Produced Water
RMP Revision
9/29/2005

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Summary

Preliminary investigation of ground water quality for both the main coal bed methane (CBM) targets, the Mesaverde Group and Fort Union Formations indicates a general trend of fresher more recent recharge in the southeast in the vicinity of the outcrops to more saline in the center and north and northwestern parts of the basin away from the outcrops. This is supported by greater amounts of precipitation, and therefore recharge, in the eastern mountains and near the outcrops compared to the center and western part of the basin. The production of CBM water in the southeast is feasible in terms of disposal costs since the water could potentially be used for livestock and crop irrigation. A closer look at comparing sodium adsorption ratio (SAR) and total dissolved solids (TDS) will determine the potential for crop irrigation in areas where both SAR and TDS are high. CBM water production will be more costly in the center and northwest part of the basin due to disposal costs (i.e. costs for re-injection or facility disposal). Potential for re-injection disposal would include injection into the Dakota Sandstone or Cedar Mountain Formations. Further investigation of formation permeability and water quality needs to be performed for determining actual re-injection potential. Potential impacts to stream flow must be considered when planning production in the southeast portion of the basin and can incur additional costs to support the claim of un-appropriated water and prevent potential litigation. Additionally, water produced in areas near recharge may produce significantly greater amounts of water in order to lower the pressure of the system. If the water is put to beneficial use there is no additional costs. Water produced from more saline areas will most likely produce less water over the life of the well and disposal costs will be less if compared to re-injection of fresher water where water production will be greater.

Introduction

Produced water from convention oil and gas wells is well documented within the Little Snake Field Office (LSFO). Most of the more than two thousand existing and historic wells produce less than five barrels of water per month. There are several ways of disposing of produced water; injection, disposal pit, surface discharge, or by hauling produced water to an approved disposal facility. Injection disposal needs the underground injection control (UIC) permit pursuant to 40 CFR Parts 144 and 146 from the EPA/state, and must meet the Onshore Order numbers1 and 2. Pits are approved by the BLM through the sundry notice (SN) process and can either by lined or unlined depending on conditions. Most operators elect to use storage tanks in lieu of disposal pits. Water from these tanks is then hauled to authorized disposal facilities and approval is granted by the BLM through the SN process. Surface discharge under the National Pollutant Discharge Elimination System (NPDES) requires a SN to the BLM and copies of the NPDES permit. The state of Colorado has primacy over surface discharge but looks for concurrence from the surface owner or surface management agency before granting approval. Operations from the point of origin to the point of discharge are the jurisdiction of the BLM. Operations from the point of discharge downstream are under the jurisdiction of the State.

Information and procedural requirements for an application for the disposal of produced water as well as the design, construction, and maintenance requirements of pits can be found in Onshore Order #7.

Several CBM pilot projects exist within the LSFO (Map1). Most of these pilots have produced copious amounts of water. Water production has been a detriment to the economic feasibility of these pilots. In the eastern part of the field office (FO) the water quality is very good and surface discharge is occurring on fee mineral and surface estate. These pilots are near the outcrops which are recharge areas, and as a result large amounts of water need to be disposed of. Pilots located further west toward the basin center are further away from the outcrop and as a result have less water, but the water is of poorer quality and does not meet the NPDES standards for surface discharge. Other methods of produced water disposal must be used.

CBM waters produced within the Sand Wash basin have been sampled from the two major coal bearing formations; Mesaverde and Fort Union. Ground water from both formations indicates areas of relatively fresh water and areas of significantly older ground water. This is indicated by the total dissolved solids and chloride concentrations. Ground water hydraulically connected to recent recharge exhibits low TDS and chloride concentrations while older ground water will be correlated with higher TDS and chloride due to the presence of connate saline water and to geochemical evolution associated with the time the water is in contact with the aquifer matrix. Fresh water found within these formations contain TDS below 500 mg/L while the higher TDS ground water is saline (15,000 – 30,000 mg/L) and as high as sea water (38,000 mg/L) in the Fort Union formation. The majority of ground water from both formations is of underground sources of drinking water (USDW) quality in terms of TDS (TDS <10,000 mg/L), although potable water is typically less than 3,000 mg/L.

Another indicator of CBM produced water quality is the SAR. SAR is easily determined from analysis of sodium, calcium, and magnesium concentrations. SAR is used to determine if a water source is suitable for irrigation, or discharge to the environment. Significant loading of sodium (high SAR) can adversely affect soil drainage.

Mesaverde Group Water Quality

Mesaverde Group formations have groundwater that exhibits relatively fresh water near the Iles and Williams Fork outcrops in the southeast portion of the basin south of Craig. The majority of wells in this area have ground water with TDS less than 1,000 mg/L

(Map 2). Lower TDS in the area of outcrop indicates relatively short residence times and recent recharge from precipitation and snowmelt. CBM production in this area would allow for beneficial use of the produced water through either irrigation or livestock watering. Thus, "disposal" costs would be significantly reduced. Table 1 provides TDS ranges and associated livestock use. Many of the wells in this area are at a distance from perennial streams; however wells near the Williams Fork and Yampa River may be in hydraulic connection with the rivers and future production in these areas needs to consider possible stream depletion. This type of ground water is defined as "tributary" or ground water that is in hydrologic connection with a natural stream system either by surface or underground flows. If production is to occur it may need to be determined that unappropriated water is available and material injury to vested water rights will be prevented. The cost involved with "tributary" water is potentially high and may lead to costly litigation. Other water quality characteristics are also important (i.e. pH and trace metals such as barium) and should also be taken into account. However, as a first look at areas suitable for CBM development problems associated with the produced water can be readily identified by TDS, chloride, and SAR.

Table 1. Total dissolved solids ranges and livestock use.

Total dissolved solids content of waters	Uses
Less than 1,000 mg/L (EC < 1.5 mmhhos/cm)	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000-3,000 mg/L (EC = 1.5-5 mmhos/cm)	Very satisfactory for all classes of livestock and poultry.
3,000-5,000 mg/L (EC = 5-8 mmhos/cm)	Satisfactory for livestock. Poor waters for poultry.
5,000-7,000 mg/L (EC = 8-11 mmhos/cm)	Reasonably safe for livestock. Not acceptable for poultry and some risk to pregnant or lactating animals.
7,000-10,000 mg/L (EC = 11-16 mmhos/cm)	High risk for pregnant livestock. Unfit for poultry and probably for swine.
Over 10,000 mg/L (EC > 11-16 mmhos/cm)	Not recommended for use under any condition.
Soltanpour, P.N., and W. L. Raley. 1982. Evaluation of drinking water quality for livestock. Service In Action, Colorado State University Extension Service Quick Facts No. 4.908.	

Ground water samples taken from just outside the outcrop area and further into the basin are associated with higher TDS and chloride indicating older ground water that would still be reasonably safe for livestock use. However, ground water in the northwest and northeast portions of the basin are associated with potential for significantly higher TDS and chloride (Map 3) indicating re-injection of the produced water since the salinity would be considered a risk for livestock. Additionally, SAR (Map 4) values in these areas are high and indicate the potential for soil dispersion and reduced permeability and not useable as irrigation water. However, high SAR with high TDS can reduce the affects of sodium on soils and therefore allow the water to be used as irrigation water. While the ground water would need to be re-injected the cumulative amount of water produced may be significantly less than that found in the fresher ground water areas due to water being taken from storage not hydraulically linked with recharge.

