous state and federal rules and regulations have been established to ensure that water supplied to the public is safe. In order for CBM produced water to be beneficially used for drinking purposes under this alternative, the water must meet the standards that have been set up under these rules. The SDWA, passed by Congress in 1974, established the basis for rules and regulations to ensure the safety of public drinking water.

The SWDA was originally passed in 1974 and has been amended twice, in 1986 and 1996. The SDWA provides EPA the authority to set national health-based standards for drinking water, protecting the public from both natural and man-made contaminants which can be found in drinking water (EPA, 1999a). The focus of the SDWA has shifted as it has been amended from a primary focus on treatment to provide safe water, to the protection of drinking water sources and improving education of public water system operators, and providing the public information regarding safe drinking water (EPA, 1999a). The SDWA defines a public water system as having 15 or more service connections, or serves 25 or more people for 60 days out of the year. However, drinking water standards apply differently to water systems based on their size and type. The following are the two main classifications of water systems:

1. *Community Water Systems.* A public water system that serves the same people year-round. Examples of Community Water Systems include: homes, apartments, and condominiums in cities, small towns, and mobile home parks.
2. *Non-Community Water Systems.* A public water system that serves the public, but does not serve the same people year-round. There are two types of non-community systems:
    a. *Non-Transient Non-Community Water Systems.* A non-community water system serves the same people more than six months per year, but not year-round. An example would be a school with its own water supply.
    b. *Transient Non-Community Water Systems.* A non-community system that serves the public, but not the same individuals for more than six months of the year. An example would be a campground.

Through the SDWA, EPA sets national standards (National Primary Drinking Water Regulations – NPDWR) for drinking water to protect against health risks, with consideration of available technology and costs (EPA, 1999b). The NPDWR establishes the MCLs for particular constituents in drinking water, or the required manner to treat water to remove the constituents. EPA has currently set primary drinking water standards for approximately 90 contaminants in drinking water. Another 15 constituents have secondary standards that EPA recommends, but does not require water systems to comply (EPA, 1999a). A listing of these standards is given in Chapter 4 in Tables 4-2 and 4-3. Additionally, requirements for the testing of these constituents for public water systems are also established to ensure standardization; however, the direct oversight of most water systems is conducted by state drinking water programs which have obtained primacy by establishing standards at least as stringent as the EPA. Currently, all states except Wyoming and the District of Columbia have received primacy.

In Montana, MDEQ has responsibility for overseeing public water systems. The MDEQ's Public Water Supply Section regulates public drinking water supply and treatment facilities in the state. Montana also has a source water protection program overseen by the Source Water Assessment Program Section of the Planning, Prevention, and Assistance Division of the MDEQ. Montana's Water Quality rules are established under statute 75-5-101, et seq MCA and ARM 17.30.101 – 2006. Their Public Water Supply rules are established under 75-6-101, et seq., MCA and ARM 17.38.101 through 607.

In Colorado, the Department of Public Health and Environment (DPHE) maintains responsibility for overseeing public water systems through the Water Quality Control Division. Colorado also has a source water protection program overseen by the Source Water Assessment and Protection Division of the DPHE. The state's water quality rules are established under Colorado Rule 1002-1003.

In New Mexico, the Environmental Department's Drinking Water Bureau (DWB) has responsibility for overseeing public water systems. The DWB also oversees the state's source water and wellhead protection programs. The state's drinking water rules are established in Title 20 Chapter 7 Part 10 of the NMAC.

In Wyoming, the EPA Region 8 is responsible for overseeing the public water supply program. EPA Region 8 is responsible for compliance, monitoring, tracking, and enforcing the SDWA for the state's public water systems. The WDEQ oversees the public water system operator certification program, plan and specifications review and approval program, State Revolving Fund program, and the source water protection program.

Based on the quality of the current CBM produced water, these states (Montana, Wyoming, Colorado, and New Mexico) appear to have the potential to supply some water of drinking water quality, and therefore, are included in this document for discussion purposes. As CBM activities expand in other regions, additional areas may be identified to have the potential to supply high-quality produced water. If other areas having very high-quality produced water are identified or encountered, the EPA's Safe Drinking Water Act website (http://www.epa.gov/safewater/) can be accessed to provide valuable information regarding what regulatory authority oversees regulations within that state.

Although specific to the state of Montana, regulations pertaining to the production of CBM water within the Montana portion of the Powder River Basin have been adopted by the state due to concerns related to CBM development and production as it relates to groundwater. The Montana

PRB Controlled Groundwater Area Order was established to protect the groundwater supplies that are likely to be drawn down by groundwater withdrawals associated with CBM development. In order to ensure public health, safety, and welfare, groundwater withdrawals are to be monitored and controlled where existing beneficial uses of water may be affected. The Order designates the jurisdiction of groundwater withdrawals associated with CBM to the MBOGC, while the MDNR may petition the board regarding the production, use, and disposal of water from CBM development wells when they affect existing water rights. This controlled groundwater designation does not affect regulation of new water rights for conventional uses; however, under the order, beneficial use permits need to acquire water rights for wells constructed during CBM development with the standard exceptions. The standard exceptions include appropriations of 35 gallons per minute or less and not exceeding 10 acre-feet per year on wells developed for beneficial use. Currently, Montana is the only state to develop specific guidance related to drawdown affects from CBM production, however, in the future other states may develop similar guidance as regulations relating to CBM evolve.

Alternative 1 - Domestic Use

Because of its overall high quality in many areas, produced water from CBM wells has the potential to be used by residences for potable and non-potable uses. Descriptions of these uses are provided below:

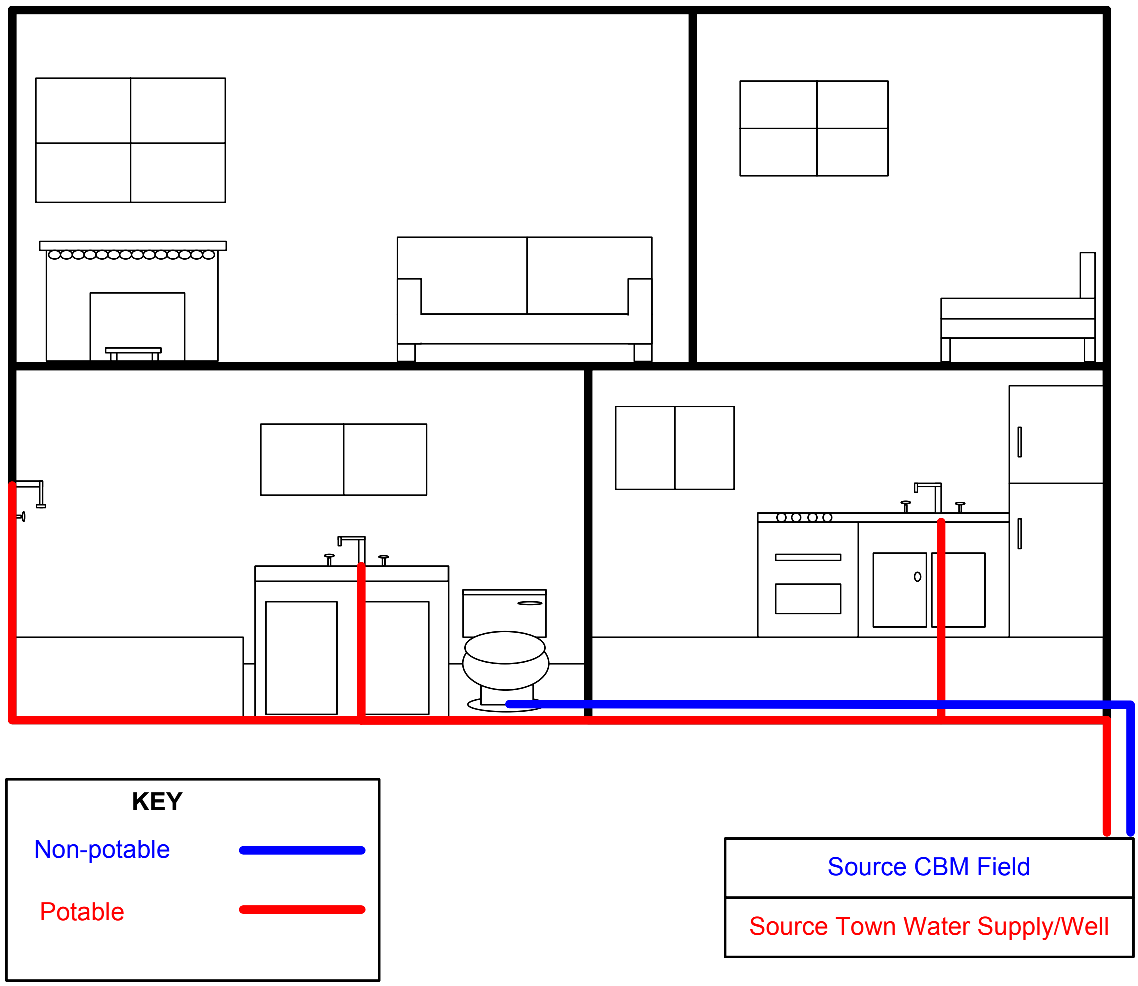
- *Potable Water Use:* High-quality produced water that meets drinking water standards can be used for human consumption, although treatment may be required (e.g., chlorination). Depending on the circumstances, quality of the produced water, treatment requirements, and other factors, it may be feasible to use produced water as a sole source for residential or domestic use. It may likewise be feasible for use in supplementing existing supplies continuously or on a periodic basis.
- *Non-Potable Water Use:* Non-potable produced water could be supplied to individual homes, perhaps using a dual water system (Figure 5-38), for uses such as lawn and garden irrigation, bathing, dishwasher and washing machine uses, vehicle washing, residential maintenance, and toilet flushing.

An important aspect of non-potable use is supply. If a separate non-potable water system is established at a residence, the water that feeds a secondary water system would need its own set of supply lines connected to the faucets or appliances that would use this water. The secondary lines would ensure that the non-potable and potable water supplies are not mixed. The internal piping of the home would have to be modified for the use of CBM produced water with shower and bath faucets; dishwasher and washing machine to connect to the secondary supplies; and external faucets used for watering lawns and gardens, and washing cars or machinery. This secondary system would result in less potable water being lost by non-consumptive uses and could result in reduced demand on potable supplies.

Applicability

The supply of high-quality produced water could have wide reaching applications in the western United States. Many western states, including those having existing CBM development as well as potential development, are arid to semi-arid regions that are over-appropriating existing water supplies. Table 5-11 shows self-supplied water use by source, per capita water use, and percent consumptive use for several states with CBM potential. The table shows that the majority of the

Figure 5-38
Dual Plumbing System
Home is supplied with potable water and non-potable water.



Source: ALL Consulting

self-supplied water systems obtain their water from groundwater sources. Although there is significant variation among the states, the percent of water that is consumptively used is generally between 35 to 40%, indicating that 60 to 65% of the potable water extracted for self-supply uses is returned to the ground. The water returned is usually discharged to the shallow alluvial aquifers and may not be the aquifer from which it was extracted. As the rural population of these states continues to grow, more water uses are formed and the water deficits will likely grow. In some of these states an effort is being made to reduce the amount of high-quality water put to non-consumptive uses. Non-consumptive uses include activities such as running a faucet while waiting for hot or cold water for drinking or cooking. It may also include such activities as showering, bathing, and washing clothes/dishes. Even with a reduction in non-consumptive uses, the need for alternative sources to supply high-quality water exists, making this alternative highly desirable.

Table 5-11
Self-Supplied Water Use in Select Western States
Self-supplied groundwater and surface water use.