Fort Union Formation Water Quality

Fort Union Formation groundwater exhibits relatively similar trends as the Mesaverde formations with fresh water near the outcrop areas in the southeast portion of the basin just northeast of Craig and brackish ground water in the northwest and northeast portion of the basin. The ground water in the vicinity of the outcrop is associated with TDS less than 1,000 mg/L. Lower TDS (Map 5) in the area of outcrop indicates relatively short residence times and recent recharge from precipitation and snowmelt. Similar to the Mesaverde, CBM production in this area would allow for beneficial use of the produced water through either irrigation or livestock watering. Thus, "disposal" costs would be significantly reduced. Production planned near the Williams Fork and Yampa River needs to consider whether or not unappropriated water is available and material injury to vested water rights will be prevented. The cost involved with "tributary" water is potentially high and may lead to costly litigation.

Fort Union SAR values (Map 6) from the ground water samples are correlated with high TDS and chloride (Map 7) in the northwest and low values (SAR<5) in the southeast. These values support that water in the southern part of the basin near the outcrop could be put to beneficial use as irrigation water. Ground water in the northwest and northeast portions of the basin are associated with potential for significantly higher TDS and chloride indicating re-injection of the produced water since the salinity would be considered a risk for livestock. Additionally, SAR values in these areas are high and indicate the potential for soil dispersion and reduced permeability. However, as previously mentioned high SAR with high TDS can reduce the affects of sodium on soils and therefore allow the water to be used as irrigation water. While the ground water would need to be re-injected the cumulative amount of water produced may be significantly less than that found in the fresher ground water areas due to water being taken from storage not hydraulically linked with recharge.

Best Management Practices

Coal bed methane development can present complex water-related challenges, as well as possible beneficial uses. Extracting CBM generally requires the withdrawal of groundwater to release the pressure within a coal seam, thus allowing the methane gas to begin flowing. Because CBM production generally begins by withdrawing a high volume of water, significant issues have been raised, including the potential waste of valued water resources; concerns about groundwater, specifically on the effects of lowering the water table, potential impacts on residential and agricultural wells, and possible contamination, and; produced water disposal or management, including downstream impacts on both water quantity and quality. When appropriate, landowners are frequently interested in putting the water to beneficial use, and consider it an asset. Adoption of BMPs can help address these and other water related concerns and potentially reduce conflicts with landowners, conservationists, anglers and other land and water users; however, BMPs must be customized to deal with a variety of considerations that vary by basin or project.

The following produced water BMPs are taken from the Western Governor's Association April 2004 Coalbed Methane Best Management Practices Handbook.

Water Best Management Practices

A. Water Management Planning

BMP 1: Prepare a Water Management Plan. Water management plans must be specifically designed for the basin or project in which they are being used, and are typically applicable to surface discharge of CBM-produced water. As part of the plan's preparation:

Consult surface owner(s) (as well as affected water-users) early in the planning process and throughout the development of Water Management Plans (WMPs).

Understanding and Application of Laws, Regulations, and Policy. Develop an understanding of the laws, regulations and policies that would apply to the development of the operation. These will vary by state and locality. For example, when considering underground injection, ensure that the components of the underground injection control program can be met, whether the EPA is administering the program or an individual state has received primacy for the program. Certain design and operating requirements should be researched through the appropriate jurisdictional agency (either the EPA or the primacy state) to ensure a complete application for approval is submitted. (See the sample Regulatory Compliance Checklist in Appendix D at www.westgov.org)

Consider Planning on a Watershed Basis. Watershed Planning in the CBM context is an emerging practice that involves coordinating with other companies, surface owners and permitting agencies within, and potentially downstream of the watershed, and entails baseline monitoring and an assessment of quantity, quality, water rights, and downstream landowners' concerns. The State of Wyoming is in the process of developing a CBM watershed planning program, which may eventually serve as a model for other locales.

Mitigate Surface Water Discharge Effects, i.e., headcuts, road crossing, impoundments, channel stability.

Discussion: Critical to the overall success of a project, is the initial planning before a project begins and refinement of the water management variables in that plan during development of a CBM prospect. To design an effective system for managing produced water, it is necessary to know the following: i) likely quality of produced water; ii) estimated water production rates at various phases of the project; iii) evaluation of the hydrologic relationship between ground- and surface water; iv) nature and existing use of any proposed receiving waters, including seasonal flow rates flora, fauna and soils associated with surface discharge; v) current or proposed permitting and regulatory restrictions; and vi) the institutional framework governing groundwater within the project area. With the need to maintain flexibility and provide for contingencies, the initial plan may change as data is collected from actual operations.

BMP 2: Produced Water Options. Take the following factors into consideration when evaluating options for managing CBM produced water:

.Landowner preference and concerns
. Quantity and quality of water to be discharged
. Quality of the receiving water standards
. Environmental/ecological effects from surface discharge
. Downstream concerns
. Economic feasibility/cost effectiveness
. Beneficial use possibilities
. Proximity to streams/ponds/reservoirs/wetlands/lakes
. Proximity to clinker/scoria and gravel deposits
. Proximity to springs
. Long-term impacts to the environment
. Protection of groundwater

Discussion: There are a variety of options for managing produced water, including reinjection (either for disposal, or for storage and later retrieval), and surface discharge, which involves release of produced CBM water onto the earth's surface, either to surface water or surface soil. One way to group alternatives for surface discharge is using the following three general categories: i) discharge to surface water, ii) discharge to land surface with possible runoff, and iii) discharge to land surface with possible infiltration into subsurface aquifers and surface water.

Decisions and use of tools for managing produced water will also involve regulatory and technical considerations including geology, and economic and engineering factors as well as surface owner needs. Evaluation of water management options and produced water use alternatives will require planning, data gathering and analysis. Planning should include a detailed understanding of water classifications, standards, water rights and any other compacts or laws that may exist. Where CBM development is proposed adjacent to or near important fisheries habitat, hydrologic mapping and analysis and other related research, it is essential to gain a better understanding of ground- and surface-water interactions, and potential impacts of CBM development on water quality and quantity.

BMP 3: Understanding the Capacity of the Receiving Aquifer.
When considering underground injection, ensure that the capacity of the receiving aquifer is adequate to handle the anticipated volume of water to be injected.

Discussion: Underground injection is a management option for produced water in some, but not all, places. It can be used for storage and retrieval (of high quality water), or for disposal. Injection is generally viewed as the emplacement of water into a zone or formation that is capable of receiving and storing water. Several important factors can influence the feasibility of injection, including availability of an injection zone, depth of the injection zone, injection pressures, needs for transportation of water, the rate of injection, the quality of water being injected, the quality of water in the receiving formation, and the ultimate storage capacity of the receiving formation(s).

B. Beneficial Use

BMP: Information for landowners. When the landowner is interested in possibly using CBM produced water, provide information about options for beneficial-use and about potential problems and liability.[1]

Discussion: Water extracted during CBM development presents challenges but may also offer opportunities for beneficial use of produced water. (See Appendix E for Beneficial Use Alternatives for CBM Produced Water, www.westgov.org). However, the quality of the water extracted influences how this water can be managed and whether it can be used for beneficial purposes. The quality of water that is produced will vary from basin to basin, within a particular basin, and over the lifetime of a CBM well.[2] There are a variety of technologies existing and evolving that may be applied to improve the quality of the water and consequently the options available for use. (See Appendix F for a discussion of Water Treatment Technologies, www.westgov.org).
Decisions about beneficial-use also need to factor in the reality that the availability of CBM- produced water is not sustained over time. The volume of produced water is typically very high for a short time after production starts and then drops off rapidly. For this reason, long-term reliance on produced water should not be encouraged. This also applies to the use of the produced water to enhance wildlife habitat. The Rocky Mountain West is characterized by semi-arid to arid conditions. It is not realistic to think that ecological conditions that are related to areas with significantly more water can be sustained in these arid areas.

C. Water Quality

Land application of produced water can be of benefit to the surface owners in some cases, but also has the potential to produce negative long-term impacts to the soil's physical and chemical properties, if not properly managed. Water quality can also be affected by the construction and maintenance of ponds, impoundments and infiltration systems. These are generally an excavation or diked area that can be used for a variety of water management options. These include treatment; storage; evaporation leakage; disposal of liquids, and storage prior to another water management option, including injection

[1] It is very important that beneficial use of produced water is consistent and meets the requirements of water rights within a given state. In addition, it may be necessary in some cases to obtain a National Pollutant Discharge Elimination System (NPDES) permit. These are important considerations that require the ultimate user of the produced water to research all legal and regulatory aspects thoroughly in order to make informed decisions about beneficially using CBM produced water.

[2] As an example of the differences between basins, as pointed out by the State of Utah, CBM produced water quality in the Colorado River drainage area of Utah is very poor compared to some other places. Consequently, the only currently approved surface water options are: a) no discharge, or b) a reverse osmosis type of treatment.

or irrigation. Beneficial uses include fishponds, livestock and wildlife watering ponds and recreational ponds. Ponds can vary from less than one acre to several acres. Non-infiltration impoundments are usually constructed in low permeable soils, to prevent or decrease raw water loss due to subsurface infiltration or percolation.[3] (See Appendix G for a description of impoundment options. Appendix G is located with the Handbook at www.westgov.org)

BMP 1: Establishing a Baseline. As mentioned elsewhere, it is important to establish a baseline for ground- and surface-water quality in the area where development will occur, relying as much as possible on existing information.

BMP 2: Monitoring Data. Provide assistance to landowners who want monitoring data, either by providing the data, or directing them to the appropriate source, such as a regulatory agency that maintains the information.[4]

BMP 3: Distance from Outcrops. When drilling near outcrops of coal formations, understand the hydrology of the basin to determine a sufficient distance for well placement to avoid contamination of water wells and methane seepage at the outcrop of coal formations.

BMP 4: Fracturing Fluids. Discontinue the use of diesel fuel in hydraulic fracturing fluids injected directly into formations that contain underground sources of drinking water (USDW).

Discussion: Water-based alternatives exist and from an environmental perspective, these water-based products are preferable compared to diesel fuel. The EPA signed an agreement in December 2003 with three major companies that provide approximately 95 percent of the hydraulic fracturing services performed in the United States. The agreement calls for the voluntary removal of diesel fuel from hydraulic fracturing fluids injected directly into those formations that contain USDWs during hydraulic fracturing for CBM production. Included in the agreement are assurances from the companies that fluids used to replace diesel fuel will not endanger USDWs. The Memorandum of Understanding is available at http://www.epa.gov/safewater/uic/pdfs/moa_uic_hyd-fract.pdf

D. Protection of Wetland/Riparian Areas

BMP 1: Location of Nonlinear Features. To protect the biological and hydrologic features of riparian areas, woody draws, wetlands, and floodplains, locate all well pads, compressors, and other nonlinear facilities to the maximum extent possible outside of these areas.

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[3] It was noted by some CBM Advisory Committee members that the beneficial use of water is perceived as a positive by many in Wyoming's Powder River Basin.

[4] Individual NPDES permits dictate what type of monitoring will be required.

BMP 2: Crossings by Linear Features. Avoid crossings of wetland/riparian areas by linear features, such as pipelines, roads, and power lines to the extent practicable. Where crossings cannot be avoided, impacts can be minimized through use of the following and other measures that may be consistent with the Corps of Engineers' nationwide permit program.[5]

. Developing site-specific mitigation plans during the permit approval process for all proposed disturbance to wetland/riparian areas

. Constructing crossings perpendicular to wetland/riparian areas

. For power lines, using the minimum number of poles necessary to cross the area

. Scheduling construction in wetland areas to minimize the duration of construction activity within the wetland, and, if possible, to concentrate such activity during dry conditions (that is, during late summer or fall), or when the ground is frozen during the winter

. Not depositing waste material below high-water lines in riparian areas, flood plains, or in natural drainage ways

. Locating the lower edge of soil or other material stockpiles outside the active floodplain

. Locating drilling mud pits outside of riparian areas, wetlands and floodplains, where practical

. Re-shaping disturbed channels to their approximate original configuration or other geomorphological configuration and ensuring they are properly stabilized

. Beginning reclamation of disturbed wetland/riparian areas as soon as possible after project activities are complete

. Conducting stream channel monitoring for erosion, degradation, and riparian health

Acknowledgments

A special acknowledgment to Konrad Quast of Applied Hydrology International, whom upon my request submitted a preliminary synopsis of water quality and potential disposal issues associated with CBM exploration and development within the LSFO. This synopsis comprises most of this report. A more detailed final report will be included in the Northwest Colorado CBM Assessment currently being worked on by Questa Engineering and Applied Hydrology. This assessment should be completed before the RMP Revision is completed and reference to this document should be included in the Revision.

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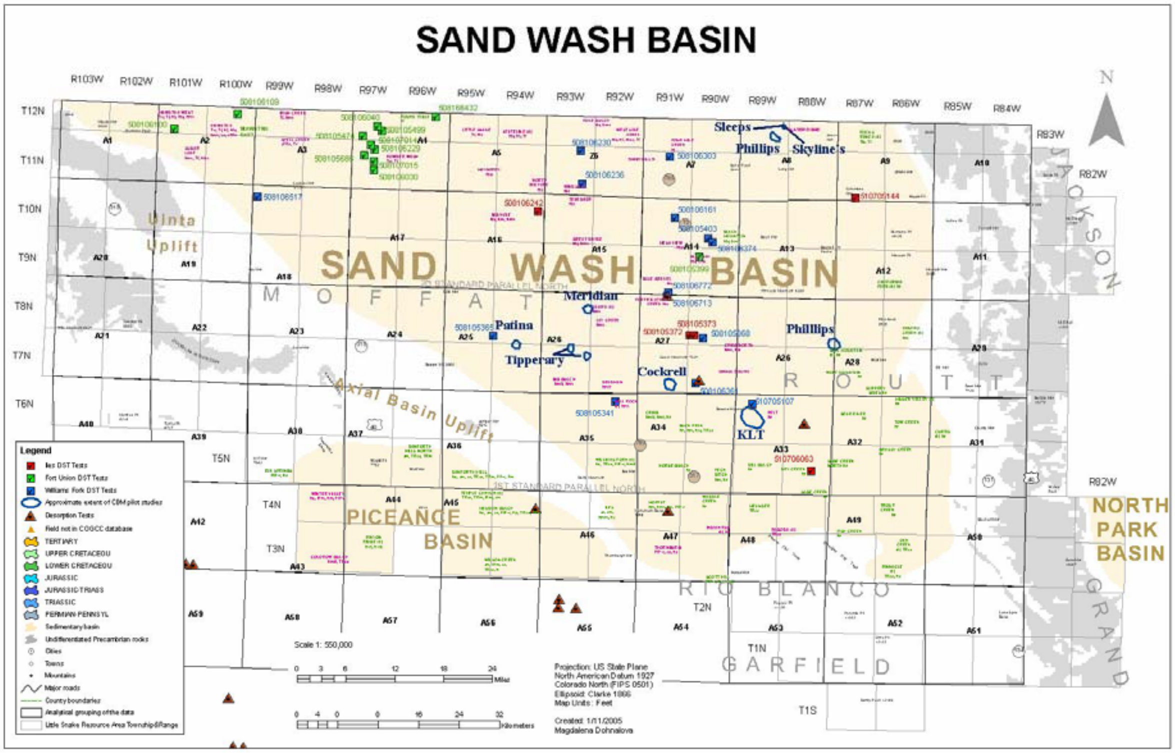
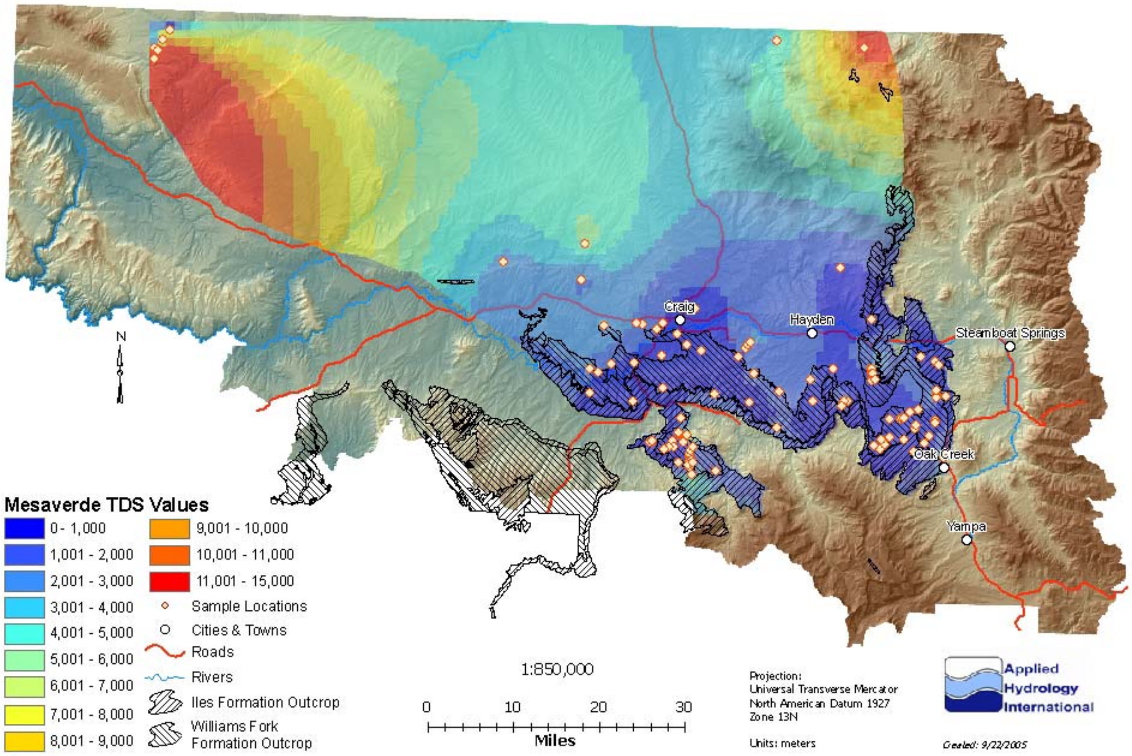
[5] See 33 CFR Parts 330.1-330.6 including Appendix A Part 330-Nationwide permits and conditions.