State	Self-Supplied Water Use Groundwater MGD[6]	Self-Supplied Water Use Surface water MGD[6]	Per Capita Water Use gpd[7]	% Consumptive Use
Colorado	27	0.0	76	30
Montana	17	1.0	78	49
New Mexico	26	0.0	86	55
North Dakota	12	0.0	79	31
Oklahoma	30	0.0	85	30
Utah	7.7	1.7	91	34
Washington	125	0.0	125	12
Wyoming	9.7	0.5	75	52

Source: 1995 USGS United States Water Survey

There are several methods in which CBM produced water could be supplied to residential areas, including:

- *Indirect Connection:* Providing CBM produced water to a residential home (or homes) can be accomplished using an indirect connection. In this case, water would first be routed to a storage or treatment system prior to being provided to a residence for either potable or non-potable use. The intended use will drive treatment requirements and the necessary design for the water delivery system. Of course, if the intended use were for consumption, only high-quality water that meets public drinking water standards would be adequate.
- *Direct Connection:* Another method to supply rural homes would be to connect the house directly to a well, or multiple wells, completed in a coal seam aquifer. Although some CBM wells will likely be located in close proximity to rural homes and the produced water line could easily be diverted to the home, this alternative may not provide a means for treatment (e.g., chlorination) and could present a danger. This alternative should only be used if the proper precautions are put in-place; for instance, natural gas must be desorbed prior to the water entering a structure.

Constraints
Several constraints to the domestic supply alternative for either direct or indirect connection include:

- *Water Quality of CBM Produced Water.* CBM produced water that is near or meets drinking water standards could be used for domestic supply and human consumption; however, this water does not exist in all CBM basins. Those basins which are developing CBM from deeper coal seams (e.g., greater than 2,000 ft) often have water that may exceed 3,000 mg/L of TDS, which may render the water unusable for many domestic

[6] MGD = Million Gallons per Day
[7] gpd = gallons per day

uses. Although lower quality water could still be supplied for non-consumptive uses, use would be limited. Further, quality can even impact some non-consumptive uses (e.g., irrigation). A stigma of perception may also be associated with the use of non-potable water in some daily activities including bathing and washing of dishes. In addition, nuisance and aesthetic issues may be associated with constituents such as iron and manganese that can stain faucets, sinks, or clothing when used in wash water.

- *Water Rights.* In some states, the water in coal seam aquifers is required to have appropriated water rights for beneficial use. Water rights for CBM produced water are often related to the classification of CBM produced waters. In some states the produced water is considered waters of the state while others consider the water to be industrial waste. In the PRB of Montana, a Controlled Groundwater Area has been established which states that producing CBM wells are exempt from water rights. In Montana, CBM operators must offer water mitigation agreements to owners of water wells or springs within one-half mile of a CBM field, or the area that the operator reasonably believes can be impacted by CBM production (MDEQ, 2001). Any beneficial use aside from the mitigation of domestic wells impacted by CBM development would require new water rights because CBM water production is considered a new water source. This would include domestic supply of water to residences not directly impacted by CBM development.
- *Economics of Delivery.* Another constraint to domestic supply is the economics of delivering the water to the residence. This can be a result of the distance between the active CBM fields and the residence that would be supplied with produced water. Another consideration is the volume of water to be delivered; this is especially true for an indirect supply as economic analysis may show that a certain volume of water would need to be delivered to justify the infrastructure necessary to supply the water. Although many areas may be in need of this water and could beneficially use the water, economics associated with the delivery of this water may limit the extent to which the water is beneficially used.
- *Operator Liability.* An additional concern for operators when supplying produced water, especially by direct connection means, is potential liability. The liability concern associated with supplying produced water includes the variability in the quality of water over time, and the potential that the water will contain methane that may accumulate in confined spaces and create a potential explosive hazard. The potential for methane to accumulate at dangerous levels within the water and reach the house would be greatest when the well is directly connected to the house. The potential methane hazard would be reduced by the use of indirect connection systems, which collect the produced water, allow the water to degas, and then distribute it separately.
- *Landowner/Rural Community Cooperation.* Landowner cooperation may be the largest constraint when considering the supply of CBM produced water for domestic use. Although all of the other constraints listed can be overcome, if the landowner or rural homeowner does not wish to accept CBM produced water, this alternative is not applicable. The landowner may also choose only to receive water that meets drinking water standards, which could limit this alternative in basins with lesser quality water. The development of relationships between CBM operators, landowners, and the local

community is critical for this alternative to be most beneficial, especially on split estate lands.

Data Needs

The domestic supply of CBM produced water would not require a significant increase in data collection over what is already collected as part of CBM field operations in most regions. The data needed for this water management alternative include:

- *Produced Water Quality.* The collection of produced water quality data accompanies CBM operations due to operators' need for this data for water management practices; however, the collection of additional water quality parameters may be necessary to ensure that produced water meets state and federal drinking water standards. Additional water quality data needs may be required for residential users to obtain water rights in some states.
- *Domestic Water Needs.* Although water quality may exceed drinking water standards, the application of this alternative requires the identification of areas that are in need of this water. Residential water quality and water needs data may be available from some state engineer's offices or county water commissions; however, in some areas this data may need to be collected from individual residences and wells.
- *Existing Domestic Water Quality.* In addition to produced water quality data, the water quality of the existing domestic supply needs to be obtained for comparison purposes. Identifying the quality of the existing water supply will assist both the operator and landowner in determining if the produced water is of equal or better quality than the existing supply.
- *Water Rights.* Water rights are a complex issue in many western states; identifying and obtaining water rights for the beneficial use of CBM produced water is critical under this alternative. Ensuring the landowner has, or can obtain, the legal rights to the produced water will require site-specific research.
- *Cooperating Landowners.* The identification of landowners who are willing to cooperate with CBM producers is critical to the success of this alternative. Developing relationships with landowners prior to CBM development will assist operators in identifying landowners who are willing to cooperate with them. Communication with landowners would assist operators in creating development plans that minimizes other constraints.

Alternative 2 - Municipal Water Use

In addition to supplying water to rural landowners, CBM produced water could be used to augment municipal water supplies both for potable and for non-potable uses, including:

- *Potable Water Use:* Similar to domestic supply, high-quality produced water that meets drinking water standards could be used for human consumption. High quality water could be supplied upstream of the existing water treatment facilities and distributed through the existing infrastructure with some modifications (such as gas separators). Depending on the circumstances such as quality of the produced water, treatment requirements, and other factors, using produced water as a sole source may be feasible for a certain portion of the municipality, in mixed distribution with the existing supply, or as a seasonal or period augmentation of over appropriated supplies.

- *Non-Potable Water Use:* The potential for the distribution of lesser quality produced water for non-potable uses within a municipality may be greater than potable use. The potential non-potable use for produced water in a municipality includes a dual water system for household uses as described in the previous section: showering, bathing, lawn and garden watering, and washing clothes and cars. In addition, municipalities could use produced water to supply water to fire hydrants, street cleaning equipment, and certain industries including commercial car washes.

Applicability

Supplying water that meets drinking water standards could have wide reaching applications in the western United States. Many western states, including those that have existing CBM development as well as potential development, are arid to semi-arid regions that are over-appropriating existing water supplies. Table 5-12 shows the water withdrawals from surface water and groundwater sources, per capita water use, and the withdrawals that go to domestic supply from public water supply systems for some of these states. The table shows the variability in the primary water source from either surface water (in Colorado, Montana, Oklahoma, and Wyoming) or groundwater (in New Mexico), to a nearly even split in some states (Utah and Washington). It should also be noted that the per capita water use for municipal supplied water as shown in Table 5-12 exceeds the per capita water use from self-supplied water, as shown in Table 5-12. The municipalities in these states have the potential to benefit from CBM produced water by not only augmenting their supplies, but by preventing the waste of high-quality produced water.

Larger municipalities that are located near CBM producing fields have the potential to provide a greater beneficial use of produced water than individual rural homes. The data provided in Tables 5-11 and 5-12 indicates that the municipalities in these states have higher per capita consumption rates than the average rural home. Per capita water use in Table 5-12 includes water that is supplied for industrial and commercial use. Produced water of varying water quality could be supplied to municipalities for the following:

- *Potable Water Supply:* Municipal water systems supply larger volumes of water than individual rural supplies, and thus would be capable of using larger volumes of high quality produced water. Municipal water supply systems already have the infrastructure necessary for some of the treatment (chlorination at a minimum) and subsequent distribution of CBM water to homes and businesses. Additional infrastructure would be needed for the transportation of produced water to the municipal facilities as well as adequate gas separators. The high quality produced water could be collected at a CBM water management facility then transported to a municipal supply facility for treatment and subsequent distribution.

Table 5-12
Public Water Supply in Select Western States
Surface and groundwater withdrawals for domestic use.

State	Water withdrawals from surface water MGD	Water withdrawals from Groundwater MGD	Per Capita Water Use gpd	Withdrawals that go to Domestic Supply MGD
Colorado	605	100	208	481
Montana	89	55	222	77
New Mexico	34	277	225	188
North Dakota	43	30	149	40
Oklahoma	468	99	194	241
Utah	204	293	269	340
Washington	548	631	266	565
Wyoming	52	38	261	54

Source: 1995 USGS United States Water Survey.

- *Non-Potable Water Supply:* Lesser quality produced water can also be collected at the CBM field and distributed directly from the field or from a municipal facility. A non-potable/potable dual water system could be developed for an entire city as well as to supply lesser quality produced water in a similar manner to what was previously discussed for residential systems. A municipal dual water system could be used to supply fire hydrants and businesses such as commercial car washes with non-potable water for a separate supply. Dual water systems have been proven to be practical in other countries and other states (such as Florida) to conserve high-quality water.

Potable water use varies by municipality and by season within the municipality. The city of Gillette, Wyoming's public water supply system has seasonal variation from 2.5 MGD during the winter and can peak as high as 12.5 MGD during the summer months (personal communication with City of Gillette employee). This volume of water supplies a population of approximately 25,000 people. City estimates of per capita water use for the summer of 2002 were approximately 107 gpd. The city of Gillette is an example of a municipality that could potentially benefit from high quality CBM produced water; the city has a substantial population located within an area that has existing CBM development and considerable foreseeable development. During the dry summer months, especially in recent times of drought, a city such as Gillette would benefit from augmented water supplies supplied with high quality CBM produced water.

For non-consumptive applications, a municipal water system could use lesser quality CBM produced water in a dual water system for uses including: make-up water in wastewater treatment; home applications (including showering, bathing, clothes washing, etc.); fire protection; and lawn and garden irrigation. In most municipal systems, drinking water is used for these water applications. Establishing a separate supply that uses CBM produced water to supply homes, hotels, restaurants, and public bathrooms would reduce the use of high quality water and allow that water to be reserved for human consumption. This system would require additional infrastructure to be put in-place to transport the water to homes and businesses, as well as require additional plumbing work within these buildings.

Other non-potable uses include supplying CBM produced water to municipal fire hydrants and as a secondary supply for lawn and garden watering. In recent years, municipalities in the western United States have had numerous water restrictions which prevent the watering of lawns for more than one day per month, or during certain times of the day. The supply of CBM produced water, as a secondary supply, would allow this water to be used to water lawns, plants, and in gardening. Restrictions may still be required when applying water to edible foods based on water quality; but for non-edible plants and landscaping, using CBM produced water would be beneficial. Also, the SAR and salinity of the water may limit its use with certain plants, causing detrimental effects on plants and soils if these values are too high. The fire hydrants in most cities and towns are tied to the municipal drinking water supply; these systems could also be converted to be fed by a secondary system which is supplied by CBM produced water.

In some wastewater treatment systems, sufficient water is not always available to facilitate the treatment process, requiring make-up water. This is not typical of most municipal wastewater treatment facilities but, with the growing popularity of low flow toilets and other water conservations techniques, lack of water is an evolving problem in some regions. The make-up water that is added during the waste treatment process often comes from potable water supplies, but does not need to be of such high quality. CBM produced water that does not meet drinking water standards could be supplied to these facilities for this purpose.

Constraints

Constraints for the beneficial use of CBM produced water in municipal applications include some of the constraints from the domestic use discussed previously, as well as other constraints. The constraints for municipal use include:

- *Water Quality:* The quality of the produced water must be at or near drinking water quality, meeting state and federal standards if the water is to be used for human consumption. Water that meets drinking water standards could be used in any of these regions, while water that is of lesser quality may be more selectively used. The produced water that is near drinking water quality could be used in non-consumptive applications depending on the constituents of concern. For instance, water with high metals content may not be used because it can cause faucets and drains to become stained. The constituents which constrain the use of the produced water will depend on the municipality's treatment process because some facilities may treat for the constituents in their existing processes. Constituents that would require additional treatment technologies, however, would have to be evaluated on a cost effective basis by individual municipalities.