Appendix

Map 1



Map 2


N
Craig
Hayden
Steamboat Springs
Oak Creek
Yampa
Mesaverde TDS Values
0 - 1,000
1,001 - 2,000
2,001 - 3,000
3,001 - 4,000
4,001 - 5,000
5,001 - 6,000
6,001 - 7,000
7,001 - 8,000
8,001 - 9,000
9,001 - 10,000
10,001 - 11,000
11,001 - 15,000
Sample Locations
Cities & Towns
Roads
Rivers
Iles Formation Outcrop
Williams Fork Formation Outcrop
1:850,000
0
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20
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Miles
Projection:
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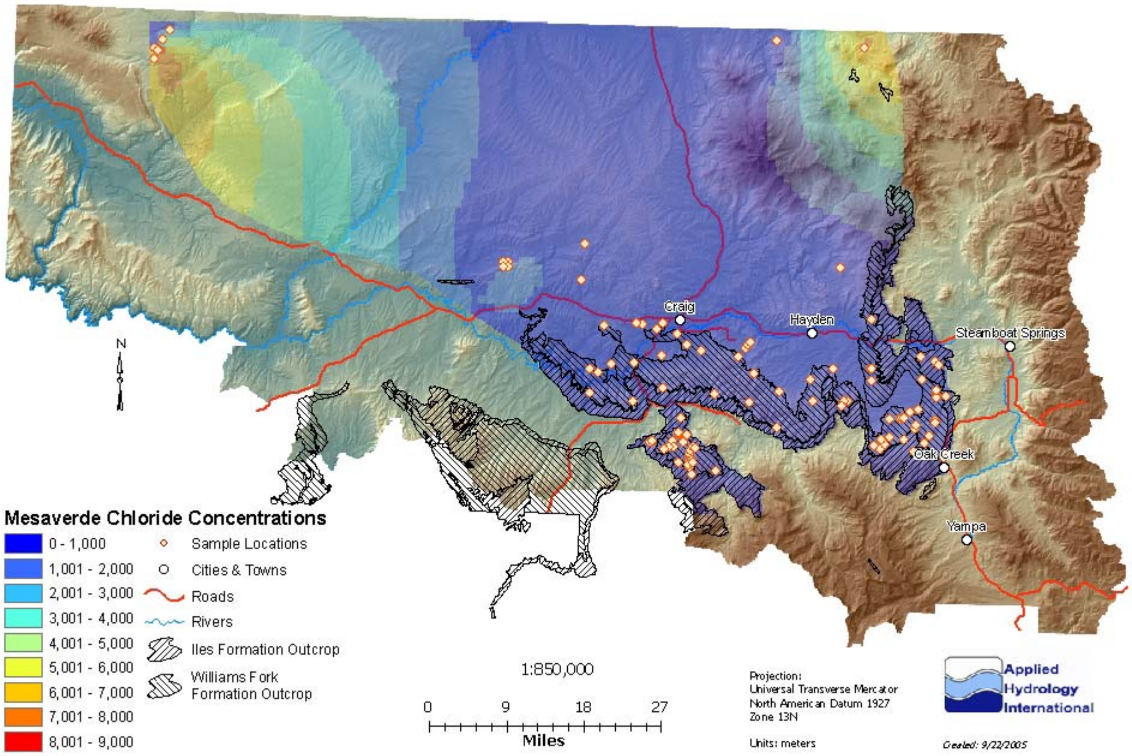
North American Datum 1927
Zone 13N
Units: meters
Applied Hydrology International
Created: 9/22/2005