- *Water Rights:* Water rights would also be a constraint that municipalities and CBM operators will have to evaluate. The classification of water produced in association with CBM development varies by water rights definitions in different states. An understanding of water rights, as discussed in Chapter 4 of this document, is critical in applying this alternative.

- *Infrastructure Changes:* The non-consumptive use of CBM produced water would be constrained by additional infrastructure required for such an application. If CBM produced water were to be supplied for non-potable water uses to a municipality, additional piping and control mechanisms would be required. Depending on the extent to which this application would be used throughout the area and the extent to which a continued supply could be provided for these applications, the long term cost effectiveness of reduced potable water use may justify this application. In addition, there is the stigma associated with non-potable water that would need to be addressed for this approach to be widely accepted.

- *Supply of Produced Water:* The use CBM produced water for municipal applications would also be constrained by the volume and duration of the supply of produced water. CBM wells have a limited well life and produce at a declining rate over time, a municipality may not want to make a significant investment if the volume to be supplied is not significant or is only a short term supply. Existing CBM development around Gillette, Wyoming, had been supplying CBM produced water to the city municipal supply through an ASR process. However, since the project was initiated the CBM development in the area has been unable to provide sufficient quantities of high quality water to meet the city's needs.

- *Cost:* The final constraint to consider when evaluating the supply of produced water from CBM development to municipal supplies is the cost associated with transporting these supplies to the municipal storage and treatment facilities. This cost could limit areas that are more removed from CBM development from obtaining water supplies, or smaller municipalities that cannot afford the additional costs to transport the water.

Data Needs

The data needs for municipal supply would include some of the needs identified for domestic water use, as well as some needs specific to municipal use:

- *Produced Water Quality.* Because CBM operators need to know water quality data for effective water management practices, produced water quality data is already being collected. The collection of additional water quality parameters may, however, be necessary to ensure that produced water meets state and federal drinking water standards. Additional water quality data needs may be required for residential users to obtain water rights in some states.

- *Municipal Water Needs.* Although produced water may meet drinking water standards, the application of this alternative requires the identification of areas that are in need of potable quality water. Municipal water supply data should be available from the municipal water district, the state engineer's offices, or county water commissions. Non-potable water needs may be more difficult to identify or quantify in some areas, however, the existing municipal facility should be able to provide insight on the potential for non-potable water applications.

- *Existing Municipal Treatment Technologie*s. Once the produced water quality has been identified and the municipal needs have been quantified, the existing municipal treatment capabilities should be easily identifiable. If constituents exist within the produced water that exceed primary or secondary drinking water standards, the municipality may have existing treatment capabilities to reduce the level of these constituents to meet drinking water standards.

- *Water Rights.* The identification of a municipality's existing water rights and obtaining new water rights are critical to the success of this alternative. Water rights regulations vary by state and are evolving relative to CBM development. A municipality, however, that is currently over-appropriating their existing water supply or experiencing drought conditions should be able to obtain water rights for high quality CBM produced water.

Chapter 6
Case Studies

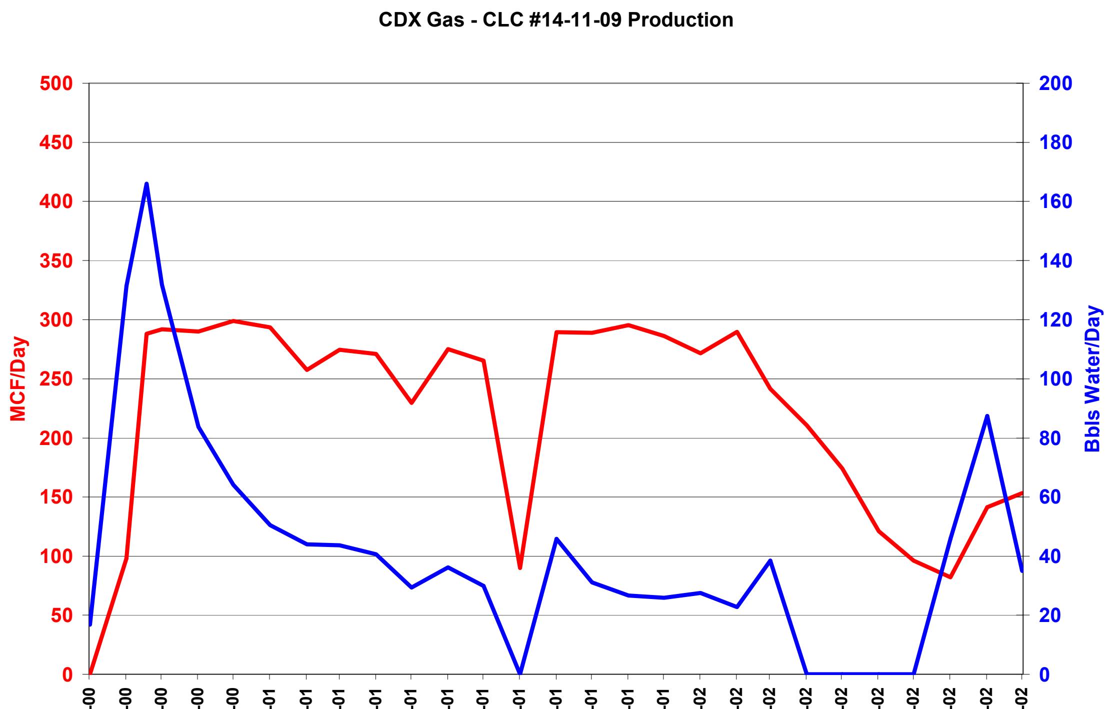
Perhaps the best way to convey the details of produced water management relative to CBM production and the relationship to beneficial uses of produced water is through actual case studies. Recognizing this, a number of actual case studies have been compiled as a demonstration of methods currently used throughout the United States for management of produced water. The case studies included in this section of the document present only a small sample of water management and beneficial use alternatives being used. At the time these case studies were prepared, many CBM developers were undertaking a variety of new water management feasibility studies for a variety of new uses for CBM produced water, with a significant amount of data not yet available for publication. With that in mind, it may be beneficial to update and expand this section of the document at a later date.

Finally, we express our sincere appreciation to all of the CBM developers that provided information for this and other sections of the document. The information obtained from industry was invaluable relative to the completion of this document.

CDX Gas, CBM Produced Water Management Case Study Tuscaloosa County, Alabama

CDX Gas operates approximately 43 CBM wells in Jefferson and Tuscaloosa Counties. CDX wells average less than 15 bswpd (barrels of salt water per day) but have initial productions (ips) up to 200 bswpd. Produced water is strong brine. The production decline curve for a typical CDX well is shown below:

Figure 6-1
CDX Gas Production 2000-2002
This graph shows the increased production of water in the early life of a CBM well

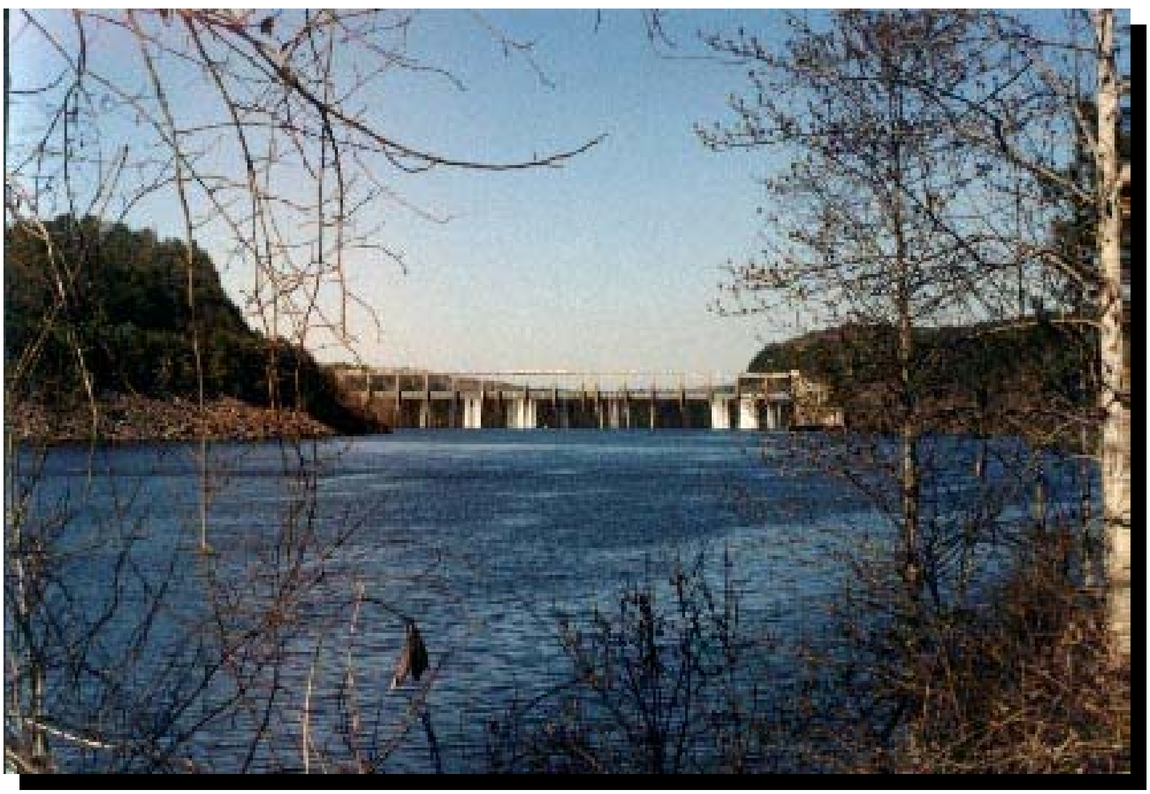


Source: CDX Gas, 2002

Water spikes early in the history of a CBM well and quickly drops off well below 50 bbls/day on average. During the summer of 2002, the captioned well was essentially shut-in and rates after that point are difficult to interpret. Waste water management needs to accommodate the early spike and later low, stabilized rates; CDX has managed the water budget by taking produced water from Chevron and El Paso.

The CDX NDES permit allows up to 10,000 bswpd to be discharged to the Black Warrior River, but discharge has historically never exceeded 4,000 bswpd. Produced water from CDX and from other operators' wells is stored in two 45,000-bbl ponds that precipitate out metals and to lower pH prior to discharge. The ponds form a Commercial Discharge Facility. Water is discharged to the Black Warrior River from the ponds.

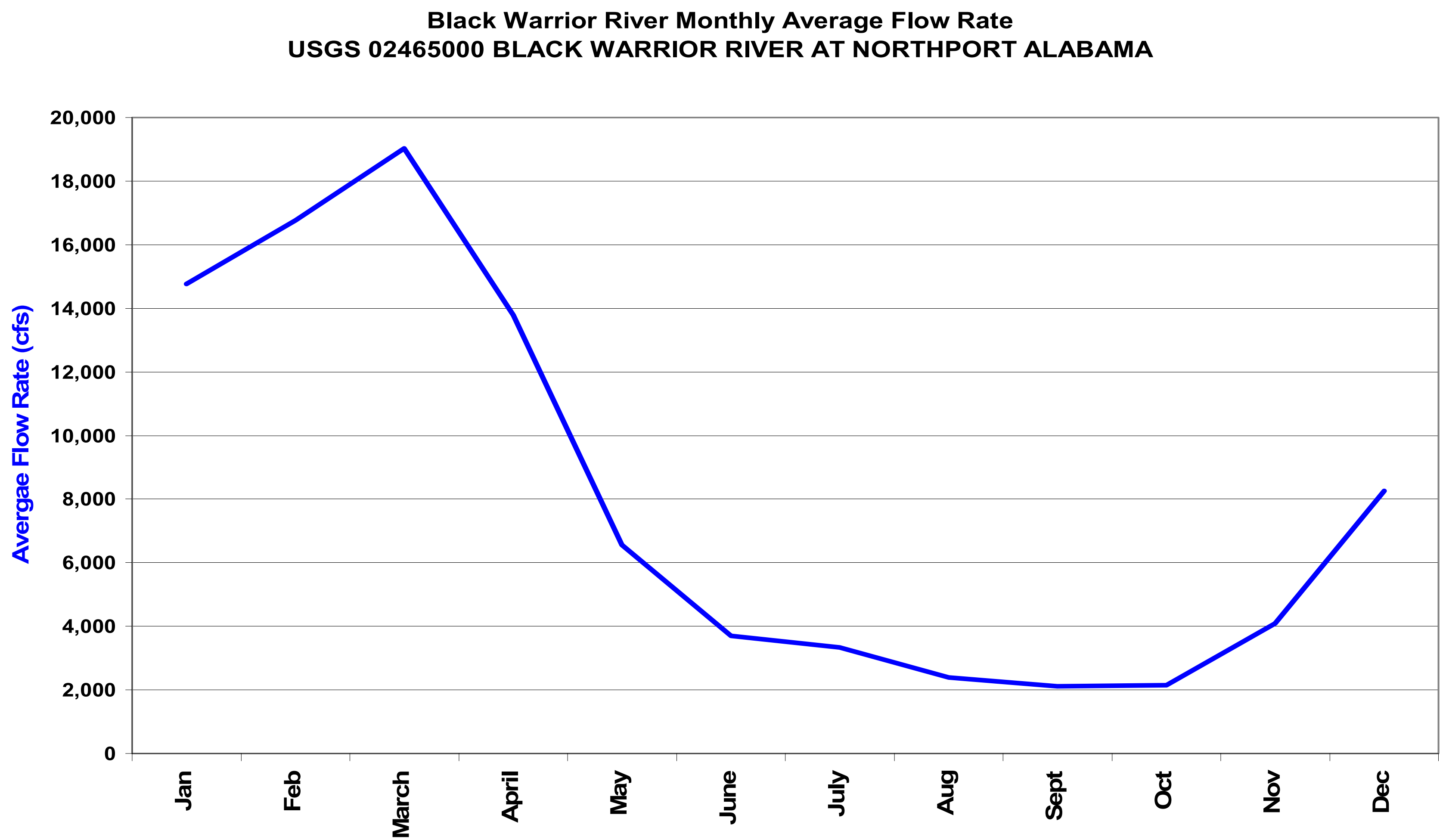
The Black Warrior River is a very large, navigable river that connects the port of Birmingham to the Gulf of Mexico; its chloride level varies up to 31 ppm with 230 ppm set as the limit for NPDES discharges managed by the Alabama Department of Environmental Management (Coal Bed Methane Assoc of Alabama, http://www.coalbed.com/slides/index.htm). The ADEM allows surface discharge to land for CBM water less than 2000 mg/L, but heavier brines need to be discharged to rivers or deep injected. The type of permit currently offered is termed a Tier II permit. Tier II permits require monitoring of water quality in streams and limit in-stream TDS concentrations to 230 mg/L. The USGS has gauged the flow rate near Tuscaloosa for the past 82 years; monthly averages show the large flow rates existing in the river throughout the year. The flow rate of the river varies by season throughout the year with higher flow rates existing from November to May and low-flow rates prevailing in the summer as shown in Figure 6-2.



Black Warrior River at Tuscaloosa County, Alabama

The CDX NPDES permit allows CDX to discharge up to 0.65 cfs to the river; this rate represents less than 0.1% of total river flow even during the lowest average month (September) (CDX, 2002).

Figure 6-2
Black Warrior River Monthly Average Flow Rate
Flow Rate Plot for the Black Warrior River Near Tuscaloosa (USGS, 2002)

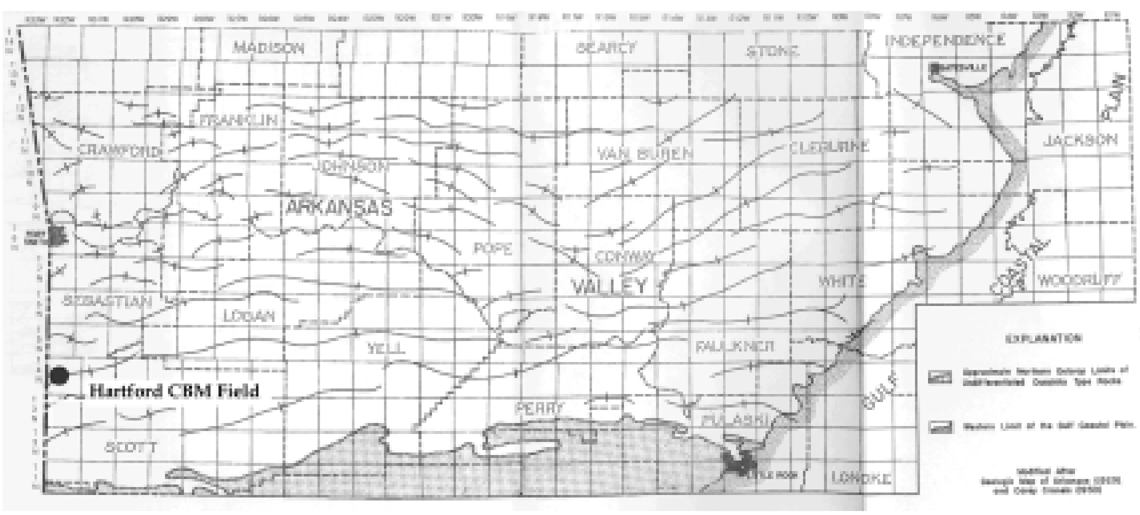


Source: CDX Gas, 2002

CDX Gas Company
Arkoma Basin Operations

The Arkoma Basin produces CBM in Oklahoma, but the basin extends east into Arkansas where less CBM activity has taken place. There is currently only one CBM field in Arkansas, which is located in the Arkoma Basin. While there have been many historical coal mines and several currently active coal mines within the basin. CDX operates approximately 19 CBM wells in the Hartford Field in western Arkansas. The figure below illustrates the position of the Hartford Field, a very short distance east of the Oklahoma-Arkansas boundary. The wells are both vertical and multi-lateral horizontals drilled into the low-volatile bituminous Hartshorne coals at depths from 500 feet to 1600 feet. The horizontal wells are drilled in a “pinnate” pattern of several parallel laterals drilled off a backbone. Since the coal seams are less than 5 feet in thickness and dips can be significant, it is difficult to steer the drillbit so that the hole remains in the coal seam. Sands near the Hartshorne are quite permeable and water-bearing, however, and these sands could “drown” the CBM potential of the cal seams if the sands are perforated with the coals. Perforating only the coal seam is vital to keep water handling costs low.

In the CDX wells, water is pumped from the coal seams via natural gas powered beam pumps controlled by a timer. Water is pumped to a water tank installed at each well and periodically trucked to commercial disposal wells. This produced water varies from 5,000 to 20,000 ppm TDS. The CBM wells produce from a few bpd to less than 100 bpd. The CDX wells (the first in Arkansas) have been producing less than 6 months and water production trends are unclear.



Position of the Hartford Field. The location is a short distance east of the Oklahoma-Arkansas boundary

Fidelity Exploration & Production Company
Managed Crop Irrigation Using CBM Water in Wyoming

Fidelity operates approximately 800 CBM wells in Montana and Wyoming and is the only company with CBM operations in Montana. In 2001, Fidelity Exploration & Production Company initiated a research, development, and demonstration program for managing CBM produced water through centralized irrigation systems to produce forage for livestock and wildlife. Nine sites were chosen in Wyoming near the Montana-Wyoming border.

One of the first two center-pivot systems started in 2001. Note the dense forage production taller than 18 inches in the irrigation area compared to low, sparse scrub forage in the background.

Pretreatment is not often used but, when necessary, sulfur or other acidulents are used to neutralize the naturally elevated bicarbonate and carbonate alkalinity often found in CBM produced waters. The alkalinity will limit the amount of calcium that can be dissolved within the soil. Putting calcium into solution (e.g., from a source such as agricultural or industrial gypsum) facilitates the exchange of calcium for sodium within the clay mineral structure to lower and control the SAR and the exchangeable sodium percentage (ESP) of the irrigated soil. Various soil and water amendments and treatments were evaluated using bench-scale soil columns

CBM water is piped to fields to be used for irrigation in this solid-set system. Note the use of "water cannons" attached to the PVC pipe. This method of irrigation has proved to be very cost-effective.

during 2001; however, good quality CBM water was often used rather than water that had been pretreated.

Corn growing in a field test, irrigated with CBM water.

A successful field-scale test using two center-pivot irrigation systems was conducted during the fall of 2001, leading to a continuation and expansion of the program into 2002. Several center-pivot and solid-set irrigation systems are now being operated in different water management areas and with water of different qualities. The management program involves site selection and soil characterization, geochemical modeling to determine soil and water amendment rates, crop selection, and soil and water monitoring. Bench-scale and field-scale results demonstrate that CBM water, in managed systems, can be used as a beneficial source of irrigation water to produce forage.

This beneficial use project involved irrigating different sites with CBM produced water that had SAR values ranging from 22 to 45 and a bicarbonate level of about 1,200 ppm. At some sites, the crops were irrigated with pure CBM water; at other sites, the CBM water was blended with surface water. The Lake Desmet project blended two parts lake water with one part CBM water. The study also showed that by using blended water, the erosional effects that result from a high SAR could be avoided.

Tall healthy crops watered with CBM produced water are in the upper right quadrant of the picture.

Results of the study indicate that seed germination is influenced by salinity (as measured by EC or TDS), not by SAR. This is to be expected because salinity is the amount of total salts in the water while SAR is the amount of sodium relative to the amounts of calcium and magnesium. High TDS water cannot enter the plant because of high osmotic pressures; therefore the plant dies from lack of water even though it is growing in wet soil. Water can be of very good quality (low TDS) and have a very high SAR because of the proportional relationship between sodium, calcium, and magnesium. Using CBM produced water; crops require twelve to twenty inches of water, approximately twice as much as high quality surface water because of the higher TDS.

Fidelity Exploration & Production Company
Use of CBM Water in Coal Mine Operations in Montana

Fidelity E & P has been providing CBM produced water to the Spring Creek Coal Mine (Spring Creek) in Bighorn County, Montana, since May 2001. The water was produced from the Carney, Dietz and Monarch coal beds within the CX Ranch field in Big Horn County and the use is permitted by the Montana DNRC. The Spring Creek mine stores water delivered by Fidelity in existing water storage ponds. They use the water primarily for dust suppression purposes as well as for equipment washing and general mine uses. Fugitive dust can be an environmental problem and regulatory issue for coal mines in arid climates. Dust can be suppressed by watering mine roads and coal piles. Water is also used to periodically wash vehicles and equipment to reduce dust. The picture below shows a water spreading truck operating within the mine. Prior to reaching an agreement with Fidelity, Spring Creek was using groundwater it was pumping from dedicated water wells. The use of CBM water from the CX Ranch field relieves the mine operators from depleting the shallow aquifers. This beneficial use of CBM produced water is expected to continue to meet Spring Creek's needs for the foreseeable future.

A water spreading truck operating at the Spring Creek Coal Mine in Montana. The truck is spreading water to minimize fugitive dust.

The Spring Creek mine had been requiring approximately 600 gpm during most of 2001. At the start of 2002, the mine encountered a shallow perched aquifer that supplied them with water for dust suppression and water demand shrank to approximately 150 gpm. The perched aquifer is nearly depleted and at the present time (November 2002) the mine requires approximately 300 gpm and usage is expected to increase.

Mine usage cuts down the amount of water discharged to the Tongue River by Fidelity. While Fidelity does possess a MPDES permit allowing discharges of up to 1,600 gpm to the river, the current rate is rarely higher than 1,100 gpm, and with large demands from the mine, their discharges are often below 600 gpm.

Devon Energy
Southeastern Kansas

Devon operates approximately 120 CBM wells in Wilson and Neosho Counties; not all of these wells are producing as yet. Producing wells are drilled to approximately 1,200 feet deep and completed in the Cherokee coals that total approximately 14 feet of net coal over approximately six zones. These wells begin their production history by making up to 600 bpd of salt water that tests between 30,000 and 40,000 ppm TDS. The produced water is pumped to the surface by beam pumps or Progressing Cavity Pumps (PCP) that discharge into plastic 4-inch waterline run in the common trench with the 6-inch gas-line as shown in the photograph.