Map 3



Craig
Hayden
Steamboat Springs
Oak Creek
Yampa
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Mesaverde Chloride Concentrations
0 - 1,000
1,001 - 2,000
2,001 - 3,000
3,001 - 4,000
4,001 - 5,000
5,001 - 6,000
6,001 - 7,000
7,001 - 8,000
8,001 - 9,000
Sample Locations
Cities & Towns
Roads
Rivers
Iles Formation Outcrop
Williams Fork Formation Outcrop
1:850,000
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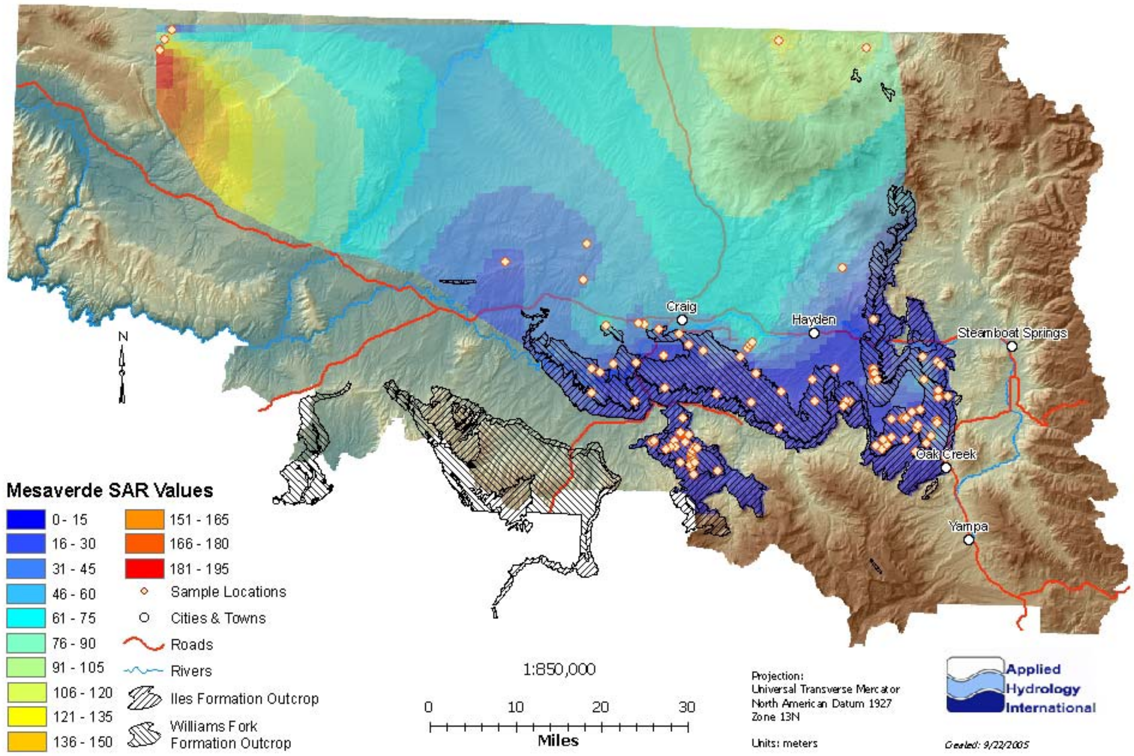
Units: meters
Applied Hydrology International
Created: 9/22/2005

Map 4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Steamboat Springs
Oak Creek
Yampa
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Mesaverde SAR Values
0 - 15
16 - 30
31 - 45
46 - 60
61 - 75
76 - 90
91 - 105
106 - 120
121 - 135
136 - 150
151 - 165
166 - 180
181 - 195
Sample Locations
Cities & Towns
Roads
Rivers
Iles Formation Outcrop
Williams Fork Formation Outcrop
1:850,000
0 10 20 30
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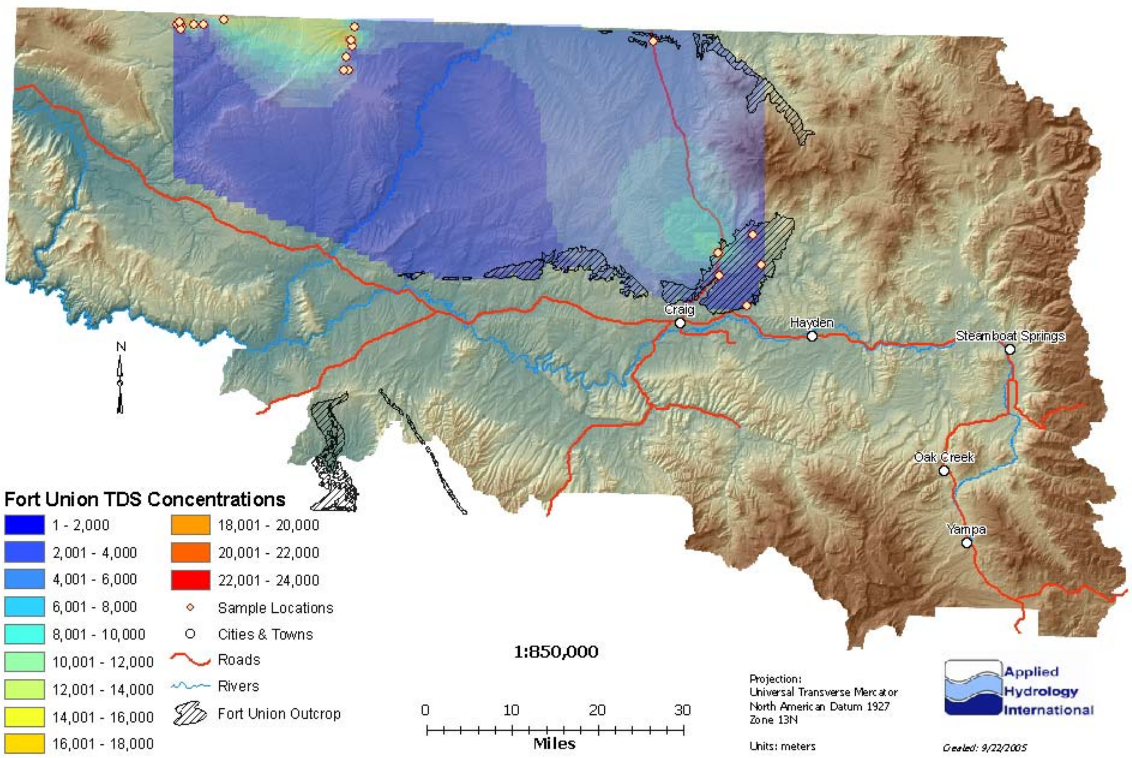
Created: 9/22/2005

Map 5



Craig
Hayden
Steamboat Springs
Oak Creek
Yampa
N
Fort Union TDS Concentrations
1 - 2,000
2,001 - 4,000
4,001 - 6,000
6,001 - 8,000
8,001 - 10,000
10,001 - 12,000
12,001 - 14,000
14,001 - 16,000
16,001 - 18,000
18,001 - 20,000
20,001 - 22,000
22,001 - 24,000
Sample Locations
Cities & Towns
Roads
Rivers
Fort Union Outcrop
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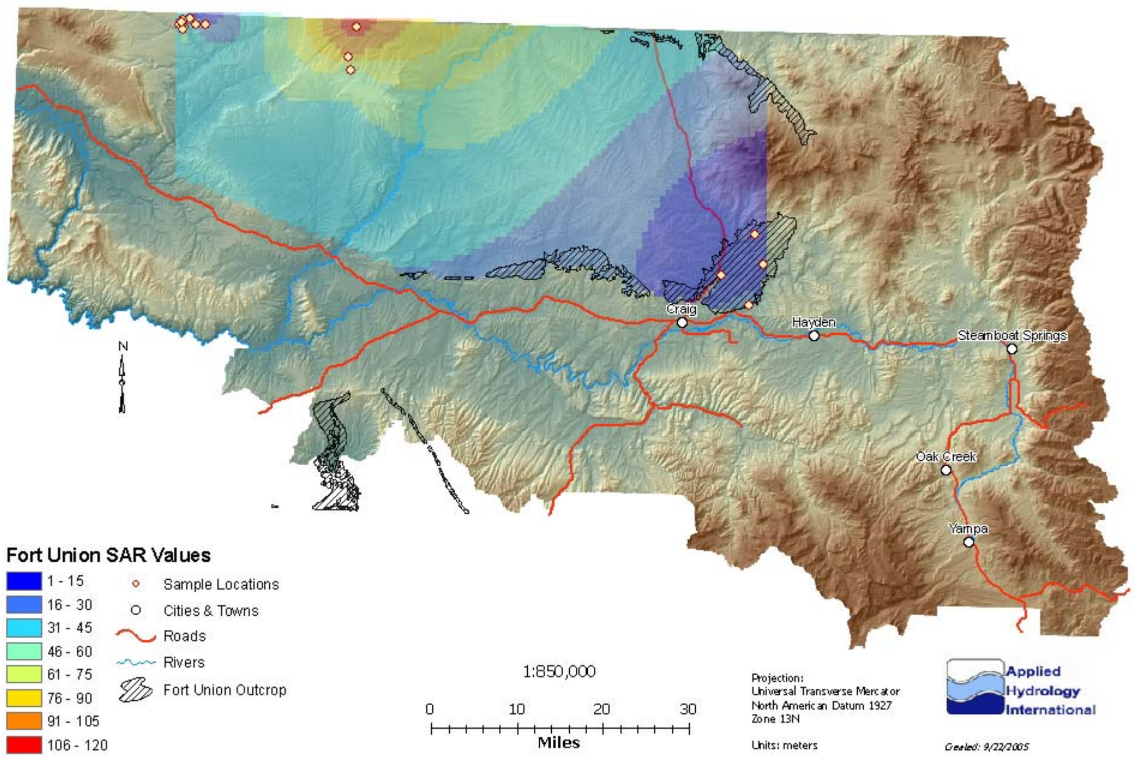
Map 6