Produced water is pumped to the surface by beam pumps or Progressing Cavity Pumps (PCP) that discharge into plastic 4-inch waterline run in the common trench with the 6-inch gas-line.

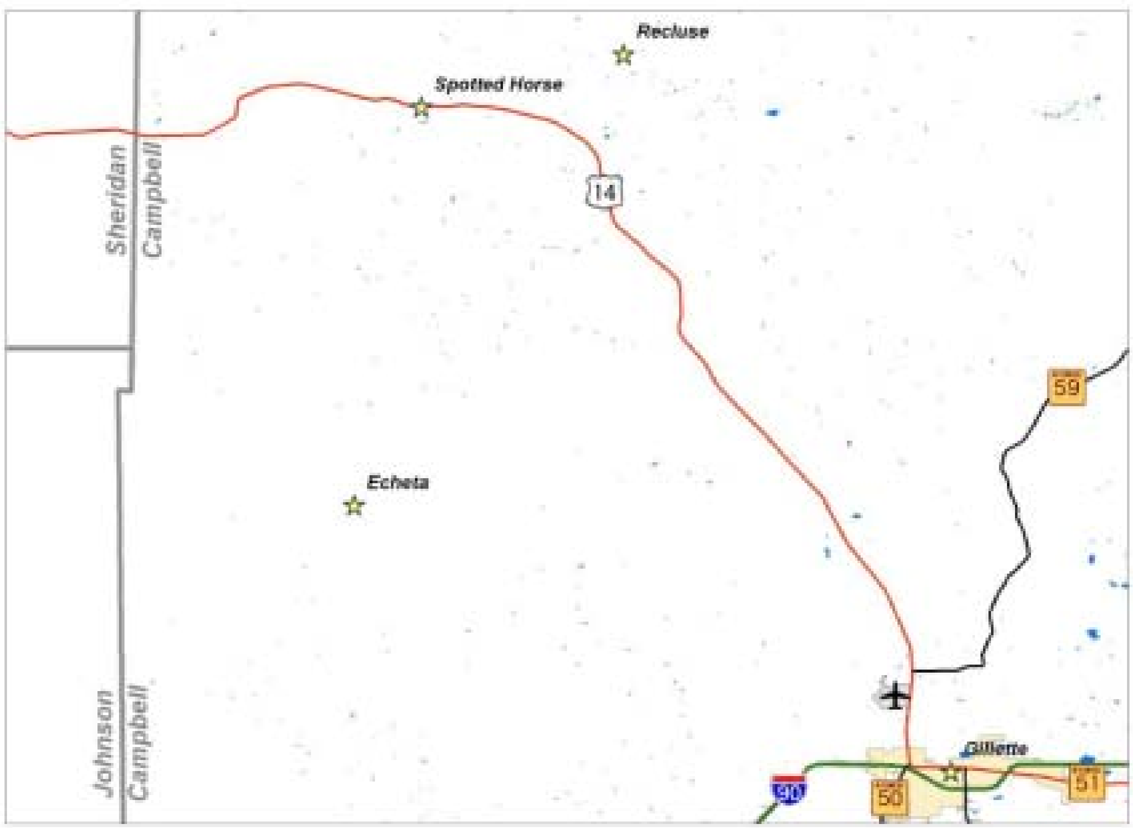
Produced water is pumped into holding tanks and manifold that empties into nine Class II disposal wells similar to the one shown below:

The small electric pump in the photo is enough to supply water to the well that takes water on a vacuum.

The photo shows the wellhead to the right background (to the right of the light blue bench). The small electric pump in the photo is enough to supply water to the well that takes water on a vacuum. The disposal wells are each permitted for 10,000 bpd at 300 psi into the Arbuckle Formation. The disposal wells were drilled by Devon for the purpose of disposal and were permitted by Devon through the Kansas Corporation Commission. The wells were drilled approximately 1,300 feet deep to the top of the Arbuckle cased, then drilled approximately 300 additional feet and completed open-hole within the vuggy portion of the upper Arbuckle Formation.

J. M. Huber Corporation, CBM Produced Water Irrigation Project Seven Ranch, Campbell County, Wyoming

J.M. Huber Corporation operates CBM wells in the Wyoming portion of Powder River Basin including the area at the Seven Ranch near the town of Recluse. In this project Huber is using on-channel and off-channel impoundments to manage produced water, combined with surface discharge, stock watering, and irrigation.



Location of the Seven Ranch project.

The Seven Ranch project involves storing CBM water in a network of on-channel and off-channel ponds of varying sizes. CBM produced water for the project is high quality, although moderate for the Powder River Basin, with SAR values averaging in the low to mid 20s. Some of the water in the ponds evaporates and infiltrates into the subsurface. At the same time, the local rancher has the use of the water stored in the ponds for livestock watering; wildlife can also make use of the water resource.

Small on-channel ponds were pre-existing on the ranch, having been installed by the rancher. One of the ponds is shown below.

On-channel Impoundment at Seven Ranch.

The impoundment shown in the picture is constructed in a dry drainage that drains from the left to the right. In this instance an existing pond has been upgraded for the rancher's use. Wyoming on-channel ponds are required to have a run-off diversion trench that will transport run-off coming from up-stream around the pond and convey the run-off down-stream. In this way, important facets of CBM water management are preserved:

- The integrity of the pond is maintained, storm water is drained away from the pond, and the dam is protected from damage.
- No CBM water is released to the drainage during storm-water events.
- Normal run-off drainage is maintained so that surface water rights located down-stream are not impaired.

Off-channel impoundments are constructed away from natural dry or live drainages in areas such as ridges between adjacent drainages. The following two photos are both of the same impoundment, showing different views of a large off-channel impoundment. The first photo shows wildlife tracks near the impoundment, demonstrating the access and availability of the water within the impoundment for wildlife watering.

The second photo shows the discharge system to the impoundment. The discharge pipe delivers water to the drainage-way protected by rip-rap that allows the water to aerate prior to entering

Wildlife tracks near a CBM produced water impoundment
Seven Ranch, Wyoming

Off-channel Pond at the Seven Ranch.

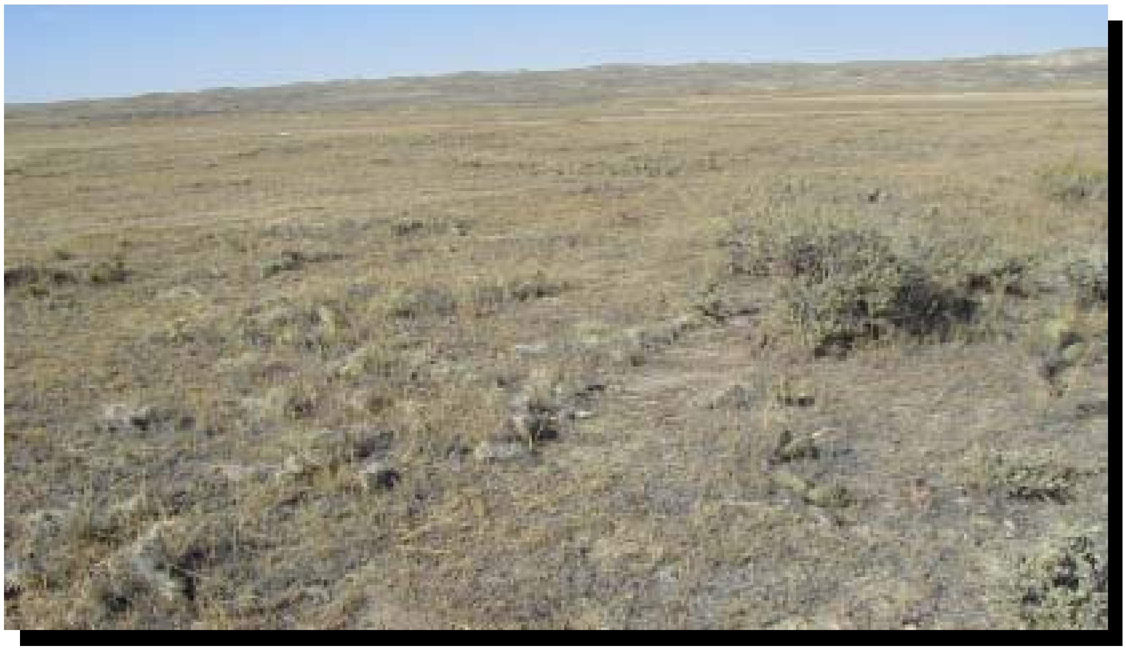
the pond. Aerating the water allows iron to precipitate on the rip-rap surface reducing the concentration prior to the water entering the impoundment. The CBM water runs down the constructed drainage to the approximately 200 acre-feet reservoir; this reservoir will cover approximately 26 acres when full. Also shown in the center of the image is one of two goose-islands that will supply predator-safe nesting spots for waterfowl. In the image to the left of the drainage fall-out is a path of animal tracks leading to and from the impoundment; the tracks appeared to be mostly deer and antelope. The impoundment represents the only water in the area and therefore is very valuable to local wildlife.

Williams, CBM Produced Water Irrigation Project
Kingsbury Project, Johnson County, Wyoming

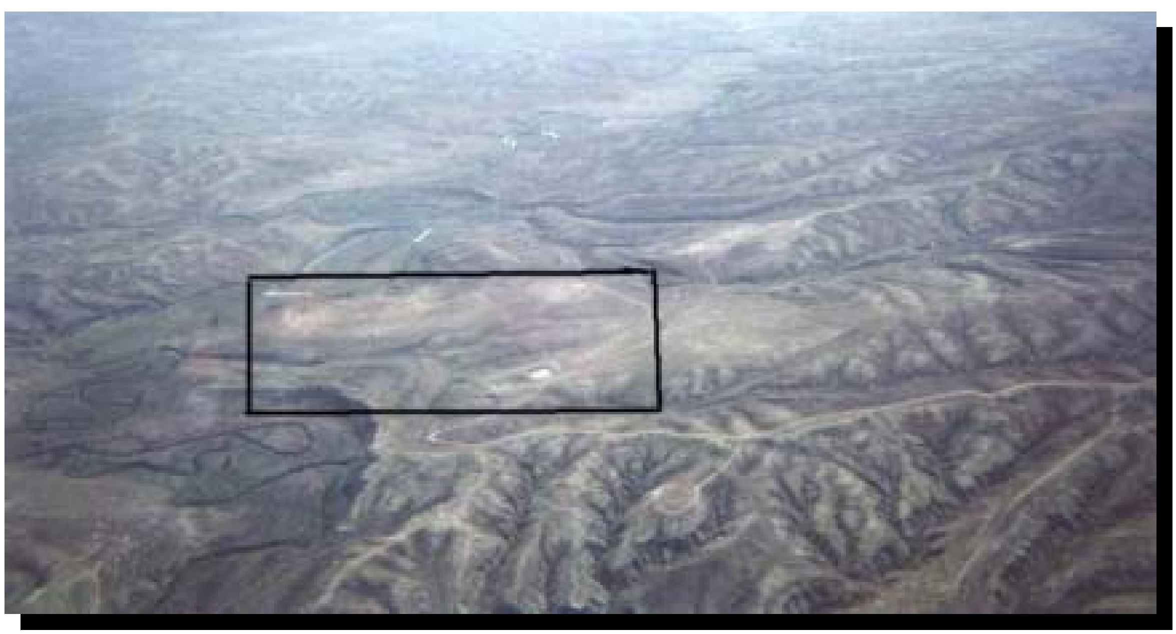
Williams is a major CBM producer in the state of Wyoming. One of their new fields is in the Kingsbury area within the Powder River Basin of Wyoming. The Kingsbury area is the site of the Pumpkin Creek drainage and an ambitious irrigation project utilizing CBM produced water. The project area is shown below:

Kingsbury Project in Johnson County, Wyoming

Prior to irrigation, groundcover consisted mostly of drought-resistant sagebrush, prickly pear cactus, and sparse grasses as shown in the first photo.



Groundcover at the Kingsbury Area Prior to Irrigation.