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Hayden
Steamboat Springs
Oak Creek
Yampa
N
Fort Union SAR Values
1 - 15
16 - 30
31 - 45
46 - 60
61 - 75
76 - 90
91 - 105
106 - 120
Sample Locations
Cities & Towns
Roads
Rivers
Fort Union Outcrop
1:850,000
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Hydrology
International
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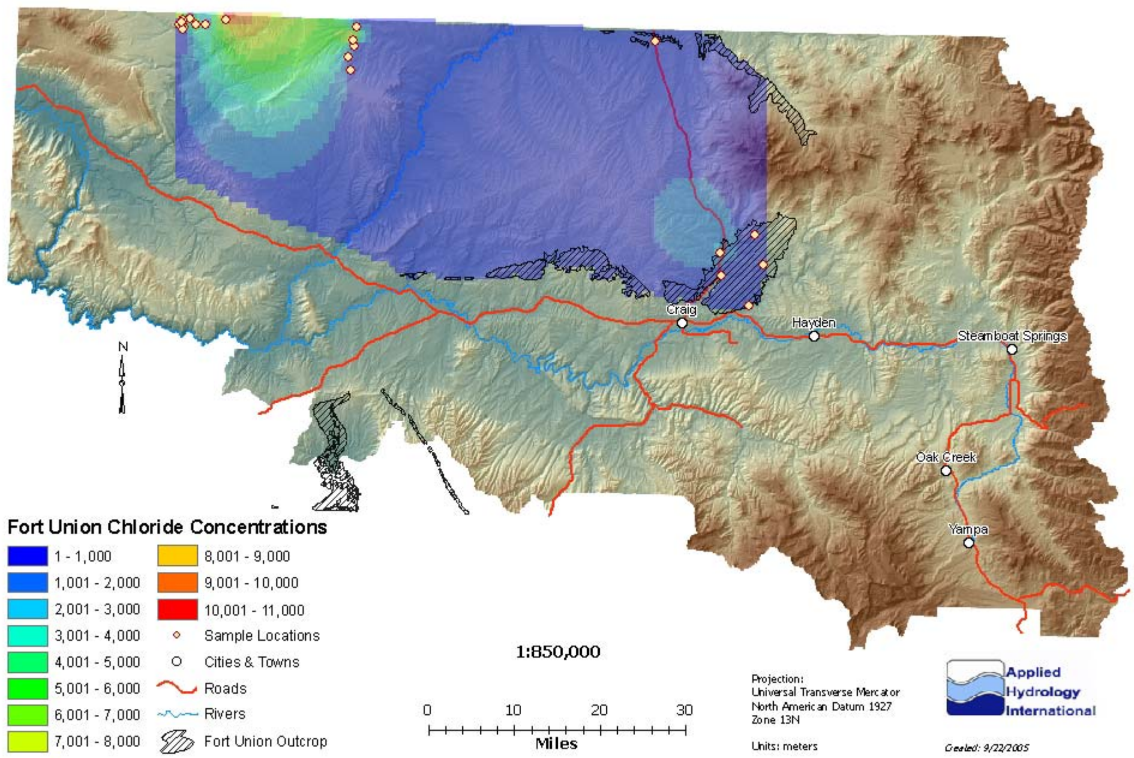
Map 7



N
Craig
Hayden
Steamboat Springs
Oak Creek
Yampa
Fort Union Chloride Concentrations
1 - 1,000
1,001 - 2,000
2,001 - 3,000
3,001 - 4,000
4,001 - 5,000
5,001 - 6,000
6,001 - 7,000
7,001 - 8,000
8,001 - 9,000
9,001 - 10,000
10,001 - 11,000
Sample Locations
Cities & Towns
Roads
Rivers
Fort Union Outcrop
1:850,000
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10
20
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Miles
Projection:
Universal Transverse Mercator
North American Datum 1927
Zone 13N
Units: meters
Applied
Hydrology
International
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APPENDIX D

REGULATORY COMPLIANCE CHECKLIST - WYOMING EXAMPLE

Federal, State, and County Permits, Approvals, and Authorizing Actions - Wyoming Example

Agency	Permit, Approval or Action	Authority
U.S. Forest Service (USFS)	Decision Record for Proposed Action. Evaluate environmental impacts of Proposed Action	National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.) Council on Environmental Quality, 40 CFR 1501, 1502
	Approval of Plan of Development for surface use of well pad	FSM 1950
	Concurrence with BLM's APD approval process on USFS administered land	FSM 1500
	Special Use Permit for access road ROW, road decommissioning, and pipeline	Forest Service Handbook (FSH) 1509.11
	Special Use Permit to utility company for installation and operation of powerline	Federal Register Notice 5-22-95
	Antiquities and cultural resource permits on USFS-administered land	Antiquities Act of 1906, as amended (16 U.S.C. 431-433); Archaeological Resources Protection Act of 1979, as amended (16 U.S.C. Sections 470aa-470ll); Preservation of American Antiquities, as amended (43 CFR 3)
Bureau of Land Management (BLM)	Decision Record for Proposed Action. Evaluate environmental impacts of Proposed Action tiered to EIS for resource management plan (land use plan), as amended	National Environmental Policy Act of 1969 (42 U.S.C. 4321 et seq.) Council on Environmental Quality, 40 CFR 1501, 1502; 43 CFR 1601 et seq.; FLPMA 43 U.S.C. 1701 et seq.

Agency	Permit, Approval or Action	Authority
	Permit to drill, deepen, or plug back on BLM-managed land or minerals (APD process)	Mineral Leasing Act of 1920, as amended (30 U.S.C. 181 et seq.) Requirements for Operating Rights Owners and Operators, as amended (43 CFR 3101,3162,3164); Onshore Order #1, BLM Buffalo Field Office Coalbed Methane Well Application for Permit to Drill and Plan of Development Preparation Guide (updates Oil and Gas Surface Operating Standards "Gold Book")
	Rights-of-way grants and temporary use permits for pipelines and central tank battery on BLM-managed land or crossing lands managed by more than one federal agency; otherwise granted by appropriate surface management agency	Mineral Leasing Act of 1920, as amended (30 U.S.C. 185); 43 CFR 2880
	Rights-of-way grants for access roads on BLM-managed land	FLPMA (43 U.S.C. 1761-1771); 43 CFR 2800
	Authorization for flaring and venting of natural gas on BLM-managed land or minerals	Mineral Leasing Act of 1920, as amended (30 U.S.C. 181 et seq.); Requirements for Operating Rights Owners and Operators, as amended (43 CFR 3162)
	Plugging and abandonment of a well on BLM-managed land or minerals	Mineral Leasing Act of 1920, as amended (30 U.S.C. 181 et seq.); Requirements for Operating Rights Owners and Operators, as amended (43 CFR 3162)

Agency	Permit, Approval or Action	Authority
	Antiquities and cultural resource permits on BLM-managed land	Antiquities Act of 1906 (16 U.S.C. Section 431-433); Archaeological Resources Public Protection Act of 1979 (16 U.S.C. Sections 470aa-47011); 43 CFR 3
	Approval to dispose of produced water on BLM-managed land	Mineral Leasing Act of 1920 (30 U.S.C. 181 et seq.); 43 CFR 3164; Onshore Oil and Gas Order No. 7; CWA 401 certification by state under 33 U.S.C.1341; compliance with applicable water quality NPDES requirements (see WDEQ); may verify use of general permits under CWA section 404(e) (33 U.S.C. 1344(e)) following Corps delineation or concurrence of WUS, and coordinates with USACE and WSEO
	Use only BLM Approved Formulations of Herbicides on BLM lands. Ensure that a Pesticide Use Proposal is submitted and approved by the proper BLM authority. Ensure that a Pesticide Application Record is completed within 24 hours after the completion of the herbicide application on BLM lands and submitted to the proper BLM Office.	Requirements by the BLM Vegetation Treatment on BLM Lands in the Thirteen Western Station Final Environmental Impact Statement 1991 and BLM Manual 9011 Chemical Pest Control, BLM Handbook H-9011-1 Chemical Pest Control, and BLM Manual 9015 Integrated Weed Management
	BLM is required to protect/preserve wetlands and floodplains	*Exec. Order 11990 (May 24, 1977), BLM Manual Section 1737, rel. 1-1611 (12/10/92); Exec. Order 11988 of 1977*
Bureau of Indian Affairs (BIA) and/or Tribe	Approval of Utilization - Provide for efficient and timely development and production of tribal oil and gas leases; Consultation for impacts to tribal lands or resources from off-reservation activities	Indian Minerals Leasing Act of May 11, 1938, 25 U.S.C. 396a-396q, 25 CFR, Part 211. Act of March 3, 1909, 25 U.S.C. 396, 25 CFR, Part 212. Indian Mineral Development Act of December 22, 1982, 25 U.S.C. 21-02-2108, 25 CFR, Part 225; NHPA (16 U.S.C. 470 et seq.); DOI Departmental Manual and various bureau Manuals

Agency	Permit, Approval or Action	Authority
	Rights of Way - Grant rights-of-way and issue temporary permits	Act of March 3, 1901, c.832 ss4.31.Stat.1084. Also 209DM8 Secretaries Order 3150 and 3177, as amended, 10 BIAM, bulletin 13, as amended, and Albuquerque Area Addendum Release 9401
	Archaeological Clearance - Issue antiquities or archaeological resource permits to remove or excavate archaeological resources on land administered by BIA	Antiquities Act of 1906, 16 USC Secs. 431-433; Archaeological Resources Protection Act of 1979 (16 USC Secs. 470a-47011), 43 CFR, Parts 3 and 7; National Historic Preservation Act, Section 106 and 36 CFR Part 800
	Air emissions inventory data - Accumulating emissions data	Clean Air Act
U.S. Army Corps of Engineers (COE)	Section 404 permits and coordination regarding dams and dikes or placement of dredged or fill material in jurisdictional waters and adjacent wetlands; Delineation of Waters of the United States and wetlands ("jurisdictional waters")	Section 404 of the Clean Water Act of 1972, as amended (33 U.S.C. 1344); 33 CFR 320-330; Section 404(b)(1) Guidelines for Specific Disposal Sites for Dredged or Filled Material, as amended (40 CFR 230)
U.S. Fish and Wildlife Service (USFWS)	Coordination, consultation, and impact review on federally listed threatened and endangered (T&E) species	Fish and Wildlife Coordination Act (16 U.S.C. 661-666c), Section 7 of the Endangered Species Act of 1973, as amended (16 U.S.C. 1536); enforcement of other ESA provisions (16 U.S.C. 1531 et seq.) ;Bald Eagle Protection Act (16 U.S.C. 668-668dd); other specialty wildlife protection Acts
	Migratory bird impact coordination	Migratory Bird Treaty Act (16 U.S.C. 704)
U.S. Department of Transportation (DOT)	Control pipeline maintenance and operation	Transportation of Natural and Other Gas by Pipeline, Annual Reports, Incident Reports, and Safety Related Condition Reports, as amended (49 CFR 191); Transportation of Natural and Other Gases by Pipeline: Minimum Safety Standards, as amended (49

Agency	Permit, Approval or Action	Authority
		CFR 192)
U.S. Environmental Protection Agency (EPA)	Spill Prevention Control and Countermeasure Plans (SPCCPs)	40 CFR 112 (Oil Pollution Control program), under Clean Water Act (FWPCA) 33 U.S.C. 1321, 1361; see also 33 U.S.C. 2701 et seq. (33 CFR 135)
	Regulation of hazardous waste treatment, storage, and/or disposal	Resource Conservation and Recovery Act (42 U.S.C. Section 6901); CERCLA 42 U.S. C. 9601 et seq.
	Produced-Water Disposal - Issue permit to allow for underground injection of produced water	Safe Drinking Water Act (42 U.S.C. 300f=300j-26), 40 CFR Parts 144 and 147
Wyoming Department of Environmental Quality - Water Quality Division (WDEQ-WQD)	Permits to construct settling ponds and waste water treatment systems, including groundwater injection and disposal wells	Wyoming Environmental Quality Act, Article 3, Water Quality, as amended (W.S. 35-11-301 through 35-11-311); Federal Safe Drinking Water Act, as administered by states (42 U.S.C. 300f=300j-26)
	Regulate disposal of drilling fluids from abandoned reserve pits	Wyoming Environmental Quality Act, Article 3, Water Quality, as amended (W.S. 35-11-301 through 35-11-311)
	NPDES permits for and stormwater runoff if greater than five acres of disturbance, and for discharging any produced water containing regulated pollutants into waters of the state or waters of the United States ("jurisdictional waters"); Clean Water Act section 401 certification for federal activities such as verification that a section 402 (NPDES) permit is not required for a federally-approved activity, and stetewide certification that use of General or Statewide CWA section 404 permits promulgated by the Corps of Engineers will comply with federal and state requirements	WDEQ-WQD Rules and Regulations, Chapter 18; Wyoming Environmental Quality Act, Article 3, Water Quality, as amended (W.S. 35-11-301 through 35-11-311); Section 405 of the Federal Water Pollution Control Act (Clean Water Act) (codified at 33 U.S.C. 1345); EPA-administered Permit Programs: NPDES, as amended (40 CFR 122); State Program Requirements (40 CFR 123); EPA Water Program Procedures for Decision-making, as amended (40 CFR 124); 33 U.S.C. 1341.

Agency	Permit, Approval or Action	Authority
	Approval for discharge of hydrostatic test	Wyoming Environmental Quality Act, Article 3, Water Quality, as amended (W.S. 35-11-301 through 35-11-311)
Wyoming Department of Environmental Quality - Air Quality Division (WDEQ-AQD)	Permits to construct and permits to operate	Clean Air Act, as amended (42 U.S.C. 7401 et seq.); Wyoming Environmental Quality Act, Article 2, Air Quality, as amended (W.S. 35-11-201 through 35-11-212)
Wyoming Department of Environmental Quality - Land Quality Division (WDEQ-LQD)	Mine permits, mine impoundments, and drill hole plugging on state lands	Wyoming Environmental Quality Act, Article 4, Land Quality, as amended (W.S. 35-11-401 through 35-11-437)
Wyoming Department of Environmental Quality - Solid Waste Division (WDEQ-SWD)	Construction fill permits and industrial waste facility permits for solid waste disposal during construction and operations	Wyoming Environmental Quality Act, Article 5, Solid Waste Management, as amended (W.S. 35-11-501 through 35-11-520); Resource Conservation and Recovery Act (42 U.S.C. Section 6901 et seq.)
Wyoming Department of Transportation (WDOT)	Permits for oversize, overlength, and overweight loads	Chapters 17 and 20 of the Wyoming Highway Department Rules and Regulations
	Access permits to state highways	Chapter 13 of the Wyoming Highway Department Rules and Regulations
Wyoming Board of Land Commissioners/ Land and Farm Loan Office	Approval of oil and gas leases, ROWs for long-term or permanent off-lease/off-unit roads and pipelines, temporary use permits, and developments on state lands	Public Utilities, W.S. 37-1-101 et seq.
Wyoming Oil and Gas Conservation Commission (WOGCC)	Permit to drill, deepen, or plug back (APD process) on state/fee minerals	WOGCC Regulations, Chapter 3, Operational and Drilling Rules, Section 2 Location of Wells
	Permit to use earthen pit (reserve pits) in off-channel areas outside of jurisdictional waters of the United States, over state/fee minerals	WOGCC Regulations, Chapter 4, Environmental Rules, Including Underground Injection Control Program Rules for Enhanced Recovery and Disposal Projects, Section 1, Pollution and Surface Damage (Forms 14A and 14B)