The Kingsbury CBM Irrigation Project. Note the location of the two impoundments in the lower right-hand portion of the project outline.

Livestock forage is extremely sparse over most of this area, primarily due to a lack of moisture, especially under the current drought conditions this area is experiencing. Beginning in September 2001, water was applied to the surface by way of large center-pivot systems. CBM water used in the project tested in excess of 20 SAR. Between waterings, soil amendments in the form of dry gypsum as well as other calcium sources, sulfur, and other additives were applied.

During 2002, plant growth was impressive in the project. The three large center pivots supported healthy grass establishment. The results can be seen in the photos below:

July 2002 photo showing green grass in the irrigated area and sparse vegetation on the non-irrigated area.

Kingsbury coal bed methane produced water irrigation project
Shows variations between irrigated and non-irrigated areas

July 2002 photo showing successful growth under the three center-pivot systems.

Variable amounts of water were added to the three plots and grasses responded differently although the results have not been completely tabulated. In the future, soil conditions will be characterized and the changes in soil salinity and SAR will be charted. The efficiencies of various soil amendments will also be determined. Williams' aim is to maximize plant production while maintaining soil structure and avoiding runoff.

Before and After Photos of Irrigated Area in the Kingsbury Project. August 2001 on the left and July 2002 on the right. Surface has been irrigated for one growing season.

J.M. Huber Corporation, CBM Produced Water Management Case Study Prairie Dog Creek Field, Sheridan County, Wyoming

J.M. Huber Corporation (Huber) began the development of its Prairie Dog Creek CBM Field, located approximately 8 miles northeast of Sheridan, Wyoming, in the summer of 1999. Prairie Dog Creek Field is located in Sheridan County, Wyoming, and lies in Townships 57 and 58 North, Ranges 83 and 84 West.

As of September 2002, 590 wells in the field were producing about 65 million cubic feet per day (MMCFD) of coal bed methane, and 140,000 barrels of water per day (bwpd). Water production peaked in June 2002 at about 150,000 bwpd. The September daily water production is the equivalent of about 4,100 gpm, 5.9 mgd, 9.1 cfs, or 18 acre-feet per day.

The average water production rate for all wells in September was about 235 bwpd per well, or 6.9 gpm per well. To place this rate into context, 6.9 gpm would be a moderately good domestic well that supplies a single family dwelling. Field-wide water production would be sufficient to supply about 6,700 families for a year, assuming each family uses 1 acre-foot of water in that year.

These CBM wells vary in total depth from about 250 feet to 1200 feet, and are generally completed in a single coal seam. Five coal seams are currently being produced at the Prairie Dog Creek Field, which are named in descending order the Anderson (Dietz 1), Dietz 2, Dietz 3, Monarch, and Carney Coals.

Produced water from the CBM wells is handled using three primary methods:

- irrigation,
- exfiltration (leakage) and evaporation from pits or ponds, and
- injection.

On the average, irrigation beneficially uses about 70% of the produced water, 25% is returned to the shallow groundwater system by infiltration or is evaporated from small (5 acre-foot) to moderate (50 acre-foot) pond or pits, and 5% is injected into 2,000-foot deep, Class V injection wells.

The traditional irrigation season near Sheridan extends from May to October, with peak irrigation water requirements in July and August. From November through April, little or no irrigation occurs. Hence, successful water management has required Huber to empty the pits and ponds during the summer and fall irrigation season, and fill the pits and ponds during the non-irrigation seasons.

Problem Statement

Water management options were of concern at Prairie Dog Creek Field in 1999 for the following reasons:

- The regulatory environment for discharge to surface streams under NPDES permits was continuously becoming more strict, and

- The produced water quality in the Sheridan area was lower (1500 mg/l TDS, 45 SAR) than that in the areas of the eastern Powder River Basin (600 to 1000 mg/l TDS, 6 to 15 SAR) then being produced or developed.

Due to these factors, Huber developed an innovative, multi-faceted approach to water management that has proven successful. Those facets include:

- surface discharge to lined pits for storage and evaporation;
- surface discharge to unlined pits for storage, evaporation and infiltration;
- surface discharge to ponds for storage, evaporation and infiltration;
- injection into a relatively shallow aquifer; and
- irrigation of crop land and meadows.

The technologies needed to implement these alternatives were all well known and developed. Huber also evaluated the feasibility of using reverse osmosis (membrane filtration) water treatment, but did not proceed with a pilot plant program due to having sufficient management capacity using other methods.

Beneficial use of relatively high TDS (1,500 mg/l), relatively high SAR (40 to 50), produced water for irrigation required several steps before implementation, including:

- initial studies to demonstrate its efficacy,
- baseline studies to define soil conditions and needed amendments,
- soil amendment applications, and
- soil chemistry and moisture monitoring.

Concerns regarding the direct use of produced water for irrigation include an increase in soil water salinity in the root zone, which can cause a decrease in crop productivity, and an increase in the SAR in the soil, which can lead to decreased soil permeability.

Regulatory Environment and History

At the time of initial drilling in Prairie Dog Creek, Huber had five NPDES permits that allowed the discharge of about 150 gpm (5,000 bwpd) from federal wells. The federal wells were then the subject of an Environmental Assessment that was successfully completed and accepted by the Buffalo Field Office of the BLM. This EA was first appealed to the State Office, and then to Washington, DC. As a result, water from federal wells has not been discharged under these initial permits, and gas has not been produced from federal leases in Prairie Dog Creek Field.

In the third quarter of 1999, Huber submitted a general permit application to the WDEQ for discharge of produced water from about 50 wells to Beatty Gulch, a tributary of the Tongue River. This application was not approved by WDEQ.

In the fourth quarter of 1999, Huber submitted three individual NPDES permit applications to WDEQ for discharge to on-channel ponds. Three applications were required in order to comply with WDEQ's requirements that no more than ten outfalls be allowed under one permit, and that a permit have outfalls only in one drainage. The three applications covered about 100 drilled and planned wells.

Two of the three NPDES permits were granted in early 2000, and form the current core for surface discharge to on-channel ponds in the Prairie Dog Creek drainage. The third permit, for discharge to Beatty Gulch, was not approved.

To construct the on-channel ponds, the WSEO must permit the dam prior to construction. Permits for all new ponds, plus permits for existing, non-permitted ponds that were being upgraded, were obtained from WSEO.

Huber began permitting and constructing off-channel pits through the WOGCC in third quarter of 1999. Several of the initial pits were required to be lined, as they were constructed using cut-and-fill methods, and WOGCC was concerned about potential dam failure. In 2001, this concern was successfully addressed from engineering and construction quality control aspects, and WOGCC began issuing permits for unlined cut-and-fill pits.

WOGCC permits for unlined pits are contingent upon the agreement from WDEQ that pit seepage will not adversely affect the water quality of shallow aquifers. To obtain this agreement, Huber was required to sample the shallow aquifer, either via test wells or from springs, to show non-degradation of that shallow aquifer.

Sampling data indicated that the shallow Wasatch aquifer in the Prairie Dog Creek area had much lower water quality than the produced water, with TDS levels as great as 4,000 mg/l. Thus, WDEQ has indicated to WOGCC its agreement with the use of unlined pits.

Injection into the relatively shallow (2,000 foot deep), lower Tongue River aquifer initially required "aquifer storage-recovery" (Class V) injection well permits issued by WDEQ. Permits for eight such wells were sought in late 2000 and early 2001, six injection wells were permitted, and four injection wells were drilled, equipped and used.

WDEQ began issuing permits under a new General Permit for Class V injection wells in late 2001, and the injection wells were re-permitted accordingly. The new permits require injection pressures to be limited to the fracturing pressure at the top of the injection zone, assuming a fracture gradient of 0.7 psi/ft. This new regulation caused Huber to stop using three of the four injection wells due to exceeding the maximum injection pressures at desired rates combined with expected production declines.

In early 2002, Huber permitted and began working on a new injection well in a new production area (commonly termed, a pod) completed at depths of about 5,000 feet.

Irrigation does not require a permit, per se, from the WSEO or WDEQ. WSEO requires that the well permit state "CBM production" as the beneficial use of the water in order for the produced water to be used for irrigation. Additionally, the WDEQ requires that tailwater, spray, or leached (deeply percolating) waters not directly reach waters of the state.

Water Management Methods

Huber has constructed approximately 25 on-channel ponds for water management purposes at Prairie Dog Creek. The total capacity of these ponds is approximately 375 acre-feet. A total of 25 off-channel pits have been constructed that have a total capacity of approximately 750 acre-feet. Water levels and available storage are measured monthly, or more often, with the results included in water management models.

Total storage capacity is currently about 1,340 acre-feet, or about 10.4 million barrels. It was estimated that at maximum, these pits and ponds can infiltrate to the shallow Wasatch aquifer about 78,000 bwpd. In addition, over a 150 day winter storage season, and with 80% capacity available at the start of the season, the maximum average fill rate would be about 55,000 bwpd.

Thus, during the winter season the maximum water handling capacity of the pits and ponds is about 133,000 bwpd. During the summer, the capacity falls to about 78,000 bwpd, as the ponds are being emptied by irrigation in preparation for the next winter.

During the summer season of 2002, Huber irrigated about 1,000 acres at a peak rate of 130,000 bwpd (3,800 gpm). Irrigation methods included sprinklers, side wheels, and 'big guns' fed by diesel-fueled pumps.

Huber will have five injection wells capable of operation by the end of 2002. The combined capacity of these wells is about 12,000 bwpd.

As part of water management, water quality in surface streams is monitored at several stations on Prairie Dog Creek and its tributaries on a quarterly basis. Water chemistry is also monitored in a system of ten shallow aquifer wells on a semi-annual basis, and annually monitors water chemistry in domestic wells in the area.

Water Management Models

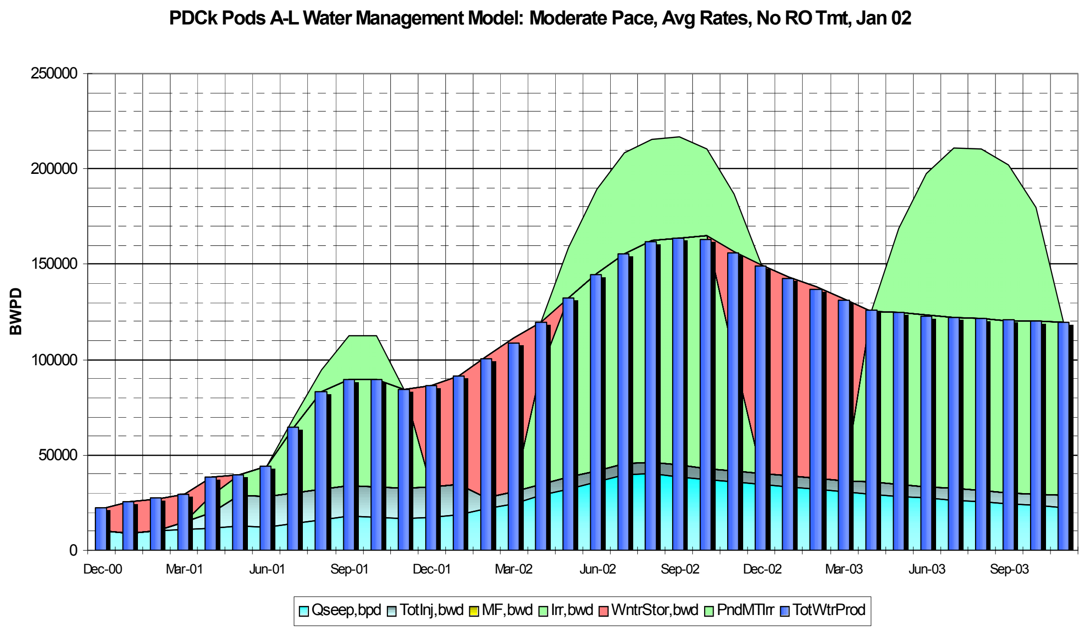
In order to plan for the construction of water management facilities, including ponds, injection wells and irrigation systems, two water management spreadsheet models were constructed. Both models balance water inputs and outflows on a monthly basis.

The first model gives a preliminary forecast for total production and management in the entire field. The second model uses observed flows and reservoir volumes to update estimates in an iterative manner, and to project future conditions, for the 13 pods (production collection/gas compression areas) that comprise the field.