Agency	Permit, Approval or Action	Authority
	Authorization for flaring or venting of gas	WOGCC Regulations, Chapter 3, Operational and Drilling Rules, Section 45 Authorization for Flaring or Venting of gas
	Permit for Class II underground injection wells	Federal Safe Drinking Water Act, as administered by states (42 U.S.C. 300f=300j-26), Underground Injection Control Program: Criteria and Standards, as amended (40 CFR 146); state Underground Injection Control Programs, State-administered program - Class II Wells, as amended (40 C.F. R. 147.2551)
	Well plugging and abandonment	WOGCC Regulations, Chapter 3, Section 14, Reporting (Form 4); Section 15, Plugging of Wells, Stratigraphic Tests, Core, or Other Exploratory Holes (Form 4)
	Change in depletion plans	Wyoming Oil and Gas Act, as amended (Form W.S. 30-5-110)
Wyoming State Engineer's Office (WSEO)	Permits to appropriate groundwater (use, storage, wells, dewatering) or water stored in impoundments or reservoirs	W.S. 41-3-901 through 41-3-938, as amended (Form U.W. 5)
	Permits to construct or modify dams and on-channel reservoirs; change in use of existing reservoirs	W.S. 41-3-301 et seq., as amended (Forms SW3, SW4)
Wyoming State Historic Preservation Office (SHPO)	Cultural resource protection, programmatic agreements, consultation	Section 106 of National Historic Preservation Act of 1966, as amended (16 U.S.C. 470 et seq.) and Advisory Council Regulations on the Protection of Historic and Cultural Properties, as amended (36 CFR 800)
County (representative)	Construction/use permits	County Code and Zoning Resolution
	Conditional use permits	County Code and Zoning Resolution
	Road use agreements/oversize trip permits	County Code

Agency	Permit, Approval or Action	Authority
	County road crossing/access permits	County Code/Engineering Department
	Small wastewater permits	County Health Department
	Hazardous material recordation and storage	County Code
	Zone changes	Zoning Resolution
	Filing Fees	County Code
	Noxious weed control	County Code

APPENDIX E

BENEFICIAL USE ALTERNATIVES FOR CBM PRODUCED WATER

Produced water quality, applicable regulations, and cost will generally dictate potential beneficial use of produced water. In some cases, produced water can be treated to make it suitable for a particular use, and treatment technologies are discussed in the next section. However, in accordance with 40 CFR, Part 435, produced water must be put to some use for livestock, wildlife, or agriculture. Otherwise, it is not to be discharged to surface waters of the Nation.

Agricultural Uses

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. Livestock benefits have been realized with increased cattle density, increased weight gain in cattle, and subsequent improvement in range use when water is made available in otherwise dry areas. New water sources may also increase aquatic habitat and provide new fisheries. However, water law and compact requirements vary between states, so a full understanding of water issues is critical.

<u>Alternative 1 - Stock Watering</u>

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.

The overflow of water into streams constitutes a discharge to surface waters thus to discharge the water as described would in most cases require a NPDES permit. There is also the potential to impact soils by allowing the water to run along the surface, depending on the water quality and soil types.

<u>Alternative 2 - Irrigation</u>

CBM produced water can be used for irrigation purposes when water quality, soil type, crop type and irrigation method are conducive for irrigation. The appropriateness of irrigation with CBM water is dependent on the site specific conditions (water quality, soils, vegetation, etc.) and the proposed management practices (application rates, soil amendments, treatment, etc.).

Industrial Uses

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 that require water include: dust suppression, slurry activities, and post mining restoration efforts.

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. In addition to livestock watering at CAFOs, produced water could be used to assist in waste management activities. The EPA, as defined in 40 CFR 122.23, Appendix B, regulates NPDES permitted discharges from CAFO's for animal waste.

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. Cold water enters the plant's heat exchanger that 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 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.

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 BMPs for controlling the spread of noxious weeds.

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.

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.

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 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 or stored in tanks at disposal wells could provide an accessible option for fighting fires in remote areas in states such as Colorado, Wyoming, New Mexico, Montana, and Utah.

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. 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 include: sod farming, solution mining for minerals, bottled drinking water, and brewery water.

Domestic and Municipal Water Use

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. 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 recharge water systems; make-up water; and other residential non-potable water uses.

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 limited 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, for uses such as lawn and garden irrigation, bathing, dishwasher and washing machine uses, vehicle washing, residential maintenance, and toilet flushing.

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. It may also be used to recharge depleted aquifers.

APPENDIX F

WATER TREATMENT TECHNOLOGIES

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. However, there are cases, particularly in the Powder River Basin where no advantage relative to permit requirements is gained in treating the water. This should be carefully assessed when evaluating treatment.

To design an effective system for treating or disposing produced water it is necessary to know the following: likely quality of produced water; estimated water production rates at various phases of the project; nature of any proposed receiving waters in terms of seasonal flow rates, existing water quality, and aquatic flora and fauna; and current or proposed permitting and regulatory restrictions.

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.

<u>Freeze-Thaw/Evaporation</u>

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.

<u>Reverse Osmosis</u>

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. 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.

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).

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.

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 range of the average American iodine intake (0.24 to 0.74 mg/day) includes levels 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 (Resin Extraction)

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-. 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).

A residual brine containing the ions removed by this process is formed by this method. This brine is typically 1-5% of the original produced water volume. The management of this brine must be considered in advance if this technology is to be used.

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).

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.

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. 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).

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 and require a large area.

Table

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	√	√	√	√	√	√		√	√ 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.

References listed in this Appendix may be located http://www.all-llc.com/CBM/.

APPENDIX G

IMPOUNDMENT ALTERNATIVES

<u>Alternative 1 - Wildlife and Livestock Watering Impoundments</u>

Wildlife watering ponds are typically small 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. 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.

<u>Alternative 2 - Fisheries</u>

Constructed fisheries are 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.

<u>Alternative 3 - Recharge Ponds</u>

Recharge ponds, also known as storm water ponds, retention ponds, or wet extended detention ponds, are constructed 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.

The infiltration of water in areas that had historically little infiltration of water will cause the soluble salts that have accumulated over time to be dissolved and moved down through the soil and bedrock. These may change the chemistry of the underlying groundwater, or, if intercepted by an impermeable layer, result in the formation of saline seeps.

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.

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. They are either lined or placed on impermeable soils. These basins may include nebulizers or other technology to enhance the evaporation process. As evaporation occurs water is removed from the pond while the salts are left behind. This results 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 a concentrated brine and eventual salt precipitation will occur. The disposal of this residual salt must be considered in advance if evaporation processes are to be used.

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.

References listed in this Appendix may be located http://www.all-llc.com/CBM/.

APPENDIX G

IMPOUNDMENT ALTERNATIVES

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