Preliminary Forecast Model

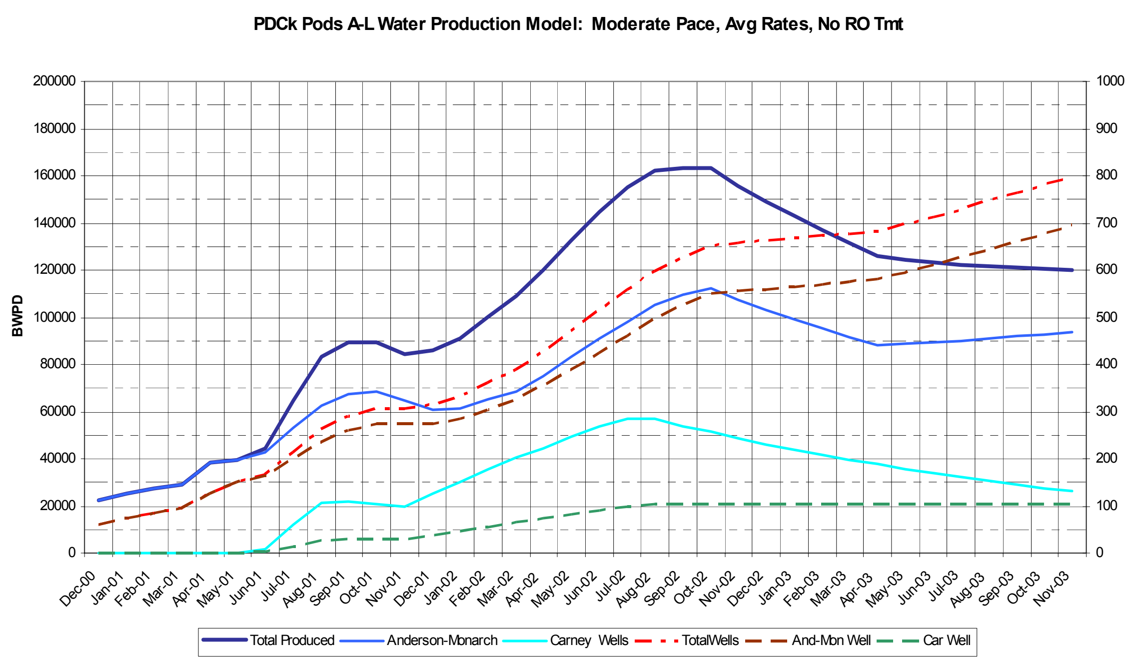
The charts below illustrate the outputs from the Preliminary Forecast Model. Inputs to this model include initial water rates and monthly decline rates for two coals, the numbers of wells by coal, initial infiltration rates and decline rates for pits and ponds, numbers of pits and ponds, injection well rates, irrigation rates, and water treatment rates.

Figure 6-3
Prairie Dog Creek Water Management Model
This graph shows outputs from the preliminary forecast model



Source: J. M. Huber, 2002

Figure 6-4
Prairie Dog Creek Water Production Model
This graph shows water production from Pods A-L

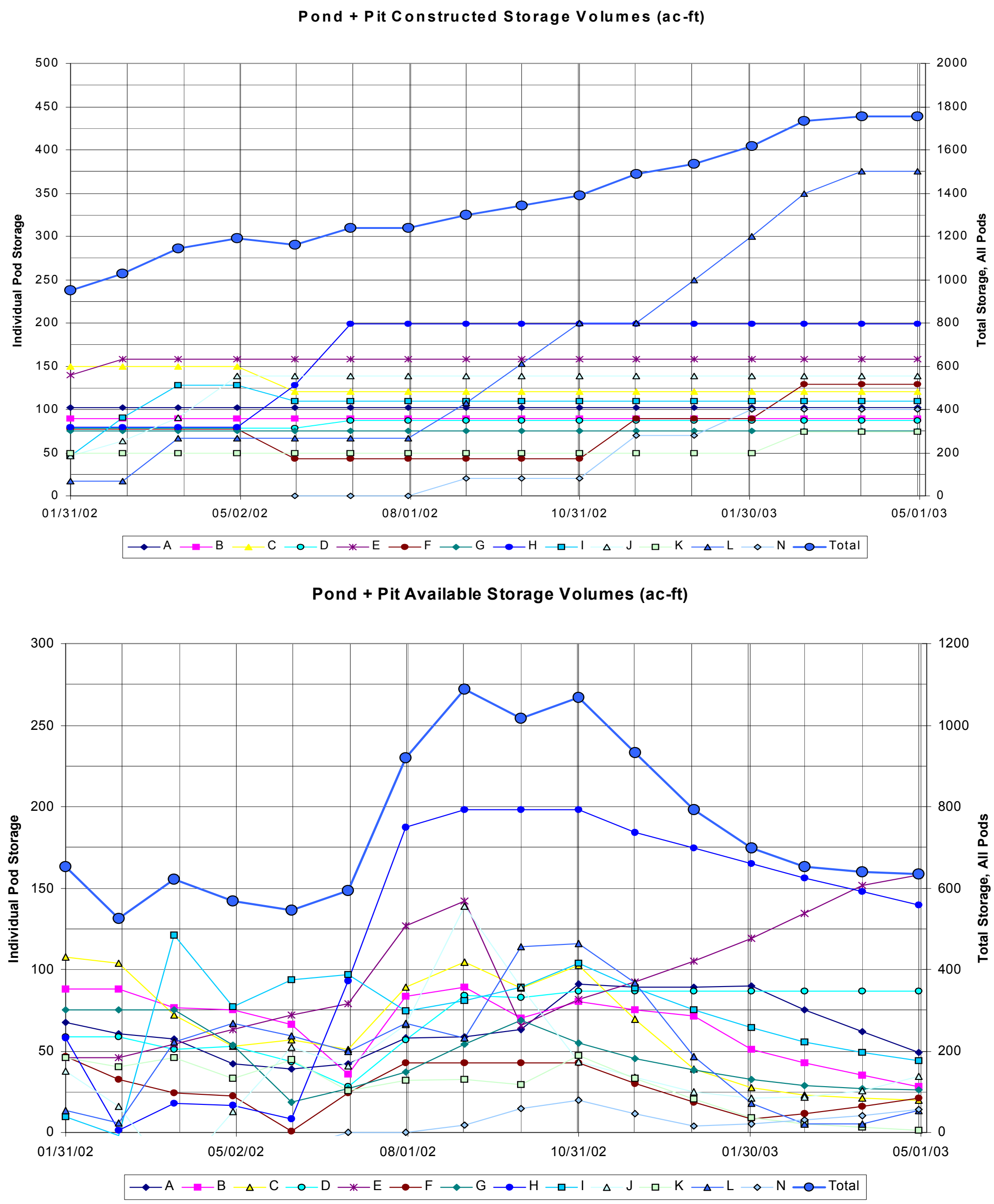


Source: J. M. Huber, 2002

Detailed Pod Model

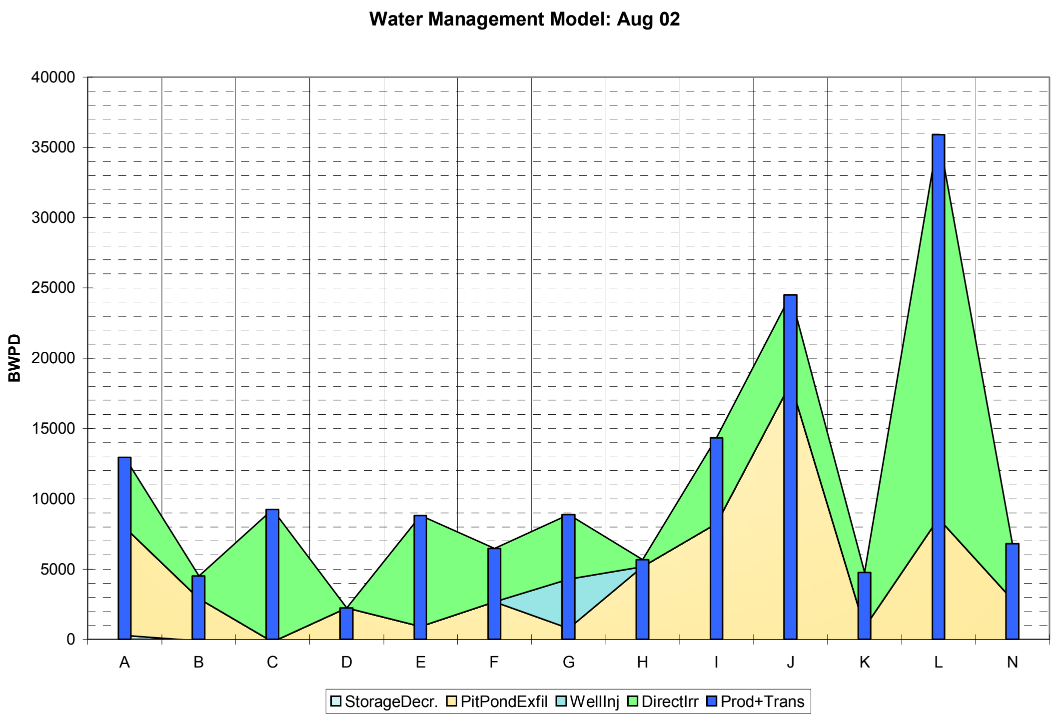
The Detailed Pod Model has inputs similar to the Preliminary Model, except that the information is on a pod-by-pod basis rather than for the entire field. The inputs are set up to allow the input of observed values, for example of water production or reservoir availability, and to use the observed values as the basis for estimates of future conditions. Examples of outputs include the charts below:

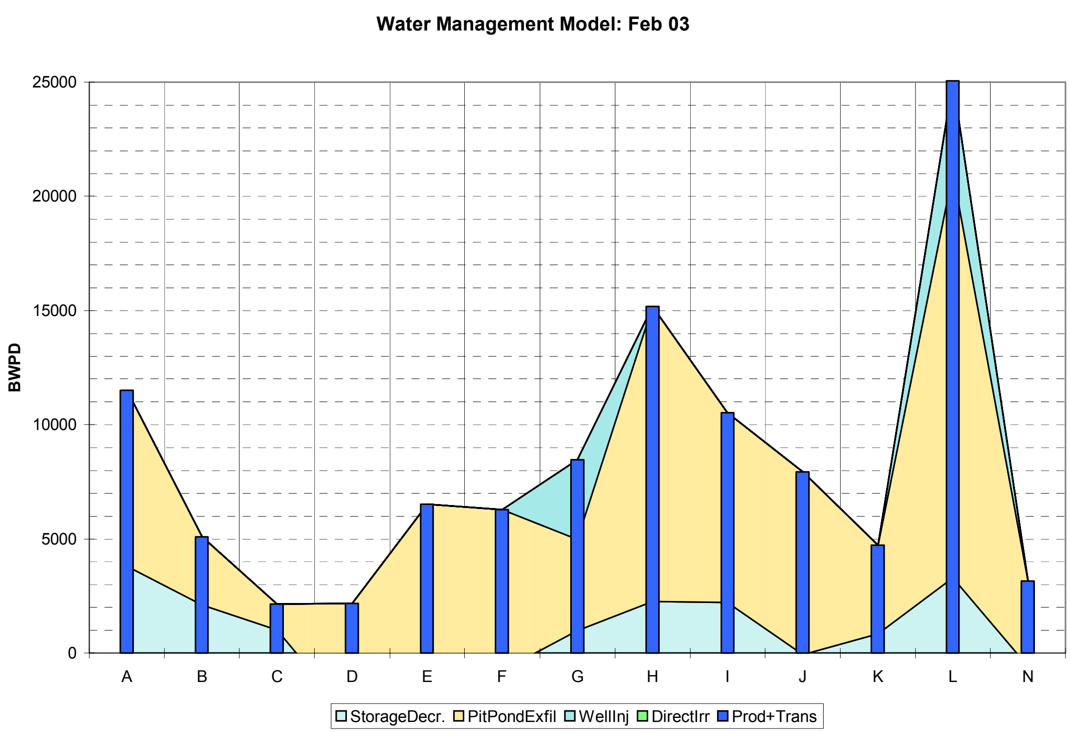
Figure 6-5
Prairie Dog Creek Detailed Pod Model Example Outputs
This graph shows water production from Pods A-L



Source: J. M. Huber, 2002

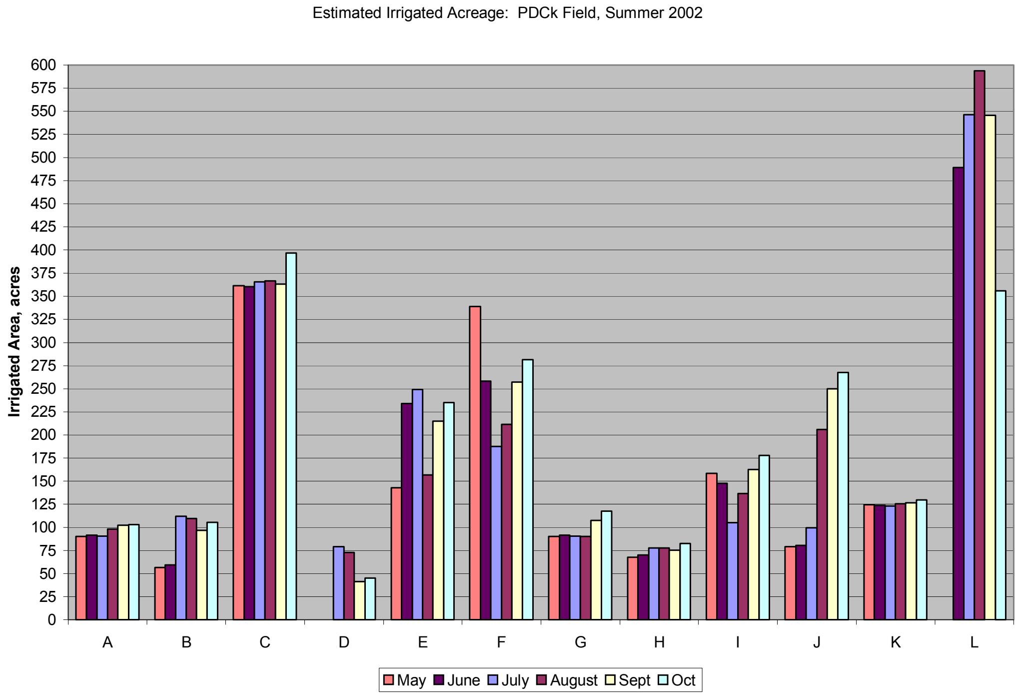
Figure 6-6
Prairie Dog Creek Water Production Model
This graph shows water production from Pods A-L

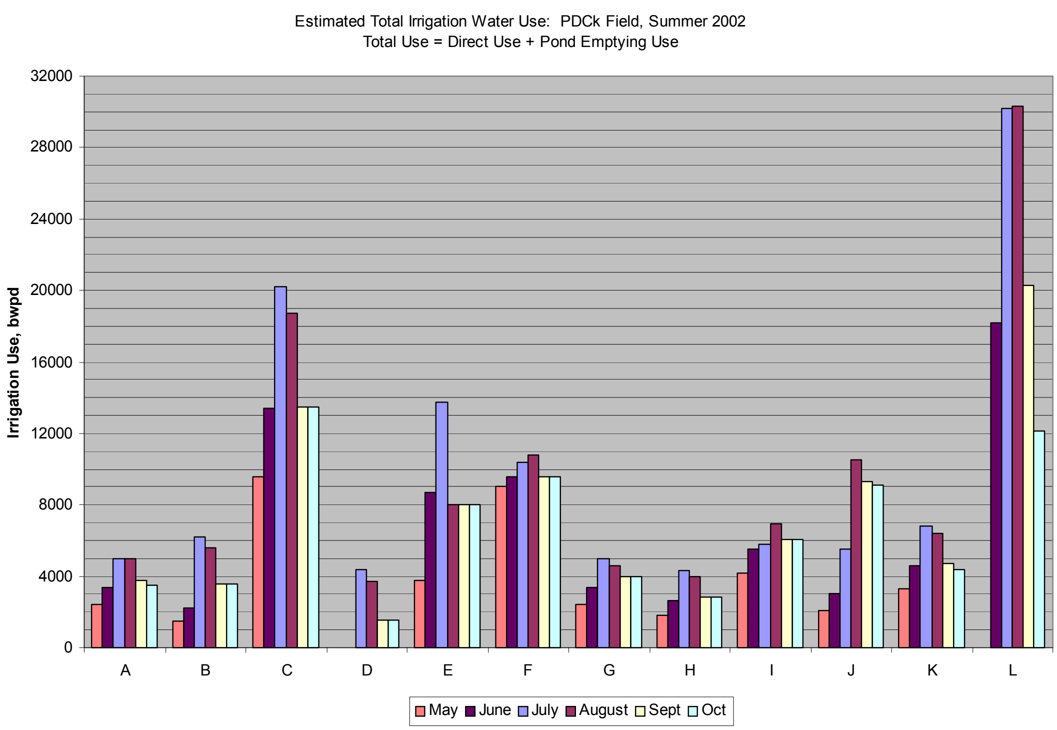




Source: J. M. Huber, 2002

Figure 6-7
Prairie Dog Creek Detailed Pod Model Example Outputs
These graphs shows Estimated Irrigated Acreage and Estimated Total Irrigation Water Use



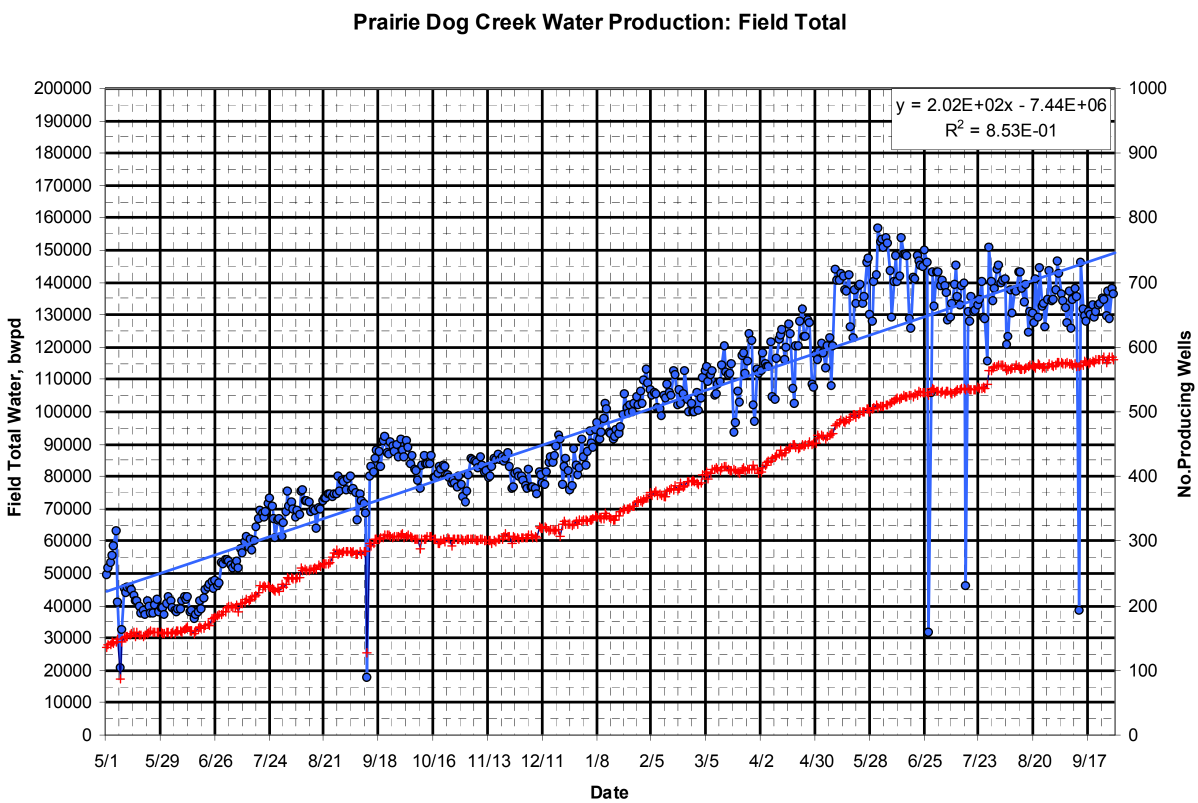


Source: J. M. Huber, 2002

Comparison of Estimates to Observed

The chart below show the observed field total water production rates in Prairie Dog creek. The predicted total flow was about 160,000 bwpd, as shown above. The observed total flow was about 150,000 bwpd, as show below. The difference, about 7% high in the prediction, was considered quite acceptable for the purpose.

Figure 6-8
Prairie Dog Creek Water Production
The graph shows Observed Field Total Water Production



Source: J. M. Huber, 2002

BP America, Inc., CBM Produced Water Surface Discharge with Treatment
San Juan Basin, Colorado

BP America, Inc. (BP), the Gas Technology Institute (GTI) and Triwatech, LLC are testing a proprietary pre-treatment and Reverse Osmosis (RO) system for CBM produced water at one of BP's operational facilities in the San Juan Basin near Durango, Colorado. The proprietary pre-treatment and RO systems are being designed by Triwatech, LLC. BP in addition to providing the CBM produced water for the study is co-funding the project with GTI. BP's operation in the SJB currently produces water from 900 CBM wells and is re-injecting this water via 13 Class II disposal wells. The produced water quality is predominately sodium-bicarbonate water that contains elevated levels of TDS (1,600), SAR, and bicarbonates.

BP is interested in evaluating the potential of treating CBM produced water prior to discharge into the Pines River, a tributary of the San Juan River. Prior to the start of the treatment system, the BP representative discussed the regulatory aspects of the project with the EPA and Colorado state agencies. The BP representative requested clarification from the EPA regarding the treatment of produced water and how it would affect several permitting issues including the Class II IW permits BP currently operates under, as well as the NPDES permit the company previously applied for and is currently being reviewed. BP personnel received a letter for the EPA Headquarters, which states that the EPA considers the treated and reject water from this operation to remain under the classification of Oil and Gas Waste. Because of this classification, BP's existing Class II IW permits are still valid and any NPDES permits that would be obtained by the company would have to meet the conditions under such classification.

The study treatment system is connected at one of BP's injection well sites in a closed loop system which separates a portion of the produced water stream (approximately 20 bbls/day) and runs this water through a pre-treatment and RO system on site. Once samples for water quality analysis of both the treated water and reject have been collected, the water is returned to the feed stream and re-injected with the rest of produced water.

Triwatech, LLC designed the proprietary pre-treatment and RO system for the tests to be portable and interchangeable. During the course of the test, different pre-treatment technologies can be added or removed and RO membranes can be changed with ease. This flexibility will also allow the test system to be moved to different basins and modified to meet the needs of operators in these areas. Information relating to the pre-treatment technology being used at the site was not available due to proprietary considerations. If the project were to go to full scale, an onsite facility would have to be constructed to handle the addition volume of produced water. It is the opinion of both the BP and Triwatech personnel that the primary reason most RO systems have not succeeded is that the pre-treatment aspect has not been fully evaluated on a site-specific level to determine what options would work best.

BP has submitted an application to the state of Colorado for a general discharge permit (NPDES) that would require discharged water to be less than 500 TDS. Additional water quality limits including barium, bicarbonates, and SAR may be established in the final permit as the state deems necessary. BP is interested in the results of this test to determine if it is technically and economically feasible to use this technology and meet the TDS requirements for this NPDES permit.

The overall objective of the project is to reduce the volume of re-injected produce water to possibly alleviate operating costs and at the same time, provide high quality water for discharge that can be beneficially used downstream. If this pilot test is successful, BP plans to discharge the high quality produced water into the Pines River and re-inject reject water into local aquifers. A contract representative of GTI was on-site to analyze the reject water to determine if any complications would arise from the re-injection of this reject water. The results of this pilot test including water quality data are expected near the end of the 2002 or the first quarter of 2003.

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